SOFTWARE RELEASE NOTICE

1. SRN Number: MGFE-SRN-267	
2. Project Title: RDTME	Project No. 20.01402.671
3. SRN Title: Dtherm v. 1.1 for Mathcad 2000 Professional (Service Release 2a)	
4. Originator/Requestor: Andrew J. Grohmann	Date: May 28, 2002

5. Summary of Actions

☐ Release of new software ☐ Change of access software

√ Release of modified software: ☐ Software Retirement

√ Enhancements made

☐ Corrections made

6. Validation Status

☐ Validated

☐ Limited Validation

√ Not Validated Explain: Scheduled for October 2002

7. Persons Authorized Access

Name	Read Only/Read-Write	Addition/Change/Delete
Dr. Doug Gute	Read - Write	Addition/Change/Delete
Andrew J. Grohmann	Read - Write	Addition/Change/Delete
Brittain Hill	Read Only	

8. Element Manager Approval: [signature] for ACH Date: 6/03/2002

9. Remarks:

Password protected version of the program is available to all CNWRA and/or NRC staff.

CNWRA Form TOP-6 (09/01)

SOFTWARE SUMMARY FORM

01. Summary Date: 5-29-02	02. Summary prepared by (Name and phone) Dr. Doug Gute ext. 2307 Andrew J. Grohmann ext. 6877	02. Summary Action: REPLACEMENT
03. Software Date: 5-29-02	04. Short Title: Dtherm	
06. Software Title: Dtherm v. 1.1 for Mathcad 2000 Professional (Service Release 2a)		07. Internal Software ID: 1.1

08. Software Type: ☐ Automated Data System ☐ Computer Program √ Subroutine/Module	09. Processing Mode: √ Interactive ☐ Batch ☐ Combination	10. Application Area a. General: √ Scientific/Engineering ☐ Auxiliary Analyses ☐ Total System PA ☐ Subsystem PA ☐ Other b. Specific: Approximates differential thermal expansion stresses in the waste package

11. Submitting Organization and Address: CNWRA/SwRI 6220 Culebra Road San Antonio, TX 78228	12. Technical Contact(s) and Phone: Andrew J. Grohmann Dr. Doug Gute Ext. 2307

13. Software Application:
Software calculates the stresses in the waste package due to differential thermal expansion.

14. Computer Platform PC	15. Computer Operating System: Windows NT 4.0	16. Programming Language(s): Mathcad 2000	17. Number of Source Program Statements: 500
18. Computer Memory Requirements: 32 MB	19. Tape Drives: N/A	20. Disk Units: N/A	21. Graphics: Open GL

22. Other Operational Requirements
Mathcad 2000's latest service release should be installed (2a at the time this was written).

23. Software Availability: ☐ Available √ Limited ☐ In-House ONLY	24. Documentation Availability: √ Available ☐ Preliminary ☐ In-House ONLY

25.

Software Developer: Andrew Grohmann   Date: 6·3·2002

CNWRA Form TOP-4-1 (05/98)

CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES
QA VERIFICATION REPORT
FOR
→ DEVELOPED OR ACQUIRED TO BE MODIFIED SOFTWARE ←

Software Title/Name: Dtherm 1.1
Version: 1.1
Demonstration workstation: PC - Vermont
Operating System: Windows NT 4.0 SP6
Developer: A. Grohmann

Software Requirements Description (SRD) [TOP-018, Section 5.3]

SRD Version: N/A
SRD Approval Date: ______

SRD and any changes thereto reviewed in accordance with QAP-002 requirements?

Yes: ☐ No: ☐ N/A: ☑

Is a Software Change Report(s) (SCR) used for minor modifications (i.e., acquired code), problems or changes to a configured version of software?

Yes: ☑ No: ☐ N/A: ☐

Comments: See SCR MGFE-SCR-402

Software Development Plan (SDP) [TOP-018, Section 5.4]

SDP Version: ______
SDP (EM) Approval Date: ______

The SDP addresses applicable sections of TOP-018, Appendix B, SDP Template?

Yes: ☐ No: ☐ N/A: ☑

Is the waiver (if used) in accordance with specified guidelines?

Yes: ☐ No: ☐ N/A: ☑

Comments: See SCR MGFE-SCR-402

Design and Development [TOP-018, Section 5.5.1 - 5.5.4]

Is code development in accordance with the conventions (i.e., coding conventions)described in the SDP/SCR?

Yes: ☐ No: ☐ N/A: ☑

Module(s) Reviewed: Reviewed header file.

Comments: changes made to header information only.

(04/01)

CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES
QA VERIFICATION REPORT
FOR
➔ DEVELOPED OR ACQUIRED TO BE MODIFIED SOFTWARE ←

Is code internally documented to allow a user to understand the function(s) being performed and to follow the flow of execution of individual routines?

Yes: ☐ No: ☐ N/A: ☑

Module(s) Reviewed:

Comments: Changes made to header information only!

Is development of the code and informal module/subroutine-level testing documented in scientific notebook and/or SCR?

Yes: ☑ No: ☐ N/A: ☐

SCR's and/or Scientific Notebook(s) Reviewed: SCR 402

Comments: Regression testing performed.

Software designed so that individual runs are uniquely identified by date, time, name of software and version?

Yes: ☑ No: ☐ N/A: ☐

Date and Time Displayed: 5/28/02 8:37 Am

Name/Version Displayed: Dtherm 1.1

Comments:

Medium and Header Documentation [TOP-018, Section 5.5.6]

A program title block of main program contains: Program Title, Customer Name, Customer Office/Division, Customer Contact(s), Customer Phone Number, Associated Documentation, Software Developer and Phone Number, Date, and Disclaimer Notice?

Yes: ☑ No: ☐ N/A: ☐

Comments: See SCR 402

Source code module headers contain: Program Name, Client Name, Contract reference, Revision Number, Revision History, and Reference to SRD/SCR requirement(s)?

Yes: ☐ No: ☐ N/A: ☑

Module(s) Reviewed:

Comments: changes made to header information only!

The physical labeling of software medium (tapes, disks, etc.) contains: Program Name, Module/Name/Title, Module Revision, File type (ASCII, OBJ, EXE), Recording Date, and Operating System(s)?

Yes: ☑ No: ☐ N/A: ☐

Comments: See QA copy of CD.

(04/01)

CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES
QA VERIFICATION REPORT
FOR
→ *DEVELOPED OR ACQUIRED TO BE MODIFIED SOFTWARE* ←

Code Reviews [TOP-018, Section 5.5.6]

Are code reviews (if implemented) documented in a scientific notebook or in another format that allows others to understand the code review process and results?

Yes: ☐ No: ☐ N/A: ☑

Documented in Scientific Notebook No.: ____________

Comments: Changes made to header information only.

Acceptance and Installation Testing [TOP-018, Section 5.6]

Does *acceptance testing* demonstrate whether or not requirements in the SRD and/or SCR(s) have been fulfilled?

Yes: ☑ No: ☐ N/A: ☐

Has *acceptance testing* been conducted for each intended computer platform and operating system?

Yes: ☑ No: ☐ N/A: ☐

Computer Platforms: PC Operating Systems: Windows NT

Location of Acceptance Test Results: SCR # 402

Comments: Changes made to header information only, Regression testing performed.

Has *installation testing* been conducted for each intended computer platform and operating system?

Yes: ☑ No: ☐ N/A: ☐

Computer Platforms: PC. Operating Systems: Windows NT

Location of Acceptance Test Results: SCR #402

Comments:

User Documentation [TOP-018, Section 5.5.7]

Is there a Users' Manual for the software and is it up-to-date?

Yes: ☑ No: ☐ N/A: ☐

User's Manual Version and Date: SCR # 402 Section 4.0

Comments:

CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES
QA VERIFICATION REPORT
FOR
➜ DEVELOPED OR ACQUIRED TO BE MODIFIED SOFTWARE ←

Are there basic instructions for the *installation* and *use* of the software?

Yes: ☑ No: ☐ N/A: ☐

Location of Instructions: SCR # 407 Section 5.0

Comments:

Configuration Control [TOP-018, Section 5.7, 5.9.3]

Is the Software Summary Form (Form TOP-4-1) completed and signed?

Yes: ☑ No: ☐ N/A: ☐

Date of Approval: 6/3/02

Is the list of files attached to the Software Summary Form complete and accurate?

Yes: ☑ No: ☐ N/A: ☐

Comments:

Is the source code available or, is the executable code available in the case of (acquired/commercial codes)?

Yes: ☑ No: ☐ N/A: ☐

Location of Source Code: CD enclosed

Comments:

Have all the script/make files and executable files been submitted to the Software Custodian?

Yes: ☑ No: ☐ N/A: ☐

Location of script/make files: CD enclosed.

Comments:

Software Release [TOP-018, Section 5.9]

Upon acceptance of the software as verified above, has a Software Release Notice (SRN), Form TOP-6 been issued and does the version number of the software match the documentation?

Yes: ☑ No: ☐ N/A: ☐

SRN Number: MGFE-SRN-267

Comments:

CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES
QA VERIFICATION REPORT
FOR
→DEVELOPED OR ACQUIRED TO BE MODIFIED SOFTWARE←

Software Validation [TOP-018, Section 5.10]

Has a Software Validation Test Plan (SVTP) been prepared for the range of application of the software?

Yes: ☐ No: ☑ N/A: ☐

Version and Date of SVTP: ____________________

Date Reviewed and Approved via QAP-002: ________________

Comments: Scheduled for August 2002.

Has a Software Validation Test Report (SVTR) been prepared that documents the results of the validation cases, interpretation of the results, and determination if the software has been validated?

Yes: ☐ No: ☑ N/A: ☐

Version and Date of SVTR: ____________________

Date Reviewed and Approved via QAP-002: ________________

Comments: Scheduled for October 2002.

Additional Comments:

[signature] 6·3·2002
Software Developer/Date

[signature] 6/3/02
Software Custodian/Date

(04/01)

Dtherm

Release Version: 1.1

Client Name: USNRC

NRC Contract: NRC 02-97-009

Programmed by:

Andrew J. Grohmann

CNWRA Contact:

Dr. Doug Gute (210) 522-2307

Table of Contents

1.0 SOFTWARE FUNCTION

The purpose of this software is to calculate the stresses and displacements of the inner and outer barrier of the waste package due to differential thermal expansion. This software will create 2-D plots of the radial displacement, radial stress, "hoop" stress, and von Mises stress as functions of radius for the inner and outer barrier. The user will be able to input all the material properties, waste package dimensions, temperatures, and internal and external pressures exerted on the waste package. The software will also be able to create 3-D plots of the von Mises stresses as functions of radial gap and axial gap for both the inner and outer barrier. The data for the 3-D plots is also outputted to a text file that can be re-opened in Mathcad, Microsoft Excel, or a similar program.

2.0 TECHNICAL BASIS: PHYSICAL AND MATHEMATICAL MODEL

The problem was to derive a closed-form method for approximating the stresses due to differential thermal expansion stresses in the waste package. The governing equations all come from the theory of elasticity and the full derivation is presented in scientific notebook 472E. The following equations are the main equations that are needed in the program.

$$u(r) = (1 + v)\cdot\alpha\cdot\frac{1}{r}\cdot\int_{r_i}^{r} T(r)\cdot r\,dr + C_1\cdot r + \frac{C_2}{r}$$

$$w(z) = \left[\frac{1}{E}\cdot\left[\sigma_z - v\cdot\left(\sigma_r(r) + \sigma_\theta(r)\right)\right] + \alpha\cdot T(r)\right]\cdot z$$

$$\sigma_r(r) = \frac{-E\cdot C_1}{(v-1)} - \frac{E\cdot C_2}{\left[r^2\cdot(1+v)\right]} - \frac{E\cdot\frac{d}{dr}\left[(1+v)\cdot\frac{\alpha}{r}\cdot\int_{r_i}^{r} T(r)\cdot r\,dr\right]}{\left[(v-1)\cdot(1+v)\right]} + \frac{\alpha\cdot T(r)\cdot E}{(v-1)} - \frac{E\cdot\alpha\cdot v}{\left[r^2\cdot(v-1)\right]}\cdot\int_{r_i}^{r} T(r)\cdot r\,dr - \frac{\sigma_z\cdot v}{(v-1)}$$

$$\sigma_\theta(r) = \frac{-E\cdot C_1}{(v-1)} + \frac{E\cdot C_2}{\left[(1+v)\cdot r^2\right]} - \frac{E\cdot v\cdot \frac{d}{dr}\left[(1+v)\cdot\frac{\alpha}{r}\cdot\int_{r_i}^{r} T(r)\cdot r\,dr\right]}{(v-1)\cdot(1+v)} + \frac{E\cdot\alpha\cdot T(r)}{(v-1)} - \frac{E\cdot\alpha}{\left[r^2\cdot(v-1)\right]}\cdot\int_{r_i}^{r} T(r)\cdot r\,dr - \frac{\sigma_z\cdot v}{(v-1)}$$

$$\sigma_{von}(r) = \sqrt{\frac{1}{2}\cdot\left[\left(\sigma_r(r) - \sigma_\theta(r)\right)^2 + \left(\sigma_\theta(r) - \sigma_z\right)^2 + \left(\sigma_z - \sigma_r(r)\right)^2\right]}$$

There are four different cases that affect the stresses in the waste package. As the inner barrier expands, it may or may not come into contact with the outer barrier. This leads to four different cases. Case 1: The inner barrier never comes into contact with the outer barrier in either the axial or radial directions. Case 2: The inner barrier comes into contact with the outer barrier in the radial direction only, without coming into contact in the axial direction. Case 3: The inner barrier comes into contact with the outer barrier in the axial direction only, without coming into contact in the radial direction. Case 4: The inner barrier comes into contact with the outer barrier in both the axial and radial directions. These four cases present four unique solutions to the problem. In order to test to see which case is applicable, the radial and axial displacement equations will be used. The inner barrier will come into contact with the outer barrier in the radial direction when:

$$r_2 + u_i(r_2) = r_3 + u_o(r_3)$$

So if the following condition is true, Case 2 or Case 4 applies.

$$r_2 + u_i(r_2) \ge r_3 + u_o(r_3)$$

The second check that must be made is to see if the inner barrier contacts the outer barrier in the axial direction. The inner barrier will contact the outer barrier in the axial direction when:

$$\frac{L_i}{2} + w_i\left(\frac{L_i}{2}\right) = \frac{L_o}{2} + w_o\left(\frac{L_o}{2}\right)$$

So if the following condition is true, Case 3 or Case 4 applies.

$$\frac{L_i}{2} + w_i\left(\frac{L_i}{2}\right) \ge \frac{L_o}{2} + w_o\left(\frac{L_o}{2}\right)$$

By testing these two conditions, it can be determined which case is applicable. The full derivations for all four cases can be found in scientific notebook 472E. However, a brief summary of the approach will be described here.

Case 1:

In this case, there is no interaction between the inner and outer barrier therefore each barrier can be solved separately. The boundary conditions that are used to solve for the constants are the pressures on the inner and outer surfaces of each barrier. These pressures correspond to the radial stresses at the inner and outer radius of each barrier.

Case 2:

Since there is contact between the inner and outer barrier, the two cannot be solved for separately. The boundary conditions that are needed to solve for the constants are again the pressures on the inner and outer surfaces of each barrier. However, the outer radial surface of the inner barrier and the inner radial surface of the outer barrier both exert and equal and opposite pressure. This pressure can be solved for and substituted back into the equations in place of the outer pressure on the inner barrier and the inner pressure on the outer barrier.

Case 3:

Again, since there is contact between the two barriers, the two barriers interact with each other and cannot be solved separately. This time the condition that both the inner and outer barrier have in common, is the force exerted on them in the axial direction. This force can be solved for and then substituted back into the equations in the axial stress term for both the inner and outer barrier.

Case 4:

In this case, the two barriers interact in two places. They contact in both the axial and radial direction. In order to solve this case, both the pressure that is exerted on the outer radius of the inner barrier and the inner radius of the outer barrier must be solved for as well as the force that acts along the axial direction. After solving for both the pressure and the force simultaneously, these forces are substituted back into the constants, stress, and displacement equations in order to solve for case 4.

3.0 COMPUTATIONAL APPROACH

3.1 The user interface for the program is a Mathcad 2000 Professional Worksheet. Some working knowledge of Mathcad will be helpful when using the software package.

3.2 Hardware and Software Requirements

This program requires Mathsoft Mathcad 2000 Professional or Premium for Windows or any later version of Mathcad. Any prior version of Mathcad or a Standard version of Mathcad will not work with this program. Following are the system requirements.

- PC with Pentium - 133 or higher
- Windows 95, 98, 2000 or NT 4.0 or higher
- 32 MB RAM minimum; 48 MB or higher recommended (64 MB RAM recommended for SmartSketch LE)
- CD-ROM drive
- SVGA or higher graphics card and monitor
- At least 80 MB disk space (30 MB Mathcad, 12 MB techexplorer, 30 MB SmartSketch LE, 8 MB VoloView); 315 MB for full installation (130 MB Mathcad, 12 MB techexplorer, 160 MB SmartSketch LE, 8 MB VoloView, 5 MB Internet Explorer)
- Mouse or compatible pointing device

The program performs a fair amount of heavy calculations, therefore the recommended system requirements are:

- Mathcad 2000 Professional/Premium with the latest service release (or later version)
- PC with Pentium 4/Athlon 1.5 GHz or higher
- Windows 2000 or NT 4.0 or higher (With the latest service pack installed)

- 512 MB RAM minimum
- CD-ROM drive
- SVGA graphics card and 21" monitor at 1280 x 1024 resolution or higher
- At least 500 MB of free hard disk space
- Microsoft Internet Explorer 5 with the latest service pack installed or higher (For help files)
- Mouse or compatible pointing device

4.0 USAGE NOTES – FEATURES/LIMITATIONS/TROUBLESHOOTING

The following is an attempt to explain any limitations and known issues that might occur within the Mathcad program as well as some of the useful features of Mathcad. This is by no means a comprehensive list, but it should be broad enough to cover most errors that might occur within the program. For more in depth support, contact Mathsoft or read through the help files included with Mathcad 2000.

4.1 SAVE YOUR PLOTS BEFORE CHANGING THE VARIABLES. In order to keep the 3-D plots, Mathcad must have the array of values in memory. After a run of the 3-D program, the plots will display. If Mathcad is closed or asked to recalculate any of the values, the plots will be lost. In order to retrieve that data for the plots, Dtherm creates .txt documents that store the values. These values can be reopened in Mathcad or any other 3-D software that can read .txt files. (Some manipulation might need to be done to the data file so it can be read into another 3-D plot package)

4.2 The system requirements (Section 3.2) as described by Mathsoft are the bare minimum needed to run this software and program. It is strongly recommended that this program run on a system that meets the recommended system requirements. This program runs very extensive computations that will require a lot of CPU time. The faster the system, the faster the results and more pleased the user will be.

4.3 Mathsoft issued Mathcad 2000 Service Release 2a on July 26, 2000. The service release concentrated in the following three areas:

1. Stability and performance
2. Improvements in calculation, display and printing
3. Compatibility issues

The details of this release are included in Appendix A. This release or a later release should be installed before running this software.

4.4 If the error message "An internal error has occurred" or a similar message is displayed using the program, it is recommended to save your current work and close the Mathcad application before continuing. Again, the more powerful and stable the system that runs Mathcad, the less likely errors like this will occur.

4.5 Ctrl+R refreshes the Mathcad display window. A refresh of the screen is recommended if any extraneous lines or display anomalies occur while running the program. Check to make sure the latest drivers are installed for the video card display adapter for your system.

4.6 If the calculations do not seem to update properly in the program, check to make sure the Automatic Calculation option is enabled. This option can be accessed under the Math menu. If it is enabled it will have a check mark next to it. If the calculations still appear to not update, try the Calculate option, which is also under the Math menu (can also be run with F9). If the calculations are still not updated, try Calculate Worksheet from the Math menu. *Note: You will know the results need updating when you see the word "Calc" on the message line at the bottom of the window.* Figure 1 shows the Math menu.

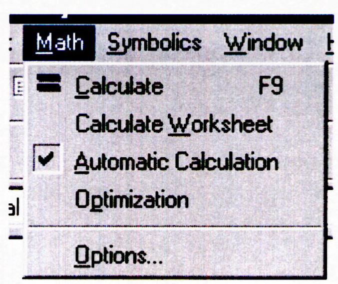


Figure 1: Mathcad 2000 Professional Math Menu

The Optimization feature should be left unchecked. The program has already been optimized during development and there will be no performance gain by enabling this option.

4.7 One of the most useful functions in Mathcad is the unit feature. Units can be added to any of the variables in the program from the Insert menu or using Ctrl+U. Mathcad has many built in units and the user is also allowed to define their own units if needed. Units can be from any system and Mathcad will work out all the conversions automatically. Included is a brief tutorial.

To associate a unit with a variable or constant, simply multiply it by the name of the unit. Click in the variable or constant.

x := 325

Press * to insert the multiplication symbol and a placeholder

x := 325·▪

Type the name of any unit in the placeholder or choose Unit from the Insert menu. From the Insert menu, all the built in units for Mathcad are displayed.

x := 325·kHz

Mathcad uses a base unit system. The program was written for SI units and it is recommended that the user leave the base unit system to SI units. The base unit system can be accessed from the Math menu under Options... This will then open the Mathcad Math Options window. By clicking on the Unit System tab the unit system can be updated. Figure 2 shows the Math Options window.

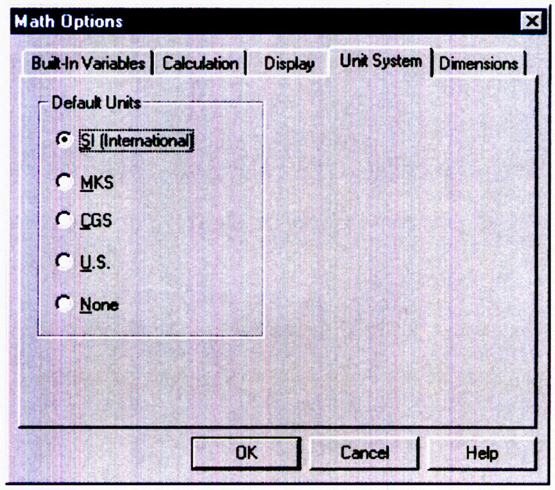


Figure 2: Mathcad 2000 Professional Math Options window

5.0 INSTALLATION

This section will describe the proper installation procedure for Dtherm software.

5.1 Install Mathcad 2000 Professional. For more details, see the Mathcad *User's Guide.*

5.2 Install the Mathcad 2000 Professional Service Pack 2a (or the latest available service pack). See Appendix A for further information on the service pack.

5.3 Copy the folder titled "Dtherm" and the entire contents of the folder to a designated place on the user's hard drive. The user can rename the folder to any name they choose and place it in any directory they choose. However, the files and folders inside the directory must not be renamed, changed, or moved.

5.4 Copy the file "fourcolor.cmp" to the "cmaps" folder of the Mathcad 2000 installation directory. This file is used for the plots that show which case applies.

5.5 In order to run the program, execute the file "Dtherm.hbk" located in the "Dtherm" directory (or the directory that it was named when copied over) and this will open Mathcad 2000 and start the Dtherm Program.

6.0 REFERENCES

Timoshenko, and Goodier, *Theory of Elasticity*, 3rd Edition, McGraw-Hill Book Company.

Shames, and Cozzarelli, *Elastic and Inelastic Stress Analysis*, Prentice-Hall, Inc.

APPENDICES

Appendix A: Mathcad 2000 Service Release 2a Documentation

Appendix B: Acceptance and Installation Tests

Appendix A:

Mathcad 2000 Service Release 2a Documentation

Mathcad 2000 Update

Other resources:

Mathcad 2000 Support

Axum Support

SmartSketch Support

Other Downloads

Mathcad 2000 *Update*

Mathcad 2000 Service Release 2a

Mathcad Service Release 2a improves the overall stability and robustness of Mathcad 2000 and addresses miscellaneous issues reported by users since Service Release 1. Specifically, Service Release 2a concentrates on the following areas:

1. Stability and performance
2. Improvements in calculation, display and printing
3. Compatibility issues

Stability and Performance

Mathcad 2000 Service Release 2a provides increased stability for your Mathcad documents. In addition to general improvements, the following operations have been specifically refined for this purpose:

- Performing general cut/copy/paste operations
- Editing large regions
- Zooming on 2D plots

In order to improve on the speed of calculation within Mathcad 2000, we have optimized many of our functions to reduce calculation time. In particular, these include:

- Vector/matrix subscripting and column operator
- Submatrix operation
- Vectorization operation

Mathcad 2000 Service Release 2a also incorporates an improved memory management system.

Improvements in Calculation, Display, and Printing

All areas of calculation have been enhanced.

- General recalculation with components and collapsed regions is much more robust: expressions now recalculate automatically when a component is updated.
- Some numeric functions and operators have been improved:
  - The *vectorize* operator of user-defined functions that involve matrices now computes more accurately.
  - The *submatrix* function is faster and now takes into account the ORIGIN of the worksheet.

- *Maximize* and *minimize* functions are now more functional within programs.
- The product operator can now be used for decreasing ranges.

- Symbolic calculations
  - Symbolic evaluation of programs has improved.
  - Mathcad 2000 can now symbolically solve for an inequality expression that consists of two or more unknowns.
  - When the atan2 function is returned from a symbolic calculation, it is returned in the form atan2 (x, y).
- In MathConnex, you can now pass nested arrays to and from a Mathcad component.

Troubles with displaying graphs and printing have been addressed.

- You can now save a bar plot stacked or side-by-side.
- The display has improved when recalculating 3D plots.
- Contour labels now display correctly in contour plots.

Compatibility

We have improved Mathcad 2000's compatibility under the following conditions:

- When running on Windows 2000, 2D plots with the line weight set greater than 1 and a line type that is not solid calculate without trouble.
- Files saved in Mathcad 2000 as HTML are now compatible with Netscape as well as Microsoft Internet Explorer.
- Issues with accessing the Mathcad Library and Collaboratory from behind firewalls via proxy have been addressed.
- A Mathcad file containing a 3D plot that was saved in Mathcad 8 format in Mathcad 2000 can now be opened in Mathcad 8 without incident.

Download Mathcad 2000 Service Release 2a.

Appendix B:

Acceptance and Installation Tests

This software has been installed on a Microsoft Windows NT 4.0 Service Pack 6 system following the guidelines in the included documentation. After installation, four test runs were performed to simulate the four different cases in the problem. All four cases returned results that were identical to the results anticipated from prior acceptance tests.

Signed: *Andrew Grohmann* Date: 5·29·02

Contents of Dtherm v. 1.1 CD

Directory Structure

- New (R:)
  - Dtherm 1.1
    - Dtherm
      - Dtherm
      - Sample
    - Mathcad 2000 Service Release 2a Documentation_files

Contents of 'R:\Dtherm 1.1'

Name	Size	Type	Modified	Attributes
Dtherm		File Folder	6/3/02 9:24 AM	R
Mathcad 2000 Service Release 2a Documentation_files		File Folder	6/3/02 9:24 AM	R
Conductivity.doc	4,053KB	Microsoft Word Document	8/16/01 11:46 AM	R
Dtherm Documentation.doc	3,122KB	Microsoft Word Document	5/29/02 8:54 AM	R
Heat Conduction.mcd	86KB	Mathcad Document	8/2/01 11:18 AM	R
Mathcad 2000 Service Release 2a Documentation.htm	12KB	HTML Document	5/29/02 9:13 AM	R
Proof of Incorrect Temperature Distribution.mcd	11KB	Mathcad Document	6/11/01 3:09 PM	R
Reference Documentation.doc	32,013KB	Microsoft Word Document	8/16/01 2:13 PM	R
SCIENTIFIC NOTEBOOK.doc	34KB	Microsoft Word Document	8/17/01 9:27 AM	R
Software Change Report.doc	24KB	Microsoft Word Document	5/28/02 4:43 PM	R
Software Release Notice.doc	23KB	Microsoft Word Document	6/3/02 8:28 AM	R
Software Summary Form.doc	27KB	Microsoft Word Document	5/29/02 8:47 AM	R
Validation Testing Coversheet.doc	21KB	Microsoft Word Document	5/31/02 5:05 PM	R
von Mises.doc	1,491KB	Microsoft Word Document	8/16/01 11:52 AM	R

Contents of 'R:\Dtherm 1.1\Dtherm'

Name	Size	Type	Modified	Attributes
Dtherm		File Folder	6/3/02 9:24 AM	R
Sample		File Folder	6/3/02 9:24 AM	R
Dtherm.hbk	1KB	Mathcad Electronic Book	5/29/02 9:49 AM	R
fourcolor.cmp	1KB	CMP File	8/13/01 11:26 AM	R

Contents of 'R:\Dtherm 1.1\Dtherm\Dtherm'

Name	Size	Type	Modified	Attributes
2-D.mcd	188KB	Mathcad Document	5/31/02 5:17 PM	R
3-D Plots.mcd	41KB	Mathcad Document	5/24/02 10:26 AM	R
3-D.mcd	281KB	Mathcad Document	5/31/02 5:17 PM	R
CONTENTS.mcd	905KB	Mathcad Document	5/29/02 9:41 AM	R
Dtherm Documentation.mcd	431KB	Mathcad Document	8/15/01 3:52 PM	R

Contents of 'R:\Dtherm 1.1\Dtherm\Sample'

Name	Size	Type	Modified	Attributes
innerbarrier.txt	77KB	Text Document	5/29/02 9:45 AM	R
innerbarrier_values.txt	2KB	Text Document	5/28/02 8:13 PM	R
outerbarrier.txt	77KB	Text Document	5/29/02 9:45 AM	R
outerbarrier_values.txt	2KB	Text Document	5/28/02 8:13 PM	R

Contents of 'R:\Dtherm 1.1\Mathcad 2000 Service Release 2a Documentation_files'

Name	Size	Type	Modified	Attributes
dhtmlMenus.js	20KB	JScript File	5/28/02 4:57 PM	R
logo.gif	2KB	GIF Image	5/28/02 4:57 PM	R
mc2000.css	2KB	Cascading Style Sheet Document	5/29/02 9:13 AM	R
trans.gif	1KB	GIF Image	5/28/02 4:58 PM	R
update.gif	4KB	GIF Image	5/28/02 4:58 PM	R

Acceptance Testing

Performed by Andrew J. Grohmann

Date: May 31, 2002

The two modules (2-D and 3-D) were inputted the same variables for each case. If the output from the two programs is equal, then because the two programs and the equations that lie within them were created independent of each other, the program will indeed be "correct." All variables will be set to the same values. The difference between the 4 cases comes from using different values for the radial and axial gap. The results are shown in the "validation" section of the output.

It should be noted that equal output doesn't necessarily mean the same exact number to 15 significant digits. For example, the stress might be equal to 0 Pa at a boundary but Mathcad might actually print this out similar to this: 5.046 x 10^{-6} Pa. That value is definitely close enough to zero considering our main concern when using this program are stress values near the failure limit of the materials.

Case 1

```
Radial Gap = 20 mm
Axial Gap  = 20 mm
```

Source Code Header

Young's Modulus:

Inner Barrier - $E_i := 1.81 \cdot 10^7 \text{ psi}$

Outer Barrier - $E_o := 22.6 \cdot 10^6 \text{ psi}$

Thermal Expansion Coefficients:

Inner Barrier - $\alpha_i := 17.5 \times 10^{-6} \frac{1}{K}$

Outer Barrier - $\alpha_o := 1.368 \times 10^{-5} \frac{1}{K}$

Inner Barrier Dimensions:

Inner Radius - $r_1 \equiv 712 \text{ mm}$

Thickness - $th_i \equiv 5 \text{ cm}$

Length - $L_i \equiv 4775 \text{ mm}$

Initial Pressures on surfaces:

Initial Pressure Inside Inner Barrier at Room Temperature - $P := 1 \text{ atm}$

Outside Outer Barrier - $P_{oo} := 7 \cdot 10^6 \text{ Pa}$

Poisson's Ratio:

Inner Barrier - $\nu_i := .27$

Outer Barrier - $\nu_o := .30$

Temperature of surface:

at r_4 - $T_4 \equiv (200 + 273) \text{ K}$

Outer Barrier Dimensions:

Thickness - $th_o \equiv 2 \text{ cm}$

Heat Terms:

Heat Generated Per Waste Package - $Q_{generated} \equiv 11.8 \text{ kW}$

Length of Entire Waste Package - $L \equiv 5165 \text{ mm}$

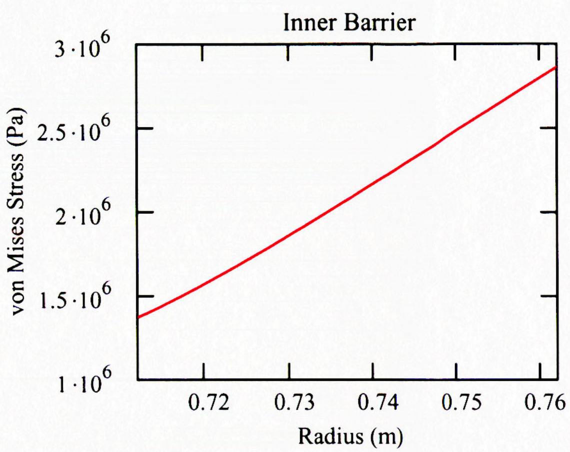
Gap Between Inner and Outer Barrier:

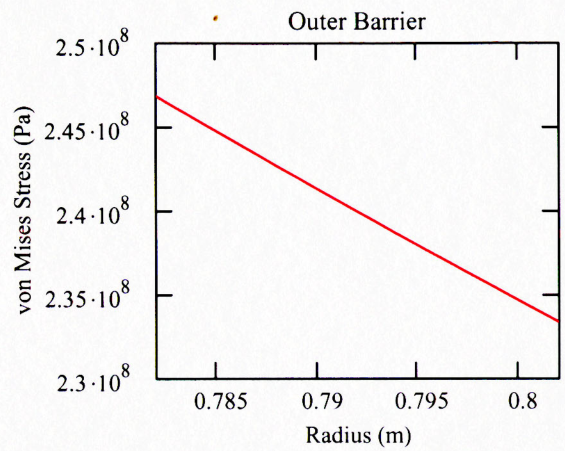
Axial Gap - $Gap_a \equiv 20 \text{ mm}$

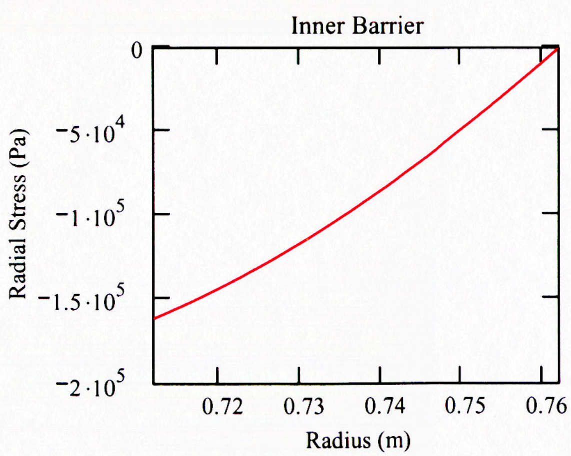
Radial Gap - $Gap_r \equiv 20 \text{ mm}$

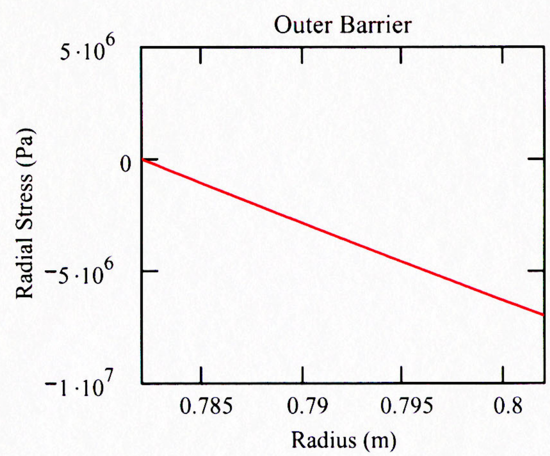
CODE

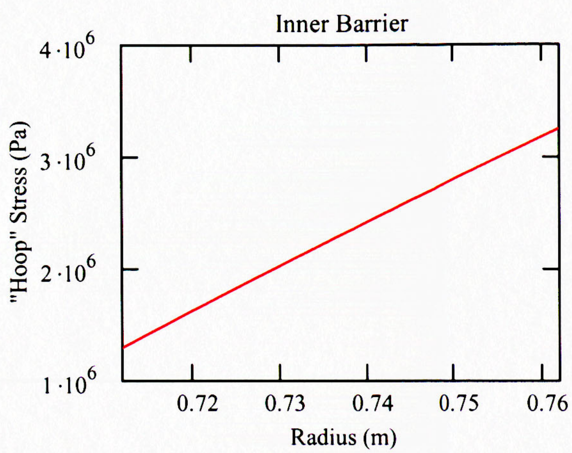
2-D Graphs

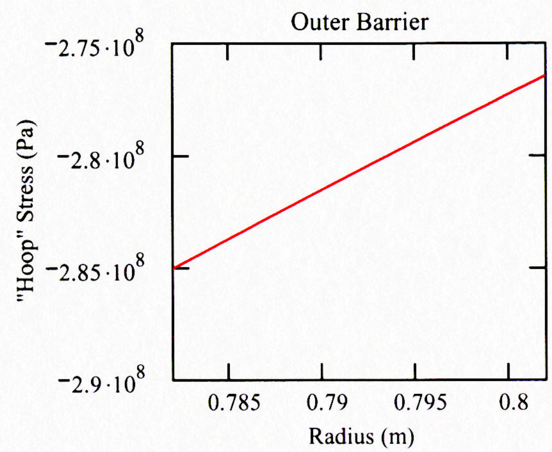

Inner Barrier
von Mises Stress (Pa)
3·10^6
2.5·10^6
2·10^6
1.5·10^6
1·10^6
0.72
0.73
0.74
0.75
0.76
Radius (m)


Outer Barrier
von Mises Stress (Pa)
2.5·10^8
2.45·10^8
2.4·10^8
2.35·10^8
2.3·10^8
0.785
0.79
0.795
0.8
Radius (m)


Inner Barrier
Radial Stress (Pa)
0
−5·10^4
−1·10^5
−1.5·10^5
−2·10^5
0.72
0.73
0.74
0.75
0.76
Radius (m)


Outer Barrier
Radial Stress (Pa)
5·10^6
0
−5·10^6
−1·10^7
0.785
0.79
0.795
0.8
Radius (m)





2-D Graphs

CaseNumber = 1

Radial Displacement of Inner Barrier

$disp_{ri} = 768.335390960326\,mm$

Radial Displacement of Outer Barrier

$disp_{ro} = 785.851459614124\,mm$

Axial Displacement of Inner Barrier

$disp_{ai} = 2407.32339964194\,mm$

Axial Displacement of Outer Barrier

$disp_{ao} = 2412.15081606335\,mm$

Radial Gap

$disp_{ro} - disp_{ri} = 0.018\,m$

Axial Gap

$disp_{ao} - disp_{ai} = 4.827 \times 10^{-3}\,m$

Radial Stresses

$\sigma_{rinner}(r_2) = -2.146 \times 10^{-6}\,Pa$

$\sigma_{router}(r_3) = 2.384 \times 10^{-6}\,Pa$

▾ Validation

The purpose of this section is to compare the results given by the 3-D module of Dtherm to the 2-D module. Since the 3-D module and 2-D module were derived separately, if they output the same values the codes can be shown to be valid.

CaseNumber = 1

Radial Stress on inner barrier at r_1

$\sigma_{rinner}(r_1) = -1.611 \times 10^{5}\ \text{Pa}$

Radial Stress on inner barrier at r_2

$\sigma_{rinner}(r_2) = -2.146 \times 10^{-6}\ \text{Pa}$

Axial Stress on inner barrier at r_1

$\sigma_{\theta inner}(r_1) = 1.294 \times 10^{6}\ \text{Pa}$

Axial Stress on inner barrier at r_2

$\sigma_{\theta inner}(r_2) = 3.251 \times 10^{6}\ \text{Pa}$

Radial Stress on outer barrier at r_3

$\sigma_{router}(r_3) = 2.384 \times 10^{-6}\ \text{Pa}$

Radial Stress on outer barrier at r_4

$\sigma_{router}(r_4) = -7 \times 10^{6}\ \text{Pa}$

Axial Stress on outer barrier at r_3

$\sigma_{\theta outer}(r_3) = -2.85 \times 10^{8}\ \text{Pa}$

Axial Stress on inner barrier at r_4

$\sigma_{\theta outer}(r_4) = -2.765 \times 10^{8}\ \text{Pa}$

Von mises Stress on inner barrier at r_1

$\sigma_{voninner}(r_1) = 1.371 \times 10^{6}\ \text{Pa}$

Von mises Stress on inner barrier at r_2

$\sigma_{voninner}(r_2) = 2.863 \times 10^{6}\ \text{Pa}$

Von mises Stress on inner barrier at r_1

$\sigma_{vonouter}(r_3) = 2.469 \times 10^{8}\ \text{Pa}$

Von mises Stress on inner barrier at r_2

$\sigma_{vonouter}(r_4) = 2.334 \times 10^{8}\ \text{Pa}$

▴ Validation

Source Code Header

Output Data File Name:
- Inner Barrier - $file_i := \text{"run1\_inner.txt"}$
- Outer Barrier - $file_o := \text{"run1\_outer.txt"}$

Young's Modulus:
- Inner Barrier - $E_i \equiv 1.81 \cdot 10^7 \text{ psi}$
- Outer Barrier - $E_o \equiv 22.6 \cdot 10^6 \text{ psi}$

Thermal Expansion Coefficients:
- Inner Barrier - $\alpha_i \equiv 17.5 \times 10^{-6} \frac{1}{K}$
- Outer Barrier - $\alpha_o \equiv 1.368 \times 10^{-5} \frac{1}{K}$

Inner Barrier Dimensions:
- Inner Radius - $r_1 \equiv 712 \text{ mm}$
- Thickness - $th_i \equiv 5 \text{ cm}$
- Length - $L_i \equiv 4775 \text{ mm}$

Initial Pressures on surfaces:
- Initial Pressure Inside Inner Barrier at Room Temperature - $P := 1 \text{ atm}$
- Outside Outer Barrier - $P_{oo} := 7 \cdot 10^6 \text{ Pa}$

Poisson's Ratio:
- Inner Barrier - $\nu_i \equiv .27$
- Outer Barrier - $\nu_o \equiv .30$

Temperature of surface:
- at r_4 - $T_4 \equiv (200 + 273) \text{ K}$

Outer Barrier Dimensions:
- Thickness - $th_o \equiv 2 \text{ cm}$

Heat Terms:
- Heat Generated Per Waste Package - $Q_{generated} \equiv 11.8 \text{ kW}$
- Length of Entire Waste Package - $L \equiv 5165 \text{ mm}$

3-D Plot Variables:
- Radial Gap Lower Bound - $gaplower_r := 0 \text{ mm}$
- Radial Gap Upper Bound - $gapupper_r := 7 \text{ mm}$
- Radial Gap Increment - $gapinc_r := 2 \text{ mm}$
- Axial Gap Lower Bound - $gaplower_a := 0 \text{ mm}$
- Axial Gap Upper Bound - $gapupper_a := 30 \text{ mm}$
- Axial Gap Increment - $gapinc_a := 10 \text{ mm}$
- Resolution to find Maximum - $res := 1 \text{ mm}$

CODE

CODE

Reference:D:\Dtherm 1.1\Dtherm\Dtherm\3-D Plots.mcd(R)

The graphs can be viewed in the file above by double clicking on it.

Time it takes to calculate entire worksheet is $\text{Time} = 0.253\text{min}$

CODE

Maximum von Mises Stress given a Radial and an Axial Gap. Type in both an Axial and Radial Gap to find the Maximum von Mises Stress.

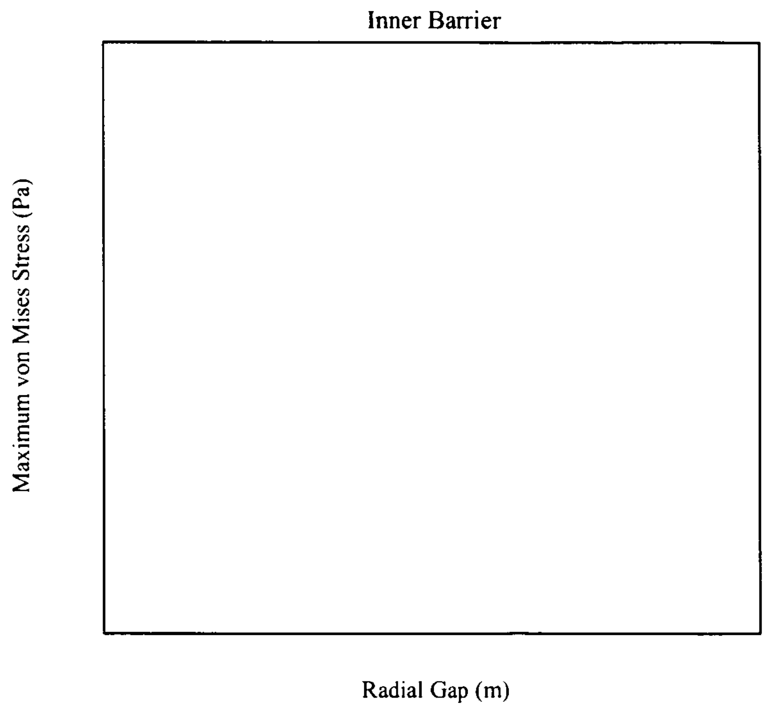
Axial Gap - $gap_a := 20mm$

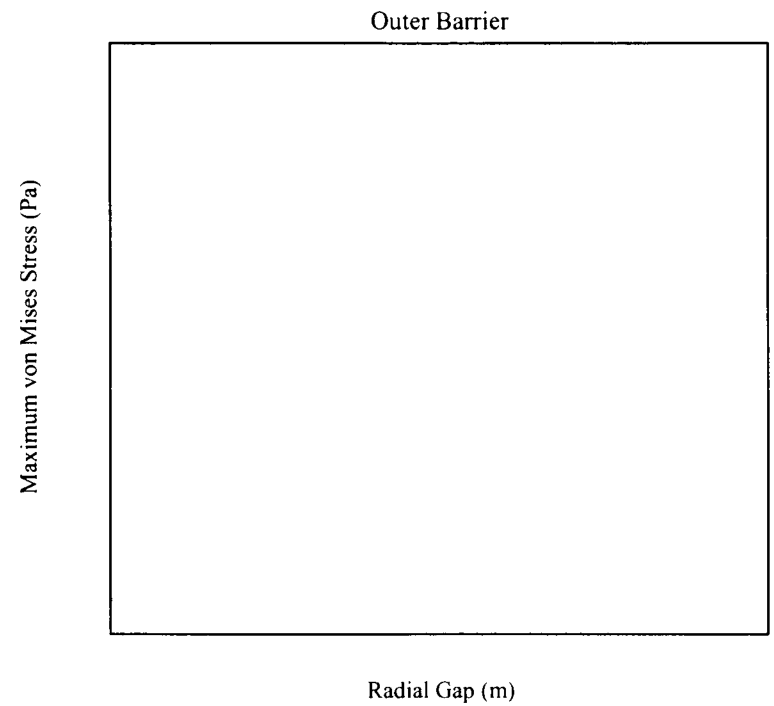
Radial Gap - $gap_r := 20mm$

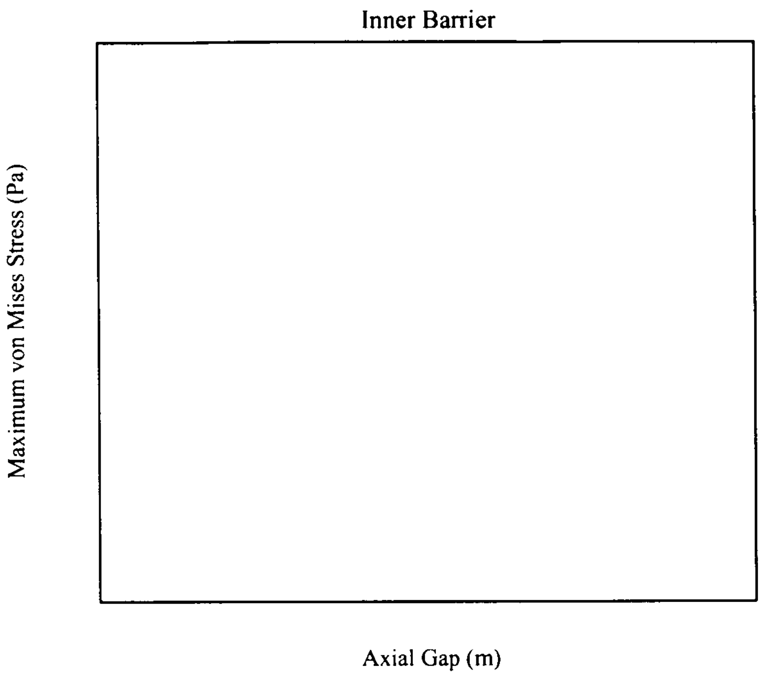
Inner Barrier - $\sigma_{voninner}(gap_a, gap_r)\cdot Pa = 2.862 \times 10^6\ Pa$

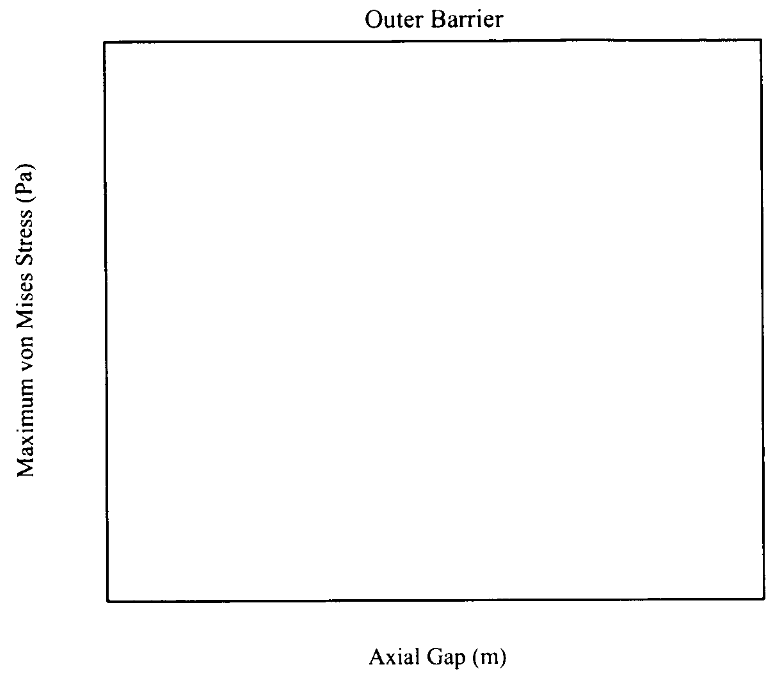
Outer Barrier - $\sigma_{vonouter}(gap_a, gap_r)\cdot Pa = 2.466 \times 10^8\ Pa$

Optional Graphs: In order to see the effect of varying one parameter such as axial gap and holding the radial gap constant use these graphs. In order to view them ... right click the graph you would like and select -> Enable Evaluation. Then select Automatic Calculation from the Math menu or Calculate [F9].






Inner Barrier
Maximum von Mises Stress (Pa)
Axial Gap (m)


Outer Barrier
Maximum von Mises Stress (Pa)
Axial Gap (m)

Validation

The purpose of this section is to compare the results given by the 3-D module of Dtherm to the 2-D module. Since the 3-D module and 2-D module were derived separately, if they output the same values the codes can be shown to be valid. The 3-D module calculates the stresses as functions of radius, axial gap, and radial gap. The 2-D module calculates the stresses solely as a function of radius with the axial gap and radial gap user defined. Therefore, if you set the axial gap and the radial gap in the 3-D module, you will in a sense recreate the 2-D module (although the 3-D module is less efficient than the 2-D module when used this way).

Note: Most of the calculations shown below are calculated much more efficiently in the 2-D module.

Axial Gap - $gap_a = 20mm$

Radial Gap - $gap_r = 20mm$

$CaseNumber(gap_a, gap_r) = 1$

$r_3 := r_2 + gap_r$ $r_4 := r_2 + gap_r + th_o$

Radial Stress on inner barrier at r_1

$\sigma_{rinner}(r_1, gap_a, gap_r) = -1.61 \times 10^5 Pa$

Radial Stress on inner barrier at r_2

$\sigma_{rinner}(r_2, gap_a, gap_r) = 2.547 \times 10^{-7} Pa$

Axial Stress on inner barrier at r_1

$\sigma_{\theta inner}(r_1, gap_a, gap_r) = 1.292 \times 10^6 Pa$

Axial Stress on inner barrier at r_2

$\sigma_{\theta inner}(r_2, gap_a, gap_r) = 3.25 \times 10^6 Pa$

Radial Stress on outer barrier at r_3

$\sigma_{router}(r_3, gap_a, gap_r) = 8.27 \times 10^{-7} Pa$

Radial Stress on outer barrier at r_4

$\sigma_{router}(r_4, gap_a, gap_r) = -7 \times 10^6 Pa$

Axial Stress on outer barrier at r_3

$\sigma_{\theta outer}(r_3, gap_a, gap_r) = -2.847 \times 10^8 Pa$

Axial Stress on inner barrier at r_4

$\sigma_{\theta outer}(r_4, gap_a, gap_r) = -2.768 \times 10^8 Pa$

Von mises Stress on inner barrier at r_1

$\sigma_{voninner\_valid}(r_1, gap_a, gap_r) = 1.37 \times 10^6 Pa$

Von mises Stress on inner barrier at r_2

$\sigma_{voninner\_valid}(r_2, gap_a, gap_r) = 2.862 \times 10^6 Pa$

Von mises Stress on inner barrier at r_1

$\sigma_{vonouter\_valid}(r_3, gap_a, gap_r) = 2.466 \times 10^8 Pa$

Von mises Stress on inner barrier at r_2

$\sigma_{vonouter\_valid}(r_4, gap_a, gap_r) = 2.336 \times 10^8 Pa$

Validation

Case 2

```
Radial Gap = 20 mm
Axial Gap  = 0 mm
```

Source Code Header

Young's Modulus:

Inner Barrier - $E_i := 1.81 \cdot 10^7\ psi$

Outer Barrier - $E_o := 22.6 \cdot 10^6\ psi$

Thermal Expansion Coefficients:

Inner Barrier - $\alpha_i := 17.5 \times 10^{-6}\ \frac{1}{K}$

Outer Barrier - $\alpha_o := 1.368 \times 10^{-5}\ \frac{1}{K}$

Inner Barrier Dimensions:

Inner Radius - $r_1 \equiv 712\ mm$

Thickness - $th_i \equiv 5\ cm$

Length - $L_i \equiv 4775\ mm$

Initial Pressures on surfaces:

Initial Pressure Inside Inner Barrier at Room Temperature - $P := 1\ atm$

Outside Outer Barrier - $P_{oo} := 7 \cdot 10^6\ Pa$

Poisson's Ratio:

Inner Barrier - $\nu_i := .27$

Outer Barrier - $\nu_o := .30$

Temperature of surface:

at r_4 - $T_4 \equiv (200 + 273)\ K$

Outer Barrier Dimensions:

Thickness - $th_o \equiv 2\ cm$

Heat Terms:

Heat Generated Per Waste Package - $Q_{generated} \equiv 11.8\ kW$

Length of Entire Waste Package - $L \equiv 5165\ mm$

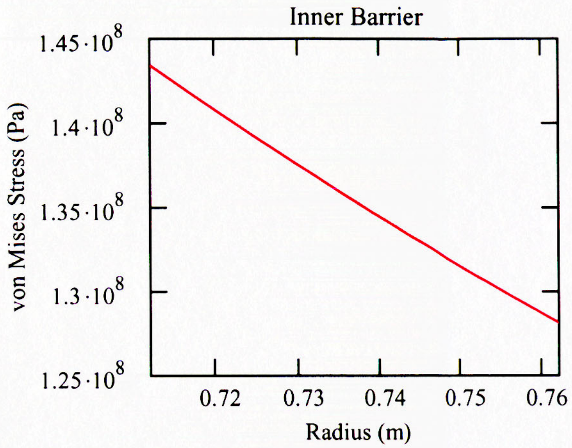
Gap Between Inner and Outer Barrier:

Axial Gap - $Gap_a \equiv 20\ mm$

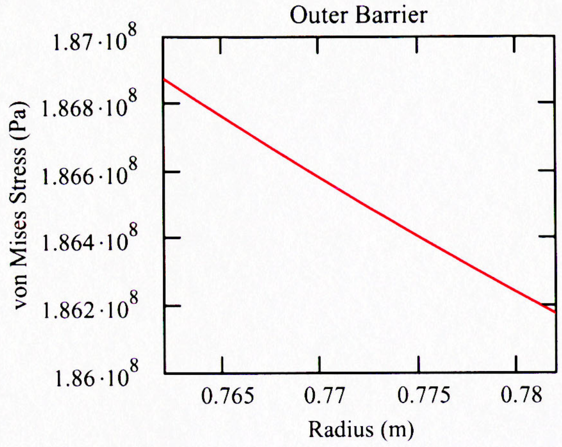
Radial Gap - $Gap_r \equiv 0\ mm$

CODE

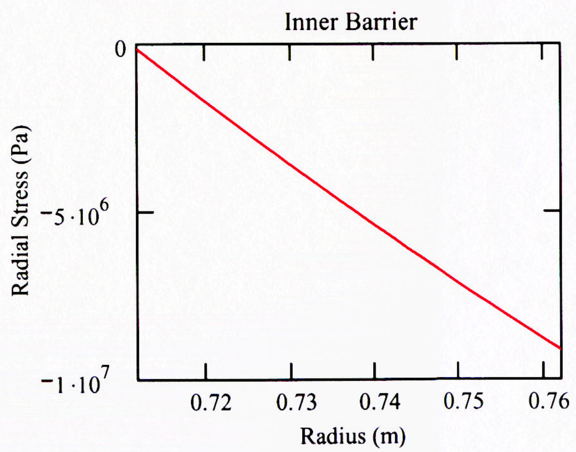
2-D Graphs



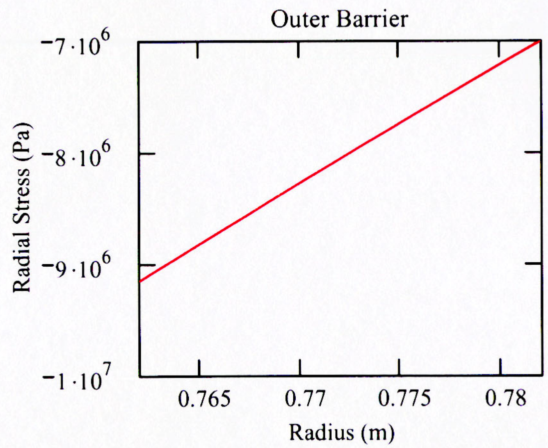
Inner Barrier
1.45·10^8
1.4·10^8
1.35·10^8
1.3·10^8
1.25·10^8
von Mises Stress (Pa)
0.72
0.73
0.74
0.75
0.76
Radius (m)



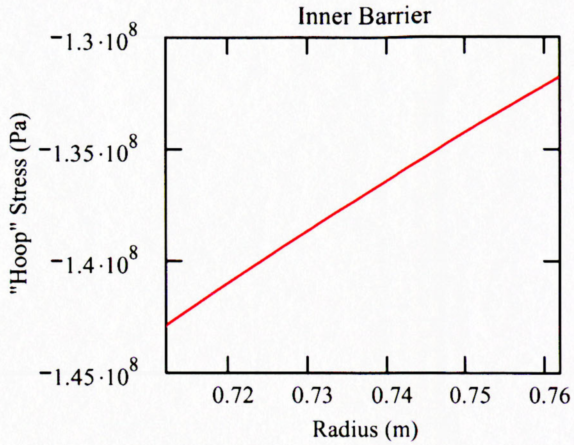
Outer Barrier
1.87·10^8
1.868·10^8
1.866·10^8
1.864·10^8
1.862·10^8
1.86·10^8
von Mises Stress (Pa)
0.765
0.77
0.775
0.78
Radius (m)

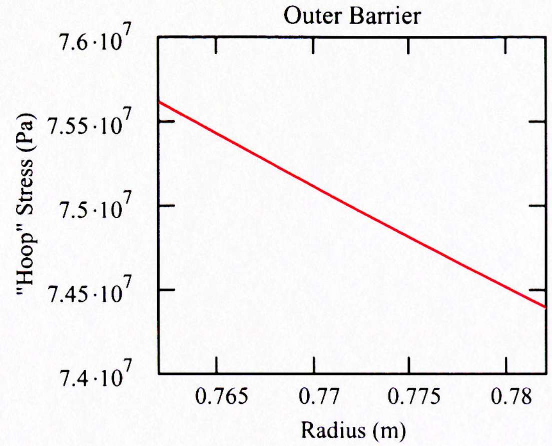


Inner Barrier
0
−5·10^6
−1·10^7
Radial Stress (Pa)
0.72
0.73
0.74
0.75
0.76
Radius (m)



Outer Barrier
−7·10^6
−8·10^6
−9·10^6
−1·10^7
Radial Stress (Pa)
0.765
0.77
0.775
0.78
Radius (m)





▲ 2-D Graphs

CaseNumber = 2

Radial Displacement of Inner Barrier

$disp_{ri} = 767.52172009484\,mm$

Radial Displacement of Outer Barrier

$disp_{ro} = 767.52172009484\,mm$

Axial Displacement of Inner Barrier

$disp_{ai} = 2408.05543640925\,mm$

Axial Displacement of Outer Barrier

$disp_{ao} = 2410.57866971229\,mm$

Radial Gap

$disp_{ro} - disp_{ri} = 0\,m$

Axial Gap

$disp_{ao} - disp_{ai} = 2.523 \times 10^{-3}\,m$

Radial Stresses

$\sigma_{rinner}(r_2) = -9.152 \times 10^{6}\,Pa$

$\sigma_{router}(r_3) = -9.152 \times 10^{6}\,Pa$

Validation

The purpose of this section is to compare the results given by the 3-D module of Dtherm to the 2-D module. Since the 3-D module and 2-D module were derived separately, if they output the same values the codes can be shown to be valid.

$CaseNumber = 2$

Radial Stress on inner barrier at r_1

$\sigma_{rinner}(r_1) = -1.61 \times 10^5$ Pa

Radial Stress on inner barrier at r_2

$\sigma_{rinner}(r_2) = -9.152 \times 10^6$ Pa

Axial Stress on inner barrier at r_1

$\sigma_{\theta inner}(r_1) = -1.429 \times 10^8$ Pa

Axial Stress on inner barrier at r_2

$\sigma_{\theta inner}(r_2) = -1.318 \times 10^8$ Pa

Radial Stress on outer barrier at r_3

$\sigma_{router}(r_3) = -9.152 \times 10^6$ Pa

Radial Stress on outer barrier at r_4

$\sigma_{router}(r_4) = -7 \times 10^6$ Pa

Axial Stress on outer barrier at r_3

$\sigma_{\theta outer}(r_3) = 7.561 \times 10^7$ Pa

Axial Stress on inner barrier at r_4

$\sigma_{\theta outer}(r_4) = 7.439 \times 10^7$ Pa

Von mises Stress on inner barrier at r_1

$\sigma_{voninner}(r_1) = 1.434 \times 10^8$ Pa

Von mises Stress on inner barrier at r_2

$\sigma_{voninner}(r_2) = 1.281 \times 10^8$ Pa

Von mises Stress on inner barrier at r_1

$\sigma_{vonouter}(r_3) = 1.869 \times 10^8$ Pa

Von mises Stress on inner barrier at r_2

$\sigma_{vonouter}(r_4) = 1.862 \times 10^8$ Pa

Validation

Source Code Header

Output Data File Name:

- Inner Barrier - $file_i := \text{"run1\_inner.txt"}$
- Outer Barrier - $file_o := \text{"run1\_outer.txt"}$

Young's Modulus:

- Inner Barrier - $E_i \equiv 1.81 \cdot 10^7\ psi$
- Outer Barrier - $E_o \equiv 22.6 \cdot 10^6\ psi$

Thermal Expansion Coefficients:

- Inner Barrier - $\alpha_i \equiv 17.5 \times 10^{-6}\ \frac{1}{K}$
- Outer Barrier - $\alpha_o \equiv 1.368 \times 10^{-5}\ \frac{1}{K}$

Inner Barrier Dimensions:

- Inner Radius - $r_1 \equiv 712\ mm$
- Thickness - $th_i \equiv 5\ cm$
- Length - $L_i \equiv 4775\ mm$

Initial Pressures on surfaces:

- Initial Pressure Inside Inner Barrier at Room Temperature - $P := 1\ atm$
- Outside Outer Barrier - $P_{oo} := 7 \cdot 10^6\ Pa$

Poisson's Ratio:

- Inner Barrier - $\nu_i \equiv .27$
- Outer Barrier - $\nu_o \equiv .30$

Temperature of surface:

- at r_4 - $T_4 \equiv (200 + 273)\ K$

Outer Barrier Dimensions:

- Thickness - $th_o \equiv 2\ cm$

Heat Terms:

- Heat Generated Per Waste Package - $Q_{generated} \equiv 11.8\ kW$
- Length of Entire Waste Package - $L \equiv 5165\ mm$

3-D Plot Variables:

- Radial Gap Lower Bound - $gaplower_r := 0\ mm$
- Radial Gap Upper Bound - $gapupper_r := 7\ mm$
- Radial Gap Increment - $gapinc_r := 2\ mm$
- Axial Gap Lower Bound - $gaplower_a := 0\ mm$
- Axial Gap Upper Bound - $gapupper_a := 30\ mm$
- Axial Gap Increment - $gapinc_a := 10\ mm$
- Resolution to find Maximum - $res := 1\ mm$

CODE

Reference:D:\Dtherm 1.1\Dtherm\Dtherm\3-D Plots.mcd(R)

The graphs can be viewed in the file above by double clicking on it.

Time it takes to calculate entire worksheet is $Time = 0.175min$

CODE

Maximum von Mises Stress given a Radial and an Axial Gap. Type in both an Axial and Radial Gap to find the Maximum von Mises Stress.

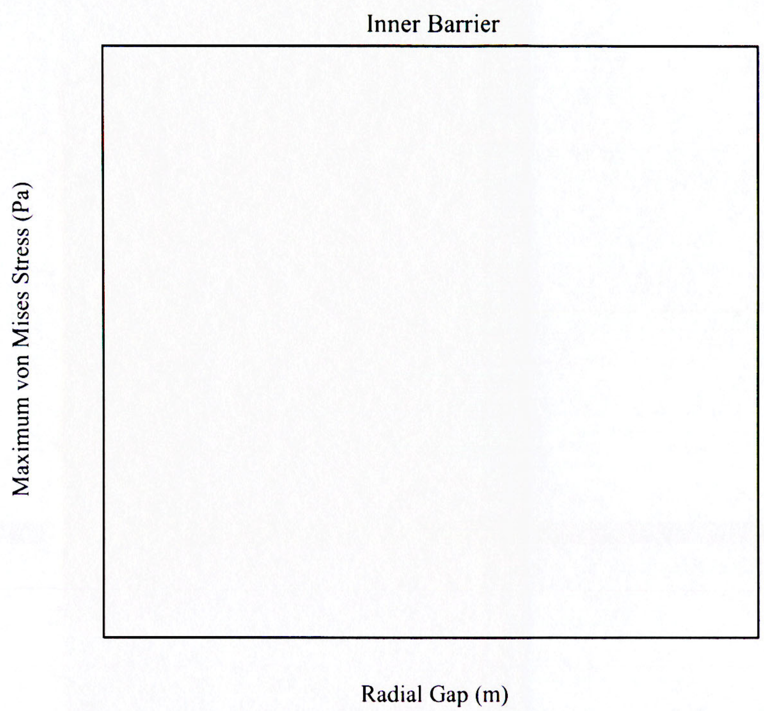
Axial Gap - $gap_a := 20mm$

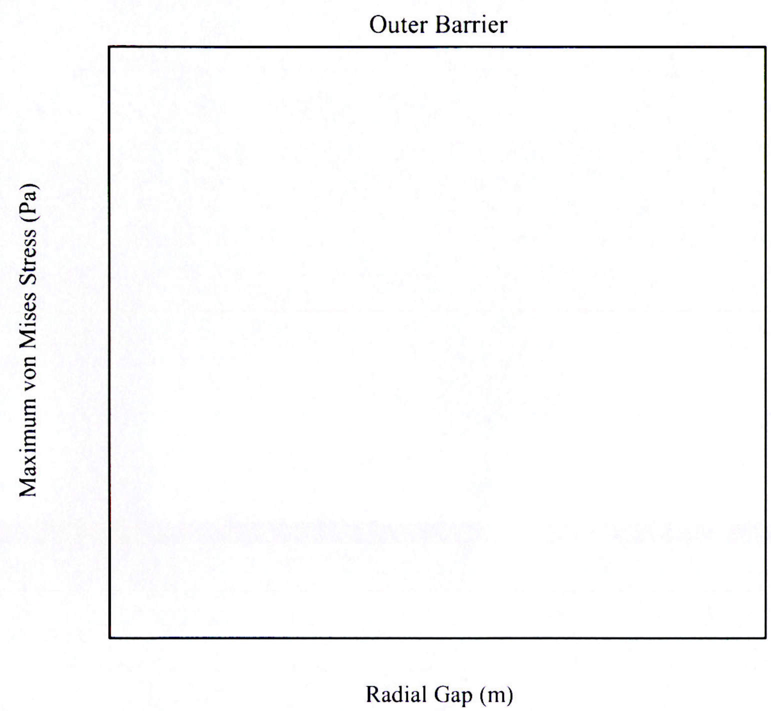
Radial Gap - $gap_r := 0mm$

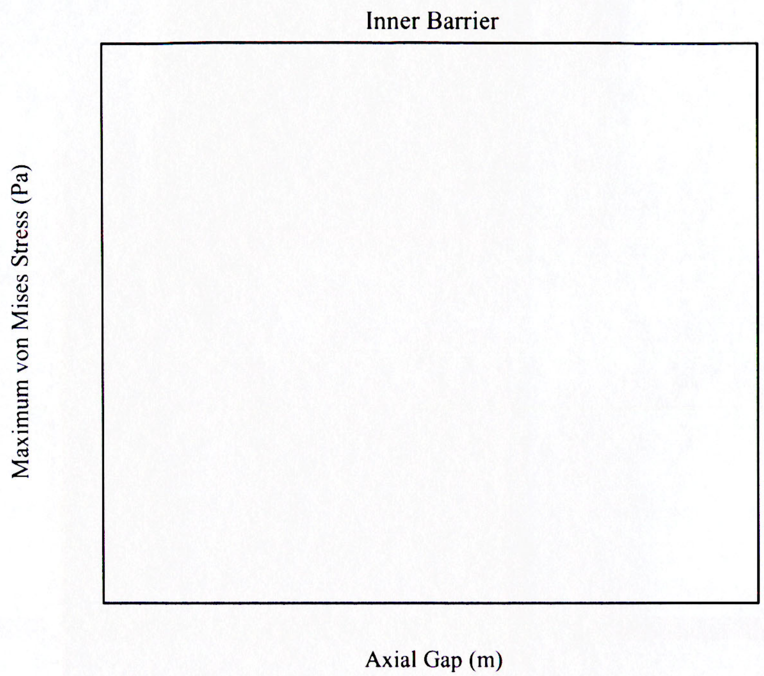
Inner Barrier - $\sigma_{voninner}(gap_a, gap_r) \cdot Pa = 1.434 \times 10^8 Pa$

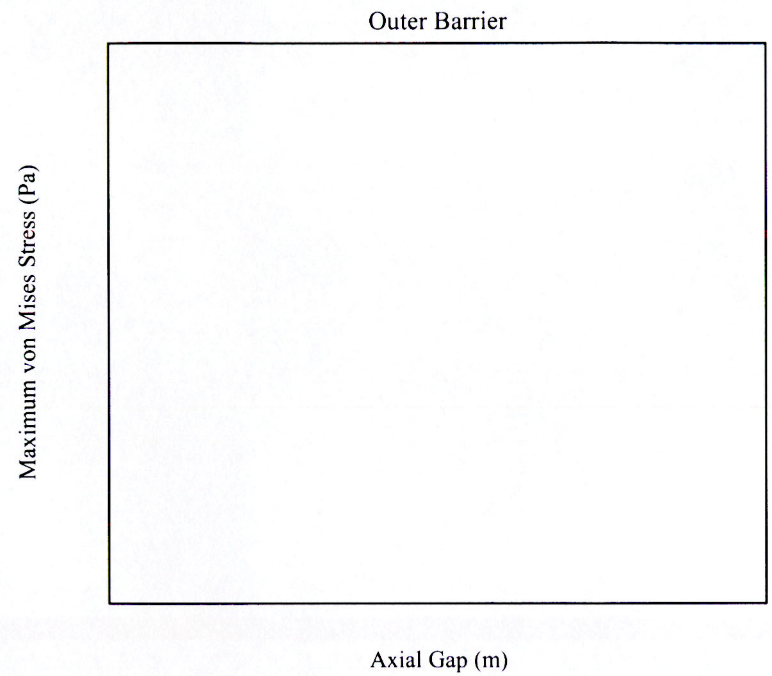
Outer Barrier - $\sigma_{vonouter}(gap_a, gap_r) \cdot Pa = 1.869 \times 10^8 Pa$

Optional Graphs: In order to see the effect of varying one parameter such as axial gap and holding the radial gap constant use these graphs. In order to view them ... right click the graph you would like and select -> Enable Evaluation. Then select Automatic Calculation from the Math menu or Calculate [F9].






Inner Barrier
Maximum von Mises Stress (Pa)
Axial Gap (m)


Outer Barrier
Maximum von Mises Stress (Pa)
Axial Gap (m)

Validation

The purpose of this section is to compare the results given by the 3-D module of Dtherm to the 2-D module. Since the 3-D module and 2-D module were derived separately, if they output the same values the codes can be shown to be valid. The 3-D module calculates the stresses as functions of radius, axial gap, and radial gap. The 2-D module calculates the stresses solely as a function of radius with the axial gap and radial gap user defined. Therefore, if you set the axial gap and the radial gap in the 3-D module, you will in a sense recreate the 2-D module (although the 3-D module is less efficient than the 2-D module when used this way).

Note: Most of the calculations shown below are calculated much more efficiently in the 2-D module.

Axial Gap - $gap_a = 20mm$

Radial Gap - $gap_r = 0mm$

$CaseNumber(gap_a, gap_r) = 2$

$r_3 := r_2 + gap_r$ $\quad$ $r_4 := r_2 + gap_r + th_o$

Radial Stress on inner barrier at r_1

$\sigma_{rinner}(r_1, gap_a, gap_r) = -1.61 \times 10^5\ Pa$

Radial Stress on inner barrier at r_2

$\sigma_{rinner}(r_2, gap_a, gap_r) = -9.152 \times 10^6\ Pa$

Hoop Stress on inner barrier at r_1

$\sigma_{\theta inner}(r_1, gap_a, gap_r) = -1.429 \times 10^8\ Pa$

Axial Stress on inner barrier at r_2

$\sigma_{\theta inner}(r_2, gap_a, gap_r) = -1.318 \times 10^8\ Pa$

Radial Stress on outer barrier at r_3

$\sigma_{router}(r_3, gap_a, gap_r) = -9.152 \times 10^6\ Pa$

Radial Stress on outer barrier at r_4

$\sigma_{router}(r_4, gap_a, gap_r) = -7 \times 10^6\ Pa$

Hoop Stress on outer barrier at r_3

$\sigma_{\theta outer}(r_3, gap_a, gap_r) = 7.561 \times 10^7\ Pa$

Axial Stress on inner barrier at r_4

$\sigma_{\theta outer}(r_4, gap_a, gap_r) = 7.439 \times 10^7\ Pa$

Von mises Stress on inner barrier at r_1

$\sigma_{voninner\_valid}(r_1, gap_a, gap_r) = 1.434 \times 10^8\ Pa$

Von mises Stress on inner barrier at r_2

$\sigma_{voninner\_valid}(r_2, gap_a, gap_r) = 1.281 \times 10^8\ Pa$

Von mises Stress on inner barrier at r_1

$\sigma_{vonouter\_valid}(r_3, gap_a, gap_r) = 1.869 \times 10^8\ Pa$

Von mises Stress on inner barrier at r_2

$\sigma_{vonouter\_valid}(r_4, gap_a, gap_r) = 1.862 \times 10^8\ Pa$

Validation

Case 3

```
Radial Gap = 0 mm
Axial Gap  = 5 mm
```

Source Code Header

Young's Modulus:

Inner Barrier - $E_i := 1.81 \cdot 10^7 \text{ psi}$

Outer Barrier - $E_o := 22.6 \cdot 10^6 \text{ psi}$

Thermal Expansion Coefficients:

Inner Barrier - $\alpha_i := 17.5 \times 10^{-6} \frac{1}{K}$

Outer Barrier - $\alpha_o := 1.368 \times 10^{-5} \frac{1}{K}$

Inner Barrier Dimensions:

Inner Radius - $r_1 \equiv 712 \text{ mm}$

Thickness - $th_i \equiv 5 \text{ cm}$

Length - $L_i \equiv 4775 \text{ mm}$

Initial Pressures on surfaces:

Initial Pressure Inside Inner Barrier at Room Temperature - $P := 1 \text{ atm}$

Outside Outer Barrier - $P_{oo} := 7 \cdot 10^6 \text{ Pa}$

Poisson's Ratio:

Inner Barrier - $\nu_i := .27$

Outer Barrier - $\nu_o := .30$

Temperature of surface:

at r_4 - $T_4 \equiv (200 + 273) \text{ K}$

Outer Barrier Dimensions:

Thickness - $th_o \equiv 2 \text{ cm}$

Heat Terms:

Heat Generated Per Waste Package - $Q_{generated} \equiv 11.8 \text{ kW}$

Length of Entire Waste Package - $L \equiv 5165 \text{ mm}$

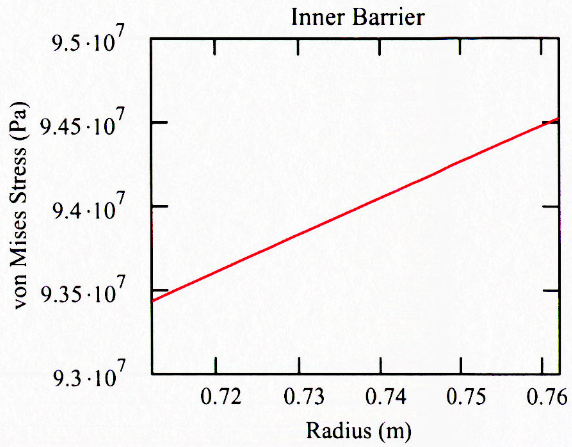
Gap Between Inner and Outer Barrier:

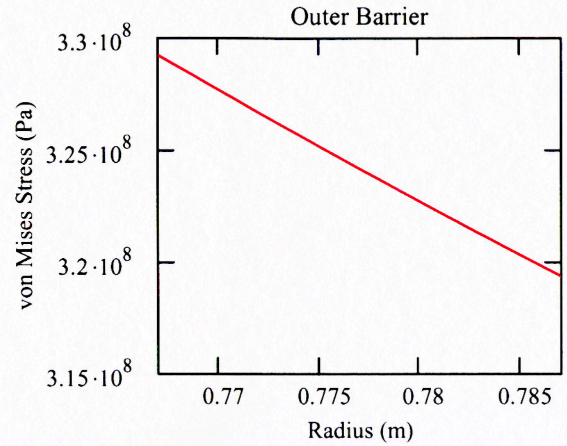
Axial Gap - $Gap_a \equiv 0 \text{ mm}$

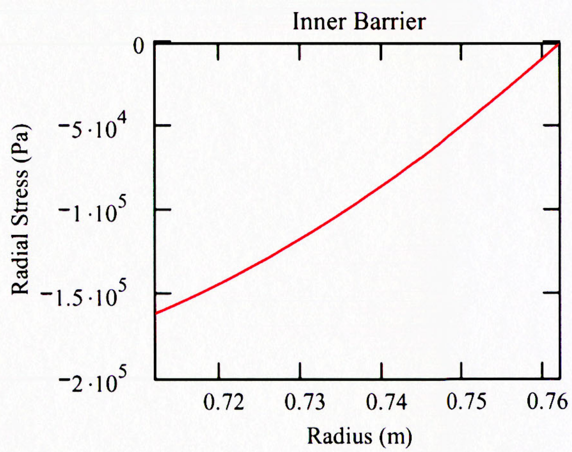
Radial Gap - $Gap_r \equiv 5 \text{ mm}$

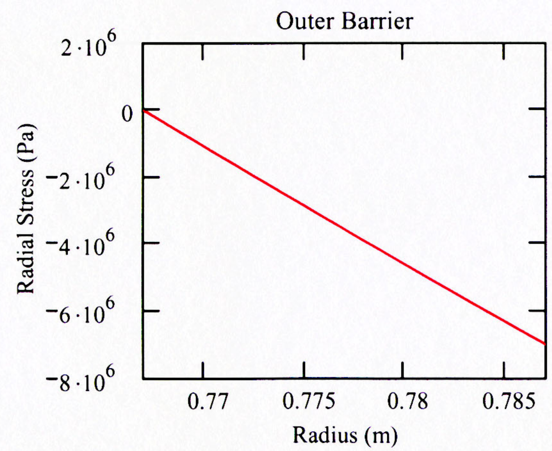
CODE

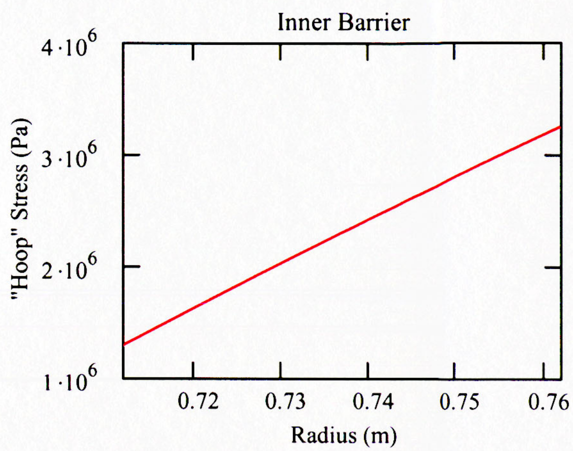
2-D Graphs

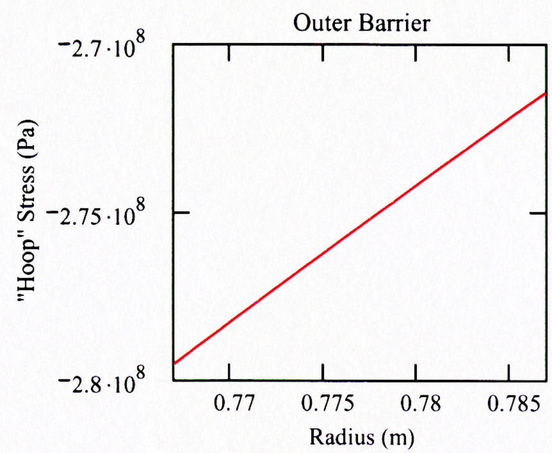

Inner Barrier
von Mises Stress (Pa)
9.5·10^7
9.45·10^7
9.4·10^7
9.35·10^7
9.3·10^7
0.72
0.73
0.74
0.75
0.76
Radius (m)


Outer Barrier
von Mises Stress (Pa)
3.3·10^8
3.25·10^8
3.2·10^8
3.15·10^8
0.77
0.775
0.78
0.785
Radius (m)


Inner Barrier
Radial Stress (Pa)
0
−5·10^4
−1·10^5
−1.5·10^5
−2·10^5
0.72
0.73
0.74
0.75
0.76
Radius (m)


Outer Barrier
Radial Stress (Pa)
2·10^6
0
−2·10^6
−4·10^6
−6·10^6
−8·10^6
0.77
0.775
0.78
0.785
Radius (m)





2-D Graphs

CaseNumber = 3

Radial Displacement of Inner Barrier

$disp_{ri} = 768.487227155394\,mm$

Radial Displacement of Outer Barrier

$disp_{ro} = 770.469310764138\,mm$

Axial Displacement of Inner Barrier

$disp_{ai} = 2405.51609065565\,mm$

Axial Displacement of Outer Barrier

$disp_{ao} = 2405.51609065565\,mm$

Radial Gap

$disp_{ro} - disp_{ri} = 1.982 \times 10^{-3}\,m$

Axial Gap

$disp_{ao} - disp_{ai} = 0\,m$

Radial Stresses

$\sigma_{rinner}(r_2) = -1.192 \times 10^{-6}\,Pa$

$\sigma_{router}(r_3) = 1.669 \times 10^{-6}\,Pa$

Validation

The purpose of this section is to compare the results given by the 3-D module of Dtherm to the 2-D module. Since the 3-D module and 2-D module were derived separately, if they output the same values the codes can be shown to be valid.

CaseNumber = 3

Radial Stress on inner barrier at r_1

$\sigma_{rinner}(r_1) = -1.61 \times 10^{5}$ Pa

Radial Stress on inner barrier at r_2

$\sigma_{rinner}(r_2) = -1.192 \times 10^{-6}$ Pa

Axial Stress on inner barrier at r_1

$\sigma_{\theta inner}(r_1) = 1.293 \times 10^{6}$ Pa

Axial Stress on inner barrier at r_2

$\sigma_{\theta inner}(r_2) = 3.25 \times 10^{6}$ Pa

Radial Stress on outer barrier at r_3

$\sigma_{router}(r_3) = 1.669 \times 10^{-6}$ Pa

Radial Stress on outer barrier at r_4

$\sigma_{router}(r_4) = -7 \times 10^{6}$ Pa

Axial Stress on outer barrier at r_3

$\sigma_{\theta outer}(r_3) = -2.795 \times 10^{8}$ Pa

Axial Stress on inner barrier at r_4

$\sigma_{\theta outer}(r_4) = -2.715 \times 10^{8}$ Pa

Von mises Stress on inner barrier at r_1

$\sigma_{voninner}(r_1) = 9.343 \times 10^{7}$ Pa

Von mises Stress on inner barrier at r_2

$\sigma_{voninner}(r_2) = 9.452 \times 10^{7}$ Pa

Von mises Stress on inner barrier at r_1

$\sigma_{vonouter}(r_3) = 3.292 \times 10^{8}$ Pa

Von mises Stress on inner barrier at r_2

$\sigma_{vonouter}(r_4) = 3.193 \times 10^{8}$ Pa

Validation

Source Code Header

Output Data File Name:

Inner Barrier - $file_i := $ "run1_inner.txt"

Outer Barrier - $file_o := $ "run1_outer.txt"

Young's Modulus:

Inner Barrier - $E_i \equiv 1.81 \cdot 10^7$ psi

Outer Barrier - $E_o \equiv 22.6 \cdot 10^6$ psi

Thermal Expansion Coefficients:

Inner Barrier - $\alpha_i \equiv 17.5 \times 10^{-6} \frac{1}{K}$

Outer Barrier - $\alpha_o \equiv 1.368 \times 10^{-5} \frac{1}{K}$

Inner Barrier Dimensions:

Inner Radius - $r_1 \equiv 712$ mm

Thickness - $th_i \equiv 5$ cm

Length - $L_i \equiv 4775$ mm

Initial Pressures on surfaces:

Initial Pressure Inside Inner Barrier at Room Temperature - $P := 1$ atm

Outside Outer Barrier - $P_{oo} := 7 \cdot 10^6$ Pa

Poisson's Ratio:

Inner Barrier - $\nu_i \equiv .27$

Outer Barrier - $\nu_o \equiv .30$

Temperature of surface:

at r_4 - $T_4 \equiv (200 + 273)$ K

Outer Barrier Dimensions:

Thickness - $th_o \equiv 2$ cm

Heat Terms:

Heat Generated Per Waste Package - $Q_{generated} \equiv 11.8$ kW

Length of Entire Waste Package - $L \equiv 5165$ mm

3-D Plot Variables:

Radial Gap Lower Bound - $gaplower_r := 0$ mm

Radial Gap Upper Bound - $gapupper_r := 7$ mm

Radial Gap Increment - $gapinc_r := 2$ mm

Axial Gap Lower Bound - $gaplower_a := 0$ mm

Axial Gap Upper Bound - $gapupper_a := 30$ mm

Axial Gap Increment - $gapinc_a := 10$ mm

Resolution to find Maximum - $res := 1$ mm

CODE

Reference:D:\Dtherm 1.1\Dtherm\Dtherm\3-D Plots.mcd(R)

The graphs can be viewed in the file above by double clicking on it.

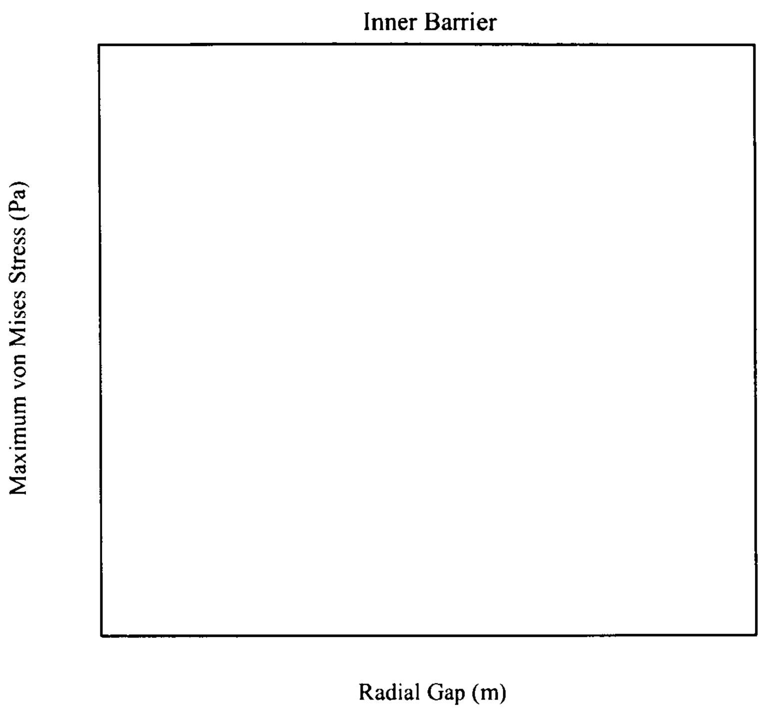
Time it takes to calculate entire worksheet is $\mathrm{Time} = 0.175\mathrm{min}$

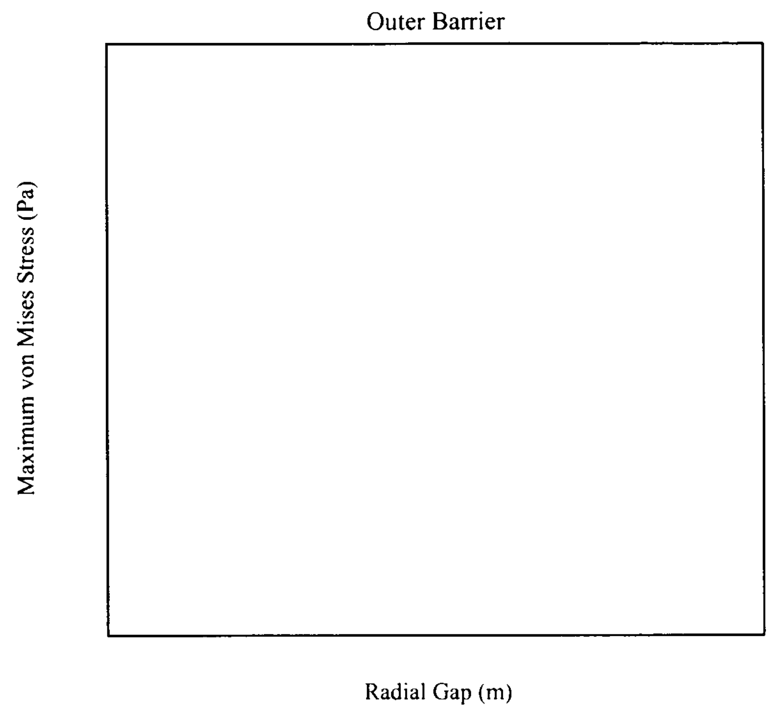
CODE

Maximum von Mises Stress given a Radial and an Axial Gap. Type in both an Axial and Radial Gap to find the Maximum von Mises Stress.

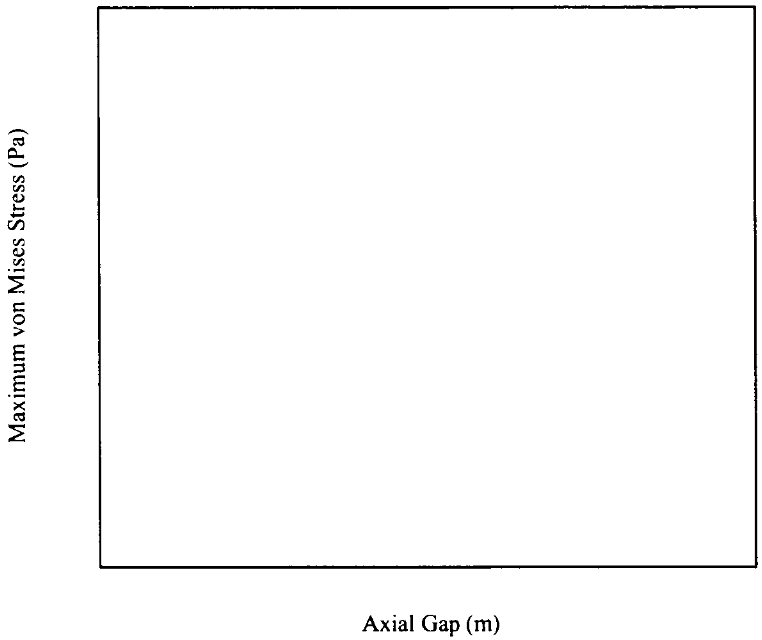
Axial Gap	-	$gap_a := 0mm$
Radial Gap	-	$gap_r := 5mm$
Inner Barrier	-	$\sigma_{voninner}(gap_a, gap_r) \cdot Pa = 9.449 \times 10^7\ Pa$
Outer Barrier	-	$\sigma_{vonouter}(gap_a, gap_r) \cdot Pa = 3.291 \times 10^8\ Pa$

Optional Graphs: In order to see the effect of varying one parameter such as axial gap and holding the radial gap constant use these graphs. In order to view them ... right click the graph you would like and select -> Enable Evaluation. Then select Automatic Calculation from the Math menu or Calculate [F9].

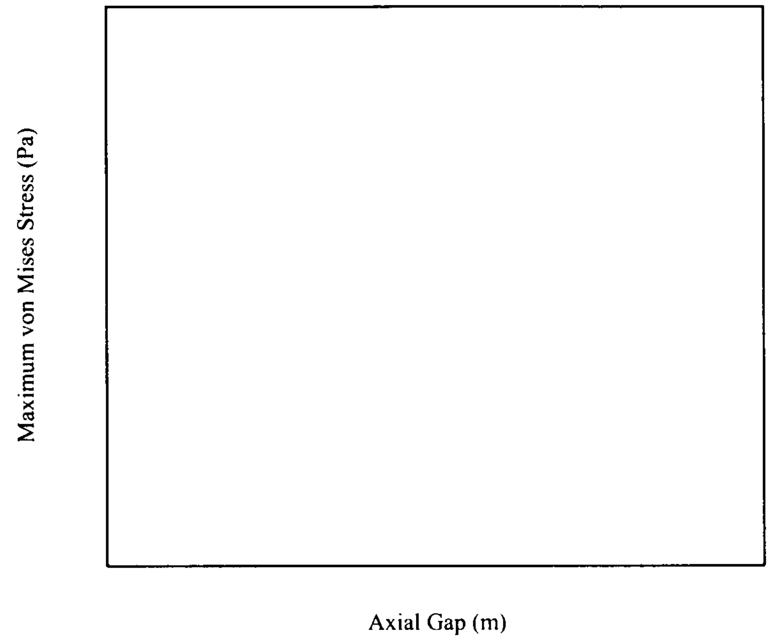




Inner Barrier



Outer Barrier



▼ Validation

The purpose of this section is to compare the results given by the 3-D module of Dtherm to the 2-D module. Since the 3-D module and 2-D module were derived separately, if they output the same values the codes can be shown to be valid. The 3-D module calculates the stresses as functions of radius, axial gap, and radial gap. The 2-D module calculates the stresses solely as a function of radius with the axial gap and radial gap user defined. Therefore, if you set the axial gap and the radial gap in the 3-D module, you will in a sense recreate the 2-D module (although the 3-D module is less efficient than the 2-D module when used this way).

Note: Most of the calculations shown below are calculated much more efficiently in the 2-D module.

Axial Gap - $gap_a = 20mm$

Radial Gap - $gap_r = 0mm$

$\boxed{CaseNumber(gap_a, gap_r) = 2}$

$r_3 := r_2 + gap_r$ $\quad r_4 := r_2 + gap_r + th_o$

Radial Stress on inner barrier at r_1

$\sigma_{rinner}(r_1, gap_a, gap_r) = -1.61 \times 10^5 \, Pa$

Radial Stress on inner barrier at r_2

$\sigma_{rinner}(r_2, gap_a, gap_r) = -9.152 \times 10^6 \, Pa$

Hoop Stress on inner barrier at r_1

$\sigma_{\theta inner}(r_1, gap_a, gap_r) = -1.429 \times 10^8 \, Pa$

Axial Stress on inner barrier at r_2

$\sigma_{\theta inner}(r_2, gap_a, gap_r) = -1.318 \times 10^8 \, Pa$

Radial Stress on outer barrier at r_3

$\sigma_{router}(r_3, gap_a, gap_r) = -9.152 \times 10^6 \, Pa$

Radial Stress on outer barrier at r_4

$\sigma_{router}(r_4, gap_a, gap_r) = -7 \times 10^6 \, Pa$

Hoop Stress on outer barrier at r_3

$\sigma_{\theta outer}(r_3, gap_a, gap_r) = 7.561 \times 10^7 \, Pa$

Axial Stress on inner barrier at r_4

$\sigma_{\theta outer}(r_4, gap_a, gap_r) = 7.439 \times 10^7 \, Pa$

Von mises Stress on inner barrier at r_1

$\sigma_{voninner\_valid}(r_1, gap_a, gap_r) = 1.434 \times 10^8 \, Pa$

Von mises Stress on inner barrier at r_2

$\sigma_{voninner\_valid}(r_2, gap_a, gap_r) = 1.281 \times 10^8 \, Pa$

Von mises Stress on inner barrier at r_1

$\sigma_{vonouter\_valid}(r_3, gap_a, gap_r) = 1.869 \times 10^8 \, Pa$

Von mises Stress on inner barrier at r_2

$\sigma_{vonouter\_valid}(r_4, gap_a, gap_r) = 1.862 \times 10^8 \, Pa$

▲ Validation

Case 4

```
Radial Gap = 0 mm
Axial Gap  = 0 mm
```

Source Code Header

Young's Modulus:

Inner Barrier - $E_i := 1.81 \cdot 10^7$ psi

Outer Barrier - $E_o := 22.6 \cdot 10^6$ psi

Thermal Expansion Coefficients:

Inner Barrier - $\alpha_i := 17.5 \times 10^{-6} \frac{1}{K}$

Outer Barrier - $\alpha_o := 1.368 \times 10^{-5} \frac{1}{K}$

Inner Barrier Dimensions:

Inner Radius - $r_1 \equiv 712$ mm

Thickness - $th_i \equiv 5$ cm

Length - $L_i \equiv 4775$ mm

Initial Pressures on surfaces:

Initial Pressure Inside Inner Barrier at Room Temperature - $P := 1$ atm

Outside Outer Barrier - $P_{oo} := 7 \cdot 10^6$ Pa

Poisson's Ratio:

Inner Barrier - $\nu_i := .27$

Outer Barrier - $\nu_o := .30$

Temperature of surface:

at r_4 - $T_4 \equiv (200 + 273)$ K

Outer Barrier Dimensions:

Thickness - $th_o \equiv 2$ cm

Heat Terms:

Heat Generated Per Waste Package - $Q_{generated} \equiv 11.8$ kW

Length of Entire Waste Package - $L \equiv 5165$ mm

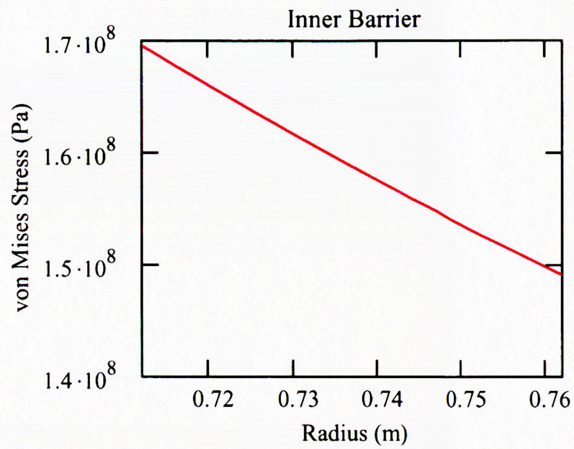
Gap Between Inner and Outer Barrier:

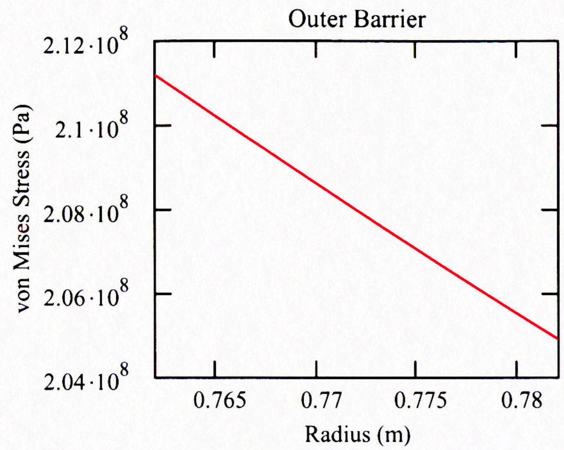
Axial Gap - $Gap_a \equiv 0$ mm

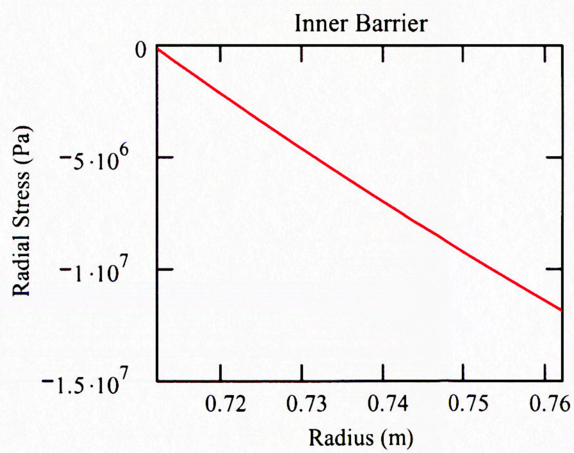
Radial Gap - $Gap_r \equiv 0$ mm

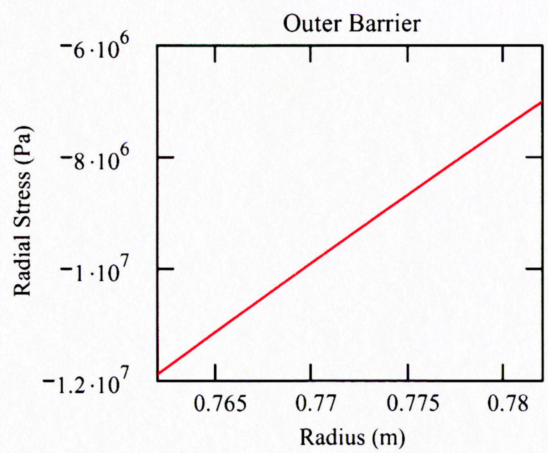
CODE

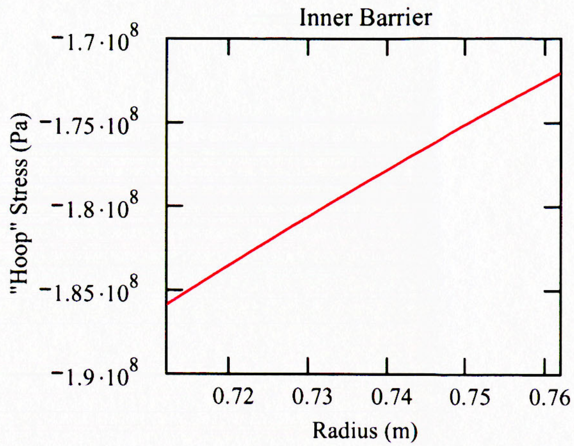
2-D Graphs

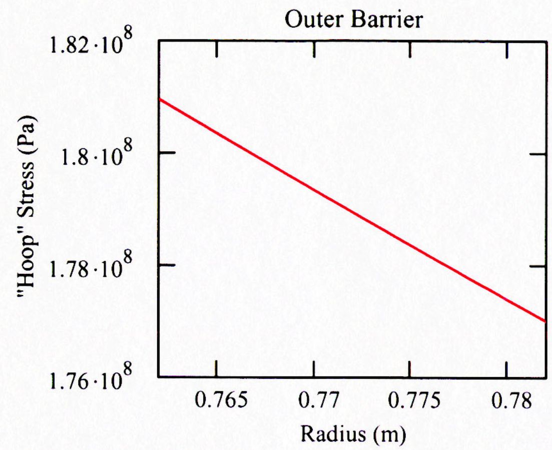

Inner Barrier
von Mises Stress (Pa)
1.7·10^8
1.6·10^8
1.5·10^8
1.4·10^8
0.72
0.73
0.74
0.75
0.76
Radius (m)


Outer Barrier
von Mises Stress (Pa)
2.12·10^8
2.1·10^8
2.08·10^8
2.06·10^8
2.04·10^8
0.765
0.77
0.775
0.78
Radius (m)


Inner Barrier
Radial Stress (Pa)
0
−5·10^6
−1·10^7
−1.5·10^7
0.72
0.73
0.74
0.75
0.76
Radius (m)


Outer Barrier
Radial Stress (Pa)
−6·10^6
−8·10^6
−1·10^7
−1.2·10^7
0.765
0.77
0.775
0.78
Radius (m)





2-D Graphs

CaseNumber = 4

Radial Displacement of Inner Barrier

$disp_{ri} = 767.523810263122\ mm$

Radial Displacement of Outer Barrier

$disp_{ro} = 767.523810263121\ mm$

Axial Displacement of Inner Barrier

$disp_{ai} = 2405.45243321429\ mm$

Axial Displacement of Outer Barrier

$disp_{ao} = 2405.45243321429\ mm$

Radial Gap

$disp_{ro} - disp_{ri} = 0\ m$

Axial Gap

$disp_{ao} - disp_{ai} = 0\ m$

Radial Stresses

$\sigma_{rinner}(r_2) = -1.188 \times 10^7\ Pa$

$\sigma_{router}(r_3) = -1.188 \times 10^7\ Pa$

Validation

The purpose of this section is to compare the results given by the 3-D module of Dtherm to the 2-D module. Since the 3-D module and 2-D module were derived separately, if they output the same values the codes can be shown to be valid.

CaseNumber = 4

Radial Stress on inner barrier at r_1

$\sigma_{rinner}(r_1) = -1.61 \times 10^5$ Pa

Radial Stress on inner barrier at r_2

$\sigma_{rinner}(r_2) = -1.188 \times 10^7$ Pa

Axial Stress on inner barrier at r_1

$\sigma_{\theta inner}(r_1) = -1.859 \times 10^8$ Pa

Axial Stress on inner barrier at r_2

$\sigma_{\theta inner}(r_2) = -1.721 \times 10^8$ Pa

Radial Stress on outer barrier at r_3

$\sigma_{router}(r_3) = -1.188 \times 10^7$ Pa

Radial Stress on outer barrier at r_4

$\sigma_{router}(r_4) = -7 \times 10^6$ Pa

Axial Stress on outer barrier at r_3

$\sigma_{\theta outer}(r_3) = 1.81 \times 10^8$ Pa

Axial Stress on inner barrier at r_4

$\sigma_{\theta outer}(r_4) = 1.77 \times 10^8$ Pa

Von mises Stress on inner barrier at r_1

$\sigma_{voninner}(r_1) = 1.695 \times 10^8$ Pa

Von mises Stress on inner barrier at r_2

$\sigma_{voninner}(r_2) = 1.491 \times 10^8$ Pa

Von mises Stress on inner barrier at r_1

$\sigma_{vonouter}(r_3) = 2.112 \times 10^8$ Pa

Von mises Stress on inner barrier at r_2

$\sigma_{vonouter}(r_4) = 2.049 \times 10^8$ Pa

Validation

Source Code Header

Output Data File Name:
- Inner Barrier - $file_i := \text{"run1\_inner.txt"}$
- Outer Barrier - $file_o := \text{"run1\_outer.txt"}$

Young's Modulus:
- Inner Barrier - $E_i \equiv 1.81 \cdot 10^7 \text{ psi}$
- Outer Barrier - $E_o \equiv 22.6 \cdot 10^6 \text{ psi}$

Thermal Expansion Coefficients:
- Inner Barrier - $\alpha_i \equiv 17.5 \times 10^{-6} \frac{1}{K}$
- Outer Barrier - $\alpha_o \equiv 1.368 \times 10^{-5} \frac{1}{K}$

Inner Barrier Dimensions:
- Inner Radius - $r_1 \equiv 712 \text{ mm}$
- Thickness - $th_i \equiv 5 \text{ cm}$
- Length - $L_i \equiv 4775 \text{ mm}$

Initial Pressures on surfaces:
- Initial Pressure Inside Inner Barrier at Room Temperature - $P := 1 \text{ atm}$
- Outside Outer Barrier - $P_{oo} := 7 \cdot 10^6 \text{ Pa}$

Poisson's Ratio:
- Inner Barrier - $v_i \equiv .27$
- Outer Barrier - $v_o \equiv .30$

Temperature of surface:
- at r_4 - $T_4 \equiv (200 + 273) \text{ K}$

Outer Barrier Dimensions:
- Thickness - $th_o \equiv 2 \text{ cm}$

Heat Terms:
- Heat Generated Per Waste Package - $Q_{generated} \equiv 11.8 \text{ kW}$
- Length of Entire Waste Package - $L \equiv 5165 \text{ mm}$

3-D Plot Variables:
- Radial Gap Lower Bound - $gaplower_r := 0 \text{ mm}$
- Radial Gap Upper Bound - $gapupper_r := 7 \text{ mm}$
- Radial Gap Increment - $gapinc_r := 2 \text{ mm}$
- Axial Gap Lower Bound - $gaplower_a := 0 \text{ mm}$
- Axial Gap Upper Bound - $gapupper_a := 30 \text{ mm}$
- Axial Gap Increment - $gapinc_a := 10 \text{ mm}$
- Resolution to find Maximum - $res := 1 \text{ mm}$

CODE

Reference:D:\Dtherm 1.1\Dtherm\Dtherm\3-D Plots.mcd(R)

The graphs can be viewed in the file above by double clicking on it.

Time it takes to calculate entire worksheet is $\mathrm{Time} = 0.175\mathrm{min}$

CODE

Maximum von Mises Stress given a Radial and an Axial Gap. Type in both an Axial and Radial Gap to find the Maximum von Mises Stress.

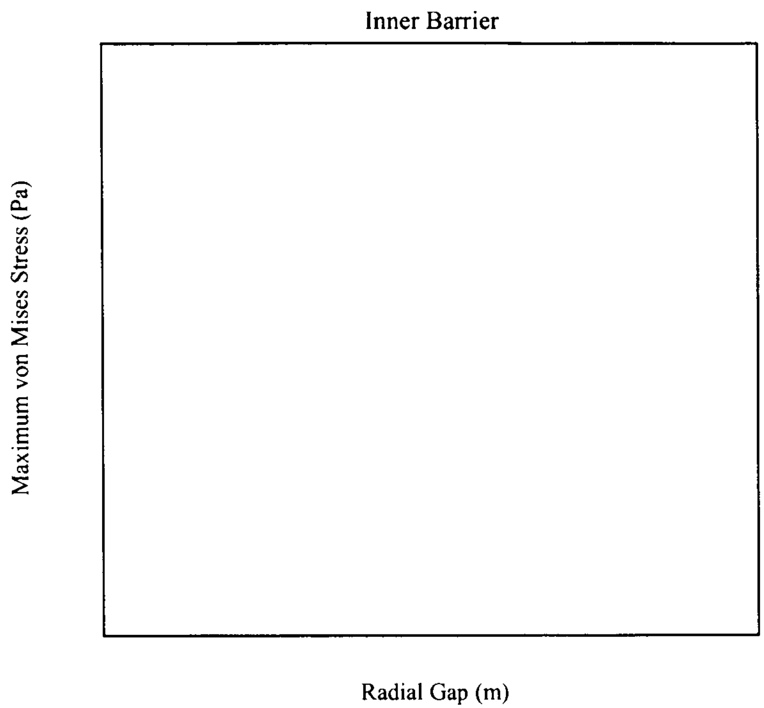
Axial Gap - $gap_a := 0\mathrm{mm}$

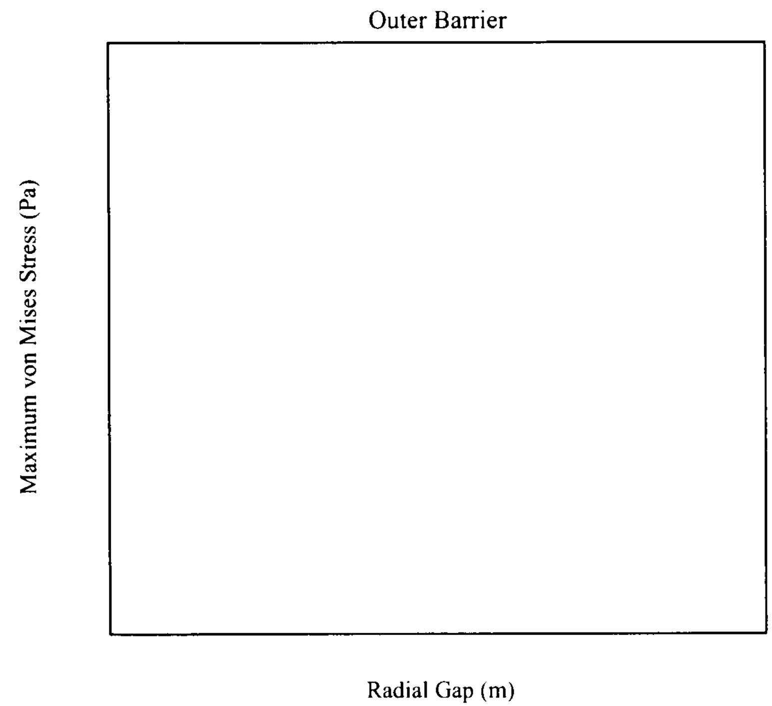
Radial Gap - $gap_r := 0\mathrm{mm}$

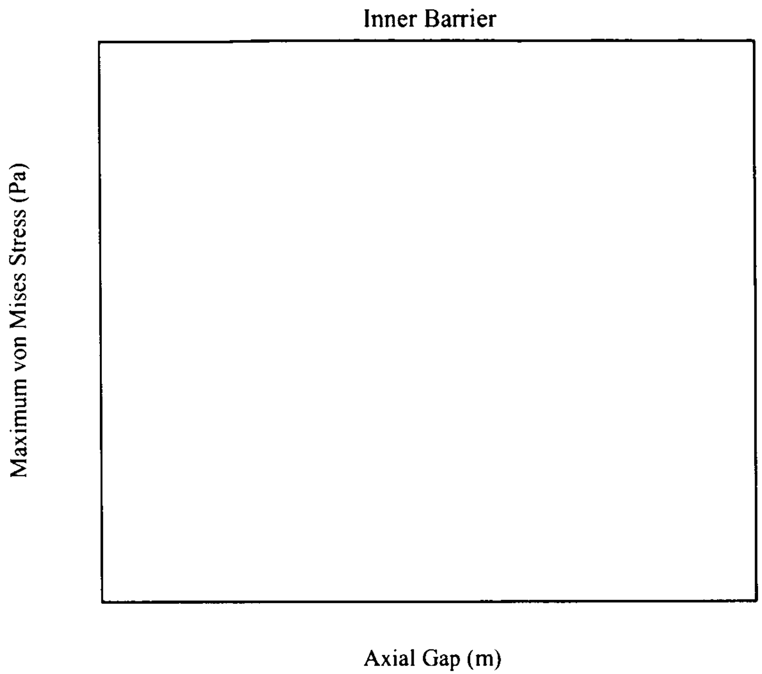
Inner Barrier - $\sigma_{voninner}(gap_a, gap_r) \cdot \mathrm{Pa} = 1.695 \times 10^8\ \mathrm{Pa}$

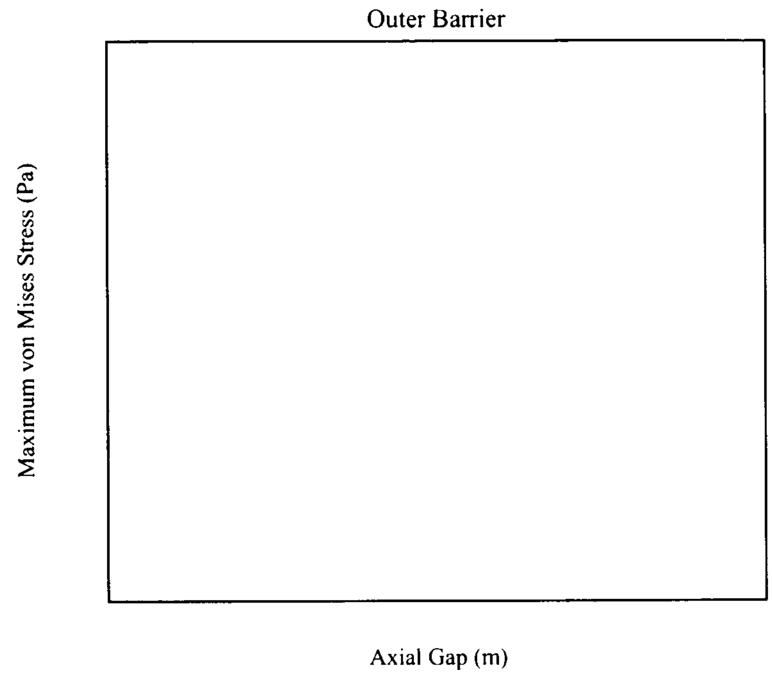
Outer Barrier - $\sigma_{vonouter}(gap_a, gap_r) \cdot \mathrm{Pa} = 2.112 \times 10^8\ \mathrm{Pa}$

Optional Graphs: In order to see the effect of varying one parameter such as axial gap and holding the radial gap constant use these graphs. In order to view them ... right click the graph you would like and select -> Enable Evaluation. Then select Automatic Calculation from the Math menu or Calculate [F9].






Inner Barrier
Maximum von Mises Stress (Pa)
Axial Gap (m)


Outer Barrier
Maximum von Mises Stress (Pa)
Axial Gap (m)

Validation

The purpose of this section is to compare the results given by the 3-D module of Dtherm to the 2-D module. Since the 3-D module and 2-D module were derived separately, if they output the same values the codes can be shown to be valid. The 3-D module calculates the stresses as functions of radius, axial gap, and radial gap. The 2-D module calculates the stresses solely as a function of radius with the axial gap and radial gap user defined. Therefore, if you set the axial gap and the radial gap in the 3-D module, you will in a sense recreate the 2-D module (although the 3-D module is less efficient than the 2-D module when used this way).

Note: Most of the calculations shown below are calculated much more efficiently in the 2-D module.

Axial Gap - $gap_a = 0mm$

Radial Gap - $gap_r = 0mm$

$CaseNumber(gap_a, gap_r) = 4$

$r_3 := r_2 + gap_r$ $\qquad$ $r_4 := r_2 + gap_r + th_o$

Radial Stress on inner barrier at r_1

$\sigma_{rinner}(r_1, gap_a, gap_r) = -1.61 \times 10^5\ Pa$

Radial Stress on inner barrier at r_2

$\sigma_{rinner}(r_2, gap_a, gap_r) = -1.188 \times 10^7\ Pa$

Hoop Stress on inner barrier at r_1

$\sigma_{\theta inner}(r_1, gap_a, gap_r) = -1.859 \times 10^8\ Pa$

Axial Stress on inner barrier at r_2

$\sigma_{\theta inner}(r_2, gap_a, gap_r) = -1.721 \times 10^8\ Pa$

Radial Stress on outer barrier at r_3

$\sigma_{router}(r_3, gap_a, gap_r) = -1.188 \times 10^7\ Pa$

Radial Stress on outer barrier at r_4

$\sigma_{router}(r_4, gap_a, gap_r) = -7 \times 10^6\ Pa$

Hoop Stress on outer barrier at r_3

$\sigma_{\theta outer}(r_3, gap_a, gap_r) = 1.81 \times 10^8\ Pa$

Axial Stress on inner barrier at r_4

$\sigma_{\theta outer}(r_4, gap_a, gap_r) = 1.77 \times 10^8\ Pa$

Von mises Stress on inner barrier at r_1

$\sigma_{voninner\_valid}(r_1, gap_a, gap_r) = 1.695 \times 10^8\ Pa$

Von mises Stress on inner barrier at r_2

$\sigma_{voninner\_valid}(r_2, gap_a, gap_r) = 1.491 \times 10^8\ Pa$

Von mises Stress on inner barrier at r_1

$\sigma_{vonouter\_valid}(r_3, gap_a, gap_r) = 2.112 \times 10^8\ Pa$

Von mises Stress on inner barrier at r_2

$\sigma_{vonouter\_valid}(r_4, gap_a, gap_r) = 2.049 \times 10^8\ Pa$

Validation

SOFTWARE CHANGE REPORT (SCR)

1. SCR No. (*Software Developer Assigns*): MGFE-SCR-402	2. Software Title and Version: Dtherm v. 1.1	3. Project No: 01402.671

4. Affected Software Module(s), Description of Problem(s):
Mathcad 2000 Professional (Service Release 2a)

Dtherm v. 1.0 was missing header information required by Top-18 in main program file. 2-D, 3-D, and 3-D Plots modules were all affected.

5. Change Requested by: Dr. G. Douglas Gute Date: May 28, 2002	6. Change Authorized by (*Software Developer*): Andrew J. Grehmann Date: May 28, 2002

7. Description of Change(s) or Problem Resolution (*If changes not implemented, please justify*):

Added header information required by Top-18 to Contents.mcd.

8. Implemented by: Andrew J. Grehmann	Date: May 28, 2002

9. Description of Acceptance Tests:

Verified by inspection that all header information was up to Top-18 specifications.

Performed Regression testing to verify that program was unchanged. — Reviewed data/output RF 6/3/02

10. Tested by: [signature]	Date: 6/3/02

CNWRA Form TOP-5 (05/2000)

Repeat of Dtherm v. 1.0 test results

Demonstrates that Dtherm v. 1.1 gives the same results as Dtherm v. 1.0

Source Code Header

Young's Modulus:

Inner Barrier - $E_i := 1.81 \cdot 10^7 \text{ psi}$

Outer Barrier - $E_o := 22.6 \cdot 10^6 \text{ psi}$

Thermal Expansion Coefficients:

Inner Barrier - $\alpha_i := 17.5 \times 10^{-6} \frac{1}{K}$

Outer Barrier - $\alpha_o := 1.368 \times 10^{-5} \frac{1}{K}$

Inner Barrier Dimensions:

Inner Radius - $r_1 \equiv 712 \text{ mm}$

Thickness - $th_i \equiv 5 \text{ cm}$

Length - $L_i \equiv 4775 \text{ mm}$

Initial Pressures on surfaces:

Initial Pressure Inside Inner Barrier at Room Temperatuere - $P := 1 \text{ atm}$

Outside Outer Barrier - $P_{oo} := 0 \text{ Pa}$

Poisson's Ratio:

Inner Barrier - $\nu_i := .27$

Outer Barrier - $\nu_o := .3$

Temperature of surface:

at r_4 - $T_4 \equiv (200 + 273) \text{ K}$

Outer Barrier Dimensions:

Thickness - $th_o \equiv 2 \text{ cm}$

Heat Terms:

Heat Generated Per Waste Package - $Q_{generated} \equiv 11.8 \text{ kW}$

Length of Entire Waste Package - $L \equiv 5165 \text{ mm}$

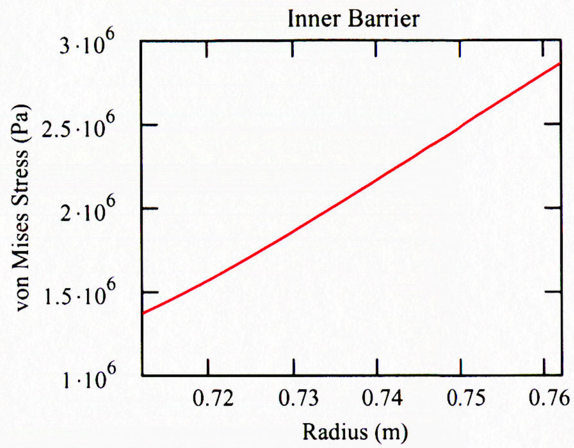
Gap Between Inner and Outer Barrier:

Axial Gap - $Gap_a \equiv 20 \text{ mm}$

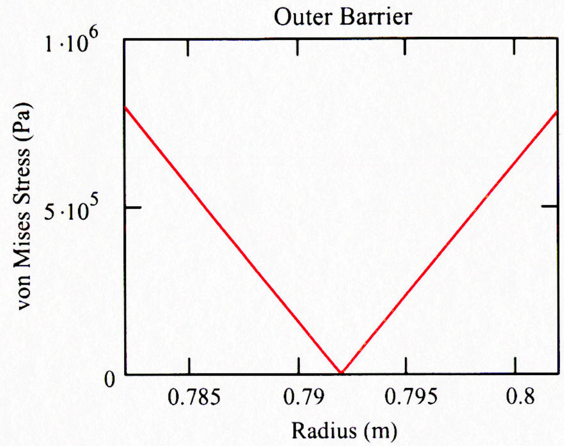
Radial Gap - $Gap_r \equiv 20 \text{ mm}$

CODE

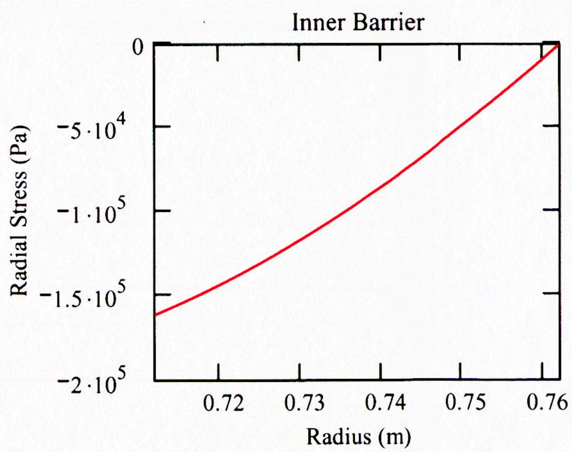
2-D Graphs



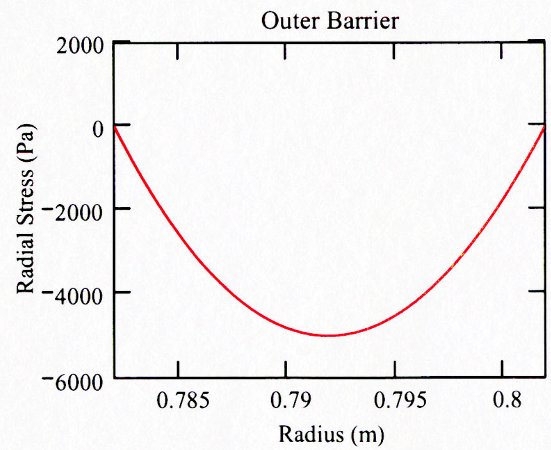
Inner Barrier
von Mises Stress (Pa)
Radius (m)



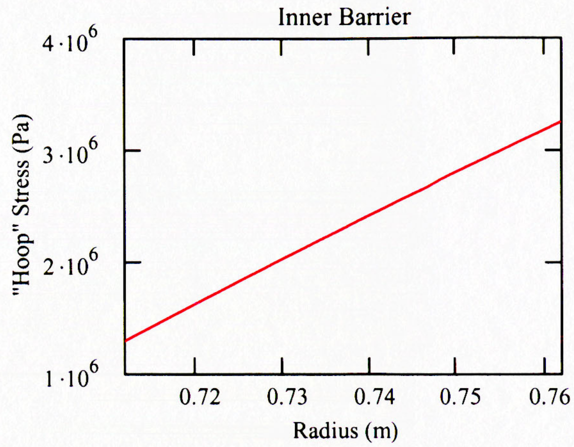
Outer Barrier
von Mises Stress (Pa)
Radius (m)

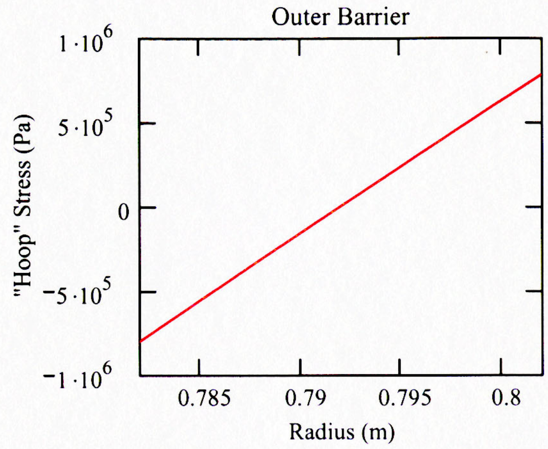


Inner Barrier
Radial Stress (Pa)
Radius (m)



Outer Barrier
Radial Stress (Pa)
Radius (m)





2-D Graphs

$CaseNumber = 1$

Radial Displacement of Inner Barrier

$disp_{ri} = 768.335390960326\,mm$

Radial Displacement of Outer Barrier

$disp_{ro} = 787.06398225312\,mm$

Axial Displacement of Inner Barrier

$disp_{ai} = 2407.32339964194\,mm$

Axial Displacement of Outer Barrier

$disp_{ao} = 2413.02550329879\,mm$

RadialGap

$disp_{ro} - disp_{ri} = 0.019\,m$

Axial Gap

$disp_{ao} - disp_{ai} = 5.702 \times 10^{-3}\,m$

Radial Stresses

$\sigma_{rinner}(r_2) = -2.146 \times 10^{-6}\,Pa$

$\sigma_{router}(r_3) = 2.623 \times 10^{-6}\,Pa$

Source Code Header

Young's Modulus:

Inner Barrier - $E_i := 1.81 \cdot 10^7$ psi

Outer Barrier - $E_o := 22.6 \cdot 10^6$ psi

Thermal Expansion Coefficients:

Inner Barrier - $\alpha_i := 17.5 \times 10^{-6} \frac{1}{K}$

Outer Barrier - $\alpha_o := 1.368 \times 10^{-5} \frac{1}{K}$

Inner Barrier Dimensions:

Inner Radius - $r_1 \equiv 712$ mm

Thickness - $th_i \equiv 5$ cm

Length - $L_i \equiv 4775$ mm

Initial Pressures on surfaces:

Initial Pressure Inside Inner Barrier at Room Temperatuere - $P := 1$ atm

Outside Outer Barrier - $P_{oo} := 0$ Pa

Poisson's Ratio:

Inner Barrier - $v_i := .27$

Outer Barrier - $v_o := .3$

Temperature of surface:

at r_4 - $T_4 \equiv (200 + 273)$ K

Outer Barrier Dimensions:

Thickness - $th_o \equiv 2$ cm

Heat Terms:

Heat Generated Per Waste Package - $Q_{generated} \equiv 11.8$ kW

Length of Entire Waste Package - $L \equiv 5165$ mm

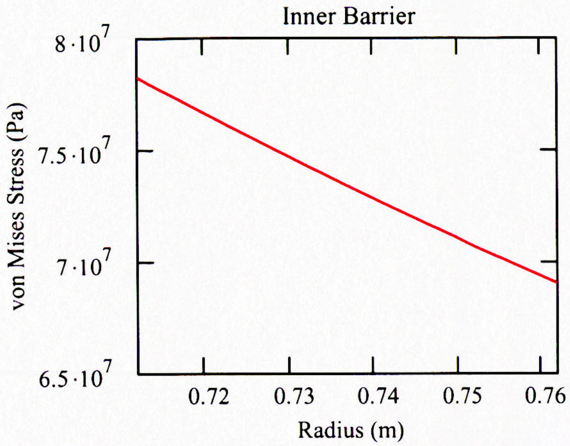
Gap Between Inner and Outer Barrier:

Axial Gap - $Gap_a \equiv 20$ mm

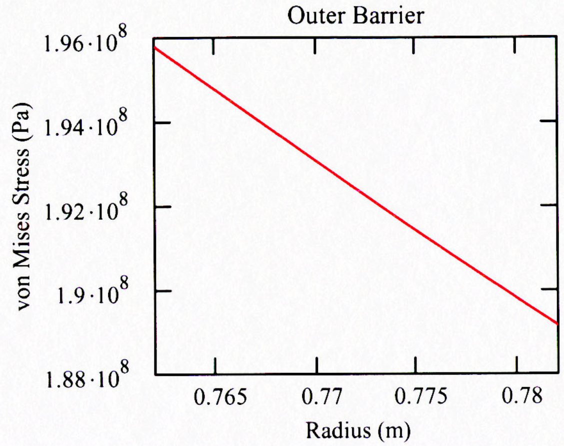
Radial Gap - $Gap_r \equiv 0$ mm

CODE

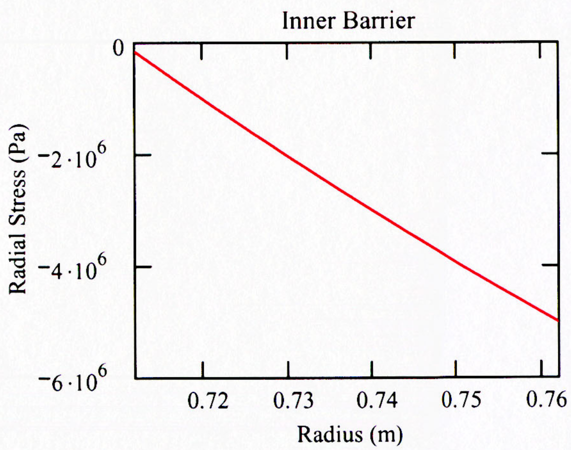
2-D Graphs



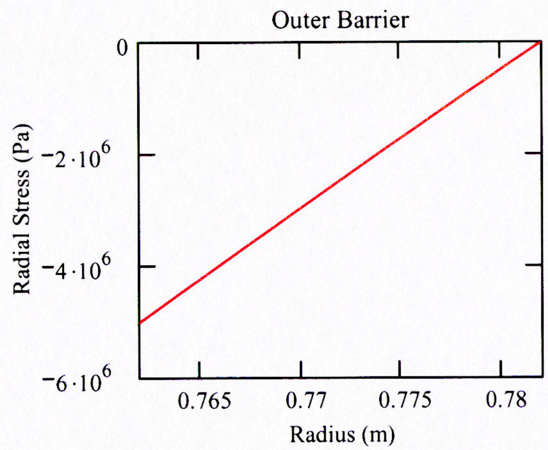
Inner Barrier
von Mises Stress (Pa)
8·10^7
7.5·10^7
7·10^7
6.5·10^7
0.72
0.73
0.74
0.75
0.76
Radius (m)



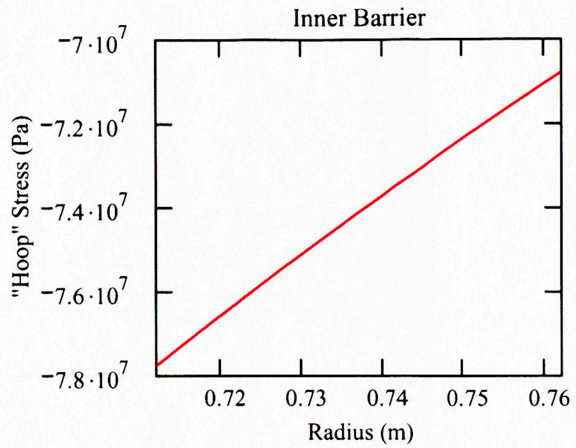
Outer Barrier
von Mises Stress (Pa)
1.96·10^8
1.94·10^8
1.92·10^8
1.9·10^8
1.88·10^8
0.765
0.77
0.775
0.78
Radius (m)

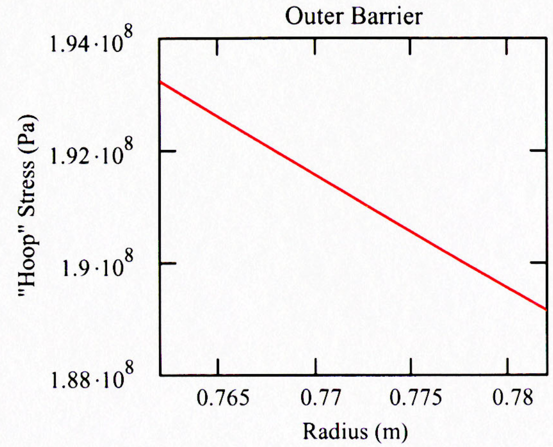


Inner Barrier
Radial Stress (Pa)
0
−2·10^6
−4·10^6
−6·10^6
0.72
0.73
0.74
0.75
0.76
Radius (m)



Outer Barrier
Radial Stress (Pa)
0
−2·10^6
−4·10^6
−6·10^6
0.765
0.77
0.775
0.78
Radius (m)





2-D Graphs

CaseNumber = 2

Radial Displacement of Inner Barrier

$disp_{ri} = 767.887466303317\ mm$

Radial Displacement of Outer Barrier

$disp_{ro} = 767.887466303317\ mm$

Axial Displacement of Inner Barrier

$disp_{ai} = 2407.7189037822\ mm$

Axial Displacement of Outer Barrier

$disp_{ao} = 2412.14954836908\ mm$

RadialGap

$disp_{ro} - disp_{ri} = 0\ m$

Axial Gap

$disp_{ao} - disp_{ai} = 4.431 \times 10^{-3}\ m$

Radial Stresses

$\sigma_{rinner}(r_2) = -5.017 \times 10^{6}\ Pa$

$\sigma_{router}(r_3) = -5.017 \times 10^{6}\ Pa$

Source Code Header

Young's Modulus:

Inner Barrier - $E_i := 1.81 \cdot 10^7 \text{ psi}$

Outer Barrier - $E_o := 22.6 \cdot 10^6 \text{ psi}$

Thermal Expansion Coefficients:

Inner Barrier - $\alpha_i := 17.5 \times 10^{-6} \frac{1}{K}$

Outer Barrier - $\alpha_o := 1.368 \times 10^{-5} \frac{1}{K}$

Inner Barrier Dimensions:

Inner Radius - $r_1 \equiv 712 \text{ mm}$

Thickness - $th_i \equiv 5 \text{ cm}$

Length - $L_i \equiv 4775 \text{ mm}$

Initial Pressures on surfaces:

Initial Pressure Inside Inner Barrier at Room Temperatuere - $P := 1 \text{ atm}$

Outside Outer Barrier - $P_{oo} := 0 \text{ Pa}$

Poisson's Ratio:

Inner Barrier - $\nu_i := .27$

Outer Barrier - $\nu_o := .3$

Temperature of surface:

at r_4 - $T_4 \equiv (200 + 273) \text{ K}$

Outer Barrier Dimensions:

Thickness - $th_o \equiv 2 \text{ cm}$

Heat Terms:

Heat Generated Per Waste Package - $Q_{generated} \equiv 11.8 \text{ kW}$

Length of Entire Waste Package - $L \equiv 5165 \text{ mm}$

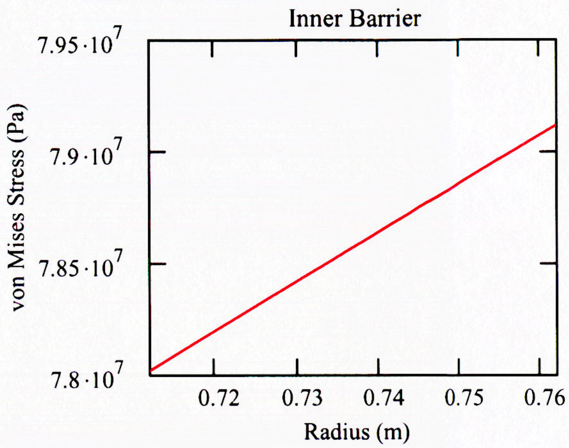
Gap Between Inner and Outer Barrier:

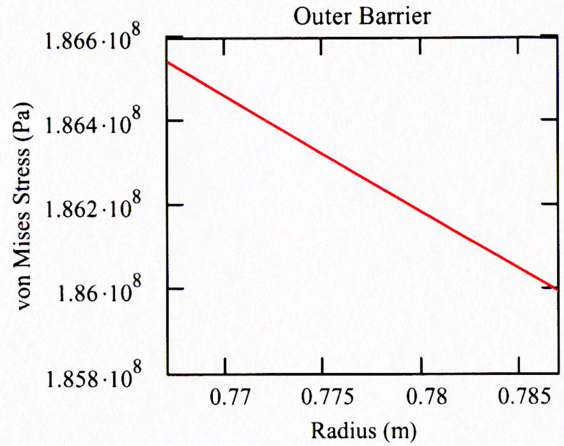
Axial Gap - $Gap_a \equiv 0 \text{ mm}$

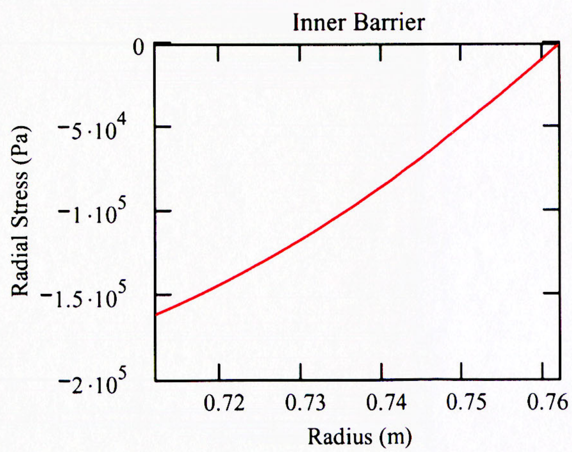
Radial Gap - $Gap_r \equiv 5 \text{ mm}$

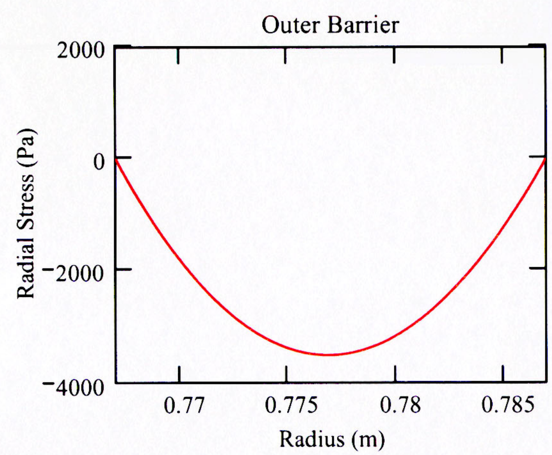
CODE

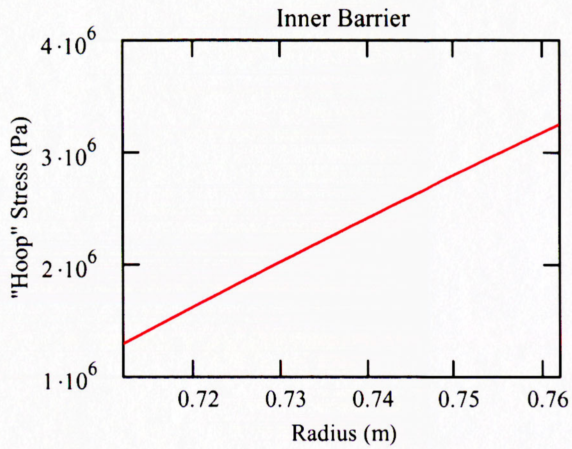
2-D Graphs

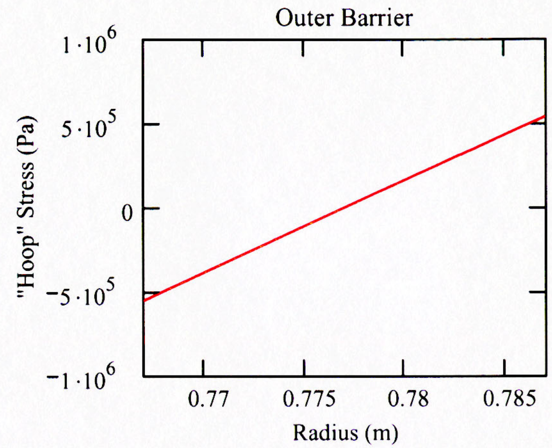

Inner Barrier
von Mises Stress (Pa)
7.95·10^7
7.9·10^7
7.85·10^7
7.8·10^7
0.72
0.73
0.74
0.75
0.76
Radius (m)


Outer Barrier
von Mises Stress (Pa)
1.866·10^8
1.864·10^8
1.862·10^8
1.86·10^8
1.858·10^8
0.77
0.775
0.78
0.785
Radius (m)


Inner Barrier
Radial Stress (Pa)
0
−5·10^4
−1·10^5
−1.5·10^5
−2·10^5
0.72
0.73
0.74
0.75
0.76
Radius (m)


Outer Barrier
Radial Stress (Pa)
2000
0
−2000
−4000
0.77
0.775
0.78
0.785
Radius (m)





2-D Graphs

CaseNumber = 3

Radial Displacement of Inner Barrier

$disp_{ri} = 768.461814569932\ \text{mm}$

Radial Displacement of Outer Barrier

$disp_{ro} = 771.690589438438\ \text{mm}$

Axial Displacement of Inner Barrier

$disp_{ai} = 2405.81098978946\ \text{mm}$

Axial Displacement of Outer Barrier

$disp_{ao} = 2405.81098978946\ \text{mm}$

RadialGap

$disp_{ro} - disp_{ri} = 3.229 \times 10^{-3}\ \text{m}$

Axial Gap

$disp_{ao} - disp_{ai} = 0\ \text{m}$

Radial Stresses

$\sigma_{rinner}(r_2) = -1.192 \times 10^{-6}\ \text{Pa}$

$\sigma_{router}(r_3) = 1.431 \times 10^{-6}\ \text{Pa}$

Source Code Header

Young's Modulus:

Inner Barrier - $E_i := 1.81 \cdot 10^7$ psi

Outer Barrier - $E_o := 22.6 \cdot 10^6$ psi

Thermal Expansion Coefficients:

Inner Barrier - $\alpha_i := 17.5 \times 10^{-6} \frac{1}{K}$

Outer Barrier - $\alpha_o := 1.368 \times 10^{-5} \frac{1}{K}$

Inner Barrier Dimensions:

Inner Radius - $r_1 \equiv 712$ mm

Thickness - $th_i \equiv 5$ cm

Length - $L_i \equiv 4775$ mm

Initial Pressures on surfaces:

Initial Pressure Inside Inner Barrier at Room Temperatuere - $P := 1$ atm

Outside Outer Barrier - $P_{oo} := 7 \cdot 10^6$ Pa

Poisson's Ratio:

Inner Barrier - $\nu_i := .27$

Outer Barrier - $\nu_o := .3$

Temperature of surface:

at r_4 - $T_4 \equiv (200 + 273)$ K

Outer Barrier Dimensions:

Thickness - $th_o \equiv 2$ cm

Heat Terms:

Heat Generated Per Waste Package - $Q_{generated} \equiv 11.8$ kW

Length of Entire Waste Package - $L \equiv 5165$ mm

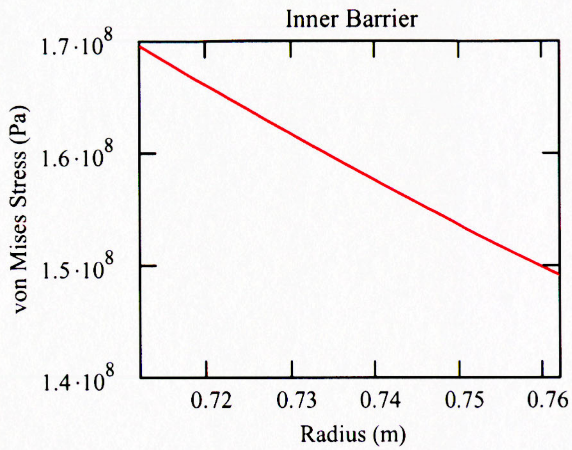
Gap Between Inner and Outer Barrier:

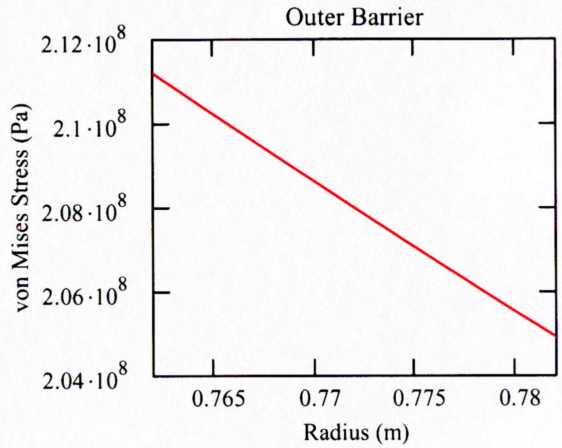
Axial Gap - $Gap_a \equiv 0$ mm

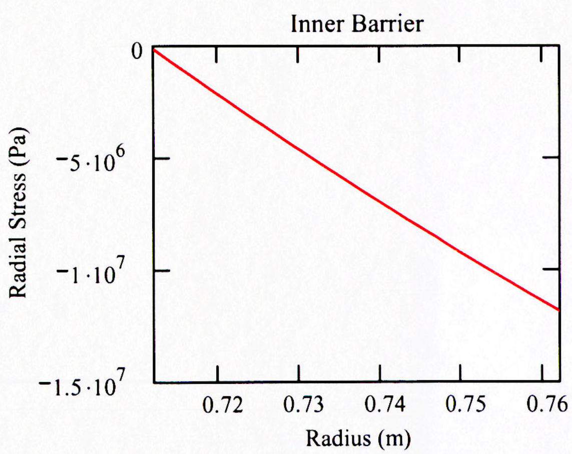
Radial Gap - $Gap_r \equiv 0$ mm

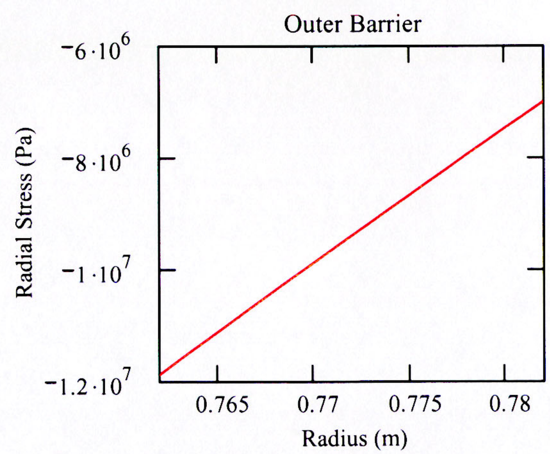
CODE

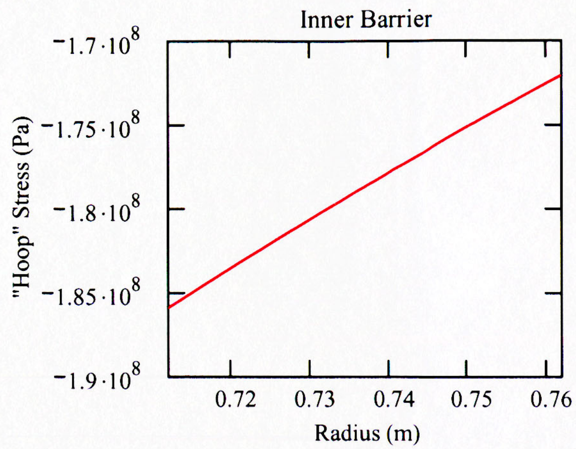
2-D Graphs

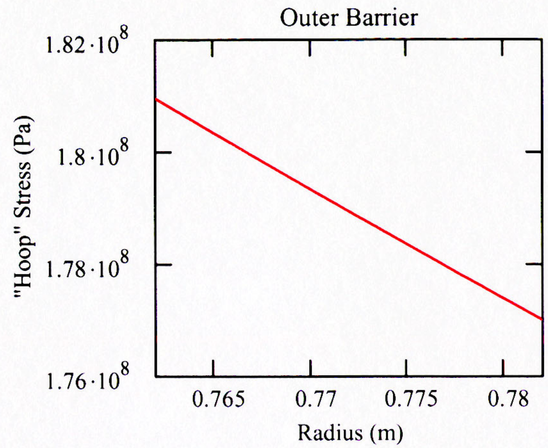

Inner Barrier
von Mises Stress (Pa)
1.7·10^8
1.6·10^8
1.5·10^8
1.4·10^8
0.72
0.73
0.74
0.75
0.76
Radius (m)


Outer Barrier
von Mises Stress (Pa)
2.12·10^8
2.1·10^8
2.08·10^8
2.06·10^8
2.04·10^8
0.765
0.77
0.775
0.78
Radius (m)


Inner Barrier
Radial Stress (Pa)
0
−5·10^6
−1·10^7
−1.5·10^7
0.72
0.73
0.74
0.75
0.76
Radius (m)


Outer Barrier
Radial Stress (Pa)
−6·10^6
−8·10^6
−1·10^7
−1.2·10^7
0.765
0.77
0.775
0.78
Radius (m)





▲ 2-D Graphs

CaseNumber = 4

Radial Displacement of Inner Barrier

$disp_{ri} = 767.523810263122\ \mathrm{mm}$

Radial Displacement of Outer Barrier

$disp_{ro} = 767.523810263121\ \mathrm{mm}$

Axial Displacement of Inner Barrier

$disp_{ai} = 2405.45243321429\ \mathrm{mm}$

Axial Displacement of Outer Barrier

$disp_{ao} = 2405.45243321429\ \mathrm{mm}$

RadialGap

$disp_{ro} - disp_{ri} = 0\ \mathrm{m}$

Axial Gap

$disp_{ao} - disp_{ai} = 0\ \mathrm{m}$

Radial Stresses

$\sigma_{rinner}(r_2) = -1.188 \times 10^{7}\ \mathrm{Pa}$

$\sigma_{router}(r_3) = -1.188 \times 10^{7}\ \mathrm{Pa}$

Source Code Header

Output Data File Name:

Inner Barrier - $file_i := "run1\_inner.txt"$

Outer Barrier - $file_o := "run1\_outer.txt"$

Young's Modulus:

Inner Barrier - $E_i \equiv 1.81 \cdot 10^7\ psi$

Outer Barrier - $E_o \equiv 22.6 \cdot 10^6\ psi$

Thermal Expansion Coefficients:

Inner Barrier - $\alpha_i \equiv 17.5 \times 10^{-6}\ \frac{1}{K}$

Outer Barrier - $\alpha_o \equiv 1.368 \times 10^{-5}\ \frac{1}{K}$

Inner Barrier Dimensions:

Inner Radius - $r_1 \equiv 712\ mm$

Thickness - $th_i \equiv 5\ cm$

Length - $L_i \equiv 4775\ mm$

Initial Pressures on surfaces:

Initial Pressure Inside Inner Barrier at Room Temperatuere - $P := 1\ atm$

Outside Outer Barrier - $P_{oo} := 7 \cdot 10^6\ Pa$

Poisson's Ratio:

Inner Barrier - $\nu_i \equiv .27$

Outer Barrier - $\nu_o \equiv .30$

Temperature of surface:

at r_4 - $T_4 \equiv (1100 + 273)\ K$

Outer Barrier Dimensions:

Thickness - $th_o \equiv 2\ cm$

Heat Terms:

Heat Generated Per Waste Package - $Q_{generated} \equiv 11.8\ kW$

Length of Entire Waste Package - $L \equiv 5165\ mm$

3-D Plot Variables:

Radial Gap Lower Bound - $gaplower_r := 0\ mm$

Radial Gap Upper Bound - $gapupper_r := 7\ mm$

Radial Gap Increment - $gapinc_r := .5\ mm$

Axial Gap Lower Bound - $gaplower_a := 0\ mm$

Axial Gap Upper Bound - $gapupper_a := 30\ mm$

Axial Gap Increment - $gapinc_a := 2\ mm$

Resolution to find Maximum - $res := 1\ mm$

CODE

Reference:D:\Dtherm\Dtherm\Dtherm\3-D Plots.mcd(R)

The graphs can be viewedin the file above by double clicking on it.

Time it takes to calculate entire worksheet is $Time = 4.816min$

CODE

Maximum von Mises Stress given a Radial and an Axial Gap

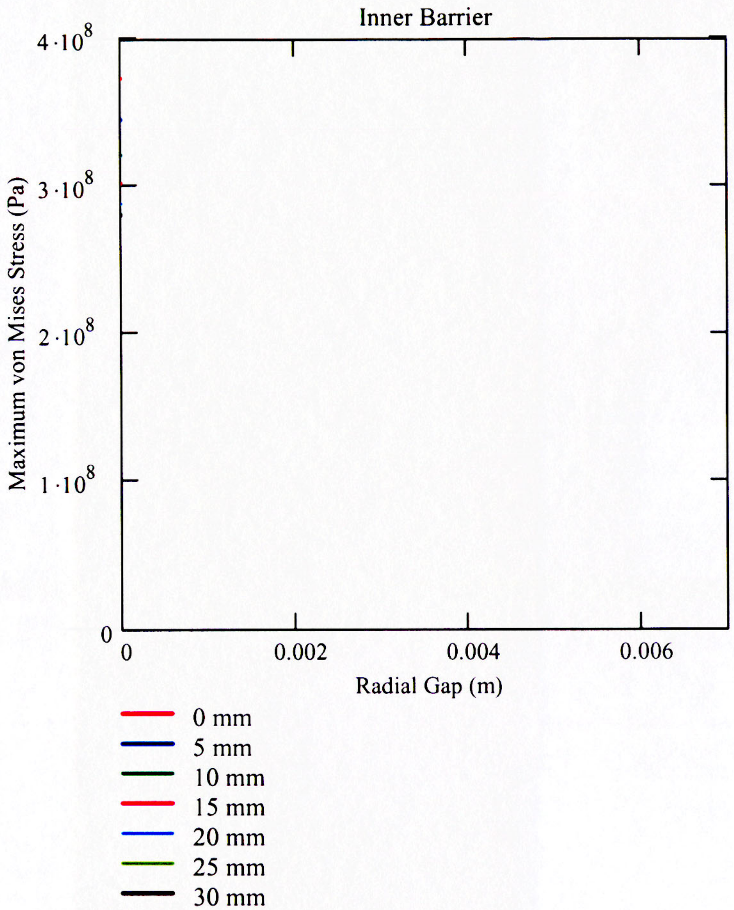
Axial Gap - $gap_a := 0\ mm$

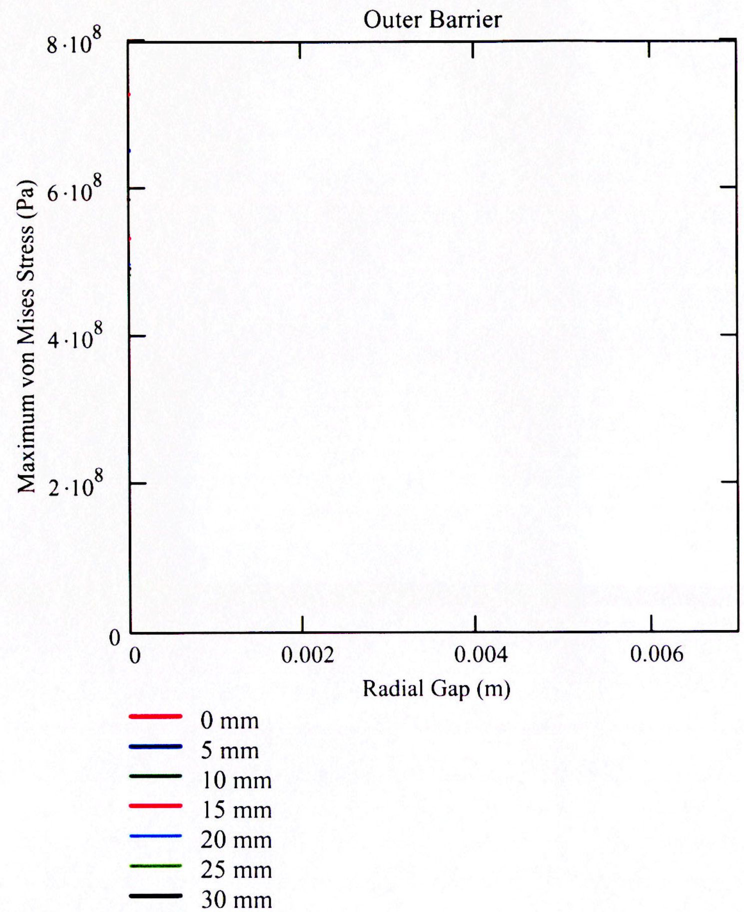
Radial Gap - $gap_r := 0\ mm$

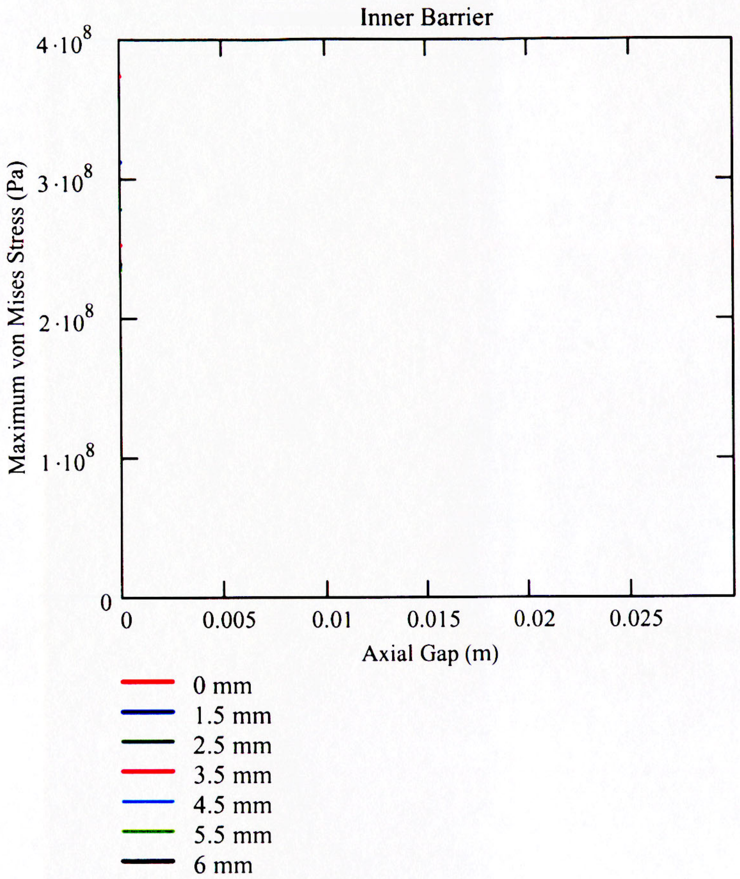
Inner Barrier - $\sigma_{voninner}(gap_a, gap_r) \cdot Pa = 3.733 \times 10^8\ Pa$

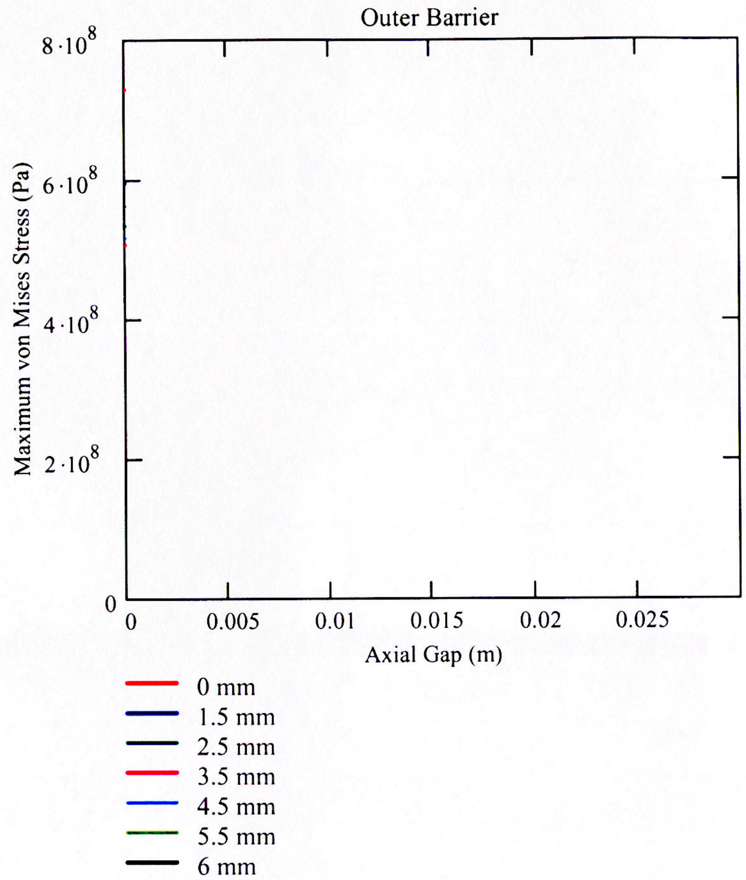
Outer Barrier - $\sigma_{vonouter}(gap_a, gap_r) \cdot Pa = 7.29 \times 10^8\ Pa$

Optional Graphs: In order to see the effect of varying one parameter such as axial gap and holding the radial gap constant use these graphs. In order to view them ... right click the graph you would like and select -> Enable Evaluation. Then select Automatic Calculation from the Math menu.






Inner Barrier
Maximum von Mises Stress (Pa)
4·10^8
3·10^8
2·10^8
1·10^8
0
0
0.005
0.01
0.015
0.02
0.025
Axial Gap (m)
0 mm
1.5 mm
2.5 mm
3.5 mm
4.5 mm
5.5 mm
6 mm


Outer Barrier
Maximum von Mises Stress (Pa)
8·10^8
6·10^8
4·10^8
2·10^8
0
0
0.005
0.01
0.015
0.02
0.025
Axial Gap (m)
0 mm
1.5 mm
2.5 mm
3.5 mm
4.5 mm
5.5 mm
6 mm

Source Code Header

Output Data File Name:

Inner Barrier - $file_i := "run1\_inner.txt"$

Outer Barrier - $file_o := "run1\_outer.txt"$

Young's Modulus:

Inner Barrier - $E_i \equiv 1.81 \cdot 10^7 \; psi$

Outer Barrier - $E_o \equiv 22.6 \; 10^6 \; psi$

Thermal Expansion Coefficients:

Inner Barrier - $\alpha_i \equiv 17.5 \times 10^{-6} \frac{1}{K}$

Outer Barrier - $\alpha_o \equiv 1.368 \times 10^{-5} \frac{1}{K}$

Inner Barrier Dimensions:

Inner Radius - $r_1 \equiv 712 \, mm$

Thickness - $th_i \equiv 5 \, cm$

Length - $L_i \equiv 4775 \, mm$

Initial Pressures on surfaces:

Initial Pressure Inside Inner Barrier at Room Tempertauere - $P := 1 \, atm$

Outside Outer Barrier - $P_{oo} := 7 \cdot 10^6 \; Pa$

Poisson's Ratio:

Inner Barrier - $\nu_i \equiv .27$

Outer Barrier - $\nu_o \equiv .30$

Temperature of surface:

at r_4 - $T_4 \equiv (1100 + 273) \; K$

Outer Barrier Dimensions:

Thickness - $th_o \equiv 2 \, cm$

Heat Terms:

Heat Generated Per Waste Package - $Q_{generated} \equiv 11.8 \, kW$

Length of Entire Waste Package - $L \equiv 5165 \, mm$

3-D Plot Variables:

Radial Gap Lower Bound - $gaplower_r := 0 \, mm$

Radial Gap Upper Bound - $gapupper_r := 7 \, mm$

Radial Gap Increment - $gapinc_r := 2 \, mm$

Axial Gap Lower Bound - $gaplower_a := 0 \, mm$

Axial Gap Upper Bound - $gapupper_a := 30 \, mm$

Axial Gap Increment - $gapinc_a := 10 \, mm$

Resolution to find Maximum - $res := 1 \, mm$

CODE

Reference:D:\Dtherm\Dtherm\Dtherm\3-D Plots.mcd(R)

The graphs can be viewedin the file above by double clicking on it.

Time it takes to calculate entire worksheet is $\mathrm{Time} = 1.33\mathrm{min}$

CODE

Maximum von Mises Stress given a Radial and an Axial Gap

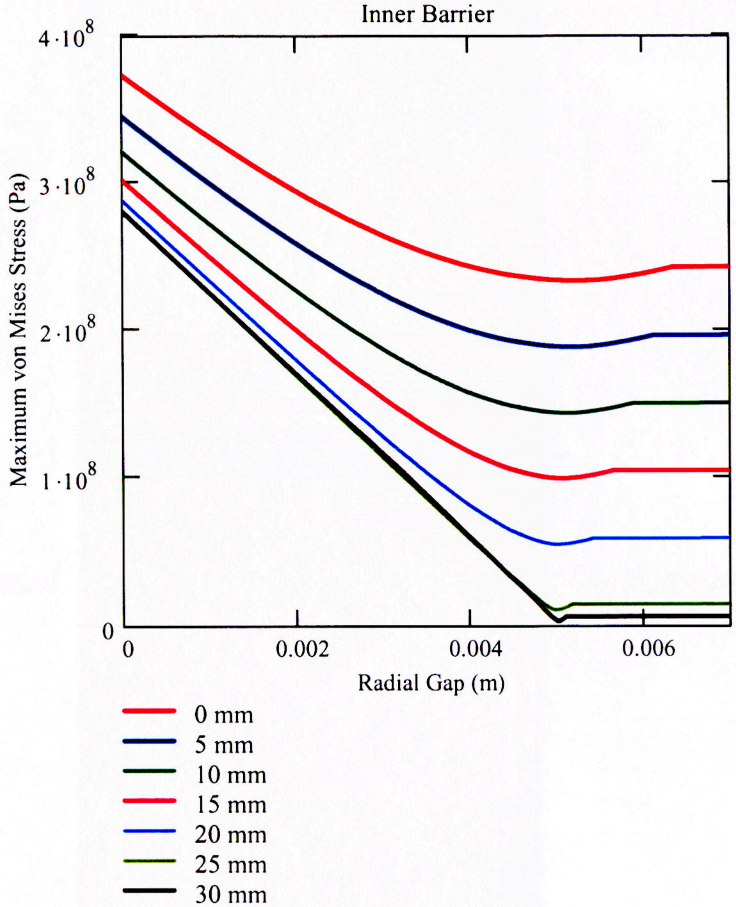
Axial Gap - $gap_a := 0\ \mathrm{mm}$

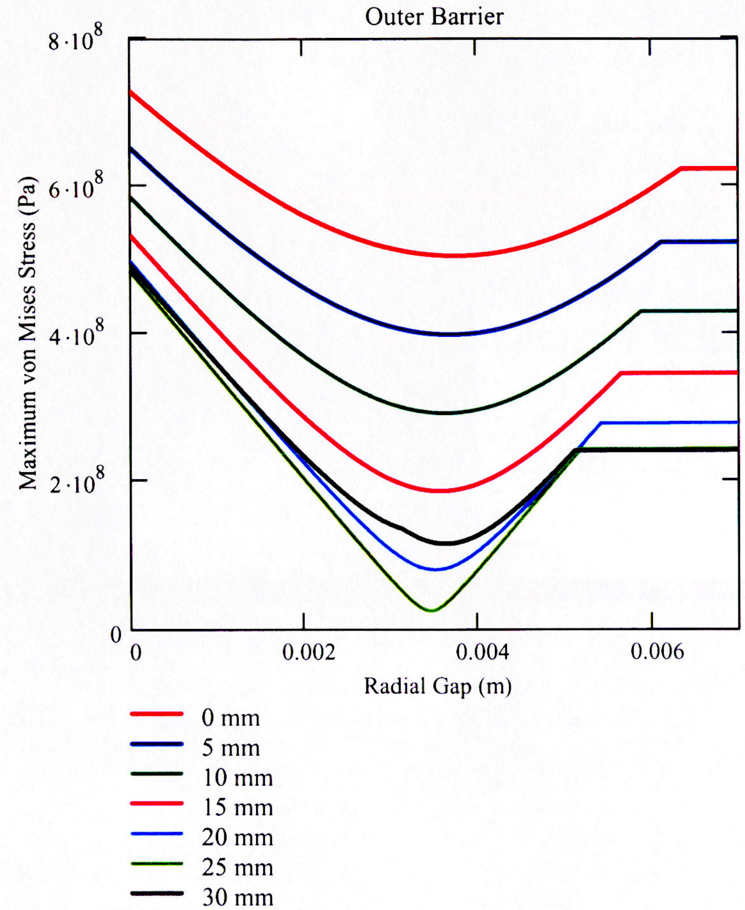
Radial Gap - $gap_r := 0\ \mathrm{mm}$

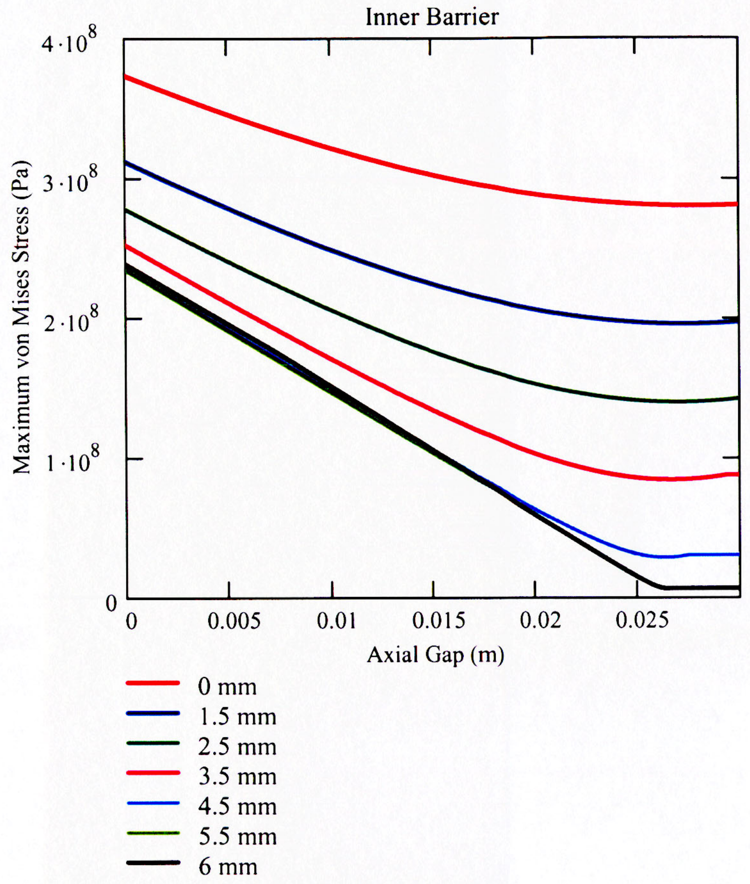
Inner Barrier - $\sigma_{voninner}(gap_a, gap_r)\cdot \mathrm{Pa} =$ ▮

Outer Barrier - $\sigma_{vonouter}(gap_a, gap_r)\cdot \mathrm{Pa} =$ ▮

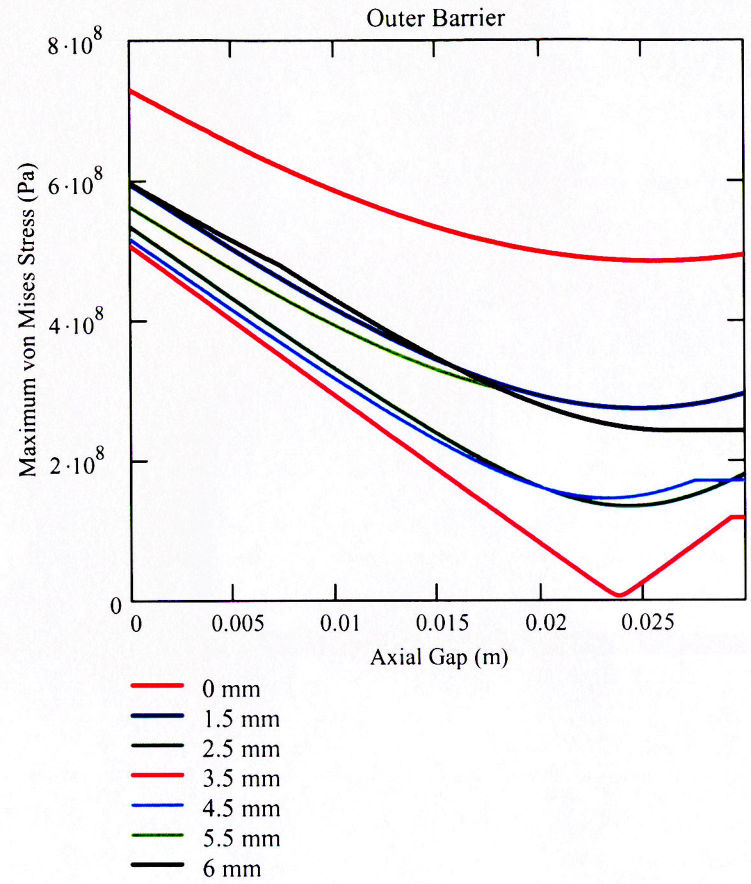
Optional Graphs: In order to see the effect of varying one parameter such as axial gap and holding the radial gap constant use these graphs. In order to view them ... right click the graph you would like and select -> Enable Evaluation. Then select Automatic Calculation from the Math menu.







Inner Barrier
Maximum von Mises Stress (Pa)
Axial Gap (m)
4·10^8
3·10^8
2·10^8
1·10^8
0
0.005
0.01
0.015
0.02
0.025
0 mm
1.5 mm
2.5 mm
3.5 mm
4.5 mm
5.5 mm
6 mm



Outer Barrier
Maximum von Mises Stress (Pa)
Axial Gap (m)
8·10^8
6·10^8
4·10^8
2·10^8
0
0.005
0.01
0.015
0.02
0.025
0 mm
1.5 mm
2.5 mm
3.5 mm
4.5 mm
5.5 mm
6 mm

Source Code Header

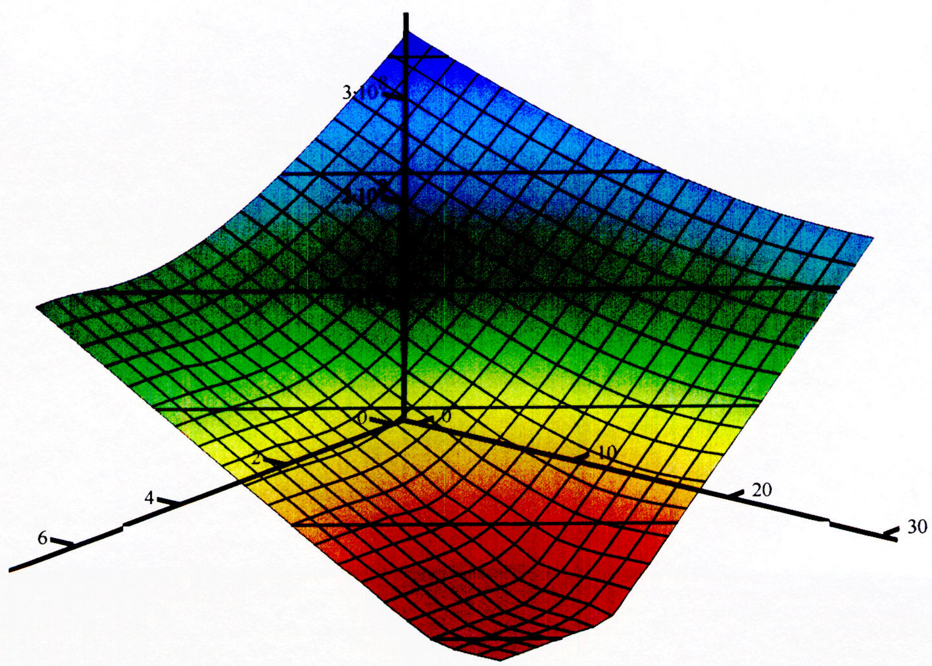
CODE

innerbarrier ≡ READPRN("innerbarrier.txt")

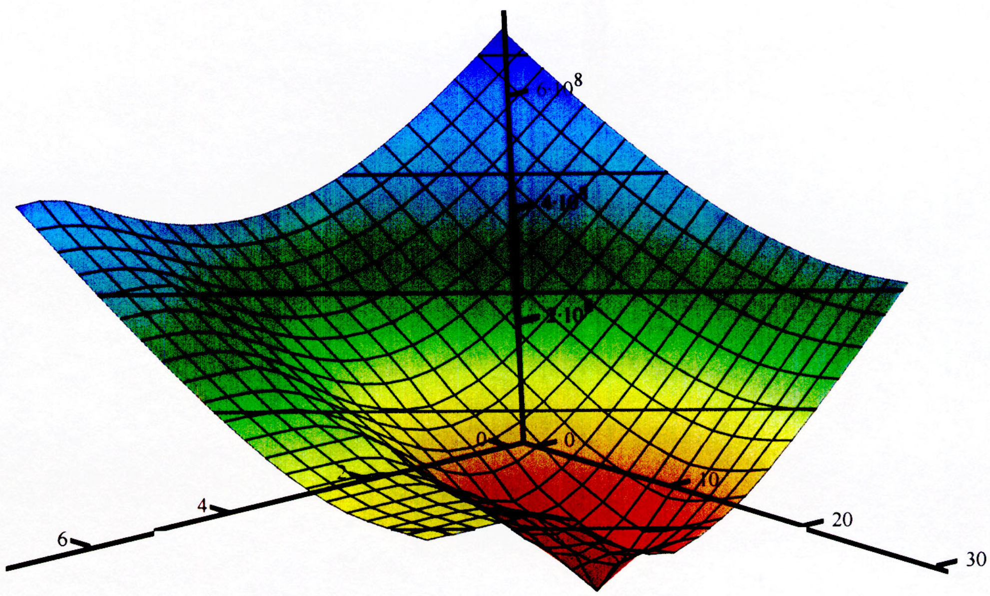
outerbarrier ≡ READPRN("outerbarrier.txt")

Type in the name of the file you would like to open between the double quotes (" "). This file must be in the same directory as this file "3-D Plots.mcd" or the path to the file must be typed out. (i.e. C:\Files\test.txt).

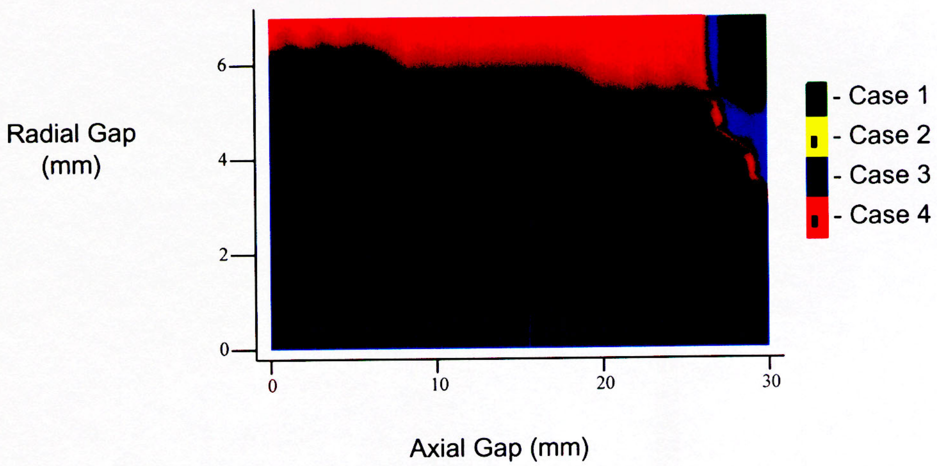
Inner Barrier von Mises Stresses as a function of Radial and Axial Gap



Outer Barrier von Mises Stresses as a function of Radial and Axial Gap



Case as a function of Radial and Axial Gap



```
// Datafile written by Mathcad 8.0
// 05/24/02 11:56:33

.MATRIX 0 0 5 1
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.MATRIX 1 0 240 1
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       0       0       0       0       0       0  0.0005  0.0005  0.0005  0.0005
  0.0005  0.0005  0.0005  0.0005  0.0005  0.0005  0.0005  0.0005  0.0005  0.0005
  0.0005  0.0005   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001  0.0015  0.0015
  0.0015  0.0015  0.0015  0.0015  0.0015  0.0015  0.0015  0.0015  0.0015  0.0015
  0.0015  0.0015  0.0015  0.0015   0.002   0.002   0.002   0.002   0.002   0.002
   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002   0.002
  0.0025  0.0025  0.0025  0.0025  0.0025  0.0025  0.0025  0.0025  0.0025  0.0025
  0.0025  0.0025  0.0025  0.0025  0.0025  0.0025   0.003   0.003   0.003   0.003
   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003   0.003
   0.003   0.003  0.0035  0.0035  0.0035  0.0035  0.0035  0.0035  0.0035  0.0035
  0.0035  0.0035  0.0035  0.0035  0.0035  0.0035  0.0035  0.0035   0.004   0.004
   0.004   0.004   0.004   0.004   0.004   0.004   0.004   0.004   0.004   0.004
   0.004   0.004   0.004   0.004  0.0045  0.0045  0.0045  0.0045  0.0045  0.0045
  0.0045  0.0045  0.0045  0.0045  0.0045  0.0045  0.0045  0.0045  0.0045  0.0045
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   0.005   0.005   0.005   0.005   0.005   0.005  0.0055  0.0055  0.0055  0.0055
  0.0055  0.0055  0.0055  0.0055  0.0055  0.0055  0.0055  0.0055  0.0055  0.0055
  0.0055  0.0055   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006
   0.006   0.006   0.006   0.006   0.006   0.006   0.006   0.006  0.0065  0.0065
  0.0065  0.0065  0.0065  0.0065  0.0065  0.0065  0.0065  0.0065  0.0065  0.0065
  0.0065  0.0065  0.0065  0.0065   0.007   0.007   0.007   0.007   0.007   0.007
   0.007   0.007   0.007   0.007   0.007   0.007   0.007   0.007   0.007   0.007
.MATRIX 2 0 240 1
       0   0.002   0.004   0.006   0.008    0.01   0.012   0.014   0.016   0.018
    0.02   0.022   0.024   0.026   0.028    0.03       0   0.002   0.004   0.006
   0.008    0.01   0.012   0.014   0.016   0.018    0.02   0.022   0.024   0.026
   0.028    0.03       0   0.002   0.004   0.006   0.008    0.01   0.012   0.014
   0.016   0.018    0.02   0.022   0.024   0.026   0.028    0.03       0   0.002
   0.004   0.006   0.008    0.01   0.012   0.014   0.016   0.018    0.02   0.022
   0.024   0.026   0.028    0.03       0   0.002   0.004   0.006   0.008    0.01
   0.012   0.014   0.016   0.018    0.02   0.022   0.024   0.026   0.028    0.03
       0   0.002   0.004   0.006   0.008    0.01   0.012   0.014   0.016   0.018
    0.02   0.022   0.024   0.026   0.028    0.03       0   0.002   0.004   0.006
   0.008    0.01   0.012   0.014   0.016   0.018    0.02   0.022   0.024   0.026
   0.028    0.03       0   0.002   0.004   0.006   0.008    0.01   0.012   0.014
   0.016   0.018    0.02   0.022   0.024   0.026   0.028    0.03       0   0.002
   0.004   0.006   0.008    0.01   0.012   0.014   0.016   0.018    0.02   0.022
   0.024   0.026   0.028    0.03       0   0.002   0.004   0.006   0.008    0.01
   0.012   0.014   0.016   0.018    0.02   0.022   0.024   0.026   0.028    0.03
       0   0.002   0.004   0.006   0.008    0.01   0.012   0.014   0.016   0.018
    0.02   0.022   0.024   0.026   0.028    0.03       0   0.002   0.004   0.006
   0.008    0.01   0.012   0.014   0.016   0.018    0.02   0.022   0.024   0.026
   0.028    0.03       0   0.002   0.004   0.006   0.008    0.01   0.012   0.014
   0.016   0.018    0.02   0.022   0.024   0.026   0.028    0.03       0   0.002
   0.004   0.006   0.008    0.01   0.012   0.014   0.016   0.018    0.02   0.022
   0.024   0.026   0.028    0.03       0   0.002   0.004   0.006   0.008    0.01
   0.012   0.014   0.016   0.018    0.02   0.022   0.024   0.026   0.028    0.03
.MATRIX 3 0 240 1
 3.733e+008 3.617e+008 3.507e+008 3.403e+008 3.305e+008 3.215e+008 3.131e+008
 3.056e+008 2.99e+008 2.933e+008 2.886e+008 2.849e+008 2.823e+008 2.807e+008
 2.803e+008 2.811e+008 3.517e+008 3.395e+008 3.278e+008 3.167e+008 3.063e+008
 2.965e+008 2.876e+008 2.794e+008 2.723e+008 2.661e+008 2.609e+008 2.569e+008
 2.541e+008 2.525e+008 2.522e+008 2.531e+008 3.312e+008 3.183e+008 3.059e+008
 2.94e+008 2.828e+008 2.723e+008 2.626e+008 2.538e+008 2.459e+008 2.391e+008
 2.335e+008 2.291e+008 2.261e+008 2.244e+008 2.241e+008 2.252e+008 3.12e+008
```

2.983e+008 2.851e+008 2.724e+008 2.603e+008 2.489e+008 2.384e+008 2.287e+008
2.2e+008 2.126e+008 2.063e+008 2.015e+008 1.981e+008 1.963e+008 1.961e+008
1.975e+008 2.942e+008 2.797e+008 2.656e+008 2.52e+008 2.39e+008 2.267e+008
2.151e+008 2.045e+008 1.949e+008 1.865e+008 1.795e+008 1.74e+008 1.703e+008
1.683e+008 1.682e+008 1.7e+008 2.781e+008 2.628e+008 2.478e+008 2.333e+008
2.193e+008 2.059e+008 1.932e+008 1.814e+008 1.706e+008 1.611e+008 1.531e+008
1.468e+008 1.425e+008 1.403e+008 1.404e+008 1.427e+008 2.64e+008 2.479e+008
2.321e+008 2.166e+008 2.016e+008 1.87e+008 1.73e+008 1.599e+008 1.477e+008
1.368e+008 1.274e+008 1.2e+008 1.149e+008 1.124e+008 1.127e+008 1.157e+008
2.523e+008 2.355e+008 2.189e+008 2.025e+008 1.864e+008 1.706e+008 1.554e+008
1.407e+008 1.269e+008 1.142e+008 1.03e+008 9.391e+007 8.755e+007 8.453e+007
8.519e+007 8.762e+007 2.432e+008 2.258e+008 2.085e+008 1.914e+008 1.744e+008
1.576e+008 1.41e+008 1.249e+008 1.093e+008 9.444e+007 8.087e+007 6.926e+007
6.074e+007 5.671e+007 5.811e+007 5.906e+007 2.371e+008 2.193e+008 2.016e+008
1.839e+008 1.662e+008 1.486e+008 1.311e+008 1.138e+008 9.659e+007 7.973e+007
6.342e+007 4.822e+007 3.556e+007 2.897e+007 3.06e+007 3.06e+007 2.341e+008
2.162e+008 1.982e+008 1.803e+008 1.624e+008 1.445e+008 1.266e+008 1.088e+008
9.09e+007 7.305e+007 5.521e+007 3.754e+007 1.989e+007 2.404e+006 3.73e+006
3.73e+006 2.344e+008 2.167e+008 1.991e+008 1.815e+008 1.639e+008 1.464e+008
1.29e+008 1.117e+008 9.452e+007 7.761e+007 5.938e+007 4.121e+007 2.329e+007
7.634e+006 6.481e+006 6.481e+006 2.388e+008 2.214e+008 2.041e+008 1.87e+008
1.694e+008 1.51e+008 1.327e+008 1.143e+008 9.599e+007 7.768e+007 5.941e+007
4.123e+007 2.331e+007 7.64e+006 6.481e+006 6.481e+006 2.432e+008 2.248e+008
2.063e+008 1.879e+008 1.695e+008 1.511e+008 1.327e+008 1.144e+008 9.604e+007
7.772e+007 5.945e+007 4.126e+007 2.333e+007 7.646e+006 6.481e+006 6.481e+006
2.433e+008 2.249e+008 2.064e+008 1.88e+008 1.696e+008 1.512e+008 1.328e+008
1.144e+008 9.609e+007 7.776e+007 5.948e+007 4.129e+007 2.335e+007 7.652e+006
6.481e+006 6.481e+006

.MATRIX 4 0 240 1

4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4
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4	4	4	4	4	4	3	3	3	3
1	1	4	4	4	4	3	3	3	3
3	3	3	3	3	3	1	1	3	3
3	3	3	3	3	3	3	3	3	3
3	3	1	1	3	3	3	3	3	3
3	3	3	3	3	3	3	3	1	1

```
// Datafile written by Mathcad 8.0
// 05/24/02 11:58:53

.MATRIX 0 0 5 1
 "Dtherm v 1.1" {1,0,240,1} {2,0,240,1} {3,0,240,1} {4,0,240,1}
.MATRIX 1 0 240 1
       0        0        0        0        0        0        0        0        0        0
       0        0        0        0        0        0   0.0005   0.0005   0.0005   0.0005
  0.0005   0.0005   0.0005   0.0005   0.0005   0.0005   0.0005   0.0005   0.0005   0.0005
  0.0005   0.0005    0.001    0.001    0.001    0.001    0.001    0.001    0.001    0.001
   0.001    0.001    0.001    0.001    0.001    0.001    0.001    0.001   0.0015   0.0015
  0.0015   0.0015   0.0015   0.0015   0.0015   0.0015   0.0015   0.0015   0.0015   0.0015
  0.0015   0.0015   0.0015   0.0015    0.002    0.002    0.002    0.002    0.002    0.002
   0.002    0.002    0.002    0.002    0.002    0.002    0.002    0.002    0.002    0.002
  0.0025   0.0025   0.0025   0.0025   0.0025   0.0025   0.0025   0.0025   0.0025   0.0025
  0.0025   0.0025   0.0025   0.0025   0.0025   0.0025    0.003    0.003    0.003    0.003
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// 05/28/02 20:13:13

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 "Outer Barrier"" "run1_outer.txt" "Poisson's Ratio" "Inner Barrier"
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 "Outer Barrier""     0.3 "Young's Modulus (Pa)" "Inner Barrier" 1.248
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 "Outer Barrier"" 1.558e+011
 "Temperature at outside radius of outer barrier (K)"    1373
 "Thermal Expansion Coefficients (1/K)" "Inner Barrier" 1.75e-005
 "Outer Barrier"" 1.368e-005 "Outer Barrier Thickness (m)"    0.02
 "Heat Generated per waste package (W)" 1.18e+004
 "Length of Entire waste package (m)"   5.165 "Inside barrier inner ra
dius (m)"
   0.712 "Thickness of the inner barrier (m)"    0.05
 "Initial length of the inner barrier (m)"   4.775
 "Initial Pressure inside the inner barrier at room temperature (Pa)"
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 "Pressure outside the outer barrier (Pa)" -7e+006 "3-D Plot variables
"
 "radial gap lower bound (m)"       0 "radial gap upper bound (m)"   0
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 "radial gap increment (m)"   0.002 "axial gap lower bound (m)"
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 "axial gap upper bound (m)"    0.03 "axial gap increment (m)"    0.01
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// Datafile written by Mathcad 8.0
// 05/28/02 20:13:13

.MATRIX 0 0 52 1
 "Dtherm v 1.1" "Output Data File Name" "Inner Barrier" "run1_inner.tx
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 "Outer Barrier"" "run1_outer.txt" "Poisson's Ratio" "Inner Barrier"
  0.27
 "Outer Barrier""     0.3 "Young's Modulus (Pa)" "Inner Barrier" 1.248
e+011
 "Outer Barrier"" 1.558e+011
 "Temperature at outside radius of outer barrier (K)"    1373
 "Thermal Expansion Coefficients (1/K)" "Inner Barrier" 1.75e-005
 "Outer Barrier"" 1.368e-005 "Outer Barrier Thickness (m)"    0.02
 "Heat Generated per waste package (W)" 1.18e+004
 "Length of Entire waste package (m)"   5.165 "Inside barrier inner ra
dius (m)"
   0.712 "Thickness of the inner barrier (m)"    0.05
 "Initial length of the inner barrier (m)"   4.775
 "Initial Pressure inside the inner barrier at room temperature (Pa)"
1.013e+005
 "Pressure outside the outer barrier (Pa)" -7e+006 "3-D Plot variables
"
 "radial gap lower bound (m)"       0 "radial gap upper bound (m)"   0
.007
 "radial gap increment (m)"   0.002 "axial gap lower bound (m)"
0
 "axial gap upper bound (m)"    0.03 "axial gap increment (m)"    0.01
```

SOFTWARE VALIDATION TEST PLAN FOR DTHERM VERSION 1.1

September 2002

Center for Nuclear Waste Regulatory Analyses
Southwest Research Institute
San Antonio, Texas

Author

Doug Gute — Oct. 21, 2002
Date

Element Manager

Asadul Chowdhury — 10-21-02
Date

1.0 Scope of the Validation

DTHERM is a software program that was developed using the MATHCAD 2000 Professional (Service Release 2a) programming environment. The DTHERM program is designed to approximate the waste package inner and outer barrier stresses that could occur as the result of the respective barrier materials having different thermal expansion properties. To facilitate the assessment of the different waste package designs (which are needed to accommodate the different waste forms that will be disposed of at the proposed geologic repository) subjected to varying environmental conditions (e.g., preclosure ventiliation, igneous intrusion, accumulated rockfall, and so on), the program allows the User to define (i) the relevant mechanical properties of the waste package inner and outer barrier materials, (ii) the dimensions of the waste package inner and outer barriers, (iii) the externally applied temperatures and pressures, and (iv) the waste form decay heat rate. The results calculated by DTHERM are graphically represented by 2-D plots of the radial displacement, radial stress, circumferential “hoop” stress, von Mises stress, and temperature as functions of the radius for the respective inner and outer barriers. The DTHERM program also creates 3-D plots of the calculated von Mises stress for both the inner and outer barriers as a function of the radial and axial gaps that exist between them at room temperature. The data for the 3-D plots is also written to a text file that can be re-opened in MATHCAD, Microsoft Excel, or a similar program.

The DTHERM program will be validated by comparing the results obtained from finite element analyses of the waste package structure with those obtained from DTHERM using a consistent set of modeling parameters. The ABAQUS/Standard finite element program developed by Hibbitt, Karlsson & Sorenson, Inc., which is an approved supplier for the Southwest Research Institute, will be used for the finite element modeling aspect of the DTHERM validation. There are four unique scenarios of differential thermal expansion that can occur between the inner and outer barriers of the waste package. Each of the four differential thermal expansion scenarios must be validated. The four contact scenarios between the inner and outer barriers of the waste package are (i) no radial or axial contact, (ii) radial contact only, (iii) axial contact only, and (iv) both radial and axial contact. Because the magnitude of differential thermal expansion depends on the waste package inner and outer barrier temperatures, the closed-form solution implemented within DTHERM to approximate these temperatures needs to be validated as well.

The closed-form solutions that are used within DTHERM to estimate the temperatures and stresses created by differential thermal expansion of the waste package inner and outer barriers are derived and documented within the DTHERM MATHCAD source program itself. The derivations of the closed-form solutions are based on standard engineering theory documented in Kreith and Bohn (2000); Shames and Cozzarelli (1992); and Timoshenko, and Goodier (1970).

2.0 References

Kreith and Bohn. Principles of Heat Transfer, 6th Edition. New York, New York: Harper & Row Publishers. 2000.

Shames and Cozzarelli. Elastic and Inelastic Stress Analysis. Englewood Cliffs, New Jersey: Prentice-Hall, Inc. 1992.

Timoshenko, and Goodier. Theory of Elasticity, 3rd Edition. New York, New York: McGraw-Hill Book Company. 1970.

3.0 Environment

3.1 Software

- ABAQUS/Standard, UNIX compatible operating system
- Mathsoft MATHCAD 2000 Professional or Premium for Windows or any later version of MATHCAD

3.2 Hardware

- Sun 1420R Server (Solaris 8 operating system)
- PC with Pentium - 133 or higher (Windows 95, 98, 2000 or NT 4.0 or higher operating system)

4.0 Prerequisites

The individual chosen to implement the software validation test plan should be knowledgeable in the use of MATHCAD and ABAQUS/Standard.

5.0 Assumptions and Constraints

No assumptions and constraints required to implement the software validation test plan.

6.0 Test Cases

6.1 Validation Test Parameters

Table 6-1 conveys the different combinations of radial and axial gaps that will be used in the construction of the finite element models. These combinations of radial and axial gaps should result in the four contact cases between the waste package inner and outer barriers that were described in Section 1.0. Specifically, Case 1 corresponds to no radial or axial contact, Case 2 is radial contact only, Case 3 is axial contact only, and Case 4 is both radial and axial contact.

Table 6-2 delineates the model parameters that remain fixed for all four radial and axial contact cases that will be validated.

Table 6-1. Radial and Axial Model Gaps Between the Waste Package Inner and Outer Barriers for the Four Cases to be Validated.

	Case 1	**Case 2**	**Case 3**	**Case 4**
Radial Gap Between the Inner and Outer Barriers (m)	0.006	0.002	0.006	0.002
Axial Gap Between the Inner and Outer Barriers (m)	0.030	0.030	0.005	0.005

Table 6-2. Fixed Validation Model Parameters.

Model Parameter	Parameter Value
Waste Form Properties:	
Waste Form Heat Decay Rate (kW)	11.8
Waste Form Effective Thermal Conductivity (W/ m•K)	10.3
Boundary Conditions:	
Ambient Temperature (K)	473
Ambient Pressure (Pa)	7.0 (10^6)
Initial Inner Barrier Internal Pressure (Pa)	1.013 (10^5)
Inner Barrier Material Properties:	
Inner Barrier Thermal Conductivity (W/ m•K)	25.4
Inner Barrier Thermal Expansion Coefficient (1/K)	17.5 (10^{-6})
Inner Barrier Modulus of Elasticity (Pa)	124.8 (10^9)
Inner Barrier Poisson's Ratio	0.27
Outer Barrier Material Properties:	
Outer Barrier Thermal Conductivity (W/ m•K)	21.6
Outer Barrier Thermal Expansion Coefficient (1/K)	13.7 (10^{-6})
Outer Barrier Modulus of Elasticity (Pa)	155.8 (10^9)
Outer Barrier Poisson's Ratio	0.30
Waste Package Dimensions:	
Inner Barrier, Inner Radius (m)	0.712
Inner Barrier Total Length (m)	4.775
Inner Barrier Thickness (m)	0.050
Outer Barrier Thickness (m)	0.020

6.2 Validation Test Procedure

The methodology used to define the validation test parameters within the DTHERM program is described in the DTHERM Release Version 1.1 documentation that is included in the software Quality Assurance folder located in the Quality Assurance records room.

6.3 Validation Test Results

The estimated stresses calculated within DTHERM for the waste package inner and outer barriers that are created by the differential thermal expansion effect are valid for the polar cross-section located at the waste package's mid-length. As a consequence, the finite element model results that will be used to validate DTHERM will be extracted from the corresponding location, i.e., the polar cross-section located at the waste package's mid-length. The specific stress results that will be used to validate the calculated DTHERM values are the radial, axial, circumferential (i.e., "hoop"), and von Mises stresses. The same finite element model cross-section will also be used to validate the approximated waste package inner and outer temperatures that are calculated within DTHERM. The results calculated by DTHERM are considered to be acceptable if they are within ± 10% of the finite element method solution.

The results of the DTHERM Release Version 1.1 validation tests will be documented and included in the appropriate Quality Assurance folder located in the Quality Assurance records room.

7.0 Notes

None.