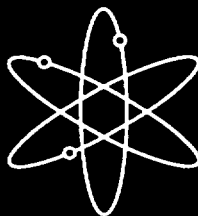


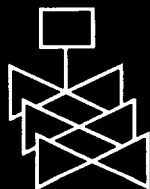
MELCOR Computer Code Manuals



Primer and User's Guide
Version 1.8.5



Sandia National Laboratories



**Office of Nuclear Regulatory Research
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MELCOR Computer Code Manuals

Primer and User's Guide
Version 1.8.5

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Abstract

MELCOR is a fully integrated, engineering-level computer code that models the progression of severe accidents in light water reactor nuclear power plants. MELCOR is being developed at Sandia National Laboratories for the U.S. Nuclear Regulatory Commission as a second-generation plant risk assessment tool and the successor to the Source Term Code Package. A broad spectrum of severe accident phenomena in both boiling and pressurized water reactors is treated in MELCOR in a unified framework. These include thermal-hydraulic response in the reactor coolant system, reactor cavity, containment, and confinement buildings; core heatup, degradation, and relocation; core-concrete attack; hydrogen production, transport, and combustion; fission product release and transport behavior. Current uses of MELCOR include estimation of severe accident source terms and their sensitivities and uncertainties in a variety of applications.

This publication of the MELCOR computer code manuals corresponds to MELCOR 1.8.5, released to users in October 2000. Volume 1 contains a primer that describes MELCOR's phenomenological scope, organization (by package), and documentation. The remainder of Volume 1 contains the MELCOR User's Guides, which provide the input instructions and guidelines for each package. Volume 2 contains the MELCOR Reference Manuals, which describe the phenomenological models that have been implemented in each package. A new volume, Volume 3 of this publication presents a portfolio of test and sample problems consisting of both analyses of experiments and of full plant problems.

Contents

Volume 1: Primer and Users' Guide

The following chapters are found in Volume 1 of this code manual set.

MELCOR Primer

Executive (EXEC) Package Users' Guide

BWR Bottom Head (BH) Package Users' Guide

Burn (BUR) Package Users' Guide

Cavity (CAV) Package Users' Guide

Condenser (CND) Package Users' Guide

Control Function (CF) Package Users' Guide

Core (COR) Package Users' Guide

Control Volume Hydrodynamics (CVH) Package Users' Guide

Decay Heat (DCH) Package Users' Guide

External Data File (EDF) Package Users' Guide

Fan Cooler (FCL) Package Users' Guide

Fuel Dispersal (FDI) Package Users' Guide

Flow Path (FL) Package Users' Guide

Heat Structures (HS) Package Users' Guide

Material Properties (MP) Package Users' Guide

NonCondensable Gas (NCG) Package Users' Guide

Passive Autocatalytic Hydrogen Recombiner (PAR) Package Users' Guide

RadioNuclide (RN) Package Users' Guide

Containment Sprays (SPR) Package Users' Guide

Tabular Function (TF) Package Users' Guide

Transfer Process (TP) Package Users' Guide

Acknowledgments

The current authors of these revised MELCOR manuals would like to acknowledge the substantial contributions made over the past 15 years by the many previous MELCOR project members. The complete list of historical participants and contributors is far too lengthy to repeat here, and no such attempt will be made. The current release of MELCOR 1.8.5 was achieved with the help and participation of the following individuals:

Randall K. Cole	code development and testing	SNL
Salvador Rodriguez	code development and testing	SNL
Michael F. Young	code development and testing	SNL
Christine Erickson	configuration management	SNL
Ronald D. Gasser	code application and user support	SNL
Richard Gido	configuration management and user support	SNL
Mary Lou Garcia	secretarial support	SNL
Randall O. Gauntt	project leader and technical manager	SNL

Executive Summary

MELCOR is a fully integrated, engineering-level computer code whose primary purpose is to model the progression of accidents in light water reactor nuclear power plants. A broad spectrum of severe accident phenomena in both boiling and pressurized water reactors is treated in MELCOR in a unified framework. Current uses of MELCOR include estimation of fission product source terms and their sensitivities and uncertainties in a variety of applications.

The MELCOR code is composed of an executive driver and a number of major modules, or packages, that together model the major systems of a reactor plant and their generally coupled interactions. Reactor plant systems and their response to off-normal or accident conditions include:

- thermal-hydraulic response of the primary reactor coolant system, the reactor cavity, the containment, and the confinement buildings,
- core uncovering (loss of coolant), fuel heatup, cladding oxidation, fuel degradation (loss of rod geometry), and core material melting and relocation,
- heatup of reactor vessel lower head from relocated fuel materials and the thermal and mechanical loading and failure of the vessel lower head, and transfer of core materials to the reactor vessel cavity,
- core-concrete attack and ensuing aerosol generation,
- in-vessel and ex-vessel hydrogen production, transport, and combustion,
- fission product release (aerosol and vapor), transport, and deposition
- behavior of radioactive aerosols in the reactor containment building, including scrubbing in water pools, and aerosol mechanics in the containment atmosphere such as particle agglomeration and gravitational settling, and,
- impact of engineered safety features on thermal-hydraulic and radionuclide behavior.

The various code packages have been written using a carefully designed modular structure with well-defined interfaces between them. This allows the exchange of complete and consistent information among them so that all phenomena are explicitly coupled at every step. The structure also facilitates maintenance and upgrading of the code.

Initially, the MELCOR code was envisioned as being predominantly parametric with respect to modeling complicated physical processes (in the interest of quick code execution time and a general lack of understanding of reactor accident physics). However, over the years as phenomenological uncertainties have been reduced and user expectations and demands from MELCOR have increased, the models implemented into MELCOR have become increasingly best estimate in nature. The increased speed (and decreased cost)

of modern computers (including PCs) has eased many of the perceived constraints on MELCOR code development. Today, most MELCOR models are mechanistic, with capabilities approaching those of the most detailed codes of a few years ago. The use of models that are strictly parametric is limited, in general, to areas of high phenomenological uncertainty where there is no consensus concerning an acceptable mechanistic approach.

Current uses of MELCOR often include uncertainty analyses and sensitivity studies. To facilitate these uses, many of the mechanistic models have been coded with optional adjustable parameters. This does not affect the mechanistic nature of the modeling, but it does allow the analyst to easily address questions of how particular modeling parameters affect the course of a calculated transient. Parameters of this type, as well as such numerical parameters as convergence criteria and iteration limits, are coded in MELCOR as sensitivity coefficients, which may be modified through optional code input.

MELCOR modeling is general and flexible, making use of a "control volume" approach in describing the plant system. No specific nodalization of a system is forced on the user, which allows a choice of the degree of detail appropriate to the task at hand. Reactor-specific geometry is imposed only in modeling the reactor core. Even here, one basic model suffices for representing either a boiling water reactor (BWR) or a pressurized water reactor (PWR) core, and a wide range of levels of modeling detail is possible. For example, MELCOR has been successfully used to model East European reactor designs such as the Russian VVER, and RMBK-reactor classes.

This update of the MELCOR computer code manuals corresponds to MELCOR version 1.8.5, released to users in October 2000. The new version contains many new modeling features as well as improvements to existing models. New models include an iodine chemistry model, a passive autocatalytic recombiner model, many improvements to the core degradation modeling, updates to several of the code default values, improvements to the hygroscopic aerosol model, and enhancements to both the user control function feature and plotting features.

While the new MELCOR release provides many improvements over the previous version, post-MELCOR 1.8.5 development activities continue, with a particular focus on further improvements to the core degradation modeling, including incorporating the core/baffle structure into the COR package and improving the modeling of crusts and molten pool regions, both to achieve a better simulation for the TMI-2 accident progression. Core reflood modeling is also in progress.

The MELCOR 1.8.5 code manuals are contained in two volumes. Volume 1 contains a primer that describes MELCOR's phenomenological scope, organization (by package), and documentation. The remainder of Volume 1 contains the MELCOR User's Guides, which provide the input instructions and guidelines for each package. Volume 2 contains the MELCOR Reference Manuals, which describe the phenomenological models that have been implemented in each package. A new volume to this publication is added with the MELCOR 1.8.5 release that contains a portfolio of sample demonstration problems. These problems are a combination of experiment analyses, which illustrate code model

performance against data, and full plant analyses showing MELCOR's performance on larger realistic problems.

MELCOR Primer

The MELCOR code models a wide range of physical phenomena including thermal-hydraulics; heat transfer; aerosol physics; the heatup, degradation, and relocation of reactor cores; ex-vessel debris behavior; and fission product release and transport. It was developed to model the progression of accidents in light water nuclear power plants, but many other applications are clearly possible.

This primer provides a starting point in understanding MELCOR and learning how to apply it. It includes an overview of the file structure, user input conventions, and the mechanics of running the code, as well as general descriptions of the phenomena modeled and of the supporting properties and utility modules that are included in MELCOR.

The information contained here is—by itself—far from sufficient to allow a new user to successfully run MELCOR. However, it provides an essential overview and introduction to the balance of the code documentation.

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1. Introduction

MELCOR is a fully integrated, relatively fast-running code that models the progression of accidents in light water reactor nuclear power plants. An entire spectrum of accident phenomena is modeled in MELCOR. Characteristics of accident progression that can be treated with MELCOR include the thermal-hydraulic response in the reactor coolant system, reactor cavity, containment, and confinement buildings; core heatup and degradation; radionuclide release and transport; hydrogen production, transport, and combustion; melt ejection phenomena; core-concrete attack; heat structure response; and the impact of engineered safety features on thermal-hydraulic and radionuclide behavior.

MELCOR has been designed to facilitate sensitivity and uncertainty analyses through the use of sensitivity coefficients. Many parameters in correlations, which are hardwired constants in most codes, are implemented as sensitivity coefficients in MELCOR. Sensitivity coefficients can be changed by the user through input as discussed in the MELCOR/MELGEN Users' Guide and in the Users' Guides for each package. For example, the coefficients in a heat transfer correlation are usually assumed to be constant. However, in MELCOR the constants are coded as sensitivity coefficients that can be changed by the user to determine the sensitivity of the results to the heat transfer correlation.

The documentation of MELCOR is divided into two areas:

- (1) Users' guides and
- (2) Reference manuals, generally written for each package in MELCOR.

The various packages are listed later in this document. Input instructions and guidelines for each package are given in the appropriate Users' Guide. The phenomenological models that have been implemented are documented in each package's reference manual. The purpose of this primer is to guide the uninitiated user through the extensive MELCOR documents.

2. General Program and File Relations

MELCOR is executed in two parts. The first part is called MELGEN, in which the majority of input is specified, processed, and checked. When the input checks are satisfied, a Restart File is written for the initial conditions of the calculation. The second part of MELCOR is the MELCOR program itself, which advances the problem through time based on the input to MELGEN and any MELCOR input. Graphics post processing is provided by the HISPLT program.

The files used by MELGEN and MELCOR are:

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- User Input** - The MELGEN User Input File contains the majority of the user input defining the problem for MELCOR. MELGEN processes and checks this input and creates a Restart File for MELCOR. MELCOR relies on the Restart File for the bulk of its input. Some timestep, problem duration, and edit information is supplied via the MELCOR User Input File. The input data for MELGEN, MELCOR, and HISPLT can be combined into a single computer file.
- Output** - Both MELGEN and MELCOR generate printed output, all of which is written to their respective normal Output Files. Selected information is written also to the Diagnostic, Message, and Terminal Files, as discussed below, for the convenience of the user. The Output Files echo the User Input Files with a complete listing of all user input. The MELGEN Output File gives a full listing of all processed data, including time-independent data. The MELCOR Output File contains successive edits of time-dependent data written to it at time intervals determined by the user.
- Plot** - The values of all MELCOR plot variables are written to the Plot File at time intervals determined by the user. This file is read by the HISPLT [1] graphic post-processing program, which generates a graphics metafile containing plots requested by the HISPLT User Input File. The metafile data can be directed to an interactive terminal or hardcopy plotter.
- Restart** - The MELCOR database, containing all the necessary data to restart MELCOR, is written to the Restart File at time intervals determined by the user. MELGEN generates the initial Restart File containing the initial conditions of the problem set up by user input. MELCOR extends this file as required.
- Message** - Special messages are written to the Message File. This file is written only by MELCOR and contains the occurrence time of significant events such as vessel bottom head failure, melt ejection, hydrogen burns, etc. As a user convenience, the Message File is copied to the end of the Output File at execution termination.
- Diagnostic** - The Diagnostic File contains certain diagnostic messages generated by MELGEN and MELCOR, including error messages and warnings that are useful to the user. As a user convenience,

the Diagnostic File is copied to the end of the Output File when there is an abnormal calculation abort.

- Extended Diagnostic - The Extended Diagnostic File contains more complete diagnostic information than the Diagnostic File but retains only the latest messages. This file is most useful to the developers to trace code problems that the user cannot control.
- Terminal - The Terminal File (or Batch Job "Log" File) contains direct terminal output from MELCOR giving a brief summary of the course of the calculation. In addition to special messages, the problem time, timestep, and CPU time are written to this file as requested by the user.
- Stop - The user may create this file at any time during a batch MELCOR execution. If this file is present, the MELCOR calculation is terminated and data are written to the Output, Plot, and Restart Files for the last cycle.
- Mail - The user may create this file at any time during a batch MELCOR execution. If this file is present, MELCOR will create a short summary of the state of the calculation and mail it to the user. The purpose of this feature is to give the user informed control over batch jobs.

The controls for these files are found in the Executive Package Users' Guide. The relationship between MELGEN, MELCOR, and HISPLT as well as the above files is shown in Figure 2.1. MACCS [2], also shown in Figure 2.1, is a program to determine off-site consequences of fission product releases to the environment.

The Diagnostic and Message Files should be closely examined following every run. The Diagnostic File contains error messages or other information that may indicate a problem with the initial conditions specified in MELGEN or with the MELCOR calculation. The user should examine this file after every run to determine if the results may be suspect. The Message File contains information concerning the timing of important events such as combustion of gases, failure of the lower head, and others. This file provides a summary of the events in the calculation without having to look through the entire output file. All the messages in these two files (Message and Diagnostic) are also included in the Output file. The Message File also contains information about the Restart File.

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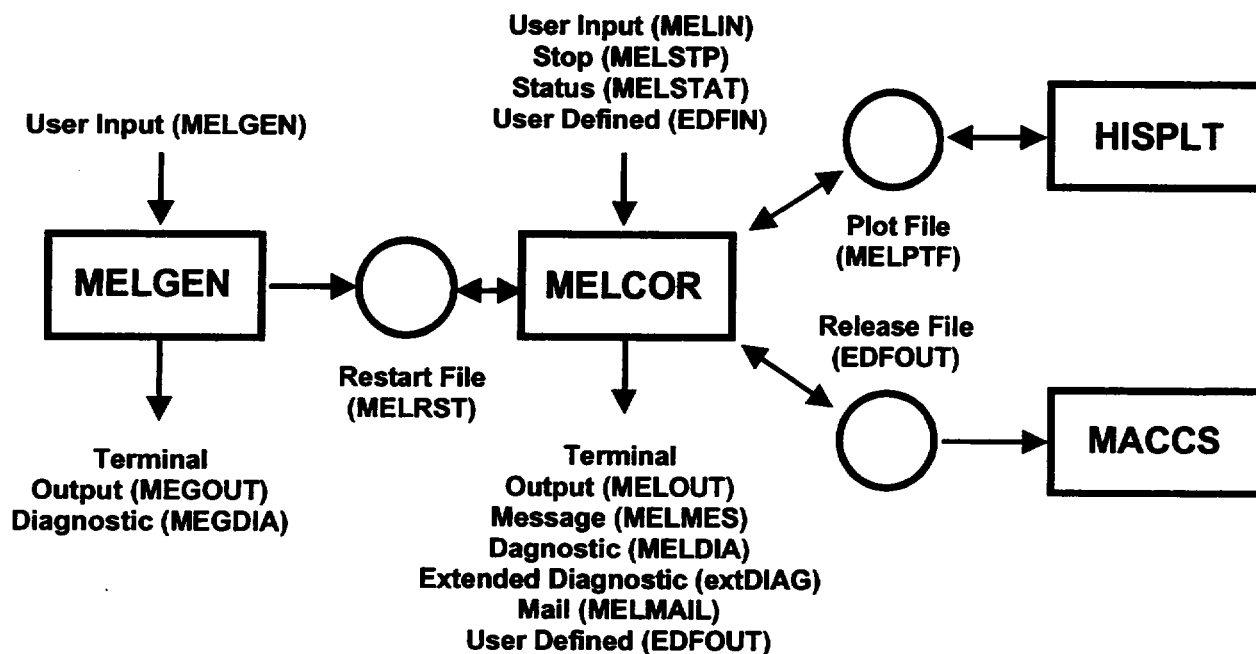


Figure 2.1 MELCOR Code and File Relations

The extended Diagnostic File contains more complete information useful to the developer when a calculation aborts. All diagnostic messages are saved in this file. Periodically, the earlier half of these messages is discarded to limit the file size.

3. MELCOR Packages

MELCOR is composed of a number of different packages, each of which models a different portion of the accident phenomenology or program control. For example, the Control Volume Hydrodynamics (CVH) package calculates the thermal-hydraulics of control volumes, and the Core (COR) package evaluates the core behavior. Each of the packages presently in MELCOR is listed below with a brief description:

- BH - Bottom Head. This model was developed by the Oak Ridge National Laboratory, and is an alternative to the lower plenum modeling in COR.
- BUR - Burn (Combustion) of Gases. Compares conditions within control volumes against criteria for deflagrations and detonations. Initiates and propagates deflagrations involving hydrogen and carbon monoxide. Calculates burn completeness and flame speed.

- CAV - Core-concrete Interactions. CORCON-MOD3 with enhanced sensitivity analysis and multi-cavity capabilities.
- CF - Control Functions. Evaluates user-specified "control functions" and applies them to define or control various aspects of the computation such as opening and closing of valves; controlling plot, edit, and restart frequencies; defining new plot variables, etc.
- COR - Core Behavior. Evaluates the behavior of the fuel and other core and lower plenum structures including heatup, candling, flow blockages, debris formation and relocation, bottom head failure, and release of core material to containment.
- CVH - Control Volume Hydrodynamics. In conjunction with the FL package, evaluates mass and energy flows between control volumes.
- CVT - Control Volume Thermodynamics. Evaluates the thermodynamic state within each control volume for the CVH package. No users' guide is written for this package since no user input is required. However, a reference manual is written.
- DCH - Decay Heat. Used by other packages to evaluate decay heat power associated with radionuclide decay.
- EDF - External Data Files. Controls the reading and writing of large external data files, in close interface with the Control Function and Transfer Process packages.
- EOS - Equation of State. The CVT, H2O, and NCG packages are stored as one block of code under this name.
- ESF - Engineered Safety Features. Models the thermal-hydraulics of engineered safety features that cannot be effectively modeled by building appropriate components or systems using the CVH, FL, HS, and CF packages. Currently, only the fan cooler model is included in ESF; the containment sprays are modeled in the SPR package.
- EXEC - Executive Package. Controls execution of MELGEN and MELCOR.

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- FDI - Fuel Dispersal Interactions. Models ex-vessel debris relocation, heat transfer, and oxidation due to fuel-coolant interactions and high pressure melt ejection.
- FL - Flow Paths. Models, in conjunction with the CVH package, the flow rates of gases and liquid water through the flow paths that connect control volumes.
- H2O - Water Properties. Evaluates the water properties based on the Keenan and Keyes equation of state extended to high temperatures using the JANAF data. This set of routines is in the "EOS" code package. No user input is required.
- HS - Heat Structures. Models the thermal response of heat structures and mass and heat transfer between heat structures and control volume pools and atmospheres. Treats conduction, condensation, convection, and radiation, as well as degassing of unlined concrete.
- MP - Material Properties. Evaluates the physical properties of materials for other packages except for common steam and noncondensable gas properties (see H2O and NCG).
- NCG - NonCondensable Gas Equation of State. Evaluates the properties of noncondensable gas mixtures using an equation of state based on the JANAF data. This set of routines is in the "EOS" code package.
- PAR - Passive Autocatalytic Hydrogen Recombiner. Includes general models for modeling hydrogen recombiners in the containment rooms.
- PROG - Part of MELGEN/MELCOR Executive package separated for computer library and link purposes.
- RN - Radionuclide Behavior. Models radionuclide releases, aerosol and fission product vapor behavior, transport through flow paths, and removal due to ESFs. Allows for simplified chemistry.
- SPR - Sprays. Models the mass and heat transfer rates between spray droplets and control volumes.
- TF - Tabular Functions. Evaluates user-selected "tabular functions" to define or control various aspects of the computation such as

mass and energy sources; integral decay heat; plot, edit, and restart frequencies, etc.

- TP - Transfer Process. Controls the transfer of core debris between various packages and the associated transfer of radionuclides within the RN package. In order to transfer core material between packages, some TP input is required, and is described in the COR, FDI, and CAV package Users' Guides.
- UTIL - Utility Package. Contains various utilities employed by the rest of the code.

Users' guides for all packages with user input are included in Volume 1 of the MELCOR Computer Code Manuals. General input information, including the general format of input records and instructions for modification of sensitivity coefficients, appears in the Executive (EXEC) Package Users' Guide. Reference manuals for the BH, BUR, CAV, COR, CVH/FL, DCH, CVT, FCL, FDI, HS, MP, NCG/H₂O, PAR, RN, and SPR packages are included in Volume 2. (Additional reference materials for several of the codes and models that have been imported into MELCOR are available separately.)

Most of these packages may be either active or inactive during a calculation. EXEC, CVH, CVT, and some of the utility packages are always active in any calculation. The default for most of the other packages is that they are inactive. For example, the default for the BUR package is inactive. Therefore, combustion will not be calculated to occur in MELCOR unless the package is activated. Usually, all packages are activated in the analysis of a full plant accident. The status of each package is given in the MELGEN output.

4. Getting Started

Experience has shown that starting with very simple thermal/hydraulic problems involving just the Executive (EXEC), Control Volume Hydrodynamics (CVH) and Flow Path (FL) packages is a very good way to learn the general features of MELCOR without being overwhelmed. After the CVH and FL packages are well understood, a simple problem can be gradually increased in complexity by adding input for additional packages. A suggested order might be to next learn the Control Function (CF) and Tabular Function (TF) utility packages in conjunction with simple valve operation, followed by the Heat Structure (HS) and Material Properties (MP) packages to model simple structures such as pipe or room walls. The NonCondensable Gas (NCG) and Burn (BUR) packages could then be introduced to add more thermodynamic complexity. Actual reactor core behavior is simulated by the Core (COR) package, which could then be added along with the Decay Heat (DCH) package using the ANS decay curve option. The BH package could then be added to give detailed analysis of the lower head.

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Addition of the Engineered Safety Features (ESF) and Sprays (SPR) packages can be attempted at any time once the basic thermal-hydraulics are understood. Inclusion of the Radionuclide (RN) package should probably await a thorough understanding by the user of all the aforementioned thermal-hydraulics-oriented packages. Finally, the Fuel Dispersal Interactions (FDI) and Cavity (CAV) packages can be added, along with the Transfer Process (TP) package to control the interfaces between them and with the COR package.

A set of small test problems is available to aid in user training and code testing. New users might profit from study of these input sets [3]. A growing set of assessment reports is available for more complex situations [4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20]. Some sample input decks are available on the Worldwide Web at URL <http://melcor.sandia.gov>. Additionally, a Volume 3 to this document is available which presents a portfolio of demonstration problems, including input decks and plotted code results, which illustrates the use of MELCOR on a variety of real problems. The demonstration problems are a combination of relevant experiments and full plant analyses.

Once the user is comfortably familiar with the basics of MELCOR input, the demonstration problem supplied with MELCOR distribution is useful to study to see how the packages interact with each other. However, be aware that this sample problem is simply designed to exercise all MELCOR packages through a complete transient in a short calculation, and that it is not intended to represent any real system nor recommended approaches to modeling real systems.

MELCOR was originally designed to be run with relatively large timesteps and coarse nodalizations for most large integral plant calculations. For a simple full reactor plant model, a base case nodalization, including reactor coolant system, containment, and auxiliary buildings, will involve typically 15 to 25 control volumes, 100 to 200 heat structures, 3 or 4 core rings, and 10 to 15 core/lower plenum levels. Sensitivity studies on a particular aspect of the sequence may dictate use of finer nodalization for some systems. Complex plant models that treat in-vessel and RCS natural circulation could make use of significantly more detailed CVH nodalization in these regions.

User-imposed maximum timesteps should range from 5 to 10 seconds during the portion of an accident sequence dominated by in-vessel thermal-hydraulics and core melt progression and from 20 to 30 seconds during the portion dominated by containment thermal-hydraulics and molten core-concrete interactions. Although many MELCOR models will reduce the timestep to lower values when needed, very rapid phenomena, certain phenomenological events, or numerical problems encountered by the code may necessitate use of a smaller maximum timestep supplied by the user for portions of the transient. As a result, the current code is somewhat dependent on the skill of the user to select proper timesteps until additional automatic timestep controls are developed.

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Executive (EXEC) Package Users' Guide

The MELCOR Executive (EXEC) package is responsible for overall execution control of MELGEN and MELCOR calculations. It coordinates various processing tasks for other MELCOR packages, including file handling, input and output processing, sensitivity coefficient modification, system timestep selection, time advancement, and calculation termination.

This document describes general input philosophy and the Executive package input required for MELGEN and MELCOR. Control directives for input processing are covered, and generic instructions for modification of sensitivity coefficients defined by other packages are given. Specific input requirements for phenomenological models in other packages are described in the users' guides for those packages. An introduction to the capabilities of MELCOR, its overall philosophy and design, and the MELCOR documentation set is given by the MELCOR Primer.

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1. Introduction

MELCOR executes in two parts. The first is a program called MELGEN, in which most of the input is specified, processed, and checked. When the input checks are satisfied, a restart file of all the information in the MELCOR database is written for the initial conditions of the calculation. The second part of MELCOR is the MELCOR program itself, which advances the problem through time based on the database generated by MELGEN and any additional MELCOR input.

MELGEN and MELCOR share a structured, modular architecture that facilitates the incorporation of additional or alternative phenomenological models. This structure consists of four primary levels. The top level is the Executive (EXEC) package, which consists of subroutines that coordinate the execution of various processing tasks and control the overall calculation sequence. The next level is composed of the database manager routines, which pass the required portions of the MELCOR database to the third level, containing the various modules or packages. Each package models a well-defined group of closely related phenomena or performs a well-defined special function. A unique two- or three-character alphanumeric identifier is assigned to each package and incorporated into the names of its subroutines and common blocks. The fourth level consists of routines performing utility-level functions such as matrix inversion, ODE integration, or transfer of mass and energy between packages. Many of these routines are contained in the MELCOR Utility (UTIL) package, which requires no user input.

In MELGEN, the Executive package calls the other MELCOR packages for each of several processing tasks that must be performed to set up and initialize the MELCOR database. The first task involves initializing all common block variables, including database pointers, sensitivity coefficients, and internal database variables, to default values. Next, all MELGEN input and output files are opened and the user input file is preprocessed to sort input records and store input data in a standard format ready for later retrieval by various packages. Input needed directly by the Executive package is then processed, and any sensitivity coefficient changes are made as prescribed by user input (see Sections 4, 5, and 7).

Most of the computational effort in MELGEN takes place during three passes of input processing. During the first pass, each package is called by the Executive package to read all the user-specified data for that package, to recalculate its database pointers for the size of the problem defined by the input, and to perform as much data initialization and error checking as is practical using only data within that package. During the second pass, each package is called by the Executive package to complete the initialization of its database with data defined in other packages during the first pass, and to perform consistency checks with other packages' data. The third pass initializes Control Functions (see the Control Function Package Users' Guide) that may depend on package data arguments defined during the second pass.

Input processing proceeds completely through each pass, but the next pass is not attempted if errors have been detected during a pass. After all input has been processed to the extent allowed, the Executive package calls each package to generate printed output and, if no fatal errors have been detected in any pass, to write the initial database into the restart file.

MELCOR execution involves two steps:

- (1) a setup mode, during which the database (generated at time zero by MELGEN or at a later time by a previous MELCOR run) is read from the restart file and any additional input is processed, and
- (2) a run mode, which advances the simulation through time, updating the time-dependent portions of the database each cycle and periodically writing the updated database into the restart file.

During setup mode, many of the tasks performed in MELGEN are repeated, including common block initialization, file opening, input preprocessing, sensitivity coefficient modification, and Executive package input processing. After the database is read from the restart file, any additional package input is read, processed, and checked with the database for consistency.

The heart of MELCOR is, of course, the problem advancement phase. The Executive package first checks to see whether it is time to end the calculation or to generate the next output edit, plot dump, or restart dump. If so, each active package is called in turn to perform the appropriate task. The Executive package then calculates the new system timestep (fixed for all packages), subject to the minimum and maximum specified by user input and according to requests by the packages themselves from the previous timestep.

Advancement across the Executive package timestep proceeds in three stages, with a loop through all active packages in each stage. The first stage allows all packages to initialize any interface of communication arrays needed by other packages during the advancement. The second stage performs the time advancement for each package, any of which may elect to subcycle across the Executive package timestep using smaller steps. A package may also elect to call for a fallback, in which case the Executive package repeats the entire current cycle with a smaller timestep. The third stage of the advancement allows each package to examine the results of calculations by other packages during the second stage. If calculated changes are excessive, a fallback may be called for at this point.

MELCOR's restart capability is extremely flexible. Each restart dump in the restart file contains all parts of the problem database required to restart MELCOR and continue the calculation. Restart dumps are generated by MELCOR at intervals specified by the user, based on either simulation time or central processing unit (CPU) time, and at the end of the calculation. Special restart dumps are also generated at key events such as vessel or containment failure. Sensitivity coefficients and selected MELCOR input variables can be

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changed at a restart to examine different calculation scenarios from that point, thus eliminating the need to repeat portions of the calculation that do not change. MELCOR restarts are exact; that is, a calculation restarted at some point with no change in input will continue along the identical calculational path that the code would have taken if it had not been stopped and restarted at that point.

One of the most important output files generated during a MELCOR run is the plot file, which contains data necessary to plot time histories of many of the variables calculated during the advancement. Although the volume of data involved is already substantial, there are many variables that a user *might* wish to plot that are not included in the file because their inclusion could make the file unmanageably large. Many of these variables are available as control function arguments, which are not directly plottable. In the past, users have been forced to deal with such variables by defining control functions "EQUAL" to the corresponding arguments. The values of these control functions, which are automatically included in the plot file, can then be plotted. (See the Control Function Package Users' Guide for details.)

Although this approach works, it is cumbersome, and often requires the definition of hundreds of control functions. Further, because all control functions must be defined in MELGEN, there is no way to add a variable to the plot file without rerunning the entire calculation. A capability has therefore been developed to allow the user to directly define a list of control function arguments to be added to the plot file in MELGEN, and to add to that list at the start, or at any restart, of MELCOR, under the control of the executive package. The necessary input is defined in Sections 4 and 5 of this Users' Guide, under the description of the PLOTxxx record.

2. MELGEN/MELCOR Input Format

Commands to MELGEN and MELCOR are contained in one or more input files. The file name is entered at the code prompt or (on most computer systems) as a parameter on the execution line.

A free-format processor (the INPPRE utility in the MELCOR Utility package) is used to preprocess all input. Every record must either have a valid identifier field, or must be an input directive record (which controls overall processing options), a comment record, or the terminator record.

The leftmost field is interpreted as an identifier field. After input processor directives have been processed, all active input records are sorted by identifier field so the input is order independent (as long as there are no duplicate identifier fields). Duplicate or "replacement" records are discussed below. The collocation sequence is:

0,1,2,...,8,9,A,B,C,...,X,Y,Z

Only alphanumeric characters may be used for identifier fields; upper and lower case letters are equivalent. User input data fields may be integers, logicals, single precision reals, double precision reals or character data. FORTRAN COMPLEX data is not supported. For example:

```
IDENT 0 1. 1.E28 1.D29 .FALSE. 'CHARACTER DATA'
```

Delimiters are blanks or commas. Multiple delimiters have the same effect as one delimiter. For example, the following three records are identical:

```
IDENT 4.4 5.5 6.6
IDENT,,,,,4.4,,,,,5.5,,,,,6.6
IDENT , 4.4 , 5.5 , 6.6
```

Character data may be enclosed by single quotes. If there are no internal blanks or commas, and the string cannot be interpreted as a number, then the single quotes may be left off. For example, the following record contains an identifier field and four character data fields:

```
IDENT BOY 'BIG BOY' '1.1' 'MY,FAVORITE,YEAR'
```

All input is case insensitive. Lower case characters are automatically converted to upper case except for character strings enclosed by single quotes. For example, the following three statements are identical:

```
ident george 1.e7
IDENT GEORGE 1.E7
Ident George 10000000.
```

When single quotes are used the situation changes. In the following the parameters are all different:

```
ident george filename
IDENT 'george' 'filename'
Ident 'George' 'Filename'
```

MELCOR packages access and interpret a specific input record by calling the CRACKR utility in the UTIL package and specifying all or part of the identifier field. CRACKR then locates the appropriate record and provides to the calling package the number of data fields and the type and value of each data field on that record. If the number of fields or their type (i.e., real, integer, logical, or character) does not agree with those expected, the calling package processes an error message.

A comment record has an asterisk (*) as the leftmost non-blank character. All characters to the right of an asterisk are interpreted as comments. Note, however, the command

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EOR as described in Section 3 is not a comment. Completely blank lines are considered comments. An example of a comment line is:

```
* THIS RECORD IS JUST A LITTLE OLD COMMENT
```

A comment field may follow a non-comment field on the same record. For example:

```
IDENT 4.4 5.5 * FORWARD AND REVERSE LOSS COEFFICIENTS
```

In some situations MELCOR uses multi-word parameters. In general the input processor will accept these quantities with blank separator in single quotes or - separator formats. For example, "STAINLESS STEEL OXIDE" can be referenced in a heat structure as

```
HS00011201 'STAINLESS STEEL OXIDE'  
HS00011201 stainless-steel-oxide  
hs00011201 Stainless-Steel-Oxide
```

In general, lower case characters should not be used in multi-word parameters inside single quotes, since they will then not be converted to upper case and may then not match the appropriate identifier or filename. See the individual package users' guides for details.

In some cases the identifier records allow optional trailing characters. This situation is denoted in this manual as

```
RESTARTF*ILE
```

For this input form, the code will recognize RESTARTF and RESTARTFILE as the same input. Only one form should be used in a given input set. This feature does not apply to the input processor directives in Section 3.

The last record in an input stream must be the terminator record. It has only a period and may optionally have a comment. For example:

```
. * THAT'S ALL FOLKS
```

The default processing of duplicate records (those with the same identifier field) generates a fatal error. An input processor record "ALLOWREPLACE" permits a duplicate record to replace any and all records with the same identifier field that appears earlier in the input stream.

The format of each MELGEN or MELCOR input record is specified in the Users' Guide for the package to which that input records belongs. For example, the specification of records describing hydrodynamic control volumes will be found in the CVH Users' Guide, while that for records describing control functions will be found in the CF Users' Guide.

All such record specifications have the same general form. For example, a hypothetical input record might be specified as

ABCnnnXX - Object Definition Record

000 ≤ nnn ≤ 999 is the user number of some object
Optional

- (1) NAME - User-defined name of the object
(type = character*20, default = none)
- (2) VAR - Value of a variable names "VAR"
(type = real, default=0.0, units = kg/s)

This describes a record with an IDENT field ABCnnnXX in which the user-defined number of an object (a volume, flow path, or such) is embedded. The record may have one or two additional fields. The first is a CHARACTER name, of maximum length 20 characters, the second, which is optional, must contain a real number if it is present. If absent, the value 0.0 will be assumed. Thus, the record

ABC101XX Peter 9.8

defines an object with the user number 101 and the associated name "Peter." The variable VAR has been assigned a value 9.8. Similarly

ABC857XX "Paul"

defines an object with the user number 857 and the associated name "Paul." The default value of 0.0 will be assigned to the variable VAR. Note that none of the records

ABC123XX 'Extremely long, verbose name' *NAME too long
ABC456XX 9.8 *NAME wrong type
ABC789XX Mary -1 *VAR wrong type

is valid, for the reasons noted in the trailing comments. In addition, none of the records

ABC1Y2XX "Tom" 37.
ABC12XX Dick -4
ABC6789XX -4 Harry

will be recognized and processed as an ABCnnnXX record because the IDENT fields do not have the correct form.

3. Input Processor Directives

There are several input commands, termed input processor directives, that control the processing of the other input. For the most part, these commands appear as any other command except when an error occurs.

ALLOWREPLACE – Allow replacement records

Optional

Records with the same identification field are duplicates. The default is to treat these duplicate or replacement records as a fatal error. This command allows replacement records where only the last record in the input set with the duplicate field is retained. A warning message is generated by replacement.

The intended use of the replacement record feature is to permit changes in QA'd and other protected input sets without having to edit the input itself. Sensitivity studies and other changes can be completed without disturbing the base case input set. When this feature is desired, the ALLOWREPLACE command is required.

This record must be placed in the input set before any replacement records. It must also be in the active range defined by any *EOR* records as described below.

EOR – Record to allow input to many codes in same file

Optional

Input sets are often moved between different computers and users in modern computer environments. All related input files for MELGEN, MELCOR, HISPLT, and other related programs can be combined into a single computer file by use of the *EOR* NAME directive. This command is designed to ensure that all the different input sets for a single problem do not get separated. The file structure is:

```
*EOR* MELGEN
:
MELGEN input with . terminator
:
*EOR* MELCOR
:
MELCOR input with . terminator
:
*EOR* HISPLT
:
HISPLT input
:
```



```

*EOR* anything else
:
  Ignored by MELGEN, MELCOR, and HISPLT
:
{end of file}

```

The leading * must be in column 1 and the record is case insensitive. These commands are basically input on/off toggles. For example, MELCOR will process only data following an *EOR* MELCOR up to the next *EOR* record or end of file. Multiple *EOR* records with the same name are allowed. This permits deactivation of a section of input by bracketing it with *EOR* records. Any records before the first *EOR* will be processed (default processing mode is on). However, since the only records recognized by all three MELCOR processing codes (MELGEN, MELCOR, and HISPLTM) are comment records, only comments common to all three codes should normally appear before the first *EOR* record. Only records in the active range for the processing code being used are echoed to the code output listing. Other information outside of the active range is ignored.

If *EOR* records are not used in input, all records in the input file are processed.

Note that the *EOR* records are not comment records as discussed in Section 2 since they are recognized and processed by the preprocessor.

R*I*F – Redefine Input File

The R*I*F command allows the input set to be spread over multiple files. This record has the identifier field R*I*F followed by a filename. The file contains input data and the last record is a terminator record. The file is read into the input string at the current position. After the new file's terminator record is read, the new file is closed and reading continues with the next record in the original file. R*I*F directives may be nested eight layers deep. An input file might look like the following:

```

:
:
R*I*F  CVHDAT      * CVH INPUT DATA
R*I*F  CORDAT     * CORE INPUT DATA
R*I*F  RNDAT      * RADIONUCLIDE INPUT DATA
R*I*F  HSDAT      * HEAT SLAB INPUT DATA
:

```

4. MELGEN Input

During MELGEN execution, the Executive package either prompts the user for an input filename or reads the filename as an execution line parameter.

MELGEN fname*

It is noted that this might not work with an executable compiled with the Digital FORTRAN compiler. All the input for the MELGEN execution is in this file. If the user responds to the input prompt with a carriage return only (blank filename), then MELGEN attempts to read input from the file MELGIN. Only the TITLE record is required, but the DTTIME record is strongly recommended for use in MELGEN instead of MELCOR.

Like all input in the MELCOR suite of codes, each MELGEN input record has an identifier field followed by the input data fields, as discussed in Section 2. The MELGEN input records are listed in alphabetic order below.

In the following, the 80-character limit should be used cautiously because only the first 80 characters of a record are recognized. As a result, less than 80 characters actually are available because of the characters required for the variable name and any spaces.

CRTOUT – Edit format flag for 80-column output Optional

Most package output routines will generate 80-column output if the CRTOUT record is present. This would be useful for examining output on an antique 80-column terminal in the unlikely event that anyone might still have such outdated article in his or her possession. If this record is not present, then some packages format output for 132-column line printers. There is no additional input for this record.

DIAGF*ILE – Filename for diagnostic output Optional

The diagnostic output from MELGEN is written to the file named on this record. If this record is not present, the diagnostic output is written to MEGDIA.

(1) DIAGFILE - Filename for diagnostic output file.
(type = character*80, default = MEGDIA)

Note that the input processor by default converts lower case characters to upper case. If a lower case filename is desired, enclose the filename in single quotes.

DTIME – Initial timestep

Optional

This record defines the initial timestep for MELCOR execution. If this record is not present, then an initial timestep of 1 s is used. MELCOR will use the timestep fallback capabilities if the initial timestep is not appropriate for the transient.

- (1) DT - Initial timestep.
 (type = real, default = 1.0, units = s)

JOBID – Job identifier

Optional

By default, each execution is assigned a unique computer-generated job identification. This record allows the user to override the default. The job identification appears in all output from the execution including plots from HISPLT.

- (1) JOBID - Job identifier field.
 (type = character*7, default = unique character string)

OUTPUT*ILE – Filename for output listing file

Optional

The listing output from MELGEN is written to the file named on this record. If this record is not present, the output is written to MEGOUT.

- (1) OUTPUTFILE
 - Alternate filename for all listable output.
 (type = character*80, default = MEGOUT)

Note that the input processor by default converts lower case characters to upper case. If a lower case filename is desired, enclose the filename in single quotes.

PLOTxxx – Control function argument to be plotted

xxx is any three-character alphanumeric string, used for sequencing only

Optional

These records may be used to add elements of the MELCOR database that are available as control function arguments to the plot file. Multiple records are required for arrays, because each record will add only a single variable. For example, plotting intact clad masses in multiple cells would require PLOTxxx records for the control function argument COR-MZR-CL.nnn for every cell (nnn) of interest. Variables added by PLOTxxx input records in MELGEN will be written to the plot file

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throughout the entire MELCOR calculation. Further variables may be added using PLOTxxx input records in MELCOR.

- (1) CHARG - Database element identifier (name of control function argument), including any indices. Refer to the Users' Guides for the various packages for permitted values.
(type = character*24, default = none)

RESTARTFILE – Filename for restart file

Optional

The binary restart file for cycle zero is written to the file named on this record. If this record is not present, then the restart file is written to MELRST.

(1) RESTARTFILE

- Filename for cycle zero restart file.
(type = character*80, default = MELRST)

Note that the input processor by default converts lower case characters to upper case. If a lower case filename is desired, enclose the filename in single quotes.

RUNONLY – Run only on specified code version

Optional

In some user environments, MELCOR code versions can be changed without the knowledge of all users. This can create problems with parametric studies which require exactly the same code to produce meaningful results. This command requires that the code must be the same as that specified by a two-character base code version identifier (e.g., 'QK' for MELCOR 1.8.4), which is identified in header information written to terminal output and to the normal output file at the beginning of execution. If this condition is not true, the execution will terminate.

- (1) ID - Two-character code version (e.g., 'NM').
(type = character*2, default = none, units = none)

TITLE – Title of the calculation

Required

Every calculation is required to have a title. This is written to the restart, edit, and plot files. The title on the MELCOR run must match a user-specified number of characters of the MELGEN title. If it contains blanks or if lower case characters are significant, the title must be enclosed in single quotes.

- (1) TITLE - Title of the calculation.
(type = character*80)

TSTART – Initial start time
Optional

The problem time may be set to a nonzero initial value. All package input must be consistent with the problem time.

- (1) TSTART - Initial problem time. Negative times are permitted.
(type = real, default = 0.0, units = s)

UNDEF – Redefine initialization of real database and scratch storage
Optional

This capability is of interest primarily to code developers, but the information is provided in the interest of completeness.

The real database for MELCOR is explicitly initialized in MELGEN to a value UNDEF. The same is done with the scratch storage area before each advancement by each package in MELCOR. By default, a value is used that is both recognizable and likely to cause a code abort; the intent is to increase the probability of detecting coding errors that result in undefined variables. On some systems, this value is the so-called IEEE "signaling Not a Number," and causes an interrupt when used as an operand in a floating point operation. On others, the value is -1.234E24. This input record allows the value of UNDEF to be changed, *but not set to 0.0*.

- (1) IUND - INTEGER equivalent to the REAL value UNDEF
(type = integer, default = machine dependent, equivalence = UNDEF)

IUND=2143289344 ≡ UNDEF='7fc00000'X on some machines using IEEE
(default on HPW)

IUND=2140143616 ≡ UNDEF='7f900000'X on some machines using IEEE
(default on I60 and SUN)

IUND=32768 results in UNDEF='80000000'X on VAXVMS *only*
(default on VAXVMS)

IUND=0 results in UNDEF= -1.234E24 rather than 0.0
(default on other machines)

5. MELCOR Input

The MELCOR Executive package either prompts the user for an input filename or reads the filename as an execution line parameter.

MELCOR frame

It is noted that this might not work with an executable compiled with the Digital FORTRAN compiler. All the input for the MELCOR execution is in this file. If the user responds to the input prompt with a carriage return only (blank filename), then MELCOR attempts to read input from file MELIN. If the input file cannot be opened, then the user will be asked if he wishes to try again. Only the CPULEFT, CPULIM, TIMEk, and TITLE records are required, but many of the remaining optional records are recommended for user convenience and flexibility.

Like all input in the MELCOR suite of codes, each MELCOR input record has an identifier field followed by the input data fields.

COMTC – Number of matching characters in MELGEN and MELCOR titles
Optional

Each MELGEN and MELCOR execution must have a title. A user specified number of the characters on these titles must agree for the MELCOR calculation to proceed. If the titles do not agree to the specified number of characters, then the calculation is stopped. This prevents the user from accidentally running the wrong problem. It also allows him to change the MELCOR runs, use the same MELGEN restart file and change the end of his title to reflect the differences in the runs. COMTC must be greater than or equal to 20 and less than or equal to 80. If the input value is less than 20, then it is set to 20.

(1) NCOMTC - Number of characters to compare in the two titles.
(type = integer, default = 20, units = none)

CPULEFT – Desired minimum number of cpu sec left at end of calculation.
Required

The calculation will stop after completing a cycle if the number of CPU seconds left in the calculation is less than the number input on this record. This record is used to stop the calculation with enough time to save files, generate plots, etc. This applies mainly to systems where jobs are submitted to a batch queue with a time limit. The description of the input MELCOR variable CPULIM discusses the method MELCOR uses in determining the number of CPU seconds remaining in a calculation.

(1) CPULEF - Desired minimum number of CPU seconds left at the end of the calculation. CPULEF must be non-negative.
(type = real, default = none, units = s)

CPULIM – Maximum number of CPU seconds allowed for this execution
Required

The maximum number of CPU seconds allowed for this execution is defined by the value for CPULIM input on this record. However, for some environments, a job CPU time limit *external to MELCOR* may also be imposed (for example, the maximum amount of job time defined on a batch submission utility). For some computer systems, the Executive package is able to determine this limit using a system-dependent utility. When the CPU time used plus the safety factor CPULEF (input on record CPULEFT) is greater than or equal to the minimum of CPULIM and the externally imposed CPU limit, then a restart dump and edit will be written and the calculation terminated.

For interactive computer environments, CPULIM can be set to a large number and the calculation controlled by the interactive menu.

- (1) CPULIM - Maximum number of CPU seconds allowed for this execution.
(type = real, default = none, units = s)

CRTOUT – Edit format flag for 80-column output
Optional

Most package output routines will generate 80-column output if the CRTOUT record is present. This would be useful for examining output on an antique 80-column terminal in the unlikely event that anyone might still have such outdated article in his or her possession. If this record is not present, then some packages format output for 132-column line printers. There is no additional input for this record.

CYMESF – Cycle Message Frequency Parameters
Optional

This record controls the frequency of the completed cycle messages written to the output and terminal files. One or two optional integer fields are allowed.

- (1) NCYEDD - Number of cycles between messages written to the terminal or job stream file (unit 6). This can be reset from the interactive menu, as described in Section 9.
(type = integer, default = 10, units = none)
- (2) NCYEDP - Number of cycles between messages written to OUTPUTFILE.
(type = integer, default = 1, units = none)

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DIAGFILE – Filename for diagnostic output file

Optional

The diagnostic output from MELCOR is written to the file named on this record. If this record is not present, the diagnostic output is written onto MELDIA.

- (1) DIAGFILE - Filename for diagnostic output.
(type = character*80, default = MELDIA)

Note that the input processor by default converts lower case characters to upper case. If a lower case filename is desired, enclose the filename in single quotes.

DTINCR – Timestep increase factor

Optional

MELCOR limits the increase in timestep between consecutive cycles to the ratio defined by this record. The default value allows an order of magnitude increase in timestep over five cycles.

- (1) DTINCR - Maximum increase factor allowed in timestep.
Allowed range $1 < DTINCR < 2$.
 $DT(next) \leq DTINCR * DT(last)$
(type = real, default = $10^{1/5} = 1.5848932$, units = none)

DTSUMMARY – Additional timestep data to output file

Optional

This record extends the edit of Δt information to the output file. One or two extra lines are produced for each cycle containing information on timestep requests by other packages. There is no additional input for this record.

DTTIME – Initial timestep

Optional

This record defines the initial timestep for this execution. If this record is not present, then the initial timestep read from the restart file is used.

- (1) DT - Initial timestep.
(type = real, default = from restart, units = s)

Normally, DTTIME should be input only in MELGEN and not in MELCOR. No differences will result when starting a new calculation at cycle = 0, but when restarting with cycle > 0, DTTIME will reset the timestep from what would be obtained in a single calculation without the restart, and results will be different.

EDITCF – Special edit control function
Optional

This record specifies the number of a LOGICAL valued control function that will generate an edit if its value is .TRUE. This is intended to force an edit at the time of some user-specified event. (If the control function is .FALSE., it will not prevent generation of an edit if requested by some other mechanism.)

- (1) IECF - This integer is the LOGICAL valued control function number.
(type = integer, default = none, units = none)

EXACTTIME_k – Define exact end-of-time-step times ($1 \leq k \leq 24$)
Optional

By default the timestep control does not attempt to “hit” any exact times in the determination of the values of Δt . The end-of-step time is simply the result of the summation of the Δt s to that time. This record tells the timestep control to reduce the timestep shortly before the specified time such that the end-of-step time matches the desired time exactly. The intended use for this record is to allow certain time-specified events, such as reactor scram, pump trip, or valve closure, to be matched exactly, thus eliminating a potential source of numerical sensitivity. Up to 25 times may be defined in any order.

- (1) TIME - Desired time.
(type = real, default = none, units = s)

Warning: This calculation will not override the minimum timestep DTMIN defined on the TIME_k input record. If multiple exact times are defined too close together, the later exact time will be ignored.

FORCEPLOT – Control of extra plot information following timestep cuts
Optional

If there is a large timestep drop between consecutive cycles, MELCOR will generate plot dumps in addition to those defined by the TIME_k records described in this document. This feature is designed to capture the features of rapid events which occur with unknown timing. This record allows the user to change the trigger for this feature and the maximum number of dump sequences generated.

- (1) DT_RATIO- Ratio of consecutive cycle timesteps to trigger extra plot dumps.
If $DT(i)/DT(i-1) < DT_RATIO$, extra dumps are generated.
DT_RATIO must be less than one.
(type = real, default = 0.2, units = none)

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(2) MAX_NUMBER_OF_SEQUENCES

- Maximum number of extra plot dump sequences allowed per execution (i.e., the number of extra dump sequences generated is reset to zero when restarting a calculation).
(type = integer, default=20, units = none)

JOBID – Job identifier Optional

By default, each execution is assigned a unique computer-generated job identification. This record allows the user to override the default. The job identification appears in all output from the execution including plots from HISPLT.

- (1) JOBID - Job identifier field.
(type = character*7, default = unique character string)

PLOTxxx – Control function argument to be plotted xxx is any three-character alphanumeric string, used for sequencing only Optional

These records may be used to add elements of the MELCOR database that are available as control function arguments to the plot file on restarts. Variables named on PLOTxxx input records in MELGEN will continue to be written to the plot file. Up to 50 further variables may be added using PLOTxxx input records at a MELCOR restart, and will be included in the plot file for the duration of the execution in which they are read.

- (1) CHARG - Database element identifier (name of control function argument), including any indices. Refer to the Users= Guides for the various packages for permitted values.
(type = character*24, default = none)

MESSAGE*ILE – Filename for event message output Optional

The event messages are written to the file named on this record. If the record is not present, then the messages are written onto file MELMES.

- (1) MESSAGEFILE
- Filename for special messages.
(type = character*80, default = MELMES)

Note that the input processor by default converts lower case characters to upper case. If a lower case filename is desired, enclose the filename in single quotes.

NOCOPY – Suppress copy of files to output file
Optional

By default MELCOR will copy the message file (and diagnostic file in an error condition) to the end of the normal output file. This command suppresses the feature for those who prefer to keep these files separate.

OUTPUT*FILE – Filename for output listing file
Optional

The listing output from MELCOR is written to the file named on this record. If this record is not present, the output is written onto file MELOUT.

(1) OUTPUTFILE

- Alternate filename for all listable output.
(type = character*80, default = MELOUT)

Note that the input processor by default converts lower case characters to upper case. If a lower case filename is desired, enclose the filename in single quotes.

PLOTCF – Special plot control function
Optional

This record specifies the number of a LOGICAL valued control function that will generate a plot dump if its value is .TRUE. If the control function is .FALSE., then a plot dump will still be generated if some other mechanism (e.g., time, physics package request) requests it.

(1) IPCF - This integer is the number of a LOGICAL valued control function.
(type = integer, default = none, units = none)

PLOT*FILE – Filename for plot file
Optional

The binary plot data is written to the file named on this record. If this record is not present, the plot data is written onto the file MELPTF.

(1) PLOTFILE - Alternate filename for plot dump file.
(type = character*80, default = MELPTF)

Note that the input processor by default converts lower case characters to upper case. If a lower case filename is desired, enclose the filename in single quotes.

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RESTART – Restart dump number used to start calculation
Optional

*** NOTE: There are two forms of this command. ***

Every dump on the restart file is associated with a cycle number and problem time. All information required to continue the calculation is contained in each dump. The dump generated by MELGEN is always cycle zero. The frequencies of dumps generated by MELCOR are specified on the TIMEk record series. A restart file dump is always generated when the calculation terminates gracefully, either at the time specified on the TEND record or when terminated by a MELCOR-detected error from which it cannot recover. On some systems, a restart dump will also be successfully generated on abnormal terminations (i.e., system-generated aborts or "bombs") through the use of system-dependent error recovery routines. The user may specify which dump in the restart file to use when starting the calculation. This allows the user to run part of the calculation, stop it, and then restart and continue the calculation. The user may also stop the calculation, change limited input parameters in order to run a variation in a sensitivity study, and continue the new calculation.

FORM 1. - cycle number input

(1) NREST - If ≥ 0 , Cycle number to start the calculation.
If -1 is input, the last restart dump is used.
If -2 is input, an interactive mode is entered.
The user will then be queried at each restart dump found on whether it is the desired restart point.
(type = integer, default = -1, units = none)

Example: RESTART -1 * restart from last cycle

FORM 2. - calculational time input

(1) TIME - the character string 'TIME'
(type = character, default = none)

(2) PROBLEM_TIME

- Calculation time to restart execution.
The code will restart from the first time on the restart file with time greater than or equal to the input.
(type = real, default = none, units = s)

Example: RESTART TIME 3600.0 * restart at first dump \geq 3600. s

RESTARTCF – Special restart control function

Optional

This record specifies the number of a LOGICAL valued control function that will generate a restart dump if its value is .TRUE. If the control function is .FALSE., then a restart dump will still be generated if some other mechanism (e.g., time, physics package request) requests it.

- (1) IRCF - This integer is the LOGICAL valued control function number.
(type = integer, default = none, units = none)

RESTARTFILE – Filename for restart file

Optional

The binary restart file to restart the calculation is specified by the file named on this record. If this record is not present then the restart file used is MELRST.

- (1) RESTARTFILE
- Filename for restart file.
(type = character*80, default = MELRST)

Note that the input processor by default converts lower case characters to upper case. If a lower case filename is desired, enclose the filename in single quotes.

RFMOD – Restart file modification option

Optional

This record allows the user to copy selected restart dumps into a new restart file. User input history stored on the old restart file is also copied to the new file. This option allows the user to delete unnecessary restart dumps (i.e., dumps written at predetermined intervals for insurance but not actually needed to provide restart points) that merely consume file space. An arbitrary number of CYCLEN fields may follow the first field. No other input records are required if the RFMOD record is present, but the RESTARTFILE record may be used to specify the old restart file.

- (1) NRESTF - File name for new restart file.
(type = character*80, default = none)

Note that the input processor by default converts lower case characters to upper case. If a lower case filename is desired, enclose in single quotes.

- (N) CYCLEN - Cycle numbers of restart dumps to be written to new restart file. An arbitrary number of these may be included on this record. The last field may be "-1" to designate the final restart dump

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without specifying its cycle number. An interactive option may be invoked by specifying "-2" for the first CYCLEN field instead of a list of cycle numbers. The user will then be queried for each restart dump found in the old restart file on whether it is to be included in the new restart file.

(type = integer, default = none, units = none)

RUNONLY – Run only on specified code version

Optional

In some user environments, MELCOR code versions can be changed without the knowledge of all users. This can create problems with parametric studies which require exactly the same code to produce meaningful results. This command requires that the code must be the same as that specified by a two-character base code version identifier, which is identified in header information written to terminal output and to the normal output file at the beginning of execution. If this condition is not true, the execution will terminate.

- (1) ID - Two-character code version.
(type = character*2, default = none, units = none)

SOFTDTMIN – Define conditions for limited under-run of DTMIN input

Optional

There are models in some MELCOR packages which require a major reduction in timestep at some event. An example is the High Pressure Melt Ejection which may be activated at vessel failure. The exact timing of this event cannot be predicted by the user before running the calculation. The code requires a timestep at the start of ejection (e.g., $\Delta t \leq 10^{-4}$ s) that is too small to use throughout the calculation. This input allows the user to accommodate this situation without restarting the execution and without specifying an excessively small DTMIN.

This input allows the timestep to be cut below the current DTMIN by a user-specified fraction for a limited number of times. Only cycles with Δt less than DTMIN and where Δt is decreasing from the previous cycle are counted. Δt less than DTMIN but increasing is allowed as many times as necessary to get within the user-specified range. See the TIMEk input for user-defined limits.

(1) UNDERRUN_FRACTION

- This is the fraction of DTMIN which is allowed. 10^{-2} to 10^{-3} are normally acceptable. Acceptable values are from 1 to 10^{-8} . The default condition does not allow under-runs.

(type = real, default = 1.0, units = none)

(2) NUMBER_OF_OCCURRENCES

- This is the number of occurrences allowed per execution. The counter is reset to zero at restart.
(type = integer, default = 0, units = none)

As an example, consider the situation where the code was running with DTMIN=0.01 and $\Delta t > DTMIN$. The input record

SOFTDTMIN 0.005 3

would allow the timestep to be suddenly dropped to as low as 5×10^{-5} s up to three times during the execution without terminating the run.

STATUS*ILE - Filename for MELCOR status request file

Optional

To allow the user to get information from a "batch" execution, MELCOR will check for the existence of a 'status' file (using the FORTRAN INQUIRE statement). If the status file exists, MELCOR will then generate and release a file named "MELMAIL" in the directory where the code is executing with a short execution status summary. The status file is then deleted. The default name is "MELSTAT" (in the current directory). The file contents are unimportant since the file is never read. Also see STOPFILE to terminate batch execution.

- (1) STATUSFILE - Filename for MELCOR 'status' file.
(type = character*80, default = MELSTAT)

Note that the input processor by default converts lower case characters to upper case. If a lower case filename is desired, enclose the filename in single quotes.

STOPF*ILE - Filename for MELCOR stop file

Optional

To allow the user to terminate a batch execution, MELCOR will check for the existence of a 'stop' file (using the FORTRAN INQUIRE statement). If the stop file exists, then an edit, a plot dump, and a restart dump are generated, the calculation terminates, and the stop file is deleted. The default name of the stop file is MELSTP. The file is never read, so the contents of the file are unimportant. Also see STATUSFILE for control of batch executions.

- (1) STOPFILE - Filename for MELCOR 'stop' file.
(type = character*80, default = MELSTP)

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Note that the input processor by default converts lower case characters to upper case. If a lower case filename is desired, enclose the filename in single quotes.

TIME_k – Timestep, edit, plot and restart control ($1 \leq k \leq 24$)

Required - at least one of these records is required

The maximum and minimum timesteps, edit, plot and restart frequency may be controlled using these records. The first input record determines when the remaining variables go into effect. Before that time the data on the previous record are used. After that time the data remain in effect until the problem time is greater than the time on the next record. The values on the last record remain in effect until the calculation finishes. MELCOR calculates its system timestep based on directives from the packages but it cannot take timesteps greater than the maximum timestep or smaller than the minimum timestep. The maximum timestep must be at least a factor of two larger than the minimum. The edit, plot and restart dump frequencies are controlled by these records. If a user specifies an edit frequency of 120 s, then every 120 s a new edit is generated. Any of the following can be changed from the interactive menu.

- (1) TIME - Time the data on this record go into effect.
(type = real, default = none, units = s)
- (2) DTMAX - Maximum timestep allowed during time interval.
(type = real, default = none, units = s)
- (3) DTMIN - Minimum timestep allowed during time interval.
(type = real, default = none, units = s)
- (4) DTEDIT - Edit frequency during this time interval.
(type = real, default = none, units = s)
- (5) DTPLOT - Plot frequency during this time interval.
(type = real, default = none, units = s)
- (6) DTREST - Restart frequency during this time interval.
(type = real, default = none, units = s)
- (7) DCREST - Restart frequency based on CPU time during this time interval.
This field is optional.
(type = real, default = 10^{10} , units = s, minimum=100.0)

TEND – End of calculation time
Optional

The calculation will stop when the problem time is greater than or equal to TEND. The calculation may also terminate because the CPU time is exhausted, interactive termination is requested, or one or more packages request the calculation be stopped. A restart file is written at the last cycle before the calculation terminates. This variable can be reset from the interactive menu, as discussed in Section 9.

- (1) TEND - End of calculation time.
(type = real, default = 5.4321×10^{20} , units = s)

TITLE – Title of the calculation
Required

Every calculation is required to have a title. This is written to the restart, edit, and plot files. The title on the MELCOR run must match a user-specified number of characters of the MELGEN title (see the COMTC command). If it contains blanks or if lower case characters are significant, the title must be enclosed in single quotes.

- (1) TITLE - Title of the calculation.
(type = character*80)

UNDEF - Redefine initialization of real database and scratch storage
Optional

This capability is of interest primarily to code developers, but the information is provided in the interest of completeness.

The real database for MELCOR is explicitly initialized in MELGEN to a value UNDEF. The same is done with the scratch storage area before each advancement by each package in MELCOR. By default, a value is used that is both recognizable and likely to cause a code abort; the intent is to increase the probability of detecting coding errors that result in undefined variables. On some systems, this value is the so-called IEEE "signaling Not a Number," and causes an interrupt when used as an operand in a floating point operation. On others, the value is -1.234E24. This input record allows the value of UNDEF to be changed, *but not set to 0.0*.

- (1) IUND - INTEGER equivalent to the REAL value UNDEF
(type = integer, default = machine dependent, equiv =UNDEF)

IUND=2143289344 ≡ UNDEF='7fc00000'X on some machines
using IEEE

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(default on HPW)
IUND=2140143616 \equiv UNDEF='7f900000'X on some machines
using IEEE
(default on I60 and SUN)
IUND=32768 results in UNDEF='80000000'X on VAXVMS only
(default on VAXVMS)
IUND=0 results in UNDEF= -1.234E24 rather than 0.0
(default on other machines)

WARNINGL*EVEL – Define level for warning and information messages Optional

MELCOR can generate many forms of warning and information messages during an execution. These messages go to the output, terminal, and/or diagnostic files. In some cases, the volume of messages can be a problem. This record allows the user to control the volume and severity of the messages. Each message is assigned a level in the range 0 to 5. A fatal error is assigned the level 0. The least important messages (to the user in a successful execution) are assigned the level 5, and other messages are assigned intermediate levels according to relative importance. Messages with levels 4 and 5 are normally of interest only in the location of a code problem. This record tells the code to only record messages with a level equal to or less than the values input.

This feature applies only to the time advancement (run) mode of MELCOR. Messages generated during the setup mode (MELGEN) are always listed.

The range of each of the following is 0 to 5 except for terminal output. The terminal parameter allows an additional input of -1 to suppress messages from the message package being displayed on the terminal. This was the situation before MELCOR 1.8.2.

- (1) MLEVO - Output file message level
(type = integer, default = 2, units = none)
- (2) MLEVD - Diagnostic file message level. If input field is not present, then level is set to the output file level.
(type = integer, default = 2, units = none)
- (3) MLEVT - Terminal message level. If input field is not present, then level is set to the output file level.
(type = integer, default = -1, units = none)

Note: Many of the MELCOR packages have not yet been modified to utilize this feature. The modifications will be included as rapidly as possible.

6. Plot Variables and Control Function Arguments

The elements of the Executive package's database that may be used for plot variables and control function arguments are listed and described below. If the variable is a plot variable, then a 'p' will appear between the slashes '/'. If the variable is a control function argument, then a 'c' will appear between the slashes '/'.

TIME	/pc/	Problem time. (units = s)
DT	/pc/	Timestep. (units = s)
CYCLE	/pc/	Cycle number. (units = dimensionless)
CPU	/pc/	CPU time used. (units = s)
WARP	/p/	Problem time minus initial problem time, divided by CPU time. (units = dimensionless)
LOCALWARP	/p/	Same as WARP except computed with decaying time history (i.e., calculated over a few cycles, weighted more heavily for the more recent cycles) to indicate current performance. (units = dimensionless)

7. MELCOR Sensitivity Coefficient Modification

A goal for MELCOR is to implement as sensitivity coefficients all model or correlation constants and parameters, convergence criteria, and similar system parameters that are not normally accessible via input. These sensitivity coefficients are grouped into numbered arrays that represent a set of similar parameters, such as the several constants appearing in a single correlation. These arrays are identified by a four-digit number *nnnn* incorporated into the array names. Each MELCOR package is assigned a range of identifier numbers for the sensitivity coefficients in that package. The various sensitivity coefficients are described in the individual package users' guides.

These sensitivity coefficients can be redefined in MELGEN or changed at any restart via MELCOR input (rather than modification of any code) so that the effects of modeling changes on the calculation can be examined. The sensitivity coefficient modification utility in the UTIL package coordinates the processing of any input that modifies the sensitivity coefficients. The value of any sensitivity coefficient is changed using an input record of the following form:

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SCiiii – Sensitivity Coefficient Identifier

00000 ≤ iiiii ≤ ZZZZZ is used for identifying and ordering the input

- (1) NNNN - Unique four-digit identifier of the sensitivity coefficient array.
- (2) VALUE - New value of the sensitivity coefficient. Values must be real-valued only - no integer values are allowed.
- (3) NA - First index of the sensitivity coefficient
- (4) NB - Second index of the sensitivity coefficient (if required)

The number of indices required will depend on the sensitivity coefficient.

For example, the following sensitivity coefficient input will change the default temperature of the control volume thermodynamics package from the value of 298 K to 368 K:

```
SC00000 2090 368. 1 * CHANGE NATURAL TEMPERATURE TO 368 K
```

The Executive package does not have any sensitivity coefficients.

8. MELGEN and MELCOR Execution

MELGEN and MELCOR can be executed with or without command line parameters. The following forms are acceptable for MELGEN execution:

- (1) melgen
- (2) melgen filename
- (3) melgen i=filename
- (4) melgen i=filename id=runid
- (5) melgen id=runid

It is noted that only (1) works with an executable compiled with the Digital FORTRAN compiler. In cases (1) and (5), the code will prompt for the input filename. The runid parameter is one or two alphanumeric characters which are appended to the named files created by the execution. The filenames are those discussed in relation to the commands DIAGFILE, OUTPUTFILE, RESTARTFILE, MESSAGEFILE, and PLOTFILE. No blanks are allowed around the "=" in the keyword=parameter format. The same form is used for MELCOR execution.

As an example, consider the MELCOR execution

```
melcor i=myinput id=22
```

where the file myinput contains the following commands:

```
outputfile  'myout'
plotfile    'myplot'
restartfile 'myresf'
```

Execution generates the following files:

```
myout22    the output file
myplot22   the plot file
myresf22   the restart file
MELDIA22   the default diagnostic file
MELMES22   the default message file
```

If filename extensions are used, such as

```
outputfile  'my.out'
```

the resulting filename would be

```
my22.out
```

Command line processing is always available on UNIX and PC-DOS systems. It will only function correctly on VAX-VMS if the MELGEN and MELCOR executables are installed as VMS DCL "foreign" commands.

9. MELCOR Interactive Interrupts

Interactive executions of MELCOR can be interrupted by certain messages typed at the terminal. Processed messages are:

```
STATUS! or !   for one-line status message
HELLO!         for interactive menu
STOP!, QUIT!, END!, or EXIT! to terminate execution
OFF!           to turn off interactive input (required for some debuggers to
               function correctly)
```

Commands are case-insensitive. Any character string not on this list will produce a brief list of recognized commands.

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The interactive menu options are somewhat limited at the present time and will be expanded in future releases. Current options include:

- (1) List DT data including statistical information
- (2) Terminate calculation at end of cycle
- (3) Interactive full edit (standard long edit with editor)
- (4) Reset stop time
- (5) Write full edit to separate file and release
- (6) Reset terminal cycle message frequency
- (7) Suspend execution for specified time
- (8) Reset CPU limit
- (9) Reset time interval input for timestep minimum and maximum limits, edit interval, plot interval, etc.

After the interactive options are completed, MELCOR returns to normal execution.

10. MELCOR Status from Batch Jobs

Many users prefer to run long executions as batch jobs to free their terminal for other functions. The ability to stop execution of these jobs is provided by the STOPFILE input in MELCOR. It is also possible to obtain the status of an executing batch job while it is running. The user can create a file specified by the STATUSFILE input record (default name "MELSTAT," with .DAT on VAX/VMS) in the directory where MELCOR is executing. The contents of the file do not matter; only the existence of the file is significant. MELCOR will detect and DELETE the MELSTAT file. MELCOR will then generate and release a file named "MELMAIL" in the same directory with a short execution status.

On most systems, only one such file is allowed at any time; a second mail request will overwrite the first message.

11. Example Input

The following example input illustrates the use of several of the MELGEN and MELCOR input records.

* Comments common to MELGEN and MELCOR

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```

*
*EOR* MELGEN
TITLE          TMI-2
RUNONLY        NM
RESTARTFILE    tmirest
OUTPUTFILE     tmioutg
DIAGFILE       tmidiagg
DTTIME         0.1
CRTOUT
R*I*F          cvhinput
R*I*F          corinput
R*I*F          hsinput
R*I*F          rninput
R*I*F          otherinput
PLOT000        COR-MZR-CL.103
PLOTabc.....COR-MZR-CL.104
...
PLOTxyz        COR-MZR-CL.412
.
*
*EOR* MELCOR
TITLE          TMI-2
RUNONLY        NM
RESTARTFILE    tmirest
OUTPUTFILE     tmiout
DIAGFILE       tmidiag
MESSAGEFILE    tmimes
PLOTFILE       tmiplot
CPULEFT        30.0
CPULIM         36000.0
CRTOUT
NOCOPY
RESTART        0
TIME1          0.0    5.0    0.0001    500.0    2.0    500.0
TIME2          1000.0  10.0   0.0001   1000.0   5.0   1000.0
TEND           6000.0
R*I*F          scinput
PLOT000        RN1-ADEP-1-2-1.30001
PLOTabc.....RN1-ADEP-1-4-1.30001
...
PLOTxyz        RN1-ADEP-1-16-1.30001
.

```

Bottom Head (BH) Package Users' Guide

The Bottom Head (BH) package calculates the thermal response of the lower plenum debris, the heatup of the reactor vessel bottom head, and the release of core and structural materials from the reactor vessel to the containment. Calculations are initiated when sufficient solid debris mass has accumulated to form the foundation of a debris bed. Material subsequently relocated downward from the core region (solids and liquids) is added to the upper surface of the bed. Potential debris bed/water pool interactions can be evaluated subsequent to the initiation of the package. Materials released from the lower plenum via penetration failures or bottom head creep rupture are transferred to the containment.

These models were originally developed by Larry J. Ott at Oak Ridge National Laboratory (ORNL) for use with the Boiling Water Reactor Severe Accident Response (BWR SAR) Code. In this form, they have been applied in accident analyses for the Containment Performance Improvement (CPI) Program and the Mark I shell survivability study, and in assessments of candidate accident management strategies (NUREG/CR-5869, see the BH Package Reference Manual). Subsequently, these models have been modified first to operate independently and then to operate while driven directly by MELCOR in an interactive mode. When exercised with MELCOR, these are the central algorithms of the BH package.

This document provides information concerning the user input necessary for running MELGEN and MELCOR with the BH package activated. Detailed information concerning the package organization including the arrangement of subroutines and commons and the interface with MELCOR is provided in Section 8 of the BH Package Reference Manual. Supporting interface model descriptions are presented in Section 9 of the Reference Manual.

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The BH Package Reference Manual also provides a detailed discussion of the physics models and the numerical solution schemes employed by the package. Some examples of the printed output generated by the BH package are shown in Section 6 of the Reference Manual.

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1. Introduction

The Bottom Head (BH) package is intended for use in MELCOR BWR (Boiling Water Reactor) and PWR (Pressurized Water Reactor) calculations for which a large debris bed remains after dryout of the reactor vessel lower plenum. Accident sequences producing such conditions include BWR Station Blackout, for which the water of the lower plenum is boiled away by both quenching of debris falling from the core region and the subsequent decay heat release. Although penetration integrity is not expected to be threatened while water remains, and penetration failures and debris relocation from the BWR reactor vessel are unlikely to occur before lower plenum dryout, transition to the BH package is initiated on the arrival of "sufficient" fuel mass in the lower plenum, as described below.

BH package modeling enhancements permit use of this package for analysis of certain Loss of Coolant Accident (LOCA) sequences in which core material is relocated to the lower plenum. For such cases, calculations of lower plenum debris/bottom head response by the COR package are continued until such time that sufficient solid debris has accumulated within the lower plenum to adequately define the initial debris bed structure as required by the BH package. (Should penetration failure and debris relocation to the containment be predicted by the COR package to the extent that sufficient lower plenum mass to initiate the BH debris bed models is never accumulated, then BH package operation will be precluded.)

Once sufficient solid debris mass has accumulated in the lower plenum, the COR package calculation of lower plenum debris and bottom head interactions is bypassed and the BH package representation of such interactions begins. Also, COR package fission product release calculations for debris located in the lower plenum are replaced by BH package calculations.

Previous bottom head models provided for the reflooding of the lower plenum by direct ejection into the BH model. This provision has been removed so that water can be introduced into the lower plenum only through the usual MELCOR sources. The models that provide for the interaction of water with core debris in the lower plenum remain intact.

This Users' Guide provides all of the instructions necessary for preparation of the MELGEN input that will be used by the lower plenum debris bed and bottom head response models of the BH package. Since one of the purposes of this package is to specifically consider the curvature of the vessel bottom head and its effect upon the shape of the debris bed control volume boundaries, more detail with respect to the bottom head configuration is required to be input when the BH package is utilized.

Another important function of the BH package is to adequately represent the large amount of stainless steel present within the reactor vessel lower plenum. This steel structure, which is distributed to a good approximation evenly across the lower plenum in the form of control rod guide tubes, instrument guide tubes, and shroud support structures, would

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be surrounded by the debris relocated from the core region. So that this stainless steel can be properly subsumed into the surrounding debris as the bed height increases, the MELGEN input for the BH package includes a detailed table of solid structural stainless steel volume versus height.

The BH package considers that the lower plenum debris bed is comprised of a set of materials that can melt, relocate, and refreeze either independently or as constituents of eutectic mixtures. Here the term "eutectic mixture" is applied loosely to mean any combination of constituents whose melting temperature is lower than the melting temperature of any individual constituent. The characteristics of the eutectic mixtures (if any) to be considered in the calculation must be supplied as part of the MELGEN input.

Finally, it is important to recognize that a major purpose of MELCOR is to serve as a vehicle for parametric variation studies. To this end, most of the BH package input variables are applied in a manner that permits their values to be changed upon a MELCOR restart. This capability and the means for its use are described in Section 2.14 of this manual.

2. MELGEN Input Requirements

This section describes the special input requirements for the BH package, including a brief discussion of the characteristics of the user-supplied quantities with their units and default values, if any. A detailed description of the manner in which these input variables are employed in the lower plenum debris bed and bottom head response calculations can be found in the BH Package Reference Manual.

Input record identifiers for the BH package all begin with the character string "BH." Record identifiers between BH0000 and BH0500 are used to specify the reactor vessel lower plenum geometry, the material species from which the debris bed is composed, bed characteristics such as porosity and particle size, and the arrangement of stainless steel structures within the lower plenum (steel volume versus height). Input records BH0600 and BH0700 provide information concerning the structure of the reactor vessel bottom head wall and metal/water reaction parameters.

Records BH1800, BH18JJ, BH18JJKK, and BH181KK provide input for the interface modeling of the thermal response for selected structures overlying the lower plenum debris bed. This interface modeling thermally couples the debris bed surfaces of the BH package, the lower core boundary sections modeled by the HS package, and the radial core plate sections modeled by the COR package. Phenomena represented in this debris-to-overlying structure interface model include:

- (1) heatup, failure, and melting of the lower core boundary below the core plate;
- (2) gross collapse of the remaining core upon lower core boundary failure; and

- (3) gross downward movement of the upper core boundary toward the lower plenum as the core boundary melts and relocates into the debris bed.

An important component in this interface modeling is the radiative heat transfer from the outer surfaces of the failed core boundary to the relatively cool massive heat sinks typically represented by the reactor vessel wall. Prior to core boundary failure, this radiative heat transfer is calculated by the BH package structure-to-structure radiation model. After core boundary failure, however, this radiative heat transfer is calculated by the BH interface model. The radiative heat sinks for this model are identified by input records BH1400 and BH142JJ.

The parameters necessary for the calculation of material ablation in the lower portion of the debris bed and in the vessel wall are provided by input record BH1100. The MELCOR control volumes representing the downcomer region and the containment are identified by input record BH1200. The print edit interval for the BH package is specified on input record BH1300, as is the maximum rate of debris transfer to the lower plenum from the core region.

The information necessary to specify the type of heat transfer boundary condition to be used for the calculation of the localized heat transfer coefficient along the external surface of the bottom head wall is specified on input record BH15CC. Information is entered on records BH1600 and BH16LL to identify the HS package heat structure numbers (modeling the lower head portion of the reactor vessel wall) to be deactivated once the BH package is initiated. Input record BH1700 identifies the HS package lower vessel wall structures that are specifically considered in the BH package interface with the HS package of MELCOR.

A model has also been developed for calculating interactions between the lower plenum debris bed and a potential overlying water pool. This pool might be created either by the presence of water in the lower plenum at the time of arrival of core debris, or by water injected after initiation of the BH package. A lower plenum water pool may arise only from systems' interactions such as pressurizer and accumulator discharge or by source term injections into the CVH volume associated with the lower plenum. The user can no longer limit the rate at which water from the CVH lower plenum pool is added to the BH debris bed/water pool model. This was previously prescribed via sensitivity coefficient 5010, which has now been removed. The bottom head package now "sees" all coolant inventory present in the lower plenum as it arrives from source terms.

Fission product release is calculated and is based upon COR package modeling. Most of the input for the release modeling is taken from COR package input with the exception of the RN class associations for the BH materials being volatilized. The RN classes into which the released BH materials are grouped are specified by the user on input record BHRN10K.

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Many of the input variables utilized by the BH package can be adjusted upon a MELCOR restart. These are listed in Section 2.14, where the limitations (if any) as to the amount of change allowed are discussed.

The flow of gas and water from the lower plenum to the containment is calculated by the MELCOR/BH interface during the interval between calculation of penetration failure and calculation of gross bottom head failure. The flow leaving the lower plenum atmosphere is modified appropriately before entering the containment to reflect heat transfer and chemical reaction with any zirconium present in the lower plenum debris bed. The user controls the size of the break area by specifying the number of a real valued control function (whose value is the break area) on input record BH1900.

After the occurrence of gross bottom head failure either through creep rupture or ablation, BH calculation of this gas flow is terminated, and the value of the BH-FFLAG control function variable is changed from 0.0 to 1.0. Modeling of gas exchange between the lower plenum and the containment after this time can only be represented by an appropriate FL package flow path whose area fraction is controlled by a control function based on the value of BH-FFLAG. (See FL package input record FLnnnVk.)

There are several special MELGEN input requirements for other packages when the BH package is used, since the RN1, COR, HS, CAV, CVH, and DCH packages are also active. For the CVH package, a single control volume must be used to model the lower plenum. Therefore, the finer nodalization scheme used for natural circulation enhancement may not be utilized beyond the bottom of the fuel. Also, the region representing the downcomer is assumed to be a single control volume.

Special coding has been implemented into the COR package (CORPSE routine) for use during calculations that utilize the BH package. For these calculations, a pseudo COR package water height is determined for each CVH volume interfaced with the COR package. This pseudo water pool height is a primary interface variable between the COR and CVH packages. It is used to determine core cell atmosphere fractions and the axial segment adjacent to the liquid level. As a result, it identifies the axial boundary below which certain phenomena such as radiative heat transfer and oxidation are not evaluated.

Care must be taken when developing input for the CVH volumes, specifically if coarse segmentation is used in defining the CVH altitude versus volume table. **For the CVH volumes representing the core region, including the lower plenum, the user must ensure that the following two criteria are met:**

- (1) the CVH hydrodynamic fluid volume is identical to the fluid volume defined in the COR package and
- (2) each core cell channel CVH volume is paired with a unique core cell bypass CVH volume.

For example, in a BWR, if one CVH volume is used to represent all of the core cell channel volumes, then one and only one bypass CVH volume may be used. Likewise, if five CVH volumes are used to represent the core cell channel volumes, a set of five corresponding core cell bypass CVH volumes must be used. For the channel and bypass volumes, the input in both the COR and CVH package should be identical in both total fluid volume as well as axial distribution. If the channel/bypass volume-pairing criterion is not met, then an error message is printed on the first restart timestep from the CORPSE routine, and if the calculation is continued, unphysical results may occur.

Also, the user may note in the CVH package output that the swollen water elevation is inconsistent with that indicated in the COR package output. This difference is the result of the pseudo water height being calculated in the COR package.

2.1 Lower Plenum Geometry and Debris Bed Materials

BH0000 – Calculation Title Required

This record provides an identification title for the lower plenum debris bed/bottom head response calculation, which can differ from the overall MELCOR calculation title.

The title should be enclosed in quotation marks and comprise not more than 80 characters.

BHTITL - Title for the lower plenum/bottom head response calculation.
(type = Character * 80, default = none)

Initialization Characteristics of BH

The presence of this input record in MELGEN processing acts as a flag to activate the BH package. The BH package may be used for the reactor types BWR, SBWR, or PWR as identified on COR package input record COR00002. Special provisions for the SBWR and PWR are described in Sections 10 and 12, respectively, of the BH Package Reference Manual. If BH0000 is entered, then all remaining BH input is processed. In this case, BH will override the COR package models in the lower plenum once the following conditions are met: (a) the lower plenum is dry, and (b) there is sufficient solid debris to fill the lower plenum to at least a depth of H1MAX (see card BH0500).

Prior to meeting these conditions, the original COR package models are used to determine the lower plenum debris bed/bottom head response and to calculate boiloff of the lower plenum water pool. Significant uncertainties exist in the determination of heat transfer from falling debris to a surrounding water pool and

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in the debris-to-water heat transfer once the debris has formed a well-defined bed in the lower plenum. Modeling of these processes is described in the COR Package Reference Manual. Significant user control of the calculation of these processes has been provided via COR package and sensitivity coefficient input (specifically input records COR00009 and COR00012, plus sensitivity coefficients 1020 and 1244).

Inappropriate input for these COR package debris-to-water heat transfer models may lead to unintended results for users attempting to employ the BH package. For instance, if the debris quenching heat transfer coefficient (input record COR00012, entry 1) is too large, then the calculated pressure pulse produced immediately after core plate failure may lead to vessel failure by overpressure prior to BH package initiation. On the other hand, insufficient heat transfer from the debris to the water would not only prevent (or inordinately delay) lower plenum dryout, but may also lead to COR package calculation of thermal failure of the bottom head penetrations prior to BH package initiation. Thus, judicious use of COR package input is required to calculate the initial conditions acceptable for the BH package.

Mitigation of the calculated pressure spike may be gained by decreasing the debris quenching heat transfer coefficient (COR00012, entry 1), by increasing the time constants associated with the radial spreading of solid and molten debris (sensitivity coefficient 1020 entries 1 and 2 respectively), and by increasing the minimum debris bed porosity allowed in the calculation of the dryout heat flux from the Lipinski debris bed correlation (sensitivity coefficient 1244, entry 3).

Experience has shown that large variations in the timing of lower plenum dryout may be calculated depending on the values of these input parameters. To give the user some guidance however, reasonable estimates of these input parameters include:

- (1) 750 W/m²-K for the debris quenching heat transfer coefficient,
- (2) 360.0 s time constant for the radial spreading of solid debris,
- (3) 60.0 s time constant for the radial spreading of molten debris, and
- (4) 0.4 for the minimum porosity used in the evaluation of the Lipinski debris bed heat flux.

(See also Section 8.2.3 of the BH Package Reference Manual.)

To preclude calculation of bottom head penetration failure by the COR package prior to lower plenum dryout and BH package initiation, the user should enter an artificially high failure temperature (e.g., 10000.0 K) on COR package input record COR00009. Such is the recommended procedure for a BWR station blackout calculation for which the debris would be expected to quench during its relocation

from the core region into the lower plenum and underwater penetration failures are considered unrealistic.

For accident sequences such as bottom head LOCA, the user should provide best-estimate data for COR package input records COR00009, CORLHDii, and CORPENNN. In these cases, lower plenum dryout may occur prior to the accumulation of significant debris mass within the lower plenum. If this occurs, the COR package may calculate failure of the lower head penetrations and the initial period of debris relocation from the vessel to the containment floor. Whether or not the BH package is eventually exercised in this calculation depends on the instantaneous solid debris mass present in the lower plenum. If debris melts and is relocated to the containment faster than it accumulates within the lower plenum, then the BH package will not be exercised. If, on the other hand, sufficient solid debris mass does accumulate, then the BH package will be initialized and exercised for the remainder of the calculation.

Finally, do not include the BH0000 input record if the user wishes to use the original COR package modeling throughout the calculation. In this case, the user should again provide best-estimate data for COR package input records COR00009, CORLHDii, and CORPENnn. The remainder of BH package input is ignored and the BH package will remain inactive. (See discussion in Section 8.2.4 of the BH Package Reference Manual.)

**BH0100 – Lower Plenum Geometry and Treatment of Debris Melting
Required**

This record provides information concerning the reactor vessel lower plenum dimensions and the method of material melting to be considered during the heatup of the lower plenum debris. The following four fields must be present.

- (1) HBSB - For a BWR, HBSB represents the bottom of the shroud baffle and corresponds to the elevation of the lower surface of the downcomer baffle plate. This elevation also defines the lowermost boundary of the BH wall node NWALL at the interface with wall node NWALL - 1.

For a PWR, this input field is ignored, and HBSB is computed internally based on the value of DRXID ($HBSB = DRXID/2 - 0.076$) entered on record BH0700. The computed value, as is the case for BWRs, defines the interface elevation between wall nodes NWALL and NWALL - 1. For both BWR and PWR applications, see the relationship between HBSB and DRXID on input record BH0700.

(type = real, default = none, units = m)

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- (2) NA - Number of corresponding height and volume entries [HH(I), VCORE(I), VSHRD(I) (input record BH03LL)] that describe the free volume versus height relationship within the reactor vessel lower plenum (maximum = 100).
(type = integer, default = none, units = none)
- (3) NPS - Number of table entries describing the relationship of structural (stainless steel) solid volume to height above vessel zero (input record BH04LL) (maximum = 30).
(type = integer, default = none, units = none)
- (4) IEUTEC - Number of debris eutectic mixtures to be considered (input record BH08LL) (maximum = 10).
(type = integer, default = none, units = none)

The number of line entries in the VCORE versus HH and VPS versus HPS tables (NA and NPS respectively) must each be greater than 2 to preclude code interrupt. These entries form tables that are intended to provide detailed information describing the configuration of the lower plenum as a function of elevation. It is perhaps easiest to prepare input such that the HH and HPS elevations coincide, but this is not required. At any rate, it is recommended that at least 20 entries for VCORE and 10 entries for VPS be provided. It is particularly important to adequately represent the effects of curvature at the lower elevations, where the variations of volume with height are the greatest.

BH02JJ – INDEPENDENT Constituents of Debris

01 ≤ JJ ≤ 20, JJ is the material identification integer

Optional

This record identifies the individual chemical species or constituents of eutectic mixtures to be considered in the calculation. The material identification integers are assigned as follows:

1	Zr	6	Ag	11	ZrO ₂	16	NiO
2	Fe	7	CdIn	12	FeO	17	B ₂ O ₃
3	Cr	8	blank	13	Fe ₂ O ₃	18	UO ₂
4	Ni	9	blank	14	Fe ₃ O ₄	19	blank
5	blank	10	B ₄ C	15	Cr ₂ O ₃	20	blank

Each of these 20 records provides the melting temperature, the molecular weight, and the heat of fusion for the pure species. Any rearrangement of the order of species would have to be supported by internal code modifications of the lower

plenum model since several of the imbedded calculations make use of the fact that Zr occupies position 1 in the series, Fe occupies position 2, and UO₂ has index 18. New use of the currently blank array elements (5, 8, 9, 19, and 20) can be accomplished relatively easily, however, simply by making the associated additions to the physical properties DATA statements (see Section 2 of the BH Package Reference Manual). The following three fields must be present on each record: (Zeros should be provided for the blank species 5, 8, 9, 19, and 20.)

- (1) AMTMEL - Melting temperature of debris constituent
(type = real, default = see Table 2.1, units = K)
- (2) AMMLWT - Molecular weight of debris constituent
(type = real, default = see Table 2.1, units = kg/kg-mole)
- (3) AMLAMF - Heat of fusion of debris constituent
(type = real, default = see Table 2.1, units = J/kg)

The user should note that the masses of debris bed species 6 (Ag) and 7 (CdIn) are calculated by partitioning the MELCOR mass of PWR poison (Ag-In-Cd) that has relocated from the core region. This calculation is necessary because the COR package tracks the Ag-In-Cd mixture mass as a single species. The mass fractions of Ag and InCd in the control rod material used in the partitioning of poison are specified via BH package sensitivity coefficient 5001.

Table 2.1 Default BH Package Material Properties

ID	Material	AMMLWT Molecular Weight (kg/kg-mole)	AMTMEL Melting Temperature (K)	AMLAMF Heat of Fusion (J/kg)
1	zr	91.220	2124.8	2.51208E+05
2	fe	55.847	1808.0	2.72142E+05
3	cr	51.996	2130.0	3.16336E+05
4	ni	58.700	1728.0	3.00054E+05
5		0.000	0.0	0.00000E+00
6	ag	107.870	1234.0	1.04796E+05
7	cdin	114.215	1200.0	3.49550E+04
8		0.000	0.0	0.00000E+00
9		0.000	0.0	0.00000E+00
10	b4c	55.260	2727.6	1.89336E+06
11	zro2	123.220	2977.6	7.07104E+05
12	feo	71.850	1649.8	4.41940E+05
13	fe2o3	159.690	1733.2	5.25676E+05
14	fe3o4	231.540	1838.7	5.95456E+05

ID	Material	AMMLWT Molecular Weight (kg/kg-mole)	AMTMEL Melting Temperature (K)	AMLAMF Heat of Fusion (J/kg)
15	cr2o3	152.020	2572.0	6.88496E+05
16	nio	74.710	2244.	6.79192E+05
17	b2o3	69.620	2727.6	3.44248E+05
18	uo2	270.070	3010.9	2.74468E+05
19		0.000	0.0	0.00000E+00
20		0.000	0.0	0.00000E+00

BH03LL – Table of Lower Plenum Free Volume Versus Height

01 ≤ LL ≤ NA, where LL is the index of the corresponding lower plenum height and cumulative free volume entries, and NA is the total number of entries (BH0100).
Required

This record type identifies the free volume versus height relationship within the portion of the lower plenum inside the shroud and the total volume-versus-height relationship within the downcomer region. The former is used to apportion the relocating debris within the bed control volumes. The entries must be in order of increasing height above vessel zero. The first record (BH0301) indicates the bottom of the vessel, where the height, free volume within the shroud, and volume outside the shroud boundary are all zero. The volume outside the shroud boundary remains zero for each record that represents a height below the bottom of the downcomer (at elevation HBSB on input record BH0100). The last record (BH03NA) represents the height of the bottom of the core plate and provides the total free volume beneath this height within the lower plenum (inside the shroud) and the total volume within the downcomer region (outside the shroud boundary). The term "free volume" is defined in the sense that the sum of VCORE, VSHRD, and the structural steel solid volume VPS (see input record BH04LL) equals the total volume enclosed within the reactor vessel wall between 0.0 and height HH. The following three fields must be provided for each record.

- (1) HH - Height above vessel zero.
(type = real, default = none, units = m)
- (2) VCORE - Cumulative free volume within the lower plenum (inside the shroud) between vessel zero and height HH.
(type = real, default = none, units = m³)
- (3) VSHRD - Cumulative total volume within the downcomer region (outside the shroud boundary) between HBSB (input record BH0100) and HH.
For values of HH ≤ HBSB, enter values of 0.0 for VSHRD. For

PWRs, all entries of VSHRD should be zero; see Table 12.3 in the BH Package Reference Manual.
(type = real, default = none, units = m³)

The user should be aware that the information contained in the VCORE and VSHRD versus height tables, while normally much more detailed, is redundant with the CVH volume versus height table for the CVH volumes corresponding to the lower plenum and the downcomer annulus. **The user should ensure that the information contained in the CVH volume versus height and in the BH volume versus height tables is consistent.**

BH04LL – Table of Lower Plenum Stainless Steel Volume versus Height

$01 \leq LL \leq NPS$, where LL is the index of the corresponding lower plenum height and structural stainless steel (solid) volume entries, and NPS is the total number of entries (BH0100).

Required

This record type identifies the stainless steel volume versus height relationship within the portion of the lower plenum inside the shroud. This is used to calculate the stainless steel mass to be assimilated into the surrounding debris. It is also used to determine the initial stainless steel mass of debris bed layer three after the control rod guide tubes fail (see TFAIL2 on input record BH0700). The sum of the stainless steel volume and the volumes VCORE and VSHRD (on Record BH03LL) must equal the total volume enclosed within the reactor vessel wall. The entries must be in order of increasing height above vessel zero. The first record (BH0401) indicates the inner bottom of the vessel, where the height and stainless steel volume are both zero. The last record (BH04NPS) represents the height of the bottom of the core plate and provides the total solid volume of all stainless steel beneath this point that is either within the shroud or below HBSB. The following two fields must be present for each record:

- (1) HPS - Height above vessel zero.
(type = real, default = none, units = m)
- (2) VPS - Volume of (solid) stainless steel (and Inconel for PWRs) inside the shroud within the lower plenum between vessel zero and height HH. (Does not represent the material volume of the downcomer structures or the shroud wall as these structures are not assimilated into the BH debris bed.)
(type = real, default = none, units = m³)

It should be noted that separate logic exists within the code for melting of the shroud wall and entrance of the relocating liquid into the debris bed.

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The stainless steel mass implied by the VPS table, while normally described in much greater detail, is redundant with the COR package input for the mass of the ISS structure for axial segments below the core plate. **The user should ensure that the steel mass information is consistent between the COR and BH packages for this region of the vessel.**

BH0500 – Porosities, Time Constant, Heights, and Debris Particle Diameter Required

This record provides the metallic and oxidic porosities associated with the particulate debris, the time constant for movement of liquids vertically or horizontally within the bed, and the specified maximum thickness of the bottom debris layer. The following five fields must be provided:

- (1) PORBOX* - Porosity of the lower plenum debris bed solid oxides.
(type = real, default = none, units = none)
- (2) PORBM* - Porosity of the lower plenum debris bed solid metals.
(type = real, default = none, units = none)
- (3) DTHEAD* - Time constant for downward relocation of molten material among debris bed control volumes. Horizontal movement (when the underlying control volume has no remaining free volume) will occur at one-half the downward rate.
(type = real, default = none, units = s)

* PORBOX and PORBM as entered here have no direct relationship to the particulate debris porosity PORDB entered on input record CORZjj01. However, the user is cautioned against inputting a value close to unity for PORBOX, PORBM, or PORDB. This is because there must be sufficient free volume below the core plate to house all of the slumped core debris regardless of its packed volume. If the user inputs a value of 0.9 for PORDB, then the packed volume of any debris slumping into the lower plenum will be a factor of 10 higher than that calculated for an input porosity of zero. Thus, for an artificially high debris porosity, insufficient free volume may exist in the lower plenum to completely house the relocating debris, and the COR package will calculate that a portion will remain above the core plate.

* DTHEAD is used in calculating the debris flow from the lower head after penetration failure. If prior COR package penetration failure has occurred, DTHEAD can be adjusted such that a smooth, continuous flow can be maintained during initiation of the BH package. Actual release of material from the debris bed is controlled by the rate of debris melting.

- (4) H1MAX** - Maximum height (above vessel zero) of the upper surface of the bottom debris layer. Enter 0.6625 for SBWR calculations.
(type = real, default = none, units = m)
- (5) HD1D2 - Height above vessel zero at which the reactor vessel wall thickness changes from THKHD1 to THKHD2 (see BH0600). For PWRs with uniform bottom head thickness, set HD1D2 to any height greater than HCYL (see BH0700).
(type = real, default = none, units = m)
- (6) DPART - Diameter of the lower plenum debris bed (spherical) particles. This single value, which is used for all bed control volumes, affects the metal oxidation rates, the effective bed thermal conductivities, and the interaction of the bed control volumes with any overlying water.
(type = real, default = none, units = m)

2.2 Vessel Wall Reaction Parameters and Metal/Water

BH0600 – Skirt Height, Wall Thickness, and Creep Rupture Temperature/Time Constants Required

This record identifies the attachment point of the reactor vessel support skirt, the thickness of the crust nodes (adjacent to the vessel wall) for debris layers two and three, the thicknesses of the vessel wall in the region of the penetrations and above, and the temperature/time constants used for calculation of failure of the bottom head penetration welds. The following six fields must be present:

- (1) HSKIRT - Height above vessel zero at which the reactor vessel support skirt attaches to the vessel wall. For reactor vessels without a support skirt, set HSKIRT to any value greater than HCYL (see BH0700).
(type = real, default = none, units = m)
- (2) THKCRS - Thickness of debris bed control volumes (2,5) and (3,5), which are adjacent to the vessel wall.
(type = real, default = none, units = m)

** H1MAX is important to the initialization of the BH representation of the lower plenum debris bed and must lie within the range of the HH table entered on Record BH03LL. See the discussion of the initialization characteristics of BH included with input record BH0000. For the SBWR (only), the upper surface of the bottom layer corresponds to the height of the interface between the lower and upper spherical portions of the bottom head wall.

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- (3) THKHD1 - Vessel wall thickness in region of penetrations (below height HD1D2 [see BH0500]).
(type = real, default = none, units = m)
- (4) THKHD2 - Vessel wall thickness above height HD1D2 (BH0500).
(type = real, default = none, units = m)
- (5) THK6 - Temperature for creep rupture of the bottom head penetration welds in six minutes.
(type = real, default = none, units = K)
- (6) THK60 - Temperature for creep rupture of the bottom head penetration welds in 60 minutes.
(type = real, default = none, units = K)

Typical values for creep rupture failure at normal BWR operating pressure, based upon data for Inconel-stainless steel welds, are THK6 = 1295 K and THK60 = 1210 K. (Differential pressure across the weld is assumed to be 7.239×10^6 Pa [Reference: Figure 2.9 of NUREG-1265.]) Higher failure temperatures should be used for cases where the reactor vessel is depressurized.

BH0700 – Metal/Water Reaction Parameters and Vessel Dimensions Required

This record controls the extent of metal/steam reaction in the lower plenum debris bed, sets a debris temperature for collapsing the lower plenum structures (such as the BWR control rod guide tubes) and initiating formation of debris bed layer three*, and provides the dimensions of the lower plenum so that the transition point from spherical to cylindrical geometry is clearly defined. The following eleven fields must be present:

- (1) IMWDEB - Flag to indicate the desired control of the metal oxidation reactions within the debris bed control volumes (see BH Package Reference Manual, Section 3.4). A value of
 - 0 = no metal/steam reaction
 - 1 = metal/steam reaction according to cylindrical geometry

* Although collapsing of lower plenum structures is used to initiate debris layer three, in-core components, such as the core plate, supported by the lower plenum structures are not automatically added to the debris layer three inventory.

- reaction kinetics and the availability of steam
- 2 = SS oxidation only; no Zr oxidation
- 3 = Zr oxidation only; no SS oxidation.
- (type = integer, default = none, units = none)
- (2) SFCRDB - Shape factor used to limit the extent of zirconium oxidation to adjust for non-cylindrical geometry and the decreased surface-to-volume ratio. This can also be used to account for the effect of steam tunneling through the lower plenum debris bed. For SFCRDB greater than 1.0, the Zr/water reaction is limited to 1.0/SFCRDB of that otherwise calculated.
(type = real, default = none, units = none)
- (3) SFCRSS - Same as (2), except applies to stainless steel oxidation.
(type = real, default = none, units = none)
- (4) FZRMX1 - Maximum fraction of initial (at time of BH initiation) Zr metal inventory in lower plenum that can be reacted.
(type = real, default = none, units = none)
- (5) FSSMX1 - Same as (4), except applies to initial inventory of stainless steel.
(type = real, default = none, units = none)
- (6) DRXID - Inner diameter of spherical portion of reactor vessel bottom head. DRXID is also used in the nodalization of the bottom head wall, where the uppermost node NWALL is defined such that its interface with node NWALL - 1 is located at elevation HBSB while its upper surface is located at max (DRXID/2, HBSB + 0.076).
(type = real, default = none, units = m)
- (7) TFAIL2 - Temperature flag used to initiate formation of the uppermost debris bed layer 3. Layer 3 is set up when either the debris in layer 2 exceeds TFAIL2, if there is any molten pure species or eutectic in layer 2, or if the debris layer 2 upper surface exceeds elevation HCYL. Addition of material relocating from the core region to debris bed layer 2 is closed and formation of layer 3 begins at this time.
(type = real, default = none, units = K)
- (8) HCYL - Height above vessel zero at which the geometry of the vessel wall shifts from spherical to cylindrical.
(type = real, default = none, units = m)

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- (9) RCYL - Radius to the inner surface of the cylindrical portion of the reactor vessel wall. HCYL and RCYL are necessary for plants such as Grand Gulf where the interface between the cylindrical and spherical sections occurs before the bottom head hemisphere is complete. For other applications, HCYL and RCYL should be set equal to one-half of DRXID.
(type = real, default = none, units = m)
- (10) XOZRMX - Maximum zirconium oxide thickness. Oxidation logic assumes that any oxide in excess of this thickness sloughs away. As XOZRMX is increased, the oxidation rate at the zirconium surface is decreased.
(type = real, default = none, units = m)
- (11) XOSSMX - Same as (10), except applies to SS oxide layer thickness.
(type = real, default = none, units = m)

2.3 Eutectic Mixtures

BH08LL – Parameters for Eutectic Mixtures

$01 \leq LL \leq IEUTEC$, where LL is the index of the eutectic mixture and IEUTEC is the number of eutectic mixtures to be considered (BH0100).
Required if IEUTEC is greater than 0

This record type provides the melting temperature for each eutectic, identifies the "key" constituent of each eutectic mixture (see BH Package Reference Manual, Section 4.2), and establishes the mole fraction of the key constituent within each mixture. The records must be entered in the order of ascending melting temperatures and each eutectic mixture must have a unique material identification integer IEUKEY. The following four fields must be provided for each record:

- (1) TMLIEU - Melting temperature of the eutectic mixture.
(type = real, default = none, units = K)
- (2) IEUKEY - Material identification integer corresponding to the following FRCKEY entry. The identification integers must correspond to species in the BH data base having non-zero entries on input records BH02JJ.
(type = integer, default = none, units = none)

- (3) FRCKEY - Mole fraction of the key material species that identifies eutectic mixture LL. The value of FRCKEY should be the same as the corresponding value input via Record BH10LLK.
(type = real, default = none, units = none)
- (4) EKYMIN - Minimum mole fraction of key material species required for formation of eutectic where mole fraction is defined as moles of key constituent available divided by total constituent moles available to form the eutectic. (Not currently used—enter 0.0.)
(type = real, default = none, units = none)

BH09LLK – Identify Constituents of Each Eutectic Mixture

$01 \leq LL \leq IEUTEC$, LL is the index of the eutectic mixture

$1 \leq K \leq 4$, card counter

Required if IEUTEC is greater than 0

Four cards are entered for each eutectic mixture, with five fields per card. Field entries of 0 indicate that the material species is not included within the eutectic; a field entry of 1 indicates that the material species is a constituent of the eutectic.

Card Number	Material Species Represented				
LL1	Zr	Fe	Cr	Ni	-
LL2	Ag	CdIn	-	-	B ₄ C
LL3	ZrO ₂	FeO	Fe ₂ O ₃	Fe ₃ O ₄	Cr ₂ O ₃
LL4	NiO	B ₂ O ₃	UO ₂	-	-

For example, if the second eutectic mixture were to represent stainless steel, then

BH09021	0	1	1	1	0
BH09022	0	0	0	0	0
BH09023	0	0	0	0	0
BH09024	0	0	0	0	0

(type = integer, default = none, units = none)

BH10LLK – Constituent Mole Fractions for Each Eutectic Mixture

$01 \leq LL \leq IEUTEC$, LL is the index of the eutectic mixture

$1 \leq K \leq 4$, card counter

Required if IEUTEC is greater than 0

Four cards are entered for each eutectic mixture, with five fields per card. Non-zero entries are made only for material species for which "1" was entered in the series BH09LLK.

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Card Number	Material Species Represented				
LL1	Zr	Fe	Cr	Ni	-
LL2	Ag	CdIn	-	-	B ₄ C
LL3	ZrO ₂	FeO	Fe ₂ O ₃	Fe ₃ O ₄	Cr ₂ O ₃
LL4	NiO	B ₂ O ₃	UO ₂	-	-

Continuing the example begun in the discussion of BH09LLK, if the second eutectic mixture represents stainless steel, then

BH10021	0.0	.73308	.19152	.07540	0.0
BH10022	0.0	0.0	0.0	0.0	0.0
BH10023	0.0	0.0	0.0	0.0	0.0
BH10024	0.0	0.0	0.0	0.0	0.0

The sum of the individual constituent mole fractions for each eutectic mixture must equal 1.00.
(type = real, default = none, units = none)

The user should be aware that the mole fractions entered for any stainless steel eutectic should be consistent with the corresponding mass fractions entered for stainless steel on MPMATxxx99 in the MP Package User's Guide. If these numbers are not consistent, the current modeling of stainless steel eutectic in the BH package may result in unintended amounts of pure species Fe, Cr, or Ni in the bottom head debris bed.

2.4 Parameters for Material Ablation

BH1100 – Ablation of Surrounding Material by Release of Molten Liquids via Penetration Failure Pathways
Required

This record provides the parameters to be used for the calculation of ablation of the debris surrounding the bottom head penetrations in the bottom debris layer and the vessel wall (BH Package Reference Manual, Section 5). These parameters are employed only after flow of the molten liquids through the penetration locations has been initiated. If it is desired that penetration failures not be considered in the calculation, then NPIPES(1) through NPIPES(3) should each be set to 0 and all liquids will be retained within the lower plenum until bottom head creep rupture is predicted. The following six fields must be provided:

(1) NPIPES(1)- Number of bottom head penetrations passing through the central control volume of the debris bed bottom layer.

(type = integer, default = none, units = none)

- (2) NPIPES(2) - Number of bottom head penetrations passing through the second control volume of the debris bed bottom layer.
(type = integer, default = none, units = none)
- (3) NPIPES(3) - Number of bottom head penetrations passing through the outermost (third) control volume of the debris bed bottom layer. If penetration failures are to be considered in the calculation, then NPIPES (1) through NPIPES (3) should sum to the total number of penetrations for the reactor under consideration.
(type = integer, default = none, units = none)
- (4) DPIPES - Penetration inner diameter
(type = real, default = none, units = m)
- (5) HPIPES - Heat transfer coefficient between molten material flowing through the penetration locations in the bottom debris layer (or the vessel wall) and the surrounding medium.
(type = real, default = none, units =W/m²·K)
- (6) TABLAT - Ablation temperature of material in the bottom debris layer.
(type = real, default = none, units = K)

The reader should note that the term "penetration" is used generically for both BWRs and PWRs, and that DPIPES is used as the initial characteristic diameter for penetration locations through which molten debris ablates layer 1 material, ablates the bottom head wall, and enters the containment. For scrammed BWR applications, it is recommended that only the instrument guide tube penetration be identified, since the control rod guide tube passageways would remain almost completely blocked by the internal control blade index tubes. Thus, for BWR applications, the sum of the NPIPES variables above should correspond to the total number of instrument guide tubes passing through the lower head wall.

2.5 Identification of the CVH Control Volumes that Interface with the BH Package

BH1200 – Control Volume Network and BH-CVH Volume-Height Consistency Required

This record identifies the CVH volumes representing the downcomer (jet pump) region of the reactor vessel and the drywell heat sinks. In addition, the user is encouraged to check that the BH and CVH downcomer volume-height tables are consistent. The following four fields must be provided.

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- (1) ICVJP - CVH control volume representing the downcomer region.
(type = integer, default = none, units = none)
- (2) ICVDWS - Control volume representing the containment CVH volume receiving heat transferred from the exterior surface of the reactor vessel bottom head wall above the point where the reactor vessel support skirt attaches to the vessel wall (HSKIRT, BH0600). ICVDWS may be the same as ICVCAV entered on card CORLHDII or it may be different depending on the containment nodalization employed by the user. CVH volume ICVCAV receives heat transfer from the exterior surface of the vessel wall from nodes at and below HSKIRT. For containment flooding situations, heat transfer from the exterior wall surface is either to the pool or to the atmosphere of the associated CVH volume depending on the location of the swollen liquid level along the exterior surface.
(type = integer, default = none, units = none)
- (3) ICVHBH - Flag to remind the analyst that lower plenum and downcomer annulus volume-height data need to be consistent. Unless the user sets ICVHBH=1 or the databases are consistent, the code will abort.
(type = integer, default = 0, units = none)
- (4) IBHLP - Control volume representing the lower plenum.
(type = integer, default = 0, units = none)

Note that when ICVHBH=1, no code abort will occur during MELGEN. However, by setting ICVHBH to 1, the analyst is reminded to check that the volume-height input for the CV and BH lower plenum and downcomer annulus are consistent. The number of pairs in both packages need not be the same; consistency here means that, if the height in the CV and BH input are equal for a given data pair, then the volume magnitude must be equal in both packages.

2.6 BH Package Print Edit Intervals

BH1300 – Print Edit Intervals and Maximum Debris Relocation Rate Required

This record identifies the time interval between lower plenum debris bed printed output edits produced by BH package subroutine BHED2. Information is printed to the normal MELCOR output but with a frequency specified by the DTPNTB

variable. Also, the maximum rate of debris relocation into the lower plenum debris bed is specified.

The following two fields must be provided.

- (1) DTPNTB - Time interval between BH package print edits.
(type = real, default = none, units = s)

- (2) DBDRPR - Maximum rate (kg/s) in which debris will be added to the BH package debris bed from the core region. If the COR package attempts to relocate debris into the lower plenum faster than this rate, the excess mass, energy, and fission product inventories will be stored in a mass and energy "accumulator" and will be added to the debris bed over a series of timesteps at a rate equal to DBDRPR until the excess disappears. When material is added to the accumulator, it is equilibrated with the material currently being held. This input variable is intended to give the user a means of distributing over several cycles the large instantaneous debris relocations typically calculated by the COR package when core plate failure occurs. It has a direct impact on the magnitude of steam production and pressurization occurring as a result of any falling debris/water pool interactions described in Section 7 of the BH Package Reference Manual.
(type = real, default = none, recommended value = 2000.0, units = kg/s)

2.7 Failed Core Boundary to Vessel Wall Radiation Model Input

BH1400 – Number of Vessel Wall Heat Structures Involved in Radiation Model Required for BWRs, ignored for PWRs

This input record identifies the number of structures modeled by the HS package that are to be used as radiation heat sinks for and adjacent to the failed core boundary model. Typically, these are vessel wall heat structures.

The failed core boundary model is described in Section 9.2.4 of the BH Package Reference Manual (see input record BH181KK).

- NVWALL - Number of HS package structures adjacent to the core boundary.
($0 < NVWALL \leq 99$)
(type = integer, default = none, units = none)

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BH142JJ – Vessel Wall Heat Structures

01 ≤ JJ ≤ 99, card counter

Required for BWRs, ignored for PWRs

- (1) IHSBH(J) - NVWALL HS package structure numbers required and stored in IHSBH(J) where $(NSHDLP+2)^* \leq J \leq (NSHDLP+1+ NVWALL)$ with $00000 \leq IHSBH(J) \leq 99999$. NSHDLP is the number of sections of the failed core boundary that radiate to the vessel wall (see Record BH1800). The multiplicity of heat structure IHSBH(J) must be unity as entered on input record HSCCCCC003 in HS package input. An arbitrary number of entries allowed per input record JJ with $01 \leq JJ \leq 99$.
(type = integer, default = none, units = none)

Note: The vessel wall heat structures must be entered sequentially as one traverses from the bottom of the vessel wall adjacent to the downcomer to the top of the vessel wall. Also the left-hand side control volume number (IBVL) as entered on the HSCCCCC400 input record for vessel wall heat structures must also be ICVJP as entered on BH1200.

2.8 BH Package Right (Outside) Boundary Surface Data for Reactor Vessel Bottom Head

BH15CC – Right (Outside) Boundary Surface Data for Reactor Vessel Bottom Head Nodalization

01 ≤ CC ≤ 18, CC is lower head node number (node 1 is the lowermost wall node while node 18 is the uppermost wall node).

Required

The following fields must be provided.

- (1) IBCBH - Boundary condition type. IBCBH must be one of the following integers specifying the type of boundary condition that is applied at the exterior boundary surface of wall node CC.
- = 1 A convective boundary condition is applied with the heat transfer coefficients calculated by the HS package.
 - = 4XXX A convective boundary condition is applied with the heat transfer coefficients given as a function of time by Tabular Function XXX. The units of quantities obtained from Tabular Function XXX are assumed to be W/m²-K.

* The first NSHDLP + 1 entries of IHSBH are dummies and are not used.

= 5XXX A convective boundary condition is applied with the heat transfer coefficients given as a function of the surface temperature by Tabular Function XXX. The units of quantities obtained from Tabular Function XXX are assumed to be $W/m^2 \cdot K$.

= 6XXX A convective boundary condition is applied with the heat transfer coefficients specified by Control Function XXX. The units of quantities obtained from Control Function XXX are assumed to be $W/m^2 \cdot K$.

(type = integer, default = none, units = none)

For details of the input required for tabular functions, see the Tabular Function Package Users' Guide. If control functions are used to specify boundary conditions with ICBH = 6XXX, their values must be initialized through their respective CFX01 cards. For details on control function input, see the Control Function Package Users' Guide.

(2) IFLOBH - Indicator for type of flow over right (outside) boundary surface of node CC. This value is used to determine the type of convective heat transfer correlation to be used in evaluating the heat transfer coefficient on this surface.

0 = internal flow

1 = external flow

No other values are permitted for this field.

(type = integer, default = none)

(3) FCRITR (POOL) Critical pool fraction for pool. This is the minimum value of the pool fraction such that heat transfer to the pool is from the entire node surface calculated for the right (outside) boundary surface of node CC. It must be between 0.0 and 1.0, inclusive. (See note.)

(type = real, default = none, units = none)

(4) FCRITR (ATM) - Critical pool fraction for atmosphere. This is the maximum value of the pool fraction such that heat transfer to the atmosphere from the entire node surface is calculated for the right (outside) boundary surface of node CC. It must be between 0.0 and 1.0, inclusive. (See note.)

(type = real, default = none, units = none)

Note: Although allowance has been made to read in separate "critical" pool fractions for each of the bottom head wall nodes (consistent with HS package

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format), MELGEN input processing will terminate execution if these two variables are not identical.

2.9 HS Package to BH Package Modeling Transfer

BH1600 – Number of Affected HS Package Structures Required

This record specifies the number of heat structures to be deactivated upon initiation of the BH package. This information is required in order to eliminate duplicate modeling of the bottom head wall by both the HS and BH packages subsequent to initiation of the BH package.

IHSOFF - Number of heat structures to be deactivated;
($1 \leq \text{IHSOFF} \leq 99$);
(type = integer, default = none, units = none)

BH16LL – Deactivated Heat Structure Numbers

$1 \leq \text{LL} \leq \text{IHSOFF}$

Required if IHSOFF (Card BH1600) is greater than zero

(1) IHSOFN(LL) - Heat structure number as identified in the HS package input ($00000 \leq \text{IHSOFN} \leq 99999$); this heat structure is deactivated once the BH package is initiated; IHSOFF structure numbers must be input and are stored in IHSOFN(LL) where $01 \leq \text{LL} \leq \text{IHSOFF}$.
(type = integer, default = none, units = none)

Note: As described on input record BH0700, BH package modeling of the bottom head wall terminates at max (DRXID/2, HBSB+ 0.076m). Thus, the user should set up bottom head/reactor vessel wall heat structures in the HS package input such that one of the structures terminates at that elevation and then specify that wall heat structures at and below that elevation be deactivated via the BH16LL input.

The user should note that upon BH package initiation, the surface area available for settling of aerosols from the lower plenum atmosphere will be reduced consistent with deactivation of the structures identified by the IHSOFN array. If no other lower plenum HS package structures remain active, then the RN package will produce an abort. This abort can be avoided by entering the RNSETXXX input record with the IVOLF and IVOLT entries both identifying the lower plenum CVH volume. This measure effectively resuspends any aerosol settling from the atmosphere.

2.10 BH/HS Package Structure

BH1700 – HS Package/BH Package Interface Structure Indices Required.

- (1) IHSBOT - User number for heat structure that is turned off by card series BH16LL and which is also represented as node NWALL by the BH package vessel wall model. The portion of the reactor vessel bottom head represented by IHSBOT and NWALL begins at an elevation HBSB (input record BH0100) and continues to the elevation defined by $\max(\text{DRXID}/2, \text{HBSB} + 0.076)$ above vessel zero.
(00000 ≤ IHSBOT ≤ 99999)
- (2) IHSTOP - User number of heat structure with which BH package upper wall node NWALL exchanges heat by conduction. Its geometry type (IGEOM) must be cylindrical as entered on input record HSCCCCC0000. In order that this heat structure may receive the conduction energy, the control function option of specifying internal heat sources for this structure must be specified on Record HSCCCCC300. The associated control function number must have "BH-COND-POW" as its argument (see input record CFnnkk). This structure continues to receive heat by conduction until the BH package calculates that the bottom head experiences gross failure by either creep rupture or complete wall ablation.
(00000 ≤ IHSTOP ≤ 99999)
(type = integer, default = none, units = none)

Although not required, it is recommended that the inner surfaces of HS structures IHSBOT and IHSTOP be identified to receive radiative heat transfer from the hot outer surfaces of core boundary structures surrounding the core (the core boundary structures are typically identified by COR package input variable IHSA on record CORZjj02). Radiative heat transfer from the boundary structures to the vessel wall structures can be calculated by the HS package surface-to-surface radiation model (see HS input record HSRDCCCC0).

If the inner surface of IHSBOT is active in the radiation model, then subsequent to its deactivation at BH initiation, the inner surface temperature of structure IHSBOT is replaced by that of BH wall node NWALL. The net radiative heat transfer to wall node NWALL is communicated to the BH package for inclusion in the energy balance for NWALL. If IHSBOT is not considered in the HS radiation model, then a warning message is issued to the BH package user during MELGEN input processing and no radiative heat transfer will be calculated to wall node NWALL.

The user should be aware that the thermal response of heat structures (such as those modeling the reactor vessel wall adjacent to the water pool of the downcomer annulus) are strongly influenced by the critical pool fractions entered on input records HSCCCCC400 and HSCCCCC600. It is recommended that if the vessel wall axial noding is coarse, then CPFPL and CPFAL should be less than 10% in order that proper pool cooling of reactor vessel wall can be calculated.

2.11 BH Package Lower Plenum Debris to Overlying Surface Model Input

The BH18 record series identifies input required to evaluate the heat transfers associated with radiation from the surfaces of the lower plenum debris bed to selected overlying structures prior to core boundary failure. For BWRs, it defines the temperature at which the core boundary is assumed to fail and the HS package structures to be deactivated upon boundary failure (see Section 9 of the BH Reference Manual). Figure 2.1 identifies the five debris bed surfaces (I to V) and a typical nodalization of the lower plenum overlying surfaces (1 to 8). Dimensions listed are for a large (251 in., 3.188 m ID) BWR reactor vessel such as Grand Gulf.

Surface 1 is the exposed wall above the debris, 2 is the baffle plate, 3 and 4 are the lower core boundary, and 5 to 8 are the rings of core plate. There are a total of $1 + \text{NSHDLP} + \text{NRAD}$ total overlying surfaces with NSHDLP and NRAD specified via input for the BH and COR packages, respectively. NRAD is specified via input record COR00000. The following input is required for the BH package to support use of this model.

Also presented is a short summary of the execution sequence followed when initiating the failed core boundary model of the BH package.

BH1800 – Global Input Data for the Lower Plenum Debris Bed to Overlying Surface Model Required

This input record determines the number of BWR downcomer baffle plate and lower core shroud heat structures below the core plate that participate in the model. For the PWR, no baffle plate exists, and so this record identifies only the number of lower core boundary structures active in the model.

(1) NSHDLP - for BWRs

Number of HS package structures representing the baffle plate and lower core shroud
 $2 \leq \text{NSHDLP} \leq 10$.

- for PWRs

Number of HS package structures representing the lower core boundary. The user input value of NSHDLP is increased by 1

internally to account for the non-existent baffle plate. See discussion for input record BH18JJ.

$$1 \leq \text{NSHDLP} \leq 9.$$

(type = integer, default = none, units = none)

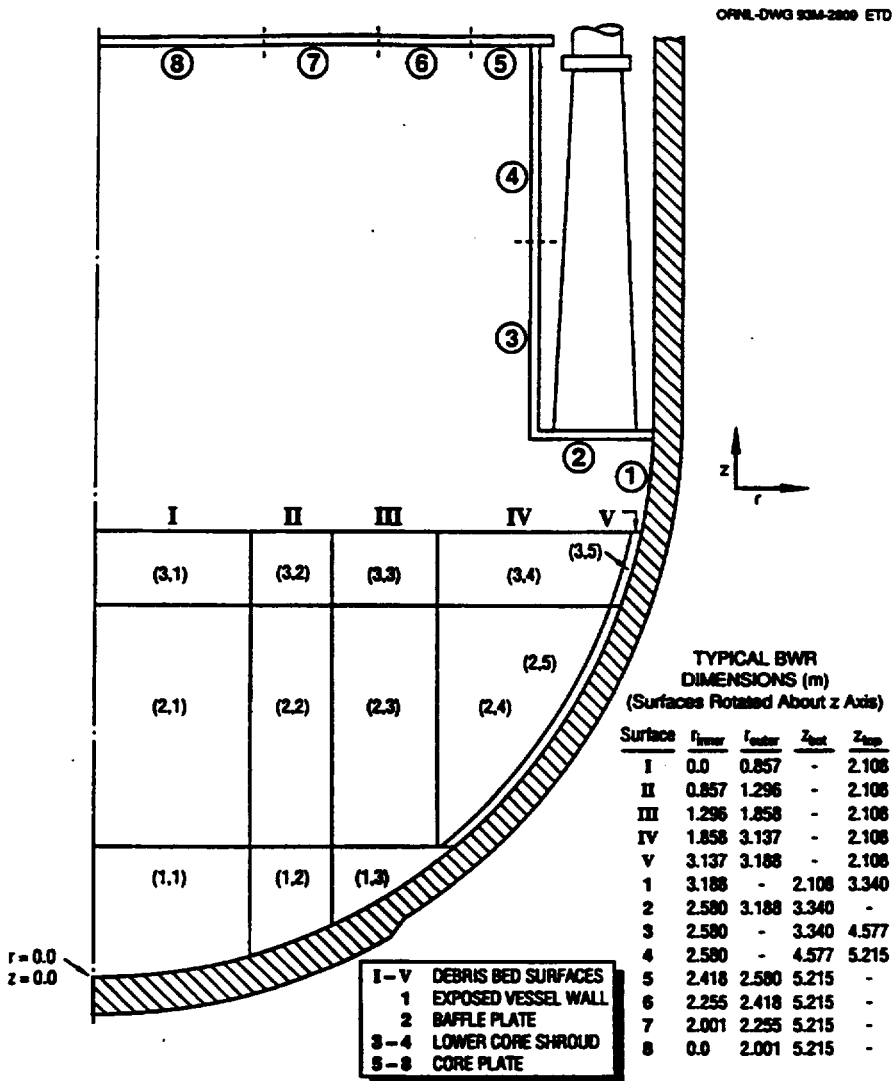


Figure 2.1 Typical Geometry of BWR Lower Plenum Debris Bed and Overlying Structures.

For BWRs
(2) TFAILS

- Average temperature of structure ISHDLP(1) (or ISHDLP(2) for PWR) at which the entire core boundary is assumed to fail and

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relocate onto the lower plenum debris bed (see input record BH18JJ.)

(type = real, default = none, units = K).

- (3) NHSOF2 - Number of HS package structures representing the entire core boundary (e.g., for a BWR, NHSOF2 includes the baffle plate, the lower core shroud, and the upper core shroud). These structures are deactivated upon boundary failure with subsequent heatup and melting calculated by the BH package.

(As with the NSHDLP variable, the input value of NHSOF2 is automatically increased by 1 for PWR reactors to account for the non-existent baffle plate.) $NSHDLP < NHSOF2$.

(type = integer, default = none, units = none)

For PWRs No other values may be input.

BH18JJ – HS Package Heat Structures that Participate in the Debris-to-Structure Radiation Model Prior to Core Boundary Failure

$01 \leq JJ \leq 99$

Required

- (1) ISHDLP(I) - $1 \leq I \leq NSHDLP$

For a BWR, the user-specified NSHDLP number of lower core shroud and baffle plate heat structures are stored in ISHDLP beginning at index 1 and ending at index NSHDLP. For a PWR, the user-specified number of lower core boundary heat structures NSHDLP are stored in ISHDLP beginning at index 2 and ending at index NSHDLP+1 with index 1 reserved for the non-existent baffle plate. (Also—as mentioned before—for PWRs, the internal value stored for NSHDLP is the user-input value plus 1. Thus in the remaining discussion, the quantity NSHDLP refers to the internally stored value of NSHDLP.) The sequence of structures entered is assumed to follow the counterclockwise numbering scheme indicated in Figure 2.1. Therefore, the correspondence of the structures identified in ISHDLP to the overlying surface indexing scheme employed in the debris to overlying surface radiation model is as follows:

Overlying Surface	ISHDLP Index
1 = exposed wall	-
2 = baffle plate	1 (dummy stored for PWR)
3 = lowermost core boundary segment	2
.	.
.	.
NSHDLP + 1 = core boundary segment immediately below the core plate	NSHDLP

Input processing in the BH package enforces an HS package multiplicity of unity for the structures identified in ISHDLP. It also requires that the user identify the downcomer CVH volume ICVJP on input record BH1200 as the right-hand side or outer boundary control volume and that the left-hand side or inner boundary control volume be that associated with the lower plenum [ICVHC(1,1) entered on input record COR10101]. These checks are made to ensure proper heat structure orientation and multiplicity consistent with assumptions made within the model. If the checks are violated, then MELGEN processing terminates. (type = integer, default = none, units = none)

BH18JJKK – Debris Surface to Overlying Structure View Factors

01 ≤ JJ ≤ (1 + NSHDLP + NRAD)

01 ≤ KK ≤ 99 card counter

(Optional if NRAD = 4 and NSHDLP = 3; otherwise required)

- (1) VIEW2 (LL, JJ) - The view factor from each of the five debris bed surfaces to each of the overlying structure surfaces must be input for the model. Therefore, a total of 5 * (1 + NSHDLP + NRAD) view factors are required. Five entries are required for each overlying surface index JJ [1 ≤ JJ ≤ (1 + NSHDLP + NRAD)*. Sequential entries on each input record are stored as VIEW2 (LL, JJ) 1 ≤ LL ≤ 5, where LL corresponds to the debris surface index. An arbitrary number (≤5) of view factors are allowed on each record KK. **The sum of the view factors VIEW2 (LL, JJ) 1 ≤ JJ ≤ (1 + NSHDLP**

* For PWR applications, the value input on record BH1800 for NSHDLP is increased by 1 prior to processing view factor information. The additional surface index is required (along with appropriate view factors) to account for the open region below the downcomer.

+ NRAD) for each debris surface LL must lie within 2% of unity or MELGEN will abort.

It is recommended that the user employ methods such as those described in the BH Package Reference Manual to evaluate view factors to be used in the model. The view factors should be evaluated for the debris bed geometry that exists after layer three has formed and the debris bed is fully developed. The entire set of view factors is used in the radiation calculation. Prior to layer three setup, the only view factors used are from debris surfaces IV and V to overlying surfaces 1 and 2. This is because of the shielding between the debris of layer 2 and the core boundary (and core plate) provided by the mass of standing lower plenum structures. The view factors are assumed constant throughout the calculation (prior to core boundary failure) even through the debris bed geometry changes as a result of debris bed nodal merging, debris relocations from the failed reactor vessel, and debris relocations into the debris bed from the core region.

View factors have been evaluated for the typical large BWR lower plenum/debris bed geometry shown in Figure 2.1 and reported in Table 2.2. If the user does not have access to a numerical integration scheme to determine the view factors for the nodalization of choice, it is recommended that the nodalization shown in Figure 2.1 be approximated and the view factors reported in Table 2.2 be employed. Default values for the view factors are taken from Table 2.2 for the geometry shown in Figure 2.1.

(type = real, default = Table 2.2, units = none)

Table 2.2 Typical View Factors for Debris Surface to Overlying Structures Radiation Model (see Figure 2.1), VIEW2(I,J), I = debris surface index, J = overlying structure index

	Debris Surface Index							
	I = 1	I = 2	I = 3	I = 4	I = 5			
J = 1	.135	.154	.191	.376	.564	J = 1 :	exposed wall	
J = 2	.062	.080	.118	.220	.219	J = 2 :	JP baffle*	
J = 3	.290	.285	.262	.121	.049	J = 3 :	core boundary structure 10014	

* For PWR applications, this index represents the open area at the base of the downcomer.

Debris Surface Index								
	I = 1	I = 2	I = 3	I = 4	I = 5			
J = 4	.110	.101	.086	.046	.024	J = 4 :	core.boundary structure 10004	
J = 5	.031	.031	.031	.022	.006	J = 5 :	COR ring 4	
J = 6	.032	.032	.032	.022	.007	J = 6 :	COR ring 3	
J = 7	.051	.051	.048	.036	.013	J = 7 :	COR ring 2	
J=8	.283	.259	.225	.152	.098	J = 8 :	COR ring 1	
Sum =	.994	.993	.993	.995	.980			

BH181KK – Deactivated HS Structures after Core Boundary Failure
 01 ≤ KK ≤ 99 card counter
 Required for BWRs, ignored for PWRs

NHSOF2 (see BH1800) identifies how many HS package structures representing the entire core boundary to be deactivated at the time of boundary failure. After the time of failure, modeling of the core boundary is performed by the BH package and is described in Section 9 of the BH Package Reference Manual.

- (1) IHSOF2(I) - Heat structure number as identified in the HS package input ($00000 \leq IHSOF2(I) \leq 99999$) $1 \leq I \leq NHSOF2$. The structure numbers should be input sequentially (starting with the lowermost structure and progressing to the top of the core boundary) and their multiplicities must be unity. **Checks are made to ensure that the first NSHDLP structures of IHSOF2 are the same as ISHDLP identified on input record BH18JJ. The checks are made to enforce ordering consistent with assumptions made in the model. If the checks fail, MELGEN termination will occur.**
 (type = integer, default = none, units = none)

It should be recognized that these steel core boundary structures may be considered for melting prior to failure. Melting may be calculated by special application of the HS degassing model employing the "SS" degassing material (see input record HSDGCCCC0).

Initiation Sequence for Failed Core Boundary Model

For BWR applications, these data input for the BH18 card series are also used as input by the failed core boundary model. The sequence of steps identifying the core boundary segments used to initialize the failed core boundary model is listed as follows:

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- (1) Core boundary is assumed to collapse when the average temperature of structure ISHDLP(1) for the BWR meets or exceeds TFAILS.
- (2) The structures identified by IHSOF2 are deactivated and the mass of the baffle plate structure ISHDLP(1) = IHSOF2(1) is immediately added to the lower plenum debris bed. Also, the remaining COR components at and above the core plate are relocated into the lower plenum at this time.
- (3) The masses of structures ISHDLP(2)...ISHDLP(NSHDLP) are used to initialize the masses of core boundary segments (2...NSHDLP) of the failed core boundary model of BH. Segment 1 mass remains zero corresponding with non-existence or degradation of the baffle plate mass.
- (4) The masses of deactivated structures IHSOF2(NSHDLP+1) to IHSOF2(NHSOF2) are combined and used to initialize the uppermost structure of the failed core boundary model. The index of this uppermost structure is NSHDLP+1.

2.12 BH Package Lower Plenum Vessel Penetration Break Size

BH1900 – BH Lower Plenum Penetration Break Size–Control Function Required

- (1) IABCFN - Control function number specifying area of failed penetration (m²).
(type = integer, default = none, units = none)

This card has been altered from previous code versions. It heretofore included input for two control function identification numbers (ICFRLP(1) and ICFRLP(2)), which were used to specify the flow rate and temperature for water injected directly into the BH package. This water was independent of, and unrecognized by the CVH package. These options have been removed as part of the effort to make the bottom head package consistent with all other packages with regard to ownership of CVH materials and the exchange of these materials between packages.

It is recommended that the control function that specifies the penetration break area be structured so that the break area has a value no more than about 0.0005 m² when water is being or has been injected into the lower plenum. This is to recognize the partial plugging of the penetration pathways that would occur due to freezing of some of the flowing metals.

2.13 Fission Product Release

BHRN10K – BH-to-RN Class Mappings for Fission Product Releases
Optional

ICLSBH(I) - RN class index identified to receive volatilized material from BH package pure species I, where $1 \leq I \leq 20$ and I is identified on BH02JJ. **The RN class indices must be entered in order from low to high species numbers corresponding to the BH package materials.** Other input required for the fission product release modeling is taken from the RN package release modeling selected by the user for materials of the COR package. These include the release model flag ICRLSE on the RNFP000 input record where the CORSOR or CORSOR-M release models may be chosen with or without the surface area-to-volume ratio option.

The CORSOR-Booth model is not currently available for BH fission product release calculations. If CORSOR-Booth is chosen for COR package fission product modeling, the CORSOR-M model with the surface area-to-volume option is employed for BH Package releases. Because of the uncertainty in determining the surface area-to-volume ratio for a two-phase mixture of solid/molten debris, this parameter is simply set to $6/D$, where D is the diameter of debris particles used throughout the BH package and is input via COR package input record CORIJJ04.

However, because this parameter is important to the release modeling, the user may vary the calculated release rates by use of RN package sensitivity coefficient 7104, where the surface area-to-volume ratio base may be changed from the default value of 422.5 m^{-1} .

If the user does not input the BHRN10K record, the default BH-to-RN class mappings are shown in Table 2.3.
(type = integer, default = below, units = none)

Table 2.3 Default BH Material to RN Class Mappings

BH Species	RN Class	BH Species	RN Class
1	Zr	8	11
2	Fe	7	12
3	Cr	7	13

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BH Species	RN Class	BH Species	RN Class		
4	Ni	7	14	Fe ₃ O ₄	7
5	—	0	15	Cr ₂ O ₃	7
6	Ag	12	16	NiO	7
7	CdIn	12	17	B ₂ O ₃	13
8	—	0	18	UO ₂	10
9	—	0	19	—	0
10	B ₄ C	13	20	—	0

2.14 MELCOR Input

The input records that may be specified on MELCOR restart are listed in Table 2.4. The variables for each record are separated into three categories: first, those permissible to change on MELCOR restart at any point in the calculation; second, those permissible to change only prior to the initiation of the BH package; and third, those that may not be changed after MELGEN processing.

All required entries on an input record must be included. For input records in which the variables are not all in the same category, the input for the variables that may not be changed at the time of the restart must be the same as that used by MELCOR during the previous execution. As an example, the input record BH1800 may be included on MELCOR restarts, but only the input variable TFAILS is permitted to change. This allows the user to vary the core boundary failure temperature prior to failure. If BH1800 is entered in MELCOR input, then NSHDLP and NHSOF2 entries must also be provided and must be the same as entered in MELGEN. Otherwise MELCOR restarts will be aborted.

As stated earlier the view factors for the debris surface to structures, input record BH18JJJK, are assumed constant throughout the calculations (prior to core boundary failure) even though the debris bed geometry changes, unless changed by user input. However, when a debris bed surface node is covered by water, the radiation to the overlying structures is ignored—in essence the debris bed node surface view factor is zeroed.

Upon core boundary failure in BWR applications, the debris bed to the overlying structures' view factors are automatically adjusted. The view factors corresponding to the core plate radial sections for each debris bed node surface are lumped together to form the new view factor from the debris bed node surface to the entire length of the core shroud previously above the core plate. Second, the view factors from the interior debris bed node (I-III) surfaces to the exposed vessel wall are zeroed. Likewise the view factors corresponding to the lowermost portion of the core shroud are correspondingly enhanced. Finally, since the baffle plate has failed and relocated into the debris bed and because the entire core shroud has moved downward to rest upon the bed surface, the view factors from the debris bed node surfaces to the lowermost portion of the core shroud are again enhanced by the

baffle view factors, which are then zeroed. A complete description of the way in which the view factors are adjusted is given Section 9.2.4.1 of the BH Package Reference Manual. Thus, if a user decides to change the view factors after core boundary failure, then the new view factors should be determined in accordance with the preceding geometric adjustments and not for the geometry shown in Figure 2.1.

The user should be aware that in addition to changing the control function identification number on input record BH1900 the value of the previously identified control functions may be modified via MELCOR restarts (see allowable MELCOR input for Control Function package).

Table 2.4 Adjustment of BH Package Input Variables on MELCOR Restarts

Card Number Identifier	Variable Name	Condition Under Which Variables May Be Changed on MELCOR Restarts			Notes
		Anytime	Prior to BH Initiation	Never	
BH0000	BHTITL	X			
BH0100	HBSB NA NPS IEUTEC	X	X X X		
BH02JJ	AMTMEL AMMLWT AMLAMF		X X X		
BH03LL	HH VCORE VSHRD		X X X		
BH04LL	HPS VPS		X X		
BH0500	PORBOX PORBM DTHEAD H1MAX HD1D2 DPART	X X X X	 X X		1,9 1,9 2,10

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Card Number Identifier	Variable Name	Condition Under Which Variables May Be Changed on MELCOR Restarts			Notes
		Anytime	Prior to BH Initiation	Never	
BH0600	HSKIRT		X		
	THKCRS		X		
	THKHD1		X		
	THKHD2		X		
	THK6	X			3
	THK60	X			3
BH0700	IMWDEB	X			4
	SFCRDB	X			5,10
	SFCRSS	X			
	FZRMX1	X			4
	FSSMX1	X			4
	DRXID		X		
	TFAIL2	X			
	HCYL		X		
	RCYL		X		
	XOZRMX	X			
	XOSSMX	X			
BH08LL	TMLIEU	X			
	IEUKEY	X			
	FRCKEY	X			
	EKYMIN	X			
BH09LLK	Eutectic Constituents (IEU)	X			
BH10LLK	Constituent Mole Fractions (XRNKEY)	X			
BH1100	NPIPES(1)	X			6
	NPIPES(2)	X			6
	NPIPES(3)	X			6
	DPIPES		X		
	HPIPES	X			7
	TABLAT	X			8

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Card Number Identifier	Variable Name	Condition Under Which Variables May Be Changed on MELCOR Restarts			Notes
		Anytime	Prior to BH Initiation	Never	
BH1200	ICVJP ICVDWS			X X	11
BH1300	DTPNTB DBDRPR	X X			
BH13NN	BHTIME DTPNTB	X X			
BH1400	NVWALL			X	11
BH142JJ	IHSBH(J)			X	11
BH15CC	IBCBH IFLOBH FCRITR(POOL) FCRITR(ATM)	X X X X			
BH1600	IHSOFF			X	11
BH16LL	IHSOFN(LL)			X	11
BH1700	IHSBOT IHSTOP			X X	11
BH1800	NSHDLP TFAILS NHSOF2	X		X X	12
BH18JJ	ISHDLP(I)			X	11
BH18JJKK	VIEW2(LL,JJ)	X			
BH181KK	IHSOF2(I)			X	11
BH1900	IABCFN	X			

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Card Number Identifier	Variable Name	Condition Under Which Variables May Be Changed on MELCOR Restarts			Notes
		Anytime	Prior to BH Initiation	Never	
BHRN10K	ICLSBH(I)	X			

Table Notes

- (1) Changing these porosities after BH package initiation will affect the volume occupied by:
 - (a) debris that subsequently enters the lower plenum from the core region, and
 - (b) any bed control volume that is reconfigured due to liquid formation within and drainage from the control volume. It should be recognized that debris control volume geometries are not automatically reinitialized to be consistent with changed values of PORBOX and PORBM. (When the free volume fraction exceeds $1.25 \cdot \text{PORBOX}$, tumbling of the remaining solids into a new configuration is modeled, and the current values of PORBOX and PORBM are used to set the new free volume.)
- (2) Should be maintained at values greater than the maximum timestep length.
- (3) The predicted bottom head penetration weld creep rupture failure time is never allowed to increase once set. Therefore, increasing the values of THK6 and THK60 after the BH package is initiated may not delay penetration weld creep rupture.
- (4) For IMWDEB equal to 2 or 3, code logic will internally set IMWDEB equal to 0 (and write a message that "lower plenum Zr oxidation stopped") whenever the ratio of zirconium reacted to the initial zirconium mass exceeds FZRMX1.
- (5) Each timestep, the oxidation rate determined by the reaction kinetics equations is multiplied by the factor $1.0/\text{SFCRDB}$.
- (6) If zero at the time the BH package is initiated, then must remain zero throughout the calculation. But if NPIPES(j) has a value NPI when BH is initiated, then it may be shifted from NPI to zero (to simulate plugging of penetrations) and back again on subsequent restarts.
- (7) If set to zero, will terminate ablation both within the layer 1 debris and in the wall.
- (8) If set to a value greater than the temperature TLLIQ of the flowing liquids, will terminate ablation of the lower layer solid debris. Within subroutine BHDBMX, the temperature of the ablating surface is set to:

$\text{MAX} [\text{TABLAT}, 1/3 * \text{TLLIQ} + 2/3 * \text{TMLPO}(1, \text{jj})]$,

where $\text{TMLPO}(1, \text{jj})$ is the average temperature of the debris control volume jj in layer 1. Thus adjustments to TABLAT for values less than $\text{TMLPO}(1, \text{jj})$ will have no effect.

- (9) Values must be less than 1.0.
- (10) Entries with value zero will cause divide-by-zero and code aborts.
- (11) Input record is ignored during MELCOR input processing.
- (12) Only the first value of this card may be input for PWR applications. In addition, this value must be identical to that entered in MELGEN.

2.15 Sensitivity Coefficients

This section lists the BH sensitivity coefficients that are accessible to the user, along with a brief description and gives their default values, units, and EQUIVALENCE variable names. All BH package sensitivity coefficients are in the 5000 to 5199 range.

5001 – Control Rod Poison (Ag-In-Cd) Composition Fractions

The control rod poison Ag-In-Cd for PWR applications is defined in the COR package as a single species. When passed to the BH package, this material is partitioned into Ag and InCd. Sensitivity coefficient 5001 defines the mass fractions of Ag and InCd in the poison.

C5001(1)- mass fraction of Ag
(default = 0.8, units = none, equiv = PWRXMF(1))

C5001(2)- mass fraction of In-Cd
(default = 0.2, units = none, equiv = PWRXMF(2))

5010 – INACTIVATED

Formerly the maximum water transfer rate from the CVH lower plenum pool into the BH debris/water interaction model. Because the BH package no longer has ownership of CVH materials, this sensitivity coefficient is no longer required and has been removed.

C5010 - Removed.

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5020 – BH/FDI-CAV - Initial Debris Holdup Mass.

Due to numerical problems encountered in the CAV package arising from the existence of small quantities of debris on the containment floor, logic has been implemented to delay the initial debris ejection into either the FDI or CAV package from BH. As implemented, no initial debris transfer will be allowed until the integrated mass of debris leaving the failed reactor vessel has reached the value specified by this sensitivity coefficient. When this threshold has been exceeded, all of the ejected debris is transferred into either CAV or FDI. After this point, no holdup occurs, and debris is transferred into FDI or CAV as it leaves the vessel.

If the user encounters abnormal MELCOR terminations shortly after BH package penetration failure occurs, it is recommended that the value of this sensitivity coefficient be increased to 5000.0 kg.

C5020 - Initial debris holdup mass
(default = 0.0, units = kg, equiv = AMLOSI)

3. Plot Variables and Control Function Arguments

The plot variables and control function arguments included in the BH package are listed below, along with a brief description of each. Within slashes (/ /) a 'p' indicates a plot variable and a 'c' indicates a control function argument. Also, these variables, unlike other MELCOR plot variables, are in lower case, and must be entered as such as input to HISPLT—lower case enclosed in quotes.

bh-cpu	/p/	Total CPU usage required in executing the BH package. (units = s)
bh-gas-ener.n	/p/	Cumulative gas enthalpy released or extracted by the BH package during gas release. n = 1 for the lower plenum atmosphere. n = 2 for the containment atmosphere. (units = J)
bh-gsms-lh.n	/p/	Cumulative gas mass extracted from the lower plenum atmosphere by the BH package for n = 1 to nmat gases; the gas indices are identified in the printed output for the BH package. (units = kg)
bh-gsms-dw.n	/p/	Cumulative gas mass exhausted into the containment atmosphere by the BH package for n = 1 to nmat gases; the gas indices are identified in the printed output for the BH package. (units = kg)

bh-rad-ener	/p/	Cumulative energy added to the lower plenum atmosphere by the BH package. Before failure and collapse of the lower plenum structures, this variable may be negative. This is due to the large thermal mass and surface area of these cold structures at the time of lower plenum dryout and, thus, their cooling effect on the lower plenum <u>atmosphere</u> . After they fail and collapse into the lower plenum debris bed, the lower plenum atmosphere rapidly heats due to radiative exchange from the surface of the debris bed and this variable becomes positive. (units = J)
bh-jp-ener	/p/	Cumulative energy added to the water pool in the downcomer by the BH package. (units = J)
bh-cav-ener	/p/	Cumulative energy added to the reactor cavity CVH volume (ICVCAV) atmosphere since the initiation of the BH package. (units = J)
bh-dwl-ener	/p/	Cumulative energy added to the containment CVH volume (ICVDWS) atmosphere immediately above the reactor vessel skirt since the initiation of the BH package. (units = J)
bh-pour-temp	/p/	Temperature of debris pouring from the reactor vessel bottom head over a system cycle. (units = K)
bh-species- rate.index*	/p/	Rate of species' mass ejection as calculated by the BH package; if no ejection is calculated, then 0.0 is plotted. (units = kg/s)
bh-oxides-rate	/p/	Rate of oxide mass ejection from the lower plenum as calculated by BH; represents the sum of species flows for species 10 to 18. (units = kg/s)
bh-metals-rate	/p/	Rate of metal mass ejection from the lower plenum as calculated by BH; represents the sum of species flows for species 1 to 9. (units = kg/s)

**For plot variables "bh-species-rate.index" and "bh-species-cumul.index", the following table must be used to identify the pure species index to be used in the plotting input. (Blank species' names are for future use.)*

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bh-total-rate	/p/	Total rate of debris ejection from the lower plenum as calculated by BH summed over species 1 to 18. (units = kg/s)
bh-ex-ves-dk-pow	/p/	Not currently available. (units = W)
bh-species-cumul.index*	/p/	Cumulative mass of debris species ejected from the reactor vessel. (units = kg)
bh-oxides-cumul	/p/	Cumulative mass of oxidic debris ejected from the reactor vessel summed over species 10 to 18. (units = kg)
bh-metals-cumul	/p/	Cumulative mass of metallic debris ejected from the reactor vessel summed over species 1 to 9. (units = kg)
bh-debris-cumul	/p/	Cumulative debris mass ejected from the reactor vessel summed over species 1 to 18. (units = kg)
bh-wall-power-nn	/p/	Instantaneous heat transfer rate for BH package bottom head node nn external surface ($01 \leq nn \leq 18$). (units = W)
bh-fflag	/c/	Flag switching from 0.0 to 1.0 to indicate gross failure of the bottom head wall by either creep rupture or ablation. This control function is useful in controlling a "valve" in a CVH/FL flow path. If such a flow path between the lower plenum and containment CVH volumes is not specified, then there is no gas or water pool flow from the lower plenum to the containment after gross failure of the bottom head wall.
bh-cond-pow	/c/	Conduction power calculated from node NWALL of the BH package wall model to IHSTOP of the HS (see input record BH1700). (units = W)

**For plot variables "bh-species-rate.index" and "bh-species-cumul.index", the following table must be used to identify the pure species index to be used in the plotting input. (Blank species' names are for future use.)*

bh-shroud-mass.i /p/ mass of core boundary structures represented by the BH after failure of the core boundary structure. (units = kg); $1 \leq i \leq (\text{NSHDLP}+1)$ where i is the structure index having the following meaning:

<u>i</u>	<u>Identifier</u>
1	baffle plate for BWR; blank for PWR
2	lowermost core boundary segment
.	.
.	.
.	.
NSHDLP	core boundary segment immediately below the core plate location
NSHDLP+1	entire core boundary portion above the core plate

bh-shroud-temp.i /p/ Temperature of core boundary structures represented by the BH package after failure of the core boundary; $1 \leq i \leq (\text{NSHDLP}+1)$; see plot variable 22 for definition of i . (units = K)

bh-shroud-tmIt /p/ Total mass of core boundary that has melted and relocated into the core or the lower plenum regions after dryout of the downcomer annulus. (units = kg)

bh-lp-water-mass /p/ Lower plenum water mass present in the BH package model of debris/water pool interactions. (units = kg)

bh-lp-water-temp /p/ Temperature of the lower plenum water pool mass present in the BH package model of debris/water pool interactions. (units = K)

bh-accum-mass /p/ Instantaneous mass of all debris that has left the core region but that has not yet entered the BH package lower plenum debris bed. (units = kg)

bh-fprls-rate.n /p/ Instantaneous elemental radioactive class release (e.g., fission products) rate of RN package class n summed over

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all control volumes of the BH debris bed; does not include nonradioactive released masses associated with class n; see RN Package Users' Guide for RN class definitions.
(units = kg/s)

bh-fprls-cum.n	/p/	Cumulative elemental radioactive (e.g., fission product) class release of RN package class n summed over all control volumes of the BH debris bed; does not include nonradioactive released masses associated with class n; see RN Package Users' Guide for RN class definitions. (units = kg)
bh-energy-err	/p/	BH package energy error; see Section 11.4.4 of the BH Package Reference Manual. (units = J)
bh-rel-engy-err	/p/	BH package relative energy error; see Section 11.4.4 of the BH Package Reference Manual.

Index	Species Name	Index	Species Name
01	Zr	10	B ₄ C
02	Fe	11	ZrO ₂
03	Cr	12	FeO
04	Ni	13	Fe ₂ O ₃
05	blank	14	Fe ₃ O ₄
06	Ag	15	Cr ₂ O ₃
07	CdIn	16	NiO
08	blank	17	B ₂ O ₃
09	blank	18	UO ₂

4. Example Input

4.1 Example MELGEN Input

The following are sample MELGEN input records for the BH package.

```
*
*
* ORNL BOTTOM HEAD INPUT
BH0000 'GRAND GULF SHORT TERM STATION BLACKOUT WITH ADS ACTUATION'
*
*           HBSB      NA      NPS  IEUTEC
```

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```

BH0100    3.340    26    26    4
*HBSB at bottom of downcomer
*
*          AMTMEL    AMMLWT    AMLAMF
*          (K)              (J/KG)
BH0201    2124.8    91.22    2.51208E5    * ZR
BH0202    1808.0    55.847    2.72142E5    * FE
BH0203    2130.0    51.996    3.16336E5    * CR
BH0204    1728.0    58.700    3.00054E5    * NI
BH0205         0.0         0.0         0.0    * c -> blank
BH0206    1234.0    107.870    1.04796E5    * ag
BH0207    1200.0    114.215    3.49550E4    * cdin
BH0208         0.0         0.0         0.0    *
BH0209         0.0         0.0         0.0    *
BH0210    2727.6    55.260    1.89336E6    * B4C
BH0211    2977.6    123.220    7.07104E5    * ZRO2
BH0212    1649.8    71.850    4.41940E5    * FEO
BH0213    1733.2    159.690    5.25676E5    * FE2O3
BH0214    1838.7    231.540    5.95456E5    * FE3O4
BH0215    2572.0    152.02    6.88496E5    * CR2O3
BH0216    2244.3     74.710    6.79192E5    * NIO
BH0217    2727.6     69.620    3.44248E5    * B2O3
BH0218    3010.9    270.070    2.74468E5    * UO2
BH0219         0.0         0.0         0.0    *
BH0220         0.0         0.0         0.0    *
*
*
*          HH          VCORE          VSHRD
*          (M)          (M**3)          (M**3)
BH0301     0.0           0.0           0.0
BH0302     .15113       1.68429E-1     0.0
BH0303     .27686       6.21753E-1     0.0
BH0304     .39726       1.32452E0      0.0
BH0305     .56134       2.66651E0      0.0
BH0306     .76454       4.87033E0      0.0
BH0307     1.02870       8.51884E0      0.0
BH0308     1.29540       1.33883E1      0.0
BH0309     1.83515       2.68349E1      0.0
BH0310     2.28600       4.02051E1      0.0
BH0311     2.70510       5.28351E1      0.0
BH0312     3.02514       6.21827E1      0.0
BH0313     3.0861        6.40303E1      0.0
BH0314     3.3401        7.17287E1      0.0    * bot of downcomer
BH0315     3.59918       7.73934E1      2.18771E0
BH0316     3.75158       8.06903E1      3.50982E0
BH0317     4.41198       9.27526E1      1.14633E1
BH0318     4.48056       9.42169E1      1.20776E1
BH0319     4.57200       9.61589E1      1.29060E1
BH0320     4.75234       1.00110E2      1.44221E1
BH0321     4.85394       1.02490E2      1.51216E1
BH0322     5.08000       1.07740E2      1.67233E1
BH0323     5.21462       1.10416E2      1.75386E1
BH0324     5.26796       1.11414E2      1.79240E1
BH0325     5.36702       1.13392E2      1.86398E1
BH0326     5.49402       1.15998E2      1.95573E1 * BAF
*
*          HPS          VPS
*          (M)          (M**3)

```


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```

BH0401  0.0      0.0
BH0402  .15113   7.94850E-2
BH0403  .27686   2.00115E-1
BH0404  .39726   3.47646E-1
BH0405  .56134   6.18128E-1
BH0406  .76454   1.09838E0
BH0407  1.02870   1.99424E0
BH0408  1.29540   2.81399E0
BH0409  1.83515   3.77871E0
BH0410  2.28600   4.58458E0
BH0411  2.70510   5.33370E0
BH0412  3.02514   6.20283E0
BH0413  3.08610   6.30123E0
BH0414  3.34010   6.71138E0
BH0415  3.59918   7.12976E0
BH0416  3.75158   7.37583E0
BH0417  4.41198   8.44221E0
BH0418  4.48056   8.55296E0
BH0419  4.57200   8.70061E0
BH0420  4.75234   8.99179E0
BH0421  4.85394   9.15588E0
BH0422  5.08000   9.52089E0
BH0423  5.21462   1.03269E1
BH0424  5.26796   1.03269E1
BH0425  5.36702   1.03269E1
BH0426  5.49402   1.03269E1

```

```

*
*      PORBOX  PORBM  DTHEAD  H1MAX  HD1D2  DPART
BH0500  0.4    0.32  10.0   0.6096  2.04749  0.004

```

```

*      HSKIRT  THKCRS  THKHD1  THKHD2  THK6  THK60
BH0600  1.59106  0.050801  0.17356  0.18415  1672.0  1560.9

```

```

*-----+-----+-----+-----+-----+-----+-----+-----+
*      I  S  S  F  F
*      M  F  F  Z  S
*      W  C  C  R  S
*      D  R  R  M  M
*      E  D  S  X  X
*      B  B  S  1  1  DRXID  TFAIL2  HCYL  RCYL  KOZRMX  XOSSMX
BH0700  1  1.0  1.0  1.0  1.0  7.0104  1523.0  2.047494  3.187699  1.0E-6  1.0E-6

```

```

*      TMLIEU  IEUKEY  FRCKEY  EKYMIN
BH0801  1523.0  2  .65977  0.0
BH0802  1700.0  3  .19152  0.0
BH0803  1873.2  18  .02756  0.0
BH0804  2573.2  11  .86800  0.0

```

```

*      IEU(J,LL) 1.LE.J.LE.20, 1.LE.LL.LE.IEUTEC, 1.LE.K.LE.4
*      PURE SPECIES INDEX:J
*      /1  2  3  4  5  = /  ZR  FE  CR  NI  -
*      6  7  8  9  10  =  AG  CDIN  -  -  B4C
*      11 12 13 14 15  =  ZRO2  FEO  FE2O3  FE3O4  CR2O3
*      16 17 18 19 20/=  NIO  B2O3  UO2  -  - /

```

```

*      IEU(J,LL)=0 MEANS THAT SPECIES J IS NOT IN EUTECTIC LL
*      =1 MEANS THAT SPECIES J IS IN EUTECTIC LL

```

*BH09LLK

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```

*      LL=EUTECTIC INDEX
*      J=PURE SPECIES INDEX
*      K=CARD COUNTER

```

```

* EUTECTIC 1
BH09011  1  1  1  1  0
BH09012  0  0  0  0  0
BH09013  0  0  0  0  0
BH09014  0  0  0  0  0

```

```

* EUTECTIC 2
BH09021  0  1  1  1  0
BH09022  0  0  0  0  0
BH09023  0  0  0  0  0
BH09024  0  0  0  0  0

```

```

* EUTECTIC 3
BH09031  1  1  1  1  0
BH09032  0  0  0  0  0
BH09033  0  0  0  0  0
BH09034  0  0  1  0  0

```

```

* EUTECTIC 4
BH09041  0  0  0  0  0
BH09042  0  0  0  0  0
BH09043  1  0  0  0  0
BH09044  0  0  1  0  0

```

```

*
*BH10LLK
*      LL=EUTECTIC INDEX
*      J=PURE SPECIES INDEX
*      K=CARD COUNTER
*      XRNKEY(J,LL)  1.LE.J.LE.20, 1.LE.LL.LE.IEUTEC, 1.LE.K.LE.4

```

```

* EUTECTIC 1
BH10011  0.100  0.65977  0.17237  0.06786  0.0
BH10012  0.0    0.0      0.0      0.0      0.0
BH10013  0.0    0.0      0.0      0.0      0.0
BH10014  0.0    0.0      0.0      0.0      0.0

```

```

* EUTECTIC 2
BH10021  0.0    .73308  .19152  .07540  0.0
BH10022  0.0    0.0      0.0      0.0      0.0
BH10023  0.0    0.0      0.0      0.0      0.0
BH10024  0.0    0.0      0.0      0.0      0.0

```

```

* EUTECTIC 3
BH10031  .36712  0.44375  0.11593  0.04564  0.0
BH10032  0.0    0.0      0.0      0.0      0.0
BH10033  0.0    0.0      0.0      0.0      0.0
BH10034  0.0    0.0      0.02756  0.0      0.0

```

```

* EUTECTIC 4
BH10041  0.0    0.0      0.0      0.0      0.0
BH10042  0.0    0.0      0.0      0.0      0.0
BH10043  .868    0.0      0.0      0.0      0.0
BH10044  0.0    0.0      .132     0.0      0.0

```

```

*
*      ---- NPIPES----  DPIPES  HPIPES  TABLAT
*      (1)  (2)  (3)  (M)  (W/M**2-K)  (K)
BH1100  10  26  22  .04572  1.0214E3  1755.4
*      CVH VOLUME  CVH VOLUME  VOLUME/HEIGHT  CVH VOLUME
*      REPRESENT.  REPRESENT.  CONSISTENCY  REPRESENT.
*      JET PUMP  D W S  CHECK FLAG  LOWER PLENUM
*
BH1200  105  201  1  120

```

BH Package Users' Guide

```
*
*
*
*   user controlled
*   print frequency
*   for bottom head
*   DTPNTB(sec)      dbdrpr(kg/sec)
BH1300      300.0      2000.0
*   BHTIME (sec)      DTPNTB (sec)
BH1301      0.0        200.0
*
*
* failed core shroud to vessel wall thermal radiation model input
*   nwall
BH1400      1
*
*   enter the vessel wall heat structure numbers
*   nwall entries required
*   JJ is the card counter
*BH142JJ
BH14201     10502
*
**
*BH15CC heat transfer characteristics of bottom head
* external surface
*   ibcbh(jj) iflobh(jj)   fcrtr(pool,jj) fcrtr(atm,jj)
BH1501      1      1      0.5      0.5
BH1502      1      1      0.5      0.5
BH1503      1      1      0.5      0.5
BH1504      1      1      0.5      0.5
BH1505      1      1      0.5      0.5
BH1506      1      1      0.5      0.5
BH1507      1      1      0.5      0.5
BH1508      1      1      0.5      0.5
BH1509      1      1      0.5      0.5
BH1510      1      1      0.5      0.5
BH1511      1      1      0.5      0.5
BH1512      1      1      0.5      0.5
BH1513      1      1      0.5      0.5
BH1514      1      1      0.5      0.5
BH1515      1      1      0.5      0.5
BH1516      1      1      0.5      0.5
BH1517      1      1      0.5      0.5
BH1518      1      1      0.5      0.5
*
*bh16 series: hsoff option in hsrn3
BH1600      4
BH1601     10001 * bottom head; axial seg 1
BH1602     10002 * bottom head; axial seg 2
BH1603     10003 * bottom head; axial seg 3
BH1604     10501 * bottom head; top bh package wall
*
* input HS wall structures interfaced with BH
*   IHSBOT IHSTOP
BH1700     10501 10502
*
* input for the BH package lower plenum debris to overlying
* structure radiation model (BH18... series)
```

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```

*      NSHDLP   TFAILS  NHSOF2
BH1800  3      850.0    14
*      ISHDLP(i) 1.le.i.le.nshdlp
BH1801 10013 10014 10004
*
*      IHSOF2(i) 1.le.i.le.nhsf2
BH18101 10013 10014 10004 10005 10206 10207
BH18102 10208 10209 10210 10211 10212 10213
BH18103 10301 10302
*
*BH18JJKK record
*   where JJ is 1.le.JJ.le.(1+NSHDLP+NRAD) index of overlying structure
*   kk is the card counter associated with the JJ index
*   information entered sequentially on the BH18JJKK record
*   is VIEW2(ii,JJ) where:
*   ii is the lower plenum debris bed upper surface radial index
*   (1.le.ii.le.5)
*   JJ is overlying structure index(1.le.JJ.le.(1+nshdlp+nrad))
*   NRAD is from the COR package
*debris surface index i
* use default values
*---JJ--   i=1     =2     =3     =4     =5
*BH180101  0.135  0.154  0.191  0.376  0.564 * JJ=01:exposed vessel wall
*BH180201  0.062  0.080  0.118  0.220  0.219 * JJ=02:JP baffle
*BH180301  0.290  0.285  0.262  0.121  0.049 * JJ=03:shroud 10014
*BH180401  0.110  0.101  0.086  0.046  0.024 * JJ=04:shroud 10004
*BH180501  0.031  0.031  0.031  0.022  0.006 * JJ=05:COR ring 4
*BH180601  0.032  0.032  0.032  0.022  0.007 * JJ=06:COR ring 3
*BH180701  0.051  0.051  0.048  0.036  0.013 * JJ=07:COR ring 2
*BH180801  0.283  0.259  0.225  0.152  0.098 * JJ=08:COR ring 1
*
* sum      = 0.994  0.993  0.993  0.995  0.980
*
* bh lp abrk control functions
BH1900 193
*
CF19300 'BH BREAK AREA'   EQUALS 1   1.0  0.0
CF19301 0.0 * initialize
CF19310 0.0 0.01 TIME * area=0.01 m**2
*
* RN classes associated with the NPURE BH package species
* (ICLSBH(I) 1.le.I.le.20)
BHRN101  8  7  7  7  0  12  12  0  0  13   8  7  7  7  7  13  10  0  0
*
*****
* MELGEN input associated with BH      ****
*****
*
* BH controlled flow path valve for flow from vessel
* after gross head failure
FL03200 'GROSS VES FAIL'   100 201 0.   -0.2254
FL03201 0.01 0.2254 0.0          * INITIALLY CLOSED
FL03202 0 0 0 0
FL03203 1.0 1.0
FL032S0 0.01 0.2254 0.1128
FL032V0 -1 132 132
*
CF13200 'GROSS VES FAIL'   EQUALS 1 1.0 0.0

```

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```
CF13201  0.0 * initial value
CF13210  1.0 0.0  BH-FFLAG
*
CF13300  'HEAD FAIL MESS' L-GT 2  1.0  0.0
CF13301  .FALSE. * initial value
CF13306  2 'BH PACKAGE : GROSS HEAD FAILURE OCCURS'
CF13310  1.0 0.0  BH-FFLAG
CF13320  0.0 0.5  TIME
*
* REACTOR VESSEL WALL AROUND DOWNCOMER (CORE)
HS10502000  5  2  -1  0 * no ss temp calc
HS10502001  'MAIN CYL CORE  '
HS10502002  3.5052  1.00 * start at DRXID/2=3.5052
HS10502003  1.0 * MULTIPLICITY
HS10502100  -1  1  3.18754
HS10502102  3.231988  2
HS10502103  3.276436  3
HS10502104  3.320883  4
HS10502105  3.365331  5
HS10502200  -1
HS10502201  'CARBON STEEL  ' 4
HS10502300  9013 -111  1.0 * use cf-013 to determine source (w)
* power fractions for intervals
HS10502301  0.2449  1
HS10502302  0.2483  2
HS10502303  0.2517  3
HS10502304  0.2551  4
*
* control function to determine internal power source for HS10502
CF01300  'CONDUCTION POWER'  EQUALS 1  1.0  0.0
CF01301  0.0 * initial value
CF01310  1.0 0.0  BH-COND-POW
* rest of HS10502 input data
HS10502400  1  105  'INT'  0.05  0.05
HS10502401  0.7000  'EQUIV BAND'  0.20
HS10502500  242.15  0.50  11.9248
HS10502600  5120  201  'EXT'  1.00  1.00
HS10502700  255.66  0.20  11.9248
HS10502800  -1
HS10502801  560.0  5
*
*CV100 settling flow through to itself for when the lower plenum
* heat structures are deactivated at BH initiation
* go away (area=1.0e-6 to allow MAEROS somewhere to settle aerosols)
RNSET017  100  100  0.0  1.0e-6
*****
* end of MELGEN input associated with BH
*****
*
* terminator record
```

4.2 Example MELCOR Input

The following are sample MELCOR input records for the BH package.

```
* ORNL MELCOR BOTTOM HEAD INPUT
BH0000  'Modified, GRAND GULF SHORT TERM STATION BLACKOUT WITH ADS ACTUATION'
```

BH Package Users' Guide

```

*
* increase number of entries in the vcore/vshrd and vps input by one
*
*      HBSB      NA      NPS      IEUTEC
BH0100  3.340      27      27      4
*HBSB at bottom of downcomer
*
* reiterate the properties for UO2
*
*      AMTMEL      AMMLWT      AMLAMF
*      (K)          (J/KG)
BH0218  3010.9      270.070      2.74468E5      * UO2
*
*
*      HH          VCORE          VSHRD
*      (M)          (M**3)          (M**3)
BH0326  5.49400      1.15996E2      1.95572E1 * BAF
BH0327  5.49402      1.15998E2      1.95573E1 * BAF
*
*      HPS          VPS
*      (M)          (M**3)
BH0426  5.49400      1.03269E1
BH0427  5.49402      1.03269E1
*
* increase the debris porosity
*
*      PORBOX      PORBM      DTHEAD      H1MAX      HD1D2      DPART
BH0500  0.45      0.34      10.0      0.6096      2.04749      0.004
*
* increase the temperature of thk60
*
*      HSKIRT      THKCRS      THKHD1      THKHD2      THK6      THK60
BH0600  1.59106      0.050801      0.17356      0.18415      1672.0      1561.0
*
* increase the temperature of tfail2
*
*      I      S      S      F      F
*      M      F      F      Z      S
*      W      C      C      R      S
*      D      R      R      M      M
*      E      D      S      X      X
*      B      B      S      1      1      DRXID      TFAIL2      HCYL      RCYL      XOZRMX      XOSSMX
BH0700  1 1.0 1.0 1.0 1.0 7.0104 1524.0 2.047494 3.187699 1.0E-6 1.0E-6
*
* reiterate the fourth eutectic
*
*      TMLIEU      IEUKEY      FRCKEY      EKYMIN
BH0804  2573.2      11      .86800      0.0
*
*      IEU(J,LL) 1.LE.J.LE.20, 1.LE.LL.LE.IEUTEC, 1.LE.K.LE.4
*
*      PURE SPECIES INDEX:J
*      /1 2 3 4 5 = / ZR      FE      CR      NI      -
*      6 7 8 9 10 = AG      CDIN      -      -      B4C
*      11 12 13 14 15 = ZRO2      FEO      FE2O3      FE3O4      CR2O3
*      16 17 18 19 20/= NIO      B2O3      UO2      -      - /
*
*      IEU(J,LL)=0 MEANS THAT SPECIES J IS NOT IN EUTECTIC LL
*      =1 MEANS THAT SPECIES J IS IN EUTECTIC LL
*
* BH09LLK
*      LL=EUTECTIC INDEX
*      J=PURE SPECIES INDEX
*      K=CARD COUNTER
*
* EUTECTIC 4
BH09041  0 0 0 0 0

```

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BH09042 0 0 0 0 0
 BH09043 1 0 0 0 0
 BH09044 0 0 1 0 0

*
 *BH10LLK
 * LL=EUTECTIC INDEX
 * J=PURE SPECIES INDEX
 * K=CARD COUNTER
 * XRNKEY(J,LL) 1.LE.J.LE.20, 1.LE.LL.LE.IEUTEC, 1.LE.K.LE.4

* EUTECTIC 4
 BH10041 0.0 0.0 0.0 0.0 0.0
 BH10042 0.0 0.0 0.0 0.0 0.0
 BH10043 .868 0.0 0.0 0.0 0.0
 BH10044 0.0 0.0 .132 0.0 0.0

* zero the number of penetrations
 * ---- NPIPES---- DPIPES HPIPES TABLAT
 * (1) (2) (3) (M) (W/M**2-K) (K)
 BH1100 0 0 0 .04572 1.0214E3 1755.4

* user controlled
 * print frequency
 * for bottom head
 * DTPNTB(sec) dbdrpr(kg/sec)
 BH1300 180.0 2000.0

**
 *BH15CC heat transfer characteristics of bottom head
 * external surface
 * ibcbh(jj) iflobh(jj) fcrtr(pool,jj) fcrtr(atm,jj)
 BH1509 1 1 0.45 0.45
 BH1514 1 1 0.45 0.45
 BH1517 1 1 0.45 0.45
 BH1518 1 1 0.45 0.45

* reset tfails
 * input for the BH package lower plenum debris to overlying
 * structure radiation model (BH18... series)
 * NSHDLP TFAILS NHSOF2
 BH1800 3 1700.0 14

* reiterate the view factors for the debris bed to COR ring 3
 *BH18JJKK record
 * where JJ is 1.le.JJ.le.(1+NSHDLP+NRAD) index of overlying structure
 * kk is the card counter associated with the JJ index
 * information entered sequentially on the BH18JJKK record
 * is VIEW2(ii,JJ) where:
 * ii is the lower plenum debris bed upper surface radial index
 * (1.le.ii.le.5)
 * JJ is overlying structure index(1.le.JJ.le.(1+nshdlp+nrad))
 * NRAD is from the COR package
 *debris surface index i
 * use default values
 *---JJ-- i=1 =2 =3 =4 =5
 BH180601 0.032 0.032 0.032 0.022 0.007 * JJ=06:COR ring 3

```

* bh lp abrk control functions
BH1900 193
*
* RN classes associated with the NPURE BH package species
* (ICLSBH(I) 1.le.I.le.20)
BHRN101 8 7 7 7 0 12 12 0 0 13 8 7 7 7 7 7 13 10 0 0
*
*****
*****
CF01300 'CONDUCTION POWER' EQUALS 1 1.0 0.0 * use BH to HS
* conduction power up wall
*****
*
* reset minimum initial liquid debris pour mass for BH
SC00231 5020 5000.0 1
* terminator record

```

5. BH Package Output: Other Package Output

In general, the BH package output is self-explanatory. Examples are provided in Section 6.0 of the Bottom Head (BH) Package Reference Manual, together with a detailed description of each item of the pictorial display and tabulated output.

For a MELGEN run and on the first cycle of a MELCOR restart, all of the input information to the BH package is printed, including much of the time-independent database. The temperature, masses, and energy exchange are written during succeeding edit cycles controlled by DTPNTB on BH1300 and BH13NN input records. In addition, the cumulative energy/enthalpy and gas mass exchanges between BH and CVH are included in the normal MELCOR print edits. Localized heat transfer coefficients and computed flow regime identifiers for the bottom head external surface are also included.

A summary of the various terms of the BH package energy balance is included. All three models (debris/wall, debris/pool, and post core boundary failure model) are summarized.

In addition to the discussion above concerning BH printed output, the user should be aware that during the period that BH is exercised, the COR package output does not contain information pertaining to axial segments below the level of the core plate. (All values below index NTLP are set to zero.) This is because COR package processing is bypassed for the lower plenum region and the user should consult the output from the BH package. Affected portions of the following COR package output include: component temperatures, component decay power, component masses, cell volumes, and component surface areas. In addition, the COR package output concerning the lower head penetrations and the lower head is also bypassed during this period.

Output concerning fission product distributions, the associated decay heats, and the release fraction information should be interpreted with special understanding. No fission product release calculations are performed by the COR package for debris in the lower plenum once the BH package has begun processing.

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However, fission product releases from this debris are performed by the BH package. To facilitate the integration of the release information into the RN package from BH, the transfer arrays and the RN package processing logic developed for COR releases are utilized with no modification to accept BH-derived information. As a result, the RN package printed edits for inventory and release information do not distinguish between the COR package and the BH package. In particular, the printed RN inventories of elemental radioactive masses for each class appearing to reside in core cell 101 for the particulate debris component (6) are equivalent to the sum for each class over all of the control volumes of the BH package debris bed.

To clarify and identify fission product information of interest to the BH package, printouts of the current fission product class mass inventories in each debris bed control volume as well as the instantaneous and cumulative fission product class releases from the entire bed calculated by the BH package are summarized in the BH package section of MELCOR output.

Burn (BUR) Package Users' Guide

The Burn (BUR) package models the combustion of gases in control volumes. The models consider the effects of burning on a global basis without modeling the actual reaction kinetics or tracking the actual flame front propagation. The BUR package models are based on the deflagration models in the HECTR 1.5 code. New in MELCOR 1.8.5 is a diffusion flame model, also derived from HECTR 1.5.

This Users' Guide describes the input to the BUR package, including a brief description of the models employed, the input format, sample input, discussion of the output, sensitivity coefficients, plot variables, and control variables. Details on the models can be found in the BUR Package Reference Manual.

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1. Introduction

The Burn (BUR) package models the combustion of gases in control volumes. The bulk burn models consider the effects of burning of premixed gases without modeling the actual reaction kinetics or tracking the actual flame front propagation. New in MELCOR 1.8.5 is a simple diffusion flame model which allows for the burning of hydrogen rich mixtures upon entry to volumes containing oxygen. The models in the BUR package are based on the models in the HECTR 1.5 code. The only significant modifications made were to provide more direct user control of the models through the implementation of sensitivity coefficients and to include optional model parameters that are used to override the nominal parameters in control volumes in which direct containment heating (DCH) is occurring. Note that the diffusion flame model can be used to model the burning occurring during DCH while leaving the bulk burn parameters at their nominal values.

Deflagrations are ignited if the mole fraction composition in a control volume satisfies a form of LeChatelier's formula. Tests for sufficient H_2 and O_2 are performed, as well as an inerting test for the presence of excessive diluents (H_2O and CO_2). Deflagrations are propagated into adjoining control volumes if additional tests for the H_2 and CO mole fractions in those volumes are satisfied and if the flow path is open to gas flow (i.e., the area is nonzero and the flow path is not covered by water). There is, however, no test for check valves.

The combustion rate is determined by the flame speed, the volume characteristic dimension, and the combustion completeness. The flame speed and combustion completeness can each be input as constant values, or they may be calculated from either user-specified control functions or the default HECTR correlations. The latter are derived from experimental data and depend on combustible and diluent gas concentrations.

For user convenience, the BUR package also prints messages to warn the user when the detonability criteria are satisfied in a control volume. However, only deflagrations are modeled; detonations are merely flagged.

Note: The gases hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2), and oxygen (O_2) must be defined in the NonCondensable Gas (NCG) package whenever the BUR package is active. Steam (H_2O) is automatically present for all MELCOR calculations, so no special action need be taken to include it in a calculation.

2. User Input

The input for the BUR package consists of combustion parameters in the MELGEN and MELCOR input and timestep values for the start of each burn in the MELCOR input. If a BUR record is included in the user's input, all entries for that record must be included, except for cases noted in the following description:

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2.1 MELGEN Input

BUR000 - Activation Record Optional

This record activates the BUR package.

- (1) IACTV - Activation Parameter
= 0, BUR package active
= 1, BUR package not active
(type = integer, default = 1, units = none)

BUR001 - Ignition Parameters Optional

The ignition parameters for deflagrations are input on this record. Input for the first six or all ten entries must be specified if this record is included. See Section 2.2 of the Burn Package Reference Manual.

- (1) XH2IGN - H₂ mole fraction limit for ignition without igniters.
(type = real, default = 0.10, units = none)
- (2) XCOIGN - CO mole fraction limit for ignition without igniters.
(type = real, default = 0.167, units = none)
- (3) XH2IGY - H₂ mole fraction limit for ignition with igniters.
(type = real, default = 0.07, units = none)
- (4) XCOIGY - CO mole fraction limit for ignition with igniters.
(type = real, default = 0.129, units = none)
- (5) XO2IG - Minimum O₂ mole fraction for ignition.
(type = real, default = 0.05, units = none)
- (6) XMSCIG - Maximum H₂O plus CO₂ mole fraction for ignition.
(type = real, default = 0.55, units = none)
- (7) XH2DCH - H₂ mole fraction limit for ignition during DCH.
(type = real, default = XH2IGY, units = none)
- (8) XCODCH - CO mole fraction limit for ignition during DCH.
(type = real, default = XCOIGY, units = none)

- (9) XO2DCH - O₂ mole fraction limit for ignition during DCH.
(type = real, default = XO2IG, units = none)
- (10) XINDCH - H₂O plus CO₂ mole fraction limit for ignition during DCH.
(type = real, default = XMSCIG, units = none)

BUR002 - Detonation Parameters

Optional

The parameters to indicate a detonation are input on this record. Input for all three entries must be specified if this record is included. See Section 2.7 of the Burn Package Reference Manual.

- (1) XH2DET - Minimum H₂ mole fraction for detonation.
(type = real, default = 0.14, units = none)
- (2) XO2DET - Minimum O₂ mole fraction for detonation.
(type = real, default = 0.09, units = none)
- (3) XH2ODT - Maximum H₂O mole fraction for detonation.
(type = real, default = 0.30, units = none)

BUR003 - Combustion Completeness and Propagation Parameters

Optional

The parameters controlling the extent of combustion and propagation to connected volumes are input on this record. Input for either the first eight or all ten entries must be specified if this record is included. See Sections 2.3 and 2.6 of the Burn Package Reference Manual.

- (1) XH2CC - H₂ mole fraction value for calculating combustion completeness.
(type = real, default = 0.08, units = none)
- (2) XCOCC - CO mole fraction value for calculating combustion completeness.
(type = real, default = 0.148, units = none)
- (3) XH2PUP - H₂ mole fraction limit for upward propagation.
(type = real, default = 0.041, units = none)
- (4) XCOPUP - CO mole fraction limit for upward propagation.
(type = real, default = 0.125, units = none)

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- (5) XH2PHO - H₂ mole fraction limit for horizontal propagation.
(type = real, default = 0.06, units = none)
- (6) XCOPHO - CO mole fraction limit for horizontal propagation.
(type = real, default = 0.138, units = none)
- (7) XH2PDN - H₂ mole fraction limit for downward propagation.
(type = real, default = 0.09, units = none)
- (8) XCOPDN - CO mole fraction limit for downward propagation.
(type = real, default = 0.150, units = none)
- (9) XH2CCD - Value of XH2CC during DCH.
(type = real, default = XH2CC, units = none)
- (10) XCOCCD - Value of XCOCC during DCH.
(type = real, default = XCOCC, units = none)

BUR004 - Plot Edit Control Optional

The plot edits requested by the BUR package are controlled by this input.

- (1) IFLAGS - Plot controlling variable.
 - ≥ 0, Plot edit will be requested at start and end of each burn if control function number IFLAGS is true; no BUR plot edits will be requested if it is false.
 - = -1, Plot edits will be requested at the start and end of each burn.
 - = -2, No plot edits will be requested by the BUR package.(type = integer, default = -1, units = none)

BUR005 - Diffusion flame activation and burn parameters Optional

This record activates the diffusion flame model and specifies the burn parameters for the flame. The default values are set to essentially burn most of the incoming hydrogen and CO in a flow path during DCH, and are quite different than the typical settings for the bulk burn model.

- (1) IACTF - Diffusion flame model activation flag. Default is 0 (off); set to 1 (on) to activate model.
 - = 0, Off
 - = 1, On

(type = integer, default = 0, units = none)

- (2) XH2FLM - Minimum hydrogen mole fraction of the flow path to burn. This should be set lower than the usual bulk burn default for realistic simulation (default is 0.0; and up to about 0.03 is reasonable).
(type = real, default = 0.0, units = none)
- (3) XCOFLM - Minimum carbon monoxide mole fraction of the flow path to burn. Default is typical of bulk burn during DCH.
(type = real, default = 0.129, units = none)
- (4) XO2FLM - Minimum oxygen mole fraction in downstream control volume to burn.
(type = real, default = 0.01, units = none)
- (5) XSCFLM - Maximum inerting gas concentration in downstream control volume (steam+carbon dioxide) before burn stops.
(type = real, default = 0.9, units = none)
- (6) XH2CCF - Hydrogen mole fraction to use in the LeChatelier formula for the combustion completeness of the diffusion flame. This is set to the DCH bulk burn value as default.
(type = real, default = 0.08, units = none)
- (6) XCOCCF - Carbon monoxide mole fraction to use in the LeChatelier formula for the combustion completeness of the diffusion flame. This is set to the DCH bulk burn value as default.
(type = real, default = 0.148, units = none)

BURCFxx - Diffusion flame combustion completeness parameters.

01 ≤xx ≤99

Optional

This record specifies the diffusion flame combustion completeness parameters for a flow path. A constant completeness (CC) factor may be specified, or alternatively, the HECTR correlation is available, although the validity of the HECTR correlation for a diffusion flame is unknown.

- (1) IFLNUM - Flow path number. Putting -1 as the flow path will cause the value of CC to be used for all flow paths.
(type = integer, default = none, units = none)
- (2) ICCFLG - Option to use for combustion completeness. For all options, the completeness must satisfy $0.0 \leq CC \leq 1.0$.

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- = -1, use constant CC.
- = 0, use HECTR correlation.

(3) CC - Combustion completeness, $0.0 \leq CC \leq 1.0$.

BUR1XX - Burn Rate and Propagation Speed Parameters

$01 \leq XX \leq 99$

Optional

The parameters determining the burn rate and the speed of propagation are on this record series. If fewer than four entries are included on the record, default values will be used for the remaining entries. See Sections 2.4, 2.5, and 2.6 of the Burn Package Reference Manual.

- (1) ICVNUM - User control volume number.
(type = integer, default = none, units = none)
- (2) IGNTR - Igniter variable
< 0, IGNTR variable (0 or 1) given by REAL control function number ABS(IGNTR)
= 0, igniter not active in control volume
= 1, igniter is active in control volume
= 86, burning prohibited in control volume
(type = integer, default = 0, units = none)
- (3) CDIM - Characteristic dimension of control volume.
If -1 is input, the radius of a sphere whose volume is the control volume total volume $\{3V/(4\pi)\}^{1/3}$ will be used.
(type = real, default = -1, units = m)
- (4) TFRAC - Time fraction of burn before propagation is allowed. It must satisfy $0.0 \leq TFRAC \leq 1$.
(type = real, default = 0.0, units = none)
- (5) CDDH - Value of CDIM during DCH.
(type = real, default = CDIM, units = m)
- (6) TFDH - Value of TFRAC during DCH.
(type = real, default = TFRAC, units = none)

BURCCXX - Combustion Completeness Option

01 ≤ XX ≤ 99

Optional

The parameters determining the option used to calculate the combustion completeness for each volume are on this record series. The first two entries are required if this record is present.

- (1) ICVNUM - User control volume number. If -1 is entered, then this combustion completeness specification will be used in all the volumes except those redefined on subsequent BURCCXX records.
(type = integer, default = none, units = none)
- (2) ICCFLG - Option to use for combustion completeness. For all options, the combustion completeness must satisfy $0.0 \leq CC \leq 1.0$.
< 0, use constant value for completeness. Input the constant as entry 3 on this record
= 0, use correlation (sensitivity coefficient C2202)
> 0, calculate completeness from control function ICCFLG
(type = integer, default = 0, units = none)
- (3) CC - If ICCFLG < 0, this is the combustion completeness to use. Otherwise, a value is required as a placeholder, but will not be used, see entries (4) and (5).
(type = real, default = none, units = none)
- (4) ICCDCH - Value of ICCFLG, during DCH.
(type = integer, default = ICCFLG, units = none).
- (5) CCDH - Value of CC during DCH.
(type = real, default = CC, units = none)

BURFSXX - Flame Speed Option

01 ≤ XX ≤ 99

Optional

The parameters determining the option used to calculate the flame speed for each volume are on this record series. The first two entries are required if this record is present.

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- (1) ICVNUM - User control volume number. If -1 is entered, then this flame speed specification will be used in all the volumes except those redefined on subsequent BURFSXX records.
(type = integer, default = none, units = none)
- (2) IFSFLG - Option specifying how the flame speed is determined.
< 0, use constant value for flame speed. Input the constant as entry 3 on this record
= 0, use correlation (sensitivity coefficient C2200)
> 0, calculate flame speed from control function IFSFLG
(type = integer, default = 0, units = m/s)
- (3) FS - If IFSFLG < 0, enter the flame speed to use. Otherwise, a value is required as a placeholder, but will not be used, see entries (4) and (5).
(type = real, default = none, units = none)
- (4) IFSDCH - Value of IFSFLG during DCH.
(type = integer, default = IFSFLG, units = none)
- (5) FSDH - Value of FS during DCH.
(type = real, default = FS, units = m/s)

2.2 MELCOR Input

Records BUR001, BUR003, BUR004, BUR1XX, BURCCXX, and BURFSXX may also be included in MELCOR input for any restart. In addition, the initial timestep size at burn initiation can be controlled through the following record.

BURTIM - Burn Timestep Information Optional

The information controlling the system timestep at the initiation of a burn is given on this record. (BUR or other packages may further reduce the size of this initial timestep if necessary and may control the size of subsequent timesteps.)

- (1) BURNDT. - Burn timestep variable
< 0.0 The first system timestep during a burn will be $ABS(BURNDT) \times \text{Total time of burn}$
= 0.0 First system timestep is 0.2 s
> 0.0 The first system timestep is BURNDT
(type = real, default = 0., units = s)

3. Sensitivity Coefficients

The *sensitivity coefficient* feature in MELCOR is a powerful feature that gives the user the ability to change selected parameters in the physics models that would otherwise require modification of the Fortran source code. The use of sensitivity coefficients is described in Section 7 of the MELCOR EXEC Users' Guide.

3.1 BUR Sensitivity Coefficients

C2200 - Flame Speed Parameters

The flame speed in meters per second is evaluated from the equation

$$V = V_{base} * C_{dil}$$

where V_{base} and C_{dil} are calculated by the following expressions depending on the value of Y_{max} , which is the value of y (described below), at the start of the burn and XD , which is the diluent concentration at the start of the burn.

If $0.0 \leq Y_{max} \leq Y_1$,

$$V_{base} = C_1 * Y_{max} + C_2$$

If $Y_1 < Y_{max} \leq Y_2$,

$$V_{base} = [C_1 + (C_2 - C_3)/Y_1] * Y_{max} + C_3$$

If $Y_2 < Y_{max} \leq Y_3$,

$$V_{base} = [C_1 + (C_2 - C_3)/Y_1 + (C_3 - C_4)/Y_2] * Y_{max} + C_4$$

If $Y_3 < Y_{max} \leq Y_4$,

$$V_{base} = [C_1 + (C_2 - C_3)/Y_1 + (C_3 - C_4)/Y_2 + (C_4 - C_5)/Y_3] * Y_{max} + C_5$$

If $Y_4 < Y_{max} \leq Y_5$,

$$V_{base} = [C_1 + (C_2 - C_3)/Y_1 + (C_3 - C_4)/Y_2 + (C_4 - C_5)/Y_3 + (C_5 - C_6)/Y_4] * Y_{max} + C_6$$

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If $Y_5 < Y_{max} \leq 1$,

$$V_{base} = [C1 + (C2 - C3)/Y1 + (C3 - C4)/Y2 + (C4 - C5)/Y3 + (C5 - C6)/Y4 + (C6 - C7)/Y5] * Y_{max} + C7$$

If $0.0 \leq Y_{max} \leq Y_2$,

$$C_{dil} = \max [C11, C8 + C9 * XD + C10 * XD^2]$$

If $Y_2 < Y_{max} \leq Y_3$,

$$C_{dil} = \max [C11, C8 + C9 * XD + C10 * XD^2] * (Y_3 - Y_{max}) / (Y_3 - Y_2) + \max [0.0, C12 + C13 * XD] * (Y_{max} - Y_2) / (Y_3 - Y_2)$$

If $Y_3 < Y_{max} \leq 1$,

$$C_{dil} = \max [0.0, C12 + C13 * XD]$$

where

$$Y_{max} = XH_2 + (XH_2CC / XCOCC) * XCO$$

$$XD = XH_2O + XCO_2$$

$$C_i = C2200(i)$$

$$Y_i = C2200(13 + i)$$

The values of C2200(i) are sensitivity coefficients as described below:

- (1) - Constant in base flame speed correlation.
(default = 59.2, units = m/s, equiv = none)
- (2) - Constant in base flame speed correlation.
(default = 1.792, units = m/s, equiv = none)
- (3) - Constant in base flame speed correlation.
(default = 9.576, units = m/s, equiv = none)

- (4) - Constant in base flame speed correlation.
(default = 15., units = m/s, equiv = none)
- (5) - Constant in base flame speed correlation.
(default = 45., units = m/s, equiv = none)
- (6) - Constant in base flame speed correlation.
(default = 55., units = m/s, equiv = none)
- (7) - Constant in base flame speed correlation.
(default = 48.58, units = m/s, equiv = none)
- (8) - Constant for flame speed diluent effect.
(default = 1.0, units = none, equiv = none)
- (9) - Constant for flame speed diluent effect.
(default = -4.53, units = none, equiv = none)
- (10) - Constant for flame speed diluent effect.
(default = 5.37, units = none, equiv = none)
- (11) - Constant for flame speed diluent effect.
(default = 0.05, units = none, equiv = none)
- (12) - Constant for flame speed diluent effect.
(default = 1.0, units = none, equiv = none)
- (13) - Constant for flame speed diluent effect.
(default = -1.29, units = none, equiv = none)
- (14) - Range limit for flame speed correlation.
(default = 0.1, units = none, equiv = none)
- (15) - Range limit for flame speed correlation.
(default = 0.2, units = none, equiv = none)
- (16) - Range limit for flame speed correlation.
(default = 0.3, units = none, equiv = none)
- (17) - Range limit for flame speed correlation.
(default = 0.4, units = none, equiv = none)
- (18) - Range limit for flame speed correlation.
(default = 0.6, units = none, equiv = none)

C2201 - Maximum Overshoot of Ignition Limit

A time advancement is vetoed and repeated with a smaller timestep if either the combustible fraction overshoots the ignition limit excessively while flammable or if the diluent or oxygen concentration overshoots the deinjecting limit excessively while the combustible concentration is above the ignition limit.

- (1) - Overshoot allowed on combustible gas concentration.
(default = 0.005, units = none, equiv = TEST1)
- (2) - Overshoot allowed on deinjecting limit (O_2 or $CO_2 + H_2O$).
(default = 0.01, units = none, equiv = TEST2)

C2202 - Combustion Completeness Parameters

The default combustion completeness (CC) is evaluated as follows

$$CC = 1 - Y_{min}/Y_{max} \quad (CC \text{ constrained such that } 0 \leq CC \leq 1)$$

where for $Y_{max} \leq C2202(2)$:

$$Y_{min}/Y_{max} = C2202(1)$$

and for $Y_{max} > C2202(2)$:

$$Y_{min}/Y_{max} = C2202(1) - C2202(3) (Y_{max} - C2202(2))$$

Y_{max} is LeChatelier's parameter (described above) at the start of the burn, Y_{min} is LeChatelier's parameter at the end of the burn, and the values of C2202(i) are sensitivity coefficients as described below.

- (1) - Slope of combustion completeness correlation for low combustible gas concentrations.
(default = 1.0, units = none, equiv = none)
- (2) - Combustible gas concentration where slope of combustion completeness correlation changes.
(default = 0.03746, units = none, equiv = none)
- (3) - Multiplier for combustion completeness correlation at high combustible gas concentration.
(default = 23.4116, units = none, equiv = none)

C2203 - Minimum Debris Temperature to Invoke DCH Parameters

If the temperature of the airborne debris in a control volume falls below this value, then ignition limits and flame speed and combustion completeness correlations will revert to their non-DCH values.

- (1) - Minimum airborne debris temperature for DCH parameters.
(default = 600., units = K, equiv = none).

4. Plot Keys and Control Function Variables

The plot keys (/p/) and control function argument (/c/) are described below.

BUR-CPUC	/p/	CPU time used by the calculation routines in the BUR package. (units = s)
BUR-CPUE	/p/	CPU time used by the edit routines in the BUR package. (units = s)
BUR-CPUR	/p/	CPU time used by the restart routines in the BUR package. (units = s)
BUR-CPUT	/p/	Total CPU time used by the calculational, edit, and restart routines of the BUR package. (units = s)
BUR-N-SE.n	/p/	Number of times a burn has started or ended in control volume n. It is odd if a burn is occurring in the volume, and even if no burn is occurring. (units = none)
BUR-LOG	/c/	Logical control function argument that is TRUE if any control volume is burning and FALSE otherwise. (type = logical, units = none)
BUR-O2-RAT.n	/cp/	The rate of oxygen consumption from burning in CVH volume n. (units = kg/s)
BUR-O2-TOT.n	/cp/	The total amount of oxygen consumed by burning in CVH volume n. (units = kg)

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BUR-H2-RAT.n	/cp/	The rate of hydrogen consumed from burning in CVH volume n. (units = kg/s)
BUR-H2-TOT.n	/cp/	The total amount of hydrogen consumed by burning in CVH volume n. (units = kg)
BUR-CO-RAT.n	/cp/	The rate of carbon monoxide consumption from burning in CVH volume n. (units = kg/s)
BUR-CO-TOT.n	/cp/	The total amount of carbon monoxide consumed by burning in CVH volume n. (units = kg)
BUR-H2O-RAT.n	/cp/	The rate of steam production from burning in CVH volume n. (units = kg/s)
BUR-H2O-TOT.n	/cp/	The total amount of steam produced by burning in CVH volume n. (units = kg)
BUR-CO2-RAT.n	/cp/	The rate of carbon dioxide production from burning in CVH volume n. (units = kg/s)
BUR-CO2-TOT.n	/cp/	The total amount of carbon dioxide produced by burning in CVH volume n. (units = kg)
BUR-POWER.n	/cp/	The power generated by burning in CVH volume n. (units = W)
BUR-ENERGY.n	/cp/	The energy produced by burning in CVH volume n. (units = J)
BUR-O2-FTOT.n	/p/	Total oxygen burned in flow path n. (units = kg)
BUR-H2-FTOT.n	/p/	Total hydrogen burned in flow path n. (units = kg)

BUR-D2-FTOT.n	/p/	Total deuterium burned in flow path n. (units = kg)
BUR-CO-FTOT.n	/p/	Total carbon monoxide burned in flow path n. (units = kg)
BUR-H2O-FTOT.n	/p/	Total steam produced in flow path n. (units = kg)
BUR-CO2-FTOT.n	/p/	Total carbon dioxide produced in flow path n. (units = kg)
BUR-FENERGY.n	/p/	Total energy produced in flow path n.

5. Illustrative Input

The illustrative input for the BUR package is a four-volume problem. The inputs for MELGEN and MELCOR are given below. Only the parameters for burn rate, propagation speed, and timestep control are changed from the defaults for this problem.

5.1 MELGEN Input

```

TITLE ...
JOBID ...
*
* NONCONDENSIBLE GAS INPUT
*
NCG001  H2
NCG002  O2
NCG003  CO2
NCG004  CO
*
* CONTROL VOLUME SETUP ...
*
* FLOW PATH INPUT ...
*
* BURN PACKAGE INPUT
*
BUR000  0    * ACTIVATE BURN PACKAGE
*
* INPUT BURN RATE AND PROPAGATION SPEED PARAMETERS
*

```

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BUR100	4	0	10.	.7
BUR101	7	1	20.	.5
BUR102	8	1	25.	.6
BUR103	9	0	8.	.1

5.2 MELCOR Input

```
TITLE ...
JOBID ...
RESTART ...
*
* OTHER INPUT
*
* BURN Timestep INPUT
*
BURTIM, -.15
```

6. Discussion of Output

In the regular edits in MELGEN and MELCOR, most of the output is self-explanatory and directly reflects user input. For each MELCOR edit, the volumes that are burning or are inert are summarized. In addition, burning volumes are indicated at every timestep regardless of whether an edit is appropriate. An area that requires further explanation, however, is the node connectivity table for burn propagation. In that table, the orientation is given as -1, 0, or 1. These values represent downward, horizontal, and upward propagation directions and are determined from the user input values of the flow path elevations.

Messages are written to the output file and the special message file for a detonation, the start and end of a deflagration, and for propagation. The ID's are

- BUR001 - Detonation
- BUR002 - Deflagration has started
- BUR003 - Propagation
- BUR004 - Deflagration has ended

The message lists the time as well as the applicable volumes. These messages are written to the files regardless of whether an edit was desired or not. In addition, when the appropriate input is specified on record BUR004, a plot dump is requested at the same time the message is written out.

7. Error Messages

The error messages in MELGEN pertain to the input and are self-explanatory. The only error messages in MELCOR for the BUR package reflect errors returned from calls to the control function package.

Cavity (CAV) Package Users' Guide

The Cavity (CAV) package in MELCOR models the attack on the basemat concrete by hot (often molten) core materials. The effects of heat transfer, concrete ablation, cavity shape change, and gas generation are included. These phenomena may be calculated in more than one location ("cavity") in a MELCOR calculation, and debris may be transferred between cavities. Specific models are described in more detail, with appropriate references, in the Cavity Package Reference Manual. The CAV package has interfaces to the Control Volume Hydrodynamics (CHV) package, the RadioNuclide (RN) package and, through the Transfer Process (TP) package, to the Core (COR) and Fuel Dispersal Interactions (FDI) package.

This Users' Guide gives a brief introduction to the models in the Cavity package, and describes the Cavity package input necessary to run MELGEN and MELCOR. Examples are provided. The available control function arguments, plot variables, and sensitivity coefficients are listed and described. Example input decks for running the Cavity package in MELCOR are provided, as are brief explanations of the printed output and possible error messages.

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1. Model Description

The MELCOR Cavity package is used to model the interactions between core debris and concrete in one or more locations in a MELCOR calculation; modeling is based on the CORCON-Mod3 code. The capabilities of the Cavity package are briefly summarized in this section. More details and references are provided in the Cavity Package Reference Manual.

The physical system considered by the Cavity package consists of an axisymmetric concrete cavity containing debris in one or more layers. The package calculates heat transfer rates from the debris to the concrete and to the top surface of the debris, as well as the heat transfer between layers. After calculating the heat transfer rates, the concrete ablation rate is determined and the ablation products are added to the cavity contents. Chemical reactions involving gaseous products of concrete decomposition (H_2O and CO_2) with the material in the cavity are calculated and the products are transported to the appropriate layer.

Boundary conditions for the top surface of the debris are obtained from an associated control volume in the Control Volume Hydrodynamics (CVH) package, which also serves as a sink for heat and gases released during the interaction. If there is a water pool in the associated volume, it is assumed to overlie the debris; heat transfer to it is calculated using the same full boiling curve employed in CORCON. (The effects of the introduction of gas bubbles at the lower surface of the pool—referred to as “barbotage”—and of subcooling were added in CORCON-Mod3. These enhancements may be disabled, if desired.)

By default, the Cavity package considers all debris, metallic and oxidic, to be mixed into a single layer. However, the user may choose modeling that considers multiple layers. Two options are available. The first, equivalent to modeling in CORCON-Mod2, does not permit mixing of metals and oxides. It allows a maximum of three layers: metal, heavy oxide below the metal, and light oxide above the metal. The second option invokes mechanistic calculations that consider the possibility of mixing heavy oxides into the metals and/or metals into the light oxides by gas flows at their mutual interfaces (in competition with reseparation under gravity).

The user may choose to specify the initial contents of one metal layer and/or one oxide layer, or of a single mixed-phase layer. If both pure layers are specified, their initial orientation will be determined by their calculated densities, with the densest on the bottom and the lightest on top. Subsequent behavior will be determined by the mixing option in effect.

In most cases, however, *no* initial contents will be specified; debris will be deposited into the cavity from the Core (COR) package or the Fuel Dispersal Interactions (FDI) package,

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through the Transfer Process (TP) package. The user may also specify deposition rates directly by using the External Data File (EDF) package and the TP package. In either case, relative densities and mixing options will determine the layering of the deposited debris.

The decay heat for the cavity can be obtained directly from a user-input control function or calculated using the Decay Heat (DH) and RadioNuclide (RN) packages. In the former case, or if the RN package is not active to track fission-product relocation, two additional user-input control functions must be specified to define the fraction of total decay heat appearing in each phase (oxide and metal). The user may specify these functions in any case, overriding the MELCOR-calculated results. The simple decay heat model from stand-alone CORCON is not available.

If the RN package is active, it will track the radionuclide inventories associated with the debris. Any initial inventory must be specified by input to the RN package on RNFPNijjXX records. When material is transferred into a cavity by the TP package, a parallel transfer of radionuclides is made, also by the TP package. This requires specific input to the TP package, as will be discussed later.

If there is more than one cavity, material may be transferred between cavities. If the RN package is active, the radionuclide inventory associated with the transferred material is also relocated. In this case, the TP package is not involved.

Transfer of material between cavities can be initiated under three types of conditions: axial rupture, radial rupture, or a TRUE value returned from a Control Function. Each of the three types of ruptures (axial, radial, and Control Function) can result in overflow to another cavity, but only "one-way" transfers are allowed between cavities (e.g., cavity 1 can overflow to cavity 2, which then overflows to cavity 3, but cavity 3 cannot overflow back to cavity 1 or 2). Rather than specifying an overflow cavity, if desired, the user can either 1) force the calculation to be stopped when rupture is predicted, or 2) specify that any ruptures will be "ignored" and the calculation continued (with no material transferred out of the cavity) as if additional concrete still remained.

A cavity is considered to have ruptured axially if the basemat is breached and to have ruptured radially if the outer wall is breached. Any material above the elevation at which the rupture occurs will be transferred to a second (user-specified) cavity. The rupture elevation for axial rupture is that of the lowest ablated point, while that for radial rupture is the elevation with minimum remaining wall thickness. Alternatively, the user can control the occurrence of a rupture and the corresponding elevation with Control Functions. If more than one of the three rupture conditions occurs, the one corresponding to the lowest elevation is chosen.

2. User Input

The user input for the Cavity package is described in this section. In MELGEN, one complete set of records is required for each cavity. An arbitrary number of cavities may be defined (subject to total storage available); 100 are permitted by the format of the input records. In MELCOR, certain properties of an *inactive* cavity (one which does not yet contain material) may be altered, but the number of cavities defined in the problem cannot be changed.

2.1 MELGEN Input

A complete set of the following records (at least the required one) must be input for each cavity. They define:

- (1) the initial cavity size, shape, concrete type, and contents (if any),
- (2) the control volume which provides boundary conditions and the transfer process (if any) which will deposit material into the cavity,
- (3) the method for calculating internal (decay) heating, (if not the default), and
- (4) miscellaneous control and model parameters,

although not necessarily in that order.

CAVnn00 – Cavity Declaration

$00 \leq nn \leq 99$, nn is the cavity number

Required

This record identifies the control volume associated with each cavity and, if desired, defines a name for the cavity. An optional field allows deactivation of the scrubbing of RN aerosols and/or iodine vapor that are released with cavity gases into overlying CVH water pools.

- (1) ICAVN - User number of associated control volume
(type = integer, default = none, units = dimensionless)
- (2) CAVNAM - User-defined cavity name
(type = character*16, default = control volume name)
- (3) IBUBX - Optional RN pool scrubbing activation flag
(type = integer, default = 0, units = dimensionless)
= 0 RN scrubbing of aerosols and iodine vapor is active

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- = -1 all RN scrubbing is inactive
- = -2 RN scrubbing of aerosols only is active
- = -3 RN scrubbing of iodine vapor only is active

CAVnnm0 – Initial Layer Definition

$00 \leq nn \leq 99$, nn is the cavity number

$1 \leq m \leq 9$, m is the layer number, used for input only

Optional

This record can be used to specify that material will be present in cavity nn at the start of a calculation. Normally, material is not present in the cavity at the start of a calculation, but is introduced into the cavity during the transient from the other packages of MELCOR.

If it is desired to begin a calculation with material in cavity nn, the initial temperature for each layer in the cavity must be entered on a CAVnnm0 record. One layer containing only metals and/or one layer containing only oxides, or a single layer containing both metals and oxides may be defined. No use is made of the actual value or values input for m; the ordering of the layers, if there are two, will be determined by their calculated densities.

If elimination of a layer that was defined in a previous version of the input deck is desired, this record can also be used to delete it. (Note that if the replacement feature of the input processor is used, only the *last* CAVnnm0 record in the input stream will be used.) Any CAVnnmx records with the same m will then be ignored.

Form 1, defining a layer:

- (1) - Keyword. The character variable TEMP must be entered.
(type = character, default = none)
- (2) TEMP - Initial temperature of layer
(type = character, default = none, units = K)

Form 2, deleting a layer:

- (1) - Keyword. The character variable DELETE must be entered.
(type = character, default = none)

CAVnnmk – Layer Contents

$00 \leq nn \leq 99$, nn is the cavity number, m is the layer number

$1 \leq m \leq 9$, m is the layer number, used for input only.

$1 \leq k \leq 9$

Required, if record CAVnnm0 (first form) is present

These records specify the initial layer contents. There can be up to 9 of them, with each record consisting of one or more pairs of data. The first entry of each pair is a character

variable identifying a species and the second entry is a real variable that specifies the initial mass of the species. Multiple data pairs can be specified on a record, but pairs cannot be split between records. No more than two layers are permitted, as discussed above.

For each data pair:

- (1) - Keyword identifying species. Possible values include AL2O3, CAO, CR2O3, FEO, NIO, SIO2, UO2, ZRO2, AL, C(C), CR, FE, NI, U, and ZR. Other species listed in Appendix A of the Cavity Package Reference Manual may also be used.
(type = character, default = none)
- (2) SPMASS - Initial mass of material
(type = real, default = none, units = kg)

CAVnnC0 – Concrete Declaration

00 ≤ nn ≤ 99, nn is the cavity number

Required

This record specifies the type of concrete in the cavity. There are three options:

Form 1, Standard concrete from CORCON:

- (1) - Keyword. The character variable CORCON must be entered.
(type = character, default = none)
- (2) ICON - CORCON concrete type (type = character, default = none)
 - = 1 Basaltic aggregate concrete
 - = 2 Limestone aggregate/common sand concrete
 - = 3 Generic SE United States concrete
 - = 4 Savannah River Site concrete

Form 2, Standard concrete with simplified composition:

- (1) CONTYP - Type of concrete in cavity
(type = character*16, default = none)
 - = BASALT basaltic concrete
 - = LIMESTONE/CS limestone/common sand concrete
 - = CRBR Clinch River Breeder Reactor concrete

Form 3, Nonstandard concrete:

- (1) CONTYP - Name of nonstandard concrete type
(type = character*16, default = USER-INPUT)

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CAVnnCk – Concrete Composition

$00 \leq nn \leq 99$, nn is the cavity number

$1 \leq k \leq 9$

Required if CONTYP is not a standard composition

Otherwise, optional to modify standard composition

There can be up to 9 of these records. The data are entered in pairs consisting of a character keyword and a real number. The keyword identifies the species and the real number specifies the species mass fraction in the concrete. Multiple data pairs can be specified on a record, but pairs cannot be split between records.

Reinforcing bars are considered part of the concrete composition in MELCOR, unlike stand-alone CORCON. The default compositions for standard concretes contain no rebar; therefore, the rebar content should be included as part of these data, even for standard concretes. The composition is not limited to iron. This feature can be used to model metal inserts in the concrete in some experiments.

If a nonstandard composition was specified for CONTYP, these records specify the concrete composition. For this case, unnormalized mass fractions may be entered.

If a standard concrete type was specified for CONTYP, its default composition is given in Table 2.1. The CAVnnCk record can be used to modify the default composition (e.g., to add rebar or to modify the water content). For this case, the specified (input) mass fraction(s) for the material(s) being modified will be used directly, and the mass fraction(s) of all other materials contained in the standard composition will be renormalized so that the sum of the mass fractions of all of the concrete materials will equal 1.

For each data pair:

- (1) - Keyword identifying species. Possible values include AL2O3, CAO, CR2O3, FEO, NIO, SIO2, UO2, ZRO2, AL, C(C), CR, FE, NI, U, and ZR. Other species listed in Appendix A of the Cavity Package Reference Manual may also be used.
(type = character, default = none)
- (2) XMFRCT - Mass fraction of material.
(type = real, default = none, units = dimensionless)

Table 2.1 Default Concrete Compositions (in mass %)

SPECIES	CORCON				BASALT	LIMESTONE/CS	CRBR
	1	2	3	4			
SIO2	54.84	35.80	3.60	67.05	65.00	36.00	4.00
TIO2	1.05	0.18	0.12	1.00	.	.	.
MNO	.	0.03	0.01	.	.	.	.
MGO	6.16	0.48	5.67	2.68	.	.	.
CAO	8.82	31.30	45.40	13.41	.	.	.
NA2O	1.80	0.082	0.078	1.00	.	.	.
K2O	5.39	1.22	0.68	1.00	.	.	.
FE2O3	6.26	1.44	1.20	1.00	.	.	.
AL2O3	8.32	3.60	1.60	6.26	20.00	5.00	3.00
CR2O3	.	0.014	0.004	.	.	.	.
CO2	1.50	21.154	35.698	1.50	.	.	.
H2OCHEM	2.00	2.00	2.00	2.00	.	.	.
CACO3	.	.	.	.	3.00	48.00	81.00
CA(OH)2	.	.	.	.	8.00	8.00	8.00
H2OEVAP	3.86	2.70	3.94	3.10	4.00	3.00	4.00

CAVnnCa – Other Concrete Properties

$00 \leq nn \leq 99$, nn is the cavity number

$A \leq a \leq Z$

All except TINCT and EMISCT are required if CONTYP is not a standard composition. Defaults for standard concretes are given in Table 2.2.

There can be up to 26 of these records, with data entered in pairs consisting of a character keyword and a real number. The keyword identifies a concrete property and the real number specifies the value of the property. Multiple data pairs can be specified on a record, but pairs cannot be split between records. Default values are

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available for the standard concrete types (values are listed below), but these defaults should not be considered as recommended values. The character keywords and corresponding variables are:

- DENSCT - Density of concrete.
(type = real, units = kg/m³, default = Table 2.2 for standard concrete, none for other concrete)
- TSOLCT - Solidus temperature of concrete.
(type = real, units = K, default = Table 2.2 for standard concrete, none for other concrete)
- TLIQCT - Liquidus temperature of concrete.
(type = real, units = K, default = Table 2.2 for standard concrete, none for other concrete)
- TABLCT - Ablation temperature of concrete.
(type = real, units = K, default = Table 2.2 for standard concrete, none for other concrete)
- TINCT - Initial temperature of concrete.
(type = real, default = 298.0, units = K)
- EMISCT - Emissivity of concrete.
(type = real, default = 0.6, units = dimensionless)

Table 2.2 Default Concrete Properties

PROPERTY	CORCON				BASALT	LIMESTONE/CS	CRBR
	1	2	3	4			
DENSCT (kg/m ³)	2340.	2340.	2340.	2400.	2400.	2340.	2340.
TSOLCT (K)	1350.	1420.	1690.	1353.	1350.	1420.	1690.
TLIQCT (K)	1650.	1670.	1875.	1653.	1650.	1670.	1875.
TABLCT (K)	1450.	1500.	1750.	1450.	1450.	1500.	1750.

CAVnnDH – Control Functions for Decay Heat

00 ≤ nn ≤ 99, nn is the cavity number

Optional

By default, the decay heat power input to the cavity is determined by MELCOR using the inventory of radionuclides in the cavity (calculated by the RN package) and their specific decay powers (defined by the DCH package). If the RN package is inactive (as in analysis of a simulation experiment) or if the user wishes to override or modify its results, control functions may be specified on this record which will then be used in calculation of the decay heat. This provides the capability to define a total decay heat other than that calculated by MELCOR and/or to define the partition of heat input among layers in the pool.

Unless IPDHCF = -1 and the RN package is active, both IPOXCF and IPMCF must be specified ≥ 0 as MELCOR has no other way to determine the partition of heating between layers.

- (1) IPDHCF - Flag for total decay heat.
 (type = integer, default = none)
 < -1 Set decay heat to zero.
 = -1 Use calculation from decay heat and radionuclide packages.
 ≥ 0 Number of the control function which defines the total decay heat in the cavity.
- (2) IPOXCF - Flag for fraction of heat in oxide phase.
 (type = integer, default = none)
 < 0 Use split calculated by MELCOR
 ≥ 0 Number of control function which specifies fraction of total decay heat to be put into the oxide phase
- (3) IPMCF - Flag for fraction of heat in metal phase.
 (type = integer, default = none)
 < 0 Use split calculated by MELCOR
 ≥ 0 Number of control function which specifies fraction of total decay heat to be put into the metal phase

CAVnnDL – Ablation Delay

00 ≤ nn ≤ 99, nn is the cavity number

Optional

This record may be used to delay the start of concrete ablation until a user-defined criterion is met in addition to the requirements of the CORCON model. It may be used to model such phenomena as the burn-through of a steel liner. If this record

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is present, the possibility of ablation will not be considered until the specified logical control function becomes .TRUE.

If the control function is already .TRUE. in MELGEN, a warning will be issued. If, during MELCOR time advancement, the function is .TRUE. and there is material in the cavity, ablation will be considered for that timestep and all subsequent ones. A "latch" is set within the Cavity package so that further changes in the control function will be ignored.

- (1) IPDEL - Number of a logical control function to define an additional criterion that must be met before ablation will be calculated.
(type = integer, default = none)

CAVnnG0 – Cavity Geometry

$00 \leq nn \leq 99$, nn is the cavity number

Required

This record specifies the initial geometry of the concrete cavity. The only option available at this time is the "flat-bottom cylinder" option of CORCON. Note that CORCON uses its own coordinate system, with z positive down, which is currently totally independent of the rest of MELCOR.

- (1) CORCON - Keyword. The character variable CORCON must be entered.
(type = character, default = none, units = dimensionless)
- (2) IGEOM - CORCON geometry type. The value 2 must be entered.
(type = integer, default = none)

CAVnnG1 – Parameters of CORCON Coordinate System

$00 \leq nn \leq 99$, nn is the cavity number

Required

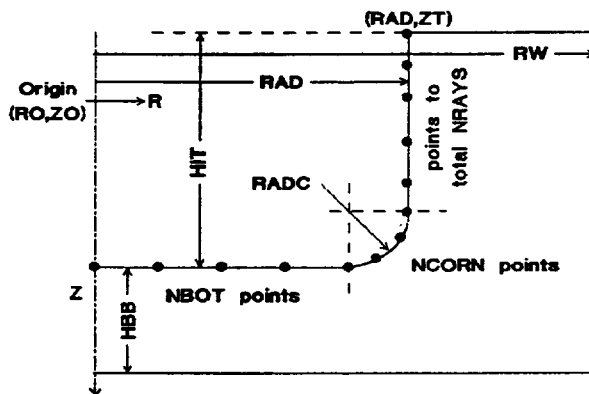
- (1) NRAYS - Number of rays in CORCON system (≤ 100)
(type = integer, default = none, units = dimensionless)
- (2) RO - Radial coordinate of center of ray system. The value 0. must be entered.
(type = real, default = none, units = m)
- (3) ZO - Axial coordinate of center of ray system
(type = real, default = none, units = m)

CAVnnG2 – Cavity Shape

$00 \leq nn \leq 99$, nn is the cavity number

Required

This record specifies the initial cavity shape. The associated variables are illustrated in the figure below, where NBOT=5, NCORN=2, and NRAYS=13.



- (1) ZT - Z coordinate of cylinder top edge
(type = real, default = none, units = m)
- (2) RAD - Radius of cylindrical activity
(type = real, default = none, units = m)
- (3) HIT - Height of cylindrical cavity
(type = real, default = none, units = m)
- (4) RADC - Radius of corner (transition from cylindrical wall to floor) of cavity
(type = real, default = none, units = m)
- (5) RW - > 0 External radius of concrete
(type = real, default = none, units = m)
≤ 0 Negative of number of Tabular Function that defines external radius of concrete as a function of z
(type = real, default = none, units = dimensionless)
- (6) HBB - Thickness of concrete below bottom of cavity
(type = real, default = none, units = m)
- (7) NBOT - Number of points defining flat bottom of cavity, ≥ 2
(type = integer, default = none, units = dimensionless)
- (8) NCORN - Number of points defining corner
(type = real, default = none, units = dimensionless)

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CAVnnGa – Additional Geometry Points

$A \leq a \leq Z$, used for sequencing

Optional

There may be up to 26 of these records, with data entered in triplets. Each triplet is used to add one or more points to the geometry description above the top of the cavity, as previously specified, with decreasing z coordinates in the upward direction. The total number of points may not exceed the maximum of 100. More than one triplet can be specified on a record, but triplets cannot be split between records. If multiple triplets are specified, each must define points lying above all previous points (with records ordered according to the final character, a, of the identifier). In each triplet, the variables are

- NEXTRA - Number of points to be added. If NEXTRA > 1, the points will be uniformly spaced along a line segment from the old last point to the new one.
(type = integer, default = none, units = none)
- REXTRA - R coordinate of new last point
(type = real, default = none, units = m)
- ZEXTRA - Z coordinate of new last point
(type = real, default = none, units = m)

CAVnnRa – Rupture/Overflow Input

$00 \leq nn \leq 99$, nn is the cavity number

a = R, A, or T

Optional

This record identifies the cavity to which material will be moved if the present cavity ruptures, and optionally identifies Control Functions to control when rupture will occur and the elevation of the rupture. Any combination of the three different types of rupture may be specified: axial (a = A), radial (a = R), or Control Function (a = T).

The tests for each type of rupture are discussed in Section 1.

- (1) NOVC - User number of the cavity that will receive overflowing material following a rupture. Setting NOVC to -1 signals MELCOR to stop the calculation if this type of rupture occurs. Setting NOVC to -2 specifies that the calculation should continue unchanged (as if infinite concrete were available), even if rupture is predicted
(type = integer, default = -1, units = dimensionless)

- (2) NCFRUP - Number of the logical Control Function that will trigger rupture of this cavity. This input is optional for a = A or R, and required for a = T (see Section 1 for further details)
(type = integer, default = none, units = dimensionless)
- (3) NCFREL - Number of the real-valued Control Function that specifies the rupture elevation for this cavity. Note that the elevation must be given in the CORCON coordinate system (positive downward). This input is optional for a = A or R, and required for a = T (see Section 1 for further details)
(type = integer, default = none, units = dimensionless)

CAVnnSP – Definition of Parametric Debris Spreading

00 ≤ nn ≤ 99, nn is the cavity number

Optional

This record may be used to model spreading of debris in the cavity. It requires that the user define a maximum debris radius as a function of time through a Tabular Function, Control Function, or channel of an external data file.

The second field on the record is optional. If it is absent, heat transfer from the radial surface of the spreading debris will be considered. If it is present, the only permitted value is ADIABATIC, which will result in suppression of the heat transfer calculation for this surface.

- (1) SOURCE - Source of data for maximum debris radius as a function of time.
(type = character, default = none, units = dimensionless)
= TF.nnn Data from tabular function nnn.
= CF.nnn Data from control function nnn.
= EDF.nnn.m Data from channel m of external data file nnn.
- (2) HTSIDE - Treatment of heat transfer from radial face of spreading debris.
(type = character, default = heat transfer activated, units = dimensionless)
= ADIABATIC Heat transfer suppressed.

CAVnnTP – Out Transfer Process Number

00 ≤ nn ≤ 99, nn is the cavity number

Optional

This record identifies the “out” transfer process number for transferring mass from the COR or FDI packages to the cavity. If absent, no mass will be transferred into the cavity from the core or fuel debris interactions packages.

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- (1) NTPOT - "Out" transfer process number ("nnn" on the TPOTnnn00 record) associated with the "in" transfer process for masses and energies from the COR or FDI package.
(type = integer, default = none, units = dimensionless)

Note that this requires input to the TP package. The appropriate input on the TPOTnnn00 record is NMSOT = 5, NPOTOI = "in" process number on either the COR00004 record or the FDIInn00 record as appropriate. For transfer from FDI, a unity translation matrix should be used (OUTMTX=DEF.1). For transfer direct from COR, a user-defined matrix should be used (OUTMTX = UIN.mmm, where "mmm" is the number of the translation matrix), the corresponding TPMmmm0000 record should define NROW = 5 and NCOL = 6 (the Cavity package does nothing with control poison from the core), and the remaining TPMmmm... records should define matrix elements 1/1, 2/2, 3/3, 4/4, and 5/5 equal to 1.0.

In order to transfer the radionuclides along with the total masses, additional Transfer Process numbers must be defined. Currently, these radionuclide TP numbers must be exactly 500 greater than the corresponding TP numbers defined for total mass and energy transfers by the COR or FDI and CAV input. The appropriate TP parameters are a number of masses (which is equal to the total number of radionuclide classes), N THERM = 1, and a unity translation matrix (DEF.1 on the TPOTnnn00 record).

CAVnnak – Miscellaneous Control and Model Parameters

$0 \leq nn \leq 99$, nn is the cavity number

$U \leq a \leq Z$

k arbitrary

Optional

There can be up to 216 of these records with data entered in pairs consisting of a character keyword and either a real or integer variable. The keyword identifies the parameter and the real or integer variable specifies the value of the parameter. Multiple data pairs can be entered on a record, but data pairs cannot be split between records.

The character variables are:

- BOILING - Treatment of enhancements to the boiling curve for heat transfer to overlying coolant. A multiplier may be applied to the standard curve (including subcooling and gas barbotage enhancements), or the enhancements may be suppressed.
(type = real, default = 0., units = none)
= 0. Use standard CORCON-Mod3 model, including enhancements

- > 0. Use value as multiplier on standard model
 - < 0. Suppress enhancements (the CORCON-Mod2 model)

- COKE - Coking flag. A value of zero will enable production of condensed carbon during oxidation of zirconium. If enabled by previous input, a non-zero value will suppress the reaction.
(type = real, default = 1., units = none)

- CTOXYREA - Treatment of chemical reactions involving concrete decomposition products. Any non-zero value will suppress the reduction of ablated oxides by debris metals. If suppressed by previous input, a value of zero will enable the reaction.
(type = real, default = 0., units = none)
 - = 0. Include oxides and gases as reactants
 - ≠ 0. Exclude oxides, and consider gases only (the CORCON-Mod2 model)

- EMISS.OX - Emissivity of the oxide phase.
(type = real, default = 0.6, units = dimensionless)

- EMISS.MET - Emissivity of the metal phase.
(type = real, default = 0.6, units = dimensionless)

- EMISS.SUR - Emissivity of the surroundings.
(type = real, default = 0.6, units = dimensionless)

- GFILMBOTT - Selection of gas or slag film model for the melt/concrete interface at the bottom surface of the debris. Any non-zero value selects the gas film model.
(type = real, default = 1., units = none)
 - = 0. Use slag film model
 - ≠ 0. Use gas film model (the CORCON-Mod2 model)

- GFILMSIDE - Selection of gas or slag film model for the melt/concrete interface at the radial surface of the debris. Any non-zero value selects the gas film model.
(type = real, default = 1., units = none)
 - = 0. Use slag film model
 - ≠ 0. Use gas film model (the CORCON-Mod2 model)

- HTRBOT - Treatment of debris-to-surface heat transfer at the bottom surface of the debris. Either a multiplier on the standard model or an alternate analytic form may be specified.
(type = real, default = 0., units = dimensionless)

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- = 0. Use standard CORCON-Mod3 model
 - > 0. Use value as multiplier on standard model
 - < 0. Use alternate form of correlation with coefficients defined by sensitivity coefficients C2309(1-3)

- HTRINT - Treatment of debris-to-surface heat transfer at interior interfaces between debris layers. Either a multiplier on the standard model or an alternate analytic form may be specified.
(type = real, default = 0., units = dimensionless)
 - = 0. Use standard CORCON-Mod3 model
 - > 0. Use value as multiplier on the standard model
 - < 0. Use alternate form of correlation with coefficients defined by sensitivity coefficients C2309(7-9)

- HTRSIDE - Treatment of debris-to-surface heat transfer at the radial surface of the debris. Either a multiplier on the standard model or an alternate analytic form may be specified.
(type = real, default = 0., units = dimensionless)
 - = 0. Use standard CORCON-Mod3 model
 - > 0. Use value as multiplier on the standard model
 - < 0. Use alternate form of correlation with coefficients defined by sensitivity coefficients C2309(4-6)

- MIXING - Treatment of mixing between metallic and oxidic components of the debris.
(type = real, default = -1., units = none)
 - = 0. Suppress mixing (the CORCON-Mod2 model)
 - > 0. Calculate mixing and separation rates from correlations
 - < 0. Enforce mixing (all debris forms a single mixed layer)

- NONIDEAL - Treatment of chemical free energies in the VANESA fission product release model. Because the nonideal oxide model is not operational, options invoking it cannot be used.
(type = real, default = -1., units = none)
 - = 0. Nonideal model for both metals and oxides - not available for use
 - > 0. Ideal model for both metals and oxides
 - = -1. Nonideal model for metals, ideal model for oxides
 - = -2. Ideal model for metals, nonideal model for oxides - not available for use

- RADLEN - Path length for the optional aerosol opacity calculation in the calculation of radiative heat loss from the debris surface.
(type = real, default = 0., units = m)

- SHAPEPLOT** - Inclusion of cavity shape data in the plot file in the form of r and z coordinates of the defining body points. By default these are omitted to reduce the size of the plot file. (see Section 4 for details)
 (type = real, default = 0., units = none)
 = 0. Exclude cavity shape data from plot file
 ≠ 0. Include cavity shape data in plot file
- TDEBUG** - Time to start CORCON diagnostic print.
 (type = real, default = "infinity", units = s)

2.2 MELCOR Input

Certain elements of the input for an application of the cavity model may be modified at a restart *if the model is not yet active (if the cavity contains no material)*. These allow changes to initial geometry, concrete type, and miscellaneous model parameters. This is intended to allow a user to perform several calculations which vary on cavity parameters without the need to rerun the pre-vessel-failure part of the calculation.

In addition, cavity rupture/overflow input can be changed such that a cavity continues to ablate (without any material being transferred out of it) even if rupture is predicted. This change can be made even if a cavity is already active.

The input is a subset of that described for MELGEN; the permitted records are listed below (any others will be ignored). Details for each record are provided in Section 2.1.

CAVnn00 – Cavity Declaration

Only the cavity name may be changed from MELGEN.

CAVnnC0 – Concrete Declaration

CAVnnCk – Concrete Composition

CAVnnCa – Other Concrete Properties

If CAVnnC0 is present, a complete concrete definition must be included. If CAVnnC0 is absent, other CAVnnC* records will be ignored.

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CAVnnG0 – Cavity Geometry

CAVnnG1 – Parameters of CORCON Coordinate System

CAVnnG2 – Cavity Shape

If CAVnnG0 is present, all of the following records must be included, even though the data elements involved may be unchanged from MELGEN. If CAVnnG0 is absent, other CAVnnG* records will be ignored.

CAVnnGa – Additional Geometry Points

This may not be included without CAVnnG0, CAVnnG1, and CAVnnG2, even if these involve no changes from MELGEN.

CAVnnRa – Rupture/Overflow Input

The only overriding change permitted is to change NOVC to -2. NCFRUP and NCFREL need not be entered. If they are, they must be identical to the values previously input to MELGEN.

CAVnnak – Miscellaneous Model and Control Parameters

Any appropriate combination described in the preceding section may be entered, whether or not present in MELGEN input.

3. Sensitivity Coefficients

The sensitivity coefficients for the Cavity package have identifier numbers from 2300 to 2499. Sensitivity coefficient array 2301, recognized by MELCOR 1.8.2, was eliminated in favor of similar capabilities available through a new array, 2309, in MELCOR 1.8.3. Most of the other sensitivity coefficients from previous versions of the CAV package (specifically, 2302, 2304, 2305, part of 2306, 2307, and 2308), have not yet been connected to CORCON-Mod3. This situation will be corrected in later versions of MELCOR.

2300 – Ablation Enthalpy

This coefficient may be used to modify the heat of ablation of concrete. At this time, it has no effect on restart unless the concrete is also redefined.

The heat of ablation is defined herein as the heat required to convert a unit mass of virgin concrete at the user-specified initial temperature, to condensed-phase and gaseous decomposition products, all at the specified ablation temperature. It contains contributions from sensible heat, heat of chemical decomposition, and heat of fusion, and is internally calculated from the CORCON thermochemical database. It is important to realize that all enthalpies are calculated from the *same* database. Therefore, while increasing the ablation temperature will increase the value calculated for the heat of ablation, it will lead to an equal reduction in the heat necessary to raise the ablation products to a given pool temperature. Thus, the net

effect of a change in ablation temperature on the heat necessary to ablate a unit mass of concrete and bring the ablation products to pool temperature is only indirect, through a possible change in the pool temperature predicted. In order to change the energy balance associated with ablation, it is necessary to modify the heat of ablation *at a given ablation temperature*.

- (1) - Additional ablation enthalpy to be added to internally-calculated value.
(default = 0.0, units = J/kg, equiv = DDELH)

2306 – Heat Transfer, Above Melt

These coefficients may be used to modify heat transfer from the surface of the debris pool.

- (1) - Convective heat transfer coefficient in atmosphere.
(default = 10.0, units = W/m²K, equiv = HA)
- (2) - Convective heat transfer coefficient in water pool.
(default = 1000.0, units = W/m²K, equiv = HCONV)

2309 – Heat Transfer, Layer Bulk to Interface

These coefficients may be used to modify the coefficients in the alternate correlations used for gas-enhanced heat transfer between the interior of a liquid layer (or sublayer) and its surfaces. These alternate correlations are selected by the HTRBOT, HTRINT, and HTRSIDE keywords on CAVnnak records. (Note that the model also includes natural convection and conduction limits which are *not* modifiable through these coefficients.)

The alternate correlation has the form

$$Nu = A * Re^B * Pr^C$$

Here the length scale in the Nusselt and Reynolds numbers is the bubble radius. The velocity in the Reynolds number is the superficial velocity of gas flowing through the layer. The alternate correlation has the form used for bottom and interfacial heat transfer in CORCON-Mod2, and the default values for the coefficients are those used there. Differences in evaluation of materials properties in CORCON-Mod3, however, will result in differences in calculated heat transfer. Also, CORCON-Mod2 used a different correlation for side heat transfer. Although detailed agreement is impossible, the default coefficients A, B, and C have been

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chosen to give heat transfer coefficients in rough agreement with those in CORCON-Mod2 for a limited number of cases.

- (1) - Constant A for bubble injection (at the bottom of lowest layer).
(default = 5.05, units = dimensionless, equiv = CCAHTB)
- (2) - Exponent B for bubble injection.
(default = 0.5, units = dimensionless, equiv = CCBHTB)
- (3) - Exponent C for bubble injection.
(default = 0.8, units = dimensionless, equiv = CCCHTB)
- (4) - Constant A for side heat transfer.
(default = 2.0, units = dimensionless, equiv = CCAHTS)
- (5) - Exponent B for side heat transfer.
(default = 0.3, units = dimensionless, equiv = CCBHTS)
- (6) - Exponent C for side heat transfer.
(default = 0.0, units = dimensionless, equiv = CCCHTS)
- (7) - Constant A for interfaces between layers.
(default = 5.05, units = dimensionless, equiv = CCAI)
- (8) - Exponent B for interfaces between layers.
(default = 0.5, units = dimensionless, equiv = CCBI)
- (9) - Exponent C for interfaces between layers.
(default = 0.8, units = dimensionless, equiv = CCCI)

4. Plot Variables and Control Function Arguments

The Cavity package variables that may be used for plot variables and control function arguments are listed and described below. The control function arguments are denoted by a 'c'. The plot variable arguments are denoted by a 'p'. The 'c' or 'p' characters are inside slashes '/' following the variable name. In the following list, n refers to the cavity number ($0 \leq n \leq 99$), "lay" refers to the desired layer, with HOX referring to the heavy oxide layer, LOX to the light oxide layer, MET to the metal layer, HMX to the heavy mixture layer, and LMX to the light mixture layer. Here "heavy" and "light" are in comparison to the metal. Finally "gas" refers to one of the four gases (H₂, H₂O, CO, or CO₂), and "spc" to one of the condensed-phase species (oxides and metals) in the CORCON species list.

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CAV-ACTIVE.n	/c/	Activity flag for cavity n. (logical)
CAV-MTOT.n	/p/	Total mass in cavity n. (units = kg)
CAV-HTOT.n	/p/	Total enthalpy for cavity n. (units = J)
CAV-DHR.n	/cp/	Decay heat rate for cavity n. (units = W)
CAV-MASS.spc.n	/c/	Total mass of requested condensed-phase species in cavity n (summed over all debris layers). (units = kg)
CAV-M.lay.n	/p/	Mass of layer. (units = kg)
CAV-T.lay.n	/cp/	Layer temperature. (units = K)
CAV-RHO.lay.n	/p/	Layer density. (units = kg/m ³)
CAV-THICK.lay.n	/cp/	Layer thickness. (units = m)
CAV-VOL.lay.n	/cp/	Volume occupied by layer. (units = m ³)
CAV-VF.lay.n	/p/	Layer void fraction. (units = dimensionless)
CAV-MAXRAD.n	/cp/	Maximum cavity radius. (units = m)
CAV-MINALT.n	/cp/	Minimum cavity altitude. (units = m)
CAV-TMEX.n	/p/	Total mass of gas released from cavity n. (units = kg)
CAV-MEX.gas.n	/cp/	Total mass of requested gas released from cavity n. (units = kg)
CAV-QREA.n	/cp/	Heating rate by chemical reactions in cavity n. (units = W)
CAV-QCNCT.n	/cp/	Heat loss to concrete in cavity n. Under the assumptions of CORCON-Mod2, this heat goes to the ablation of concrete. (units = W)

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CAV-QSURF.n	/cp/	Heat loss from the surface of debris in cavity n. It may go to either a pool or the atmosphere in the bounding control volume. (units = W)
CAV-TGASMOL.n	/cl/	Total moles of gas released from cavity n. (units = mol)
CAV-R.n.i	/cp/	Radial coordinate of i-th body point in cavity n. (units = m) Available as a plot variable if and only if the SHAPEPLOT flag has been set on a CAVnnak record (see the description of <u>this flag in Section 2.1</u>). <u>Note the order of the indices.</u>
CAV-Z.n.i	/cp/	Axial coordinate of i-th body point in cavity n. (units = m) Available as a plot variable if and only if the SHAPEPLOT flag has been set on a CAVnnak record (see the description of this flag in Section 2.1). Note the order of the indices.
CAV-CPUT	/p/	Total CPU time used in Cavity package, including computation and I/O. (units = s)
CAV-CPUC	/p/	CPU time used for computation in Cavity package. (units = s)

Partial coding has been included for several other plot variables. The names CAV-DHTOT.n, CAV-HEX.n, CAV-MABLA.n, CAV-MSRC.n, and CAV-RUPALT.n will be recognized by the plot program, but the values plotted will be identically zero.

5. Example Input

Two examples are included in this section. The first example shows typical input for a calculation that begins with an empty cavity and then receives mass from the core package during the calculation, while the second example shows typical input for a calculation that is initiated with mass in the cavity.

5.1 Example for Normal Cavity Input

In this example, cavity 1 is associated with control volume number 201 and is named Cavity 1. It is empty at the start of the calculation but receives mass after the core melts through the vessel lower head. The molten core is transferred from the core package to the Cavity package using the Transfer Process package; CAV receives the debris through "out" transfer process number 102. CORCON type 2 concrete (limestone/common sand)

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is specified in this example and 13.5% reinforcing steel is included. The initial cavity is a flat-bottomed cylinder with a radius of 3.0 m and a depth of 5.0 m. The cavity is defined with 95 points, of which 10 are initially on the bottom and 10 on the 0.1 m radius transition between bottom and side. The emissivity of the metal layer is changed from the default value to 0.7.

```
*****      CAVITY INPUT      *****
CAV0100  201  'CAVITY 1'
** Concrete type **
CAV01C0  CORCON  2          * Concrete type
CAV01C2  FE  0.135        * Include rebar
** Cavity geometry **
CAV01G0  CORCON  2          * Geometry type
*          NRAYS  RO      ZO
CAV01G1  95      0.0     0.5
*          ZT   RAD  HIT  RADC  RW   HBB  NBOT  NCORN
CAV01G2  0.0   3.0   5.0   0.1   4.0   2.0   10   10
** Transfer process to introduce debris **
CAV01TP  102          * RN will use TP 602
** Miscellaneous parameters **
CAV01Y1  EMISS.MET  0.7
*****      END OF CAVITY INPUT      *****
```

Input to the Transfer Process package will be required in the form

```
TPOT10200  5      101  UIN.103  * Transfer process for debris
TPM1030000  5      6          * Translation matrix
TPM1030001  1/1  1.0   2/2  1.0   3/3  1.0   4/4  1.0   5/5  1.0
TPOT60200  15     601  DEF.1    * Transfer process for RN
```

where it is assumed that the Core package uses "in" Transfer process 101 and that RN is active with the default 15 classes. For further discussion, see the TP, RN, and COR Users' Guides.

By default, the debris will form a single mixed layer. Complete stratification (the CORCON-Mod2 model) may be enforced by including the record

```
CAV01XA 0.0 * suppress mixing of phases
```

Alternatively, a mechanistic calculation of mixing and reseparation may be specified by including the record

```
CAV01XA 1.0 * perform mechanistic mixing calculation
```

When and if the debris has eroded through the two meters of concrete below cavity 1, the MELCOR calculation will be terminated. It may be restarted by including the record

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CAV01RA -2 * ignore axial rupture

and will then continue as if there were infinite concrete available. If the user desires that the debris fall into a second cavity and the calculation continue, the record

CAV01RA 7 * axial rupture with overflow to cavity 7

should be included in MELGEN input, along with complete input for cavity 7. (MELGEN must run because a cavity cannot be added on restart.)

5.2 Stand-Alone Cavity Example

This example shows typical input for a "stand-alone" cavity calculation. As in the previous example, cavity 1 is associated with control volume 201, but in this example, the calculation begins with mass present in the cavity. Two layers are initially present: an oxide layer and a metal layer. Both layers are initially at 2500°K. Basalt concrete is specified, but the composition is modified slightly from the default composition, the initial temperature is raised to 350°K, and the ablation temperature is changed to 1773°K (1500°C). The initial cavity geometry is as in the preceding case.

```
***** CAVITY INPUT *****
CAV0100 201 'CAVITY 1'
** Initial layer contents **
CAV0110 TEMP 2500.
CAV0111 UO2 100000. ZRO2 14000.
CAV0112 FEO 6000.
CAV0120 TEMP 2500.
CAV0121 ZR 10000. FE 70000.
CAV0122 CR 10000. NI 6000.
** Concrete input **
CAV01C0 BASALT * Concrete type
CAV01C1 H2OEVAP 0.060 * Water content
CAV01C2 SIO2 0.700 * SiO2 content
CAV01CA TINCT 350.0 * Initial concrete temperature
CAV01CB TABLCT 1773.0 * Ablation temperature
** Cavity geometry **
CAV01G0 CORCON 2 * Geometry type
* NRAYS RO ZO
CAV01G1 95 0.0 0.5
* ZT RAD HIT RADC RW HBB NBOT NCORN
CAV01G2 0.0 3.0 5.0 0.1 4.0 2.0 10 10
***** END OF CAVITY INPUT *****
```

Input must be provided for control volume 201, from which temperature and pressure boundary conditions for the cavity will be obtained. These properties may be directly

specified as tabular functions of time by treating this volume as a "time-specified volume." See the Control Volume Hydrodynamics Users' Guide for details.

By default, the initial debris will be placed in a single, mixed-phase layer, *despite the definition of separate metallic and oxidic layers*. The treatment of mixing may be modified by input for the MIXING keyword on a CAV01ak record, as described in the previous example.

6. Discussion of Output

The Cavity package output should be self-explanatory. Basically, each edit identifies the cavity, its associated control volume, and the status of the cavity ("sleeping" if there is no material presently in cavity, "active" if material is currently present). This is followed by a summary of the major CORCON options in effect and, if the cavity is active, by detailed output (in CORCON format) in several sections as described in the CORCON Reference Manual. This output includes:

- (1) A general summary giving the pool configuration, maximum depth and radius, an approximate energy budget, and checks on conservation of mass and energy. As noted in CORCON documentation, the energy budget is approximate, and should not be expected to balance exactly. The entry for "changes in pool enthalpy" contains latent heats, and may be significant at times when the pool temperature is nearly constant, but the freezing point of a layer is changing as a result of changing composition. MELCOR calculations frequently require a far larger number of timesteps than do calculations with stand-alone CORCON. Therefore, the errors in mass and energy conservation may become larger than a user is accustomed to seeing. Simple accumulation of roundoff would lead to relative errors of approximately $\text{SQRT}(n)$ times unit roundoff after n timesteps. This would be roughly 10^{-11} on a typical 64-bit machine or 10^{-4} on a typical 32-bit machine after 10^4 steps.
- (2) Gas generation results, giving generation rates and cumulative releases, both as masses and in moles. Because generation of trace gases has been suppressed, only the major species H_2O , H_2 , CO_2 , and CO are included.
- (3) Geometry of the cavity. Information includes the locations of body points defining the cavity, inclinations of the walls, locations of layer interfaces, and local void fractions.
- (4) Details of heat transfer at the interface between the debris pool and the concrete. This includes ablation rates, thickness of the gas film, and temperature of the pool/film interface.
- (5) Results of chemical reactions during the timestep.

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- (6) Pool composition.
- (7) Layer properties, including thermochemical and transport properties of each (occupied) layer. Gas-bubble and layer-oriented heat transfer results including crust-model quantities are also given, as are important terms in the energy equation for each layer.
- (8) Properties of the individual phases in mixed-phase (HMX or LMX) layers, if present, including mass, density, and melting range.

If the cavity is inactive, the first edit for each calculation will still include geometric and other relevant data. In any case, it will be followed by a summary of concrete properties, including the composition, the composition of reinforcing bar (if present), the melt range, the ablation temperature, and the heat of ablation.

7. Diagnostic and Error Messages

Diagnostic and error messages may be printed either in MELGEN or in MELCOR. Messages resulting from errors or unrecognized records in user input to MELGEN include the record identifier and sufficient information to allow the user to identify the error. Error messages may be printed during the subsequent calculation of rates in MELGEN or during execution of MELCOR to warn of possibly inaccurate results or indicate the cause of problem termination.

The CORCON manual lists a number of nonfatal errors involving such things as failure of the crust model to converge within the requested tolerance. Because an alternate treatment is provided, and conservation laws are *not* violated, the default treatment in MELCOR is not to print these messages except to the extended diagnostic file, which is primarily of interest to code developers. In any case, there is little or nothing that a code user can (or should) do about them. See the WARNINGLEVEL input record in the Executive (EXEC) Package Users' Guide; the messages referred to above have been given a severity level of 3.

There are also several errors beyond which the code cannot continue, and the calculation will be stopped after a restart dump is written. These errors include the appearance of a singular matrix in the chemical equilibrium routine CCMLTR or in the heat transfer/energy conservation routines CCENR1, CCENR2, CCHLAY, or CCINTP. The first of these has been reported, the others have not. The user's only option is to restart the calculation with some modification to input—a change in timestep is frequently sufficient—to try to avoid the error. It may be necessary to pick the calculation up from an earlier restart rather than the final one.

Another set of fatal errors includes failure in the iterative determination of layer temperatures in subroutine CCTMPF, which is called from subroutines CCENR1 and

CCPLAY, or of boundary layer heat transfer in subroutine CCFILM. Here, also, the user's only option is usually to restart the calculation with some input modification. In the former case (involving subroutine CCTMPF), the printed output should first be checked to assure that the debris temperatures are reasonable. If they are not, the problem may have been caused by an error in definition of the heat source in CAV, and the associated input and output should be checked carefully.

In the interest of completeness, we note that there are a number of additional points in the Cavity package coding where execution will be terminated if an apparent corruption of the database is detected. Examples include, but are not limited to, the overwriting of table bounds in expansion of specific heat tables in subroutine CCCFND (because the array dimensions are adequate), or the appearance of mass in a mixed-phase layer (because there is no provision for creating such a layer in CAV). Several nonfatal messages not mentioned in this section, such as a warning that the emissivity tables in subroutine CCEMIS are being extrapolated (because the CAV package does not allow the table option in CORCON) can only result from corruption of the database. Unfortunately, it was determined that these terminations would not be executed or the warnings issued (short of a machine error) in distributed versions of MELCOR. Therefore, if one should be encountered (and is reproducible), *the user must first eliminate the possibility that it resulted from an error in a local modification to the code*. If it can be demonstrated that this is *not* the case, the only recourse is to contact the code development team.

Condenser (CND) Package Users' Guide

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 proposed new 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. This Users' Guide provides basic information needed to run the CND model with the rest of MELCOR, including a detailed explanation of the user input and package output for MELGEN and MELCOR. Required and optional input, sensitivity coefficients, control function arguments, plot variables, and error messages are all covered.

More detailed information of the technique used to simulate the effects of the operation of the two types of condensers can be found in the CND Package Reference Manual.

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1. Introduction

The input for the condenser model described here is based upon the concept that the MELCOR code should adequately represent the effects of the condensers 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 and is a task not compatible with the role that a fast-running PRA analytical tool should play. 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 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 impractical large CPU and wall clock time consumption.

The condenser model was originally developed to model the passive containment cooling system (PCCS) and the isolation condenser system (ICS). Several older boiling water reactors and the new simplified boiling water reactor (SBWR) design contain isolation condensers to condense steam created in the core and return it to the primary system. However, only the SBWR utilizes the PCCS to provide steam suppression in the drywell in the event of a LOCA or when the depressurization valves are used to reduce the differential pressure between the reactor vessel and containment. Therefore, the model has an implied geometry and also contains limitations set forth by the normal operating characteristics of the PCCS and ICS. Their geometries are shown in Figure 1.1 and Figure 1.2.

For the ICS, the source volume is assumed to be the upper portion of the reactor vessel and the drain to be the reactor vessel annulus. For the PCCS, the source volume is assumed to be the volume representing the upper drywell and the drain volume to be any CVH volume located in the drywell. In either case, it is assumed that the drain volume is at approximately the same pressure as the source volume; therefore, the gravity head is sufficient to allow free flow of condensate from the condenser. It is important to note that a flow calculation to flush the condensers of noncondensable gases is performed based on the differential pressure between the source volume and the vent volume, but back flow through either the drain or vent line is not permitted.

Although the PCCS and ICS models were designed exclusively for SBWR applications, allowances have been made in the CND package input processing such that the PCCS and ICS condenser models can be used for either BWR or PWR reactor types.

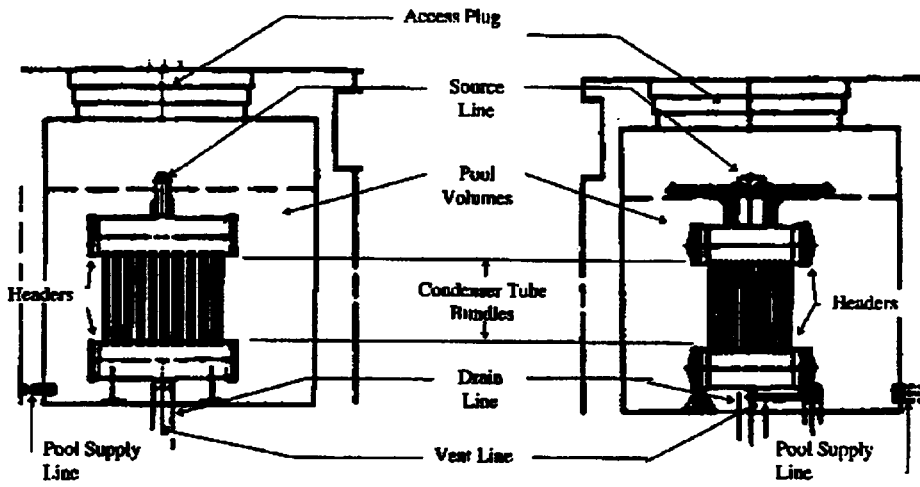


Figure 1.1 Typical Passive Containment Cooler Condenser (left) and Isolation Condenser (right)

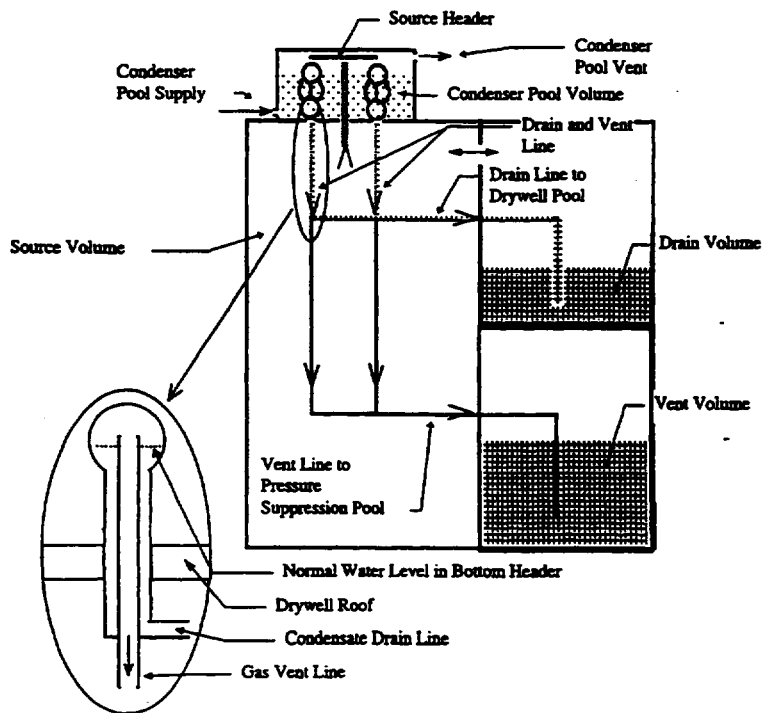


Figure 1.2 Example Flow Diagram of the Passive Containment Cooling System

The condenser model has been written to allow up to three (the maximum number of condensers contained in an SBWR) of the installed independent PCCS or ICS units to be in operation. If multiple units are installed, they are assumed to be identical. Because they may reject heat to different pools, however, the performance of the units may differ.

2. Input Requirements

2.1 MELGEN Input

This section provides the input requirements for the CND package, including a short description of the input quantities and their units and default values, if any. Further description of the input variables and their meaning in the models can be found in the CND Package Reference Manual.

Input record identifiers for the CND model all begin with the character string "ESFCND."

ESFCND0100 – CVH Volumes that Interface with the PCCS Required for Activation of the PCCS Condenser Model

This record identifies the CVH volumes that represent the heat sink for the heat exchangers (a total of three pools), the volume from which material is removed (drywell), the volume containing the vent (wetwell), and the volume containing the drain (GDCS pool).

- (1) IVPCPL(1)* - CVH volume for the primary PCCS unit pool.
(type = integer, default = none, units = none)
- (2) IVPCPL(2)* - CVH volume for the secondary PCCS unit pool.
(type = integer, default = none, units = none)
- (3) IVPCPL(3)* - CVH volume for the third PCCS unit pool.
(type = integer, default = none, units = none)
- (4) IVPCSO - CVH volume representing the drywell, i.e., the source for the PCCS units.

* A CVH volume number should be input for each of the three installed PCCS units. However, the same CVH volume number may be input for one or all of the PCCS unit pools.

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(type = integer, default = none, units = none)

- (5) IVPCVN - CVH volume representing the wetwell, i.e., the PCCS vent.
(type = integer, default = none, units = none)
- (6) IVPCDN - CVH volume representing the GDCS pool(s), i.e., the PCCS drain.
(type = integer, default = none, units = none)

Initialization Characteristics of the PCCS Model

The presence of this input record acts as a flag to activate the PCCS model. If entered, then all remaining PCCS model input cards are processed. If this card is absent or if the value of 0 is entered for IVPCPL(1), then the storage area of the PCCS model variables in the ESF portion of the MELCOR database is skipped along with the definition of the PLOT variables unique to the PCCS model.

ESFCND0200 – Tabular Function for the Variation of Capacity Required

This record provides the input for the variation in capacity caused by various containment conditions that would affect the operation of the PCCS heat exchanger. This does not include any effects of filling of the condenser volume with noncondensable gas (i.e., "bounding") because these effects are calculated by the model.

- (1) IPCDPR - Tabular Function number that represents the variation in capacity due to the increase in differential pressure between the drywell (the volume from which the PCCS removes material) and the wetwell (the vent volume for the PCCS).
(type = integer, default = none, units = none)
- (2) IPLTMP - Tabular Function number for the variation in capacity because of increase in noncondensable mole fraction in the PCCS for an ICS/PCC pool temperature of 323.16 K (50° C).
- (3) IPCNCN - Tabular Function number for the variation in capacity because of increase in noncondensable mole fraction in the PCCS for an ICS/PCC pool temperature of 373.16 K (100° C)
(type = integer, default = none, units = none)
- (4) IPSRPR - Tabular Function number for the variation in capacity because of a decrease in pressure in the PCCS source volume.
(type = integer, default = none, units = none)

Note: The Tabular Function IPCDPR should consist of differential pressures between the drywell and the wetwell and the corresponding coefficients that are to be used as multipliers to the maximum capacity to obtain the adjusted capacities of the PCCS. See CND Package Reference Manual Table 2.1.

The Tabular Functions IPLTMP and IPCNCN should consist of noncondensable gas mole fractions and the corresponding coefficients for ICS/PCC pool temperatures of 50 °C and 100 °C, respectively. See CND Package Reference Manual Tables 2.2 and 2.3.

The Tabular Function IPSRPR should consist of the pressure in the drywell and the corresponding coefficients that are to be used as multipliers to the maximum capacity to obtain the adjusted capacities of the PCCS. See CND Package Reference Manual Table 2.4.

**ESFCND0300 – Geometric Input for the PCCS Vent Line
Required**

This record provides the input for the geometric configuration of the PCCS vent line.

- (1) ELBTVT - Elevation of the bottom of the vent line, assumed to be submerged in the volume normally occupied by the pressure suppression pool.
(type = real, default = none, units = m)
- (2) VNTLND - Diameter of the vent line.
(type = real, default = none, units = m)
- (3) VNTLEN - Total equivalent length of the PCCS vent line. No input is allowed for elbows. Therefore, a total equivalent length should be used in place of the actual length, as explained, for example, in Crane Technical Paper #410.
(type = real, default = none, units = m)

**ESFCND0400 – PCCS Unit(s) Description
Required**

This record provides the input for the description of the PCCS unit and the number of units that are in operation. A PCCS unit is defined as two heat exchangers with a single source line coming from the drywell and a combined exit line. The combined exit separates outside of the PCCS enclosure into separate drain and vent lines returning to the GDCS pool and the wetwell, respectively. If multiple units are in operation, they work in parallel, with separate but identical connecting lines.

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- (1) VOLPCS - Volume of one PCCS unit. It is assumed that the source line and the four barrels, located at the top and bottom of the tube bundles, are sufficiently insulated to preclude significant heat transfer from the steam to the ICS/PCC pool. Therefore, the input volume should be limited to the volume inside the two sets of tube bundles.
(type = real, default = none, units = m³)
- (2) PCMXPF - Maximum capacity of a single PCCS unit, two heat exchangers, when filled with saturated steam. The capacity provided here should correspond to the conditions for which multipliers of 1.00 are provided by the tabular functions identified in input record ESFCND0200.
(type = real, default = none, units = MW)
- (3) NMPCCS - The number of PCCS units in operation, maximum of 3. If a negative value is input, then two special data files are produced (see Section 3). The heat loads for the PCCS units in operation are always assumed to be distributed evenly between the ICS/PCC pools corresponding to the number of units in operation starting with IVPCPL(1).
(type = integer, default = none, units = none)
- (4) VLPCSL = Volume of one PCCS unit source line composed of the two barrels located at the top of the tube bundles, the source line, and the header. This volume is used in the determination of the minimum delta P between the PCCS and the drywell to cause return of the contents of the condenser tube to the drywell.
(type = real, default = none, units = m³)

ESFCND0500 – CVH Volumes that Interface with the ICS Required for Activation of the ICS Condenser Model

This record identifies the CVH volumes that represent the heat sink for the heat exchangers (a total of three pools), the volume from which material is removed (reactor vessel steam dome), the volume containing the vent (wetwell), and the volume containing the drain (reactor vessel annulus).

- (1) IVICPL(1)* - CVH volume for the primary ICS unit pool.
(type = integer, default = none, units = none)
- (2) IVICPL(2)* - CVH volume for the secondary ICS unit pool.
(type = integer, default = none, units = none)
- (3) IVICPL(3)* - CVH volume for the third ICS unit pool.
(type = integer, default = none, units = none)
- (4) IVICSO - CVH volume representing the reactor vessel upper steam dome, i.e., the source for the ICS units.
(type = integer, default = none, units = none)
- (5) IVICVN - CVH volume representing the wetwell, i.e., the ICS vent.
(type = integer, default = none, units = none)
- (6) IVICDN - CVH volume representing the reactor downcomer, i.e., the ICS drain.
(type = integer, default = none, units = none)

Initialization Characteristics of the ICS Model

The presence of this input record acts as a flag to activate the ICS model. If entered, then all remaining ICS model input cards are processed. If this card is absent or if the value of 0 is entered for IVPCPL(1), then the storage area of the ICS model variables in the ESF portion of the MELCOR database is skipped along with the definition of the PLOT variables unique to the ICS model.

ESFCND0600 – Tabular Function for the Variation of Capacity for the ICS Required

This record provides the input for the variation in capacity caused by various containment conditions that would affect the operation of the ICS heat exchanger. This does not include any effects of filling of the condenser volume with noncondensable gas (i.e., "bounding") because these effects are calculated by the model.

- (1) IICDPR - Tabular Function number that represents the variation in capacity due to the increase in differential pressure between the reactor

* A CVH volume number should be input for each of the three installed ICS units. However, the same CVH volume number may be input for one or all of the ICS unit pools.

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vessel (the volume from which the ICS removes material) and the wetwell (the vent volume for the ICS).
(type = integer, default = none, units = none)

- (2) IILTMP - Tabular Function number for the variation in capacity because of increase in noncondensable mole fraction in the ICS for an ICS/PCC pool temperature of 323.16 K (50 °C).
(type = integer, default = none, units = none)
- (3) IICNCN - Tabular Function number for the variation in capacity because of increase in noncondensable mole fraction in the ICS for an ICS/PCC pool temperature of 373.16 K (100 °C)
(type = integer, default = none, units = none)
- (4) IISRPR - Tabular Function number for the variation in capacity because of a decrease in pressure in the ICS source volume.
(type = integer, default = none, units = none)

Note: The Tabular Function IICDPR should consist of differential pressures between the reactor vessel and the wetwell and the corresponding coefficients that are to be used as multipliers to the maximum capacity to obtain the adjusted capacities of the ICS.

The Tabular Functions IILTMP and IICNCN should consist of noncondensable gas mole fractions and the corresponding coefficients for ICS/PCC pool temperatures of 50 °C and 100 °C, respectively.

The Tabular Function IISRPR should consist of the pressure in the reactor vessel and the corresponding coefficients that are to be used as multipliers to the maximum capacity to obtain the adjusted capacities of the ICS. See CND Package Reference Manual Table 3.1.

ESFCND0700 – Geometric Input for the ICS Vent Line Required

This record provides the input for the geometric configuration of the ICS vent line.

- (1) ELVICT - Elevation of the bottom of the vent line, assumed to be submerged in the volume normally occupied by the pressure suppression pool.
(type = real, default = none, units = m)

- (2) VNTICD - Diameter of the vent line.
(type = real, default = none, units = m)
- (3) VNTICL - Total equivalent length of the ICS vent line. No input is allowed for elbows. Therefore, a total equivalent length should be used in place of the actual length, as explained, for example, in Crane Technical Paper #410.
(type = real, default = none, units = m)
- (4) ICCFL2 - Control function number that controls the operation of the ICS. A control function value of other than zero simulates opening of the drain line valves activating the ICS model.
(type = integer, default = none, units = none)

ESFCND0800 – ICS Unit(s) Description
Required

This record provides the input for the description of the ICS unit and the number of units that are in operation. An ICS unit is defined as two heat exchangers with a single source line coming from the reactor vessel, two drain lines that merge before returning to the reactor vessel downcomer, and two vent lines that merge before returning to the wetwell. If multiple units are in operation, they work in parallel, with separate but identical connecting lines.

- (1) VOLIC - Volume of one ICS unit. It is assumed that the source line and the four barrels, located at the top and bottom of the tube bundles, are sufficiently insulated to preclude significant heat transfer from the steam to the ICS/PCC pool. Therefore, the input volume should be limited to the volume inside the two sets of tube bundles.
(type = real, default = none, units = m³)
- (2) PFICMX - Maximum capacity of a single ICS unit, two heat exchangers, when filled with saturated steam. The capacity provided here should correspond to the conditions for which multipliers of 1.00 are provided by the tabular functions identified in input record ESFCND0600.
(type = real, default = none, units = MW)
- (3) NMIC - The number of ICS units that are currently in operation, maximum of 3. If a negative value is input, then two special data files are produced (see Section 3). The heat loads for the ICS units in operation are always assumed to be distributed evenly between

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the ICS/PCC pools corresponding to the number of units in operation starting with IVICPL(1).
(type = integer, default = none, units = none)

- (4) VNSTP(1) - Reactor vessel pressure at which the vent line valves open.
(type = real, default = none, units = Pa)
- (5) VNSTP(2) = Reactor vessel pressure reset point for the ICS vent line valves (pressure at which the valves close).
(type = real, default = none, units = Pa)
- (6) VNSTP(3) - Minimum time delay before the vent line valves are allowed to close. A control function may also be used to control the operation of the ICS vent valve by making VNSTP(3) the negative of the control function number.
(type = real, default = none, units = s)
- (7) VLICSL - Volume of one ICS unit source line composed of the two barrels located at the top of the tube bundles, the source line, and the steam header. This volume is used in the determination of the minimum delta P between the ICS and the reactor vessel steam dome to cause return of the contents of the condenser tubes to the reactor vessel.
(type = real, default = none, units = m³)

2.2 MELCOR Input

Input records ESFCND0400 and ESFCND0800, defined in the previous sections for MELGEN, may also be included in MELCOR input but are not required. If input, then all values must be present. In effect, insertion of this record allows for modifying of the number of PCCS or ICS units in operation on MELCOR restarts. However, the number of units in operation is limited to the number of ICS/PCCS pools defined on input record ESFCND0100 for the PCCS and record ESFCND0500 for the ICS. Also, the creation of the external data files can be controlled by changing the sign of the NMPCCS or NMIC variable in the MELCOR input upon restart.

3. Special Output Data Files

The CND package has the capability to produce data files containing detailed performance data, see Table Table 3.1. The file names are currently defined within the code, and may be unacceptable for some PC systems.

If a negative value is input for NMPCCS (record ESFCND0400), then two special data files are produced by the PCCS model routine CNDRNI. The first data file is named

'PLOT.DAT.' The second is 'PLOTSPECIAL.DAT.' These data files include detailed information on the performance of the PCCS units that are in operation for every timestep. In both files, the time is printed in Column 1.

The PLOT.DAT file contains the overall performance characteristics of the PCCS units that are in operation. The second column is the amount of power transferred to the ICS/PCC pools, E2ADIC. The amount of power transferred to each individual pool can be determined by dividing E2ADIC by the number of PCCS units in operation. The third column is the maximum capacity that can be used if the PCCS has not become blocked; PLTCEF. The difference between PLTCEF and E2ADIC is the amount of power that could not be utilized during the current timestep because of noncondensable gas blocking of the PCCS.

The fourth column provides the total flow of material from either the drywell or the PCCS through the vent line to the wetwell, PLTIFL. The fifth column is the amount of noncondensable gases that flow through the vent line to the wetwell, PLTNF. The difference between PLTIFL and PLTNFL is the flow of uncondensed steam through the vent.

The sixth column, PLTVLL, is the amount of void left in the PCCS at the end of the current timestep (see CND Reference Manual for information concerning the significance of this variable). The seventh column, PRPSOU, is the noncondensable mole fraction in the source volume determined by using partial pressures. The last two variables (columns eight and nine) are the differential pressure between the drywell and the wetwell, DELPRE, and the differential pressure required to produce flow between the drywell and the wetwell, REQPRE.

The data file PLOTSPECIAL.DAT contains information useful for detailed analysis of various internal calculational steps performed by the PCCS model. As before, the first column provides the time. The second column (ENCDCL) is the power used to cool any noncondensable gases that remained in the PCCS at the end of the previous timestep, to the ICS/PCC pool temperature.

The third and fourth columns contain the powers associated with the materials that are vented to the wetwell. The first of these variables is the power given up to the pressure suppression pool by the fog or uncondensed steam or by heating/cooling of the noncondensable gases passing through the water to the wetwell atmosphere, PS_WW_PL. The second variable is the amount of power added to the wetwell atmosphere; this is the power associated with the noncondensable gases at equilibrium with the temperature of the wetwell pool, PS_WW_ATM.

The fifth column provides the pressure in the PCCS at the beginning of the timestep after the iterative operation of filling the PCCS is performed, PRPCS_2. PRPCS_2 should be the same as the sixth variable, the pressure in the drywell, P_DRYWELL.

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The four subsequent columns, seven through ten, provide the amount of steam before and after the call to the equilibration routine, STM_MASS_BEF and STM_MAS_AFT, and the amount of fog before and after the call to the equilibration routine, FOG_MAS_BEF and FOG_MAS_AFT.

Column eleven is the temperature of the noncondensable gases that remain in the PCCS from the end of the previous timestep, TATPCS_1. This is followed by the temperature of the PCCS gases after the call to the equilibration routine, TATPCS_2 in column twelve. The temperature of the drywell, T-DRYWELL, is provided in column thirteen. Finally, the number of iterations performed in filling the PCCS, NCOUNT, is listed in the last column.

If a negative value is input for NMIC (record ESFCND0800) then two special data files are produced by the modeling routine CNDRN1. The first of these data files for the ICS is named "PLOT.RX.DAT." The second is "PLOTSPECIAL.RX.DAT." Similar to the corresponding files for the PCCS, these data files include detailed information on the performance of the ICS units that are in operation every timestep. Table 3.1 gives a short description of each variable in the four data files.

The ICS data files contain exactly the same information as described previously for the PCCS, except that the source volume is the reactor vessel instead of the drywell.

A data set is produced every time the PCCS and ICS models are called; therefore, if a fallback occurs, one or more data point sets will be produced for the same beginning time. To remove the timestep information rejected by the fallback maneuver and to improve the appearance of the data files, a separate post processor was written to change the data over to a format that could be easily placed into either a consistent plotting package or a spreadsheet package.

Upon running the post-processor program, POST, the program prompts the user for both the input and output file names. If the input file does not exist or the output file does, the program requests the user to confirm the entry. The output will be in a form that can be placed into various plotting packages that are capable of accepting columns of data in ASCII format.

Table 3.1 Description of Variables in ICS/PCCS Data Files

PLOT.DAT			
	Variable Name	Units	Description
1	TIME	s	Beginning of timestep value
2	E2ADIC	W	Power transferred to the ICS/PCC pools
3	PLTCEF	W	Maximum capacity of the PCCS unit(s) in operation
4	PLTIFL	kg/s	Flow rate of material through the vent line(s)
5	PLTNFL	kg/s	Flow rate of noncondensable gases through the vent line(s)
6	PLTVLL	m ³	Void left in the PCCS at the end of the current timestep
7	PRPSOU	(no units)	Mole fraction of noncondensable gases in source volume
8	DELPRE	Pa	Differential pressure between the source volume (drywell) and the vent volume (wetwell)
9	REQPRE	Pa	Minimum differential pressure required to produce flow
PLOTSPECIAL.DAT			
	Variable Name	Units	Description
1	TIME	s	Beginning of timestep value
2	ENCDCL	W	Power used to cool any noncondensable gases that remained in the PCCS at the end of the previous timestep, to the ICS/PCC pool temperature
3	PW_WW_PL	W	Power passed to the pressure suppression pool
4	PW_WW_ATM	W	Power passed to the wetwell atmosphere
5	PRPCS 2	Pa	Pressure in the PCCS after the iterative filling operation
6	P_DRYWELL	Pa	Pressure in the drywell
7	STM_MAS_BEF	kg	Steam mass before the equilibration of the material in the condenser
8	STM_MAS_AFT	kg	Steam mass after the equilibration of the material in the condenser
9	FOG_MAS_BEF	kg	Fog mass before the equilibration of the material in the condenser
10	FOG_MAS_AFT	kg	Fog mass after the equilibration of the material in the condenser
11	TATPCS_1	K	Temperature of noncondensable gases that remain in the PCCS from the end of the previous timestep
12	TATPCS_2	K	Temperature of the PCCS gases after equilibration of the material in the condenser
13	T-DRYWELL	K	Temperature of the gases in the drywell
14	NCOUNT	(no units)	Number of iterations performed in filling the PCCS
PLOT.RX.DAT			
	Variable Name	Units	Description
1	TIME	s	Beginning of timestep value
2	E2ADIC	W	Power transferred to the ICS/PCC pools
3	PLTCEF	W	Maximum capacity of the ICS unit(s) in operation
4	PLTIFL	kg/s	Flow rate of material through the vent line(s)
5	PLTNFL	kg/s	Flow rate of noncondensable gases through the vent line(s)

Table 3.1 Description of Variables in ICS/PCCS Data Files

6	PLTVLL	m ³	Void left in the ICS at the end of the current timestep
7	PRPSOU	(no units)	Mole fraction of noncondensable gases in source volume
8	DELPRE	Pa	Differential pressure between the source volume (reactor vessel) and the vent volume (wetwell)
9	CLRPRE	Pa	Differential pressure required to clear the water column from the vent line in the wetwell pool
PLOTSPECIAL.RX.DAT			
	Variable Name	Units	Description
1	TIME	s	Beginning of timestep value
2	ENCDCL	W	Power used to cool any noncondensable gases that remained in the ICS at the end of the previous timestep, to the ICS/PCC pool temperature
3	PW_WW_PL	W	Power passed to the pressure suppression pool
4	PW_WW_ATM	W	Power passed to the wetwell atmosphere
5	PRIC_2	Pa	Pressure in the ICS after the iterative filling operation
6	P_RPV	Pa	Pressure in the reactor vessel
7	STM_MAS_BEF	kg	Steam mass before the equilibration of the material in the condenser
8	STM_MAS_AFT	kg	Steam mass after the equilibration of the material in the condenser
9	FOG_MASS_BEF	kg	Fog mass before the equilibration of the material in the condenser
10	FOG_MAS_AFT	kg	Fog mass after the equilibration of the material in the condenser
11	TATIC_1	K	Temperature of noncondensable gases that remain in the ICS from the end of the previous timestep
12	TATIC_2	K	Temperature of the ICS gases after equilibration of the material in the condenser
13	T-RPV	K	Temperature of the gases in the reactor vessel
14	NCOUNT	(no units)	Number of iterations performed in filling the ICS

4. Plot Variables and Control Function Arguments

The plot variables and control function arguments included in the ESFCND package are listed below, along with a brief description of each. Within slashes (/ /) a 'p' indicates a plot variable and a 'c' indicates a control function argument. Also, these variables, unlike other MELCOR plot variables, are in lower case, and must be entered as such as input to HISPLT—lower case enclosed in quotes.

esf-pccs-ventfl /p/ The integrated total flow through the PCCS vent line into the pressure suppression pool.
(units = kg)

esf-pccs-toteng /p/ Integrated energy added to the ICS/PCC pools (PCCS heat sink).
(units = J)

esf-pccs-totstm /p/ Cumulative steam removed from the drywell.
(units = kg)

esf-ics-vntfl /p/ The integrated total flow through the ICS vent line into the pressure suppression pool.
(units = kg)

esf-ics-toteng /p/ Integrated energy added to the ICS/PCC pools (ICS heat sink).
(units = J)

esf-ics-toststm /p/ Cumulative steam removed from the reactor vessel.
(units = kg)

5. Example Input

The following are sample MELGEN input records for the CND package and associated control functions. An example MELCOR input deck follows.

5.1 Example MELGEN Input

```
*****
*
* Ivpcpl - cvh volumes receiving heat transfer from PCCS
* Ivpcso - cvh volume from which the source is taken for the PCCS
* Ivpcvn - cvh volume containing the vent line from the PCCS
* Ivpcdn - cvh volume containing the drain line from the PCCS
**      ivpcpl(1) ivpcpl(2) ivpcpl(3) ivpcso      ivpcvn      ivpcdn
esfcnd0100  400      401      402      210      230      240
*
tf30300      'PCCS Source pres'      14      1.0      0.0
*
*      Pressure      Multiplier to
*      Pa      PCCS
*      Performance
*
tf30311      0.00E+00      0.0000
tf30312      6.11E+02      0.0000
tf30313      5.00E+04      0.0000
tf30314      1.00E+05      0.0000
* For pressures below .15 MPa the saturation
* temperature is below 100 C; therefore,
* no heat transfer is allowed
tf30315      1.50E+05      0.4250
```

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```

tf30316      2.00E+05      0.6660
tf30317      2.50E+05      0.8495
*   Base operating pressure is approx. 0.3 MPa
tf30318      3.00E+05      1.0000
*   at higher pressure the steam is more
*   dense; therefore, the pccs becomes
*   more effective
tf30319      3.50E+05      1.1289
tf30320      4.00E+05      1.2425
tf30321      4.50E+05      1.3450
tf30322      5.00E+05      1.4386
tf30323      6.50E+05      1.6807
tf30324      7.00E+05      1.7518
*
*   ipcdpr - variation in efficiency due to difference in
*           differential pressure between the drywell and
*           wetwell
*   ipltmp - variation in efficiency due to increase of
*           noncondensable partial pressure in the pccs
*           for a pool temperature of 50 degree C
*   ipcncn - variation in efficiency due to increase of
*           noncondensable partial pressure in the pccs
*           for a pool temperature of 100 degree C
*   ipsrpr - variation in efficiency due to decrease in source
*           pressure
*
*           ipcdpr      ipltmp      ipcncn      ipsrpr
esfcnd0200    300          301          302          303
*
*   The base case is chosen to be the PCCS at the following
*   conditions:
*   IC/PCCS pool Temperature = 100 C
*   Delta P = 15.4 Kpa
*   a NC Mole Fraction of 0.0
*   and a base capacity of 10.6 MWt
*
*   values from ge for a typical pccs unit
tf30000      'delp rduct pccs'      5      1.0      0.0
*           pa - verification in capacity
tf30010      0.0      0.9434      7500.0      0.9434      15400.      1.00
tf30011      23400.0      1.0094      1.0e+06      1.0094
*
*   values from ge for a ic/pccs pool
*   temperature of 50 c
tf30100      'nncn rd 50 pccs'      21      1.0      0.0
*           mole fraction of noncondensibles - variation in cap.
tf30110      0.00      2.2547      0.0071      1.5094      0.0287      1.3302
tf30111      0.0570      1.1981      0.1142      1.0377      0.1718      0.9085
tf30112      0.2290      0.7925      0.2861      0.6887      0.3429      0.5962
tf30113      0.3999      0.5123      0.4571      0.4368      0.5140      0.3689
tf30114      0.5718      0.3075      0.6289      0.2509      0.6852      0.1981

```

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```

tf30115    0.7429    0.1491    0.8006    0.1028    0.8568    0.0620
tf30116    0.9141    0.0266    0.9708    0.0012    1.0000    0.0000
*
* values from ge for a ic/pccs pool
* temperature of 100 c
tf30200    'nncn rd 100 pccs'    16    1.0    0.0
* mole fraction of noncondensibles - variation in cap.
tf30210    0.00    1.0000    0.0071    0.9434    0.0287    0.7726
tf30211    0.0570    0.6858    0.1142    0.5811    0.1718    0.4972
tf30212    0.2290    0.4255    0.2861    0.3585    0.3429    0.2962
tf30213    0.3999    0.2396    0.4571    0.1868    0.5140    0.1387
tf30214    0.5718    0.0926    0.6289    0.0514    0.6852    0.0152
tf30215    1.0    0.0000
*
*
* elbtvt - elevation of the bottom of the vent line from pccs
* vntlnd - the minimum diameter of the vent line in meters
* vntlen - the vent line length in meters
*
* elbtvt    vntlnd    vntlen
esfcnd0300    9.350    .25451    62.67
*
* volpcs - volume of one unit of the pccs in m**3
* pcmxpf - maximum performance at design operating conditions MWt
* nmpccs - number of pccs units operating
* vlpcsl - volume of one unit of the pccs source line in m**3
*
* volpcs    pcmxpf    nmpccs    vlpcsl
esfcnd0400    1.58    10.6    3    2.01
*****
*
* Ivicpl - cvh volumes receiving heat transfer from ICS
* Ivicso - cvh volume from which the source is taken for the ICS
* Ivicvn - cvh volume containing the vent line from the ICS
* Ivicdn - cvh volume containing the drain line from the ICS
**
** ivicpl(1) ivicpl(2) ivicpl(3) ivicso    ivicvn    ivicdn
esfcnd0500    300    301    302    160    230    100
*
* variation values from ge for a ic/pccs pool
* temperature of 50 c obtained from PCCS data. Upper value
* limited to 1.5 for a mole fraction of 0.0
tf31100    'nncn rd 50 ics'    2    1.0    0.0
* mole fraction of noncondensibles - variation in cap.
tf31110    0.00    1.5    0.0071    1.5094    0.0287    1.3302
tf31111    0.0570    1.1981    0.1142    1.0377    0.1718    0.9085
tf31112    0.2290    0.7925    0.2861    0.6887    0.3429    0.5962
tf31113    0.3999    0.5123    0.4571    0.4368    0.5140    0.3689
tf31114    0.5718    0.3075    0.6289    0.2509    0.6852    0.1981
tf31115    0.7429    0.1491    0.8006    0.1028    0.8568    0.0000
tf31116    0.9141    0.0266    0.9708    0.0012    1.0000    0.0000

```

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```
*
tf30400  'ICS Source pres'    46    1.0    0.0
*
*          Pressure          Multiplier to
*                               ICS
*          Pa                Performance
*
tf30411  0.00E+00            0.0000
tf30412  6.11E+02            0.0000
tf30413  5.00E+04            0.0000
tf30414  1.00E+05            0.0000
*   For pressures below .15 MPa the saturation
*   temperature is below 100 C; therefore,
*   no heat transfer is allowed
tf30415  1.50E+05            0.1080
tf30416  2.00E+05            0.1692
tf30417  2.50E+05            0.2159
tf30418  3.00E+05            0.2541
tf30419  3.50E+05            0.2869
tf30420  4.00E+05            0.3157
tf30421  4.50E+05            0.3418
tf30422  5.00E+05            0.3655
tf30423  6.50E+05            0.4271
tf30424  7.00E+05            0.4451
tf30425  7.50E+05            0.4624
tf30426  8.00E+05            0.4787
tf30427  8.50E+05            0.4943
tf30428  9.00E+05            0.5092
tf30429  9.50E+05            0.5237
tf30430  1.00E+06            0.5376
tf30431  1.10E+06            0.5643
tf30432  1.20E+06            0.6507
tf30433  1.30E+06            0.6139
tf30434  1.40E+06            0.6368
tf30435  1.50E+06            0.6591
tf30436  1.75E+06            0.6661
tf30437  2.00E+06            0.6980
tf30438  2.25E+06            0.7259
tf30439  2.50E+06            0.7512
tf30440  3.00E+06            0.7956
tf30441  3.50E+06            0.8328
tf30442  4.00E+06            0.8645
tf30443  5.00E+06            0.9159
tf30444  6.00E+06            0.9556
tf30445  7.00E+06            0.9883
tf30446  7.20E+06            0.9942
*   Base operating pressure is approx. 7.4 MPa
tf30447  7.40E+06            1.0000
tf30448  7.60E+06            1.0054
tf30449  7.80E+06            1.0106
```

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```

tf30450      8.00E+06      1.0156
tf30451      8.20E+06      1.0204
tf30452      8.40E+06      1.0252
tf30453      8.60E+06      1.0298
tf30454      8.80E+06      1.0340
tf30455      9.00E+06      1.0381
tf30456      1.00E+07      1.0568
*
*
* no variation in performance is assumed for increase delta p in
* the vent line
tf31000      'delp rduct ics'      2      1.0      0.0
*
* pa - variation in capacity
tf31010      0.0      1.00      1.0e+06      1.00
*
*
* iicdpr - variation in efficiency due to difference in differential
* pressure between the reactor vessel and
* wetwell
* iiltmp - variation in efficiency due to increase of
* noncondensable partial pressure in the ics
* for a pool temperature of 50 degree C
* iicncn - variation in efficiency due to increase of
* noncondensable partial pressure in the ics
* for pool temperature of 100 degree C
* ipsrpr - variation in efficiency due to decrease
* in source pressure
**
**      iicdpr      iiltmp      iicncn      iisrpr
esfcnd0600  310      311      302      304
*
* Values for IICDPR, IILTMP, IICNCN, have not been obtained from
* GE, thus the same values for the PCCS are used for the ICS
*
* elvict - elevation of the bottom of the vent line from ics
* vnticd - the minimum diameter of the vent line in meters
* vnticl - the vent line length in meters
* iccfl2 - control function indicating initiation of the ICS,
* a non-zero number initiates operation
* the value can be + or -
*
*      elvict      vnticd      vnticl      iccfl2
esfcnd0700  9.5      0.01885      17.4      805
*
* volic - volume of one unit of the ics in m**3
* pficmx - maximum performance at design operating conditions MWT
* nmic - number of ics units operating
* vnstp(1) opening reactor vessel pressure for ics vent Pa
* vnstp(2) reset reactor vessel pressure for ics vent Pa
* vnstp(3) time delay before which the vent can not close
* if vnstp(3) is negative then a CF value must be
* provided that controls the function of the vent valve

```

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```
* vlics1 - volume of one unit of the ics source line in m**3
*          volic  pficmx nmic  vnstp(1)  vnstp(2)  vnstp(3)  vlics1
esfcnd0800  0.7368  30.0    3    7.653e6   7.584e6   240.0    2.986
*
*
*****
*
*****
*
** The following cf's are an example of the use of the CF logic
**
** to approximate the ics vent valve operation
*****
*
*****
*
*
cf30100 true 1-ge 2  1.0  0.0
cf30101 .true.
cf30110 1.0 100.0 time * 100 + current time
cf30111 0.0  0.0 time * zero
**
cf30200 false 1-ge 2  1.0  0.0
c30201  .false.
cf30210 -1.0  0.0 time  * negative of the current time
cf30211  1.0 100.0 time  * 100 + current time
**
cf30300 vnt-vlv-open 1-ge 2  1.0    0.0
cf30301 .false.
cf30310 1.0 0.0  cvh-p.160 * pressure in reactor vessel, CVH volume
160
cf30311 0.0 7.65e06 time  * upper set point of vent valve
**
cf30400 vnt-vlv-clos 1-ge 2 1.0 0.0 * note: since 1-1e is not supported
*                                     both values had to be
*                                     multiplied by (-1) then the
*                                     1-ge input type could
*                                     be utilized
*
cf30401 .true.
cf30410 -1.0 0.0          cvh-p.160 * pressure in reactor vessel
cf30411 0.0 -7.584e06 time          * lower set point for vent valve
closure
**
cf30500 inv-timer 1-not 11.0  0.0
cf30501 .false.
cf30510 1.0 0.0 cfvalu.313
**
cf30600 chk-tim-init 1-and 2  1.0  0.0
cf30601 .false.
```


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cf30610 1.0 0.0 cfvalu.303
cf30611 1.0 0.0 cfvalu.305
**
cf30700 init-tim 1-1-ifte 3 1.0 0.0
cf30701 .false.
cf30710 1.0 0.0 cfvalu.306 * check to see if p>set point and .not.timer
cf30711 1.0 0.0 cfvalu.301 * set the timer equal to true
cf30712 1.0 0.0 cfvalu.313 * set the timer equal to its old value
**
cf30800 set-cls-tim 1-a-ifte 3 1.0 0.0
cf30801 0.0
cf30810 1.0 0.0 cfvalu.306 * check to see if p>set point and .not.timer
cf30811 1.0 60.0 time * set the closure time to current time + 60s
cf30812 1.0 0.0 cfvalu.308 * set the closure time to the old value
**
cf30900 vlv-open 1-a-ifte 3 1.0 0.0
cf30901 0.0
cf30910 1.0 0.0 cfvalu.303 * check to see if p>set point
cf30911 0.0 1.0 time * set the valve opening to 1.0
cf30912 1.0 0.0 cfvalu.312 * set the opening to the old value
**
cf31000 timer-out 1-ge 2 1.0 0.0
cf31001 .true.
cf31010 1.0 0.0 time * current time
cf31011 1.0 0.0 cfvalu.308 * time valve can close
**
cf31100 chk-cls-cnd 1-and 2 2.0 0.0
cf31101 .true.
cf31110 1.0 0.0 cfvalu.304 * true if pressure has dropped
cf31111 1.0 0.0 cfvalu.310 * true if timer has passed current time
**
cf31200 cls-vent-vlv 1-a-ifte 3 1.0 0.0
cf31201 0.0
cf31210 1.0 0.0 cfvalu.311 * if true close valve
cf31211 0.0 0.0 time * value of zero
cf31212 1.0 0.0 cfvalu.309 * valve is open set to the old value
**
cf31300 reset-timer 1-1-ifte 3 1.0 0.0
cf31301 .false.
cf31310 1.0 0.0 cfvalu.311 * if true close valve
cf31311 1.0 0.0 cfvalu.302 * set timer to false value
cf31312 1.0 0.0 cfvalu.307 * valve is open set to the old value
**

*

*
* TRIP FOR RPV WATER LEVEL 2

*

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```
*****
*
* The following are the control functions that are used to initiate the
* operation of the ICS
*
* >>>>
* First, test to see if the collapsed water level has fallen to L2.
* >>>>
*
CF80300 'LEVEL-2-TEST' L-GE 2 1. 0.
CF80301 .TRUE. * initial value
CF80305 'LATCH' * Latch False When water level drops below L2
CF80306 2 'Collapsed Water Level Has Dropped Below L2'
CF80310 1.0 0.0 CVH-CLIQLEV.100 * collapsed liquid level in annulus
CF80311 0.0 13.593 TIME
*
* >>>>
* Second, trap and hold the time at which the level reaches L2
* >>>>
* Following function will trip-on-reverse when CF800 fires, yielding
* a negative value, the absolute value of which is the time (s)
* since trip.
*
CF80400 'L2-TIME-LATCH' TRIP 1 1. 0.
CF80401 0. * initial value
CF80405 'NORMAL'
CF80410 1.0 0.0 CFVALU.803
* >>>>
* Third, trap and hold the absolute value of CF804. This will be the
* actual time since the vessel water level dropped to L2.
* >>>>
CF80500 'TIME-OF-L2' ABS 1 1. 0.
CF80501 0.
CF80505 'NORMAL'
CF80510 1.0 0.0 CFVALU.804
```

5.2 Example MELCOR Input

```
*****
*
* PCCS Input
* decrease the number of pccs in operation from 3 to 2
*
* volpcs - volume of one unit of the pccs in m**3
* pcmxpf - maximum performance at design operating conditions MWt
* nmpccs - number of pccs units operating
* vlpcsl - volume of one unit of the pccs source line in m**3
*
* volpcs pcmxpf nmpccs vlpcsl
esfcnd0400 1.58 10.6 2 2.01
```

```

*
*           ICS Input
* decrease the number of ics in operation from 3 to 1
* also start to use the control function logic to control
* the operation of the vent valves
*
*   volic      - volume of one unit of the ics in m**3
*   pficmx     - maximum performance at design operating conditions Mwt
*   nmic       - number of ics units operating
*   vnstp(1)   opening reactor vessel pressure for ics vent Pa
*   vnstp(3)   time delay before which the vent can not close if
*               vnstp(3) is negative then a CF value must be
*               provided that controls the function of the vent valve
*   vlicsl     - volume of one unit of the ics source line in m**3
*
*   volic      pficmx  nmic  vnstp(1)  vnstp(2)  vnstp(3)  vlicsl
esfcnd0800  0.7368  30.0   1      7.653e6   7.584e6   -311    2.986

```

6. CND Model Output

In general, the CND model output is self-explanatory. The integrated mass transfer through the vent to the CVH volume representing the suppression pool, the integrated energy transfer to the condenser pools, and the integrated mass of steam removed from the source are output for each condenser type.

7. Diagnostics and Error Messages

Diagnostic messages will be written by MELGEN to report errors or inconsistencies in input. Typical errors include errors in record format and failure to supply all required input records. Inconsistencies between input to different packages are also identified; each of the volumes that a condenser connects to must be defined; any tabular functions or control functions referred to by the condenser model must be properly defined.

No restart file will be written until all errors identified during input processing have been corrected. This does not, of course, assure that the accepted input properly describes the physical system that the user intended to model. The analyst should always examine the initial edit produced by MELGEN prior to running MELCOR.

Messages from MELCOR report problems encountered during the time advancement of a calculation. If an error is severe, the calculation will be stopped and a restart dump written corresponding to conditions at the beginning of the fatal timestep.

Error or warning messages may be issued during execution of MELCOR for any number of reasons. These include: an attempt by the Condenser package to subtract more mass of energy than is contained in the associated CVH control volume, an attempt to add more mass or energy to a CVH volume than is allowed, and errors found in tabular or control

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functions. Execution will continue, with a reduced system timestep, when it makes sense to do so; the request for a system fallback will be noted with one of the following messages:

TIMESTEP CUT IN CND PACKAGE
TOO LARGE A MASS SINK GENERATED

TIMESTEP CUT IN CND PACKAGE
TOO LARGE AN ENERGY SINK GENERATED

TOO LARGE AN ENERGY SINK GENERATED IN ATMOSPHERE
TIMESTEP CUT IN CND PACKAGE

When a problem is encountered with a tabular function or a control function, one of the following messages will be produced by routine CNDRN1:

tabular function error in subroutine cndrn1:50C

An error occurred when trying to determine the capacity reduction factor, determined from a user-defined tabular function, for a pool temperature of 50° C.

tabular function error in subroutine cndrn1:100C

An error occurred when trying to determine the capacity reduction factor, determined from a user-defined tabular function, for a pool temperature of 100° C.

tabular function error in subroutine cndrn1:FLOW

An error occurred when trying to determine the capacity reduction factor, determined from a user-defined tabular function, for the differential pressure between the source and the vent CVH volumes.

tabular function error in subroutine cndrn1:PRES

An error occurred when trying to determine the capacity reduction factor, determined from a user-defined tabular function, for the pressure in the source volume.

tabular function error in subroutine cndrn1:vnstp

An error occurred when trying to determine the status of the vent valve from a user-defined control function (a value greater than zero means the valve is open).

Once the condenser is filled from the source volume, an initial pass is made through an equilibration routine. The equilibration routine that is utilized is CVTWGE. CVTWGE is the routine used by the CVH package to equilibrate the CVH volumes when the equilibrium option is used on card CVnnn00, i.e., $T_{pool} = T_{atmos}$. If an error occurs in evaluating the properties of the materials in the condenser, the following error message will be sent"

```
error from call to CVTWGE in subroutine cndrnl
```

In addition to this message, this error condition will result in a restart file being written and immediate termination of the calculation.

As explained in Section 2.4 of the Condenser Package Reference Manual, an iteration process is used to fill the condenser; however, to prevent an infinite loop, the logic is limited to a maximum number of iterations. If the pressure of the source volume is not obtained within the allowable limit, the following error message is produced:

```
message from subroutine cndrnl  
iteration process failed
```

Two energy balance checks are performed during MELCOR execution. The first is performed to ensure that the equilibration routine conserves energy. If energy is not conserved, then the following message is produced:

```
cndrnl:internal energies out of bound
```

The second check is an overall energy balance on the package. The energy error is defined as the current energy minus the integrated energy transferred to the package plus the integrated energy transferred from the package. The relative energy error is given by the energy error divided by the sum of the current energy and the integrated energy transferred out of the package. If the relative energy error exceeds 0.5 percent, the following message is written:

```
*****  
Message from CNDRN2  
CND Package Energy Balance Greater than 0.5%  
*****
```

Control Function (CF) Package Users' Guide

The Control Function (CF) package allows the user to define functions of variables in the MELCOR database, and makes the values of these functions available to other packages in MELCOR. As a result, the user can utilize the time-dependent values of variables that will be calculated during execution of MELCOR. The CF package has a number of uses, some of which may not be immediately obvious. For example, the pressures in appropriate control volumes may be used to control the opening of a valve or the failure of a blow-out panel, the temperature in a volume may define the enthalpy associated with a mass source/sink, or the particle loading on a filter may modify the flow resistance in the corresponding flow path. Complicated control logic may be simulated, involving the values of a number of variables in the system. New variables, not ordinarily part of MELCOR output, may be defined for printed or plotted output. The occurrence of specified conditions may be tested and used to initiate generation of additional output (a single line message, a complete list edit, or an additional plot or restart dump) from MELCOR.

This document includes an introduction to control functions, the concepts involved, and how they may be defined and used. It contains a list of the available types of Control Functions, with the necessary descriptions of each, and describes the relevant MELGEN and MELCOR input. It also presents a number of detailed examples of control function input. This is intended both to aid the new user in getting started, and to illustrate a number of "tricks" which can simplify the task of writing control function definitions.

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1. Introduction

The following subsections give an introduction to control functions as implemented in MELCOR: what they are, how they are used, and how they are defined by user input. Control functions provide a powerful tool which is intended to alleviate the need to reprogram MELCOR for special cases, permitting the user to effectively modify coding through normal user input.

1.1 Concept of Control Functions

The Control Function (CF) package allows the user to define functions of variables in the MELCOR database, and makes the values of these functions available to the various physics packages. The values of the control functions are themselves variables in the database, each calculated from the start-of-step values of the variables which define its arguments, and are therefore also available for printing and/or plotting as desired. Both real-valued and logical-valued control functions are available.

Note that each control function has a unique value at any time, because all of its arguments (other variables in the MELCOR database) are explicit functions of time. It is therefore itself an implicit function of time. This is in contrast to tabular functions, which are functions in the pure mathematical sense of a rule for accepting arguments and returning function values. In order to obtain a value from the tabular function package, a physics package must specify the argument of the function. (This is the reason that tabular functions cannot be plotted directly, although a control function may be defined as a tabular function of time—or any other available argument—and plotted as desired.)

The Control Function package serves primarily as a utility. It is extremely powerful, but its application is limited to cases where the use has been foreseen and appropriate coding has been provided.

- (1) In principle, the Control Function package has access to the entire MELCOR database for use as arguments. This access requires that specific coding be included in the packages which calculate the various data. Therefore, only a limited number of variables in the database are actually available for use as control function arguments; these are listed in the Users' Guides for the various packages to which the data belong.
- (2) The executive or any physics package may refer to a control function (meaning the value of that control function) by number and use it in any way desired. Here again, the actual use of control functions is limited to cases where specific coding is included in the package that will use the data; this is indicated in the input descriptions in the various package Users' Guides. Whenever a control function is specified as part of MELGEN input, it is the user's responsibility to see that the

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function he defines is appropriate. The Control Function package cannot anticipate how a function value will be used, and can only check for consistency of its input. Most packages do only limited error checking—primarily for existence of the function—in MELGEN, and trap only the most obvious errors in function values in MELCOR.

1.2 Applications of Control Functions

A real-valued control function may be used to define an input quantity for a physics package, allowing the input to be a function of current conditions in the system being modeled. The possibilities include:

- (1) rate of mass or enthalpy addition, or temperature of a mass source or sink (negative source) in the CVH package;
- (2) value of an independent thermodynamic variable in a time-specified volume in the CVH package;
- (3) velocity in a "time-dependent" flow path in the FL package;
- (4) fraction of a flow path which is open (to represent valves, breaches, blow-out panels, etc.) in the FL package;
- (5) laminar friction coefficient in a flow path segment in the FL package (this is used to model the effects of filter loading);
- (6) spray flow rate in the SPR package;
- (7) inlet temperature for the dT/dz model in the COR package;
- (8) fission power in the COR package; and
- (9) partition of decay heat between metallic and oxidic phases in the CAV package.

Logical- or real-valued Control Functions may be used to initiate or control the operation of components or models as conditions change in a calculation (and in some cases provide the only way to do so). Examples include:

- (1) opening and closing of valves in the FL package;
- (2) operation of pumps in the FL package;
- (3) actuation of spray sources in the SPR package;
- (4) failure of the lower head in the COR package;

- (5) operation of igniters in the BUR package; and
- (6) operation of the PAR.

Logical-valued control functions may be used to initiate additional MELCOR output as an additional list, plot, restart dump, or a short message. This may allow close examination of "interesting" parts of a calculation or capture peak pressures or temperatures in the list or plot files. It may also permit restarts from potential branch points in an accident sequence, or record the time of occurrence of specified events. Control Functions may also be used simply to evaluate desired quantities that would not otherwise appear in the list or plot files. Note, however, that MELCOR 1.8.5 allows values of specified control function arguments to be added directly to the plot file, *without* defining a control function "EQUAL" to that argument. See the EXEC Users' Guide for details.

In all of these cases, complex functions may be built up as desired. For example, a relief valve may be controlled as a function of the pressure difference between two control volumes, including appropriate static head terms. The different setpoints in a multi-bank relief valve system may also be modeled, and a block or bypass valve included if desired.

1.3 Definition of Control Functions

A control function is referred to by a user-assigned number. It also has a mnemonic name for edit purposes. Further input defines what type of a function it is; for example, CF 102 may be called 'TEST 1' and be evaluated as a square root; CF 232 may be called 'REACTOR SCRAM' and be evaluated using one of several varieties of trips.

Each control function has one or more arguments, which may be real-valued or logical valued; the number and type of the arguments depend on the specific function involved. The specification of each real-valued argument includes a user-input multiplier and an optional additive constant to be applied to the element of the database to which it refers. That is, if "X" is a real-valued element of the database which is listed as an available control function argument, the actual argument used in evaluation of a control function has the form $A X + B$. A value must be specified for A; B has the default value of 0.0. For example, the control function argument CVH-P.102 refers to the pressure in control volume 102 (assuming that this volume exists); the actual argument to be used by a control function could be specified as $a_1 = 2.0 * CVH-P.102 - 1.7E6$.

A real-valued control function may be modified by an overall multiplier and additive constant after the basic function has been evaluated. Thus, using the basic SIN function, the final value of the control function could be specified as $5.3 * SIN(a_1) + 1.8$. Optional upper and/or lower bounds on the value may also be specified.

A logical-valued control function may be forced to "latch," so that its value cannot change more than once. It may also be converted to a "one-shot," so that it can be true no more

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than once. Further, it may be made to "alarm" when it changes state, producing a user-specified message in MELCOR output files.

Optional initial values may be specified for each control function. These values may be required to completely define the value of a function with "history" (dependence on past values) such as an integral or a hysteresis function. They may also be used for initialization purposes by other packages during execution of MELGEN. (Note that, in some cases, the definition might otherwise be circular. For example, the value of a control function defining a heat transfer coefficient might depend on a temperature that in turn depended on that control function.)

The definition of a control function may also include the input of one or more *miscellaneous numbers* such as the setpoint for a trip, or the user number of a tabular function. This will become clear when particular cases are examined. (When additional data—such as the values of arguments on the previous timestep—must be saved in the CF database, they are simply added to the list of miscellaneous numbers during input processing. Therefore, the number of miscellaneous numbers shown in edits may be greater than the number input.)

The value of a control function is itself available for use as a control function argument, so that complicated functions may be built if desired. The user should be aware that control functions are evaluated in numerical order. Thus, if one control function refers to another with a higher (user) number, the value used for the latter will always be out-of-date by one timestep.

2. List of Control Functions

The control functions currently available in MELCOR are listed and described below. In each case, the listing and description correspond to the basic function, and do not include the possible scaling or bounding of real-valued functions, or conversion of logical-valued functions to "latches" or "one-shots," which was discussed in Section 1.3. The formal arguments referred to may include scaling from the actual elements of the MELCOR database.

2.1 Real-Valued Control Functions

In the following, it is to be understood that, in general, the value of the N-th control function, with n arguments, a_i , and m miscellaneous numbers, c_j , is

$$FUNCT_N = SC_N f(a_1, a_2, \dots, a_n; c_1, c_2, \dots, c_m) + AC_N$$

where f is the basic function described below, and SC_N and AC_N are input scaling and offset parameters for the control function. Further, the i -th argument has the general form,

$$a_i = SA_i X + AA_i$$

where X is a *control function argument* available in some package of MELCOR, and SA_i and AA_i are scaling and offset parameters input to the Control Function package.

2.1.1 Elementary and FORTRAN Functions

The first group of real-valued functions are elementary and FORTRAN functions. Their definitions should be clear from the following table, which contains a descriptive name, a short name used as the input type, and a mathematical or FORTRAN definition. In some cases, an additional input parameter, referred to as a "miscellaneous number," is required to complete the definition of the function.

In the list that follows, the order is not strictly alphabetical; similar functions have been grouped together. Except as noted (for L-A-IFTE), all arguments are real. Miscellaneous numbers may be real or integer, depending on their usage.

Function Name	Input Type	# arg	Mathematical or FORTRAN Definition	Miscellaneous Numbers
Equals	EQUALS	1	$f = a_1$	none
Absolute Value	ABS	1	$f = |a_1|$	none
Add	ADD	≥ 2	$f = a_1 + \dots + a_n$	none
Positive Diff	DIM	2	$f = \text{DIM}(a_1, a_2)^{[a]}$	none
Multiply	MULTIPLY	≥ 2	$f = a_1 * \dots * a_n$	none
Divide	DIVIDE	$2^{[b]}$ 1	$f = a_2/a_1$ $f = 1.0/a_1$	none none
Power-Integer	POWER-I	1	$f = (a_1)^J$	1:J = integer exponent
Power-Real	POWER-R	1	$f = (a_1)^R$	1:R = real exponent
Power-Variable	POWER-V	2	$f = (a_1)^{a_2}$	none
Exponential	EXP	1	$f = \exp(a_1)$	none
Natural Log	LN	1	$f = \ln(a_1)$	none
Base 10 Log	LOG	1	$f = \log_{10}(a_1)$	none
Square Root	SQRT	1	$f = \sqrt{a_1}$	none
Cosine	COS	1	$f = \cos(a_1)$	none
Sine	SIN	1	$f = \sin(a_1)$	none
Tangent	TAN	1	$f = \tan(a_1)$	none

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Function Name	Input Type	# arg	Mathematical or FORTRAN Definition	Miscellaneous Numbers
Arccosine	ARCCOS	1	$f = \cos^{-1}(a_1)$	none
Arcsine	ARCSIN	1	$f = \sin^{-1}(a_1)$	none
Arctangent	ARCTAN	1	$f = \tan^{-1}(a_1)$	none
Hyperbolic Cos	COSH	1	$f = \cosh(a_1)$	none
Hyperbolic Sin	SINH	1	$f = \sinh(a_1)$	none
Hyperbolic Tan	TANH	1	$f = \tanh(a_1)$	none
Maximum	MAX	≥ 2	$f = \max(a_1, \dots, a_n)$	none
Minimum	MIN	≥ 2	$f = \min(a_1, \dots, a_n)$	none
Type one Sign	SIGN	2	$f = \text{SIGN}(a_2, a_1)^{[c]}$	none
Type two Sign	SIGNI	1	$f = \text{SIGN}(1.0, a_1)^{[c]}$	none
Unit Normalize	UNIT-NRM ^[d]	1	IF (a ₁ .EQ.0.0) THEN f = 0.0 ELSE f = SIGN(1.0, a ₁) ^[c] END IF	none
Tabular Func	TAB-FUN	1	$f = \text{TF}_N(a_1)^{[e]}$	1:N = Tab. Fcn number
If Then Else	L-A-IFTE	3 ^[f]	IF (a ₁) THEN f = a ₂ ELSE f = a ₃ END IF	None

[a] DIM(x,y) \equiv max (x-y, 0.0) is a FORTRAN intrinsic function.

[b] DIVIDE may be invoked with one argument or with two.

[c] SIGN (x,y) $\| |x|, y \geq 0 \quad | -|x|, y < 0 |$ is a FORTRAN intrinsic function.

[d] UNIT-NRM differs from SIGNI only in the value for a₁ = 0.

[e] TF_N is the MELCOR Tabular Function with user number N.

[f] The first argument of L-A-IFTE is logical, the second and third are real.

2.1.2 Derivatives and Integrals

Two finite-difference approximations to derivatives and one finite-difference approximation to an integral are available as control functions. Each requires two arguments and no miscellaneous numbers, with the first argument being the dependent variable and the

second the independent variable. Note that the independent variable is general, and need *not* be time.

These functions employ values from the MELCOR database at more than one time level. The old values needed are preserved by the Control Function package as part of its own database. In what follows, the time level is indicated by a superscript cycle number n , $n-1$, or $n-2$. The Control Function package is called at the end of a MELCOR advancement, to calculate values for use on the next step. Therefore, " n " refers to the end of the just-completed advancement, " $n-1$ " to the start of that advancement, and " $n-2$ " to the start of the immediately preceding advancement. Note that because of the dependence on past history, the definition of appropriate initial values may be important in initializing these functions. The three functions are:

Derivative-Centered Difference DER-C

This function evaluates a derivative using information at three time levels in the form

$$f^n = \frac{1}{2} \left(\frac{a_1^n - a_1^{n-1}}{a_2^n - a_2^{n-1}} + \frac{a_1^{n-1} - a_1^{n-2}}{a_2^{n-1} - a_2^{n-2}} \right) \quad (2.1)$$

Derivative-Forward Difference DER-F

This function evaluates a derivative using information at only two time levels in the form

$$f^n = \left(\frac{a_1^n - a_1^{n-1}}{a_2^n - a_2^{n-1}} \right) \quad (2.2)$$

Integral INTEG

This function evaluates an integral using information at two levels. It does not use the additive constant (AC) in converting f to FUNCT; if a value for AC is input, it must be 0.0. The integral is calculated as

$$f^n = f^{n-1} + \frac{1}{2} (a_1^n + a_1^{n-1}) (a_2^n - a_2^{n-1}) \quad (2.3)$$

2.1.3 Proportional-Integral-Differential Control Function

This control function has the short input name PID, and requires one argument. It is used in control systems, and is defined by the equation

$$f^n = R_1 a_1^n + R_2 \int_{t_0}^{t^n} a_1(t) dt + R_3 \left. \frac{da_1}{dt} \right|_{t^n} \quad (2.4)$$

where $R1$, $R2$, and $R3$ are input as miscellaneous REAL numbers. The PID function is evaluated as being equivalent to the composite function

$$\begin{aligned} \text{PID}(a_1) = & R_1 \text{EQUALS}(a_1) + R_2 \text{INTEG}(a_1, \text{TIME}) \\ & + R_3 \text{DER-F}(a_1, \text{TIME}) \end{aligned} \quad (2.5)$$

using equations equivalent to Equations (2.2) and (2.3).

2.1.4 Hysteresis Function

This control function has the short input name HYST, and requires one argument. It is used to model the type of hysteresis behavior exhibited by components such as relief valves which are opened as the controlling variable (e.g., differential pressure) is increasing and closed as it is decreasing, with a dead band between. A typical hysteresis function is shown in Figure 2.1.

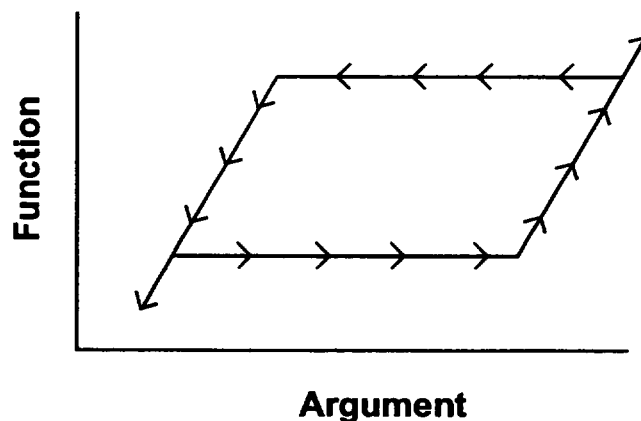


Figure 2.1 Hysteresis Function

The control function value lies between the loading curve, describing the limiting behavior for an increasing argument, and the unloading curve, describing the limiting behavior for a decreasing argument. The value changes only when it is "pushed up" by the loading curve or "pushed down" by the unloading curve. Thus, when argument and function value lie within the open loop of Figure 2.1, the function value remains unchanged until the

argument has either increased to encounter the loading curve or decreased to encounter the unloading curve. In either case, the function value will then follow the appropriate bounding curve.

This may be stated somewhat differently as: When the argument is increasing, the value of the hysteresis function is the maximum of its old value and that defined by the loading curve; when the argument is decreasing, the function takes the minimum of its old value and that given by the unloading curve. That is,

$$f^n = \begin{cases} \max [f^{n-1}, f_{\text{LOAD}}(a_1^n)], & a_1^n \geq a_1^{n-1} \\ \min [f^{n-1}, f_{\text{UNLOAD}}(a_1^n)], & a_1^n < a_1^{n-1} \end{cases} \quad (2.6)$$

The two functions, f_{LOAD} and f_{UNLOAD} , may be specified by tabular functions or other control functions. Two miscellaneous numbers are required; the first identifies the function defining the loading curve and the second identifies the function defining the unloading curve. A number ≥ 0 is interpreted as the number of a control function, while a number < 0 is interpreted as the negative of the number of a tabular function.

Note that if the loading and unloading curves are specified by control functions, it is the user's responsibility to ensure that either

- (1) these functions have the same argument as the hysteresis function, and lower function numbers (so that they are evaluated first), consistent with Equation (2.6)

or

- (2) the user understands how the function will be evaluated (Equation (2.6) with the argument of the loading and unloading function *not* equal to a_1), and truly desires that result.

Necessary old values are maintained within the Control Function package database; proper specification of initial function values may be important to achieve the desired results.

2.1.5 Trips

The MELCOR Control Function package includes a variety of TRIP functions. Each requires a single argument. In one case, this argument is logical. In all others, the argument is real and either two or four miscellaneous numbers are required to define setpoints. The latter class of function is used to model switching phenomena involving a dead band (such as a heater which turns on when the temperature falls below T_1 and

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doesn't turn off until the temperature has risen above T_2 , after which it *remains* off until the temperature is again below T_1).

In simplest form, such a control has only two states, *off* and *on*, and could be represented as a logical function. MELCOR, however, employs a more general implementation where trips have been implemented as real-valued functions. The function value is zero if the trip is off and non-zero if it is on. There are two possible *on* states: *on-forward*, indicated by a positive function value, and *on-reverse*, indicated by a negative value. If a trip is on-forward or on-reverse, the magnitude of the function value is equal to the time (in seconds) since it was last in some different state, and can therefore be used for timing or delay purposes. The terms "forward" and "reverse" refer to the direction of counting time when a trip is on; in practice, either type of trip could be used with appropriate (positive or negative) scaling.

The simplest trip, with the short input name of TRIP, is a function of a single logical variable and requires no miscellaneous numbers. It is initially off (with value zero), and remains off until its argument changes state; thereafter, it is on-forward (with positive value) if its argument is true, or on-reverse (with negative value) if its argument is false, and can never again be off. When the trip is on, the magnitude of the function value is the time elapsed since the last change of state occurred. (For the timestep on which the change took place, this time is taken as roundoff compared to the timestep.)

Of the trips which are functions of a real variable, one of the simplest is TRIP-OFF-FORWARD, abbreviated as T-O-F for input purposes. (The name is intended to indicate that it is off for small argument values and on-forward for large ones.) Two setpoints, S_1 and S_2 , $S_1 < S_2$, divide the argument domain into a region where the trip is off, one where it is on-forward, and a dead band in between:

$a_1 \leq S_1$ trip is off
 $S_1 < a_1 < S_2$ state = previous state, off or on-forward
 $S_2 \leq a_1$ trip is on-forward.

The setpoints are input as miscellaneous numbers, in the order S_1, S_2 . If the trip is off, the function value is 0.0; if it is on-forward, the value is the time elapsed since it was last off. (For the timestep on which the change took place, the time at which the argument crossed the setpoint is estimated by linear interpolation.) The behavior may be compactly summarized as

T-O-F	off	S_1	dead-band	S_2	on-fwd
-------	-----	-------	-----------	-------	--------

Another simple case involving a real argument is TRIP-REVERSE-OFF, abbreviated as T-R-O. Here, two setpoints, S_1 and S_2 , $S_1 < S_2$, divide the argument domain into a region where the trip is on-reverse, one where it is off, and a dead-band in between:

$a_1 \leq S_1$ trip is on-reverse

$S_1 < a_1 < S_2$ state = previous state, off or on-forward
 $S_2 \leq a_1$ trip is off.

If the trip is off, the function value is 0.0; if it is on-reverse, the value is the negative of the time elapsed since it was last off. (Again, the time at which the argument crossed the setpoint is estimated by linear interpolation.) This may be compactly summarized as

T-R-O	on-rev	S ₁	dead-band	S ₂	off
-------	--------	----------------	-----------	----------------	-----

The remaining cases, including several with four setpoints, which define two dead-bands, are constructed in exact analogy to the preceding two, and should be easily understood from the following summaries. (In all cases, the time at which the argument crosses a setpoint is estimated by linear interpolation.)

T-O-R	off	S ₁	Dead-band	S ₂	on-rev				
T-F-O	on-fwd	S ₁	Dead-band	S ₂	off				
T-O-F-O	off	S ₁	Dead-band	S ₂	on-fwd	S ₃	dead-band	S ₄	off
T-O-R-O	off	S ₁	Dead-band	S ₂	on-rev	S ₃	dead-band	S ₄	off
T-F-O-F	on-fwd	S ₁	Dead-band	S ₂	off	S ₃	dead-band	S ₄	on-fwd
T-R-O-R	on-rev	S ₁	Dead-band	S ₂	off	S ₃	dead-band	S ₄	on-rev
T-F-O-R	on-fwd	S ₁	Dead-band	S ₂	off	S ₃	dead-band	S ₄	on-rev
T-R-O-F	on-rev	S ₁	Dead-band	S ₂	off	S ₃	dead-band	S ₄	on-fwd

For each of these trips, the setpoints must be input as miscellaneous numbers in the order S₁, S₂, or S₁, S₂, S₃, S₄ as appropriate. Necessary old data are maintained within the Control Function database. Because of the dead-band, the state of a trip may depend on past history. Therefore, proper definition of initial function values in MELGEN may be important to achieve the desired results.

2.1.6 User-Defined Functions

In order to simplify the addition of special-purpose functions, interfaces are provided for ten user-defined functions with names FUN1, FUN2, ..., FUN10. Each is coded as a function of five real arguments and includes an error flag in its calling sequence.

In standard versions of MELCOR, these functions are coded as dummies that do nothing but set their error flag if called. This will prevent the writing of a restart file by MELGEN if a user-defined function is referenced in its input.

In order to make use of the interfaces, the user must generate his own FORTRAN FUNCTION in the form

```
REAL FUNCTION FUNn (A1, A2, A3, A4, A5, IERROR)
```

The arguments A1 through A5, defined as for any other type of control function, may be used as desired in evaluating FUNn, but must not be changed by the FUNCTION routine. Five arguments *must* be specified. The value of FUNn is used as the control function value (before any user-specified scaling is performed). IERROR is returned as 1 if an error was encountered and as 0 otherwise. If the error flag is set to 1 during MELCOR execution, the CF package will halt execution and generate a restart dump. MELGEN and MELCOR must be linked with the new routine used to *replace* the dummy. The exact procedure for linking will, of course, be different at different computing sites.

2.2 Logical-Valued Control Functions

Logical-valued control functions are not, of course, amenable to scaling. They may, however, be modified to latch or to function as a one-shot. If a control function is classified as NORMAL, its value will always change in response to change(s) of its argument(s). In contrast, a control function with a LATCH or ONE-SHOT classification becomes uncoupled from its argument(s) after the first change from the initial (MELGEN) value of the function. For the LATCH, the new value will be retained forever after, independent of changes in the function argument(s); for the ONE-SHOT, the changed value is retained for one timestep only, after which the function reverts to its initial value on the next timestep and retains that value for the duration of the calculation.

Some logical-valued control function types take logical arguments; others take real arguments: in the latter case, the argument scaling discussed previously should be understood to apply.

In the list below, the order is not strictly alphabetic; similar functions have been grouped together. FORTRAN equivalents are shown in the belief that they will be more familiar than Boolean expressions.

Except as noted (for the arithmetic comparison functions, L-EQ, L-GT, L-GE, and L-NE) all arguments are logical.

Function Name	Input Type	# arg	Mathematical or FORTRAN definition	Miscellaneous Numbers
L-Equals	L-EQUALS	1	$f = a_1$	none
L-Not	L-NOT	1	$f = .NOT. a_1$	none
L-Equivalent	L-EQV	2	$f = a_1 .EQV. a_2$	none
L-Equal	L-EQ	2 ^[a]	$f = a_1 .EQ. a_2$	none
L-Greater Than	L-GT	2 ^[a]	$f = a_1 .GT. a_2$	none
L-Greater or Equal	L-GE	2 ^[a]	$f = a_1 .GE. a_2$	none

Function Name	Input Type	# arg	Mathematical or FORTRAN definition	Miscellaneous Numbers
L-Not Equal	L-NE	2 ^[a]	$f = a_1 .NE. a_2$	none
L-AND	L-AND	≥ 2	$f = a_1 .AND. \dots .AND. a_n$	none
L-OR	L-OR	≥ 2	$f = a_1 .OR. \dots .OR. a_n$	none
L-If Then Else	L-L-IFTE	3	IF (a ₁) THEN f = a ₂ ELSE f = a ₃ END IF	none

[a] Arguments of the arithmetic comparison functions are real.

3. User Input Requirements

A description of all control functions must be provided as part of MELGEN input. Certain elements of the description may be changed on restart through input to MELCOR.

In all versions of MELCOR through 1.8.4, control function numbers were restricted to three digits by the format of the input records. This limited the number of control functions that could be defined in any calculation to 999. The restriction has been eliminated, and control function numbers can now be as long as eight digits. The number of control functions that can be defined in a calculation is thus effectively limited only by the computer memory available and the endurance of the user.

In a few cases, MELCOR packages that use control functions store the function numbers as REAL variables rather than as INTEGERS. In such uses, a control function number is not acceptable unless it is exactly representable as a REAL. For 32-bit IEEE representation, the smallest INTEGER not exactly representable is $2^{24} + 1 = 16777217$. Above this value, only even numbers are representable through $2^{25} = 33554432$, only multiples of 4 through $2^{26} = 67108864$, etc. Thus, any 7-digit number will be acceptable, but only some 8-digit numbers. The input variables and records involved are:

- (1) A loading or unloading function number for a HYST control function input as a "miscellaneous number" on a CFn...n03 or CFn...n04 record in the CF Package, if the value is > 0 indicating that it is a control function number;
- (2) The burn completeness parameters, ICCFLG and ICCDCH, input on BURCCXX records, and flame speed parameters IFSFLG and IFSDCH, input on BURFSXX records in the BUR Package, if the values are > 0 indicating that they are control function numbers;
- (3) A vent valve delay time, VNSTP(3), input on an ESFCND0800 input record, if the value is < 0 indicating that it is a control function number;

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- (4) A structural failure control function number for supporting structure input as ISSLCF input on a CORxxxSS input record (here xxx can be 000, Zjj, Rii, or ijj) in the COR package;
- (5) A laminar flow coefficient, SLAM, input on an FlnnnSk record in the FL Package, if the value is < 0.0 indicating that it is a control function number.

In each of these cases, a test of the actual input is made, and if the function number is unacceptable, an error message such as

"MISC INTEGER CANNOT BE MAPPED INTO REAL"

or

"CONTROL FUNCTION NUMBER NOT EXACTLY REPRESENTABLE AS REAL"

is generated.

In addition, although MELCOR writes control function numbers to the plot file as integers, the plot program HISPLTM compares them internally to desired indices stored as REALs. Therefore, some 8-digit CF numbers can't be plotted by HISPLTM or, presumably, by any other plot program that has copied its data acquisition logic.

3.1 MELGEN User Input

The user input for the Control Function package is described below. One set of records is required for each control function; the actual records required differ for different types of control functions (see Section 2).

Following general MELCOR practice, the number associated with a control function is embedded in the input record identifiers of all records associated with that control function. Throughout this section, the control function number is shown as "n...n", which may represent a 3- to 8-digit number, and must be greater than 0.

Older versions of MELCOR required that the number in the record identifier contain exactly three digits, with leading zeroes for functions with numbers less than 100. For example, any input record of the form CF005xx refers to control function 5, while one of the form CF873 refers to function 873. In order to maintain compatibility with older input decks, the code currently requires that *at least* three digits be included in the record identifier, with leading zeroes *required* for control functions with numbers less than 100. However leading zeroes are *not permitted* for function numbers greater than 999. (This greatly simplifies the input processing by ensuring that all records pertaining to a given control function have record identifiers of the same length.) Thus, a record identifier of the form CF12345678xx refers to control function 12345678, while one of the form CF0009999 is invalid. The

presence of such an invalid record identifier is fatal; MELGEN will exit after first-pass processing, without generating a restart file.

Unless otherwise stated, if the field variable name in a record starts with I through N, it is an integer while if it begins with A through H or O through Z it is a real number.

CFn...n00 – Control Function Definition Record

n...n is the 3- to 8-digit control function number

Required

This record defines the control function name, type, number of arguments, and the multiplicative and additive scaling constants. The allowed types are described in Section 2. Scaling of logical functions is not possible, but the scale factor and constant (CFSCAL and CFADCN) must still be input; they are not used.

The value of the control function is given by

$$\text{CFSCAL} * \text{Function Value} + \text{CFADCN}$$

- (1) CFNAME - User-defined control function name.
(type = character*16, default = none)
- (2) CFTYPE - Control function type (from Section 2).
(type = character*8, default = none)
- (3) NCFARG - Number of arguments. Must agree with description in Section 2.
(type = integer, default = none)
- (4) CFSCAL - Multiplicative scale factor for control function.
(type = real, default = none, units = dimensionless)
- (5) CFADCN - Additive constant for control function.
(type = real, default = 0.0, units = same as control function)

CFn...n01 – Initial Value of Control Function

n...n is the 3- to 8-digit control function number

Optional

The initial value of a control function may be either user-specified via this record, or calculated from the initial database. In cases where the control function involves "history" (depends on past value), it should be user-specified to assure the desired result. In other cases, identified in the Users' Guide for the package involved, it should be specified to allow initialization of the package's database.

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The value input, real or logical, must be appropriate to the function type.

(1) CFVALR - Real initial value if real-valued control function.
(type = real, default = none, units = same as control function)

or

(2) LCFVAL - Logical initial value if logical-valued control function.
(type = logical, default = none, units = dimensionless)

CFn...n02 – Upper and Lower Bounds

n...n is the 3- to 8-digit control function number

Optional

Upper and lower bounds may be specified for a real-valued control function. If no bounds are input, the function values are limited only by the internal representation of real numbers on the computer used.

(1) ICFLIM - Switch specifying bounds input.
(type = integer, default = 0, units = dimensionless)
= 0 no bounds input (default)
= 1 only lower bound input
= 2 only upper bound input (field 2 must be present, but is unused)
= 3 both bounds input

(2) CFLIML - Lower bound, required for ICFLIM = 1, 2, or 3, but unused for ICFLIM = 2.
(type = real, default = none, units = same as control function)

(3) CFLIMU - Upper bound, required for ICFLIM = 2 or 3.
(type = real, default = none, units = same as control function)

CFn...n0k – Miscellaneous Numbers

n...n is the 3- to 8-digit control function number

$3 \leq k \leq 4$, k used for ordering

Required for some types of control functions

Some control functions require input of "miscellaneous numbers" as noted in Section 2. More than one may be input on a single record; two records may be used if required.

(1) FIELDS - Appropriate integers or reals required for control function n...n, as described in Section 2.

(type = real or integer, default = none, units depend on application)

CFn...n05 – Logical Control Function Classification

n...n is the 3- to 8-digit control function number

Optional

A logical-valued control function may be converted to a "latch" or "one-shot" as described in Section 2.2. A "NORMAL" control function has a value simply defined by its argument(s). A control function with a LATCH classification will change state only once, retaining its new value thereafter; one with a ONE-SHOT classification will change state for one timestep only, reverting to its initial value thereafter.

- (1) CLASS - Classification. May be 'NORMAL', 'LATCH', or 'ONE-SHOT'.
(type = character*8, default = 'NORMAL')

CFn...n06 – Logical Control Function Switching Message

n...n is the 3- to 8-digit control function number

Optional

A logical-valued control function may be made to write a message to the output file, the special message file, and/or the log file whenever its state changes.

- (1) MSGFIL - Flag indicating files to which the message is written.
(type = integer, default = 0, units = dimensionless)
= 0 do not write message
= 1 write message to standard output file only
= 2 write message to standard output file, special message file, and log file, but only if timestep is successfully completed.
- (2) SWTMSG - Switching message.
(type = character*64, default = none)

CFn...nkk – Control Function Arguments

n...n is the 3- to 8-digit control function number

10 ≤ kk ≤ ZZ, kk is used for ordering

Required

Each control function requires one or more arguments. Each argument is constructed from an element in the database. The type (REAL or LOGICAL) of each argument is checked in MELGEN, and an error is generated if it does not match that expected for the given control function type (CFTYPE on record CFn...n00). Scaling of real arguments is allowed, and the value of argument is given by

ARSCAL * Database Element + ARADCN

Scaling of logical arguments is not possible, but the scale factor and constant must still be input; they are not used.

- (1) ARSCAL - Multiplicative scale factor.
(type = real, default = none, units = dimensionless)
- (2) ARADCN - Additive constant.
(type = real, default = 0.0, units = same as database element)
- (3) CHARG - Database element identifier. Refer to the Users' Guides for the various packages for permitted values.
(type = character*24, default = none)

3.2 MELCOR User Input

Some of the data associated with an existing control function may be changed when running MELCOR. Note that new control functions may *not* be added, nor may the *type* of an existing control function be changed. The MELCOR input is a subset of the MELGEN input described in Section 3.1; record formats are identical in both cases.

CFn...n00 – Control Function Definition Record

n...n is the 3- to 8-digit control function number
Required

This record defines the control function name, type, number of arguments, and the multiplicative and additive scaling constants. The allowed types are described in Section 2. The control function type and the number of arguments must agree with the original values input to MELGEN on the CFn...n00 record. The user-defined name and scaling parameters, however, may be changed as desired.

CFn...n01 – Initial Value of Control Function

n...n is the 3- to 8-digit control function number
Optional

This record may be used to override the value of a control function in the MELCOR database at the time of restart. At the first execution of MELCOR, it will replace the value initialized in MELGEN; for later restarts, it will replace values calculated by the CF package on the last previous MELCOR timestep.

If this record is not input, the control function will not be reevaluated until *after* the first timestep is completed. Therefore, if record CFn...n00 or CFn...n02 is present

in the MELCOR input, but record CFn...n01 is not, a warning message is generated.

CFn...n02 – Upper and Lower Bounds

n...n is the 3- to 8-digit control function number

Optional

This record may be used to replace one or both of the bounds on the value of a control function which are stored in the MELCOR database at the time of restart, whether the old limits were default or specified by input to MELGEN or a previous MELCOR run.

4. Sensitivity Coefficients

There are no sensitivity coefficients associated with the Control Function package.

5. Plot Variables and Control Function Arguments

The variables in the Control Function package which may be used for plot variables and control function arguments are listed and described below. The control function arguments are denoted by a "c," the plot variables by a "p," within slashes ("/") following the variable name.

CFVALU.n /cp/ Value of control function n. At present, only real-valued control functions can be plotted.

Control functions are evaluated in the order of their user-assigned numbers. Therefore, if the value of control function n is specified as an argument for control function m, the new value of function n will be used if $m > n$ while the old value will be used if $m \leq n$.

6. Example Input

The following examples illustrate input to the Control Function package, and suggest ways in which the package may be used.

6.1 Constants

A constant value may be defined in several ways. Two simple ones, using scale factors and offsets on the function or on its arguments, are:

```
CF00100  PI    EQUALS    1    0.0  3.1416 *Constant value 3.1416
```

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CF00110 1.0 0.0 TIME *(Argument irrelevant)

or

CF00100 PI EQUALS 1 1.0 *Constant value 3.1416
CF00110 0.0 3.1416 TIME *(Argument irrelevant)

In either case, the actual argument specified is irrelevant so long as it is a valid control function argument.

6.2 Pressure and Head Differences

The difference in pressure between two control volumes, 200 and 300, perhaps representing primary and containment, can be evaluated as:

CF00500 DELTA-P ADD 2 1.0 *Pressure difference
CF00510 1.0 0.0 CVH-P.200 *Press in volume 200
CF00511 -1.0 0.0 CVH-P.300 *Press in volume 300

Here CVH-P.nnn is a control function argument in the CVH package, and the pressures used will correspond to the pool surface.

If the static head in the pool in volume 200 is important, it could be included by modifying CF005 as follows:

CF00500 DELTA-P ADD 3 1.0 *Pressure difference
CF00510 1.0 0.0 CVH-P.200 *Press in volume 200
CF00511 1.0 0.0 CFVALU.4 *Pressure head in pool
CF00512 -1.0 0.0 CVH-P.300 *Press in volume 300
*
CF00400 POOL-HEAD MULTIPLY 2 9.81 *Pressure head in pool
CF00410 1.0 0.0 CVH-RHOP.200 *Pool density
CF00411 1.0 0.0 CFVALU.3 *Pool depth over junction
*
CF00300 POOL-DEPTH DIM 2 1.0 *Pool depth over junction
CF00310 1.0 0.0 CVH-LIQLEV.200 *Pool surface elevation
CF00311 0.0 3.57 TIME *Junction elevation=3.57m

Here CVH-RHOP.nnn and CVH-LIQLEV.nnn are the pool density and the pool-surface elevation, respectively, in volume nnn in the CVH package. The junction elevation is 3.57m (specified as $0.0 \cdot \text{TIME} + 3.57$ in CF004), and the acceleration of gravity (9.81 m/s^2) appears as the scale factor in CF003. The relative ordering of the control function numbers must be as shown so that the value of the pool depth (CF003) is current before it is multiplied by the pool density in CF004, which is done before the head is added to the

thermodynamic pressure in CF005. Note that it is the number associated with a control function that is significant and not the position of its definition in the input deck.

Clearly, all other head terms, pool and atmosphere, could be similarly included as additional arguments to the ADD function CF005.

6.3 Valve Control

The pressure differential given by CF005 above could be used to initiate a primary system failure by opening a valve in an initially closed flow path between volumes 200 and 300. For example, the differential could be used to actuate a trip by defining CF010 input such as

```
CF01000 RUPTURE      T-O-F      1      1.0      *Trip on pressure diff
CF01001      0.0      *Initial value (off)
CF01003     -2.0E7      *Lower (off) setpoint
CF01004      2.0E7      *Upper (on-fwd) setpoint
CF01010      1.0  0.0      CFVALU.5      *Pressure difference
```

Of course, the use of this trip to actuate the valve must be established in the FL package, i.e., by entering the control function number 10 as variable 1 on record FLnnnVk.

The valve state would not change from its initial value (closed) until the pressure differential rose above 20.0 MPa and the control function tripped "on-forward." Then, the open fraction would be given by the Control Function specified by variable 2 on the FLnnVk record. (If the differential dropped below the lower setpoint, the open fraction would remain constant with its last calculated value.)

After CF010 trips on-forward, its value will be the time (in seconds) since the trip. Thus the open fraction could be made a function of time after failure by simply defining the second control function as a function of CFVALU.10.

Alternatively, the pressure differential could be used to control the operation of a relief valve. In this case, no trip would be used (variable 1 negative on the FLnnnVk record), and the control function whose number was entered as variable 2 on the FLnnnVk record might define the open fraction of the relief valve area through the hysteresis function

```
CF02000 VALVE-FRACT HYST 1      1.0      *Open fract of valve area
CF02001      0.0      *Initial value (closed)
CF02003     -100      *TF100 for loading
CF02004     -200      *TF200 for unloading
CF02010      1.0  0.0      CFVALU.5      *Pressure difference
```

The opening characteristic could be made extremely detailed through appropriate definition of the tabular functions, and multiple valves included so long as their dead-bands do not

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overlap. (If the dead-bands of a bank of relief valves *do* overlap, this may be accounted for by summing two or more hysteresis functions of the form of CF020, using a higher-numbered ADD control function.)

6.4 Messages and Other Output

In either of the cases in Section 6.2, the times at which the valve opened and closed could be recorded in output files using switching messages from logical functions. For example, assuming that the trip option (using CF010) was used,

```
CF10000 VALVE-OPEN  L-GT 2      1.0      *True if valve open
CF10001 .FALSE.                *Initially false
CF10006  2      'VALVE OPENED OR CLOSED' *To out, log, message
CF10010  1.0  0.0  CFVALU.10      *Valve trip
CF10011  0.0  0.0  TIME            *Zero
```

would produce a message every time the valve opened or closed. Inclusion of the record

```
CF10005          LATCH                *First opening only
```

would terminate messages after the first opening of the valve, in which case the message itself might better be

```
CF10006  2      'FIRST OPENING OF VALVE' *To out, log, message
```

Finally, the control function

```
CF11000 EDIT-FLAG  L-EQUALS  1      1.0      *For record EDITCF
CF11001 .FALSE.                *Initially false
CF11005 ONE-SHOT                *True at most once
CF11010  1.0  0.0  CFVALU.100      *Valve open
```

could be used to trigger a special (complete) edit the first time the valve opened through use of the EDITCF record described in the MELCOR/MELGEN Users' Guide. The ONE-SHOT classification prevents more than one such edit from being produced.

6.5 New Output Variables

The values of control functions are included in printed edits and in plot dumps. Thus, the pressure differences, etc., defined in Section 6.2 would appear directly in the printed output of MELCOR and could be plotted as functions of time if desired. The values printed could, of course, be obtained by hand calculations from other edited quantities, but the plots could not be obtained in any other way (using the current version of HISPLT).

Many variables, particularly in the RadioNuclide (RN) package, are available as control function arguments but not as plot variables. This is because the size and complexity of the database makes it impractical to include all quantities in the plot file. In versions of MELCOR through 1.8.4, these variables could be plotted only by defining a control function "EQUAL" to the argument, and then plotting the value of that control function. This is no longer necessary, because the values of specified control function arguments can be added directly to the plot file using PLOTxxx input records without defining a control function. In addition to simplification of the input, this allows the variables to be plotted using their mnemonic names rather than arbitrary control function numbers. See the Executive (EXEC) Package Users' Guide for details.

There will still be cases where the user will need to define a control function simply to make available the value of a quantity which would otherwise not appear in the output, but only when some arithmetic or logic is involved. As a simple example, involving hydrodynamic variables, the peak pressure in a control volume could be evaluated by a single control function as

```
CF13000 PEAK-PRESS MAX 2 1. *Peak pressure in cv 202
CF13001 0.0 *Initialize to 0.0
CF13010 1.0 0.0 CVH-P.202 *Pressure in cv 202
CF13011 1.0 0.0 CFVALU.130 *Previous peak
```

which evaluates the maximum of the pressure in control volume 202 and the previous value of that maximum.

Another way to do this, and to capture the time at which the peak occurred, is

```
CF14000 NEW-GT-OLD L-GT 2 1. 0. *True if p .gt. old max
CF14001 .TRUE. *Initialize true
CF14010 1.0 0.0 CVH-P.202 *Pressure in cv202
CF14011 1.0 0.0 CFVALU.141 *Previous peak press
*
CF14100 PEAK-PRESS L-A-IFTE 3 1. *Peak pressure in cv202
CF14110 1.0 0.0 CFVALU.140 *New .gt. old peak
CF14111 1.0 0.0 CVH-P.202 *Pressure in cv202
CF14112 1.0 0.0 CFVALU.141 *Previous peak press
*
CF14200 T-AT-PEAK L-A-IFTE 3 1. *Time at peak pressure
CF14210 1.0 0.0 CFVALU.140 *New .gt. old peak
CF14211 1.0 0.0 TIME *Time
CF14212 1.0 0.0 CFVALU.142 *Time at previous peak
```

Since CF140 is given the initial value .TRUE., CF141 and CF142 will be properly initialized to the values of their second arguments, CVH-P.202 and TIME, respectively. The uninitialized third arguments (the previous values of these control functions themselves) will not be used. Otherwise, the user would have to initialize (correctly) both CF141 and

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CF142, in which case no initial value for CF140 would be needed or used. The values of all three control functions would be available in printed output. The real-valued ones could also be plotted if desired.

6.6 Voting Logic

Control logic may be simulated in many ways, and there are often tricks that employ far fewer control functions than a simple translation of the logic. For example, a two-of-four voting control could be modeled using 4 logical functions for the individual channels, 6 more to test all combinations of two signals true, an 11th to "OR" these 6 possibilities, and (usually) a 12th to generate a real value from this final logical one.

A more compact, but less obvious, implementation is shown below for the case where the individual channels involve detecting a pressure greater than a threshold.

```
* Test each channel. Value =1 if Pn.ge.thresh, else =0
*
CF15100 P1.GT.TH      SIGNI      1   .5   .5   *1 or 0 form p1 test
CF15110   1.0  -1.02E5   CV-P.1                *1.02E5 is thresh
*
CF15200 PS.GT.TH      SIGNI      1   .5   .5   *1 or 0 from p2 test
CF15210   1.0  -1.02E5   CVH-P.2
*
CF15300 P3.GT.TH      SIGNI      1   .5   .5   *Same for p3
CF15310   1.0  -1.02E5   CVH-P.3
*
CF15400 P4.GT.TH      SIGNI      1   .5   .5   *Same for p4
CF15410   1.0  -1.02E5   CVH-P.4
*
* Vote 2 of 4. Result is 0.0 or 1.0
*
CF16000 2-OF-4 ADD    4     2.   -2.5 Value = 2*N - 2.5
CF16002   3     0.0   1.0                *Limit between 0 and 1
CF16011   1.0   0.0   CFVALU.151          *1 or 0 for channel 1
CF16012   1.0   0.0   CFVALU.152          *1 or 0 for channel 2
CF16013   1.0   0.0   CFVALU.153          *1 or 0 for channel 3
CF16014   1.0   0.0   CFVALU.154          *1 or 0 for channel 4
```

Note the usage of multiplicative and additive constants and of limits. For each channel (CF15n) the function value is -1.0 or +1.0 before scaling, and 0.0 or 1.0 after.

In the "vote" conducted by CF160, for the case of

0	1	2	3	4	pressures over threshold,
---	---	---	---	---	---------------------------

the function value is:

0.0	1.0	2.0	3.0	4.0	before scaling,
-2.5	-0.5	+1.5	+3.5	+5.5	after scaling, and
0.0	0.0	1.0	1.0	1.0	after limits are imposed.

CF160 could now be used to initiate a trip and start a timer. For example:

```
CF17000 VOTE-TRIP   T-O-F       1      1.0    *Trip on 2-of-4 vote
CF17001      0.0                                *Initially value (off)
CF17003      0.1                                *Lower (off) setpoint
CF17004      0.9                                *Upper (on) setpoint
CF17010      1.0  0.0  CFVALU.160              *2-of-4
```

Note that the scaling and bounding of control functions 151–154 and 160 are not essential if their only use is to actuate the trip; the setpoints of CF170 could be changed to work correctly with the unscaled, unbounded values. However, the scaling costs little and makes it easier to check the control logic.

6.7 Homologous Pump Model

The QUICK-CF Pump model in the Flow Path package uses a control function to calculate the pressure developed by a pump. The following input indicates how a control function can be constructed to yield a homologous pump model similar to that used in TRAC and RELAP.

```
* Homologous pump model for flow path 2
* CF203 = delta-p = density*grav*speed**2 * fcn (flow/speed)
*
CF20000 SPEED   any real CF                *(Normalized) pump speed
CF200..
*
CF20100 FLOW/SPEED  DIVIDE    2      1.    *(Normalized) flow/speed
CF20110      1.0  0.0  CFVALU.200          *Speed
CF20111      0.05 0.0  FL-VELLIQ.2        *1/.05 is v at rated flow
*
CF20200 PUMP-HEAD   TAB-FUN    1      1.    *Fcn (flow/speed) in m
CF20203 202                                *Pump curve
CF20210      1.0  0.0  CFVALU.201          *(Normalized) flow/speed
*
TF20200 PUMP-CURVE  n         1.    0.    *Table of n points
* Norm flow/speed Head (m)
TF20210      a.a                                x.x
TF202..      b.b                                y.y
*
CF20300 DELTA-P     MULTIPLY  4      9.81  *9.81 is grav
CF20310      1.0  0.0  CVH-RHOP.3         *Upstream volume is 3
```

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CF20311	1.0	0.0	CFVALU.202	*Head in m
CF20312	1.0	0.0	CFVALU.200	*Speed/nom_speed
CF20313	1.0	0.0	CFVALU.200	*Speed/nom_speed

The input shown is appropriate for the normal region of pump operation (positive rotation, forward flow), when the fluid is liquid only. The calculated pressure boost will be far too great for two-phase or vapor flow; because the control function defines the pressure directly rather than as a head, it must be reduced in these cases by the density ratio (in addition to any two-phase degradation factor). To do so, the density used as the first argument of CF203 should be generalized to represent the actual flow density multiplied, if desired, by a two-phase degradation term. As a first approximation, it could simply be set to zero if the flow path void fraction—available as control function argument FL-VOID.nnn—is non-zero. It might be necessary to incorporate some time-averaging through integration if oscillations are observed.

In RELAP, the head curve in the normal pump region is input in two parts, using

$$\begin{aligned} \text{HEAD} &= \text{SPEED}^{**2} * \text{FCN1}(\text{FLOW}/\text{SPEED}) && \text{for } \text{FLOW}/\text{SPEED} < 1 \text{ and} \\ \text{HEAD} &= \text{FLOW}^{**2} * \text{FCN2}(\text{SPEED}/\text{FLOW}) && \text{for } \text{SPEED}/\text{FLOW} < 1. \end{aligned}$$

(the former is referred to as "HAN" and the latter as "HVN"), but both may be accommodated in CF202. The curve can be further extended to the energy dissipation region (positive rotation, negative flow), corresponding to "HAD" and "HVD." In this case, the density argument in CF203 should also reflect the direction of flow.

The input assumes that the rotational speed of the pump is available as a control function value. In general, this will be a tabular function of time, but a truly determined user could calculate it by integration of the angular momentum equation for a pump rotor, using still more control functions and the homologous torque curves. If reversal of the pump is anticipated, it is necessary (at least) to avoid the possibility of division by zero in CF201. This is probably best done by explicitly using the alternative representation of the head curve in those regions where $\text{SPEED}/\text{FLOW} < 1$ ("HVN," etc.).

Core (COR) Package Users' Guide

The MELCOR Core (COR) package calculates the thermal response of the core and lower plenum internal structures, including the portion of the lower head directly below the core. The package also models the relocation of core and lower plenum structural materials during melting, slumping, and debris formation, including failure of the reactor vessel and ejection of debris into the reactor cavity. Energy transfer to and from the Control Volume Hydrodynamics (CVH) package and the Heat Structure (HS) package is calculated. This Users' Guide provides basic information needed to run the COR package with the rest of MELCOR, including a short discussion of the nodalization scheme and calculational framework of the package and a detailed explanation of the user input and package output for MELGEN, MELCOR, and HISPLTM. Required and optional input, sensitivity coefficients, control function arguments, plot variables, and error messages are all covered.

More detailed information on the physics models and numerical solution schemes employed in the COR package can be found in the COR Package Reference Manual.

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1. Introduction

The MELCOR COR package calculates the thermal response of the core and lower plenum structures, including the portion of the lower head directly beneath the core, and models the relocation of core materials during melting, slumping, and debris formation. It also calculates a simplified mechanical response of the lower head to the differential pressure between the lower plenum inside the vessel and the reactor cavity outside the vessel. An alternative modeling of lower plenum and lower head phenomena is optionally available through the separate Bottom Head (BH) Package. Multiple structures are modeled as separate components within a single core cell. Intact components include fuel pellets, cladding, canister boxes, and other structure (e.g., control rods). Canister boxes are only present in Boiling Water Reactors (BWRs). Particulate debris is also modeled as a possible component within a core cell. Each of these components may be composed of several materials (e.g., Zircaloy and ZrO_2 in the cladding) which are maintained in thermal equilibrium. This is discussed in more detail in Section 11.

All important heat transfer processes are modeled for each cell component. Thermal radiation among the various components within a cell and between cells in both the axial and radial directions is included, as well as radiation to boundary structures [e.g., the core shroud or upper plenum, which are modeled by the Heat Structures (HS) package] and to a liquid pool. Melting of boundary steel structures, with addition of the molten steel to the core debris, may be modeled using appropriate input to the HS package. Gap radiation/conduction between fuel and cladding and axial conduction in each of the components is modeled. Convection to the fluid in adjacent control volumes is modeled for a wide range of fluid conditions and structure surface temperatures, including nucleate and transition film boiling. Oxidation of Zircaloy and steel is modeled for both the limiting cases of solid-state diffusion of oxygen through the oxide layer and gaseous diffusion of steam or oxygen through the gas mixture. The reaction of B_4C with steam is also modeled. Although, the default B_4C oxidation model produces satisfactory results in highly oxidizing atmospheres, it is recommended that the advanced B_4C reaction model be invoked (through adjustment of sensitivity coefficient 1005) if significant hydrogen concentrations (reducing environment) are expected.

The core degradation model treats eutectic reactions that lead to liquefaction below normal melting points, dissolution reactions that lead to significant fuel relocation below the UO_2 melting temperature, "candling" of molten core materials (i.e., downward flow and refreezing), and the formation and relocation of particulate debris. Various geometric variables (e.g., cell surface areas and volumes) are updated for changing core geometry.

Changes in core flow resistance resulting from relocation of core materials may be modeled, but the connection to the hydrodynamic packages (CVH and FL), is *not* automatic. Input on FLnnnBk records is required to specify which core cells are associated with each flow path involving the core. Because only CVH and FL model the flow of water

and gases, the effects of blockages on circulation can be modeled only to the extent that the CVH/FL nodalization can resolve that circulation.

The remainder of this section briefly describes the nodalization scheme and the calculation framework used in the COR package. More comprehensive information on these topics, as well as on the specific phenomenological models used, is given in the COR Package Reference Manual.

1.1 Nodalization Scheme

The core and lower plenum regions of the reactor vessel are divided into concentric radial rings and axial levels; the numbers of rings and levels are input by the user. A particular radial ring and a particular axial level define a core cell, whose cell number is specified by a three-digit number; the first digit represents the radial ring number and the last two digits represent the axial level number. For example, cell 307 designates the third radial ring and the seventh axial level. Radial rings are numbered from the center out and axial levels are numbered from the bottom up.

The scheme described above applies only to structural materials in the core and lower plenum, and is independent of the control volume (CVH) nodalization for the reactor vessel. Each core cell interfaces with a primary, or channel, fluid volume. For BWRs, a secondary, or bypass, fluid volume is specified for cells in the core to represent the interstitial volume between fuel assemblies. Typically, a single CVH control volume will interface with many core or lower plenum cells.

Each core cell may contain one or more components. Seven intact components are modeled:

- (1) fuel pellets,
- (2) cladding, and
- (3) BWR canister walls, split into two parts: one part not adjacent to the control blade and another part that is,
- (4) "supporting structure,"
- (5) "nonsupporting structure," and
- (6) "other structure."

Because of the effects of radiation to the control blade, the two canister parts may have significantly different temperatures.

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A core cell may also contain particulate debris ("rubble") resulting from the collapse of fuel rods and other core components. In a BWR, such debris may reside either inside or outside the channel box, in the channel or bypass region, respectively. Unlike previous versions, MELCOR 1.8.5 distinguishes particulate debris in the channel from that in the bypass, using separate components for each. The distinction exists only for a BWR, and only for core cells that have distinct channel and bypass regions. Even then, most of the distinction is lost when the channel box fails, although both types of particulate debris must continue to be tracked because they typically occupy space in different CVH control volumes.

Conglomerate debris, i.e., core material that has melted and resolidified, is modeled as an integral part of the component onto which it has frozen, which may be any one of the above except fuel pellets. Heat transfer and oxidation processes are modeled separately for each component.

The following table identifies each component by its component number and component identifier, which are often used in the COR package documentation.

1	FU	intact fuel component
2	CL	intact cladding component
3	CN	intact canister component (portion <u>not</u> adjacent to the control blade)
4	CB	intact canister component (portion adjacent to the control blade)
5	OS	"other structure" component
6	PD	particulate debris component (portion in the channel for a BWR)
7	SS	"supporting structure" component
8	NS	"nonsupporting structure" component
9	PB	particulate debris component in the bypass (for a BWR)

The primary difference between the "supporting" and "nonsupporting structure" components is the ability to support other core components (core support structures) or not (control rods or blades). NS is intended to represent things like control rods/blades in Pressurized Water Reactors (PWRs) and BWRs, "stiffeners" in Phebus experiments, and other similar objects that cannot support anything except themselves. All core elements that have the capability of supporting other types of core components are intended to be modeled using the SS component. These include core plates, and CRGTs in BWRs. Modeling options involving SS and NS are discussed in Section 1.3.

The option of using OS has been retained from older versions of MELCOR, but requires that a flag be set on the COR0006 input record. It may not be used in combination with either of the "supporting" or "nonsupporting" structure components. This allows old decks to be run, but the practice is not recommended. In general, the capabilities of models involving the OS component have not been upgraded beyond those in MELCOR 1.8.4.

Each component may be composed of one or more materials. Eight materials are modeled in the COR package:

- (1) UO₂,
- (2) Zircaloy,
- (3) steel,
- (4) ZrO₂,
- (5) steel oxide,
- (6) control rod poison, which may be either boron carbide (B₄C) or silver-indium-cadmium alloy (Ag-In-Cd),
- (7) Inconel, and
- (8) electric heating element material (defined by the user).

The last of these is intended for use in analysis of electrically heated experiments. If it is present in a core cell, subroutine ELHEAT will be called to calculate the associated heating power in that cell. The distributed version is only a stub that will terminate the calculation if it is called. The user must therefore modify this subroutine as appropriate to the particular experiment under consideration, and link the modified version.

These materials melt, relocate, and freeze separately and independently unless the core materials interactions model has been activated, in which case they form a mixture that melts, relocates, and freezes coherently. Steel and steel oxide are each considered a single material within the COR package, but the user must specify (in Material Properties package input) the fractions of iron, nickel, and chromium in the steel so that oxidation can be properly treated and the right amounts of each species can be transmitted to the Cavity (CAV) package during debris ejection. The melting and candling of materials results in the possibility of any or all materials being found in a given component.

A lumped parameter approach is used for each component within a cell; therefore, each component is represented by a single equilibrium temperature. All thermal calculations are done using internal energies of the materials, and the mass and internal energy of each material in each component are tracked separately to conserve total mass and energy to within machine roundoff accuracy.

Several geometric variables are used to further describe the cells. For each structural component a surface area is defined for convection and oxidation calculations; the canister components have defined surface areas for each side to communicate separately with the channel and bypass control volumes. The effects of conglomerate debris on component surface areas are factored into the oxidation calculations, and for oxidation of debris,

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separate Zircaloy and steel surface areas are used. Equivalent diameters for each component are also specified for use in various heat transfer correlations. Cell boundary areas for inter-cell radiation (both axially and radially) are defined. Volumes of components and the "empty" fluid space are tracked for core slumping and flow blockage calculations.

For each radial ring the user can define up to three representative penetrations (e.g., instrumentation tubes or guide tubes) in the lower head, specifying their mass and surface area. The lower head is modeled as a hemispherical shell of user-specified thickness and composition. The user must specify the thickness and composition of an arbitrary number of radial nodes (not to exceed 24) beginning from the outer surface of the hemisphere and progressing inward. In addition to stainless steel, which is included in the COR package data base, the user may specify up to six materials in a composite lower head. Hence, with appropriate Materials Properties (MP) package input the user may model insulation, carbon steel and a stainless steel liner if desired. The outer node (surface) communicates with the CVH fluid in the reactor cavity, and downward-facing boiling heat transfer to a flooded cavity is modeled. The inner node (surface) communicates thermally with both the penetrations and the debris. Heat transfer from the debris to the lower head and its penetrations is modeled parametrically. A one-dimensional solution is used to determine the temperature profile through the lower head. The temperature profile and the loading of the vessel can be used by the lower-head mechanical model to predict creep-rupture failure of the lower head using the Larson-Miller parameter and a life-fraction rule.

1.2 Calculation Framework

The COR package uses an explicit numerical scheme for advancing the thermal state of the core through time. To mitigate numerical instabilities, a subcycling capability has been developed to allow the COR package to take multiple time steps across a single system cycle. All energy generation and heat transfer rates are evaluated at the beginning of a COR package subcycle based on current temperatures, geometric conditions, and an estimate of the local fluid conditions (calculated by the COR package dT/dz model to reflect the temperature variation of a control volume containing many individual core cells). The net energy gain (or loss) across the subcycle is determined for each component by multiplying these rates by the COR package time step. The temperature change for any component with total mass greater than a user-specified minimum is limited to a user-input maximum; if the calculated temperature change is greater than this limit, the core time step is reduced accordingly. If the energy input to any fluid volume changes from previous values in such a way as to possibly result in numeric instability between the COR and CVH packages, the system time step may be immediately cut or a reduction may be requested for the next system cycle.

At the end of the COR package time step, after the thermal state of the core has been updated, relocation of core materials and debris formation are calculated by the core degradation models. First, molten intact materials are moved from intact components to the conglomerate debris associated with the components. Then, if the materials

interactions model has been activated, eutectic reactions are calculated between various intact solid materials within a component if the component temperature exceeds the eutectic points, and dissolution reactions between certain intact solid materials and molten eutectic mixtures are calculated (e.g., intact UO_2 fuel dissolved by Zircaloy-bearing mixtures); these materials are also added to the conglomerate debris. Molten materials are relocated downward by the candling model (provided there is no flow blockage) and radially by the spreading model if there is a significant difference in the liquid levels in adjacent core rings. Intact components are converted to debris if various debris formation criteria are met.

Relocation of particulate debris downwards and radially by gravitational settling is normally modeled at the end of a core subcycle by logical processes through consideration of volume, porosity, and support constraints. Rates are not explicitly considered; however, a limit on the maximum rate is imposed to force the relocation to go to zero for very small timesteps. However, if the user has activated the in-vessel falling debris quench model, then debris relocation immediately following the failure of the core support plate in each radial ring is calculated assuming that the debris falls at a constant velocity. Furthermore, during a short time interval following the failure of the core support plate, heat transfer from the falling debris to the pool of water in the lower plenum is calculated. This model can be used to simulate energetic fuel-coolant interactions that may occur and threaten the integrity of the reactor pressure vessel.

Whenever mass is relocated or debris formed, energies in the new or changed components are re-evaluated to maintain thermal equilibrium, and any relevant geometric variables are recalculated to reflect the change in geometry. Failure of the core plate (or any other structure modeled as SS or OS and providing support) is predicted based on models described in Section 1.3. Failure of the lower head is assumed to occur based on any of a number of criteria:

- (1) the temperature of a lower head node or penetration reaches a critical temperature defined by the user,
- (2) the differential pressure exceeds a user-specified maximum,
- (3) the accumulated plastic strain exceeds the failure limit, which may be modified by the user, or
- (4) the value of a user-specified logical control function is found to be true.

1.3 Support of Core Structures

Only the single one-size-fits-all "other structure" component, OS, was available in older versions of MELCOR to represent control rods, control blades, core plates, and CRGTs—in fact, to represent everything in an intact core *except* fuel rods and their cladding, and the

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canister boxes in BWRs. In a sense, OS was forced to represent such a variety of things that it could represent none of them particularly well, a problem that was exacerbated by the fact that the input options associated with OS were rather primitive and inflexible. Although the OS component and models based on it have been retained for compatibility with older input decks, their use requires setting the model switch IOLDOS=1 on the COR0006 input record. The option to use OS will probably be eliminated in future versions of the code.

The preferred modeling approach in MELCOR 1.8.5 is to represent supporting structures (such as core support plates) and nonsupporting structures (such as control rods/blades) as *separate* components, SS and NS, respectively. The SS and NS components can represent only one type of structure in each core cell, but they may be used to represent quite different types of structures in different core cells. Neither can be used in conjunction with OS.

NS cannot support anything but itself. It may be supported from below like a BWR control blade, supported from above like a PWR control rod, or fixed in place like elements of certain experimental facilities (e.g., the stiffeners in Phebus). Local failure of NS is based on the remaining thickness of structural metal and on temperature. It will fail if the thickness of metal falls below a critical value or—regardless of the thickness of metal remaining—if the temperature exceeds a limiting value. The structural metal is taken as steel by default, but can be specified to be Zircaloy. The default failure temperature is the melting point of the structural metal. Both the critical thickness and the limiting temperature can be redefined if desired.

SS can support itself and other core components, with several choices available for the models to be applied in each core cell. The choice of models affects the treatment of support and loading, the failure criteria, and the consequences of failure. Structural modeling of SS in a core cell is tied to an input keyword. The options are

- (1) PLATE, representing part of an edge-supported plate that can initially support fuel assemblies and particulate debris above it, and any inner sections of the same plate. On failure, SS modeled as PLATE is converted to particulate debris along with everything supported by it, including any unfailed inner rings of the same PLATE and anything supported by them.
- (2) PLATEG, representing part of a grid-supported or eggcrate plate that can initially support fuel assemblies and particulate debris above it. On failure of SS modeled as PLATEG, only the capability to support particulate debris and intact components in cells above is removed. Thus, everything resting on that ring of the plate will fall, but the plate will remain in place until it melts. The picture corresponds to failure of the plate portion with survival of the grid, and closely resembles the modeling using OS in MELCOR 1.8.4.

- (3) PLATEB, representing part of a BWR plate that can initially support only particulate debris, although its presence is required to transfer the weight of fuel assemblies and canisters to control rod guide tubes (CRGTs) below it. On failure of SS modeled as PLATEB, only the capability to support particulate debris in cells above is removed. Thus, intact fuel and canisters can continue to be supported by the CRGTs below, and the failed plate will remain in place until it melts.
- (4) COLUMN, representing the CRGTs in a BWR that can initially support nothing but themselves and, through the mediation of PLATEB, fuel assemblies and canisters above the core plate. On failure, SS modeled as COLUMN is converted to particulate debris, along with anything supported by it including any unfailed upper sections of the same column and any other components whose weight is transferred to it by an element of PLATEB.

SS may be specified as failing when a critical temperature is exceeded or when a specified logical control function becomes true. It may also be specified as failing under load, by yielding, as a consequence of creep, or, where appropriate, by buckling. The stresses are calculated from the total load, based on simple mechanical models appropriate to the form assumed for the SS. More details may be found in the COR Package Reference Manual.

The specification of NS and SS models is very flexible. There are global defaults, which may be based on the core type, that may be overridden by optional user input. Modeling options may be redefined by axial level, by radial ring, or by individual core cell. The input records involved are COR000NS, CORZjjNS, CORRiiNS, and CORijjNS for NS, and COR000SS, CORZjjSS, CORRiiSS, and CORijjSS for SS. The records are processed in that order, and the modeling in each cell is based on the last relevant input encountered.

1.4 User Control of Core Oxidation and Material Relocation

In the oxidation of core components, there is competition among various surfaces for the available oxidizers (steam and/or oxygen). In addition to competition between surfaces within a single core cell, which is treated by internal models described in the Core Package Reference Manual, there is also competition among core cells that interface with the same CVH control volume for a share of the total oxidizer inventory of that control volume.

If one CVH control volume contains (parts of) several rings of the core, the available oxidizers are divided in proportion to the minimum open flow areas in each of those rings within the control volume. (The possibility of cross flows is not considered.) The internal calculation of areas may be used, or the user may choose to specify the flow splits using control functions as specified on the optional CORVOLxxx records. Minimum fractions may be imposed, using sensitivity coefficient array 1007, to avoid total steam starvation. If several core levels are contained in the ring, each is given access in turn to the total inventory of oxidizers remaining in that ring after oxidation is evaluated for cells that come earlier in the order. Cells are processed in the direction of assumed flow through the ring.

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By default, this is currently based on the computed direction of flow at the exit plane of the core, but can be overridden by control functions specified on optional CORRii04 records.

Core materials can relocate by melting and candling. They can also fail mechanically and be converted to particulate debris ("rubble") which can then slump to lower parts of the core if there is space available. Materials interactions (formation of "eutectics") are frequently involved in these processes. MELCOR has a materials interactions model, activated by input on the COR00006 record, but users of version 1.8.3 reported problems with the model. Although some of these problems were resolved in later versions, we presently recommend that the model be used with great care, if at all. The most important effects of materials interactions can be captured using parametric models.

When materials that form core components melt, they are usually assumed to candle immediately. The exception is molten metal (Zr and stainless steel) held up behind oxide shells; parameters used in the holdup model are part of sensitivity coefficient array 1131. If the materials interactions model is not active, the dissolution of other materials in candling molten metals is modeled by "secondary transport" parameters input on the COR00007 record.

Note that molten metal may be associated with an intact component, either held up behind an oxide shell or as conglomerate that is prevented from candling by the absence of free volume in a lower cell.

When the remaining thickness of unoxidized metal in a component in a core cell is reduced below a minimum defined by input on record COR00008, the component is converted to particulate debris. Two exceptions are made for fuel rods. First, oxidized fuel rods are assumed not to fail until the temperature has risen to a value that, by default, approximates the eutectic temperature for the UO_2/ZrO_2 system, at which materials interactions would begin to liquify the solid structure. Second, fuel rods are assumed to fail unconditionally (regardless of other input) if the fuel temperature reaches a value that, by default, approximates the melting temperature of UO_2 . The two threshold temperatures are defined by sensitivity coefficient array 1132.

Intact components are also converted to particulate debris if they lose support. A component in a core cell is supported by existence of the same component in the next lower cell (the next *higher* cell for NS supported from above). It may also be supported by unfailed SS or OS in the next lower cell. For representations using OS, all components may also be defined as "self supporting" by appropriate definition of support flags on CORZjj02 records.

Particulate debris (PD and/or PB) will slump, subject to constraints of available volume and support by SS or OS. In general, particulate debris cannot fill the entire volume that would be available to fluid in a core cell. The volume available to particulate debris in the channel and/or bypass of any cell is based on the parameters specified for the debris exclusion

model in that cell, as input on COR000DX, CORZjjDX, CORRiiDX, and/or CORijjDX records.

These parameters allow intact components to exclude particulate debris from a volume larger than their physical volume, specified as fractions of the associated total volume, either channel or bypass. (Of course, particulate debris will be excluded from the physical volume of the component in any case.)

The default values will prevent particulate debris from entering the channel region while intact fuel rods are present. In a BWR, they will also prevent it from entering the unbladed portion of the bypass region while there is intact CN, or the bladed portion of the bypass region while there is intact NS representing control blades. See Section 3.2.3 of the COR Package Reference Manual for more discussion of the model.

The porosity of a debris bed specified as PORDP on CORZjj01 input records is also considered. The "intact material porosity", PORIN, input on these records is not used in any way in MELCOR 1.8.5.

Support is determined by the specification of structural models for SS, or by support flags defined on CORZjj02 records for OS. Both SS and OS lose their ability to support particulate debris and other components when they fail. Several models are available for the loading and failure of SS; the choice is defined by input variables on COR000SS, CORZjjSS, CORRiiSS, and/or CORijjSS records. OS fails when it reaches a failure temperature defined on CORZjj04 records, or when a logical control function specified on a CORijj07 record becomes TRUE. (These inputs are not used for SS). When SS in a core cell fails, it may or may not be converted to particulate debris, depending on the specific option chosen for SS in that cell. The failure of OS does not result in its conversion to particulate debris, nor does it affect the ability of the OS to support itself. As a result, self-supporting OS (ISUP input as x1 on record CORZjj02) will remain in place until it melts.

1.5 Conversion of Older Decks for Use with MELCOR 1.8.5

Changes to COR package input are required to take advantage of many of the significant changes that have been made to core modeling in MELCOR 1.8.5. Options are available to allow acceptance of old decks, but conversion to the newer input requirements is strongly recommended. The following subsections provide more information.

1.5.1 Other Structures, SS, NS, and OS

In older versions of MELCOR, it was necessary to model control rods, control blades, core plates, CRGTs, and similar structures using a single "other structure" component, OS. This severely limited the fidelity with which such structures could be modeled. The default

Further changes may be needed to deal with errors resulting from the use of reference cells on CORijj01 input records. The problem arises if a core cell containing SS refers to one containing only NS, or vice versa, so that needed input cannot be found. This may require that the contents of one or more cells be fully defined, and/or that the cell referenced on one or more CORijj01 records be changed.

The resulting modeling of support of NS and SS may or may not be appropriate. By default, NS will be interpreted as representing a control rod for a PWR or a control blade for a BWR. SS will be interpreted as representing a grid-supported plate that fails on temperature. These defaults can be overridden by input on CORxxxNS and/or CORxxxSS input records, where "xxx" can be "000", "Zjj", "Rii", or "ijj". For the CRGTs in a BWR, it will be necessary to specify ISSMOD as "COLUMN" on CORxxxSS records. If CORZjj04 or CORijj07 records were used to modify the failure model for OS, these conditions will also need to be translated to the new format to preserve the previous modeling.

Conversion of an older input deck provides an opportunity to consider what behavior is really wanted for supporting and nonsupporting structures, without the constraints of the original models for OS. The MELGEN output file will contain a detailed summary of the models and options in effect in each core cell.

1.5.2 Input Variables NTLP and IAXSUP

There are two variables in the COR package input that might be assumed to define the position of the Core Support Plate (CSP). These are NTLP, on the COR00000 record, and IAXSUP, on the COR00012 record. These variables are used differently, but their usage in previous versions of MELCOR was not consistent. The issue of core component support, based on the input of ISUP on CORZjj02 records, further complicated the issue.

The usage has been revised and clarified in MELCOR 1.8.5. Input of NTLP, described as the "number of axial levels in the lower plenum" is required. Input of IAXSUP, described as the "level...containing the core support plate," is optional, with a default of NTLP.

NTLP is now used only as the default value for IAXSUP and, for calculations using the BH package, as the definition of the lowest level that will not be subsumed into BH. The value of IAXSUP, which can differ from NTLP as a result of explicit input on the COR00012 record, is now used for the location of the CSP in all uses within the COR package. These are: (1) the starting point for the falling debris quench model; and (2) the transition point between in-core and lower-plenum refreezing logic, and (3) special treatment of conduction and spreading for old decks using OS.

Following a suggestion from MCAP, we have added a "plausibility check" in MELGEN on the value in use for IAXSUP. A warning will be issued if it is not the lowest level containing an SS PLATE for input using SS, or the lowest level containing OS with full support

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(ISUP=11) for input using OS. The warning indicates whether the value in use is the default value (NTLP) or was explicitly input.

1.5.3 Consistency with Volume Data in CVH

Materials in the COR package displace fluid in the CVH package. Thus, when core debris is moved from one location to another, additional volume becomes available to fluids in the original location, with an equivalent volume subsequently denied to fluids in the new location. However, the initial distribution of fluid volume in the core region is specified independently in input to the COR and CVH packages. (This was motivated by the modular nature of MELCOR and the desire to allow independent spatial nodalizations in COR and CVH.) The nodalizations used are often quite different.

The COR package keeps track of occupied volume within its own nodalization, and communicates any changes to CVH. There, the corresponding changes are made within the CVH nodalization, and the results are used in advancing the hydrodynamic equations. It is thus important that the two representations of volume remain consistent. This is necessary to allow a correct calculation of water levels, and to avoid the possibility of overfilling CVH fluid volumes with core debris.

In older versions of MELCOR, the COR package could not properly account for the distinction between particulate debris in the channel and in the bypass, making it impossible to maintain consistency for a BWR as core degradation proceeded. That deficiency has been removed in MELCOR 1.8.5 and, if the initial representation of volume is consistent, it should remain consistent. A comparison of the distribution of fluid volume in COR and CVH has been added as a part of the second pass of input processing in the COR package.

If any discrepancies are found, an error message is written to the MELGEN diagnostic file and the errors are flagged in the table. The specific requirement is that the initial total fluid volume in COR lying within any Volume/Altitude (V/A) segment of a CVH control volume cannot exceed the fluid volume in that V/A segment. If this condition is met, filling the entire fluid volume in COR with debris cannot overfill CVH.

Acceptance of inconsistent volumes requires setting the model switch ICORCV=1 on the COR00006 input record. Used temporarily, it can aid in conversion of the deck, as will be discussed below. Although this allows MELGEN to run to completion and generate a restart file, permitting MELCOR to be run, we do not recommend the practice. The major risk is that fluid volumes in CVH will become overfilled by particulate debris from COR. If this occurs, mass and energy will continue to be conserved, but the representations of fluid volumes in CVH and COR will become inconsistent, and other results may appear non-physical (at least on close inspection).

In general, the cross-sectional area of each cell in a ring should agree with the "total cross-sectional area" of each ring, ASCELA, as input on the appropriate CORRii01 record. A table of cell cross-sectional areas, calculated from the total cell volume (the total of the channel and the bypass in a BWR) divided by the cell height, has been added to the MELGEN edit. This allows the user to compare cell areas to ring areas, and significant discrepancies probably indicate that the values input for AFLOWC and/or AFLOWB are inappropriate.

Once the volumes within COR appear reasonable, consistency with CVH should be addressed. Within CVH, the vertical distribution of volume is defined only within the resolution provided by the V/A table for the CVH volume. The most detailed agreement with COR will be obtained if the elevations in the CVH V/A table match those in the core nodalization. This approach could not be recommended with MELCOR 1.8.4, at least for BWRs, because it exacerbated problems arising from limitations in the representation of volumes in COR. We now wish to encourage users to try it with MELCOR 1.8.5, for which the limitation has been removed. Therefore, the two nodalizations are compared as part of input processing in the COR package. Warning messages are generated unless there are points in the appropriate CVH V/A tables in CVH input to correspond to all axial limits of core cells in COR input, with details included as part of MELGEN output.

A detailed comparison of the distribution of fluid volumes in COR and in CVH appears in a table in the MELGEN output file following the header

```
***** CORE PACKAGE PASS 2 SETUP EDIT *****
```

```
CONSISTENCY CHECK ON VOLUME REPRESENTATIONS IN COR AND CVH
```

If the V/A table includes points for every level in the COR nodalization, it is a relatively simple task to make the distribution of volumes consistent. Use of the option to specify volume increments rather than totals on CVnnnBk input records can significantly simplify this process by allowing the values from each COR level—slightly increased to provide a safety factor—to be input directly to CVH. If the resulting total volume is not correct, it may be necessary to reexamine the COR input and/or to consider the location of any regions in the CVH control volume that lie outside the core.

1.5.4 Debris Exclusion Modeling

Geometric considerations (such as the size of fuel pellets relative to interstitial spaces) may prevent particulate debris from entering regions of the core that would be accessible to molten materials. In older versions of MELCOR, the exclusion of particulate debris from the interior of fuel bundles could be modeled by using the "porosity" PORIN, input on CORZjj01 records. However, essentially similar effects, such as the possible exclusion of particulate debris from the bypass region of a BWR or from the control assemblies in VVER reactors, could not be modeled at all.

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The original approach based on PORIN was non-intuitive, and hard to generalize. Moreover, PORIN was used in other, undocumented, ways. Therefore, the original model—and all other use of PORIN—have been replaced in MELCOR 1.8.5. In the new model, each intact component present in a core cell is permitted to exclude particulate debris from some fraction of the volume of that core cell, limited in some cases to the channel or bypass region.

In many cases, no changes in input will be required. By default, intact fuel rods exclude particulate debris from the entire channel region. In a BWR, intact NS (presumed to represent control blades) excludes it from a volume that approximates the bladed portion of the bypass, and intact CN (canister not adjacent to control blades) excludes it from the unbladed portion.

Conversion of an older input deck provides an opportunity to consider what behavior is really wanted, without the constraints of the old model. New possibilities can be modeled, and considerable flexibility is available through input on CORxxxDX, where "xxx" can be "000", "Zjj", "Rii", or "ijj". The model is further described in Section 3.2.3 of the COR Package Reference Manual. The MELGEN output file contains a detailed summary of the options in effect in each core cell in the current calculation.

1.5.5 Core Flow Blockage

The core flow blockage model in MELCOR 1.8.4 was compromised by the limited ability of COR to distinguish the channel and bypass regions of a BWR. Whereas the original blockage model had to be based on the total fluid volume in both regions, more detailed flow blockage options have been defined in MELCOR 1.8.5 that distinguish channel and bypass. In addition, a new model has been included that allows the opening of a flow path between the channel and bypass regions on failure of the separating canister boxes. See Section 2.9.1 and the description of the FLnnnBk input record in the Flow Path Package Users' Guide for details.

Older input decks using the flow blockage model should be examined to determine if one of the new options is more appropriate. For decks that did not use the option, conversion provides an opportunity to consider whether the revised model could be used to advantage.

2. Input Requirements

This section gives the input requirements for the MELCOR COR package, including a short description of the input quantities and their units and default values, if any. Further description of the input variables and their meaning in the models can be found in the COR Package Reference Manual. It is strongly recommended that the beginning user consult

both documents (as well as other packages' Users' Guides) when first learning these input requirements.

Input record identifiers for the COR package all begin with the character string "COR"; several are required, but most are optional with defaults provided or obtained from previous input for other cells. Record identifiers between COR00000 and COR00012, COR000DX, COR000NS, and COR000SS are used to specify general information about the geometry, nodalization, and physics modeling for the core and lower plenum as a whole. Record identifiers of the form CORZijnn (nn = 01, 02, 03, 04, DX, NS, or SS) are used to specify information about axial level jj. Record identifiers of the form CORRiinn (nn = 01, 02, 03, DX, NS, or SS) are used to specify information about radial ring ii. Record identifiers of the form CORijjnn (nn = 01, 02, 02A, 03, 04, 05, 06, 07, DX, NS, or SS) are used to specify information about an individual core cell in radial ring i and axial level jj. For example, record COR31201 would specify information for cell 312, located in radial ring 3 and axial level 12. Records identifiers of the form CORijjKcc and CORijjYcc may optionally be used to define the initial masses of core components in a flexible form that allows specification of a degraded state, including oxidation, particulate debris, and conglomerate debris on all possible components.

Record identifiers of the form CORLHDii, CORLHNnn, and CORPENnn (ii and nn are sequence numbers) are used to specify information about the lower head and associated penetrations. Although their use is no longer either required or recommended, record identifiers of the form CORTINxx may optionally be used to specify the manner in which the inlet temperature for a core control volume is calculated in the core dT/dz model.

Hydrogen and carbon monoxide (CO) must be defined in the input for the NonCondensable Gas (NCG) package whenever the COR package is active. For BWR cores containing B₄C, the gases O₂, CO₂ and CH₄ must also be defined in NCG input.

2.1 MELGEN General Core/Lower Plenum Input

COR00000 – Nodalization Parameters Required

This record specifies the core/lower plenum nodalization parameters and is required. Note that the number of material layers in the lower head will be one less than the number of temperature nodes (NLH-1) because the temperature nodes are defined at the layer boundaries. The first six fields must be present:

NTLP is used as the default for IAXSUP on optional input record COR00012. IAXSUP is used to define the position of the core support plate in some models. If the two are not equal (as a result of explicit input for IAXSUP), the value of NTLP is used only if the BH package is active. It then defines the lowest level in the core

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nodalization that will not be subsumed into BH when the models in that package are initiated. See also Section 1.5.2 and the description of input record COR00012.

- (1) NRAD - Number of radial rings in the core and lower plenum (maximum=9).
(type = integer, default = none, units = none)
- (2) NAXL - Total number of axial levels in the core and lower plenum (maximum=99).
(type = integer, default = none, units = none)
- (3) NTLP - Number of axial levels in the lower plenum only (maximum=49).
NTLP must be less than NAXL.
(type = integer, default = none, units = none)
- (4) NCVOL - Number of CVH fluid volumes in the core and lower plenum region.
(type = integer, default = none, units = none)
- (5) NLH - Number of temperature nodes in the vessel lower head (maximum=24).
(type = integer, default = none, units = none)
- (6) NPNTOT - Total number of representative lower head penetrations modeled (maximum=19, no more than 3 per ring, but cannot use 3 for each of 9 rings).
(type = integer, default = none, units = none)
- (7) NINSLH - Total number of insulation (non-load bearing) mesh layers in the vessel lower head (maximum = NLH-1).
(type = integer, default = 0, units = none)

COR00001 – Geometric Parameters

Optional

This record specifies key geometric information for the fuel rods, control rods, and (for BWRs) canister boxes. If this record is present, it may contain from zero to seven fields. Default values will be retained for those fields that are not present and for any that contain negative numbers. Different default values are defined for a BWR (including SBWR) or a PWR, based on IRTYP input on record COR00002. These are marked as "(B)" and "(P)", respectively, in the list below.

- (1) RFUEL - Outer radius of the fuel pellets in the fuel rods.
(type = real, default = 0.00521 (B) or 0.00464 (P), units = m)

- (2) RCLAD - Outer radius of the fuel rod cladding.
(type = real, default = 0.00613 (B) or 0.00536 (P), units = m)
- (3) DRGAP - Thickness of the gas gap between fuel pellets and cladding.
(type = real, default = 0.00012 (B) or 0.00011 (P), units = m)
- (4) PITCH - Center-to-center spacing of the fuel rods.
(type = real, default = 0.0162 (B) or 0.0143 (P), units = m)
- (5) DXCAN - Thickness of the canister wall.
(type = real, default = 0.0025 (B) or 0.0 (P), units = m)
- (6) DXSS - Thickness of "other structure."
(type = real, default = 0.0014 (B) or 0.00036 (P), units = m)
- (7) DZLH - Thickness of lower head.
(type = real, default = 0.22 (B) or 0.13 (P), units = m)

DXCAN and DXSS are not currently used in the calculation.

COR00002 – Reactor Type
Optional

This record specifies the reactor type, the control rod poison material, and the electric heating element material. This record is not required, but if included, at least the first field must be present. Three character string fields are allowed:

- (1) IRTYP - Reactor type. Three choices are allowed: 'BWR', 'PWR', and 'SBWR'.
(type = character*4, default = 'BWR')
- (2) MCRP - Control rod poison material. Only two choices are allowed: 'B4C' and 'AG-IN-CD'.
(type = character*8, default = 'B4C')
- (3) MATHT - Electric heating element material.
(type = character*24, default = none)

COR00003 – Radiative Exchange Factors
Optional

This record specifies the radiative exchange factors used to model thermal radiation in the core. These exchange factors roughly correspond to the traditional view

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factors describing the geometric orientation between two pairs of surfaces. This record is not required, but if included, the following five fields must be present. Each value must be a nonnegative real number less than or equal to 1.0. For more details on the interpretation given to these parameters, see the COR Package Reference Manual, Section 2.1.2.

- (1) FCNCL - Radiative exchange factor for radiation from the canister wall to the fuel rod cladding. A value must be entered for PWRs, but is not used.
(type = real, default = 0.25, units = none)
- (2) FSSCN - Radiative exchange factor for radiation from "other structure" (e.g., control blades) to the adjacent canister walls or to fuel rods and debris if canister is not present.
(type = real, default = 0.25, units = none)
- (3) FCELR - Radiative exchange factor for radiation radially outward from the cell boundary to the next adjacent cell.
(type = real, default = 0.25, units = none)
- (4) FCELA - Radiative exchange factor for radiation axially upward from the cell boundary to the next adjacent cell.
(type = real, default = 0.25, units = none)
- (5) FLPUP - Radiative exchange factor for radiation from the liquid pool to the core components.
(type = real, default = 0.25, units = none)

COR00004 – TP Interface and Fission Power and Gap Conductance Control Functions Required

This record specifies the Transfer Process package translation matrix number (for transfer of mass and energy to the Cavity Package); it may also specify the fission power and fuel—cladding gap conductance control function numbers. This record is required and must contain at least the first of the three allowed integer fields.

- (1) NTPCOR - 'In' Transfer Process number ('nnn' on the TPINnnn00 record) that specifies the input for transferring masses and energies from the COR package to the Cavity or FDI packages. For convenience, a value of 0, indicating no TP, may be used for calculations that will not fail the lower head and eject debris. The number of masses and the number of thermodynamic variables on the TPINnnn00 record must be NMSIN=6 and NTHRM=9. Also, on the corresponding TPMnnn0000 record, NCOL=6. The order of

masses ejected for generating the translation matrix in the corresponding TPMnnnkkkk records is: (1) UO₂, (2) Zr, (3) steel, (4) ZrO₂, (5) steel oxide, and (6) control poison. Inconel is included with steel automatically. See the Transfer Process Package Users' Guide for more details.

(type = integer, default = none, units = none)

- (2) ICFFIS - Fission power control function number. If 0 or omitted, no fission power is calculated. If positive, control function ICFFIS is used to calculate the liquid water level to be used in the Chexal-Layman fission power/liquid level correlation (see Section 2.6 of the COR Package Reference Manual). If negative, control function -ICFFIS is used to calculate the whole-core fission power. If |ICFFIS| is less than 100, fission power is distributed over all core cells (not lower plenum cells) on a per fuel mass basis. If |ICFFIS| is greater than or equal to 100, fission power is distributed only over liquid-covered cells containing intact fuel. Decay heat is added to the fission power to obtain total core power, so the user input value should not include the contribution from fission product decay.
(type = integer, default = 0, units = none)
- (3) ICFGAP - Fuel-cladding gap conductance control function number. If 0 or omitted, no additional gap resistance is calculated. If a positive value is entered, the conductance is added serially to the gap gas conduction for all cells with fuel rods, in parallel to the gap radiation.
(type = integer, default = 0, units = none)

COR00005 – Candling Heat Transfer Coefficients

Optional

This record specifies the refreezing heat transfer coefficients to be used in the candling model for each of the molten core materials. This record is not required, but if included, the following six fields must be present. Each value must be positive. Due to a large degree of phenomenological uncertainty, it is very difficult to justify particular values for these coefficients. The default values are order-of-magnitude estimates that appear to produce plausible simulations of relocation phenomena, but they should be varied in sensitivity studies to determine their impact on overall melt progression behavior. For more information on how these quantities are used in the candling model, see the COR Package Reference Manual, Section 3.1.

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- (1) HFRZUO - Refreezing heat transfer coefficient for UO₂.
(type = real, default = 1000.0, units = W/m²-K)
- (2) HFRZZR - Refreezing heat transfer coefficient for Zircaloy.
(type = real, default = 1000.0, units = W/m²-K)
- (3) HFRZSS - Refreezing heat transfer coefficient for steel.
(type = real, default = 1000.0, units = W/m²-K)
- (4) HFRZZX - Refreezing heat transfer coefficient for ZrO₂.
(type = real, default = 1000.0, units = W/m²-K)
- (5) HFRZSX - Refreezing heat transfer coefficient for steel oxide.
(type = real, default = 1000.0, units = W/m²-K)
- (6) HFRZCP - Refreezing heat transfer coefficient for the control poison material.
(type = real, default = 1000.0, units = W/m²-K)

COR00006 – Model Switches

Optional

This record activates or deactivates various models and options. The default values of IHS DT, IDTDZ, IOLDOS, and ICORCV are strongly recommended.

Problems with the materials interaction model in MELCOR 1.8.3 have been reported. Some of these have been resolved in later versions, but use of the model is not recommended at this time. As discussed in Section 1.4, many of the effects of materials interactions may be captured without activating the model.

The core model in MELCOR 1.8.5 allows representation of supporting structures (such as core support plates) and nonsupporting structures (such as control rods/blades) as *separate* components, SS and NS, respectively. The single "other structure" component, OS, used in older versions of MELCOR is still available for compatibility with older input decks, but may not be retained in future versions. Its use requires setting the model switch IOLDOS=1. Mixing of the two representations is not permitted. See Section 1.5 for help in converting older input decks to the new representation.

The core model in MELCOR 1.8.5 allows a consistent representation of volumes in the COR package and that in CVH to be maintained for all reactors as core degradation progresses. In previous versions, this was not true for BWRs. The initial representations are now compared as part of input processing. Apparent discrepancies are noted, and comparison tables are provided as part of MELGEN output. Warning and/or error messages may also be generated.

If a severe discrepancy is found, no restart file will be written. The specific requirement is that the initial total fluid volume in COR lying within any Volume/Altitude segment of a CVH control volume cannot exceed the fluid volume in that V/A segment. If this condition is met, filling the entire fluid volume in COR with debris cannot overflow CVH. The requirement may be bypassed by setting the model switch ICORCV=1. See Section 1.5.3 for help in converting older input decks to the new representation.

- (1) IEUMOD - Materials interactions model switch
 - = 0 Model is inactive
 - = 1 Model is active.
 (type = integer, default = 0, units = none)

- (2) IHSMT - HS boundary condition option switch
 - = 0 dT/dz boundary condition option required for core radial boundary structures input on record CORZjj02
 - = 1 dT/dz boundary condition option not required.
 (type = integer, default = 0, units = none)

- (3) IDTDZ - dT/dz inlet specification option switch.
 - = 0 dT/dz inlet flow and temperature from default hydrodynamic calculation in CVH/FL. For this option, CORTIN records are *not allowed* as part of MELGEN input.
 - = 1 dT/dz inlet flow and temperature calculated as in MELCOR 1.8.3, with the addition of a downward-flow option. For this option, CORTIN records are *required* for at least the lowest and highest hydrodynamic control volumes containing core cells.
 (type = integer, default = 0, units = none)

- (4) IOLDOS - Other Structure option switch.
 - = 0 Input may not contain specification of OS. Structures must be modeled using SS and NS.
 - = 1 Input may not contain specification of either SS or NS; only OS may be used to model structures.
 (type = integer, default = 0, units = none)

- (5) ICORCV - CVH volume consistency switch.
 - = 0 Consistency between fluid volumes in CVH and in COR, in the sense that the volume in COR may not exceed that in CVH, is required.

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= 1 Consistency between fluid volumes in CVH and in COR is not required.

(type = integer, default = 0, units = none)

COR00007 – Candling Secondary Material Transport Parameters Optional

This record specifies the parameters needed to model the transport of secondary materials during candling. This record is not required, but if included, the following eight fields must be present. Transport mechanism 1 dictates that secondary material is relocated as a fraction of the molten mass specified by the transport parameter. Transport mechanism 2 dictates that secondary material is relocated in fractional proportion, as specified by the transport parameter (with a value of 1.0 indicating direct proportionality), to its existing fraction within a component. For more detailed information on how these parameters are used in the candling model, see the COR Package Reference Manual, Section 3.1.

- (1) MTUOZR - Transport mechanism flag for UO₂ in molten Zircaloy.
(type = integer, default = 1, units = none)
- (2) MTZXZR - Transport mechanism flag for ZrO₂ in molten Zircaloy.
(type = integer, default = 1, units = none)
- (3) MTSXSS - Transport mechanism flag for steel oxide in molten steel.
(type = integer, default = 2, units = none)
- (4) MTCPSS - Transport mechanism flag for control poison material in molten steel.
(type = integer, default = 2, units = none)
- (5) FUOZR - Transport parameter for UO₂ in molten Zircaloy.
(type = real, default = 0.2, units = none)
- (6) FZXZR - Transport parameter for ZrO₂ in molten Zircaloy.
(type = real, default = 0.0, units = none)
- (7) FSXSS - Transport parameter for steel oxide in molten steel.
(type = real, default = 1.0, units = none)
- (8) FCPSS - Transport parameter for control poison material in molten steel.
(type = real, default = 0.0, units = none)

COR00008 – Component Critical Minimum Thicknesses
Optional

This record specifies minimum thicknesses for cladding and "other structure" to maintain material intact (i.e., prevent material from becoming particulate debris). This record is not required, but if included, the following two fields must be present. Each value must be positive. The defaults are *ad hoc* values that should be varied in sensitivity studies to determine their impact on core degradation behavior. For more information on how these parameters are used in the debris formation model, see the COR Package Reference Manual, Section 3.2.1.

- (1) DRCLMN - Critical minimum thickness of unoxidized Zircaloy in cladding or canister. Set to 0.0 to allow uncollapsed "bare" fuel pellets to survive to a temperature set by sensitivity coefficient 1132.
(type = real, default = 0.0001, units = m)
- (2) DRSSMN - Critical minimum thickness of unoxidized steel in "other structure."
(type = real, default = 0.0001, units = m)

COR00009 – Lower Head Failure Modeling Parameters
Optional

This record specifies parameters needed to model failure of the vessel lower head and its penetrations. This record is not required, but if included, the following four fields must be present. The default heat transfer coefficients are order-of-magnitude parameters that should be varied in sensitivity studies to determine their impact on lower head heat transfer and failure. The default failure temperature is an approximate value for the transition to plastic behavior for steel. For more information on how these parameters are used in the lower head failure model, see the COR Package Reference Manual, Section 4.

- (1) HDBPN - Heat transfer coefficient from debris to penetration structures.
(type = real, default = 1000.0, units = W/m²-K)
- (2) HDBLH - Heat transfer coefficient from debris to lower head.
(type = real, default = 1000.0, units = W/m²-K)
- (3) TPFAL - Failure temperature of the penetrations or the lower head.
(type = real, default = 1273.15, units = K)
- (4) CDISP - Discharge coefficient for ejection of debris through failed penetration opening.
(type = real, default = 1.0, units = none)

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COR00011 – Core Boundary Conduction Parameters

Optional

This record specifies parameters for calculating conduction from the outer core ring to the boundary heat structures specified on record CORZjj02. This record is not required, but if included, the following four fields are required. For more information on how these parameters are used in the conduction model, see the COR Package Reference Manual, Section 2.2.7.

- (1) ICBCD - Component number that conducts to boundary heat structures (see Section 1.1 for component numbers).
(type = integer, default = none, units = none)
- (2) MATBCD - Gap material for conduction to boundary heat structures.
(type = character*24, default = none, units = none)
- (3) DXBCD - Gap thickness.
(type = real, default = none, units = m)
- (4) CDFBCD - Boundary conduction thermal diffusion constant.
(type = real, default = none, units = $m^2 \cdot K \cdot s^{1/2} / J$)

COR00012 – In-Vessel Falling Debris Quench Model Parameters

Optional

This record specifies parameters needed to activate the in-vessel falling debris quench model. This record is not required, but if included, the first field must be present, while the following three fields are optional. For more information on how these parameters are used in the model, see the COR Package Reference Manual, Section 2.3.7.

There are other uses of IAXSUP but, in most cases, the value defaulted from NTLP on input record COR00001 will be appropriate. See section 1.5.2 for more discussion.

- (1) HDBH2O - Heat transfer coefficient from in-vessel falling debris to pool. A value of zero turns the model off. *User Note: Large values of this parameter could result in vessel over-pressurization.*
(type = real, default = 100.0, units = $W/m^2 \cdot K$)
- (2) PPFail - Differential pressure between lower plenum volume and reactor cavity volume that will fail the lower head. This value must not exceed the critical pressure of water ($2.2e7$ Pa) or a fatal input error will result.

(type = real, default = 2.0e7, units = Pa)

- (3) IAXSUP - Axial level number of core cells containing the core support plate. It is used primarily as the starting point for tracking falling debris. (type = integer, default = NTLP [see description of input record COR00000], units = none)
- (4) VFALL - Velocity of falling debris. (type = real, default = 1.0 [*In previous versions of MELCOR this value was default to 5 m/s. The current default reflects greater resistance to falling offered by the water and rising bubbles.*], units = m/s)

COR000DX – Global Particulate Debris Exclusion Parameters

Optional

This record allows global definition of volumes from which particulate debris will be excluded by the simple presence of various other components. The exclusion volumes are specified as fractions of the associated total volume, either channel or bypass. (Particulate debris will be excluded from the physical volume of the component even if this fraction is zero.) The model is described briefly in Sections 1.4 and 1.5.4 of this manual and in detail in Section 3.2.3 of the COR Package Reference Manual.

If this record is present, it may contain from zero to seven fields. Default values will be retained for those fields that are not present and for any that contain negative numbers. The default value for FBYXNS is different for a BWR (including SBWR) than for a PWR. The choice is based on IRTYP input on record COR00002.

- (1) FCHXRD - Fraction of channel volume denied to particulate debris by presence of fuel rods, FU and/or CL. (type = real, default = 1.0, units = none)

The following three fractions are used only in cells where there is a distinct bypass.

- (2) FBYXRD - Fraction of bypass volume denied to particulate debris by presence of fuel rods, FU and/or CL. (type = real, default = 0.0, units = none)
- (3) FBYXCN - Fraction of bypass volume denied to particulate debris by presence of canister, CN. (type = real, default = 0.3, units = none)

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- (4) **FBYXCB** - Fraction of bypass volume denied to particulate debris by presence of bladed canister, CB.
(type = real, default = 0.0, units = none)

The following three fractions are applied to the bypass volume in cells where there is a distinct bypass. Otherwise, they are applied to the total cell volume.

- (5) **FBYXNS** - Fraction of applicable volume denied to particulate debris by presence of nonsupporting structure, NS.
(type = real, default = 0.7 for BWR, 0.0 for PWR, units = none)
- (6) **FBYXSS** - Fraction of applicable volume denied to particulate debris by presence of supporting structure, SS.
(type = real, default = 0.0, units = none)
- (7) **FBYXOS** - Fraction of applicable volume denied to particulate debris by presence of combined other structure, OS.
(type = real, default = 0.0, units = none)

COR000NS – Global Support Rule for NS Optional

The primary use of the NS component in modeling a commercial reactor is to represent control structures (blades and rods). This record defines the global rule for support of NS in the core. The record is optional, and the default treatment depends on the reactor type (IRTY on the COR00002 input record). If the record is input with less than four fields, default values will be used for the omitted field(s).

- (1) **INSSUP** - Support rule for NS.
= 'BELOW' NS in a cell will collapse unless there is intact NS or unfailed SS in the cell immediately below it.
= 'ABOVE' NS in a cell will collapse unless there is intact NS in the cell immediately above it.
= 'FIXED' NS in a cell will not collapse until it fails locally.
= 'BLADE' Converted internally to 'BELOW' for all cells.
= 'ROD' Converted internally to 'ABOVE' for all cells except for the top axial level, where 'FIXED' will be specified.
(type = character*6 default = 'BLADE' for a BWR or SBWR, and 'ROD' for a PWR, units = none)
- (2) **METAL** - Structural metal in NS.
= 'STEEL' Local failure is based on the thickness of steel in NS.

= 'ZIRC' Local failure is based on the thickness of Zircaloy in NS.
(type = character*6, default = 'STEEL', units = none)

(3) TNSMAX - Temperature above which NS will collapse, independent of remaining metal thickness. A zero or negative value implies collapse at the melting point of METAL.
(type = real, default = 0.0, units = K)

(4) DRNSMN - Critical minimum thickness of unoxidized metal in NS, below which it will collapse.
(type = real, default = 0.0001, units = m)

COR00SS – Global Loading and Failure Rule for SS Optional

The primary use of the SS component in modeling a commercial reactor is to represent supporting structures such as core plates and control rod guide tubes. This record defines the global rule for loading and failure of SS. The options are described briefly in Section 1.3 of this report, and in more detail in the COR Package Reference Manual.

The record is optional. The first field defines the structural model, while second and subsequent fields provide parameters for the failure calculation, which may be either parametric or stress based. The default treatment is as a grid supported plate ('PLATEG') with failure on overtemperature, which closely resembles the model used for OS. If the record is input with less than the maximum permitted number of fields for the model specified in the first field, default values will be used for the omitted field(s).

(1) ISSMOD - Structural model option for SS.
= 'PLATE' SS in a cell will be treated as an edge-supported plate.
= 'PLATEG' SS in a cell will be treated as a grid-supported plate.
= 'PLATEB' SS in a cell will be treated as a BWR core plate.
= 'COLUMN' SS in a cell will be treated as a column representing a BWR control rod guide tube.
(type = character*6, default = 'PLATEG', units = none)

For parametric models, the second field is a character variable specifying the model, and the interpretation of the third field depends on the model specified.

(2) ISSFAI - Failure model, either 'TSFAIL' or 'LOG-CF'.
(type = character*6, default = 'TSFAIL', units = none)

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followed by either

- (3) TSSFAI - Failure temperature for the TSFAIL model
(type = real, default = 1273.15, units = K)

or

- (3) ISSLCF - Number of a logical control function for the LOG-CF model. A .TRUE. value will define failure of the SS.
(type = integer, default = none, units = none)

For stress-based failure modeling, fields 2 through 4 define the parameters to be used in converting total loads borne by a structure. Their interpretation depends on the structural model option specified in field 1.

For the PLATE model, the stress at radius r in a plate of thickness h and radius a with a central hole of radius r_0 , bearing a total load W_{total} is computed as

$$\sigma_e(r; r_0) = 6 K_0 \frac{1}{\pi} \frac{1}{h^2} \left[1 - K_1 \left(\frac{r}{a} \right)^2 \right] \left[1 + \left(\frac{r_0}{r} \right)^2 \right] W_{total} \quad (\text{PLATE})$$

The input parameters are

- (2) THICK - Working thickness of plate, h , used only for stress calculations.
(type = real, default = none, units = m)
- (3) AKM0 - Lead coefficient, K_0 .
(type = real, default = 0.206, units = none)
- (4) AKM1 - Coefficient K_1 in stress concentration term for central hole.
(type = real, default = 0.576, units = none)

For the PLATEG model, the maximum stress in a plate of thickness h supported by beams of spacing h with a total load, W_{total} on an area A_{ring} is computed as

$$\sigma_{e,ring} = 6 K_G \frac{x^2}{A_{ring}} \frac{1}{h^2} W_{ring} \quad (\text{PLATEG})$$

The input parameters are

- (2) THICK - Working thickness of plate, h , used only for stress calculations.
(type = real, default = none, units = m)
- (3) SPACE - Spacing of supporting beams, x .
(type = real, default = none, units = m)
- (4) AKMG - Coefficient K_G .
(type = real, default = 0.0513, units = none)

For the PLATEB model, the maximum stress in a plate of thickness h supported by beams of spacing h with a total load, W_{total} on an area A_{ring} is computed as

$$\sigma_{e,ring} = 6 K_B \frac{x^2}{A_{ring}} \frac{1}{h^2} W_{ring} \quad (\text{PLATEB})$$

The input parameters are

- (2) THICK - Working thickness of plate, h , used only for stress calculations.
(type = real, default = none, units = m)
- (3) SPACE - Spacing of supporting beams, x .
(type = real, default = none, units = m)
- (4) AKMB - Coefficient K_B .
(type = real, default = 0.0833, units = none)

For the COLUMN model, the maximum stress in a group of N identical cylindrical columns with initial outer radius r_o and inner radius r_i with a total load, W_{total} is computed as

$$\sigma_{e,ring} = \frac{1}{N\pi(r_o^2 - r_i^2)} \frac{M_{column,0}}{M_{column}} W_{ring} \quad (\text{COLUMN})$$

The factor of the ratio of the initial column mass to the current mass is included to account for any reduction of load bearing area by oxidation or melting. The input parameters are

- (2) XNUM - Number of identical columns in ring, N
(type = real, default = none, units = none)
- (3) RADO - Outer radius of column, r_o .

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(type = real, default = none, units = m)

- (4) **RADI** - Inner radius of column, r_i .
(type = real, default = 0.0, units = m)

COR000PC – Global Pool Heat Transfer from Bottom/Top of SS Plates Optional

Unlike other core components, plates have horizontal bottom and top surfaces. When the SS component is used to model a plate, heat transfer from these surfaces to water pools below and/or above may be calculated. The model may be controlled independently for the two surfaces, and is off by default.

When the model is on, the total area of either surface is taken as the total cross-sectional area of the core cell. The fraction covered below is ramped on as the surface of the pool in the core cell below rises to the bottom surface of the plate. Similarly, the fraction covered above is ramped off as the surface of the pool in the core cell above falls to the top surface of the plate.

By default, the heat transfer coefficient for the bottom surface is evaluated from the built in correlation for downward-facing boiling and that for the top surface from the built-in pool boiling correlation. These may be overridden by constant values or by values calculated as control functions. In any case, the temperature difference is based on the average temperature of the plate in the core cell and that of the pool.

- (1) **DZBOT** - Clearance between bottom of plate and pool surface for no contact. If negative, no heat transfer is considered between the bottom surface and the pool.
(type = real, default = -1.0, units = m)
- (2) **DZTOP** - Pool depth over top surface of plate for complete coverage. If negative, no heat transfer is considered between the top surface and the pool
(type = real, default = -1.0, units = m)

optionally followed by either

- (3) **HPBOT** - Constant heat transfer coefficient between bottom surface and pool to override the default boiling correlation.
(type = real, default 0.0, units = W/m^2K)

or

- (3) IHPBOT - Number of a real control function whose value will be used as the heat transfer coefficient between bottom surface and pool.
(type = integer, default = 0, units = none)

optionally followed by either

- (4) HPTOP - Heat transfer coefficient between top surface and pool to override the default boiling correlation.
(type = real, default 0.0, units = W/m²K)

or

- (4) ICFEMI - Number of a real control function whose value will be used as the heat transfer coefficient between top surface and pool.
(type = integer, default = 0, units = none)

COR000PR – Global Downward Radiation from SS to Pool or Lower Head

Optional

By default, the general radiation model is used for radiation from the lowest surface in the core to a pool or the lower head below. The view-factor-times-area product is taken as $FLPUP \text{ MIN}(A_{surf}, ASCELA)$ or $FCELA \text{ MIN}(A_{surf}, A_{LH})$, respectively. Here FLPUP and FCELA are values input on the COR00003 record (or associated defaults), ASCELA is input for each ring on CORRii01 records, and A_{LH} is derived from input on CORLHDii records. In some cases, this may not adequately represent actual radiative heat transfer from the core support plate. This record allows generalization of the calculation. It affects *only* the specific case of radiation from SS as the lowest surface in the core to a pool or the lower head below. The input parameters are

- (1) ISSVFA - Number of a real control function whose value (subject to appropriate limits) will be used as the view-factor-times-area product for this radiation path.
(type = real, default = none, units = none)

optionally followed by either

- (2) EMISSE - Constant emissivity value to be used for the SS surface.
(type = real, default none, units = none)

or

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- (2) ICFEMI - Number of a real control function whose value (subject to appropriate limits) will be used as the emissivity of the SS surface.
(type = integer, default = none, units = none)

2.2 MELGEN Axial Level Input

CORZjj01 – Axial Level Geometric Parameters

$1 \leq jj \leq NAXL$, jj is the axial level number
Required

This record specifies various geometric parameters for axial level jj. Four floating point fields are required for each level. PORIN is no longer used, but its input is retained to preserve the format of the record; parameters input on COR000DX, CORZjjDX, CORRiiDX, and/or CORijjDX records now provide much more flexible control of debris relocation.

- (1) Z - Elevation of lower boundary of axial level.
(type = real, default = none, units = m)
- (2) DZ - Axial length of level from lower boundary to upper boundary.
(type = real, default = none, units = m)
- (3) PORIN - Unused.
(type = real, default = none, units = none)
- (4) PORDP - Porosity of particulate debris for all cells in axial level jj. The value must be nonnegative and less than 1.0.
(type = real, default = none, units = none)

CORZjj02 – Radial Boundary Heat Structure Specification, Component Support Flag

$1 \leq jj \leq NAXL$, jj is the axial level number
Required

This record specifies the heat structure number representing the outer radial boundary for axial level jj and whether components in this level are initially supported by components in the cell below or by lateral support. The first of the two allowed integer fields specifies the heat structure that provides the radial thermal boundary for this axial level of the core, and is required for each level. Melting of these structures can be modeled through appropriate input to the HS package, using HSDGCCCCn input records (see the HS package Users' Guide). When this

is done, the molten steel from the structure will be added to the outermost radial ring of the axial level containing the structure.

The second field defining the support of core components in this level is optional. It is used only when the combined other structure component, OS, is used (which requires setting IOLDOS=1 on input record COR00006). Although ISUP is defined initially for all cells in level jj, it may change in individual cells in that level according to cell temperatures (see input record CORZjj04).

If IOLDOS=0, any input for ISUP is unused. Instead, supporting structure (SS) is modeled as supporting itself, and as capable of supporting other structures until it reaches the failure temperature specified on input record CORZjj04 (equivalent to OS with ISUP=11). Nonsupporting structure (NS) is treated subject to the same support rules as other components such as cladding (CL) or canister (CN and CB), and cannot support other components.

- (1) IHSA - Boundary heat structure number for this axial level. A unique heat structure must be specified for each axial level.
(type = integer, default = none, units = none)
- (2) ISUP - Core component support flag, composed of two digits, used only for the OS component, which is allowed only if IOLDOS=1 on input record COR00006. If the first digit ("tens" digit) is nonzero, then the "other structure" component (e.g., the core plate) will support particulate debris, not allowing it to penetrate to lower axial levels, until the component reaches the structure failure temperature TSFAIL (record CORZjj04). If the first digit is 0 (or omitted), then particulate debris will not be supported by the "other structure" component at this level. If the second digit of ISUP ("ones" digit) is nonzero, intact components in cell jj will remain in that cell until they melt or form particulate debris. If the second digit is 0, an intact component in cell jj-1 must be present to support components in cell jj; otherwise these components will be converted to particulate debris.
(type = integer, default = 0, units = none)

CORZjj03 – Axial Power Density Profile

$1 \leq jj \leq NAXL$, jj is the axial level number

Optional

This record specifies the relative amount of fission power generated per unit fuel mass in axial level jj, as well as the relative amount of decay power per unit mass if the Radionuclide (RN) package is inactive. The sum of the values for all levels must be greater than 0.0 if ICFFIS on input record COR00004 is not 0 or if the RN

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package is inactive. The values are normalized for all cells containing a fuel component for $|ICFFIS|$ less than 100, or (for fission power only) for all liquid-covered cells containing fuel for $|ICFFIS|$ greater than or equal 100. This record is not required, but if included, one floating point field must be present.

- (1) FZPOW - Relative power density in this level.
(type = real, default = 1.0, units = none)

CORZjj04 – “Other Structure” Failure Temperature

$1 \leq jj \leq NAXL$, jj is the axial level number

Optional

This record defines temperature at which “other structure” will fail in axial level jj . This record is not required, but if included, one floating point field must be present. It is used only for the OS component, which is allowed only if IOLDOS=1 on input record COR00006.

- (1) TSFAIL - “Other structure” failure temperature for cells in this level. “Failure” is currently defined with regard to the capacity of “other structure” components to support other intact components and particulate debris. It has the effect of resetting the “tens” digit of the support flag ISUP (input for all cells at level jj on input record CORZjj02) to zero when this temperature is reached in a cell.
(type = real, default = 1273.15, units = K)

CORZjjDX – Particulate Debris Exclusion Parameters in Axial Level

$1 \leq jj \leq NAXL$, jj is the axial level number

Optional

These records may be used to override the global (or default) parameters for modeling of particulate debris exclusion for all core cells in an axial level. The format and options are identical to those for the COR000DX input record.

CORZjjNS – Support Rule for NS in Axial Level

$1 \leq jj \leq NAXL$, jj is the axial level number

Optional

These records may be used to override the global (or default) definition of support of NS for all core cells in an axial level. The format and options are identical to those for the COR000NS input record with the exception that the 'BLADE' and 'ROD' options are not available because the input affects only a single axial level of the core.

CORZjjSS – Loading and Failure Rule for SS in Axial Level

$1 \leq jj \leq \text{NAXL}$, jj is the axial level number

Optional

These records may be used to override the global (or default) definition of modeling of SS for all core cells in an axial level. The format and options are identical to those for the COR000SS input record.

CORZjjPC – Pool Heat Transfer from Bottom/Top of SS Plates in Axial Level

$1 \leq jj \leq \text{NAXL}$, jj is the axial level number

Optional

These records may be used to override the global (or default) definition of modeling of heat transfer from SS plate surfaces for all core cells in an axial level. The format and options are identical to those for the COR000PC input record.

CORZjjPR – Downward Radiation from SS to Pool or Lower Head in Axial Level

$1 \leq jj \leq \text{NAXL}$, jj is the axial level number

Optional

These records may be used to override the global (or default) definition of modeling of downward radiation from SS for all core cells in an axial level. The format and options are identical to those for the COR000PR input record.

2.3 MELGEN Radial Ring Input

CORRii01 – Radial Ring Cross-sectional (Axial Boundary) Area

$1 \leq ii \leq \text{NRAD}$, ii is the radial ring number

Required

This record specifies the total axial cross-sectional area of radial ring ii, including all core components, channel flow area, and bypass flow area. This value is used in the radiation model for calculating axial inter-cell radiative energy exchange. It is not used in calculating core cell volumes. These are based on component volumes and fluid flow areas entered on CORijj05 records. One floating point field is required for each ring. For further details, see the COR Package Reference Manual, Sections 1.1 and 2.1.

(1) ASCELA - Total cross-sectional area of radial ring ii [equal to $\pi(R_o^2 - R_i^2)$, where R_o and R_i are the outer and inner radii of ring ii].
(type = real, default = none, units = m²)

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CORRii02 – Upper Boundary Heat Structure and Lower Head Failure CF Specification

$1 \leq ii \leq \text{NRAD}$, ii is the radial ring number

Required

This record specifies the heat structure number representing the upper axial boundary for radial ring ii and optionally a control function to trigger lower head failure for this ring. At least the first integer field is required for each level. Melting of these structures can be modeled through appropriate input to the HS package, using HSDGCCCCCn input records. When this is done, the molten steel from the structure will be added to the outermost radial ring of the uppermost axial level of the core.

- (1) IHSR - Upper boundary heat structure number for this radial ring.
(type = integer, default = none, units = none)
- (2) ICFLHF - If ICFLHF > 0, a value of .TRUE. calculated by a logical control function with user number ICFLHF will trigger failure of the lower head penetrations in this radial ring.
(type = integer, default = 0, units = none)

CORRii03 – Radial Power Density Profile

$1 \leq ii \leq \text{NRAD}$, ii is the radial ring number

Optional

This record specifies the relative amount of fission power generated per unit fuel mass in radial ring ii, as well as the relative amount of decay power per unit mass if the Radionuclide (RN) package is inactive. The sum of the values for all rings must be greater than 0.0 if ICFFIS on input record COR00004 is not 0 or if the RN package is inactive. The values are normalized for all cells containing a fuel component for |ICFFIS| less than 100, or (for fission power only) for all liquid-covered cells containing fuel for |ICFFIS| greater than or equal 100. This record is not required, but if included, one floating point field must be present.

- (1) FRPOW - Relative power density in this ring.
(type = real, default = 1.0, units = none)

CORRii04 – Ring Flow Direction Control Functions

$1 \leq ii \leq \text{NRAD}$, ii is the radial ring number

Optional

This record allows the use of control functions to specify the direction of flow to be assumed in the oxidation calculation, and the order in which core cells within a ring will be given access to available oxidizers. If a nonzero number is entered, the

direction will be inferred from the value of the specified control function, with a positive value taken to imply upflow and a negative value to imply downflow.

- (1) ICFCHN - The number of a REAL control function from which the direction of flow in the channel will be inferred.
(type = integer, default = 0, units = none)
- (2) ICFBYP - The number of a REAL control function from which the direction of flow in the bypass will be inferred.
(type = integer, default = 0, units = none)

CORRiiDX – Particulate Debris Exclusion Parameters in Radial Ring
 $1 \leq ii \leq \text{NRAD}$, ii is the radial ring number

These records may be used to override the previous definition of particulate debris exclusion parameters for all core cells in a radial ring. The format and options are identical to those for the COR000DX input record.

CORRiiNS – Support Rule for NS in Radial Ring
 $1 \leq ii \leq \text{NRAD}$, ii is the radial ring number
Optional

These records may be used to override the previous definition of support of NS for all core cells in a radial ring. The format and options are identical to those for the COR000NS input record.

CORRiiSS – Loading and Failure Rule for SS in Radial Ring
 $1 \leq ii \leq \text{NRAD}$, ii is the radial ring number
Optional

These records may be used to override the previous definition of modeling of SS for all core cells in a radial ring. The format and options are identical to those for the COR000SS input record.

CORRiiPC – Pool Heat Transfer from Bottom/Top of SS Plates in Radial Ring
 $1 \leq ii \leq \text{NRAD}$, ii is the radial ring number
Optional

These records may be used to override the global (or default) definition of modeling of heat transfer from SS plate surfaces for all core cells in a radial ring. The format and options are identical to those for the COR000PC input record.

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CORRiiPR –Downward Radiation from SS to Pool or Lower Head in Radial Ring

$1 \leq ii \leq \text{NRAD}$, ii is the radial ring number

Optional

These records may be used to override the global (or default) definition of modeling of downward radiation from SS for all core cells in a radial ring. The format and options are identical to those for the COR000PR input record.

2.4 MELGEN Specific Cell Input

CORijj01 – Cell Reference and Fluid Boundary Volumes

$1 \leq i \leq \text{NRAD}$, i is the radial ring number

$1 \leq jj \leq \text{NAXL}$, jj is the axial level number

Required

This record specifies a reference cell for defining missing input and the fluid control volume number(s) adjacent to cell ij. Three fields are allowed; however, only the first needs to be present if it specifies a valid reference cell.

- (1) IREFN - Reference cell (3-digit cell number) for setting values not input for this cell. Any input values that are missing from the input for this cell are set to the values for cell IREFN and no input error is generated. This field may be set to -1 if no reference cell is needed, but then all other input for this cell must be included.
(type = integer, default = -1, units = none)
- (2) ICVHC - Channel control volume adjacent to this cell. This field may be missing or set to -1 if a valid cell is input for IREFN.
(type = integer, default = -1, units = none)
- (3) ICVHB - Bypass control volume adjacent to this cell. This field is reserved for BWR calculations in which the interstitial volume between canister boxes must be modeled separately from the channel volume. This field may be missing or set to -1 if a valid cell is input for IREFN, and is ignored for PWR calculations (IRTYP = 'PWR').
(type = integer, default = -1, units = none)

CORijj02 – Cell Component Masses

$1 \leq i \leq \text{NRAD}$, i is the radial ring number

$1 \leq jj \leq \text{NAXL}$, jj is the axial level number

Optional if valid IREFN entered

This record and input record CORijj02A specify the initial masses of the intact components in cell ij. The latter record is not permitted if IOLDOS=1 on input record COR00006. Neither record is required if a valid cell for IREFN has been entered on input record CORijj01. Eight floating point fields are allowed on this record; however, any of these fields may be missing or set to -1.1 if the value from reference cell IREFN is desired.

Equivalent information may optionally be provided, in a more general format, on input records CORijjKcc, where "cc" specifies a specific component.

- (1) XMFU - Mass of UO₂ in the cell fuel component.
(type = real, default = -1.1, units = kg)
- (2) XMCL - Mass of Zircaloy in the cell cladding component.
(type = real, default = -1.1, units = kg)
- (3) XMOS - Mass of steel in the cell OS component. Nonzero values are not permitted if IOLDOS=0 on input record COR00006, but a zero value may be required as a placeholder for nonzero entries in fields 5 through 8.
(type = real, default = -1.1, units = kg)
- (4) XMCP - Mass of control poison in the cell OS "other structure" component. Nonzero values are not permitted if IOLDOS=0 on input record COR00006, but a zero value may be required as a placeholder for nonzero entries in fields 5 through 8.
(type = real, default = -1.1, units = kg)
- (5) XMCN - Total mass of Zircaloy in the two cell canister components. Unless specified otherwise in sensitivity coefficient array 1501, the total canister mass entered in this field will be divided equally between the two canister components (one component is adjacent to the control blade, the other is not). This field is ignored for PWR calculations (IRTY = 'PWR') if field six is not input.
(type = real, default = -1.1, units = kg)
- (6) XMHT - Mass of electric heating element in the cell fuel component. If non-zero, a modified version of subroutine ELHEAT must be linked to MELCOR.
(type = real, default = -1.1, units = kg)

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- (7) XMIN - Mass of Inconel associated with the cell cladding component (e.g., PWR grid spacers).
(type = real, default = -1.1, units = kg)
- (8) XMGT - Mass of Zircaloy associated with the cell "other structure" component (e.g., PWR control rod guide tubes).
(type = real, default = -1.1, units = kg)

CORijj02A – Additional Cell Component Masses

$1 \leq i \leq \text{NRAD}$, i is the radial ring number

$1 \leq jj \leq \text{NAXL}$, jj is the axial level number

Optional if valid IREFN entered

This record specifies the initial mass of intact supporting structure (SS) and nonsupporting structure (NS) components in cell ijj . It is permitted only if IOLDOS=0 on input record COR00006. Five floating point fields are allowed on this record; however, any of these fields may be missing or set to -1.1 if the value from reference cell IREFN is desired.

- (1) XMSSSS - Mass of steel in cell supporting structure component.
(type = real, default = -1.1, units = kg)
- (2) XMSSZR - Mass of Zircaloy in the cell supporting structure component.
(type = real, default = -1.1, units = kg)
- (3) XMNSSS - Mass of steel in cell nonsupporting structure component.
(type = real, default = -1.1, units = kg)
- (4) XMNSCP - Mass of control poison in the cell nonsupporting structure component.
(type = real, default = -1.1, units = kg)
- (5) XMNSZR - Mass of Zircaloy in the cell nonsupporting structure component.
(type = real, default = -1.1, units = kg)

Instead of using record CORijj02 to input masses for the cell, optional input records for each component present in a cell may be used. Any given record is not generally required, but at least one mass value for at least one component must be entered if this option is exercised. For a given cell, the two options may not be mixed; use of the CORijj02 record precludes use of any of the new-format component mass records. However, different options may be used for different cells.

COR_{ijj}KFU – Fuel Component Masses

$1 \leq i \leq \text{NRAD}$, i is the radial ring number

$1 \leq jj \leq \text{NAXL}$, jj is the axial level number

Optional

This record specifies the initial masses of the fuel component in cell ijj . This record is not generally required, but component masses for at least one component must be entered if the new-format option is exercised for this cell. Two floating point fields are allowed on this record. If either field on this record is missing or set to -1.1 (or if the record is not present), the corresponding value from reference cell IREFN is used if IREFN is defined; otherwise the value is set to zero.

- (1) XMFUO - Mass of UO₂ in the cell fuel component.
(type = real, default = -1.1, units = kg)
- (2) XMFUHT - Mass of electric heating element in the cell fuel component. If non-zero, a modified version of subroutine ELHEAT must be linked to MELCOR.
(type = real, default = -1.1, units = kg)

COR_{ijj}KCL – Cladding Component Masses

$1 \leq i \leq \text{NRAD}$, i is the radial ring number

$1 \leq jj \leq \text{NAXL}$, jj is the axial level number

Optional

This record specifies the initial masses of the cladding component in cell ijj . This record is not generally required, but component masses for at least one component must be entered if the new-format option is exercised for this cell. Three floating point fields are allowed on this record. If any fields on this record are missing or set to -1.1 (or if the record is not present), the corresponding values from reference cell IREFN are used if IREFN is defined; otherwise the values are set to zero.

- (1) XMCLZR - Mass of Zircaloy in the cell cladding component.
(type = real, default = -1.1, units = kg)
- (2) XMCLIN - Mass of Inconel associated with the cell cladding component (e.g., PWR grid spacers).
(type = real, default = -1.1, units = kg)
- (3) XMCLZX - Mass of ZrO₂ in the cell cladding component.
(type = real, default = -1.1, units = kg)

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COR_{ijj}KCN – Canister (CN) Component Masses

$1 \leq i \leq \text{NRAD}$, i is the radial ring number

$1 \leq jj \leq \text{NAXL}$, jj is the axial level number

Optional

This record specifies the initial masses of the canister CN component (the portion not adjacent to a control blade) in cell ijj . This record is not generally required, but component masses for at least one component must be entered if the new-format option is exercised for this cell. Three floating point fields are allowed on this record. If any fields on this record are missing or set to -1.1 (or if the record is not present), the corresponding values from reference cell IREFN are used if IREFN is defined; otherwise the values are set to zero.

- (1) XMCNZR - Mass of Zircaloy in the cell canister (CN) component.
(type = real, default = -1.1, units = kg)
- (2) XMCNXI - Mass of ZrO_2 on the inside surface of the cell canister (CN) component.
(type = real, default = -1.1, units = kg)
- (3) XMCNXO - Mass of ZrO_2 on the outside surface of the cell canister (CN) component.
(type = real, default = -1.1, units = kg)

COR_{ijj}KCB – Canister (CB) Component Masses

$1 \leq i \leq \text{NRAD}$, i is the radial ring number

$1 \leq jj \leq \text{NAXL}$, jj is the axial level number

Optional

This record specifies the initial masses of the canister CB component (the portion adjacent to a control blade) in cell ijj . This record is not generally required, but component masses for at least one component must be entered if the new-format option is exercised for this cell. Three floating point fields are allowed on this record. If any fields on this record are missing or set to -1.1 (or if the record is not present), the corresponding values from reference cell IREFN are used if IREFN is defined; otherwise the values are set to zero.

- (1) XMCBZR - Mass of Zircaloy in the cell canister (CB) component.
(type = real, default = -1.1, units = kg)
- (2) XMCBXI - Mass of ZrO_2 on the inside surface of the cell canister (CB) component.
(type = real, default = -1.1, units = kg)

- (3) XMCBXO - Mass of ZrO_2 on the outside surface of the cell canister (CB) component.
(type = real, default = -1.1, units = kg)

COR_{ijj}KOS – “Other Structure” Component Masses

$1 \leq i \leq \text{NRAD}$, i is the radial ring number

$1 \leq jj \leq \text{NAXL}$, jj is the axial level number

Optional

This record specifies the initial masses of the OS “other structure” component in cell ijj , and is not permitted unless IOLDOS=1 on input record COR00006. Even then, it is not generally required, but component masses for at least one component must be entered if the new-format option is exercised for this cell. Five floating point fields are allowed on this record. If any fields on this record are missing or set to -1.1 (or if the record is not present), the corresponding values from reference cell IREFN are used if IREFN is defined; otherwise the values are set to zero.

- (1) XMOSSS - Mass of steel in the cell “other structure” component.
(type = real, default = -1.1, units = kg)
- (2) XMOSCP - Mass of control poison in the cell “other structure” component.
(type = real, default = -1.1, units = kg)
- (3) XMOSZR - Mass of Zircaloy associated with the cell “other structure” component (e.g., PWR control rod guide tubes).
(type = real, default = -1.1, units = kg)
- (4) XMOSX - Mass of steel oxide in the cell “other structure” component.
(type = real, default = -1.1, units = kg)
- (5) XMOSZX - Mass of ZrO_2 in the cell “other structure” component.
(type = real, default = -1.1, units = kg)

COR_{ijj}KSS – Supporting Structure Component Masses

$1 \leq i \leq \text{NRAD}$, i is the radial ring number

$1 \leq jj \leq \text{NAXL}$, jj is the axial level number

Optional

This record specifies the initial masses of the SS supporting structure component in cell ijj , and is not permitted if IOLDOS=1 on input record COR00006. This record is not generally required, but component masses for at least one component must be entered if the new-format option is exercised for this cell. Four floating point fields are allowed on this record. If any fields on this record are missing or set to

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-1.1 (or if the record is not present), the corresponding values from reference cell IREFN are used if IREFN is defined; otherwise the values are set to zero.

- (1) XMSSSS - Mass of steel in the cell supporting structure component.
(type = real, default = -1.1, units = kg)
- (2) XMSSZR - Mass of Zircaloy in the cell supporting structure component.
(type = real, default = -1.1, units = kg)
- (3) XMSSSX - Mass of steel oxide in the cell supporting structure component.
(type = real, default = -1.1, units = kg)
- (4) XMSSZX - Mass of ZrO₂ in the cell supporting structure component.
(type = real, default = -1.1, units = kg)

CORijjKNS – Nonsupporting Structure Component Masses

$1 \leq i \leq \text{NRAD}$, i is the radial ring number

$1 \leq jj \leq \text{NAXL}$, jj is the axial level number

Optional

This record specifies the initial masses of the NS nonsupporting structure component in cell ijj , and is not permitted if IOLDOS=1 on input record COR00006. This record is not generally required, but component masses for at least one component must be entered if the new-format option is exercised for this cell. Four floating point fields are allowed on this record. If any fields on this record are missing or set to -1.1 (or if the record is not present), the corresponding values from reference cell IREFN are used if IREFN is defined; otherwise the values are set to zero.

- (1) XMNSSS - Mass of steel in the cell nonsupporting structure component.
(type = real, default = -1.1, units = kg)
- (2) XMNSCP - Mass of control poison in the cell nonsupporting structure component.
(type = real, default = -1.1, units = kg)
- (3) XMNSZR - Mass of Zircaloy associated with the cell nonsupporting structure component (e.g., PWR control rod guide tubes).
(type = real, default = -1.1, units = kg)
- (4) XMNSSX - Mass of steel oxide in the cell nonsupporting structure component.
(type = real, default = -1.1, units = kg)

- (5) XMNSZX - Mass of ZrO_2 in the cell nonsupporting structure component.
(type = real, default = -1.1, units = kg)

COR_{ijj}KPD – Particulate Debris Component Masses

$1 \leq i \leq \text{NRAD}$, i is the radial ring number

$1 \leq jj \leq \text{NAXL}$, jj is the axial level number

Optional

This record specifies the initial masses of the particulate debris component in cell ijj . For a cell with a separate bypass region in a BWR, it is the mass in the channel region, and mass in the bypass region is entered on the COR_{ijj}KPB record. This record is not generally required, but component masses for at least one component must be entered if the new-format option is exercised for this cell. Seven floating point fields are allowed on this record. If any fields on this record are missing or set to -1.1 (or if the record is not present), the corresponding values from reference cell IREFN are used if IREFN is defined; otherwise the values are set to zero.

- (1) XMPDUO - Mass of UO_2 in the cell particulate debris component.
(type = real, default = -1.1, units = kg)
- (2) XMPDZR - Mass of Zircaloy in the cell particulate debris component.
(type = real, default = -1.1, units = kg)
- (3) XMPDZX - Mass of ZrO_2 in the cell particulate debris component.
(type = real, default = -1.1, units = kg)
- (4) XMPDSS - Mass of steel in the cell particulate debris component.
(type = real, default = -1.1, units = kg)
- (5) XMPDSX - Mass of steel oxide in the cell particulate debris component.
(type = real, default = -1.1, units = kg)
- (6) XMPDCP - Mass of control poison in the cell particulate debris component.
(type = real, default = -1.1, units = kg)
- (7) XMPDIN - Mass of Inconel in the cell particulate debris component.
(type = real, default = -1.1, units = kg)

COR_{ijj}KPB – Particulate Debris Component Masses in Bypass

$1 \leq i \leq \text{NRAD}$, i is the radial ring number

$1 \leq jj \leq \text{NAXL}$, jj is the axial level number

Optional

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This record specifies the initial masses of the particulate debris component in the bypass of cell *ijj*. This record is not generally required, but component masses for at least one component must be entered if the new-format option is exercised for this cell. Seven floating point fields are allowed on this record. If any fields on this record are missing or set to -1.1 (or if the record is not present), the corresponding values from reference cell IREFN are used if IREFN is defined; otherwise the values are set to zero.

- (1) XMPBUO - Mass of UO₂ in the cell bypass particulate debris component.
(type = real, default = -1.1, units = kg)
- (2) XMPBZR - Mass of Zircaloy in the cell bypass particulate debris component.
(type = real, default = -1.1, units = kg)
- (3) XMPBZX - Mass of ZrO₂ in the cell bypass particulate debris component.
(type = real, default = -1.1, units = kg)
- (4) XMPBSS - Mass of steel in the cell bypass particulate debris component.
(type = real, default = -1.1, units = kg)
- (5) XMPBSX - Mass of steel oxide in the cell bypass particulate debris component.
(type = real, default = -1.1, units = kg)
- (6) XMPBCP - Mass of control poison in the cell bypass particulate debris component.
(type = real, default = -1.1, units = kg)
- (7) XMPBIN - Mass of Inconel in the cell bypass particulate debris component.
(type = real, default = -1.1, units = kg)

COR_{ijj}Y_{cc} – Conglomerate Debris Masses

$1 \leq i \leq \text{NRAD}$, *i* is the radial ring number

$1 \leq jj \leq \text{NAXL}$, *jj* is the axial level number

cc is the component identifier (any component permitted by the value of IOLDOS on input record COR00006 except FU)

Optional

This record specifies the initial conglomerate debris masses for component *cc* in cell *ijj*. This record is not required. Seven floating point fields are allowed on this record. If any fields on this record are missing or set to -1.1 (or if the record is not present), the corresponding values from reference cell IREFN are used if IREFN is defined; otherwise the values are set to zero.

- (1) YMCCUO - Mass of UO₂ in the conglomerate debris for component cc.
(type = real, default = -1.1, units = kg)
- (2) YMCCZR - Mass of Zircaloy in the conglomerate debris for component cc.
(type = real, default = -1.1, units = kg)
- (3) YMCCZX - Mass of ZrO₂ in the conglomerate debris for component cc.
(type = real, default = -1.1, units = kg)
- (4) YMCCSS - Mass of steel in the conglomerate debris for component cc.
(type = real, default = -1.1, units = kg)
- (5) YMCCSX - Mass of steel oxide in the conglomerate debris for component cc.
(type = real, default = -1.1, units = kg)
- (6) YMCCCP - Mass of control poison in the conglomerate debris for component cc.
(type = real, default = -1.1, units = kg)
- (7) YMCCIN - Mass of Inconel in the conglomerate debris for component cc.
(type = real, default = -1.1, units = kg)

CORijj03 – Cell Initial Temperature

1 ≤ i ≤ NRAD, i is the radial ring number

1 ≤ jj ≤ NAXL, jj is the axial level number

Optional if valid IREFN entered

This record specifies the initial component temperatures for cell ij. This record is not required if a valid cell for IREFN has been entered. Nine floating point fields are allowed on this record; however, any of these fields may be missing or set to -1.1 if the value from reference cell IREFN is desired.

- (1) TFU - UO₂ fuel temperature.
(type = real, default = -1.1, units = K)
- (2) TCL - Cladding temperature.
(type = real, default = -1.1, units = K)
- (3) TOS - OS "other structure" temperature.
(type = real, default = -1.1, units = K)
- (4) TCN - Canister (CN) temperature. This field is ignored for PWR calculations (IRTYP = 'PWR').
(type = real, default = -1.1, units = K)

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- (5) TCB - Canister (CB) temperature. If omitted, the CB component will be initialized to the CN component temperature entered on the fourth field. This field is ignored for PWR calculations (IRTYP = 'PWR').
(type = real, default = -1.1, units = K)
- (6) TPD - Particulate debris temperature. If omitted, the value from reference cell IREFN is used if IREFN is defined; otherwise the value is set to zero.
(type = real, default = -1.1, units = K)
- (7) TSS - Supporting structure temperature.
(type = real, default = -1.1, units = K)
- (8) TNS - Nonsupporting structure temperature.
(type = real, default = -1.1, units = K)
- (9) TPB - Particulate debris temperature in the bypass. If omitted, the value from reference cell IREFN is used if IREFN is defined; otherwise the value is set to zero.
(type = real, default = -1.1, units = K)

CORijj04 – Equivalent Diameter Record

- $1 \leq i \leq \text{NRAD}$, i is the radial ring number
- $1 \leq jj \leq \text{NAXL}$, jj is the axial level number
- Optional if valid IREFN entered

This record specifies the equivalent diameter (for convective heat transfer) for each component in cell ijj . This record is not required if a valid cell for IREFN has been entered. Eight floating point fields are allowed on this record; however, any of these fields may be missing or set to -1.1 if the value from reference cell IREFN is desired.

- (1) DHYCL - Cladding equivalent outside diameter.
(type = real, default = -1.1, units = m)
- (2) DHYOS - OS "other structure" equivalent diameter.
(type = real, default = -1.1, units = m)
- (3) DHYPD - Particulate debris equivalent diameter. Because it is used in calculating total debris surface area, this diameter is of particular importance in calculating quenching heat transfer during material relocation from the core to the lower plenum in the falling debris quench model. If desired, a different value can be specified as DHYPB for debris in the bypass of a BWR.

- (type = real, default = -1.1, units = m)
- (4) DHYCNC - Canister inside equivalent diameter. The same value is used for both canister components. This field is ignored for PWR calculations (IRTYP = 'PWR').
(type = real, default = -1.1, units = m)
- (5) DHYCNB - Canister outside equivalent diameter. Currently, the same value is used for both canister components (i.e., the fact that one canister component is adjacent to the control blade and the other is not is not taken into account). This field is ignored for PWR calculations (IRTYP = 'PWR').
(type = real, default = -1.1, units = m)
- (6) DHYSS - Supporting structure equivalent diameter.
(type = real, default = -1.1, units = m)
- (7) DHYNS - Nonsupporting structure equivalent diameter.
(type = real, default = -1.1, units = m)
- (8) DHYPB - Particulate debris equivalent diameter in the bypass of a BWR. If this field is omitted, the diameter of particulate debris in the channel will be used.
(type = real, default = DHYPD, units = m)

CORijj05 – Cell Boundary and Flow Areas Record

$1 \leq i \leq \text{NRAD}$, i is the radial ring number

$1 \leq jj \leq \text{NAXL}$, jj is the axial level number

Optional if valid IREFN entered

This record specifies the outer radial boundary area and the intact cross-sectional flow areas for cell ijj . The flow areas will be automatically reduced to account for any debris masses present in the cell. This record is not required if a valid cell for IREFN has been entered. Three floating point fields are allowed on this record; however, any of these fields may be missing or set to -1.1 if the value from reference cell IREFN is desired.

- (1) ASCELR - Area of outer radial cell boundary ($2\pi R \cdot DZ$, where R is the outer radius of ring i and DZ is the axial level length of level jj).
(type = real, default = -1.1, units = m^2)
- (2) AFLOWC - Channel flow area of cell.
(type = real, default = -1.1, units = m^2)

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- (3) AFLOWB - Bypass flow area of cell in a BWR. For a PWR, AFLOWB will simply be added to AFLOWC.
(type = real, default = -1.1, units = m²)

COR_{ijj}06 – Surface Area Record

1 ≤ i ≤ NRAD, i is the radial ring number

1 ≤ jj ≤ NAXL, jj is the axial level number

Optional if valid IREFN entered

This record specifies the intact surface area for each intact component in cell *ijj*. These areas will be automatically adjusted to account for any debris masses present in the cell. This record is not required if a valid cell for IREFN has been entered. Four floating point fields are allowed on this record; however, any of these fields may be missing or set to -1.1 if the value from reference cell IREFN is desired.

- (1) ASFU - Fuel surface area.
(type = real, default = -1.1, units = m²)
- (2) ASCL - Cladding surface area.
(type = real, default = -1.1, units = m²)
- (3) ASOS - OS "other structure" surface area.
(type = real, default = -1.1, units = m²)
- (4) ASCN - Total canister inside surface area. The value entered in this field will be divided equally between the two canister components, unless specified otherwise in sensitivity coefficient array 1501. This field is ignored for PWR calculations (IRTYP = 'PWR')
(type = real, default = -1.1, units = m²)
- (5) ASSS - Supporting structure surface area.
(type = real, default = -1.1, units = m²)
- (6) ASNS - Nonsupporting structure surface area.
(type = real, default = -1.1, units = m²)

COR_{ijj}07 – Oxidation Shutoff and Structure Failure Control Function Record

1 ≤ i ≤ NRAD, i is the radial ring number

1 ≤ jj ≤ NAXL, jj is the axial level number

Optional

This record specifies LOGICAL control functions to control various models on a cell by cell basis. A value of 0 indicates that no control function is to be used. If this

record is absent, values default to those for reference cell IREFN, if it is defined, or to 0. One or two integer fields are allowed on this record; a value of -1 indicates that the value from the reference cell is to be used.

- (1) ICFNOX - Oxidation shutoff control function. A control function value of .TRUE. will shut off oxidation in cell *ijj* (e.g., to model the effects of a flow blockage) for all surfaces connected to the channel control volume (ICVHC on record COR*ijj*01).
(type = real, default = 0 or -1, units = none)
- (2) ICFLSF - Structure failure control function, used for other structure OS only. A control function value of .TRUE. will cause the "tens" digit of the particulate debris support flag ISUP in cell *ijj* to be reset to zero, thus eliminating support of any debris by "other structure."
(type = real, default = 0 or -1, units = none)

COR*ijj*DX – Particulate Debris Exclusion Parameters in Single Cell

$1 \leq i \leq \text{NRAD}$, *i* is the radial ring number

$1 \leq jj \leq \text{NAXL}$, *jj* is the axial level number

Optional

These records may be used to override the previous definition of particulate debris exclusion parameters for individual core cells. The format and options are identical to those for the COR000DX input record.

COR*ijj*NS – Support Rule for NS in Single Cell

$1 \leq i \leq \text{NRAD}$, *i* is the radial ring number

$1 \leq jj \leq \text{NAXL}$, *jj* is the axial level number

Optional

These records may be used to override the previous definition of support of NS for individual core cells. The format and options are identical to those for the COR000NS input record with the exception that the 'BLADE' and 'ROD' options are not available because the input affects only a single axial level of the core.

COR*ijj*SS – Loading and Failure Rule for SS in Single Cell

$1 \leq i \leq \text{NRAD}$, *i* is the radial ring number

$1 \leq jj \leq \text{NAXL}$, *jj* is the axial level number

Optional

These records may be used to override the previous definition of modeling of SS for individual core cells. The format and options are identical to those for the COR000SS input record.

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CORRiiPC – Pool Heat Transfer from Bottom/Top of SS Plates in Radial Ring

$1 \leq i \leq \text{NRAD}$, i is the radial ring number

$1 \leq jj \leq \text{NAXL}$, jj is the axial level number

Optional

These records may be used to override the global (or default) definition of modeling of heat transfer from SS plate surfaces for individual core cells. The format and options are identical to those for the COR000PC input record.

CORRiiPR – Downward Radiation from SS to Pool or Lower Head in Radial Ring

$1 \leq i \leq \text{NRAD}$, i is the radial ring number

$1 \leq jj \leq \text{NAXL}$, jj is the axial level number

Optional

These records may be used to override the global (or default) definition of modeling of downward radiation from SS for individual core cells. The format and options are identical to those for the COR000PR input record.

2.5 MELGEN Lower Head Input

CORLHDii – Lower Head Structure Record

$01 \leq ii \leq \text{NRAD}$, ii is the radial ring number

Required

Each record specifies information for one lower head radial ring; a total of NRAD of these records are required, one for each ring. For a description on how these parameters are used in the lower head model, see the COR Package Reference Manual, Section 5.1. Note that the value of RADLH for $ii=\text{NRAD}$ should be equal to the inner radius of the lower head hemispherical shell (which is also equal to the inner radius of the cylindrical reactor vessel); for all other rings, it should match the value implied by entry ASCELA on input record CORRii01.

- (1) IRS - Starting ring number. This field must be set to 1 on the first lower head record, and must be equal to IRE+1 from the preceding lower head record for each succeeding lower head record.
(type = integer, default = none, units = none)
- (2) IRE - Ending ring number. Must be input equal to IRS. The option of defining more than one ring at a time is not currently available, but the input is retained for possible future expansion.
(type = integer, default = none, units = none)

- (3) TLH - Initial temperature of lower head nodes in radial ring ii.
(type = real, default = none, units = K)
- (4) RADLH - Outer radius of radial ring ii, used to calculate the surface area and inclination angle for the lower head.
(type = real, default = none, units = m)
- (5) ICVCAV - Reactor cavity control volume number. This field need only be input for the first lower head record.
(type = integer, default = none)

CORLHNnn – Lower Head Nodalization Record

$1 \leq nn \leq NLH-1$, nn is a sequencing identifier for the lower head mesh layers

Optional

These optional records are used to define the mesh nodalization and composition in the lower head. If these records are absent, the lower head will consist of NLH-1 mesh layers of carbon steel, which are all of thickness $DZLH/(NLH-1)$. If these records are included, then all the lower head mesh layers (from 1 to NLH-1) must be described beginning from the inner surface of the lower head to the outer surface. Each record contains one or more data pairs describing an individual mesh layer, and there must be a total of NLH-1 data pairs included. The final value of DZLP must be equal to DZLH from record COR00001. If a material defined by these records is not included in the Materials Properties (MP) package data base or if the MP data base does not contain all of the required properties for a default material, then the user must provide MP input for the required properties, which are: thermal conductivity, specific heat, density, enthalpy vs. temperature, temperature vs. enthalpy, melt temperature and latent heat of fusion for the material. For a description on how these parameters are used in the lower head model, see the COR Package Reference Manual, Section 4.1. Each data pair consists of:

- (1) MATNAM - Material name from the MP package data base or a user-defined material.
(type = character*24, default = none, units = none)
- (2) DZLP - Distance from inner surface of lower head to outer boundary of this particular mesh layer. The last value of DZLP must be equal to DZLH from record COR00001.
(type = real, default = none, units = m)

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CORPENnn – Lower Head Penetration Record

$01 \leq nn \leq NPNTOT$, nn is the penetration number

Required if $NPNTOT > 0$

This record specifies information for representative lower head penetration nn. For a description on how these parameters are used in the lower head model, see the COR Package Reference Manual, Sections 5.1 and 5.2. This record must be input for each representative penetration from 1 to NPNTOT (input on record COR00000). No more than three penetrations may be defined in any radial ring. This is sufficient to define distinct models for instrumentation tubes, control rod guide tubes, and drain plugs. If the first field specifies a valid reference penetration, only the second field, specifying the radial ring number, will be processed. If the first field does not specify a valid reference penetration, all the remaining fields must be present. Total values for all structures represented by this penetration should be supplied.

- (1) IPNREF - Reference penetration number. IPNREF must be less than nn. Enter -1 if no reference penetration is needed.
(type = integer, default = none, units = none)
- (2) IRP - Radial ring where this representative penetration is located. The value of IRP on this record must be greater than or equal to the value of IRP entered on the previous penetration record.
(type = integer, default = none, units = none)
- (3) XMPN - Total mass of structures represented by this penetration.
(type = real, default = none, units = kg)
- (4) TPN - Initial temperature of representative penetration.
(type = real, default = none, units = K)
- (5) ASPN - Total surface area of structures represented by this penetration, based on the height DZ of the bottom axial level. The area of contact with debris is calculated from ASPN based on the debris height.
(type = real, default = none, units = m²)
- (6) AXPN - Total effective conduction area of structures represented by this penetration at junction with the lower head, used to control heat transfer between head and penetration.
(type = real, default = none, units = m²)

- (7) DFLPN - Initial diameter of failure opening for ejection of molten core materials (may represent single or multiple tube failures).
(type = real, default = none, units = m)

2.6 MELGEN COR Material Input

CORMATx – Core Material Specification Record

x can be any alphanumeric character

Optional

The materials to be used for “control rod poison” and “electric heater rod material” may be specified on the COR00002 input record. These optional records allow the user to redefine the properties to be used for other materials in the COR package. Only the thermal equation of state (including melting point and heat of fusion), density, thermal conductivity, and—for steel—composition will be used. The intention is to allow redefinition of properties without affecting the properties of default materials that may be used in other packages, particularly in HS. Substitution of materials will have no effect on chemical properties assumed for the materials in the oxidation or eutectics models or on any properties used for them in the FDI or CAV packages.

- (1) CORMAT - Identifier for “material” in the COR package. Permitted values are ‘UO2’, ‘ZR’, ‘ZRO2’, ‘SS’, and ‘SSOX’.
(type = character*2, default = none, units = none)
- (2) MATNAM - Material name from the MP package data base or a user-defined material whose properties are to be used for the designated COR material.
(type = character*24, default = none, units = none)

In the absence of input on CORMATx records, the properties used will be those of default materials in the MP package: ‘URANIUM DIOXIDE’ for ‘UO2’, ‘ZIRCALOY’ for ‘ZR’, ‘ZIRCONIUM DIOXIDE’ for ‘ZRO2’, ‘STAINLESS STEEL’ for ‘SS’, and ‘STAINLESS STEEL OXIDE’ for ‘SSOX’.

2.7 MELGEN CVH Fluid Flow Interface Input

CORTINxx – Inlet Temperature Specification Record

xx can be anything

Permitted only if IDTDZ = 1 on record COR00006.

If IDTDZ = 1:

Required for top and bottom volumes containing core cells

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Optional for all other control volumes

This record allows the user to specify an inlet temperature boundary condition for the dT/dz model that differs from the default modeling. For details on this model, see the COR Package Reference Manual, Section 2.5. If IDTDZ = 1 on record COR00006, a CORTIN record is required for every hydrodynamic control volume that 1) contains the lowest or highest axial core cells or 2) is directly above or below a control volume in which dT/dz calculations are disabled by some other CORTIN record. The record is optional for all other control volumes containing core cells.

- (1) IVOL - Core control volume number.
(type = integer, default = none, units = none)
- (2) ITUP - Inlet temperature specification for volume IVOL for upflow.
= 0 Use exit temperature for next lower control volume. (This is the default for all volumes not appearing on CORTIN records.)
= 1000 Disable dT/dz model for this volume
= 2000 Use the model employed for IDTDZ = 0. (Must also specify ITDN = 2000.)
> 0 Use temperature of volume ITUP ≤ 999.
< 0 Use value of control function -ITUP ≤ 999.
(type = integer, default = 0, units = none)
- (3) ITDN - Inlet temperature specification for volume IVOL for downflow.
= 0 Use exit temperature for next higher control volume. (This is the default for all volumes not appearing on CORTIN records.)
Other options are the same as for ITUP.
(type = integer, default = 0, units = none)

CORVOLxxx – Ring Flow Area Control Functions

xxx can be any three digit integer

Optional

This optional record identifies the control functions (ICFVOL) that may be used in the COR oxidation model to define the flow areas associated with each COR ring within CVH volumes interfaced with the COR package. The ring flow areas are used solely to allocate steam and oxygen from the CVH volumes to the various rings modeled by the COR package.

As specified on input record COR00000, the core is partitioned into NRAD rings, and interfaced with NCVOL CVH volumes. Each CORVOLxxx record defines

NRAD control functions for a single identified control volume. There may be as many as NCVOL such records, each containing NRAD+1 entries:

(1) IVOL- - The CVH control volume number for which the control functions on this record apply.
(type = integer, default = none, units = none)

(2) ICFVOL(1) - The number of the REAL control function from which the unblocked flow area of ring 1 is to be obtained.
(type = integer, default = none, units = none)

(3) ICFVOL(2) - The number of the REAL control function from which the unblocked flow area of ring 2 is to be obtained.
(type = integer, default = none, units = none)

ICFVOL(NRAD+1) - The number of the REAL control function from which the unblocked flow area of ring NRAD is to be obtained.
(type = integer, default = none, units = none)

The default calculation of unblocked flow area in any ring may be retained by entering 0 in the corresponding field. An entry of 0 is required for the flow area of any core ring with which volume ICFVOL does not interface. (In general, a core CVH control volume need not be interfaced with all rings of the core.)

2.8 MELCOR Input

Records COR00003 through COR00005, COR00007 through COR00009, and record COR00012 described in Section 2.1 may also be included in MELCOR input for any restart. These records input basic modeling parameters for the COR package and it is desirable to have the capacity to vary these parameters for testing purposes and perhaps some sensitivity analyses. However, the user should be aware that changing these parameters in the middle of a calculation could lead to nonphysical results.

Additional records that may be input for the COR package for a MELCOR restart run are concerned with time step control, package edit control, and physics module disabling, and are described below.

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CORDTC01 – COR Package Time Step Control Record Optional

This record allows the user to specify certain quantities needed to control the COR package internal time step. This record is not required, but if included, two floating point fields and one integer field must be present.

- (1) DTMPER - Maximum allowed temperature increase of a component during a COR package time step. This maximum is applied only to components with total mass greater than the minimum specified in sensitivity coefficient array 1502.
(type = real, default = 30.0, units = K)
- (2) DTCMIN - Minimum COR package time step allowed.
(type = real, default = 0.001, units = s)
- (3) NSUBMX - Maximum number of COR package subcycles during a single system cycle.
(type = integer, default = 64, units = none)

COREDVO1 – Edit Flags Record Optional

This record specifies edit flags which allow the user to control what variables from the COR package are edited to the print output file. This record is not required, and if present, any number of flags may be present, up to 6. The flag for a particular edit block should be set to 1 if printing of that block is desired, and to 0 if not.

- (1) ITEMP - Temperature edit flag.
(type = integer, default = 1, units = none)
- (2) IMASS - Mass edit flag.
(type = integer, default = 1, units = none)
- (3) IVOL - Volume edit flag.
(type = integer, default = 0, units = none)
- (4) IASUR - Surface area edit flag
(type = integer, default = 0, units = none)
- (5) IPMV - Component masses and volume fractions plot flag
(type = integer, default = 0, units = none)

- (6) IPOW - Decay heat/fission power edit flag
(type = integer, default = 0, units = none)

CORTST01 – Physics On/Off Switches

Optional

This record specifies switches that allow the user to disable portions of the COR package physics for purposes of debugging or testing of new physics modules. This record is not required, and any number of integer fields may be present, up to 10. Set these switches to 1 to disable a particular model, and to 0 to re-enable.

- (1) IRAD - Disable switch for radiation model, including radiation to steam, (regardless of the value of switch number 8).
(type = integer, default = 0, units = none)
- (2) ICND - Disable switch for conduction model.
(type = integer, default = 0, units = none)
- (3) ICNV - Disable switch for convection model.
(type = integer, default = 0, units = none)
- (4) IOXD - Disable switch for all oxidation models, including the B₄C reaction (regardless of the value of switch number 7).
(type = integer, default = 0, units = none)

NOTE: There are two oxidation options: the default option for hierarchical treatment in which steam oxidation does not begin until all oxygen has been consumed, and an option for treating oxidation by oxygen and steam simultaneously. Furthermore, oxidation of the conglomerate debris may be deactivated without deactivating the oxidation of intact components. The following values of IOXD may be specified:

- 0 - (default) hierarchical option for both intact components and conglomerate debris,
- 1 - no oxidation of either intact components or conglomerate debris,
- 2 - hierarchical option for intact components with no conglomerate debris oxidation,
- 3 - simultaneous option for both intact components and conglomerate debris, and
- 4 - simultaneous option for intact components with no conglomerate debris oxidation.

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- (5) IDRП - Disable switch for candling model
(type = integer, default = 0, units = none)
- NOTE: A value of IDRП=1 completely disables the candling model while a value of IDRП=2 disables only the melt holdup model.
- (6) ITDZ - Disable switch for core dT/dz model.
(type = integer, default = 0, units = none)
- (7) IB4C - Disable switch for B₄C reaction model, if not already disabled by switch 4.
(type = integer, default = 0, units = none)
- (8) IRDS - Disable switch for radiation to steam model, if not already disabled by switch 1.
(type = integer, default = 0, units = none)
- (9) IDEJ - Disable switch for solid debris ejection model.
(type = integer, default = 0, units = none)
- (10) ISPR - Disable switch for radial relocation model.
(type = integer, default = 0, units = none)
- NOTE: A value of ISPR=1 disables only the molten material radial relocation; a value of ISPR=2 disables only the particulate debris radial relocation model; and a value of ISPR=3 disables both radial relocation models.

2.9 Required Input to Other MELCOR Packages

Many of the models in the COR package require that it interface with other MELCOR packages. Thus, in order for the COR package to function properly, input may be required in other packages to complete these interfaces. This section outlines these input requirements for the Control Volume Hydrodynamics (CVH), Flow Path (FL), NonCondensable Gas (NCG), Control Function (CF), Decay Heat (DCH), Radionuclide (RN) and Heat Structure (HS) packages. The user is referred to the appropriate Users' Guides and Reference Manuals for further details regarding these packages.

2.9.1 CVH, FL, and NCG Input

The COR package models heat transfer between core structures and the liquids and/or gases which flow through the core. These flows are modeled by the CVH and FL packages. The user must specify a control volume for the coolant channel (and for the bypass for BWRs) in each core cell in order for that cell to communicate heat transfer

information. This is done through COR input records CORijj01, as described in Section 0. Each control volume referenced on these records must be defined in the CVH input. The control volumes must be interconnected by flow paths that are defined through input to FL. COR only checks that each control volume referenced by COR input exists. The user is responsible for providing CVH and FL input that is reasonable, logical, and above all, consistent with the physical realities of the core geometry to be modeled.

Some degree of consistency is required between the distribution of fluid volumes implied by input to COR and CVH. The specific requirement is that the initial total fluid volume in COR lying within any Volume/Altitude segment of a CVH control volume cannot exceed the fluid volume in that V/A segment, so that filling the entire fluid volume in COR with debris cannot overflow CVH. This requirement is new in MELCOR 1.8.5. See section 1.5.3 for suggestions on revising old input decks to comply.

Another COR input, which is found on record CORTINxx, is indirectly related to CVH and FL in that it is used to determine the inlet temperature to the core whenever the dT/dz model is used to estimate local hydrodynamic temperatures within the core. The user must ensure that any control volume or control function referenced by these records exists in the CVH or CF input.

If the user desires to perform detailed natural circulation calculations using the CVH and FL packages, one CVH control volume should be specified for a relatively small number of core cells (perhaps only one cell per volume). The core flow blockage and momentum flux models should be enabled for all flow paths involving core cells, as described in the Flow Path Package Users' Guide (input records FLnnnBk and FLnnnMk). Note that new blockage options, including a channel box model, are available in MELCOR 1.8.5. The dT/dz model should not be disabled in these flowpaths. Radial flow paths may be used in PWRs, and channel-to-bypass flow paths in BWRs. There will probably be some penalty in increased CPU time resulting from the need to invert a substantially larger flow matrix. However, use of the blockage model has been found to largely eliminate the further penalty that would otherwise be associated with reduced material Courant time step limits when control volumes are almost completely filled with core debris.

Hydrogen and carbon monoxide must be specified as active materials in the NCG package whenever the COR package is active due to the generation of these gases in the COR oxidation models. In addition, for calculations with B₄C used as the control poison material, the gases O₂, CO₂ and CH₄ must also be specified as active materials via NCG input, since they are produced by the B₄C reaction model.

2.9.2 DCH and RN Input

The COR package distributes the decay heat generated by the fission products and, if applicable, the fission energy, to the core components. The properties of the time-dependent decay heat distribution are specified through input to both the DCH and RN

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packages. The fission power is specified in the COR package through the use of a control function.

The total core decay heat is set up through input to the DCH package. In general, the user specifies the type of reactor to be modeled, the problem time at which the reactor shut down, the power level at which the reactor was operating, and the type of decay heat correlation to be used.

The decay heat is distributed among the core cells in different ways depending on whether or not the RN package is active. If the RN package is not active, the energy is distributed along with any fission power according to the axial and radial power density profiles specified on records CORZjj03 and CORRii03, respectively.

When the RN package is active, the decay heat is distributed throughout MELCOR in proportion to the radionuclide distribution as determined by the RN package. The user must specify the initial distribution of radionuclides to RN through the use of the RN package input records described in Section 3.1.2 of the RN Package Users' Guide. If these records are not used, no decay heat whatsoever may be passed to the core.

In Anticipated Transient Without SCRAM (ATWS) calculations or other problems involving fission heating, whole-core fission power may be calculated using a control function specified on record COR00004, which must be set up through input to the CF package. The power is distributed (and added to decay heat) in the COR package according to the axial and radial power density profiles specified on records CORZjj03 and CORRii03, respectively.

Furthermore, if the advanced B₄C reaction model is invoked, seven additional Radionuclide (RN) package classes must be defined to treat the additional reaction products generated by the model (see example input in Section 5.1).

2.9.3 HS Input

The COR package requires boundary heat structures to be specified in order to calculate the energy radiated from the COR cells. These heat structures must be set up through appropriate input to HS, and their existence is checked by the COR package in MELGEN. For the dT/dz model to function properly, **there must be exactly one heat structure per axial level**; otherwise the effect of these heat structures on the control volume temperature distribution will not be treated correctly. Also, no other heat structures may communicate with the core and lower plenum control volumes other than those specified on the CORZjj02 input record. Furthermore, for the dT/dz model to function correctly and for the HS package to model the heat transfer appropriately, it is important that the heat structures representing the radial core boundary (e.g., core shroud) communicate with the temperatures calculated by the dT/dz model. The outer ring core cells must therefore be

specified as the fluid temperature boundary on input records HSCCCCC004 (see the HS Package Users' Guide) unless the IHSDT option switch provided on input record COR00006 has been set to 1.

Melting of these boundary heat structures may be modeled using HSDGCCCCCn input records. As any such structure melts, the molten steel will be added to core debris in the adjoining core cell. That cell is not specified directly as part of HS input, but is inferred from the elevation of the heat structure; structures above the top of the core deliver their steel to the outermost ring of the uppermost level of the core.

2.9.4 MP Input

The COR package obtains materials properties from the Materials Properties (MP) package. In addition to general consistency of the various tables and constant properties defining the thermal equation of state, the COR package assumes that the melting range of any pure material spans exactly 0.01K. This is true for all default materials in the MP package, as noted in the introductory paragraphs of Section 2 of the MP Reference Manual.

However, if the properties of a default material used by core are modified, or if a user-defined material is specified to represent a core material, it is essential that the 0.01 K melting range be preserved. A user-defined material may be input either as the electric heating element material, MATHT, on the COR00002 input record, or as a substitute for one of the other core materials, as MATNAM on a CORMATx input record.

3. Sensitivity Coefficients

This section lists the sensitivity coefficients in the COR package that are accessible to the user, along with a brief description, and gives their default values, units, and EQUIVALENCE names. Sensitivity coefficients in the COR package are grouped as follows:

- 1001 – 1299 oxidation and heat transfer parameters
- 1301 – 1399 fission power parameters
- 1401 – 1499 numerical control parameters
- 1501 – 1599 geometric parameters
- 1600 – 1699 lower-head mechanical model parameters

More details are given in the COR Package Reference Manual on the usage of these coefficients in the models where they are applied and the basis for their default values.

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3.1 Oxidation, Heat Transfer, and Relocation Parameters

1001 – Zircaloy Oxidation Rate Constant Coefficients

These coefficients are used to calculate the rate constant for oxidation of Zircaloy by parabolic kinetics. The rate constant K ($\text{kg}^2/\text{m}^4\text{-s}$) as a function of temperature T (K) is calculated by:

$$K(T) = C1001(1,I) \exp(-C1001(2,I)/T), T \leq C1001(5,I)$$

$$K(T) = C1001(3,I) \exp(-C1001(4,I)/T), T \geq C1001(6,I)$$

where $I=1$ for oxidation by H_2O and $I=2$ for oxidation by O_2 . An interpolated value is used in the temperature range $C1001(5,I) < T < C1001(6,I)$.

- (1, I) - low temperature range constant coefficient
(default = 29.6 for $I=1$, 50.4 for $I=2$; units = $\text{kg}^2(\text{Zr})/\text{m}^4\text{-s}$, equiv = none)
- (2, I) - low temperature range exponential constant
(default = 16820.0 for $I=1$, 14630.0 for $I=2$; units = K, equiv = none)
- (3, I) - high temperature range constant coefficient
(default = 87.9 for $I=1$, 0.0 for $I=2$; units = $\text{kg}^2(\text{Zr})/\text{m}^4\text{-s}$, equiv = none)
- (4, I) - high temperature range exponential constant
(default = 16610.0 for $I=1$, 0.0 for $I=2$; units = K, equiv = none)
- (5, I) - upper temperature boundary for low temperature range
(default = 1853.0 for $I=1$, 10000.0 for $I=2$; units = K, equiv = none)
- (6, I) - lower temperature boundary for high temperature range
(default = 1873.0 for $I=1$, 10000.0 for $I=2$; units = K, equiv = none)

1002 – Steel Oxidation Rate Constant Coefficients

These coefficients are used to calculate the rate constant for oxidation of steel by parabolic kinetics. The rate constant K ($\text{kg}^2/\text{m}^4\text{-s}$) as a function of temperature T (K) is calculated by:

$$K(T) = C1002(1,I) \exp[-C1002(2,I)/T]$$

where $l=1$ for oxidation by H_2O and $l=2$ for oxidation by O_2 . No oxidation of steel by O_2 is calculated.

- (1, l) - constant coefficient
(default = 2.42E09 for $l=1$, 0.0 for $l=2$; units = $kg^2(\text{steel})/m^4\text{-s}$, equiv = none)
- (2, l) - exponential constant
(default = 4.24E04 for $l=1$, 0.0 for $l=2$; units = K, equiv = none)

1003 – Gaseous Diffusion Oxidation Coefficients

These coefficients are used to calculate the oxidation rate for Zircaloy and steel based on the gaseous diffusion of steam through hydrogen to the metal surface. The following equation gives the oxidation rate W (kg/s) in terms of the mass transfer coefficient k_c (m/s), the metal surface area A (m^2), the difference in oxidant partial pressure between the bulk gas and the surface ΔP_{ox} (Pa), the film temperature T_f (K), and the sensitivity coefficient C1003(m):

$$W = k_c A \Delta P_{ox} C1003(m) / T_f,$$

where C1003(m) is defined in terms of the universal gas constant R , the molecular weight of the metal M_m , and the number of moles of steam to oxidize one mole of metal n_m :

$$C1003(m) = M_m / (n_m \cdot R)$$

The default values may be changed to selectively increase or decrease the gaseous diffusion based oxidation rate.

- (1) - Zircaloy constant.
(default = 0.00548, units = $kg(\text{Zr})\text{-K}/\text{Pa}\text{-m}^3$, equiv = none)
- (2) - Steel constant.
(default = 0.00504, units = $kg(\text{steel})\text{-K}/\text{Pa}\text{-m}^3$, equiv = none)

1004 – Oxidation Cutoff Temperatures

These coefficients are used to prevent Zircaloy and steel oxidation below or above certain temperatures. The lower cutoff temperature prevents oxidation at temperatures that generate only minute quantities of noncondensable gases. The

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upper cutoff temperature can be used to limit the amount of oxidation for sensitivity analyses.

- (1) - Minimum oxidation temperature
(default = 1100.0, units = K, equiv = none)
- (2) - Maximum oxidation temperature
(default = 9900.0, units = K, equiv = none)

1005 – B₄C Reaction Model Parameters

These coefficients are used to select and control the simple or advanced B₄C reaction model. If reducing environments are expected (significant hydrogen concentrations), then the advanced model should be selected and the user should refer to Section 5.1 for an example of the additional required RN and DCH input.

- (1) - Model selection switch (0./1. for simple/advanced model)
(default = 0.0, units = none, equiv = none)
- (2) - Maximum B₄C fraction that may be consumed by the reaction model
(default = 0.02, units = none, equiv = none)
- (3) - Intact steel failure fraction. The B₄C reaction cannot begin until the ratio of the intact steel mass to its initial value falls below this fraction.
(default = 0.9, units = none, equiv = none)
- (4) - Reaction threshold temperature. The B₄C temperature must exceed this value or the reaction cannot proceed.
(default = 1500., units = K, equiv = none)

1006 – B₄C Reaction Rate Parameters

These coefficients are used to control the reaction rate of B₄C. The fractional reaction rate (per second) is given by

$$\frac{d(M/M_o)}{dt} = C1006(1) \exp\left(\frac{-C1006(2)}{T}\right)$$

where M_o is the initial mass of the B₄C and M and T are the current mass and temperature of the B₄C, respectively.

- (1) - Leading coefficient
(default = 1.662E5, units = s⁻¹, equiv = none)

- (2) - Exponent
(default = 2.26472E4, units = K, equiv = none)

1007 – Ring Minimum Flow Area Fractions

These coefficients establish the minimum flow area fractions to be used in the oxidation model to allocate steam and oxygen from the core CVH control volumes to the various rings associated with the control volumes. If the fraction of the CVH volume flow associated with a ring in a control volume falls below the minimum given by the corresponding element of C1007, the ring is assumed to be blocked for oxidation purposes and is assigned that minimum fraction of the oxidizer inventory. The remaining unassigned flow is divided among the unblocked rings (if there are any). If the sum over the NRAD rings in the core exceeds inventory, an error message will be printed and MELGEN/MELCOR execution terminated.

The minimum fractions may be assigned differently for the channel and bypass volumes in a BWR (when those volumes are distinguished in user input).

- (IR,1) - Minimum flow area fraction for the channel-side portion of ring IR ($1 \leq IR \leq NRAD$)
[default=0.0, units=none, equiv=ACHNNL(IR)]
- (IR,2) - Minimum flow area fraction for the bypass-side portion of ring IR ($1 \leq IR \leq NRAD$)
[default=0.0, units=none, equiv=ABYPAS(IR)]

1010 – Material Dissolution Rate Coefficients

These coefficients are used to limit the rate of dissolution of materials by parabolic kinetics. If the coefficients are defined for material j, then the mass fraction of that material in a mixture at the end of the time step cannot exceed

$$XF_j^2 = XI_j^2 + K_j \Delta t$$

where

- K_j = C1010(1,j) exp(-C1010(2,j)/T)
= dissolution constant for material j
- XF_j = final mass fraction of material j in the mixture
- XI_j = initial mass fraction of material j in the mixture
- Δt = time step size
- T = temperature (K)

j	solid	C1010(1,j) (unit = none)	C1010(2,j) (units = K)
1	Zr	-1.0(undefined)	0.0 (undefined)
2	ZrO ₂	1.47e14	8.01e04
3	UO ₂	1.02e15	8.14e04
4	steel	-1.0	0.0
5	steel oxide	-1.0	0.0
6	control poison	-1.0	0.0
7	Inconel	-1.0	0.0

1011 – Eutectic Reaction Temperatures

These coefficients are used to define the temperature at which the rate of eutectic reaction between two contacting solids is sufficiently high to cause significant liquefaction on a time scale of interest. For example, although the Zircaloy-Inconel eutectic reaction may begin as low as 1200 K, the rate of reaction is insignificant until the temperature reaches about 1400 K.

- (1) - Zircaloy-Inconel eutectic temperature
(default = 1400.0, units = K, equiv = TZRINC)
- (2) - Zircaloy-steel eutectic temperature
(default = 1400.0, units = K, equiv = TZRSS)
- (3) - Steel-B4C eutectic temperature
(default = 1520.0, units = K, equiv = TSSB4C)

1020 – Radial Relocation Model Parameters

These parameters control the operation of the routines that relocate both molten material and solid particulate debris from ring to ring.

- (1) - Time constant for the relocation of solid material
(default = 360.0 [note that significant changes in the default value have occurred], units = s, equiv = TSPRS)
- (2) - Time constant for the relocation of molten material
(default = 60.0 [note that significant changes in the default value have occurred], units = s, equiv = TSPRM)

- (3) - Lower head curvature bias for solid material (currently unused)
(default = 0.0, units = none, equiv = FDIPS)
- (4) - Lower head curvature bias for molten material (currently unused)
(default = 0.0, units = none, equiv = FDIPM)
- (5) - Fraction of cell CVH volume that is available for radial relocation
(default = 1.0, units = none, equiv = CVHFAC)

1021 – Channel-Bypass Relocation Time Constant

This parameter controls the rate of relocation of debris (molten and solid) between the channel and bypass of a BWR after failure of the canisters.

- (1) - Time constant for the relocation of debris
(default = 1.0, units = s, equiv = TSPCB)

1030 – dT/dz Model Parameters

These coefficients are associated with the dT/dz model.

- (1) - Option switch; if nonzero, the treatment reverts to that used in MELCOR 1.8.3 (and earlier versions) where the possibility of down flow was not considered.
(default = 0.0, units = none, equiv = none.)
- (2) - Time constant for averaging flows. The smoothed flows are also used in determining the flow direction if C1030(1) is zero.
(default = 10.0, units = s, equiv = TRLXZ)
- (3) - Time constant for relaxing the dT/dz temperatures towards the CVH volume temperature when the dT/dz model is disabled.
(default = 1.0, units = s, equiv = TRLXT)

1101 – Fuel-Cladding Gap Emissivities

These coefficients define the fuel and cladding surface emissivities.

- (1) - Fuel surface emissivity
(default = 0.8, units = none, equiv = EMISF)
- (2) - Cladding inner surface emissivity
(default = 0.325, units = none, equiv = EMISC)

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1131 – Molten Material Holdup Parameters

These coefficients are used to define conditions for which molten material will be held up by an oxide shell. The defaults are currently set so that there is holdup. See the COR Package Reference Manual, Section 3.1, and Section 1.3 of this manual for details on the molten material holdup model.

- (1) - Minimum ZrO_2 thickness required to hold up molten Zr.
(default = 0.00001, units = m, equiv = DZXMN)
- (2) - Maximum ZrO_2 temperature permitted to hold up molten Zr.
(default = 2400.0, units = K, equiv = TZXXM)
- (3) - Minimum steel oxide thickness required to hold up molten steel.
(default = 0.001, units = m, equiv = DSXMN)
- (4) - Maximum steel oxide temperature permitted to hold up molten steel.
(default = 1700.0, units = K, equiv = TSXXM)

1132 – Core Component Failure Parameters

These coefficients define the temperatures used in extended failure criteria for fuel after the Zr has melted and candled [by virtue of exceeding the temperature specified by C1131(2)].

In older versions of MELCOR, fuel rods were converted to particulate debris when the remaining thickness of unoxidized Zircaloy in the cladding fell below the value set by DRCLMN on input record COR00008. MELCOR 1.8.4 and later versions allow oxidized rods to continue to stand until the temperature reaches TRDFAI. In MELCOR 1.8.4, the default value was 2800 K, the approximate temperature of the UO_2/ZrO_2 eutectic. While this may be appropriate for new fuel, evidence from Phebus suggests that 2500 K is more appropriate for irradiated fuel. The variable TRDMAX defines the absolute maximum temperature at which rods can stand, regardless of Zircaloy content or the value of TRDFAI; the default value is the approximate melting temperature of UO_2 . Refer to Section 1.3 of this manual for additional information.

- (1) - Temperature to which oxidized fuel rods can stand in the absence of unoxidized Zr in the cladding.
(default = 2500.0, units = K, equiv = TRDFAI)
- (2) - Temperature at which fuel rods will fail, regardless of composition of the cladding.
(default = 3100.0, units = K, equiv = TRDMAX)

1141 – Core Melt Breakthrough Candling Parameters

These coefficients are used to control the candling model when molten material has just been released after holdup by an oxide shell or by a flow blockage (crust). For this case, the quasi-steady assumptions regarding melt generation built into the candling model are not valid, so an alternate time step size (DTBRK below) is used, along with a maximum melt flow rate (GAMBRK), to eliminate dependencies on molten pool mass and time step size. See the COR Package Reference Manual, Section 3.1.3, for more complete details. The default values are currently chosen so that the model will be active only for large molten pools breaching a crust.

- (1) - Timestep size used in candling model for molten material releases immediately after breakthrough of an oxide shell or crust.
(default = 1.0, units = s, equiv = DTBRK)
- (2) - Maximum melt flow rate per unit width after breakthrough.
(default = 1.0, units = kg/m-s, equiv = GAMBRK)

1151 – Conglomerate Debris Surface Area Coefficients

These coefficients are used in the model that calculates the surface area of conglomerate debris and the portion of the intact component surface area that remains unblocked by the conglomerate debris. These areas are currently used only in the component oxidation models. See the COR Package Reference Manual, Section 3.1.6, for details. The components are, in order, FU, CL, CN, CB, OS, PD, SS, NS, and PB.

- (1,1) - Maximum surface area fraction for debris rivulets on component I.
[default = 0.556, units = none, equiv = FA1MAX(I)]
- (1,2) - Maximum surface area fraction for voids in debris for component I.
[default = 0.807, units = none, equiv = FA2MAX(I)]
- (1,3) - Fraction of interstitial volume corresponding to FA1MAX(I).
[default = 0.143, units = none, equiv = FV1MAX(I)]
- (1,4) - Fraction of interstitial volume corresponding to FA2MAX(I).
[default = 0.396, units = none, equiv = FV2MAX(I)]
- (1,5) - Minimum surface area fraction for debris for component I.
[default = 0.0, units = none, equiv = FAMIN(I)]

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- (I,6) - Maximum fraction of intact surface area blocked.
(default = 1.0 for CL, PD, and PB, I=2, 6, and 9, 0.0 otherwise; units = none, equiv = FBMAX)
- (I,7) - Surface-to-volume ratio for debris not in interstitial volume.
(default = 100.0, units = 1/m, equiv = SVRX)

1152 – Surface to Volume Ratio for Fluid

This coefficient is used to limit the surface area for heat transfer from COR to CVH when the core is blocked and the fluid volume is very small.

- (1) - Maximum surface-to-volume ratio for fluid, defining upper bound on heat transfer area for COR surfaces.
(default = 1000., units = m^{-1} , equiv = SVRFLU)

1200 – Smoothing of Heat Transfer Coefficients

The values of heat transfer coefficients calculated from appropriate correlations for heat transfer between the surfaces of COR components and the surrounding atmosphere and/or pool are averaged with the values from previous timesteps using

$$h_{new} = f_{old} h_{old} + (1 - f_{old}) h_{calc}$$

to reduce numerical fluctuations. Different weightings of old and new are used for the atmosphere and the pool.

- (1) - Weight for old heat transfer to atmosphere.
(default = 0.5, units = none, equiv = none)
- (2) - Weight for old heat transfer to pool.
(default = 0.9, units = none, equiv = none)

1212 – Laminar Nusselt Numbers

These coefficients give the constant Nusselt number for various types of laminar forced convective flow.

- (1) - Nusselt number for fully developed flow in a circular tube with constant heat flux
(default = 4.36, units = none, equiv = none)

- (2) - Nusselt number for fully developed flow in a rod bundle
(default = 4.36, units = none, equiv = none)

1213 – Laminar Developing Flow

These coefficients are used to calculate a developing flow factor for laminar flow. The following equation gives the developing flow factor g in terms of the entrance length z , the equivalent diameter D , the Reynolds number Re , the Prandtl number Pr , and the sensitivity coefficients:

$$g = 1.0 + C1213(1)/([z/(DRePr)] + C1213(2))$$

- (1) - (default = 0.00826, units = none, equiv = none)
(2) - (default = 0.00110, units = none, equiv = none)

1214 – Turbulent Forced Convective Flow in Tubes

These coefficients are used to calculate the Nusselt number for forced convective flow in tubes, given by the following equation in terms of the Reynolds number Re and the Prandtl number Pr :

$$Nu = C1214(1)Re^{C1214(2)} Pr^{C1214(3)}$$

- (1) - constant coefficient
(default = 0.023, units = none, equiv = none)
(2) - Reynolds number exponent
(default = 0.8, units = none, equiv = none)
(3) - Prandtl number exponent
(default = 0.4, units = none, equiv = none)

1221 – Laminar Free Convection between Parallel Vertical Surfaces

These coefficients are used to calculate the Nusselt number for laminar free convection between parallel vertical surfaces. The following equation gives the Nusselt number Nu in terms of these coefficients and the Rayleigh number Ra , the height L , and the separation distance D :

$$Nu = C1221(1)Ra^{C1221(2)}(L/D)^{C1221(3)}$$

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- (1) - constant coefficient.
(default = 0.18, units = none, equiv = none)
- (2) - Rayleigh number exponent.
(default = 0.25, units = none, equiv = none)
- (3) - L/D exponent.
(default = -1./9., units = none, equiv = none)

1222 – Turbulent Free Convection between Parallel Vertical Surfaces

These coefficients are used to calculate the Nusselt number for turbulent free convection between parallel vertical surfaces. The following equation gives the Nusselt number Nu in terms of these coefficients and the Rayleigh number Ra , the height L , and the separation distance D :

$$Nu = C1222(1)Ra^{C1222(2)}(L/D)^{C1222(3)}$$

- (1) - Constant coefficient.
(default = 0.065, units = none, equiv = none)
- (2) - Rayleigh number exponent.
(default = 1./3., units = none, equiv = none)
- (3) - L/D exponent.
(default = -1./9., units = none, equiv = none)

1231 – Forced Convective Flow over a Spherical Particle

These coefficients are used to calculate the Nusselt number for forced convective flow over a single spherical particle. The following equation gives the Nusselt number Nu in terms of the Reynolds number Re and the Prandtl number Pr .

$$Nu = C1231(1) + C1231(2)Re^{C1231(3)}Pr^{C1231(4)}$$

- (1) - additive constant (Stokes flow limit)
(default = 2.0, units = none, equiv = none)
- (2) - constant coefficient
(default = 0.60, units = none, equiv = none)

- (3) - Reynolds number exponent
(default = 0.5, units = none, equiv = none)
- (4) - Prandtl number exponent
(default = 1./3., units = none, equiv = none)

1232 – Free Convective Flow over a Spherical Particle

These coefficients are used to calculate the Nusselt number for free convective flow over a single spherical particle. The following equation gives the Nusselt number Nu in terms of the Grashof number Gr and the Prandtl number Pr .

$$Nu = C1232(1) + C1232(2)Gr^{C1232(3)} Pr^{C1232(4)}$$

- (1) - additive constant (Stokes flow limit)
(default = 2.0, units = none, equiv = none)
- (2) - constant coefficient
(default = 0.60, units = none, equiv = none)
- (3) - Grashof number exponent
(default = 0.25, units = none, equiv = none)
- (4) - Prandtl number exponent
(default = 1./3., units = none, equiv = none)

By default, boiling heat transfer in the the COR package will be calculated using correlations from the HS package (see the HS Reference Manual). If C1241(5) is nonzero, the simplified correlations from the MARCH 2.0 code, specified by sensitivity coefficient arrays C1241 and C1242, will be used instead. In either case, the CHF temperature difference specified by C1241(4) will be used to determine whether debris in the core or lower head is quenched.

1241 – Simplified Nucleate Boiling Curve

If C1241(5) is nonzero, these coefficients are used to calculate a simplified nucleate boiling curve for pool boiling. The following equation gives the heat transfer coefficient h ($W/m^2 - K$) in terms of the pressure P (Pa), the temperature difference ΔT (K), and these coefficients:

$$h = C1241(1)P^{C1241(2)}\Delta T^{C1241(3)}, \Delta T < C1241(4)$$

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- (1) - Constant coefficient.
(default = 34.5, units = $W/m^2-K-Pa^{0.25}-K^{1.523}$, equiv = none)
- (2) - Pressure exponent.
(default = 0.25, units = none, equiv = none)
- (3) - Temperature difference exponent.
(default = 1.523, units = none, equiv = none)
- (4) - CHF temperature difference.
(default = 23.4, units = K, equiv = none)
- (5) - Option switch, nonzero to specify use of the simplified MARCH 2.0 model rather than correlations from the HS package.
(default = 0.0, units = none, equiv = none)

1242 – Simplified Transition Film Boiling Curve

If C1241(5) is nonzero, these coefficients are used to calculate a simplified transition boiling curve for pool boiling. The following equation gives the heat transfer coefficient h ($W/m^2 - K$) in terms of the pressure P (Pa), the temperature difference ΔT (K), and these coefficients:

$$h = C1242(1)P^{C1242(2)}\Delta T^{C1242(3)}, \Delta T \geq C1241(4)$$

- (1) - Constant coefficient.
(default = 1.41E07, units = $W/m^2-K-Pa^{0.25}-K^{-2.575}$, equiv = none)
- (2) - Pressure exponent.
(default = 0.25, units = none, equiv = none)
- (3) - Temperature difference exponent.
(default = -2.575, units = none, equiv = none)

1244 – Debris Dryout Heat Flux Correlation

These coefficients are used to calculate the dryout heat flux for particulate debris beds using the zero-dimensional Lipinski turbulent correlation, given in Section 2.3.7 of the COR Package Reference Manual.

- (1) - Leading coefficient
(default = 0.756, units = none, equiv = none)

- (2) - Capillary head for water and 0.5 mm particles
(default = 0.089, units = m, equiv = ZCAP)
- (3) - Minimum debris porosity allowed
(default = 0.15, units = none, equiv = none)

1245 – Downward-Facing Lower Head Heat Transfer Correlations

These coefficients are used to calculate downward heat transfer from the lower head to water in the reactor cavity. The critical heat flux as a function of the inclination of the surface ($\theta = 0^\circ$ for downward-facing surfaces) is given by

$$q_{CHF} = [C1245(1) + C1245(2) \cdot \theta^{C1245(3)}] (\rho_v)^{0.5} h_v [g\sigma(\rho_l - \rho_v)]^{0.25}$$

where ρ_l and ρ_v are the densities of water and steam, respectively, σ is the interfacial surface tension between steam and water, g is the acceleration of gravity and h_v is the latent heat of vaporization of water. The minimum heat flux at the beginning of stable film boiling is given by

$$q_{MIN} = [C1245(4) + C1245(5) \cdot \theta^{C1234(6)}] (\rho_v)^{0.5} h_v [g\sigma(\rho_l - \rho_v)]^{0.25}$$

and the film-boiling heat transfer coefficient is given by

$$h_{FLM} = f(\theta) k_v [h_v \rho_v g (\rho_l - \rho_v) / (\mu_v K_v \Delta T)]^{1/3}$$

where k_v is the thermal conductivity of steam, μ_v is the viscosity of steam and $\Delta T = T_{SURF} - T_{SAT}$ is the difference between the surface temperature and the saturation temperature and $f(\theta)$ gives the angular dependence. There are two options for calculating $f(\theta)$. If $C1245(7)=0.$, then $f(\theta)$ is given by

$$f(\theta) = C1245(8)(\sin \theta)^{C1245(9)}$$

otherwise, it is given by

$$f(\theta) = C1245(10) + C1245(11) \cdot \theta^{C1245(12)}$$

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Details of the model are given in Section 5.1 of the COR Package Reference Manual.

- (1) - Additive constant in q_{CHF} correlation
(default = 0.034, units = none, equiv = none)
- (2) - Multiplicative constant in q_{CHF} correlation
(default = 0.0037, units = none, equiv = none)
- (3) - Exponent of θ in q_{CHF} correlation
(default = 0.656, units = none, equiv = none)
- (4) - Additive constant in q_{MIN} correlation
(default = 4.8E-4, units = none, equiv = none)
- (5) - Multiplicative constant in q_{MIN} correlation
(default = 8.2E-4, units = none, equiv = none)
- (6) - Exponent of θ in q_{MIN} correlation
(default = 0.407, units = none, equiv = none)
- (7) - Film-boiling heat transfer coefficient correlation selection switch
(default = 0., units = none, equiv = none)
- (8) - Multiplicative constant in default film-boiling correlation
(default = 0.142, units = none, equiv = none)
- (9) - Exponent of $\sin \theta$ dependence in default film-boiling correlation
(default = 0.3333333, units = none, equiv = none)
- (10) - Additive constant in optional film-boiling correlation
(default = 0.055, units = none, equiv = none)
- (11) - Multiplicative constant in optional film-boiling correlation
(default = 0.016, units = none, equiv = none)
- (12) - Exponent of θ in optional film-boiling correlation
(default = 0.5, units = none, equiv = none)

1246 – Heat Transfer Coefficient, Lower Head to Atmosphere

This coefficient defines that heat transfer coefficient between the lower head and the atmosphere when the head is not completely covered by pool.

- (1) - Heat transfer coefficient to be used for that part of the lower head that is exposed to the atmosphere.
(default=10.0, units = W/m²K, equiv = HATCAV)

1250 – Conduction Enhancement for Molten Components

These coefficients are used to enhance heat transfer at high temperatures, where core debris is molten, to capture the qualitative effects of convection in molten pools. This is done by using an enhanced thermal conductivity in the normal model for conduction between pairs of core components. The enhancement factor is given by

$$Factor = \max\{1.0, C1250(2)[T_{max} - C1250(1)]^3\}$$

where T_{max} is the greater of the temperatures of the two components involved.

- (1) - Temperature above which enhancement is employed.
(default = 3200., units = K, equiv = TKMIN)
- (2) - Coefficient in enhancement.
(default = 0.01 units = K⁻¹, equiv = TKFAC)

3.2 Fission and Decay Power Parameters

1301 – Chexal-Layman Fission Power/Liquid Level Correlation

These coefficients define the constants in the Chexal-Layman fission power/liquid level correlation (described in Section 2.6 of the COR Package Reference Manual), given by the equations:

$$QFRAC = C1301(1)(CUNIT1 \cdot H_r)^{C1301(3)} [(P / C1301(6))^{C1301(2)} (H / H_r)^{C1301(3)}$$

and

$$H = \max(0.0, \{L + C1301(4)[P / C1301(6)]^{C1301(5)}\})$$

where QFRAC is the fraction of full operating power, P is the pressure, L is the height of the downcomer water relative to the top of active fuel, H_r is an arbitrary reference height (selected as 1 m) inserted in the correlation to render it nondimensional in form, and CUNIT1 is a dimensional constant embedded in the code equal to 3.28084 m⁻¹.

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- (1) - Multiplicative constant
(default = 3.7E-02, units = none, equiv = none)
- (2) - Pressure exponent
(default = 0.3, units = none, equiv = none)
- (3) - Liquid level exponent
(default = 0.7, units = none, equiv = none)
- (4) - Zero power liquid level
(default = 2.4384, units = m, equiv = none)
- (5) - Pressure exponent for zero power liquid level
(default = 0.45, units = none, equiv = none)
- (6) - Reference pressure
(default = 7.65318E06, units = Pa, equiv = none)

1311 – Material Fission Power Absorption Efficiencies

These coefficients specify the relative absorption efficiencies of fission power by the core materials. Zr and ZrO₂ are lumped together, as is steel with steel oxide, and Inconel associated with clad is not distinguished from Zr. The coefficients are used in conjunction with coefficients in array 1312 to distribute the fraction 1.0-C1312(1) of the fission power that “escapes” the UO₂ fuel component (i.e., gammas), and are applied only to materials in “active” components, as defined by the remainder of sensitivity coefficient array 1312. The default values differ for BWRs and PWRs. Note that if values for PWRs are modified in MELGEN, the output will print BWR values as the “old” values.

- (1) - UO₂ efficiency.
[default = 0.735 BWR, or 0.5 PWR, units = none, equiv = FEFF(1)]
- (2) - Zr + ZrO₂ efficiency.
[default = 0.4 BWR, or 0.541 PWR, units = none, equiv = FEFF(2)]
- (3) - Steel + steel oxide efficiency.
[default = 0.292 BWR, or 0.565 PWR, units = none, equiv = FEFF(3)]
- (4) - Control poison efficiency.
[default = 0.263 BWR, or 0.234 PWR, units = none, equiv = FEFF(4)]

1312 – Component Fission Power Absorption Parameters

These coefficients define the fraction of fission power that escapes the fuel component, and determine which of the various COR components (2 through 6) will absorb this "available" fission power, based on the relative absorption efficiencies in array 1311. The fraction of fission power that escapes the fuel component is given by the quantity $[1 - \text{POWFAC}(1)]$. If $\text{POWFAC}(1) = 1.0$, all fission power will be absorbed by the fuel, regardless of the material efficiencies specified in sensitivity coefficient array 1311. The remaining elements of the array, $\text{POWFAC}(2:9)$, serve as flags to indicate the participation of the corresponding component. Only components with nonzero values are considered able to absorb fission power. Currently, energy will not be conserved, with messages generated, unless all values are zero or all are nonzero.

- (1) - UO₂ fuel initial absorption fraction.
[default = 0.9, units = none, equiv = POWFAC(1)]
- (2) - Participation flag for cladding.
[default = 1.0, units = none, equiv = POWFAC(2)]
- (3) - Participation flag for canister portion not adjacent to control blade.
[default = 1.0, units = none, equiv = POWFAC(3)]
- (4) - Participation flag for canister portion adjacent to control blade.
[default = 1.0, units = none, equiv = POWFAC(4)]
- (5) - Participation flag for OS "other structure".
[default = 1.0, units = none, equiv = POWFAC(5)]
- (6) - Participation flag for particulate debris.
[default = 1.0, units = none, equiv = POWFAC(6)]
- (7) - Participation flag for supporting structure.
[default = 1.0, units = none, equiv = POWFAC(7)]
- (8) - Participation flag for nonsupporting structure.
[default = 1.0, units = none, equiv = POWFAC(8)]
- (9) - Participation flag for particulate debris in bypass.
[default = 1.0, units = none, equiv = POWFAC(9)]

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1321 – Material Absorption Efficiencies for Decay Heat

These coefficients specify the relative absorption efficiencies of decay heat by the core materials. They are used in conjunction with coefficients in array 1322 to distribute the fraction 1.0-C1322(1) of the decay power that “escapes” the UO₂ fuel component (i.e., gammas), and are applied only to materials in “active” components, as defined by the remainder of sensitivity coefficient array 1312. The default values differ for BWRs and PWRs. Note that if values for PWRs are modified in MELGEN, the output will print BWR values as the “old” values. Defaults are based on ORNL report ORNL/NRC/LTR-94/42, which provides derivations and guidance for evaluation of nondefault values.

- (1) - UO₂ efficiency.
[default = 0.735 BWR, or 0.5 PWR, units = none, equiv = FDHEFF(1)]
- (2) - Zr efficiency.
[default = 0.4 BWR, or 0.541 PWR, units = none, equiv = FDHEFF(2)]
- (3) - Steel efficiency.
[default = 0.292 BWR, or 0.565 PWR, units = none, equiv = FDHEFF(3)]
- (4) - Control poison efficiency.
[default = 0.263 BWR, or 0.234 PWR, units = none, equiv = FDHEFF(4)]
- (5) - ZrO₂ efficiency.
[default = 0.4 BWR, or 0.541 PWR, units = none, equiv = FDHEFF(5)]
- (6) - Steel oxide efficiency.
[default = 0.292 BWR, or 0.565 PWR, units = none, equiv = FEFF(6)]
- (7) - Inconel efficiency.
[default = 0.4 BWR, or 0.541 PWR, units = none, equiv = FDHEFF(7)]

1322 – Component Decay Power Absorption Parameters

These coefficients define the fraction of decay power that escapes the fuel component, and determine which of the various COR components (2 through 6) will absorb this “available” decay power, based on the relative absorption efficiencies in array 1321. The fraction of decay power that escapes the fuel component is given by the quantity $[1 - \text{PWDHFC}(1)]$. If $\text{PWDHFC}(1) = 1.0$, all decay power will be absorbed by the fuel, regardless of the material efficiencies specified in sensitivity coefficient array 1321. The remaining elements of the array, $\text{PWDHFC}(2:9)$, serve as flags to indicate the participation of the corresponding component. Only components with nonzero values are considered able to absorb

decay power. Currently, energy will not be conserved, with messages generated, unless all values are zero or all are nonzero.

- (1) - UO₂ fuel initial absorption fraction.
[default = 0.5, units = none, equiv = PWDHFC(1)]
- (2) - Participation flag for cladding.
[default = 1.0, units = none, equiv = PWDHFC(2)]
- (3) - Participation flag for canister portion not adjacent to control blade.
[default = 1.0, units = none, equiv = PWDHFC(3)]
- (4) - Participation flag for canister portion adjacent to control blade.
[default = 1.0, units = none, equiv = PWDHFC(4)]
- (5) - Participation flag for OS "other structure".
[default = 1.0, units = none, equiv = PWDHFC(5)]
- (6) - Participation flag for particulate debris.
[default = 1.0, units = none, equiv = PWDHFC(6)]
- (7) - Participation flag for supporting structure.
[default = 1.0, units = none, equiv = PWDHFC(7)]
- (8) - Participation flag for nonsupporting structure.
[default = 1.0, units = none, equiv = PWDHFC(8)]
- (9) - Participation flag for particulate debris in bypass.
[default = 1.0, units = none, equiv = PWDHFC(9)]

3.3 Numerical Control Parameters

1401 – Time Step Control Parameters

These coefficients are used to control the system time step to prevent instabilities in the interface between the COR package and the CVH package. The interpretation of these coefficients is as follows:

- (1) - Maximum ratio by which the time step for the next cycle may be increased.
(default = 1.6, units = none, equiv = DTINC)
- (2) - Minimum ratio by which the time step for the next cycle may be decreased.
(default = 0.8, units = none, equiv = DTDEC)

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- (3) - Minimum value of the ratio between current cycle energy transfer and previous cycle energy transfer before requiring a repeat of the current cycle.
(default = -1.0, units = none, equiv = RATMIN)
- (4) - Maximum value of the ratio between current cycle energy transfer and previous cycle energy transfer before requiring a repeat of the current cycle.
(default = 20.0, units = none, equiv = RATMAX)
- (5) - Maximum absolute difference from 1.0 of the ratio between current cycle energy transfer and previous cycle energy transfer for any core volume that will allow an increase in the next cycle time step.
(default = 0.5, units = none, equiv = RATINC)
- (6) - Minimum absolute difference from 1.0 of the ratio between current cycle energy transfer and previous cycle energy transfer for any volume that will force a decrease in the next cycle time step.
(default = 1.0, units = none, equiv = RATDEC)

1402 – Candling Control Parameter

This coefficient controls the fraction of a material in a component that must be molten before it is considered available to candle. The default value serves only to avoid numerical problems.

- (1) - Threshold melt fraction for candling of a material in a component.
(default = 10 times unit roundoff, units = none, equiv = EPSCND)

3.4 Geometric Parameters

1501 – Canister Mass/Surface Area Splits

These coefficients specify the fractions of the input values for canister mass and surface area that are assigned to the two canister components (one adjacent to the control blade, the other not). They also specify the split between inner and outer (bypass and channel) surfaces.

- (1) - Fraction of canister mass in component adjacent to control blade.
(default = 0.5, units = none, equiv = FMCB)

- (2) - Fraction of canister surface area on inner (fuel-side) surface of component adjacent to the control blade.
(default = 0.5, units = none, equiv = FACBC)
- (3) - Fraction of canister surface area on outer (bypass-side) surface of component adjacent to control blade.
(default = 0.5, units = none, equiv = FACBB)
- (4) - Fraction of canister surface area on inner (fuel-side) surface of component not adjacent to the control blade.
(default = 0.5, units = none, equiv = FACNC)
- (5) - Fraction of canister surface area on outer (bypass-side) surface of component not adjacent to the control blade.
(default = 0.5, units = none, equiv = FACNB)

1502 – Minimum Component Masses

These coefficients specify the minimum component mass below which the masses and energies will be discarded and the minimum component mass below which the component will not be subject to the maximum temperature change criterion. The default value of C1502(2) must be reduced to successfully simulate small-scale experiments.

- (1) - Minimum total mass of component.
(default = 1.0E-6, units = kg, equiv = XMCMN1)
- (2) - Minimum total mass of component subject to the maximum temperature change criterion for time step control.
(default = 10.0, units = kg, equiv = XMCMN2)

1503 – Core Blockage Parameters

These coefficients specify the geometric parameters affecting core flow blockage.

- (1) - Minimum porosity to be used in calculating both the area for heat transfer to fluid and the flow resistance in the flow blockage model.
(default = 1.0E-3, units = none, equiv = PMNCOR)

1504 – Core Cell Volume Consistency Tolerances

These coefficients specify the tolerances on internal consistency in representation of volumes within the COR package database. If either of the limits is exceeded in any core cell, a message will be issued (limited to 100 times each in any execution).

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If the discrepancy in total volume exceeds 100 times TOLVT, the calculation will be terminated.

- (1) - Permitted relative error in total volume in any cell.
(default = ten times unit roundoff, units = none, equiv = TOLVT)
- (2) - Permitted relative error in channel or bypass portion of cell volume in a BWR.
(default = 1.0E-4, units = none, equiv = TOLV1)

3.5 Lower-Head Mechanical Model Parameters

1600 – Model Parameters

These coefficients specify the desired level of modeling detail.

- (1) - Switch to choose zero-dimensional (0.0) or one-dimensional (1.0) modeling of the stress and strain distribution in the lower head.
(default = 0.0, units = none, equiv = none)
- (2) - Linear expansivity of the lower-head-load-bearing material. (Note, this value is only used if the one-dimensional model has been selected.)
(default = 1.E-5, units = K⁻¹, equiv = none)
- (3) - Differential pressure lower limit. The mechanical model will be bypassed whenever the effective differential pressure across the lower head falls below this value. Hence, a large value for this coefficient (e.g., 1.E10) will totally disable the mechanical model.
(default = 1.E3, units = Pa, equiv = none)

1601 – Larson-Miller Creep-Rupture Parameters for Vessel Steel

The Larson-Miller parameter for vessel steel is given by

$$P_{LN} = C1601(1) \cdot \log_{10} \sigma_e + C1601(2)$$

where σ_e is the effective stress in Pa, and the coefficients are material dependent. The default values are typical for reactor vessel carbon steel. The time to failure (rupture) in seconds is given by

$$t_R = 10^{[P/T - C1601(3)]}$$

where T is the temperature in K, and the plastic strain at time $t + \Delta t$ is given by

$$\varepsilon_{pl}(t + \Delta t) = \varepsilon_{pl}(t) + C1601(4) \cdot \Delta t / T_R$$

- (1) - Inherently negative multiplicative constant.
(default = -7.294E3, units = none, equiv = none)
- (2) - Inherently positive additive constant.
(default = 7.722E4, units = none, equiv = none)
- (3) - Additive exponential constant.
(default = 16.44, units = none, equiv = none)
- (4) - Total strain assumed to cause failure.
(default = 0.18, units = none, equiv = none)

1602 – Vessel Steel Elastic Modulus Parameters

The elastic modulus of vessel steel is given as a function of temperature, T , by

$$E(T) = C1602(1) \cdot \left(\left\{ 1 + [T / C1602(3)]^{C1602(4)} \right\}^{-1} - \left\{ 1 + [C1602(2) / C1602(3)]^{C1602(4)} \right\}^{-1} \right)$$

- (1) - Leading multiplicative constant.
(default = 2.E11, units = Pa, equiv = none)
- (2) - Temperature at which elastic modulus vanishes.
(default = 1800.0, units = K, equiv = none)
- (3) - Temperature at which elastic modulus is approximately halved.
(default = 900.0, units = K, equiv = none)
- (4) - Exponent of scaled temperatures.
(default = 6.0, units = none, equiv = none)

1603 – Vessel Steel Yield Stress Parameters

The yield stress of vessel steel is given as a function of temperature, T , by

$$\sigma_y(T) = C1603(1) \cdot \left(\left\{ 1 + [T / C1603(3)]^{C1603(4)} \right\}^{-1} - \left\{ 1 + [C1603(2) / C1603(3)]^{C1603(4)} \right\}^{-1} \right)$$

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- (1) - Leading multiplicative constant.
(default = 4.E8, units = Pa, equiv = none)
- (2) - Temperature at which yield stress vanishes.
(default = 1800.0, units = K, equiv = none)
- (3) - Temperature at which yield stress is approximately halved.
(default = 900.0, units = K, equiv = none)
- (4) - Exponent of scaled temperatures.
(default = 6.0, units = none, equiv = none)

3.6 Support Structure Mechanical Model Parameters

1604 – Larson-Miller Creep-Rupture Parameters for Support Structures

The Larson-Miller parameter for steel in support structures is given by

$$P_{LM} = C1604(1) \cdot \log_{10} \sigma_e + C1604(2)$$

where σ_e is the effective stress in Pa, and the coefficients are material dependent. The default values are typical for stainless steels. The time to failure (rupture) in seconds is given by

$$t_R = 10^{[P/T - C1604(3)]}$$

where T is the temperature in K.

- (1) - Inherently negative multiplicative constant.
(default = -7.500E3, units = none, equiv = none)
- (2) - Inherently positive additive constant.
(default = 8.100E4, units = none, equiv = none)
- (3) - Additive exponential constant.
(default = 16.44, units = none, equiv = none)

1605 – Internal Steel Elastic Modulus Parameters

The elastic modulus of steel in support structures is given as a function of temperature, T , by

$$E(T) = C1605(1) \cdot \left(\left\{ 1 + [T / C1605(3)]^{C1605(4)} \right\}^{-1} - \left\{ 1 + [C1605(2) / C1605(3)]^{C1605(4)} \right\}^{-1} \right)$$

- (1) - Leading multiplicative constant.
(default = 370.E9, units = Pa, equiv = none)
- (2) - Temperature at which elastic modulus vanishes.
(default = 1700., units = K, equiv = none)
- (3) - Temperature at which elastic modulus is approximately halved.
(default = 1650., units = K, equiv = none)
- (4) - Exponent of scaled temperatures.
(default = 3.0, units = none, equiv = none)

1606 – Internal Steel Yield Stress Parameters

The yield stress of steel in support structures is given as a function of temperature, T , by

$$\sigma_Y(T) = C1606(1) \cdot \left(\left\{ 1 + [T / C1606(3)]^{C1606(4)} \right\}^{-1} - \left\{ 1 + [C1606(2) / C1606(3)]^{C1606(4)} \right\}^{-1} \right)$$

- (1) - Leading multiplicative constant.
(default = 260.E6, units = Pa, equiv = none)
- (2) - Temperature at which yield stress vanishes.
(default = 1700., units = K, equiv = none)
- (3) - Temperature at which yield stress is approximately halved.
(default = 800., units = K, equiv = none)
- (4) - Exponent of scaled temperatures.
(default = 3.0, units = none, equiv = none)

4. Plot Variables and Control Function Arguments

The plot variables and control function arguments currently included in the COR package are listed below, along with a brief description. Within slashes (/ /) a 'p' indicates a plot variable and a 'c' indicates a control function argument. To reduce the size of the file, variables related to the canister or the bypass region are not written to the plot file for

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PWRs. These include properties of particulate debris in the bypass, and the split of volumes between channel and bypass.

Data relating to the OS, SS, and NS components are available only for those components permitted by the value of IOLDOS on MELCOR input record COR00006. In addition, control function arguments involving a component that is not permitted will not be recognized in MELGEN; if one is encountered in MELGEN input, no restart file will be generated.

4.1 Core Mass Variables

COR-MCRP.n	/p/	Total control poison mass in cell n. (units = kg)
COR-MCRP-TOT	/p/	Total control poison in core. (units = kg)
COR-MINC.n	/p/	Total Inconel mass in cell n. (units = kg)
COR-MINC-TOT	/p/	Total Inconel in core. (units = kg)
COR-MSS.n	/p/	Total steel mass in cell n. (units = kg)
COR-MSSOX.n	/p/	Total steel oxide mass in cell n. (units = kg)
COR-MSS-TOT	/p/	Total steel in core. (units = kg)
COR-MSX-TOT	/p/	Total steel oxide in core. (units = kg)
COR-MUO2.n	/p/	Total UO ₂ mass in cell n. (units = kg)
COR-MUO2-TOT	/p/	Total UO ₂ in core. (units = kg)
COR-MZR.n	/p/	Total Zircaloy mass in cell n. (units = kg)
COR-MZRO2.n	/p/	Total ZrO ₂ mass in cell n. (units = kg)
COR-MZR-TOT	/p/	Total Zircaloy in core. (units = kg)
COR-MZX-TOT	/p/	Total ZrO ₂ in core. (units = kg)

In the following four variables only, character strings are required for material m and component k, instead of integers. Acceptable strings for material are MUO2, MZR, MSS, MINC, MZRO2, MSSOX, and MCRP. (Interpretation is as in previous variables.) Acceptable strings for component are FU, CL, CN, CB, OS, SS, NS, PB, and PD. (Interpretation is given by the table in Section 1.1.) These four control function arguments are always active, but the corresponding plot variables are active only if IPMV has been set to 1 on MELCOR input record COREDV01.

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COR-DC.m.k.n	/pc/	Conglomerate debris mass for material m on component k in cell n. (units = kg)
COR-PB.m.n	/pc/	Particulate debris mass for material m in bypass of cell n. (units = kg)
COR-PD.m.n	/pc/	Particulate debris mass for material m in cell n. (units = kg)
COR-M.m.k.n	/pc/	Total mass (intact plus conglomerate) of material m in component k in cell n. (units = kg)
COR-MUO2-FU.n	/c/	Intact fuel UO ₂ mass in cell n. (units = kg)
COR-MZR-CL.n	/c/	Intact cladding Zircaloy mass in cell n. (units = kg)
COR-MZR-CN.n	/c/	Intact canister (including CB) Zircaloy mass in cell n. (units = kg)
COR-MSS-OS.n	/c/	Intact other structure (OS) steel mass in cell n. (units = kg)
COR-MCRP-OS.n	/c/	Intact other structure (OS) control poison mass in cell n. (units = kg)
COR-MZRO2-CL.n	/c/	Intact cladding ZrO ₂ mass in cell n. (units = kg)
COR-MZRO2-CN.n	/c/	Intact canister (including CB) ZrO ₂ mass in cell n. (units = kg)
COR-MSSOX-OS.n	/c/	Intact other structure steel oxide mass in cell n. (units = kg)

In the following variables, "debris" includes particulate and conglomerate.

COR-MUO2-DB.n	/c/	Total UO ₂ debris mass in cell n. (units = kg)
COR-MZR-DB.n	/c/	Total Zircaloy debris mass in cell n. (units = kg)
COR-MSS-DB.n	/c/	Total steel debris mass in cell n. (units = kg)
COR-MZRO2-DB.n	/c/	Total ZrO ₂ debris mass in cell n. (units = kg)
COR-MSSOX-DB.n	/c/	Total steel oxide debris mass in cell n. (units = kg)
COR-MCRP-DB.n	/c/	Total control poison debris mass in cell n. (units = kg)

4.2 Core Flow Area and Component Volume Variables

COR-AFLMIN.m.n	/c/	Minimum flow area open between core cells m and n, inclusive (channel and bypass combined for BWR). (units = m ²)
COR-VOL-FLU.n	/c/	Volume of fluid ("empty volume") in cell n (total for BWR). (units = m ³)
COR-VOL-FLUB.n	/c/	Volume of fluid in bypass of cell n (zero for PWR). (units = m ³)
COR-VOL-FLUC.n	/c/	Volume of fluid in channel of cell n (total for PWR). (units = m ³)

The following plot variables are active only if IPMV has been set to 1 on MELCOR input record COREDV01.

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COR-VOLF-FU.n	/p/	Intact fuel volume fraction in cell n. (units = none)
COR-VOLF-CL.n	/p/	Cladding volume fraction in cell n. (units = none)
COR-VOLF-CN.n	/p/	Canister volume fraction in cell n. (units = none)
COR-VOLF-OS.n	/p/	OS "other structure" volume fraction in cell n. (units = none)
COR-VOLF-SS.n	/p/	Supporting structure volume fraction in cell n. (units = none)
COR-VOLF-NS.n	/p/	Nonsupporting structure volume fraction in cell n. (units = none)
COR-VOLF-PB.n	/p/	Particulate debris volume fraction in bypass of cell n. (units = none)
COR-VOLF-PD.n	/p/	Particulate debris volume fraction in cell n. (units = none)
COR-VOLF-FLB.n	/p/	Fluid volume fraction in cell bypass of cell n. (units = none)
COR-VOLF-FLC.n	/p/	Fluid volume fraction in channel of cell n (BWR only). (units = none)
COR-VOLF-FL.n	/p/	Fluid volume fraction in cell n. (units = none)

4.3 Core Temperature and Melt Fraction Variables

COR-TFU.n	/pc/	Temperature of UO ₂ in cell n. (units = K)
COR-TCL.n	/pc/	Temperature of Zircaloy cladding in cell n. (units = K)
COR-TCN.n	/pc/	Temperature of canister (the part not adjacent to the control blade) in cell n. (units = K)
COR-TCB.n	/pc/	Temperature of canister adjacent to control blade. (units = K)
COR-TOS.n	/pc/	Temperature of OS "other structure" in cell n. (units = K)
COR-TSS.n	/pc/	Temperature of supporting structure in cell n.

		(units = K)
COR-TNS.n	/pc/	Temperature of nonsupporting structure in cell n. (units = K)
COR-TPB.n	/pc/	Temperature of particulate debris in bypass cell n. (units = K)
COR-TPD.n	/pc/	Temperature of particulate debris in cell n. (units = K)
COR-TSVC.n	/pc/	Local channel fluid temperature seen by cell n. (units = K)
COR-TSVB.n	/pc/	Local bypass fluid temperature seen by cell n. (units = K)
COR-MLTFR.n.m.k	/c/	Melt fraction of material number m in component number k in cell n. (units = none)

4.4 Core Energy and Heat Transfer Variables

COR-ENERGY-TOT	/p/	Total internal energy in COR package. (units = J)
COR-EFPD-TOT	/p/	Total cumulative fission power and decay heat generated in core. (units = J)
COR-EMWR-TOT	/p/	Total cumulative oxidation heat generated in core. (units = J)
COR-EB4C-TOT	/p/	Total cumulative heat from B ₄ C reactions in core. (units = J)
COR-ECNV-TOT	/p/	Total cumulative energy transfer to CVH package. (units = J)
COR-EBND-TOT	/p/	Total cumulative energy transfer to HS package. (units = J)
COR-EFPD-RAT	/p/	Total fission power and decay heat generation rate in core. (units = W)
COR-EMWR-RAT	/p/	Total oxidation heat generation rate in core. (units = W)
COR-EB4C-RAT	/p/	Total heat generation rate from B ₄ C reactions in core. (units = W)
COR-ECNV-RAT	/p/	Total convective heat generation rate in core.

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		(units = W)
COR-EBND-RAT	/p/	Total radiative heat transfer rate to boundary heat structures. (units = W)
COR-QCNV.m	/p/	Heat transfer rate to atmosphere in fluid volume m. (units = W)
COR-HTCLH.i	/p/	Heat transfer coefficient from ring i of lower head to water pool. (units = W/m ² K)
COR-HTCLH-AVE	/p/	Average heat transfer coefficient from lower head to water pool. (units = W/m ² K)
COR-QFLXLH.i	/p/	Heat flux from ring i of lower head to water pool. (units = W/m ²)
COR-QFLXLH-AVE	/p/	Average heat flux from lower head to water pool. (units = W/m ²)
COR-QTOTLH.i	/p/	Cumulative heat transferred from ring i of lower head to water pool. (units = J)
COR-QTOTLH-TOT	/p/	Total cumulative heat transferred from lower head to water pool. (units = J)

4.5 Core Structural Loading and Damage Variables

COR-SS-STRESS.ijj	/pc/	Maximum component of stress in SS in core cell ij. (units = Pa)
COR-SS-DAMAGE.ijj	/pc/	Damage fraction (fraction of damage that will produce failure) for SS in core cell ij. (units = none)
COR-SS-TLEFT.ijj	/pc/	Remaining life for SS in core cell ij (for unchanged temperature and load).

4.6 Core Oxidation and B₄C Reaction Mass Variables

COR-DMH2-TOT	/p/	Total cumulative hydrogen production in core. (units = kg)
COR-DMCO-TOT	/p/	Total cumulative carbon monoxide production in core. (units = kg)

COR-DMCO2-TOT	/p/	Total cumulative carbon dioxide production in core (available only for MCRP = 'B4C'). (units = kg)
COR-DMCH4-TOT	/p/	Total cumulative methane production in core (available only for MCRP = 'B4C'). (units = kg)

4.7 Variables Involving Melting Heat Structures and BH Package

Note that, in all cases, mass and energy transfers from the COR package are defined as positive.

COR-MCTOHS-TOT	/p/	Total mass added to HS by COR. (units = kg)
COR-ECTOHS-TOT	/p/	Total enthalpy of mass added to HS by COR. (units = J)
COR-MCTOBH-TOT	/p/	Total mass added to BH by COR. (units = kg)
COR-ECTOBH-TOT	/p/	Total enthalpy of mass added to BH by COR. (units = J)
COR-RCTOBH-TOT	/p/	Total energy radiated to BH debris by COR. (units = J)

4.8 Core Penetration, Lower Head, Breach and Melt Ejection Variables

COR-TPN.n	/pc/	Temperature of penetration n. (units = K)
-----------	------	--

In the following three variables, *ijj* refers to node *jj* of ring *i*, where *jj=01* is on the outside of the lower head. (Although nodal information on CORLHNnn records is entered from inside to outside, the nodes are actually numbered in the opposite direction.)

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COR-TLH.ijj	/p/	Temperature of vessel lower head node. (units = K)
COR-VSTRAIN.ijj	/p/	Plastic strain in vessel lower head node. (units = dimensionless)
COR-VSTRESS.ijj	/p/	Stress in vessel lower head node. (units = Pa)
COR-ABRCH	/c/	Total flow area of vessel breach. (units = m ²)
COR-MEJEC-TOT	/p/	Total debris mass ejected through vessel breach. (units = kg)

4.9 Core Accounting Variables

COR-DT	/p/	COR package time step. (units = s)
COR-NCYCLE	/p/	Total number of COR package subcycles. (units = none)
COR-CPU	/p/	Total CPU usage by run portion of COR package. (units = s)
COR-MASSERR	/p/	Total mass error for COR package. (units = kg)
COR-ENERGYERR	/p/	Total energy error for COR package. (units = J)
COR-REL-ENGY-ERR	/p/	COR relative energy error, defined as COR-ENERGYERR/ COR-ENERGY-TOT (units = dimensionless)
COR-REL-ENGY-ERM	/p/	COR relative energy error, modified to include enthalpy of mass transfers to BH and HS, defined as COR- ENERGYERR/(COR-ENERGY-TOT + debris to BH and CAV) (units = dimensionless)

5. Example Input

5.1 Example MELGEN Input

The following are sample MELGEN input records for the COR package for a 3-ring by 12-level nodalization. It corresponds to the input example presented in previous versions of

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this guide, with the substitution of supporting and nonsupporting structures (SS and NS) for undifferentiated "other structure" (OS), and uses CORijjKcmp input records rather than CORijj02 records. Pending improvements to the core structures support model, a small amount of NS is required in level 1 to support the control rod guide tubes in levels 2 through 5. This example does not represent any real reactor system.

* GENERAL CORE INPUT

*

	NRAD	NAXL	NTLP	NCVOL	NLH	NPNTOT
COR00000	3	12	6	3	5	3

*

	RFUEL	RCLAD	DRGAP	PITCH	DXCAN	DXSS	DZLH
COR00001	.005207	.0061341	.0001143	.016	.00254	.0012	.2254

*

	IRTP	MCRP
COR00002	BWR	B4C

*

	FCNCL	FSSCN	FCELR	FCELA	FLPUP
COR00003	0.25	0.95	0.25	0.25	0.25

*

	NTPCOR	ICFFIS	ICFGAP
COR00004	101	-51	61

*

	HFRZFU	HFRLIR	HFRZSS	HFRLIX	HFRZSX	HFRZCP
COR00005	2000.0	2000.0	2000.0	2000.0	2000.0	2000.0

*

	IEUMOD
COR00006	1

*

	MTUOZR	MTZXZR	MTSXSS	MTCPSS	FUOZR	FZXZR	FSXSS	FCPSS
COR00007	1	2	2	2	0.2	1.0	1.0	0.0

*

	HDBPN	HDBLH	TPFAIL	CDISPN
COR00009	500.0	500.0	1273.15	1.0

*

* CELL ELEVATIONS

*

	Z	DZ	PORIN	PORDP	
CORZ0101	0.0	1.2954	0.0	0.3	* PORIN NOT USED
CORZ0201	1.2954	0.9803	0.0	0.3	
CORZ0301	2.2757	0.9803	0.0	0.3	
CORZ0401	3.2560	0.9803	0.0	0.3	
CORZ0501	4.2363	0.9803	0.0	0.3	
CORZ0601	5.2166	0.2777	0.0	0.3	
CORZ0701	5.4943	0.635	0.0	0.3	
CORZ0801	6.1293	0.635	0.0	0.3	
CORZ0901	6.7643	0.635	0.0	0.3	
CORZ1001	7.3993	0.635	0.0	0.3	
CORZ1101	8.0343	0.635	0.0	0.3	
CORZ1201	8.6693	0.635	0.0	0.3	

*

* CELL AXIAL BOUNDARY AREAS

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* ASCELA
CORR0101 5.729
CORR0201 5.729
CORR0301 5.729
*
* OUTER BOUNDARY HEAT STRUCTURES
CORZ0102 10001 * ISUP NOT USED FOR IOLDOS=0
CORZ0202 10002
CORZ0302 10003
CORZ0402 10004
CORZ0502 10005
CORZ0602 10006
CORZ0702 10207
CORZ0802 10208
CORZ0902 10209
CORZ1002 10210
CORZ1102 10211
CORZ1202 10212
*
* UPPER BOUNDARY HEAT STRUCTURES AND LOWER HEAD FAILURE CF'S
CORR0102 10301 52
CORR0202 10302 53
CORR0302 10303 54
*
* AXIAL POWER DENSITY PROFILE
CORZ0703 0.75
CORZ0803 0.90
CORZ0903 1.20
CORZ1003 1.20
CORZ1103 0.90
CORZ1203 0.75
*
* RADIAL POWER DENSITY PROFILE
CORR0103 1.2
CORR0203 0.9
CORR0303 0.75
*
* SS AND NS OPTIONS
*
* TREAT ALL NS IN INPUT AS CONTROL BLADE
*
COR000NS BLADE * NOT REQUIRED, SINCE DEFAULT FOR BWR
*
* TREAT ALL SS IN INPUT AS COLUMN, EXCEPT FOR LEVEL 6.
* LEVEL 6 TO BE TREATED AS PLATEB
*
*
COR000SS COLUMN XNUM RADO RADI
50. 0.14 0.13
*
CORZ06SS PLATEB THICK SPACE AKMB * AKMB INCREASED FOR HOLES
0.08 0.3 0.15
*
* LOWER PLENUM INPUT

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```

*
* CRD HOUSING - *** NOTE: ALL MASS INPUT WITH PENETRATION INPUT
*
*      IREFN   ICVHC   ICVHB
COR10101  -1      100      100

COR101KFU 0.0      * EMPTY: EXPLICITLY SPECIFY COMPONENT OF ZERO MASS
*
*      TFU    TCL    TOS    TCN    TCB    TPD    TSS    TNS
COR10103  560.0  560.0  560.0  560.0  560.0  560.0  560.0  560.0
*
*      DHYCL  DHYOS  DHYDP  DHYCNC  DHYCNB  DHYSS  DHYNS
COR10104  1.0     1.0     0.005  1.0     1.0     1.0     1.0
*
*      ASCELR  AFLOWC  AFLOWB
COR10105  10.99   5.729   0.0
*
*      ASFU    ASCL    ASOS    ASCN    ASSS    ASNS
COR10106  0.0     0.0     0.0     0.0     0.0     0.0
*
COR20101  101     * REFERENCE TO CELL 101 FOR MISSING INPUT
COR20105  15.54
*
COR30101  101     * REFERENCE TO CELL 101 FOR MISSING INPUT
COR30105  21.98
*
* CR GUIDE TUBES (185)
COR10201  -1      100      100
COR102KSS 1750.0
COR10203  560.0  560.0  560.0  560.0  560.0  560.0  560.0  560.0
COR10204  1.0     1.0     0.005  1.0     1.0     1.0     0.3
COR10205  8.3177  5.5039  0.0
COR10206  0.0     0.0     0.0     0.0     106.1   0.0
COR10301  102     * REFERENCE TO CELL 102 FOR MISSING INPUT
COR10401  102     * REFERENCE TO CELL 102 FOR MISSING INPUT
COR10501  102     * REFERENCE TO CELL 102 FOR MISSING INPUT
*
COR20201  102     * REFERENCE TO CELL 102 FOR MISSING INPUT
COR20205  11.763
COR20301  202     * REFERENCE TO CELL 202 FOR MISSING INPUT
COR20401  202     * REFERENCE TO CELL 202 FOR MISSING INPUT
COR20501  202     * REFERENCE TO CELL 202 FOR MISSING INPUT
*
COR30201  102     * REFERENCE TO CELL 102 FOR MISSING INPUT
COR30205  16.6354
COR30301  302     * REFERENCE TO CELL 302 FOR MISSING INPUT
COR30401  302     * REFERENCE TO CELL 302 FOR MISSING INPUT
COR30501  302     * REFERENCE TO CELL 302 FOR MISSING INPUT
*
* LOWER CORE SUPPORT STRUCTURE (FUEL SUPPORT PIECES, CORE PLATE,
*                               AND FUEL ASSEMBLY NOSE PIECES)
*
COR10601  -1      100      100

```

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```

COR106KSS 5000.0
COR10603 560.0 560.0 560.0 560.0 560.0 560.0 560.0 560.0
COR10604 1.0 1.0 0.005 1.0 1.0 0.15 1.0
COR10605 2.356 3.4585 0.0
COR10606 0.0 0.0 0.0 0.0 50.0 0.0
COR20601 106 * REFERENCE TO CELL 106 FOR MISSING INPUT
COR20605 3.332
COR30601 106 * REFERENCE TO CELL 106 FOR MISSING INPUT
COR30605 4.712
*
* CORE INPUT
*
COR10701 -1 101 102
COR107KFU 9360.0
COR107KCL 1968.0
COR107KNS 596.0 99.2
COR107KCN 730.0
COR107KCB 730.0
COR10703 595.0 560.0 560.0 560.0 560.0 560.0 560.0
COR10704 0.005 1.0 0.005 0.005 0.003 1.0 0.003
COR10705 5.3879 2.65 0.8
COR10706 328.0 399.0 0.0 86.7 0.0 127.0
COR10801 107 * REFERENCE TO CELL 107 FOR MISSING INPUT
COR10803 595.0 560.0 560.0 560.0
COR10901 107 * REFERENCE TO CELL 107 FOR MISSING INPUT
COR10903 595.0 560.0 560.0 560.0
COR11001 107 * REFERENCE TO CELL 107 FOR MISSING INPUT
COR11003 595.0 560.0 560.0 560.0
COR11101 107 * REFERENCE TO CELL 107 FOR MISSING INPUT
COR11103 595.0 560.0 560.0 560.0
COR11201 107 * REFERENCE TO CELL 107 FOR MISSING INPUT
COR11203 595.0 560.0 560.0 560.0
*
COR20701 107 * REFERENCE TO CELL 107 FOR MISSING INPUT
COR20705 7.6196
COR20801 207 * REFERENCE TO CELL 207 FOR MISSING INPUT
COR20901 207 * REFERENCE TO CELL 207 FOR MISSING INPUT
COR21001 207 * REFERENCE TO CELL 207 FOR MISSING INPUT
COR21101 207 * REFERENCE TO CELL 207 FOR MISSING INPUT
COR21201 207 * REFERENCE TO CELL 207 FOR MISSING INPUT
*
COR30701 107 * REFERENCE TO CELL 107 FOR MISSING INPUT
COR30705 10.7758
COR30801 307 * REFERENCE TO CELL 307 FOR MISSING INPUT
COR30901 307 * REFERENCE TO CELL 307 FOR MISSING INPUT
COR31001 307 * REFERENCE TO CELL 307 FOR MISSING INPUT
COR31101 307 * REFERENCE TO CELL 307 FOR MISSING INPUT
COR31201 307 * REFERENCE TO CELL 307 FOR MISSING INPUT
*
* LOWER HEAD INPUT
*
* IRS IRE TLH RADLH ICVCAV

```

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```

CORLHD01  1    1    560.0  1.350  205  * RADIUS OF RING 1
CORLHD02  2    2    560.0  1.910          * RADIUS OF RING 2
CORLHD03  3    3    560.0  2.800          * RADIUS OF LOWER HEAD
* BY DEFAULT, THE LOWER HEAD WOULD BE MODELED AS CARBON STEEL WITH
* NLH=5 EQUALLY SPACED NODES AND A TOTAL THICKNESS OF DZLH=0.2254M
* THE FOLLOWING RECORDS DEFINE A HEAD WITH 1 INCH OF STAINLESS
* STEEL INSIDE A CARBON STEEL SHELL, USING UNEQUALLY-SPACED NODES.
CORLHN01  STAINLESS-STEEL  0.0254  CARBON-STEEL  0.0754
CORLHN02  CARBON-STEEL    0.1754  CARBON-STEEL  0.2254
*
* LOWER HEAD PENETRATIONS INPUT
*
* ALL PENETRATIONS ARE CRD HOUSINGS AND STUB TUBES
* GEOMETRIC VALUES ARE ESTIMATES
*
*          IPNREF  IRP      XMPN      TPN      ASPN      AXPN      AFLPN
CORPEN01  -1      1      704.0    560.0    18.3     0.431    1.03
CORPEN02  1       2
CORPEN03  1       3
*
* COR DT/DZ INLET SPEC INPUT
* THIS INPUT IS NO LONGER REQUIRED OR RECOMMENDED.
* SEE DISCUSSION OF CORTIN RECORD
*

```

The following are sample MELGEN input records for the DCH and RN packages to treat the additional reaction products generated when the advanced B₄C reaction model is selected by overriding the default (simple model) selection with sensitivity coefficient 1005. RN classes 17 – 23 have been defined to treat the additional reaction products, and the DCH input assigns zero decay heat to those classes.

```

*****
* DECAY HEAT DEFINITION *
*****
*
DCHREACTOR 'BWR'
*
*          USE ALL DEFAULT RADIONUCLIDE CLASSES
DCHDEFCLS0 ALL
DCHNEM0000 'CI'  1.E-9
DCHNEM0001 0.  0.
DCHNEM0100 'B2'  1.E-9
DCHNEM0101 0.  0.
DCHNEM0200 'B3'  1.E-9
DCHNEM0201 0.  0.
DCHNEM0300 'B4'  1.E-9
DCHNEM0301 0.  0.
DCHNEM0400 'B5'  1.E-9
DCHNEM0401 0.  0.
DCHNEM0500 'B6'  1.E-9
DCHNEM0501 0.  0.

```


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```
DCHNEM0600 'B7' 1.E-9
DCHNEM0601 0. 0.
DCHNEM0700 'B8' 1.E-9
DCHNEM0701 0. 0.
DCHCLS0160 'CSI'
DCHCLS0161 'CI'
DCHCLS0170 'H3B306'
DCHCLS0171 'B2'
DCHCLS0180 'HBO2'
DCHCLS0181 'B3'
DCHCLS0190 'BH3'
DCHCLS0191 'B4'
DCHCLS0200 'B2H6'
DCHCLS0201 'B5'
DCHCLS0210 'BOH'
DCHCLS0211 'B6'
DCHCLS0220 'B(S)'
DCHCLS0221 'B7'
DCHCLS0230 'C(S)'
DCHCLS0231 'B8'
```

*

* RADIONUCLIDE INPUT *

*

* ACTIVATE RN1 PACKAGE

```
RN1000 0
```

*

* DEFINE 23 RN CLASSES

```
*           NUMSEC NUMCMP NUMCLS NCLSW NCLSBX NUMSRA NUMSRV NCLCSI
RN1001 5           1           23       14       13       0       0       16
```

*

5.2 Example MELCOR Input

The following are sample MELCOR input records for the COR package.

```
*           DTMPCR DTCMIN NSUBMX
CORDTC01 30.0       0.005   32
```

*

```
*           ITEMP IMASS IVOL IASUR IPMV
COREDV01 1       1       1       0       0
```

*

```
*           IRAD ICND ICNV IOXD IDRPT ITDZ IB4C IRDS IDEJ ISPR
CORTST01 0       0       0       0       0       0       1       0       1       0
```

6. COR Package Output

The COR package output provides a description of the current state of the reactor core, including any debris. Many two-dimensional arrays dimensioned (NAXL, NRAD) are printed in a matrix format from the top down to aid in visualizing the physical processes modeled in the core.

For a MELGEN run and on the first cycle of a MELCOR restart, all the available information from the COR package is printed, including much of the time-independent data base. By default, only temperatures and masses, along with energy and mass balances and some statistical information, are written for succeeding edit cycles. However, the user may also specify the editing of various geometric variables, such as surface areas or cell flow areas, or may eliminate nearly all the COR package edit information, through use of the edit flags specified on the COREDV01 MELCOR input record.

Special messages are written to the message file at the time of failure for each supporting structure and each lower head penetration, at the beginning and end of the falling debris quench calculation in each ring, and at the beginning of debris ejection to the cavity.

Complete output for a sample problem can be found in the output listing for the demonstration problem distributed with MELCOR.

7. Diagnostics and Error Messages

Diagnostics and error messages generated during MELGEN are concerned with input processing and are generally self-explanatory. If these messages seem obscure or are otherwise unhelpful in isolating an input problem, please contact the MELCOR code development group.

A variety of messages may be generated during the execution phase of MELCOR. Some of these are merely informative, and should not be of much concern unless they occur very frequently during the calculation. Others indicate very serious problems in the calculation and should be referred to the MELCOR code development group. If a calculation aborts (gracefully or not) please save all input, output, plot, and restart files for use by the code developers in resolving the error.

The following list describes in some detail various messages generated during MELCOR execution and the appropriate action to be taken by the user.

Nonfatal Diagnostics:

- (1) WARNING FROM COR PACKAGE
ENERGY ERROR IS BECOMING LARGE

COR Package Users' Guide

The relative energy error has exceeded a preset limit (currently 5.E-5). The magnitude of this error is indicative of its importance in the calculation and should normally be within a factor of 100 of machine roundoff. Any error over 5.E-4 should be reported to the MELCOR code development group.

(2) **WARNING FROM COR PACKAGE
MASS ERROR IS BECOMING LARGE**

The relative mass error has exceeded a preset limit (currently 5.E-5). The magnitude of this error is indicative of its importance in the calculation and should normally be within a factor of 100 of machine roundoff. Any error over 5.E-4 should be reported to the MELCOR code development group.

(3) **WARNING FROM COR PACKAGE
VOLUME ERROR IS BECOMING LARGE**

The relative volume error has exceeded a preset limit (currently 5.E-5). The magnitude of this error is indicative of its importance in the calculation and should normally be within a factor of 100 of machine roundoff. Any error over 5.E-4 should be reported to the MELCOR code development group.

(4) **WARNING FROM COR PACKAGE
INTERNAL ENERGIES DID NOT CONVERGE IN CELL nnnn, COMPONENT nn
DECOR=x.xxxEyy,SUMMCP=x.xxxEyy,TNEW=xxx.xx,ENEW=x.xxxEyy**

Difficulty was encountered in equilibrating the internal energies of the materials within a cell component. The COR package continues the calculation by repeating the subcycle with a smaller time step. Frequent occurrences of this message should be reported to the MELCOR code development group.

(5) **TIME STEP CUT IN COR PACKAGE
TOO LARGE AN ENERGY SINK GENERATED IN VOLUME nnn
DELE=x.xxxEyy, ETOT=x.xxxEyy**

Energy transfer calculated from the control volume fluid to the core materials is greater than the available energy in the volume. The system time step is reduced and the cycle is repeated. Frequent occurrences of this message should be reported to the MELCOR code development group.

(6) **TIME STEP CUT IN COR PACKAGE
TOO LARGE A MASS SINK GENERATED IN VOLUME nnn
DELM=x.xxxEyy, XMASS=x.xxxEyy**

The consumption of steam by metal oxidation calculated by the COR package is greater than the available mass in the volume. The system time step is reduced

and the cycle is repeated. Frequent occurrences of this message should be reported to the MELCOR code development group.

- (7) CORRAD – Implied View Factor > 1
s1 IN CELL ijj <-> s2 IN CELL kll

As a result of inappropriate input or change in geometry, some view factor implied by reciprocity ($A_i F_{ij} = A_j F_{ji}$) exceeds unity.

Here, "s" may be any of the surfaces "PELLET", "CLAD", "CAN", "CAN-B", "OTH.STR", "PRT.DBR", "CAN.OUT", "CAN-B.O", "RAD.BND", or "AXL.BND", where, "AXL.BND" and "RAD.BND" refer to an unnamed component in one cell that provides an axial or radial boundary for a named component in another. Axial level NAXL+1 and radial ring NRAD+1 refer to the heat structures providing the radiative boundary condition specified by input record CORRii02 or CORZjj02, respectively.

- (8) VIEW FACTOR ERROR IN CORVF
SUM OF VIEW FACTORS EXCEEDS UNITY FOR SURFACE s IN CORE CELL ijj

The sum of view factors input or implied for a single surface may exceed unity. This is not a particularly serious problem, because only pairs of surfaces are considered (MELCOR does not use a net enclosure model.)

In neither case 7 nor case 8 will the message be repeated more than 50 times; the last will include a final line

FURTHER MESSAGES SUPPRESSED

If such warnings are seen in MELGEN diagnostics (under conditions of intact geometry), user input should be reexamined and, in most cases, modified.

- (9) VOLUME CONSISTENCY WARNING IN CELL ijj at location
Channel volume error = x.xxxEeee (m3)
Bypass volume error = x.xxxEeee (m3)
Net volume error = x.xxxEeee (relative)

Here "at location" indicates the point in the advancement through the time step where the problem was detected. This message normally represents an incursion of channel components into the bypass region of a BWR, or vice versa, by more than the limit set by Sensitivity coefficient C1504(2). It is not a significant cause of concern unless the magnitude is large.

- (10) VOLUME CONSISTENCY ERROR IN CELL ijj at location
Net volume error = x.xxxEeee (relative)

COR Package Users' Guide

Here "at location" indicates the point in the advancement through the time step where the problem was detected. This message is a result of an inconsistency in the internal representation of volumes in the COR package by more than the limit set by Sensitivity coefficient C1504(1). It is indicative of a more severe error than the preceding message.

In neither case 9 nor case 10 will the message be repeated more than 100 times; the last will include a final line

FURTHER MESSAGES SUPPRESSED

Fatal Error Messages:

(1) MATERIALS PROPERTIES ERROR DETECTED IN COR PACKAGE

An error flag was set by one of the materials properties subroutines called by the COR package. This may indicate bad input data for a material property table or an error generated by the COR package. All material property data should be checked by the user, and if the error is not resolved, it should be reported to the MELCOR code development group.

(2) COR PACKAGE TIME STEP IS TOO SMALL

DTC = xxx.xxxxEyy

The subcycling time step used in the COR package has been cut to less than 1.E-5 seconds. Report this error to the MELCOR code development group.

(3) TOO MANY SUBCYCLES OR TOO SMALL A TIME STEP IN COR PACKAGE or SUBCYCLE TIME STEP IN COR PACKAGE IS TOO SMALL

Too many COR package subcycles were generated during a single system cycle, or the subcycle time step was reduced to below the user-specified minimum. User input variables on record CORDTC01 can be adjusted, but if the COR package then consumes an excessive amount of CPU time or if the error message reoccurs, it should be reported to the MELCOR code development group.

(4) ERROR IN CALL TO TPIN FROM CORMEJ

An error flag was set by the Transfer Process package during melt ejection. Transfer Process package input should be checked for consistency with requirements by the COR package (see input record COR00004).

(5) CONVERGENCE FAILURE IN SUBROUTINE CORPAE

Convergence while equilibrating material energies in a cell component could not be obtained even after reducing the subcycle time step to the user-specified minimum. Report this error to the MELCOR code development group.

(6) ERROR IN SUBROUTINE CORUVN

TOTAL MASS IS ZERO IN COMPONENT nn OF CELL nnnn

ATTEMPT TO ADD ENERGY = x.xxxxEyy

An error has been detected during an attempt to transfer energy to or from a cell component that has zero mass. This error should be reported to the MELCOR code development group.

(7) CONTROL FUNCTION ERROR IN SUBROUTINE CORabc

An error flag was set by the Control Function package during a call from subroutine CORabc. The user input for the control function should be checked. If the error cannot be resolved, it should be reported to the MELCOR code development group.

(8) TABULAR FUNCTION ERROR IN SUBROUTINE CORabc

An error flag was set by the Tabular Function package during a call from subroutine CORabc. The user input for the tabular function should be checked. If the error cannot be resolved, it should be reported to the MELCOR code development group.

(9) VOLUME CONSISTENCY ERROR IN CELL ijj at location

Net volume error = x.xxxEeee (relative)

MUST INCREASE VOLT=SC1504(1) TO CONTINUE

Here "at location" indicates the point in the advancement through the time step where the problem was detected. This message is a result of an inconsistency in the internal representation of volumes in the COR package by more than 100 times the limit set by Sensitivity coefficient C1504(1). It is indicative of a severe error, and should be reported to the MELCOR code development group.

(10) ERROR IN SUBROUTINE CORabc

An error was detected in subroutine CORabc. Any errors of this form should be reported to the MELCOR code development group.

Control Volume Hydrodynamics (CVH) Package Users' Guide

The Control Volume Hydrodynamics (CVH) and Flow Path (FL) packages are responsible for modeling the thermal-hydraulic behavior of liquid water, water vapor, and gases in MELCOR. Modeling is based on a control volume/flow path formulation and is described in detail in the Thermal Hydraulic (CVH and FL) Package's Reference Manual.

This Users' Guide describes input to the CVH package, which is concerned with the geometry and contents of control volumes. CVH input describes the initial state of each volume; optional input allows the definition of sources and sinks of mass and/or energy, in terms of data from the Control Function (CF) and Tabular Function (TF) packages. Additional sources and sinks may be imposed by other packages during a MELCOR calculation; these are treated automatically and do not require input to CVH. Similarly, changes in control volume geometry resulting from relocation of nonhydrodynamic materials is communicated to CVH during MELCOR execution; no CVH input is required.

Connections *between* control volumes, through which the control volume contents may flow, are defined by input to the Flow Path package, which is described in the FL Package Users' Guide.

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1. Control Volume Models

All hydrodynamic material, together with its associated energy, in a MELCOR calculation resides in *control volumes*. Hydrodynamic material includes the coolant (water), vapor and fog, and noncondensable gases; it does not include core structures or core debris, other heat structures, fission products, aerosols, water films on heat structures or ice in ice condensers.

1.1 Control Volume Geometry

The spatial geometry of a control volume is defined by a volume/altitude table. Each point in the table gives an altitude and the cumulative volume available to hydrodynamic materials in the CVH package below that altitude in that control volume. The volume at the lowest altitude (the bottom of the control volume) must be zero; the difference in altitude between the last point and the first one defines the height of the control volume, and the last volume entry defines its total volume. Volume is assumed to be a linear function of altitude between the table entries (see Figure 1.1). There may be an arbitrary number of entries in the table.

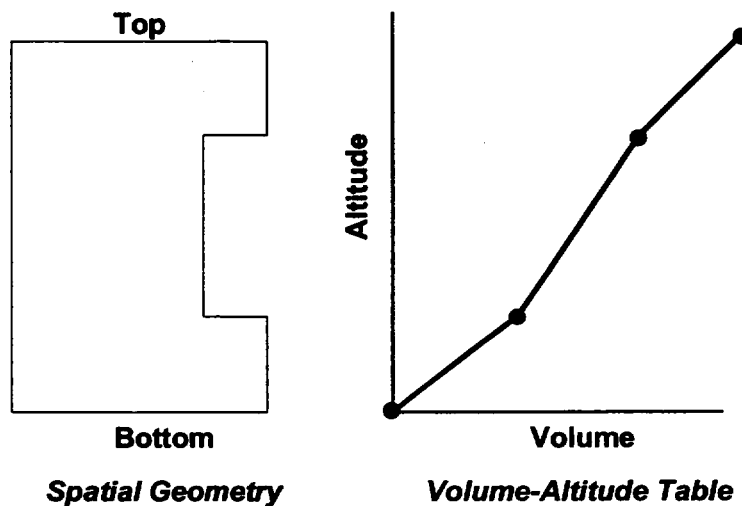


Figure 1.1 Spatial Geometry (left) and Volume/Altitude Table (right)

All altitudes input to MELCOR must be relative to a single, common, reference point to allow determination of the difference in elevations of control volumes and of the location of connections to flow paths. The same reference point must be used in the CVH, FL, Core (COR), and Heat Structure (HS) packages. Any consistent reference point may be used; consequently, both positive and negative values of altitude are allowed.

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CVH input defines the volume *initially* available to hydrodynamic materials; it should *not* include either the volume occupied by intact core components or that occupied by ice in an ice condenser. Such volume is referred to as *virtual volume*, and represents space occupied by material in another MELCOR package (and therefore denied to hydrodynamic materials) that is subject to relocation. For example, when the core melts down and relocates to the lower plenum, some or all of the volume that it initially occupied will be freed, but the resulting debris will occupy space in the lower plenum. In addition to the core, core debris, and ice, water films on surfaces occupy virtual volume.

Initial values of virtual volume are defined by the package (COR or HS) that models the associated material. An initial virtual-volume/altitude table is constructed using the set of altitudes defined by CVH input, and added to the table defined by CVH input to define a *total* volume/altitude table that does not change during a MELCOR calculation. However, the virtual-volume/altitude table changes as nonhydrodynamic material is relocated, and the volume available for the hydrodynamic material, defined as the difference between total and virtual volume, changes as a function of time. This is illustrated in Figure 1.2, where core debris has been moved into the volume of Figure 1.1. Note that the tables are always based on the altitudes defined in CVH.

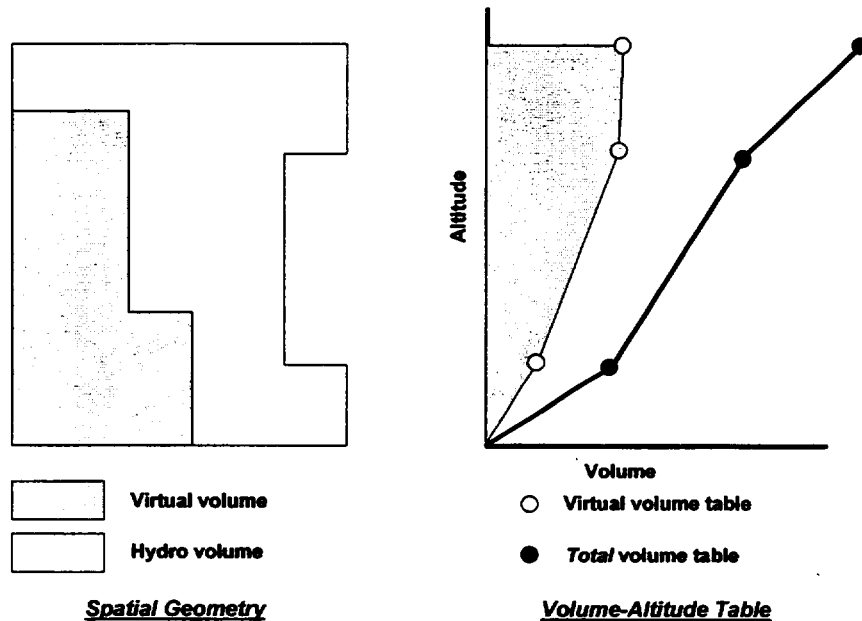


Figure 1.2 Total, Hydrodynamic, and Virtual Volume

1.2 Control Volume Contents

The contents of each control volume are divided between a so-called *pool* and an *atmosphere*, as shown in Figure 1.3. The pool is depicted as filling the lower portion of the control volume and the atmosphere filling the remainder. As discussed in the Thermal

Hydraulic (CVH and FL) Packages Reference Manual, this picture is not interpreted so narrowly that it invalidates use of MELCOR hydrodynamics in other situations.

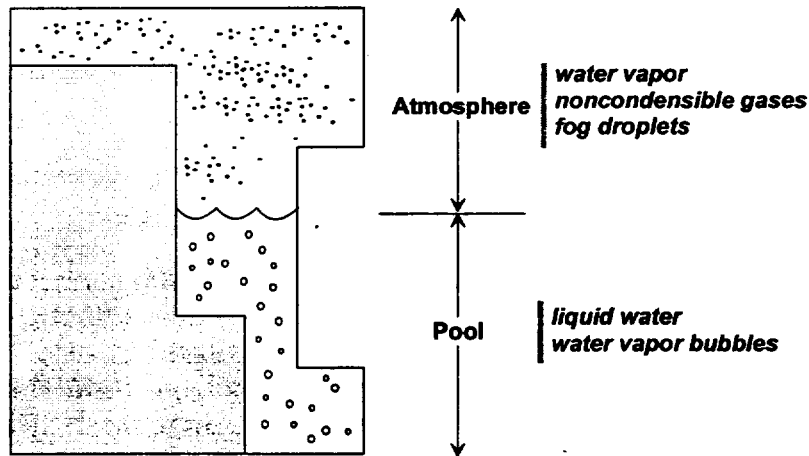


Figure 1.3 Location of Material in Control Volume

The pool can be single-phase liquid water or two-phase water. The atmosphere contains water vapor and/or noncondensable gases. The atmosphere may also have suspended water droplets (referred to as fog). Although the interactions of rising gases with the pool may be modeled (see SPARC input in the FL Users' Guide), current modeling does not permit noncondensable gases to reside in the pool. The total volume is divided among the pool, the gaseous atmosphere, and the fog.

Materials are numbered within MELCOR. Materials 1, 2, and 3 are always the pool, the fog, and water vapor in the atmosphere, respectively. Materials with numbers greater than three (if included) are noncondensable gases, and must be defined by input to the NonCondensable Gas (NCG) package.

The user can define the thermodynamic state of the material in the control volume in one of three ways:

- (1) Specify sufficient properties of the pool and the atmosphere to uniquely define—but not *over-define*—their thermodynamic states.
- (2) Define the mass and total internal energy of each material. The internal energy must be consistent with the equations of state used in MELCOR.
- (3) Specify the control volume pressure and the partial pressure of the water vapor in the atmosphere, the pool and atmosphere temperatures, water distribution in terms of mass fractions, and the mass fractions of noncondensable gases.

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The first of these is the default, and will be used in most cases. The second option may be useful in defining the input to one MELCOR calculation from the output of another. The third is retained for consistency with older versions of MELCOR. Because it provides no unique capabilities and its use will often require extensive hand calculations, reference to steam tables, and/or trial-and-error iteration in MELGEN, it is not recommended for new calculations. In all cases, the input is checked for completeness and consistency. A number of details are available to reduce the amount of information which must be supplied to define, for example, a saturated volume.

1.3 Pool/Atmosphere Mass and Energy Transfer

CVH input allows two choices for thermodynamic modeling in each control volume, referred to as *equilibrium* and *nonequilibrium*; the user should be aware that the latter is *not* the same as "nonequilibrium" models in codes such as TRAC and RELAP5. Details may be found in the Control Volume Thermodynamics (CVT) Package Reference Manual. We recommend that the nonequilibrium option be used in general; the equilibrium option is retained primarily for historical reasons, but may be appropriate in special cases.

When nonequilibrium thermodynamics is used in control volume, mass and energy transfers between the pool and atmosphere are determined by the thermomechanical state of the materials in the control volume. In particular, these transfers depend on the temperatures of the pool and atmosphere, the materials in the atmosphere, the velocity of the materials, etc. The control volume hydrodynamics package calculates this energy and mass transfer between the pool and atmosphere explicitly. The transfer is decomposed into a conduction/convection mode and a boiling/flashing mode.

When equilibrium thermodynamics is specified, the transfer of mass and energy between the pool and the atmosphere is implicitly determined by the assumption that the pool and the atmosphere have equal temperatures. Thus, for example, if energy is deposited only in the atmosphere, the pool temperature will also rise and water vapor may be generated. Mass and energy transfers between pool and atmosphere are effectively instantaneous.

1.3.1 Conduction/Convection Driven Transfer

Description of phenomena at the pool surface requires simultaneous solution of the equations of heat and mass transfer. This involves finding the temperature of the pool surface which satisfies the requirements that

- (1) The evaporation or condensation mass flux is that given by the mass diffusion equation for the existing gradient in the partial pressure of water vapor between the surface and the bulk atmosphere,

- (2) The net heat delivered to the interface by convection, conduction, and radiation is consistent with the latent heat required by the evaporation or condensation mass flux, and
- (3) The partial pressure of water vapor at the pool surface corresponds to saturation at the surface temperature.

The heat flows from the atmosphere to the pool surface and from the pool to the pool surface are calculated from heat transfer coefficients (subject to a lower limit defined by conduction) and the bulk pool and atmosphere temperatures. Both convection and radiation are considered in evaluating the heat transfer coefficients. Energy may also be deposited "in" the surface by other packages; this option is currently used only for radiation from the COR package. The constants in the heat transfer coefficients are defined by sensitivity coefficients in C4407(*). For more details, see the CVH/FL Reference Manual.

1.3.2 Flashing Mode Mass and Energy Transfer

A source of heat within the pool or a reduction in pressure in the control volume may result in pool boiling or flashing, respectively. Water vapor appears in the pool, steam bubbles rise to the surface, and mass and energy are transferred from the pool to the atmosphere. The remaining pool may be two phase if all the steam bubbles have not risen to the surface.

The model in the control volume package is simple. It assumes a constant bubble rise velocity, v_B , given by sensitivity coefficient C4407(1), with a default value of 0.3 m/s. It also assumes that the steam flow is a linear function of altitude in the pool, zero at the bottom, and constant throughout a timestep. These assumptions are sufficient to calculate the mass transferred to the atmosphere during a timestep. If the resulting transfer of water vapor is not sufficient to reduce the void fraction in the pool to 0.40 or below, an additional mass of water vapor is instantaneously transferred to do so. The maximum permitted void fraction is coded as a sensitivity coefficient, C4407(11). For more details, see the CVH/FL Reference Manual.

1.4 Mass and Energy Sources and Sinks

CVH input allows the definition of explicit sources and sinks (negative sources) of mass and/or energy. Additional sources and sinks may be imposed by other packages during a MELCOR calculation; these are treated automatically and do not require input to CVH. Heat sources are included from the Core (COR), Cavity (CAV), Fan Cooler (FCL), Fuel Dispersal Interactions (FDI), RadioNuclide (RN), Spray (SPR), and Heat Structure (HS) packages. Because a thermochemical reference point is used in thermodynamics, gas combustion modeled in the Burn (BUR) package does *not* involve an explicit heat source; the heat of combustion is implicit in the enthalpy functions as discussed in the CVH/FL

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Reference Manual. Mass sources arise from CAV and SPR, from oxidation reactions in BUR, COR, and FDI, and from condensation/evaporation, structural degassing, and melting of ice (in ice condensers) in HS.

Explicit CVH sources may be defined in terms of data from the Control Function (CF), Tabular Function (TF), and/or External Data File (EDF) packages; multiple sources may be defined in each control volume. Each mass source is associated with a specific numbered material. An energy source is associated with either the pool or the atmosphere. The association may be either direct or implicitly defined by the appropriate phase for a coupled mass source.

Sources may be defined as integrals or as rates. Rates may be either absolute or normalized per unit mass or per unit volume. For a source that changes rapidly, the user should give serious consideration to use of the integral source (IESFLG = 0 or 1 on the CVHnnnCk input record). With these sources, the mass or energy added during each CVH advancement is defined by differences in the running integral. The total added through any point in time is therefore forced to match the desired total given by the defining tabular or control function. If rates are specified, on the other hand, an interpolated value is imposed as a constant over a CVH advancement; the integral of the interpolated values may be very different from the integral of the original data.

Energy sources and sinks may be defined independent of any mass sources, but if a mass source is present in a control volume, the associated enthalpy must be included in the energy source(s) for the corresponding phase—pool or atmosphere—of that volume. (Enthalpy must be used rather than internal energy, to account for volume work done in the addition process.) Energy sources may be combined if desired; there is no need to define an energy source for each mass source. Input checking is restricted to confirming that each volume containing a mass source contains at least one energy source.

In order to deposit mass with the enthalpy corresponding to a known temperature, the contribution to the energy source must be consistent with the corresponding equation of state in MELCOR. Reference points in MELCOR are defined so that all chemical heats of reaction are implicit in the enthalpy functions, as in JANAF tables. However, in order to allow use of the familiar Keenan and Keyes equation of state for water, the reference points for water, oxygen, and all other oxygen-containing species were modified from the JANAF values. See the H₂O/NCG Reference Manual for more details.

As a result, while the user can obtain correct values for water from Keenan and Keyes steam tables, enthalpies for noncondensable gases must be calculated from data in the H₂O/NCG Reference Manual. However, noncondensable gases in MELCOR are modeled as ideal gases, and the enthalpy of an ideal gas is a function of temperature only. Therefore, additional input options, IESFLG = 8 and 9 on the CVHnnnCk record, are provided to allow the user to associate a temperature with a mass source. For these options (only) the tabular or control functions which define sources are associated in pairs, with the second function of each pair defining the *temperature* of the material added by the

immediately-preceding mass source function. This is sufficient to uniquely determine the enthalpy of a noncondensable gas (but not that of water). Therefore, these options are strongly recommended for use with sources of noncondensable gases.

The temperature options are much less useful for water sources, and should be used with care (if at all). Alternate methods of source definition are recommended; an example, using a time-specified volume (see Section 1.5) is given in Section 5.

If a temperature option *is* used for water, the definition of enthalpy is made unique by making a further assumption about the state of the added water. *It is because this assumption may not correspond to the user's intentions that the temperature option is not recommended for water.* If liquid water is added (as pool, material 1, or as fog, material 2), at a temperature below the critical temperature, it is assumed to be saturated at the designated temperature. If the intention was to add subcooled water, the difference can be substantial, particularly for low temperatures and high pressures. For temperatures above critical, the enthalpy of "liquid" water will be calculated at critical density; the results will almost certainly not be what the user desired. For addition of water vapor, material 3, the enthalpy will be calculated at the designated temperature and a density corresponding to saturation at 0.1 MPa. Because water vapor is far from ideal, the result may differ significantly from that desired.

1.5 Boundary Volumes

MELCOR hydrodynamics allows thermal-hydraulic boundary conditions to be defined by specifying the state of one or more volumes as functions of time. A *time-independent* volume may be defined by simply setting a flag on record CVHnnn01 and defining its state in the same manner as for a normal volume, using CVHnnnAk records. An alternate value of this switch allows the user to define a *time-specified* volume, with properties that change as a function of time to follow a history defined by tabular functions, control functions, and/or external data files. In this case, the numeric fields on CVHnnnAk records are simply replaced by references to appropriate tabular or control functions, or data channel of an external data file.

Initialization of a calculation to the normal operating conditions in a power plant (or other facility) can be tedious because of the numerous mass, momentum, and energy balances involved. Time-independent volumes can be used to establish fixed boundary conditions; for example, the state of the pressurizer serves to define the system pressure, while that of the steam generator secondaries is critical in defining the system temperature. Other parameters will stabilize after relatively short calculations with these volumes defined as time-independent, and the results reentered as initial conditions for the transient calculation of interest.

An option is available in MELCOR 1.8.4, to define a volume as time-independent until a user-specified time is reached, at which time it is *activated* and treated thereafter as a

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normal volume. This allows the initialization calculation to be performed as part of the transient calculation, with the time to end initialization defined on the optional CVHTENDINI record.

The essential difference from a normal volume is that the new state in a time-independent or time-specified volume is *defined* in the solution of the hydrodynamic equations. Any mass and/or energy sources (in addition to masses and energies advected by CVH or transferred by other packages) required to achieve that state are computed and recorded as additional sources created in the CVH package.

These volumes may be used in any way that a normal volume may be used, including definition of conditions for vapor and aerosol phenomena in the RN package. Fission products in the RN package are transported with material flows into and out of normal control volumes. They are treated as infinitely dilute in time-independent and time-specified volumes, and are therefore transported *into, but not out of* them. This is necessary to prevent fission products from being drawn back into a failed containment from the environment (modeled as a time-independent volume) if containment pressure falls below atmospheric pressure.

A time-specified volume may also be used to define the enthalpy of mass sources, and is particularly useful for water sources. See Section 1.4 and the example in Section 5.

2. User Input

CVH input to MELGEN defines the initial state of control volumes. There is no provision to modify conditions on restart; CVH input to MELCOR is limited to activation of additional optional output, which may be useful in identifying the source of calculational difficulties.

Several input options are included with the comment "do not use." These correspond to situations where the input will be accepted by MELCOR 1.8.4 but, because only partial coding has been provided, the option does not function properly. The information is provided as a warning to the user, because inadvertent activation of such an option could lead to a code failure that might be difficult to diagnose.

2.1 MELGEN User Input

The user input for the control volume hydrodynamics package is described below. The first set of input (CVTYPE n records) is optional and is used to define general types of control volumes for editing and accounting purposes (currently only used in the RN package edit routine). The second set of input (CV nnn XX records) is required and is used to describe each individual control volume defined for the given application. Up to 999 control volumes may be defined. Practically, the number is limited only by the available memory on the computer. Unless otherwise stated, if the field variable starts with I through N, it is an

integer. Unless otherwise stated, if the field variable starts with A through H or O through Z, it is a real number.

CVHTENDINI – Time to end initialization

Optional

The ICVACT input on record CVHnnn01 may be used to declare volumes as time-independent for an initialization segment of a calculation to allow stabilization of normal operating conditions in a power plant or other facility. With ICVACT = -3, this record defines the end of the initialization period; if absent, any volume so declared will be activated at the start of the MELCOR calculation. See discussion in Section 1.5.

- (1) TENDIN - Time to end initialization and activate all volumes with ICVACT = -3
(type = real, default = TSTART, units = s)

CVTYPEnn – Control volume type names

$01 \leq nn \leq 99$, nn is the control volume type number (ICVTYP) associated with input records CVnnn00 described below and with the control volume type number (ICVTYP) on RN input record RN2FLTxx00

Optional

This record allows the user to associate customized names with groups of related CVH package control volumes or RN package filters. For example, each of the control volumes associated with the reactor coolant system might be assigned ICVTYP=3 on the CVnnn00 record (described below) for each control volume in the group, and then this record would appear here as: CVTYPE03 'RCS.'

- (1) CVTYPE - User defined control volume type name.
(type = character*7, default = TYPEnn for nn < 99, or default = FILTERS for nn = 99)

CVnnn00 – Control volume name and switches

$1 \leq nnn \leq 999$, nnn is the user-assigned control volume number

Required

This record defines the name of the control volume and the attributes of the control volume.

- (1) CVNAME - User defined control volume name.
(type = character*16, default = none)

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- (2) ICVTHR - Control volume thermodynamics switch. The nonequilibrium option is recommended in general.
= 1 equilibrium ($T_{\text{pool}} = T_{\text{atmos}}$)
= 2 nonequilibrium ($T_{\text{pool}} \neq T_{\text{atmos}}$)
(type = integer, default = none, units = dimensionless)
- (3) ICVFF - Control volume flow flag. This flag is currently unused, but an input value from the following list must be specified.
= 0 not defined
= 1 horizontal flow
= 2 vertical flow
(type = integer, default = none, units = dimensionless)
- (4) ICVTYP - Type of control volume. This entry must be an integer between 1 and 99, inclusive. It is used to defined groups of associated control volumes for editing and accounting purposes only (currently only the RN package editing/accounting routine uses this flag to permit editing by CV type; see the RN Users' Guide for more information). The user may define a name to be associated with each type of control volume specified by this entry by including the CVTYPE $_{nn}$ records described above. By default the name associated with control type nn is TYPE $_{nn}$ for $01 \leq nn \leq 98$, while control type 99 is reserved for FILTERS by default.
(type = integer, default = none, units = dimensionless)

CV $_{nnn}01$ – Control volume switches

$1 \leq nnn \leq 999$, nnn is the user-assigned control volume number
Optional

This record allows the user to specify that no fog may exist in the control volume atmosphere. In this case, all water will be put into the pool.

A volume may also be declared "time-independent" or "time-specified." A volume may further be declared to be "time-independent" only during an initialization segment of a calculation, and become a normal volume thereafter. See discussion in Section 1.5. The time to end initialization is defined on the CVHTENDINI record.

Other options, marked "do not use" are listed. While the input may be accepted by the input processor, the models are incomplete, and do not function correctly.

- (1) IPFSW - Pool/no pool, fog/no fog switch.
= 0 pool, fog allowed (default)
= 1 no pool, fog allowed** do not use**
= 2 pool allowed, no fog (any liquid water is moved to pool)\

(type = integer, default = none, units = dimensionless)

- (2) ICVACT - Active/inactive switch.
 = 0 active, with state advanced by integrating the conversation equations, (default)
 = 1 inactive** do not use**
 = -1 time-independent
 = -2 properties specified as a function of time
 = -3 equivalent to -1 (time-independent) for TIME < TENDIN, and to 0 (active) for TIME ≥ TENDIN. TENDIN is defined on record CVHTENDINI
 (type = integer, default = 0, units = dimensionless)

CVnnn02 – Control volume initial velocities

1 ≤ nnn ≤ 999, nnn is the user-assigned control volume number

Optional

Average velocities in the control volume atmosphere and pool are used by the CVH, COR, and HS packages in calculation of heat transfer coefficients. This record may be used to define nonzero initial values of these velocities, which will be used until internally calculated values become available during the first advancement in MELCOR.

- (1) VLATMO - Velocity of atmosphere.
 (type = real, default = 0.0, units = m/s)
- (2) VLPOLO - Velocity of pool.
 (type = real, default = 0.0, units = m/s)

CVnnn03 – Control volume area for velocity calculation

1 ≤ nnn ≤ 999, nnn is the user-assigned control volume number

Optional

During advancement, the velocities in each control volume are internally calculated from the area of the control volume and the area, void fraction and velocities in the flow paths connected to that control volume. The default value for the control volume area is given by its volume divided by its height.

- (1) CVARA - Control volume area used for velocity calculation.
 (type = real, default = volume/height, units = m²)

CvnnnA0 – Switch for type of thermodynamic input

1 ≤ nnn ≤ 999, nnn is the user-assigned control volume number

Optional

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The user must provide sufficient information to define the initial thermodynamic state of the control volume. The fundamental internal variables in MELCOR are mass and internal energy, but options are provided which allow the user to specify the state in terms of more commonly available quantities. If these options are employed, the user-input quantities are used to calculate mass and energy. These are then used as arguments to the equation of state in the Control Volume Thermodynamics package, which may not reproduce input pressures and temperatures exactly. In addition, if nonequilibrium conditions (unequal pool and atmosphere temperatures) are input for a volume in which equilibrium thermodynamics is specified (ICVTHR = 1 on record CVnnn00), the input will be processed and the resulting (nonequilibrium) contents equilibrated. Three input options are available:

- (1) Direct mass and energy input. This option is useful primarily for matching conditions in previously-performed MELCOR calculations.

Input the mass and total internal energy of each material present. The internal energy must be consistent with equations of state used in MELCOR with respect to the thermochemical reference point employed.

- (2) Pressures, temperatures, and mass fractions input. This option is retained for compatibility with MELCOR versions prior to 1.7.0.

Input pressures and/or temperatures. Specify the location of water as mass fractions in the pool, fog, and/or atmosphere. Specify the composition of the noncondensable gas in the atmosphere as mass fractions. Actual amounts of all materials are then inferred from pressures and temperatures.

- (3) Separate pool and atmosphere input. This option is recommended for normal applications. It is the only option permitted for time-specified volumes (ICVACT = -2 on the CVnnn01 record).

Input pressures and/or temperatures. Specify the amount of pool as a mass, volume, or surface elevation. Specify the composition of the atmosphere in terms of its water content (partial pressure, relative humidity, or dewpoint temperature) and the mole fractions of noncondensable gases. An initial void fraction in the pool and/or fog content in the atmosphere may also be specified.

- (1) ITYPH - Type of thermodynamic input
(type = integer, default = 3, units = dimensionless)
= 1 material masses and energies
= 2 pressures, temperatures, and mass fractions
= 3 separate pool and atmosphere input

CVnnnAk – Thermodynamic input

$1 \leq nnn \leq 999$, nnn is the user-assigned control volume number

$1 \leq k \leq Z$, k is a sequencing character

Required

The thermodynamic input consists of data pairs. The first datum is a character variable identifying the quantity input, and the second is a real number giving its value. The character variable (first datum) may be constructed from one or two fields; if two, the second is a material number, separated from the first by a period. Both elements of a data pair must be on the same record.

Recall that

n = 1 is pool.

n = 2 is fog (liquid water in atmosphere).

n = 3 is water vapor in atmosphere.

n = 4,5,... are noncondensable gases (identified by input to the NCG package), and that MELCOR pressures are defined at the pool/atmosphere interface, the top of the pool or bottom of the atmosphere.

The input variables required, and the treatment of defaults, are different for each type of thermodynamic input (ITYPTH). The input for time-independent volumes is the same as for normal volumes; that for time-specified volumes is discussed following the description of input for ITYPH = 3.

For ITYPH = 1 (Mass and energy input)

ETOT.n - Total internal energy of material n.
(type = real, default = 0.0, units = J)

MASS.n - Mass of material n.
(type = real, default = 0.0, units = kg)

For ITYPH = 2 (Mass fraction input)

Input the total volume pressure, the partial pressure of water vapor in the atmosphere, and the temperatures of the pool and of the atmosphere. Specify the partition of water among pool, atmosphere, and fog as water mass fractions; the actual masses are implicitly defined by the temperatures, the pressures and the total volume. (If both water vapor and fog are present, the partial pressure of water in the atmosphere must correspond to saturation at the atmosphere temperature.)

Specify the composition of the noncondensable gas in the atmosphere as noncondensable gas mass fractions; the actual amounts are implicitly defined by the difference between the partial pressure of water vapor in the atmosphere and the total pressure. The control volume pressure is defined as the pressure at the

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pool/atmosphere interface. If no pool is present, it is the pressure at the lowest elevation in the cell. If no atmosphere is present, it is the pressure at the highest elevation of the cell.

- MFRC.n - Mass fraction of material n. If water is present, the mass fractions for materials 1 through 3 must sum to 1.0. If noncondensable gases are present, the mass fractions for materials 4,... must sum to 1.0.
(type = real, default = 0.0, units = dimensionless)
- PVOL - Control volume pressure (pool pressure if a pool is present). Must be input if a pool is present (MFRC.1 > 0.0). If there is no pool, and PVOL is not input, the pressure in the control volume will be set to the pressure of water vapor in the atmosphere. In this case, no noncondensable gas is allowed.
(type = real, default = see discussion, units = Pa)
- PH2O - Partial pressure of water vapor in the atmosphere. If negative, the partial pressure of water vapor will be set to the input total volume pressure (PVOL); if PVOL is not input (permitted if there is no pool), PH2O is interpreted as the total pressure. In either case, no noncondensable gases are allowed. PH2O should be input as 0.0 if there is no pool and no water is present in the atmosphere.
(type = real, default = see discussion, units = Pa)
- TATM - Temperature of atmosphere. If negative or not input, the saturation temperature at the partial pressure of water in the atmosphere (PH2O) will be used.
(type = real, default = -1.0, units = K)
- TPOL - Temperature of pool. If negative or not input, the temperature of the pool is set to saturation at the pool pressure (PVOL).
(type = real, default = -1.0, units = K)

For ITYPH = 3 (Separate pool and atmosphere input)

Pool Input

If a pool is present, specify the amount of pool using one (and only one) of the following (if there is no pool, *none* of these variables should be input):

- MASS.1 - Mass of pool.
(type = real, default = 0.0, units = kg)
- VPOL - Volume of the pool.
(type = real, default = 0.0, units = m³)

- ZPOL - Elevation of the pool surface.
(type = real, default = none, units = m)

If a pool is present, specify its thermodynamic state: specify both its pressure *and* temperature (less than saturation for the given pressure) if subcooled; either its pressure *or* temperature if saturated. If it is subcooled, the pressure may be defined by the corresponding saturation temperature. If it is saturated, an initial void fraction may also be defined.

- PVOL - Control volume (pool) pressure. If zero, negative, or not input, the volume pressure is set to saturation at either TSAP, if input, or at the pool temperature (TPOL).
(type = real, default = 1.0, units = Pa)

- TPOL - Temperature of pool. If zero, negative, or not input, the temperature of the pool is set to saturation at the pool pressure (PVOL).
(type = real, default = -1.0, units = K)

- TSAP - Saturation temperature of pool, used to define the pressure (which is also the total control volume pressure). If both PVOL and TSAP are zero, negative, or not input, the pressure of the pool is set to saturation at the pool temperature (TPOL).
(type = real, default = -1.0, units = K)

- VOID - Void fraction in the pool, in the range $0.0 \leq \text{VOID} < 1.0$. Because noncondensibles may not reside in the pool, any bubbles must be water vapor. Therefore, input of VOID is permitted only for a saturated pool. If not input, the pool void fraction will be zero.
(type = real, default = 0.0, units = dimensionless)

The atmosphere, including fog if present, then occupies the remainder of the control volume. *If the pool fills the volume (as specified by VPOL or ZPOL), no atmosphere properties may be input.* If a pool is present, the volume pressure has already been defined; if *no* pool is present, the control volume pressure must still be specified.

- PVOL - Control volume pressure. If zero, negative, or not input, and not defined by pool input (as saturation at the pool temperature), the volume pressure is set to saturation at the atmosphere temperature (TATM), which must then be included in the input.
(type = real, default = -1.0, units = Pa)

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Atmosphere Input

If an atmosphere is present: specify both the partial pressure of water vapor in the atmosphere (directly or by the relative humidity or the dewpoint temperature) and the temperature (greater than saturation for the given vapor pressure) if the atmosphere is superheated; specify only the partial pressure of water or the temperature if it is saturated. Note that input of a non-negative value for PH2O or of a value for either RHUM or TDEW fully defines the water vapor content of the atmosphere. Over-specification (by input of more than one of these) is not permitted.

- PH2O, - Partial pressure of water vapor in the atmosphere. If negative or not input, the partial pressure of water in the atmosphere will be set to saturation or to an optionally input relative humidity (RHUM) at the atmosphere temperature (TATM), or to saturation at an optionally input dewpoint temperature (TDEW), one of which must then be input.
(type = real, default = -1.0, units = Pa)
- RHUM - Relative humidity of the atmosphere, in the range $0.0 \leq \text{RHUM} \leq 1.0$. Relative humidity is defined as the ratio of the partial pressure of water vapor to saturation pressure at the atmosphere temperature.
(type = real, default = 1.0, units = dimensionless)
- TATM - Temperature of atmosphere. If zero, negative, or not input, the saturation temperature at the partial pressure of water in the atmosphere (PH2O) will be used.
(type = real, default = -1.0, units = K)
- TDEW - Dewpoint temperature in the atmosphere. The dewpoint temperature is defined as the saturation temperature corresponding to the partial pressure of water vapor.
(type = real, default = none, units = K)

If noncondensable gas is present in the atmosphere, specify its composition as mole fractions; the actual amounts of the various gases are implicitly defined by the difference between the partial pressure of water vapor in the atmosphere and the total pressure. If this difference is zero, no input is permitted.

- MLFR.n - Mole fraction of noncondensable gas n. Used only for ITYPH = 3. If noncondensable gases are present (not present), the sum for materials 4,... should equal 1.0 (0.0).
(type = real, default = 0.0, units = dimensionless)

If an atmosphere is present, and the partial pressure of water vapor corresponds to saturation for its temperature, optionally specify the fog content either directly by its mass or indirectly by the volume fraction in the total atmosphere (but not both).

- MASS.2 - Mass of fog.
(type = real, default = 0.0, units = kg)
- VFOG - Volume fraction of fog in the atmosphere in the range $0.0 \leq$
VFOG < 1.0 .
(type = real, default = 0.0, units = dimensionless)

For Time-Specified Volumes

The properties of a volume may be specified as user-defined functions of time by setting ICVACT = -2 on record CVnnn01. The permitted input variables are a subset of those described above for ITYPH = 3 (which is the only permitted value of ITYPH for this type of volume). The same keywords (PVOL, etc.) are used, but with a function or file reference replacing the constant value. Permitted references are TF.n, CF.n, or EDF.n.m, denoting tabular function n, control function n, or channel m of external data file n, respectively. A constant value must be specified by reference to a constant tabular or control function or a constant EDF data channel.

Keywords that are currently recognized are PVOL, ZPOL, TPOL, VOID, TATM, PH2O, and MLFR.n. They are interpreted as follows:

- PVOL - Control volume pressure. Required.
(type = real, default = none, unit = Pa)
- ZPOL - Elevation of pool surface. Optional. **If absent, no pool will ever be present, and input of TPOL or ZPOL is not permitted.**
(type = real, default = none, unit = m)
- TPOL - Temperature of pool. Optional, permitted only if ZPOL is input. Note that TPOL must be specified if a subcooled pool will ever be present. During periods when there is no pool (as specified by ZPOL), the value of TPOL will not be used. When a pool is present, a value of TPOL equal to or not more than C4409(6) (default, 1.0 K) above saturation of PVOL will be interpreted as saturation. Any greater superheat will result in termination of the calculation. Note that MELCOR thermodynamics does not permit a superheated pool; the tolerance on input is intended only to accommodate minor discrepancies resulting from interpolation in tabular data when a saturated pool is intended.

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If ZPOL is input and TPOL is not, the pool (if present) will be saturated at PVOL.

(type = real, default = -1.0, unit = K)

- VOID** - Void fraction in the pool. Optional, permitted only if ZPOL is input. Ignored unless the pool is saturated. If not input, the pool void fraction will be zero.
(type = real, default = 0.0, unit = dimensionless)
- TATM** - Temperature of atmosphere. Optional. If an atmosphere is present and TATM is not input, the atmosphere will consist of saturated water vapor at PVOL. Note that TATM must be specified if the atmosphere will ever be superheated or contain noncondensable gases. It is impossible for input checking to assure that PVOL and TATM will always specify a superheated state. Therefore, if TATM is specified, the composition of noncondensibles (MLFR.n) must also be specified, see below.
(type = real, default = 1.0, unit = K)
- PH2O** - Partial pressure of water vapor in the atmosphere. Optional, currently permitted only if TATM is input. In execution, a value of PH2O corresponding to saturation at TATM or at a temperature not more than C4409(6) (default, 1.0 K) below TATM will be interpreted as saturation at TATM. Any greater subcooling will result in termination of the calculation. Note that MELCOR thermodynamics does not permit a supersaturated atmosphere; as discussed for keyword TPOL, the tolerance on input is intended only to allow for imprecision in interpolation. If TATM is input and PH2O is not, the partial pressure will be the minimum of PVOL and saturation at TATM.
(type = real, default = 1.0, unit = Pa)
- MLFR.n** - Mole fraction of noncondensable gas n ($n \geq 4$). Required if TATM is input, not permitted otherwise. (If TATM is input, both P and T will be specified. If input, the values must sum to 1.0 within C4409(5) (default, .001); the tolerance allows for some imprecision in interpolation of tabular data.
(type = real, default = 0.0, unit = dimensionless)

The tabular function, control function, or external data file should define the variable as a function of time in the appropriate SI units. For example, given the input

PVOL EDF.101.3

channel 3 of external data file 101 should contain the desired pressure in Pascals.

CVnnnBk – Altitude/volume table

$1 \leq nnn \leq 999$, nnn is the user-assigned control volume number

$0 \leq k \leq Z$, k is a sequencing character

Required

The input data are altitude-hydrodynamic volume pairs. The first element of a pair is the altitude and the second is the volume initially available to be occupied by material in the CVH package (free volume). Virtual volume is not included in these input data. At least two pairs (four numbers) must be input. The volume corresponding to the lowest elevation must be zero. For other data pairs: if the input volume is positive, it is interpreted as the total volume between the bottom (lowest elevation input) and the current input elevation; if it is negative, the absolute value of the volume is interpreted as the volume change from the next-lower input elevation.

Multiple data pairs may be on one record, limited only by the permitted length of input records (100 characters). A data pair may not be split between two records. (type = real, default = none, units = m and m³)

CVnnnCk – External Mass and Energy Sources

$1 \leq nnn \leq 999$, nnn is the user-assigned control volume number

$0 \leq k \leq Z$, is a sequencing character

Optional

These records are used to define user input mass and energy (enthalpy) sources and sinks, in addition to those calculated by other packages. As discussed in Section 1.4, such sources may be prescribed using control functions, tabular functions or external data files. Two formats are allowed; the first (original) format permits only control or tabular functions. The second allows additional options, including use of external data files and imposition of a scaling factor, but does not allow use of a temperature to specify the energy associated with a mass source.

Format 1

Each record consists of an identifier field, a character field specifying the destination of the mass or energy, the tabular function or control function number and a switch specifying the interpretation of the function.

Mass and energy sources may, in general, be defined independently so long as the enthalpy associated with each mass source is properly accounted for. However, a "TE" type source defines an energy source in terms of the temperature of an associated "MASS.n" source. This mass source must immediately precede the "TE" source when the list of sources for the control volume is ordered according to record

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identifiers (that is, by the sequencing character k in CVnnnCk). If this requirement is not met, and there is no "MASS.n" source record immediately preceding a "TE" source record, MELGEN will trap the error, write a diagnostic, and not write a cycle zero restart.

The only values of the input switch IESFLG that may be used with a "TE" source are 8 and 9; conversely, these values may only be used with a "TE" source. These sources are *not* recommended for use with water. See the discussion in Section 1.4.

- (1) CTYP - Character field defining mass or energy source.
- AE External enthalpy source for the atmosphere.
 - PE External enthalpy source for the pool
 - TE Specific enthalpy of the previous mass source is defined as a function of temperature. Temperature is defined by the tabular function or control function. An atmosphere or pool destination is determined by the mass source.
- MASS.n Mass source for material n (as always, material 1 is pool, 2 is fog, 3 is atmospheric vapor, and $n \geq 4$ is a noncondensable gas identified by input to the NCG package).
- (type = character*8, default = none)
- (2) IESTYP - The control function or tabular function numbers associated with the third field (IESFLG).
- (type = integer, default = none, units = dimensionless)
- (3) IESFLG - Input switch.
- = 0 Use tabular function IESTYP for cumulative source through the current time.
 - = 1 Use control function IESTYP for cumulative source through the current time.
 - = 2 Use tabular function IESTYP for source rate.
 - = 3 Use control function IESTYP for source rate.
 - = 4 Use tabular function IESTYP for source rate per unit mass.
 - = 5 Use control function IESTYP for source rate per unit mass.
 - = 6 Use tabular function IESTYP for source rate per unit volume.
 - = 7 Use control function IESTYP for source rate per unit volume.
 - = 8 Use tabular function IESTYP for temperature to define specific enthalpy of immediately-preceding mass source.

= 9 Use control function IESTYP for temperature to define specific enthalpy of immediately-preceding mass source.
(type = integer, default = none, units = dimensionless)

Format 2

Each record consists of an identifier field, a character field specifying the type of source, a field specifying whether the data are rates or integrals, a field specifying the source of the data, and an optional scale factor for that data.

- (1) CTYP - Type of source.
 - ENERGY.A Enthalpy source for the atmosphere.
 - ENERGY.P Enthalpy source for the pool.
 - MASS.n Mass source for material n (as always, material 1 is pool, 2 is fog, 3 is atmospheric vapor, and n ≥ 4 is a noncondensable gas identified by input to the NCG package).
 - FILE Vector of mass and enthalpy sources, obtained from an external data file. The optional FLnnn06 record can be used to record the mass and enthalpy flows through a flow path in an appropriate format for this use, with the INTEGRAL option below.
(type = character*8, default = none)

- (2) INTERP - Interpretation of source data.
 - RATE Data are to be interpreted as rates (W or kg/s)
 - INTEGRAL Data are to be interpreted as cumulative (J or kg)
 (type = character*8, default = none)

- (3) IESSRC - Character field defining location of source data.
 - For ENERGY.f or MASS.n sources:
 - CF.nnn Data from control function nnn
 - TF.nnn Data from tabular function nnn
 - EDF.nnn.iii Data from channel iii of external data file nnn
 (type = character*11, default = none)

 - For FILE sources:
 - EDF.nnn Data from external data file nnn, which must contain at least NUMMAT+2 channels (where NUMMAT is the number of materials in the problem). Of these, the first NUMMAT+2 channels will be used as data for MASS.1, MASS.2, ..., MASS.NUMMAT, ENERGY.P and ENERGY.A sources, in that order.

- (4) ESSCAL - Scale factor for data from IESSRC.
(type = real, default = 1.0, units = dimensionless)

2.2 MELCOR User Input

The CVH database cannot be modified at a MELCOR restart at this time. However, a diagnostic tracing option may be activated as an aid in identifying problem areas in a calculation.

CVHTRACE – Calculational trace activation Optional

If this record is present, the progress of the solution of the CVH hydrodynamic equations will be tracked, and informative messages will be written to the diagnostic file (MELDIA). See Section 7.2 for a discussion of these messages. The output is voluminous, and the trace should only be activated for short runs. Presence of the CVHTRACE record is *not* recorded in the restart file. Therefore, the trace is active if and only if this record is present in MELCOR input for the current execution.

3. Sensitivity Coefficients

The *sensitivity coefficient* feature in MELCOR is a powerful feature that gives the user the ability to change selected parameters the physics models that would otherwise require modification of the Fortran source code. Their use is described in Section 7 of the MELCOR EXEC Users' Guide.

3.1 CVH Sensitivity Coefficients

The sensitivity coefficients for all hydrodynamic modeling involving the CVH and FL packages have identifier numbers from 4400 to 4599. This section contains brief descriptions of these sensitivity coefficients. Additional information, including references for models and equations, may be found in the Thermal Hydraulic (CVH and FL) Packages Reference Manual; Appendix A in that Reference Manual provides information to aid in locating the specific locations where each sensitivity coefficient is discussed.

The CVH package may use two or more smaller steps to advance through a MELCOR system timestep; each such step is referred to as *subcycle*. Timestep controls are based on changes over the system timestep. If an iteration fails to converge, or if an error is encountered in the thermodynamics, CVH will attempt to repeat the calculation with a reduced subcycle step before modifying the MELCOR system timestep.

Several sensitivity coefficients in the CVH database are currently unused. Input for unused coefficients is accepted (for compatibility with older versions of MELCOR), but has no effect on the calculation. For completeness, these coefficients are still listed in the discussion below.

4400 – Timestep Control

These coefficients are used to control the system timestep. Array elements 4-11 are used to define limits on the maximum change desired or permitted in the pressure or temperature in any volume during a single timestep. For example, the CVH package will attempt to control the maximum pressure change in any volume to satisfy $|P^n - P^o| \leq C4400(4)P + C4400(5)$ by requesting a system timestep for the *next* timestep such that this condition would not be violated for the rates of change calculated on the last completed timestep. If, however, the result on completion of a timestep is that $|P^n - P^o| > C4400(6)P + C4400(7)$ for some volume, CVH will request a MELCOR fallback, and the entire advancement will be repeated with an appropriately reduced timestep. Changes in pool and atmosphere temperatures are treated similarly.

The default values for C4400(4-11) were chosen to permit a safety factor of roughly 2 between the desired maximum changes and the changes which will lead to a fallback. A similar safety factor should be maintained if the default values are modified.

- (1) - Maximum fraction of material Courant timestep allowed.
(default = 0.5, units = dimensionless, equiv = DTFRCC)
- (2) - Timestep reduction fraction used when the number of significant digits from the matrix solver is less than two. If the matrix is poorly conditioned, the number of significant digits for the velocities may be so small as to be meaningless. When the number of significant digits is less than two, then the system timestep will be reduced for the next cycle.
(default = 0.9, units = dimensionless, equiv = DTFRCD)
- (3) - The fraction of the (old) system timestep used when the equation of state package returns an error for a calculation involving no flow paths; the cycle is repeated with the system timestep cut to this fraction of its previous value. (For a calculation involving flow paths, CVH will first reduce the subcycle step.)
(default = 0.15, units = dimensionless, equiv = DTEOSF)
- (4) - Relative change contribution to the maximum desired pressure change in any volume during a single timestep. Used with C4400(5).

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(default = 0.05, units = dimensionless, equiv = DPROK)

- (5) - Absolute change contribution to the maximum desired pressure change in any volume during a single timestep. Used with C4400(4).
(default = 0.0, units = Pa, equiv = DPAOK)
- (6) - Relative change contribution to the maximum permitted pressure change in any volume during a single timestep. Used with C4400(7).
(default = 0.1, units = dimensionless, equiv = DPRCUT)
- (7) - Absolute change contribution to the maximum permitted pressure change in any volume during a single timestep. Used with C4400(6).
(default = 0.0, units = Pa, equiv = DPACUT)
- (8) - Relative change contribution to the maximum desired temperature change in any volume during a single timestep. Used with C4400(9).
(default = 0.1, units = dimensionless, equiv = DTROK)
- (9) - Absolute change contribution to the maximum desired temperature change in any volume during a single timestep. Used with C4400(8).
(default = 1.0, units = K, equiv = DTAOK)
- (10) - Relative change contribution to the maximum permitted temperature change in any volume during a single timestep. Used with C4400(11).
(default = 0.2, units = dimensionless, equiv = DTRCUT)
- (11) - Absolute change contribution to the maximum permitted temperature change in any volume during a single timestep. Used with C4400(10).
(default = 1.0, units = K, equiv = DTACUT)

4401 – Velocity Convergence Criteria

The velocities are calculated by inverting a system of linear equations. The coefficients in the matrix and the inhomogeneity vector are functions of the velocity. The velocities are iterated until the difference between successive iterates is sufficiently small that $|v^i - v^{i-1}| \leq C4401(1) (|v^i| + |v^{i-1}|) + C4401(2)$ for all flows (the superscript refers to the iteration number). Additional tests identify reversed flows.

- (1) - Relative convergence criterion.
(default = .09, units = dimensionless, equiv = CVELR)
- (2) - Absolute velocity convergence criterion.
(default = 0., units = m/s, equiv = CVELA)

- (3) - Maximum number of iterations permitted before solution is repeated with a decreased (subcycle) timestep. The default value of 0.0 is used to specify a limit scaled to the size of the problem; the actual value used is 8. + the number of flow paths in the nodalization.
(default = 0., units = dimensionless, equiv = XPASMX)
- (4) - Number of iterations after which velocities will be considered converged if there is no significant effect (less than 0.05%) on pressures. A value of 0.0 gives the default treatment, which is not to consider the relaxed convergence criterion. (*Treatment in versions prior to 1.8.2 corresponded to a value of 8.0.*)
(default = 0.0, units = dimensionless, equiv = XPASP)

4402 – Minimum velocity to be considered for choking calculation

Velocities calculated from the flow (momentum) equations subjected to limits imposed by critical flow correlations. The tests will be bypassed unless either the pool velocity or the atmosphere velocity is greater than a threshold value.

- (1) - Velocity below which choking tests are bypassed.
(default = 20., units = m/s, equiv = CVELMN)

4403 – Not used

4404 – Friction Factor Parameters

A two phase friction factor is calculated for each flow path segment. Laminar flow is assumed if the Reynolds number is less than C4404(14), turbulent flow is assumed if the Reynolds number is greater than C4404(15), and a transition region for Reynolds numbers between these values. The friction factor for laminar flow is determined by dividing the value of the variable SLAM by the value of the Reynolds number. The default value of SLAM is C4404(13). The Colebrook-White equation

$$\frac{1}{\sqrt{f}} = C4404(1) - C4404(2) \log_{10} \left(C4404(3) \frac{e}{D} + \frac{C4404(4)}{Re \sqrt{f}} \right)$$

is used to define the friction factor, f , for turbulent flow, where e is the surface roughness and D is the hydraulic diameter.

Re is the Reynolds number based on the hydraulic diameter and a two-phase mixture viscosity, μ_M , defined by

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$$\mu_M = \mu_p [C4404(6) - \alpha] [C4404(10) + C4404(11) \alpha] + \alpha \mu_A$$

where μ_p is the pool viscosity, α is the void fraction, and μ_A is the atmosphere viscosity. Note that, if $C4404(6) = 1.0$, it has the proper limits for $\alpha \rightarrow 0.0$ and $\alpha \rightarrow 1.0$.

- (1) - Coefficient in Colebrook-White correlation.
(default = 3.48, units = dimensionless, equiv = none)
- (2) - Coefficient in Colebrook-White correlation.
(default = 4.0, units = dimensionless, equiv = none)
- (3) - Coefficient in Colebrook-White correlation.
(default = 2.0, units = dimensionless, equiv = none)
- (4) - Coefficient in Colebrook-White correlation.
(default = 9.35, units = dimensionless, equiv = none)
- (5) - Value used in iterative solution. Should not be modified.
(default = $1.0/\ln(10) = 0.43429448190325182765$, units = dimensionless, equiv = none)
- (6) - Coefficient in two-phase viscosity correlation. Must be 1.0 to get proper limit for $\alpha = 1.0$.
(default = 1.0, units = dimensionless, equiv = none)
- (7) - Value used in iterative solution. Should not be modified.
(default = 14.14, units = dimensionless, equiv = XINOLD)
- (8) - Value used in iterative solution. Should not be modified.
(default = 0.0005, units = dimensionless, equiv = RELC)
- (9) - Value used in iterative solution. Should not be modified.
(default = 0.0, units = dimensionless, equiv = RELA)
- (10) - Coefficient in two-phase viscosity equation.
(default = 1.0, units = dimensionless, equiv = none)
- (11) - Coefficient in two-phase viscosity equation.
(default = 2.5, units = dimensionless, equiv = none)

- (12) - If the void fraction is less than this number, the atmosphere friction factor is set to zero. For greater void fractions, the atmosphere friction factor is linearly interpolated between zero and the value given by the basic model. (default = 0.9, units = dimensionless, equiv = none)
- (13) - Default coefficient for calculating laminar flow friction factor. (default = 16.0, units = dimensionless, equiv = none)
- (14) - Maximum value of Reynolds number for laminar flow. (default = 2000.0, units = dimensionless, equiv = none)
- (15) - Minimum value of Reynolds number for turbulent flow. (default = 5000.0, units = dimensionless, equiv = none)

4405 – SPARC Bubble Physics Parameters

The user may specify on an FLnnn02 input record that mass and energy exchange terms should be calculated for hot gases entering a pool from a flow path which connects to a control volume below the pool surface in that volume. Such gases are not considered to reside in the pool, but their interactions will be accounted for before the exiting gases are allowed to join the atmosphere in the control volume. Parametric models are used in MELCOR; efficiency terms are calculated to account for bubble rise distance and liquid subcooling. The bubble rise efficiency is given by

$$\varepsilon_z = \max \left\{ 0.0, \min \left[1.0, \frac{\Delta z - C4405(1)}{hC4405(2)} \right] \right\}$$

where z is the distance that bubbles rise through the pool and h is the flow path opening height. The water temperature efficiency is given by

$$\varepsilon_T = \max \left\{ 0.0, \min \left[1.0, \frac{T_{sat}(P) - T_p - C4405(3)}{C4405(4)} \right] \right\}$$

where $T_{sat}(P)$ is the saturation temperature at total pressure and T_p is the pool temperature. The net efficiency used is the product of ε_z and ε_T .

- (1) - Zero efficiency bubble rise height. (default = 0.01, units = m, equiv = DZZERO)

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- (2) - Full efficiency bubble rise height in terms of flow path junction heights.
(default = 1.0, units = dimensionless, equiv = DZEFF)
- (3) - Zero efficiency temperature difference between the pool and saturation temperatures.
(default = 0.1, units = K, equiv = DTMPZR)
- (4) - Full efficiency temperature difference between the pool and saturation temperatures.
(default = 5.0, units = K, equiv = DTEFF)
- (5) - Relative humidity of the steam at the surface.
(default = 0.99, units = dimensionless, equiv = PEFF)

4406 – Maximum Allowed Fog Density

The maximum mass of liquid water in the atmosphere (fog) divided by the volume of the atmosphere that will not be permitted to be larger than FOGDEN. Any excess liquid water is moved to the pool.

- (1) - Maximum fog density.
(default = 0.1, units = kg/m³, equiv = FOGDEN)

4407 – Pool/Atmos Heat/Mass Transfer Parameters

Energy and mass transfer occurs between the pool and atmosphere of a nonequilibrium volume when their temperatures differ. The models used are outlined briefly in Section 1.3 of this report, and described in greater detail in the CVH/FL Reference Manual.

The heat transfer coefficient for each phase is given by

$$h = \max(h_{forced}, h_{free})$$

Here h_{forced} is given by the TRAC correlation for horizontal stratified flow,

$$h_{forced} = C4407(2)\rho_{\varphi}c_{p,\varphi}V_{V,\varphi}$$

and h_{free} from the correlations for natural (free) convection for horizontal surfaces

$$h_{free,A} = \max \left[C4407(3)(Gr Pr)^{C4407(4)}, C4407(5)(Gr Pr)^{C4407(6)} \right] \frac{k_A}{X_A}$$

$$h_{free,P} = \max \left[C4407(7)(Gr Pr)^{C4407(8)}, C4407(9)(Gr Pr)^{C4407(10)} \right] \frac{k_P}{X_P}$$

where ρ is density, c_p is specific heat, v_V is volume velocity, k is thermal conductivity, X is characteristic length, ϕ refers to the phase (pool (P) or atmosphere (A)) and Gr and Pr are the Grashof and Prandtl numbers, respectively.

- (1) - Bubble rise velocity.
(default = 0.3, units = m/s, equiv = VELBUB)
- (2) - Coefficient for TRAC heat transfer coefficient correlation.
(default = 0.02, units = dimensionless, equiv = TRACC)
- (3) - Coefficient for turbulent atmosphere heat transfer correlation.
(default = 0.14, units = dimensionless, equiv = CTLATA)
- (4) - Exponent for turbulent atmosphere heat transfer correlation.
(default = 1/3, units = dimensionless, equiv = ETLATA)
- (5) - Coefficient for laminar atmosphere heat transfer correlation.
(default = 0.54, units = dimensionless, equiv = CTLALA)
- (6) - Exponent for laminar atmosphere heat transfer correlation.
(default = 1/4, units = dimensionless, equiv = ETLALA)
- (7) - Coefficient for turbulent pool heat transfer correlation.
(default = 0.25, units = dimensionless, equiv = CTLATP)
- (8) - Exponent for turbulent pool heat transfer correlation.
(default = 1/4, units = dimensionless, equiv = ETLATP)
- (9) - Coefficient for laminar pool heat transfer correlation.
(default = 0.25, units = dimensionless, equiv = CTLALP)
- (10) - Exponent for laminar pool heat transfer correlation.
(default = 1/4, units = dimensionless, equiv = ETLALP)

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- (11) - Maximum void fraction permitted in a control volume pool (enforcement is approximate)
(default = 0.4, units = dimensionless, equiv = ALPMAX)
- (12) - Maximum fraction of atmospheric water vapor permitted to condense during a (subcycle) timestep.
(default = 0.9, units = dimensionless, equiv = CFRMAX)

4408 – Pressure Iteration Parameters

Several submodels in the flow solution may be turned off if the user so desires. This capability is intended primarily for use in debugging by the code developers. The first element of the sensitivity coefficient array, C4408(1), entered as a single real number, is interpreted as five packed decimal digits, each controlling a single model. Setting any digit $\neq 0$ disables the corresponding model. Any or all of the digits may be nonzero as desired.

Setting the 100,000's digit $\neq 0$ disables the implicit treatment of bubble separation from two-phase pools. The resulting explicit calculation is similar (but not identical) to the model used in previous MELCOR versions through 1.8.2.

Setting the 10,000's digit $\neq 0$ disables the limitation on void fraction by depletion of the atmosphere.

Setting the 1,000's digit $\neq 0$ disables the redefinition of "old" velocities to preserve the "old" volume flow as the void fraction changes during the iteration.

Setting the 100's digit $\neq 0$ disables the calculation of momentum exchange between pool and atmosphere sharing a flow path.

Setting the 10's digit $\neq 0$ results in using pressures at the nominal junction elevation, rather than at the average elevation of a phase in the junction opening, in the acceleration term in the momentum equation.

Setting the 1's digit $\neq 0$ eliminates calculation of the implicit contributions to the head terms in the momentum equation.

- (1) - Submodel flags, controlling submodels in the flow solution.
(default = 0., units = dimensionless, equiv = XOPTN)
- (2) - A parameter used to allow the subcycle timestep to be increased whenever the convergence of velocities is much tighter than required by tolerances specified by sensitivity coefficient array 4401.
(default = 0.005, units = dimensionless, equiv = XXCONV)

4409 – Limits and Tolerances for Time-Specified Volumes

Certain limits are placed on values input from functions or tables to define the properties of time-specified volumes. If a pool is present, it must also be between the freezing point and the critical point. In addition, discrepancies greater than roundoff are tolerated in the consistency of input, to allow for such things as imprecise interpolation in coarse tables. Of particular concern is the need to be able to specify a saturated state when *both* temperature and pressure are input. Values outside these limits and/or tolerances will result in failure to create a restart file in MELGEN or in termination of the calculation in MELCOR.

- (1) - Minimum temperature.
(default = 1.0, units = K, equiv = TMIN)
- (2) - Maximum temperature.
(default = 1.0E4, units = K, equiv = TMAX)
- (3) - Minimum volume pressure.
(default = 1.0, units = Pa, equiv = PMIN)
- (4) - Maximum volume pressure.
(default = 1.0E8, units = Pa, equiv = PMAX)
- (5) - Tolerance on sum of NCG mole fractions compared to 1.0.
(default = 0.001, units = dimensionless, equiv = TOLMFR)
- (6) - Tolerance on saturation temperature, within which input corresponding to a superheated pool or a subcooled atmosphere will be treated as saturated.
(default = 1.0, units = K, equiv = TOLTS)

4410 – Vapor Velocity Enhancement during Direct Containment Heating

The largely parametric treatment of High Pressure Melt Ejection (HPME) in the Fuel Dispersal Interactions (FDI) package does not model coupling between the velocity of airborne debris and that of the volume atmosphere. One potentially important effect of the neglected coupling would be to increase the local gas velocities and therefore to enhance heat transfer from the atmosphere to structures in the volume. These coefficients (used only in volumes where HPME is occurring) allow a parametric treatment of the enhancement through modification of the velocities that will be used in evaluating heat transfer coefficients.

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- (1) - Enhancement factor applied to volume-averaged vapor velocities during direct containment heating.
(default = 1.0, units = dimensionless, equiv = VMULT)
- (2) - Minimum temperature of airborne debris for application of the enhancement.
(default = 1500., units = K, equiv = TDBMIN)

4411 – Limits and Tolerances for Iterations in the CVT Package

These coefficients are used to control the iterative calculations in evaluation of the mixed-material equation of state in the CVT package.

- (1) - Tolerance (relative) in determination of the temperature, given the density and the specific internal energy.
(default = 1.0E-6, units = dimensionless, equiv = TOLTR)
- (2) - Tolerance (relative) in matching the pressures of the pool and the atmosphere in a control volume. (The volume pressure is returned as a compressibility-weighted average of the two.)
(default = 2.0E-5, units = dimensionless, equiv = TOLPR)
- (3) - Tolerance (absolute) in matching the pressure of a subcooled pool to that of the atmosphere in a control volume. The alternate tolerance is made necessary by the near incompressibility of liquid water. The default value is slightly greater than the pressure change associated with roundoff in liquid density at atmospheric pressure on a 32-bit computer, and represents the limit in precision with which the pressure of a subcooled liquid can be determined from its density. Because the volume pressure is returned as a compressibility-weighted average of pool and atmosphere pressures, the effect on final pressure is greatly reduced if the volume contains a significant volume of atmosphere.
(default = 300.0, units = Pa, equiv = TOLPA)
- (4) - Minimum volume fraction to be assigned to the pool or the atmosphere in a control volume after thermodynamic calculation have been completed. Although MELCOR 1.8.2 used a (hard-wired) value of 1.0E-6, a nonzero value will result in inconsistent properties for a very small pool or atmosphere and interfere with convergence of iterations. This coefficient is provided to allow return to the older model, should the need arise.
(default = 0.0, units = dimensionless, equiv = VPHMIN)

4412 – Limits and Tolerances for Iterations in the CVH Package

These coefficients are used to control the iterative calculations in solution of the hydrodynamic equations in the CVH package.

- (1) - Permitted discrepancy between the implicitly projected value and the final value of the pool void fraction in any volume during solution of the implicit flow equations.
(default = 0.01, units = dimensionless, equiv = ALPTOL)

4413 – Flow Blockage Friction Parameters

These parameters are used to calculate the friction loss in a flow path that has been at least partially blocked by debris. The pressure drop will be based on a generalized Ergun equation in the form

$$K_{eff} = \left[C4413(1) + C4413(2) \left(\frac{1-\varepsilon}{Re} \right) + C4413(3) \left(\frac{1-\varepsilon}{Re} \right)^{C4413(4)} \right] \frac{(1-\varepsilon)L}{\varepsilon D}$$

where ε is the porosity, L is the path length, D is the particle diameter, and $Re = \rho j D / \mu$ is the Reynolds number based on the superficial velocity (volumetric flux) j , the fluid viscosity μ , and the particle diameter.

- (1) - Coefficient of turbulent term in generalized Ergun equation.
(default = 3.5, units = dimensionless, equiv = CTERG)
- (2) - Coefficient of laminar term in generalized Ergun equation.
(default = 300.0, units = dimensionless, equiv = CLERG)
- (3) - Coefficient of Achenbach term in generalized Ergun equation.
(default = 0.0, units = dimensionless, equiv = CCACH)
- (4) - Exponent in Achenbach term in generalized Ergun equation.
(default = 0.4, units = dimensionless, equiv = CPACH)
- (5) - Minimum porosity to be used in evaluating the correlation, imposed as a bound before K_{eff} is evaluated.
(default = 1.0E-6, units = dimensionless, equiv = PORMIN)

4414 – Minimum Hydrodynamic Volume Fraction

This parameter defines a fraction of the initial hydrodynamic volume in a control volume (as specified on CVHnnnBk records) that will be considered as available to hydrodynamic materials, regardless of virtual volume changes resulting from relocation of nonhydrodynamic materials such as core debris.

- (1) - Minimum fraction of the initial volume in a control volume that will always be available to hydrodynamic materials.
(default = 1.0E-4, units = dimensionless, equiv = FVMIN)

4. Plot Variables and Control Function Arguments

The variables in the control volume hydrodynamics package that may be used for plot variables and control function arguments are listed and described below. Within slashes (/ /) a 'p' indicates a plot variable and a 'c' indicates a control function argument.

CVH-CLIQLEV.n	/cp/	Collapsed liquid elevation in control volume n. (units = m)
CVH-CPUT	/p/	Total CPU usage by the RUN (time-advancement) portion of CVH package. (units = s)
CVH-CPUE	/p/	CPU usage for edit in RUN portion of CVH package. (units = s)
CVH-CPUC	/p/	CPU usage for calculations in RUN portion of the CVH package. (units = s)
CVH-CPUR	/p/	CPU usage to process restart file in RUN portion of CVH package. (units = s)
CVH-E.n	/p/	Specific internal energy in control volume n. (units = J/kg)
CVH-E.m.n	/cp/	Specific internal energy of material m in control volume n. (units = J/kg)
CVH-ECV.n	/p/	Total internal energy in control volume n. (units = J)
CVH-ECV.m.n	/p/	Total internal energy of material m in control volume n. (units = J)
CVH-H.n	/cp/	Specific enthalpy in control volume n. (units = J/kg)

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CVH-H.m.n	/cp/	Specific enthalpy of material m in control volume n. (units = J/kg)
CVH-LIQLEV.n	/cp/	Swollen liquid elevation in control volume n. (units = m)
CVH-MASS.n	/p/	Mass of material in control volume n. (units = kg)
CVH-MASS.m.n	/cp/	Mass of material m in control volume n. (units = kg)
CVH-P.n	/cp/	Pressure of control volume n. (units = Pa)
CVH-PPART.m.n	/cp/	Partial pressure of material m in control volume n. (units = Pa)
CVH-PSAT(TLIQ).n	/cp/	Saturation pressure of water at pool temperature in control volume n. (units = Pa)
CVH-PSAT(TVAP).n	/cp/	Saturation pressure of water at atmosphere temperature in control volume n. (units = Pa)
CVH-QUALITY.n	/p/	"Quality" (non-pool, non-fog mass fraction) in control volume n. (units = dimensionless)
CVH-RHO.n	/cp/	Net mass density of all materials in control volume n. (units = kg/m ³)
CVH-RHO.m.n	/p/	Mass density of material m in control volume n. (units = kg/m ³)
CVH-RHOA.n	/c/	Mass density of atmosphere in control volume n. (units = kg/m ³)
CVH-RHOP.n	/c/	Mass density of pool in control volume n. (units = kg/m ³)
CVH-TLIQ.n	/cp/	Pools temperature in control volume n. (units = K)
CVH-TOT-E	/p/	Total internal energy in the control volume hydrodynamics package. (units = J)
CVH-TOT-E.m	/p/	Total internal energy of material m in the control volume hydrodynamics package. (units = J)

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CVH-TOT-M	/p/	Total mass in the control volume hydrodynamics package. (units = kg)
CVH-TOT-M.m	/p/	Total mass of material m in the control volume hydrodynamics package. (units = kg)
CVH-TSAT(A).n	/cp/	Water saturation temperature at the partial pressure of water vapor in the atmosphere of control volume n. (units = K)
CVH-SAT(P).n	/cp/	Water saturation temperature at the pressure control volume n. (units = K)
CVH-TVAP.n	/cp/	Atmosphere temperature in control volume n. (units = K)
CVH-VELVAPCV.n	/p/	Velocity of atmosphere in control volume n. (units = m/s)
CVH-VELLIQCV.n	/p/	Velocity of pool in control volume n. (units = m/s)
CVH-VIRVOVAP.n	/p/	Virtual volume in atmosphere in control volume n. (units = m ³)
CVH-VIRVOLIQ.n	/p/	Virtual volume in pool in control volume n. (units = m ³)
CVH-VOID.n	/p/	Void (non-pool) volume fraction in control volume n. (units = dimensionless)
CVH-VOLFOG.n	/cp/	Volume of fog in control volume n. (units = m ³)
CVH-VOLLIQ.n	/cp/	Swollen volume of pool (including any vapor bubbles) in control volume n. (units = m ³)
CVH-VOLVAP.n	/cp/	Volume of gaseous atmosphere in control volume n. (units = m ³)
CVH-X.m.n	/cp/	Mole fraction of gaseous material m (m ≥ 3) in the atmosphere of control volume n. (units = dimensionless)

5. Example Input

This section will give several examples of input to the CVH package. Anything following an asterisk is a comment.

The first example is for a control volume with user-assigned number 1, and unimaginatively name "VOLUME ONE." It uses nonequilibrium thermodynamics, specifies horizontal flow, and is part of the reactor coolant system. (The flow direction is not used by any model; designation as part of the reactor coolant system will be used, if at all, in organizing RN package output.) The volume contains 150 m³, is 10 m high with a base at 0 m, and has a constant horizontal cross-section. Its flow area, for the purposes of defining an average velocity, is 12.5 m². It is initially filled to the 9.5 m elevation with saturated liquid water at 7.0 MPa, and the remaining space is filled by saturated water vapor.

```
CV00100  'VOLUME ONE'  2    2    1    * NEQ, vert flow, RCS
CV00101  0 0                                * Pool + fog, active
CV00103  12.5                                * Flow area
CV001A0  3                                    * Pool, atmos input
CV001A1  PVOL      7.0E6      ZPOL 9.5    * See discussion
CV001B0  0.0        0.0                                * Bottom at 0 m
CV001B1  10.0       150.0                               * 150 m3 total volume
```

The pool will be saturated because *only* its pressure is defined. The atmosphere will consist of saturated water vapor, because no additional properties are defined. If the record

```
CV001A2  TATM 650.0                                * Superheated
```

is added, the atmosphere will consist of superheated water vapor at 650 K and 7.0 MPa.

Records CV00101 and CV001A0 specify default values, and could be omitted; conditions in the volume can be made time independent by replacing the former with

```
CV00101  0    -1                                * Time-indep
```

A more complicated shape, with only a third of the total volume in the lower half of the volume height, will be defined if record CV110B1 is replaced by

```
CV001B1  5.0  50.0  10.0  150.0                * 50 m3 below 5 m
```

The next example defines a volume with user-assigned number 200 named "Wet Well." It uses nonequilibrium thermodynamics. Its volume is 8000 m³, with a constant cross-section between elevations of -25 m and -5 m. The initial pressure is 110 kPa, and the volume is filled to the -15 m elevation with subcooled water at 313 K. The atmosphere, at 323 K, has a relative humidity of 90%. The balance consists of noncondensable gases, materials 4 and 5; the mole fractions are 80% and 20%, respectively.

```
CV20000  'Wet Well'      2    1    3    * NEQ, hrz flo, wet well
CV200A1  PVOL 1.1E5      ZPOL -15.0    * Pressure, pool surface
CV200A3  TPOL 313.0      TATM 323.0    * Pool, atmos temps
CV200A4  RHUM 0.90                                * RHUM implies PH2O
```

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CV200A6 MLFR.4 0.8 MLFR.5 0.2 * Noncondensibles
CV200B1 -25.0 0.0 -5.0 8.0E3 * Volume/Altitude table

The partial pressure of water vapor in the atmosphere will be 0.9 of the saturation pressure (12.2 kPa) at 323 K, or 11.0 kPa. Noncondensable gases will make up the remaining 99.0 kPa of the total pressure, with partial pressures in a 4 to 1 ratio. Note that these gases must be defined by input to the NCG package. For example, the records

NCG001 N2 4 * Material 4 is N2
NCG010 O2 5 * Material 5 is O2
NCG025 H2 6 * Material 6 is H2

will define material 4 as nitrogen, material 5 as oxygen, and material 6 as hydrogen.

To add a hydrogen source to volume 200, at a constant rate of 1 kg/s and a temperature of 800 K, simply add source records and tabular function definitions such as

CV200C4 MASS.6 101 2 * Rate from TF 101
CV200C5 TE 102 8 * Temperature from TF 102
*
TF10100 H2-RATE 1 1.0 * 1-point table, scale by 1.0
TF10110 0.0 1.0 * Constant value 1.0
*
TF10200 H2-TEMP 1 1.0 * 1-point table, scale by 1.0
TF10210 0.0 800.0 * Constant value 800.0

See the TF Package Users' Guide for information on more complicated tables. Control functions could also be used. An example will be shown later.

The third example defines a time-specified volume with user assigned number 456, name "BOUNDARY." It has a volume of 10 m³, between elevations of 1 and 2 m, and is assigned to the class "miscellaneous 1" for RN accounting purposes. It contains a pool of subcooled water with pressure and temperature given by channels 3 and 5 of external data file 7, respectively. The surface elevation as a function of time is given by tabular function 12. The atmosphere temperature is given by channel 4 of the same external data file. It is saturated (or superheated); the composition of any noncondensibles present is defined by control functions 3 and 8 (perhaps to match the composition in some other control volume).

CV45600 BOUNDARY 2 1 7 * NEQ, horiz flow, misc 1
CV456A1 PVOL EDF.7.3 TPOL EDF.7.5 * Pool P, T from EDF 7
CV456A2 ZPOL TF.12 * Pool surf from TF 12
CV456A3 TATM EDF.7.4 * Atm T from EDF 7
CV456A4 MLFR.4 CF.3 MLFR.5 CF.8 * NCG from CFs 3 and 8
CV456B3 1.0 0.0 2.0 10.0 * Volume/altitude table

The various tabular and control functions and the external data file must, of course, be defined. See the TF, CF, and EDF Package Users' Guides for discussion of the required input.

The final example defines a source of subcooled water to volume 1 with properties corresponding to the water in volume 456—that is, with the pressure and temperature given by channels 3 and 5 of external data file 7, respectively. The cumulative mass to be added is given as a function of time by control function 66.

```

CV001C3  MASS.1      66  0      * Integral mass source from CF 66
CV001CB  PE         88  2      * Energy rate source from CF 88
*
CF07700  POOL-RATE  DER-F  1    1.0  * Construct mass rate as
CF07700  1.0    0.0  CFVALU-66  * derivative of CF 66
*
CF08800  ENERGY-RATE MULTIPLY 2 1.0 * Multiply mass rate
CF08810  1.0    0.0  CFVALU.77  * by specific h of
CF08811  1.0    0.0  CVH-H.1.456 * pool in CV 456
*
CF06600  INT-MASS-SOURCE . . . * Input as appropriate

```

This input calculates the appropriate rate of enthalpy addition as control function 88. The procedure is to first differentiate the cumulative mass source, given by control function 66, to define the source rate in control function 77, and then multiply this rate by the specific enthalpy of the pool (material 1) in control volume 456. See the Control Function (CF) Package Users' Guide for more information on specific CF input.

6. CVH Package Output

Each printed edit generated by the CVH package in MELGEN and MELCOR contains a snapshot description of the state of all control volumes, with the output organized in tabular form. Many column headings are abbreviated, but most are relatively clear—particularly when it is understood that “LIQ” refers to pool and “VAP” to atmosphere. One frequent source of confusion is that, in CVH output, “VOID FRACTION” and “QUALITY” refer to the partition of volume and of water mass, respectively, between pool and atmosphere. The vapor bubble content of the pool may be inferred from the difference between the swollen liquid level, “S-Z-POOL,” and the collapsed liquid level “C-Z-POOL.” The edit includes a summary of the integrated sources in each control volume, and of the current partition of volume between hydrodynamic (“MATL”) and virtual volume.

A description of the nodalization, including a list of all flow paths connected to each volume, will be found in the “FLOW PATH TIME INDEPENDENT DATA EDIT” generated by the FL package in MELGEN and in the first edit for each MELCOR run.

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Users are strongly advised to check the initial edit generated by MELGEN—in addition to the contents of the diagnostic file (MEGDIA)—before proceeding with a calculation.

7. Diagnostics and Error Messages

Diagnostic messages may be written either by MELGEN or by MELCOR. Messages from MELGEN ordinarily report errors or inconsistencies in input; problems encountered while completing the definition of initial conditions may also be reported. If an error is encountered, no restart file will be written; errors must be corrected before MELCOR can be run.

Messages from MELCOR report problems encountered during the time advancement of a calculation. If an error is severe, the calculation will be stopped and a restart dump written corresponding to conditions at the beginning of the fatal timestep.

A user input option, CVHTRACE, turns on a detailed, step-by-step tracing of the numerical solution of the hydrodynamic equations, with information written to the diagnostic file (MELDIA). If the calculational performance of the CVH package is poor, this information may be useful in determining the cause.

If any package requires a timestep below the user-specified minimum value, the MELCOR executive will stop the calculation. (The SOFTDTMIN record in the Executive Package Users' Guide allows this treatment to be modified.) When this occurs, the executive will repeat the last attempt *with CVHTRACE turned on*. In most such cases, the unacceptable timestep cut will have been demanded by the CVH package; in a large fraction of these, this will be found to be a result of unacceptable boundary conditions imposed by other packages. The output from CVHTRACE is often helpful in identifying the underlying cause.

7.1 Input and Execution Messages

Messages resulting from errors in record formats or unrecognized records in user input to MELGEN include the record identifier and sufficient information to allow the user to identify the error. Typical errors include failure to supply all required input records, and incomplete specification or overspecification of the initial thermodynamic state of a control volume. Inconsistencies with MELGEN input to other packages, including failure to correctly define any tabular or control functions or external data files required to define sources, will also be identified.

Input processing continues after an error has been found in order to identify multiple errors, but MELGEN will not write an initial restart until all input errors have been eliminated. The default assumptions used to allow processing to continue may themselves lead to additional error messages. If one of a group of input diagnostics appears irrelevant to the

actual input, the proper strategy is to make as many corrections as possible and rerun MELGEN; the other error messages will be eliminated or clarified.

Error or warning messages may be issued during execution of MELCOR for any of a number reasons. These include attempts by another package or a CVH sink to remove more mass or energy than is contained in the associated control volume, improper relocation of virtual volume by other packages, and errors in tabular or control functions or external data files defining CVH sources or the properties of time-specified volumes. Execution will continue, with a reduced system timestep, when it makes sense to do so; the request for a system fallback will be noted.

In some cases, the thermodynamics routines will transfer energy between the pool and atmosphere of a control volume rather than return a subfreezing temperature for one of them. Such occurrences are noted; a problem with input is usually involved. A special case is the discharge of a high-pressure accumulator, where the gas temperature will fall below freezing under adiabatic expansion. Although MELCOR thermodynamics does not permit temperatures below 273.15 K, this energy transfer allows the calculation to continue with an isothermal expansion of gas after the freezing point is reached. (After fifty occurrences of such energy transfer, further warnings are suppressed.)

Coding of the CVH package includes a number of messages warning of apparent logic errors, with the text identifying them as such. The appearance of a message of this type probably involves a coding error in MELCOR; the code development team should be informed.

7.2 CVHTRACE Option

Inclusion of the CVHTRACE record in MELCOR input enables tracing of the calculations through which the CVH package advances. The result will be a large number of informative messages written to the diagnostic file (MELDIA). These messages follow very closely the description of the CVH solution algorithm outlined in the CVH/FL Reference Manual.

The volume of messages, while not nearly so large as was produced by the obsolete MELCOR DEBUG option, is large enough that it should not be used for more than a few cycles. Therefore, its activation is not recorded in the restart file; tracing is active if and only if the CVHTRACE record is present in MELCOR input for the current run.

The CVHTRACE option evolved as a partial substitute for problem debugging using system-specific debugging software such as dbx on UNIX systems. In essence, it automates the tracing and examination of variables habitually used by the code developers to investigate problems in calculations. The output assumes that the user knows a little about MELCOR numerics, but is not (intended to be) excessively cryptic.

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Use of the CVHTRACE option should aid in identification of "problem areas" in a calculation. If a calculation is proceeding smoothly but with very small timesteps, the information provided by the message

NEXT TIME STEP LIMITED TO n.nnnnEeee S BY <something>

should identify the reason. If the timesteps are limited by the material Courant condition in some volume, it may be appropriate to combine this volume with a larger neighbor to ease the constraint. If the limit is the rate of change in temperature or pressure in some volume, the cause may be simply a rapid transient in conditions, after which the timestep should recover. If the system is underdamped, such a transient may persist long after the initial perturbation has passed. This may reflect input data that places too little frictional loss in flow paths. If no such transient should be occurring, the problem may be a rapidly fluctuating boundary condition imposed on that volume by some other package. It may be possible to modify input to the other package to reduce the fluctuation.

If, on the other hand, each advancement is found to involve many iterations with repeated subcycle and timestep fallbacks, it is likely that one or two volumes or flow paths will appear repeatedly in the lists of "last to converge" or "failed to converge." Attention should then be focused on these volumes and/or flow paths, and their relationships to the core, heat structures, and other elements of MELCOR modeling. Simple changes in nodalization, particularly in junction opening heights, inertial lengths, momentum exchange lengths and loss coefficients in the Flow Path input may be sufficient to eliminate the problem. Another strategy is to restrict the timestep using TIME_n records in the Executive package input to a value commensurate with the successful subcycle advancements.

If convergence problems are seen for a flow path which is ultimately found to be choked, it may be appropriate to increase the loss coefficients for that path and/or to increase the momentum exchange length to reduce the change in velocity calculated before choking is considered.

If a volume is repeatedly mentioned in association with the message

*****ADVANCEMENT FAILED: THERMO ERROR**

any sources or sinks in that volume, from CVH input or other packages, should be closely examined. The most common cause of such an error is a source in the volume that drives the volume out of the range of validity of the equation of state.

Throughout the process, however, the user should remain aware that CVHTRACE can only display symptoms. The underlying causes of a problem may lie in areas of the calculation which are apparently experiencing no difficulties at all.

An outline of the contents of the diagnostic file is given below, for a case where the CVHTRACE option is enabled. Four character strings in the messages should be noted as potential search patterns for the diagnostic file:

- "===" marks the start of a MELCOR timestep;
- "..." marks the start of an attempted step (full or subcycle) in CVH;
- "—" marks the successful completion of such an advancement; and
- "****" marks a problem, a point where a calculation had to be repeated, or a point where a compromise was required (for example, the user input minimum timestep overrode the value desired by CVH).

Indentation is used as a further aid to scanning the contents of the diagnostic file. This indentation is duplicated in the example messages shown below.

7.2.1 Main Advancement

The start of each MELCOR timestep is marked by the message

```
===CVH ADVANCEMENT FOR CYCLE nnnnnn DT = x.xxxxEeee S
```

If sinks (negative sources) of mass and/or energy specified by CVH input require more mass or energy than is present in one or more volumes, the problem volumes are listed, followed by the message

```
***FALLBACK: EXCESSIVE MASS OR ENERGY SINK
```

and a MELCOR fallback is performed. Tracing will begin again at "===CVH ADVANCEMENT ..." with a smaller value of DT.

The start of each attempted CVH (sub)cycle is marked by the message

```
...ATTEMPT (SUB)STEP OF x.xxxxEeee S, PRESSURE ITERATION n
```

"Pressure iteration" refers to (re)linearization of terms involving new volume pressures in the acceleration of flows, and (re)solution of the resulting flow equations.

Diagnostic messages are generated during solution of the flow equations. These are discussed below, in Section 7.2.2. If the solution fails, a fallback within CVH is executed, and tracing will generally begin again at "...ATTEMPT (SUB)STEP ..." with a smaller substep. However, if the substep has become too small, the message

```
***FALLBACK: SUBCYCLE STEP TOO SMALL COMPARED TO DT
```

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is generated, a MELCOR fallback is executed. Tracing will begin again at "===CVH ADVANCEMENT ..." with a smaller value of DT.

Once the flow solution is complete, mass and energy moves are computed, the (material) Courant limit is calculated and noted as

COURANT LIMIT OF x.xxxEee S SET BY VOLUME nnn

(A further message is provided for if this limit is exceeded, but should not appear given current coding.)

The new volume pressures are computed from the new masses and energies. If the discrepancy from the linearly-projected pressure is excessive, the offending volumes are noted, and the message

*****ADVANCEMENT FAILED: PRESSURE CONVERGENCE FAILURE**

is generated. Tracing begins again at "...ATTEMPT (SUB)STEP ..." either as a new pressure iteration or, if the maximum number of iterations has been reached, with a decreased substep size following an internal fallback.

If errors occur in evaluation of the equation of state, the problem volumes are noted, the message

*****ADVANCEMENT FAILED: THERMO ERROR**

is written, an internal fallback is executed, and tracing begins again at "...ATTEMPT (SUB)STEP ..." with a decreased substep size.

Messages are coded for a possible "water pack fix-up", but this is not enabled in current versions of MELCOR.

When a (sub)step is completed successfully, the net advancement to that point is noted as

---ADVANCEMENT SUCCESSFUL THROUGH x.xxxEeeee S

The possibility of choking is then evaluated. If it is detected, the step is repeated with the message

*****REPEAT FOR CHOKING IN FLOW PATHS nnn nnn ...**

When the advancement reaches the end of the MELCOR timestep, the net changes during the step are examined and, if all are acceptable, a proposed new timestep is estimated. This is noted as

NEXT TIME STEP LIMITED TO n.nnnnEee S BY <something>

where "<something>" may be a change in pressure or temperature (using limits defined by Sensitivity Coefficients in array 4400) in some volume (the volume number will be noted), the Courant limit (the relevant volume number has already been noted), or the estimated accuracy of some solution procedure. This will be followed by the message

***MINIMUM TIMESTEP OVERRIDES LIMIT

if appropriate.

If some change is excessive (again based on Sensitivity Coefficients in array 4400), however, a message is issued:

***EXCESSIVE CHANGE IN <something>, VOLUME nnn

where "<something>" may be POOL TEMPERATURE, ATMOSPHERE TEMPERATURE, or PRESSURE. It will generally be followed by the message

***FALLBACK: CHANGE DURING TIMESTEP TOO GREAT

and the entire MELCOR step will be repeated with a decreased value of DT. However, if the step is already within a factor of 2 of the minimum, the calculation will continue with the warning message

***MINIMUM TIMESTEP PREVENTS FALLBACK

7.2.2 Flow Solution

Solution of the flow equation is iterative, because donor properties and friction terms are nonlinear functions of the flow velocities. When the iteration converges, the message

VELOCITIES CONVERGED IN CVHMOM ON ITERATION nn

is written. If iteration was required, this is followed by either or both of the messages

LAST VELOCITIES TO REVERSE INCLUDE nnc nnc <etc>

LAST VELOCITIES TO CONVERGE INCLUDE nnc nnc <etc>

where nnn is a flow path number and c is P for pool or A for atmosphere. If the number of flows in either list exceeds 10, the list is truncated. "Reversal" is with respect to the previous iteration (so that donoring must be switched). "Convergence" requires a change in magnitude from the previous iteration within the limits set by Sensitivity Coefficients in array 4401.

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In some cases, the volumetric flows converge even though the velocities do not, because of iteration-to-iteration changes in the flow-path void fraction. If this is the case, the messages will be

VOLUME FLOWS CONVERGED IN CVHMOM ON ITERATION nn
UNCONVERGED VELOCITIES INCLUDE nnc nnc <etc>

If, after a number of iterations defined by a Sensitivity Coefficient in array 4401, neither velocities nor flows have converged, but the unconverged ones do not contribute significantly to the projected new pressure, the iteration is terminated with the message

PRESSURES CONVERGED IN CVHMOM ON ITERATION nn

and either or both of the messages

REVERSED VELOCITIES INCLUDE nnc nnc <etc>
UNCONVERGED VELOCITIES INCLUDE nnc nnc <etc>

(The default is not to allow acceptance of a velocity solution on this basis.)

The solution may fail, with either the message

***VELOCITY ITERATION FAILED IN CVHMOM

or the message

***FLOW MATRIX IN CVHMOM 'SINGULAR' ON ITERATION nn

The maximum number of iterations is set by a Sensitivity Coefficient in array 4401.