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:

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.

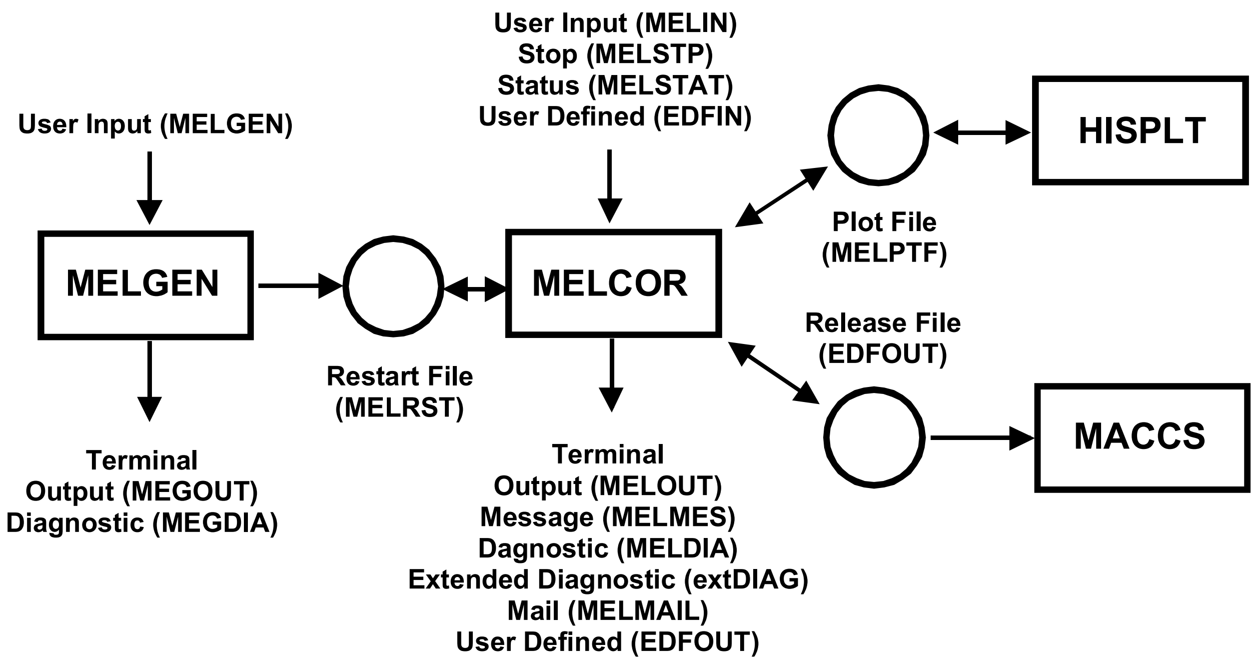

Figure 2.1 MELCOR Code and File Relations

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.

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 noncondensible gas properties (see H2O and NCG).
NCG	-	NonCondensible Gas Equation of State. Evaluates the properties of noncondensible 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 NonCondensible 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.

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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