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PRCI Thermal Analysis Model for Hot-Tap Welding - V 4.2

Users Guide - Revision 3

Contract PR-185-9632

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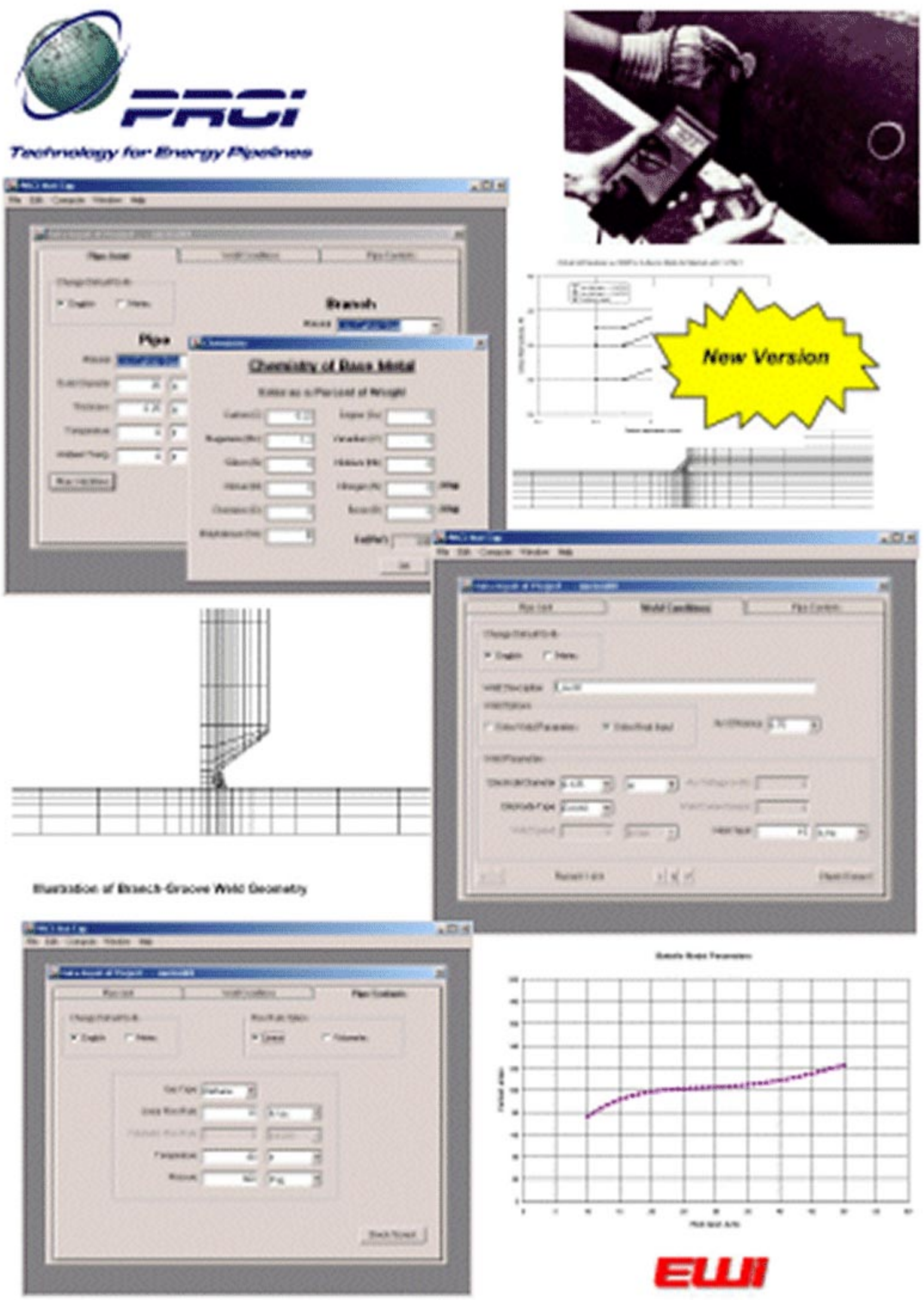

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PRCI Thermal Analysis Model for Hot-Tap Welding - V 4.2

Users Guide - Revision 3

1.0 Introduction

This manual describes the use of the PRCI Thermal Analysis Model for Hot-Tap Welding - V 4.2, which was developed by Edison Welding Institute (EWI) for PRCI. The model is intended to provide welding engineers with guidance for establishing safe parameters for welding onto in-service pipelines (hot-tap welding).

There are two primary concerns with welding onto in-service pipelines. The first is for welder safety during welding, since there is a risk of the welding arc causing the pipe wall to be penetrated allowing the contents to escape. The second concern is for the integrity of the pipeline following welding, since welds made in-service cool at an accelerated rate as the result of the ability of the flowing contents to remove heat from the pipe wall. These welds, therefore, are likely to have hard heat-affected zones (HAZ) and a subsequent susceptibility to hydrogen cracking. The model allows burnthrough risk to be controlled by limiting inside surface temperature and hydrogen cracking risk to be controlled by limiting weld cooling rates.

The use of this model is not a substitute for procedure qualification. The model provides guidance for establishing safe parameters, but provides no means for demonstrating that these parameters are practical under field conditions. To demonstrate that the parameters are practical, a welding procedure based on these predictions should be qualified under simulated conditions.(1) A brief history of cooling rate prediction methods for welds made onto in-service pipelines is given in Appendix A.

Because of the research nature of PRCI Thermal Analysis Model for Hot-Tap Welding - V 4.2, the user undertakes the sole responsibility for the consequences of any use of, misuse of, or inability to use, any information or results obtained from the model predictions. Neither PRCI or EWI is liable for any damages resulting, directly or indirectly, from the use of this product.

2.0 Getting Started

Running the PRCI Thermal Analysis Model for Hot-Tap Welding - V 4.2 software requires the following:

- 200 MHz or higher processor clock speed recommended
- Intel Pentium/Celeron or AMD K6/Athlon/Duron or compatible processor

- Windows 95/98/NT/2000/XP
- 32 MB of RAM
- 20 MB of free disk space
- Microsoft Excel required to plot heat input selection curves.

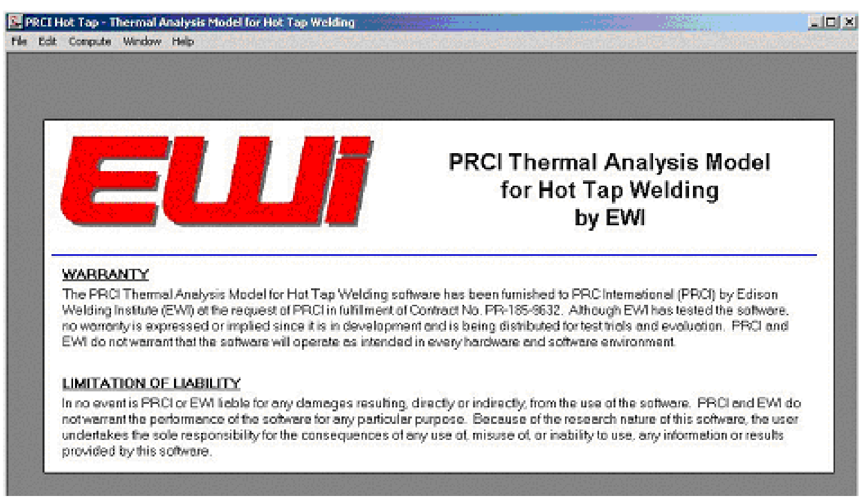
This manual comes with one CD-ROM disk, which contains the program, and all the related related software. Also included in the program is the PRCI Hot Tap - Program Manual in PDF format.

Installing the PRCI Thermal Analysis Model for Hot-Tap Welding software:

o Insert the Hot Tap compact disc into the CD-ROM drive of your PC.
o The CD will "auto start"
o Follow the instructions on the screen for installation. (The software installation will automatically install all the program files into folder C:\Program Files\PRCI Hot Tap)

After the program has been installed, you will have a folder named PRCI Hot Tap under the Start / Windows / Programs Menu and a shortcut named PRCI Hot Tap to initiate the PRCI Hot-Tap Analysis program.

Starting the PRCI Thermal Analysis Model for Hot-Tap Welding program:
· This is the initial screen you will see when you start the program.



3.0 Menu Bar

The Menu Bar is located at the top of the screen, as shown in Figure 1. There are five options displayed: **File, Edit, Compute, Window,** and **Help**.

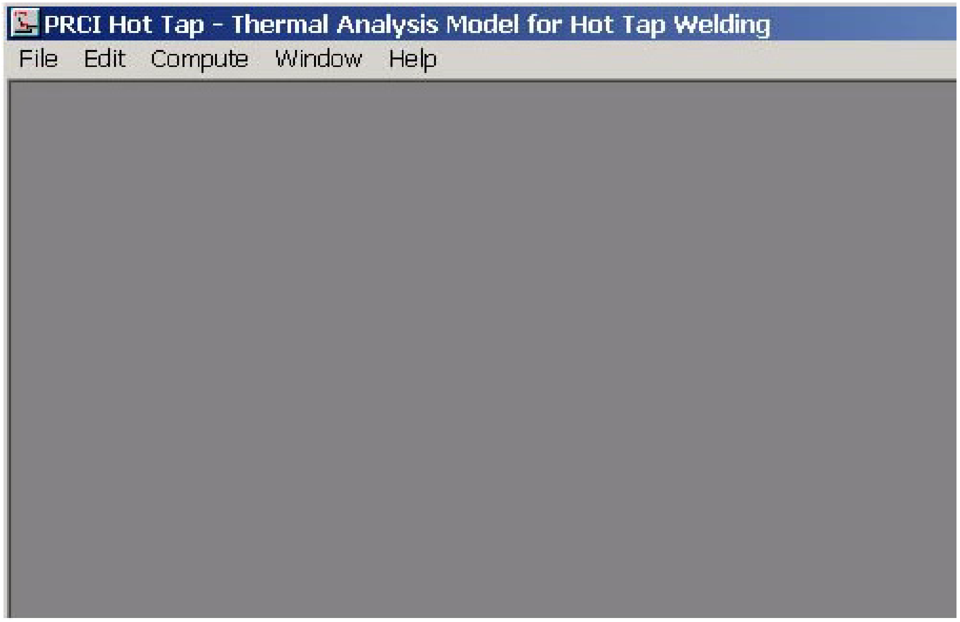


Figure 1. Menu Bar

The Menu Bar options can be accessed via the pointing device or keyboard. To use the keyboard, press and hold the ALT key while pressing the key associated with the first letter of the option. For example, ALT-F will select the File menu. The LEFT and RIGHT ARROW keys on the keyboard can be used to navigate from left to right across the five options. Pull-down menus are associated with each of the five options. The pointing device and the UP and DOWN ARROW keys can be used to navigate these menus.

3.1 File

Selecting this Menu Bar option will generate a menu as shown in Figure 2. The File menu options are: **New Project, Open Project, Delete Project, Duplicate Project, Import Data, Review Input, Print Report, Page Setup**, and **Exit**.

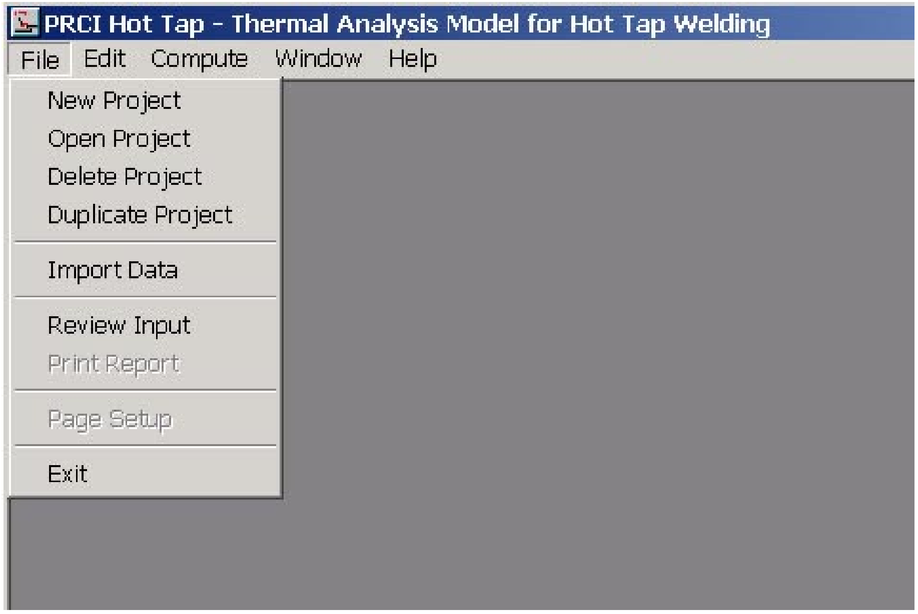


Figure 2. File Menu

3.1.1 New Project

The New Project option under the File menu activates the Project Initialization panel, which allows a new data file to be generated. The Project Initialization panel is shown in Figure 3. To begin a new project, enter a unique Project ID (file name) - from 1 to 15 alphanumeric characters - and an optional Title (description) - from 1 to 30 alphanumeric characters . Next, select the geometry of interest and the type of pipe contents. Geometry options include Sleeve (sleeve-fillet weld), Branch (branch-groove weld), Bead-On-Pipe (buttering pass or weld deposition repair), and Heat-Sink Capacity [torch-heated, 2-in. (50-mm) -diameter area]. Pipe Contents options includes Gas or Liquid.

After entering this information, clicking on the OK push button will lead the user to the first of three data input screens, which are described in Section 4.

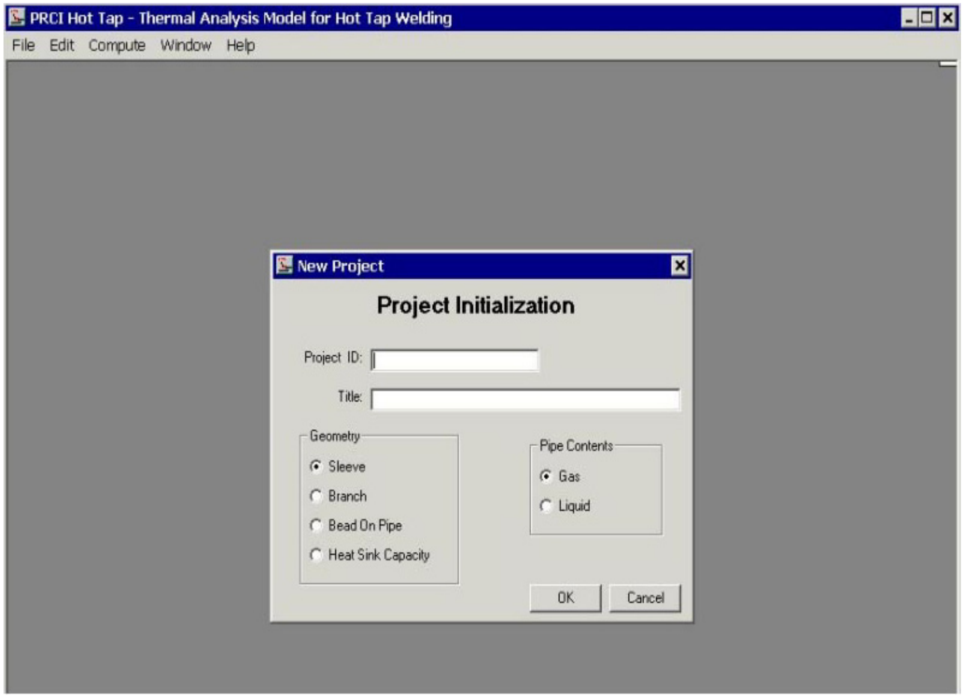


Figure 3. Project Initialization Panel

3.1.2 Open Project

The Open Project option under the File menu activates a file selection panel, from which an existing data file can be selected. This selection panel is shown in Figure 4. Select a file from the list of existing files; double clicking on the file name, or clicking on the OK push button will open the file. Changes can then be made to any of the fields in the three data input screens, which are described in Section 4.

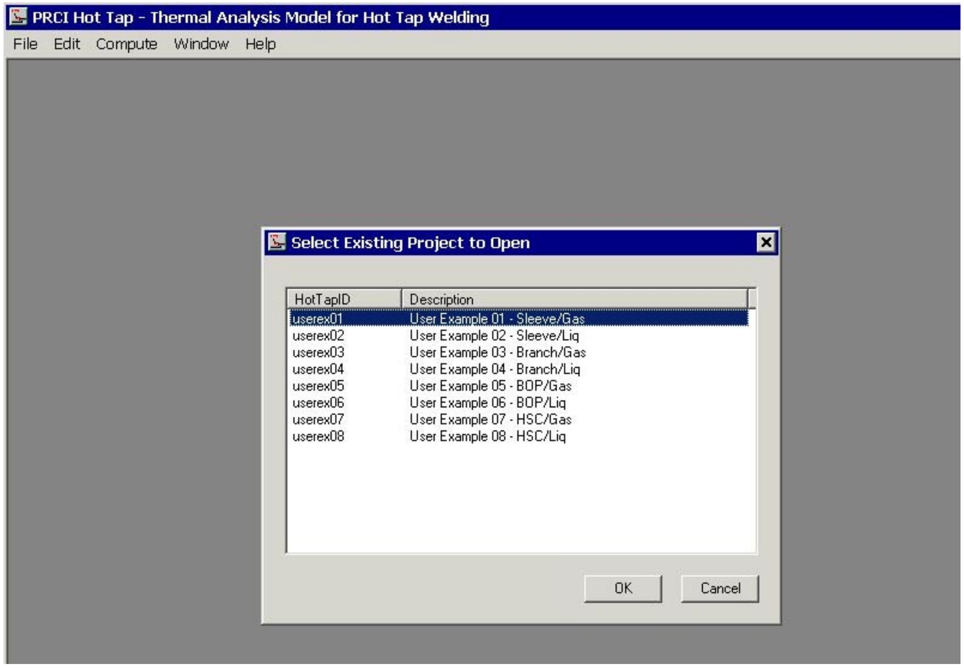


Figure 4. Open Project File Selection Panel

3.1.3 Delete Project

The Delete Project option under the File menu activates a file selection panel that allows a previously entered data set to be deleted. Select a file from the list of existing files; double clicking on the file name, or clicking on the OK push button will delete the file.

3.1.4 Duplicate Project

The Duplicate Project option under the File menu activates a file selection panel that allows a previously-entered data set to be duplicated under a different file name. The pointing device can be used to select a file from the list of existing files; clicking on a file name will cause it to be highlighted. To duplicate a project, enter a unique Project ID (file name), and an optional Title (description). Clicking on the OK push button will duplicate the file.

The duplicate file can then be opened as described in Section 3.1.2. Changes can then be made to any of the fields in the three data input screens, which are described in Sections 4 and 5.

3.1.5 Import Data

The Import Data option under the File menu is inactive at this time, but will be included in a future release of the software. This option will allow data sets from previous versions of the model to be imported into the current version.

3.1.6 Review Input

The Review Input option under the File menu activates a file selection panel that allows the user to review the input data for previously-entered data sets in tabular form. The Review Input options are: **Preview, Print, Output in Rich Text Format**, or **Exit**.

3.1.7 Print Report

The Print Report option under the File menu activates a file selection panel that allows the user to review input data and results for previously-entered data sets in tabular form. The Print Report options are: **Preview, Print, Output in Rich Text Format**, or **Exit**.

3.1.8 Page Setup

The Page Setup option under the File menu activates the Windows® "Page Setup" dialog, which allows the user to set page margins, page orientation, select a printer, etc.

3.1.9 Exit

The Exit option under the File menu terminates PRCI Thermal Analysis Model for Hot-Tap Welding - V 4.2, saves all data files, and exits to the operating system.

3.2 Edit

This Menu Bar menu option is intended for use only when the Weld Conditions panel is displayed. Selecting this option will generate a pull-down menu as shown in Figure 5. The Edit menu options are: **Duplicate Weld Condition** and **Delete Weld Condition**. A further description of these options is given under the description of Weld Conditions panel in Section 4.2.

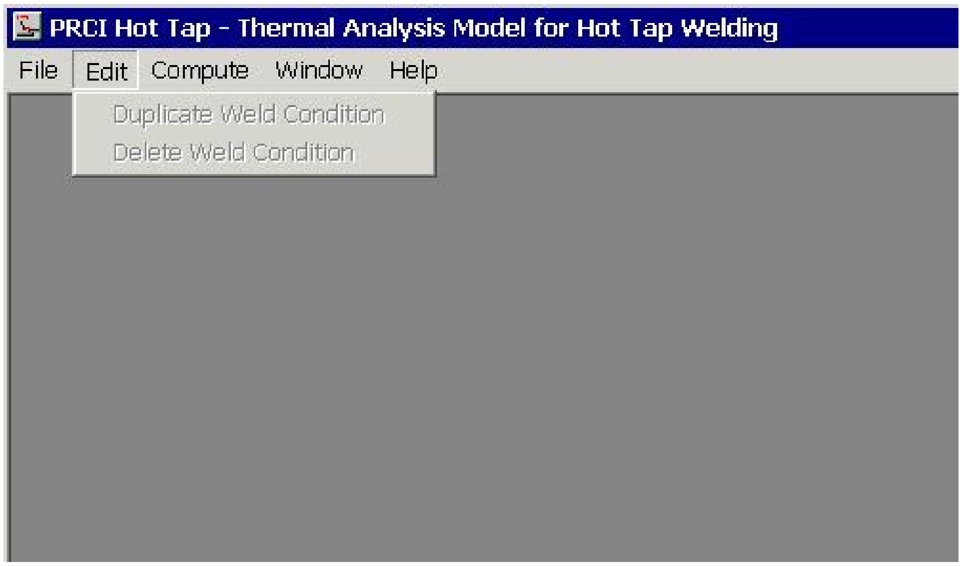


Figure 5. Edit Menu

3.3 Compute

Selecting this Menu Bar option will generate a pull-down menu as shown in Figure 6. The Compute menu options are: **Analyze** and **Graph Results**. Selecting the Analyze option activates a file selection panel that allows the user to run the finite-element solver and generate results for the file selected, as described in Section 6. Selecting the Graph Results option activates a file selection panel that allows the user to generate a heat input selection curve, as described in Section 7, for the file selected. The Graph Results option is only functional after the solver has been run for a particular file.

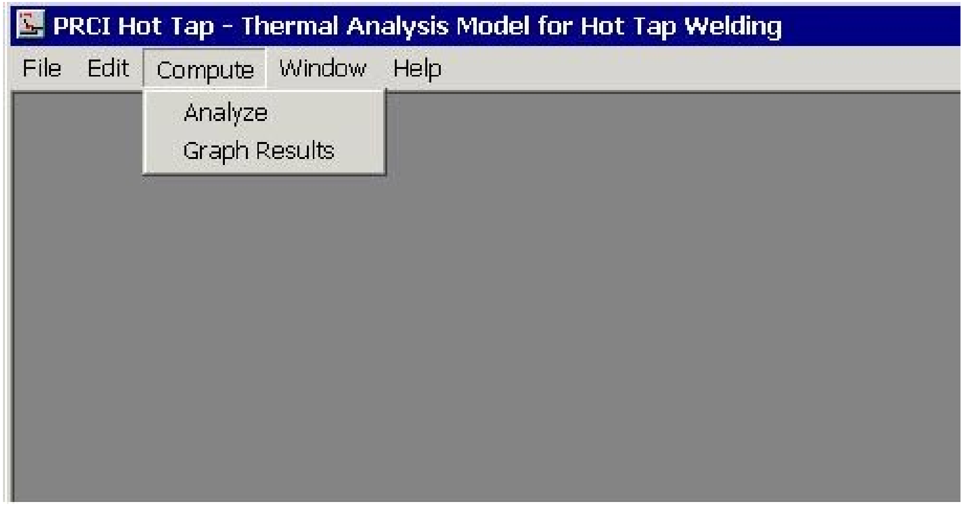


Figure 6. Compute Menu

3.4 Window

Selecting this Menu Bar menu option allows the user to navigate between windows.

3.5 Help

At this time, the Help menu option displays a standard Windows® "About" screen. This option will allow the user to access help screens, and will be included in a future release of the software.

4.0 Entering Data

Selecting the New Project option under File on the Menu Bar will activate the Project Initialization panel, as shown in Figure 3. After entering a Project ID (file name), and optional Title (description), and selecting a Geometry and Pipe Contents, clicking on the OK button will display the first of three data input panels: Pipe Joint, Weld Conditions (or Heating Conditions), and Pipe Contents. Each of the three data input panels contains a feature that allows the user to select either English or Metric units as a default. Each of the three data input panels also contain a data integrity check routine. Clicking on the push button labeled "✔" will check that the value for each parameter entered falls within pre-defined limits. These limits are shown in Table 1. If a given value falls outside these limits, an error message will be displayed. After entering data, closing any of the three data input panels will cause the data that was entered to be saved.

Table 1. Pre-Defined Input Data Limits

Parameter	Limit
Pipe outside diameter in. (m)	0-100 (0-2.54)
Pipe thickness, in. (mm)	0.1-2 (2.5-50.8)
Pipe temperature, °F (°C)	-50-400 (-46-204)
Ambient temperature, °F (°C)	-50-200 (-46-93)
Sleeve or branch thickness, in. (mm)	0.1-2 (2.5-50.8)
Sleeve or branch temperature, °F (°C)	-50-400 (-46-204)
Gap between pipe and sleeve, in. (mm)	0-0.125 (0-3.2)
Branch root gap, in. (mm)	0-0.125 (0-3.2)
Angle between pipe and edge of branch, deg	0-45
Branch outside diameter, in. (m)	0-100 (0-2.54), ≤ Pipe OD
Weld current, amps	20-200
Arc voltage, volts	4-30
Weld travel speed, in./min (mm/sec)	0.5-20 (0.2-8.5)
Weld heat input, kJ/in. (kJ/mm)	10-80 (0.4-3.2)*
Pressure, psi (kPa) gage	0-10,000 (1397)
Velocity, ft/sec (m/sec)	0-200 (61.0)
Gas temperature, °F (°C)	-50-400 (-46-204)

* Rounded to the nearest whole number in kJ/in.

4.1 Pipe Joint

The Pipe Joint data input panel contains fields for entering details pertaining to the pipe material of interest and other details depending on which geometry has been selected. This input panel is shown in Figure 7 for a sleeve-fillet weld example. Illustrations of the three weld geometries are shown in Figures 8-10. Fields pertaining to the pipe material include Material, Outer Diameter, Thickness, Temperature, and Ambient Temperature. For cases involving a sleeve-fillet weld, fields pertaining to other details include Material, Thickness, Temperature, and Gap Between Pipe and Sleeve. For cases involving branch-groove welds, fields pertaining to other details include Material, Thickness, Temperature, Branch Root Gap, Angle Between Pipe and edge of Branch (i.e., the branch bevel angle), and Branch Outer Diameter. For Bead-on-Pipe or Heat-Sink Capacity cases, no other details are required.

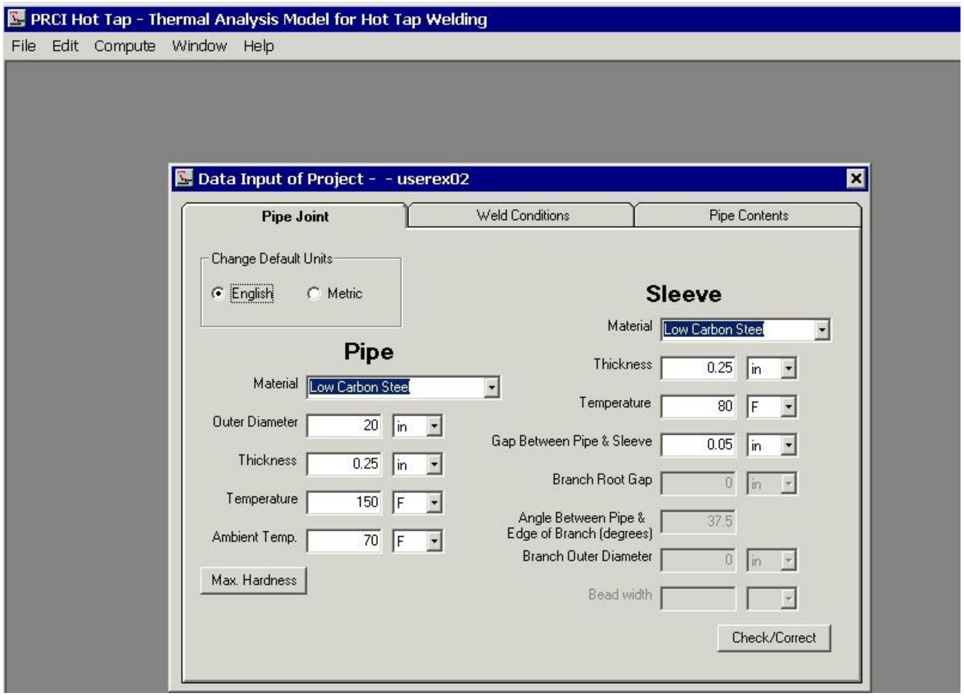


Figure 7. Pipe Joint Data Input Panel

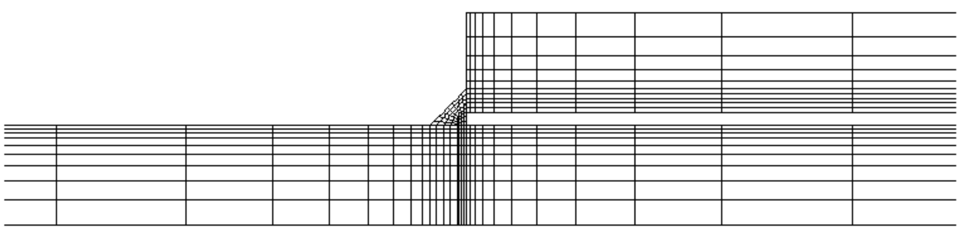


Figure 8. Illustration of Sleeve-Fillet Weld Geometry

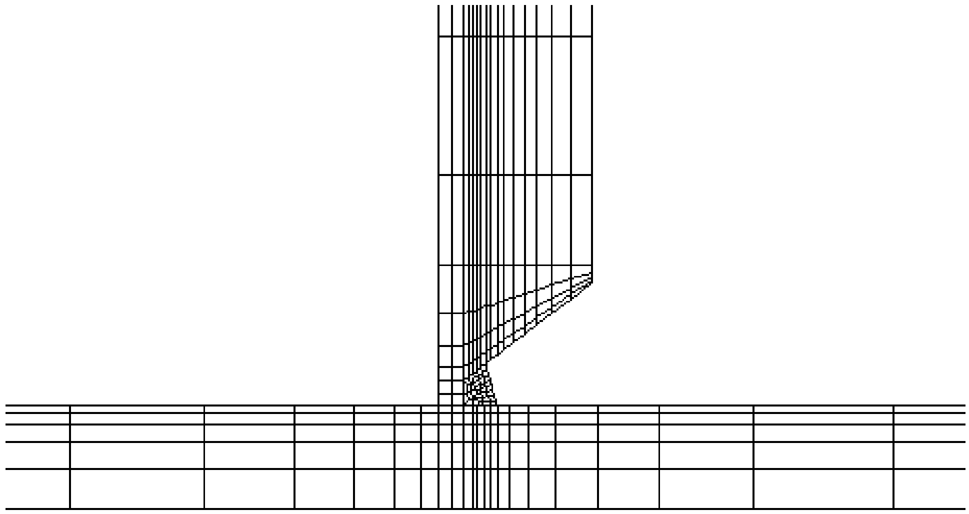


Figure 9. Illustration of Branch-Groove Weld Geometry

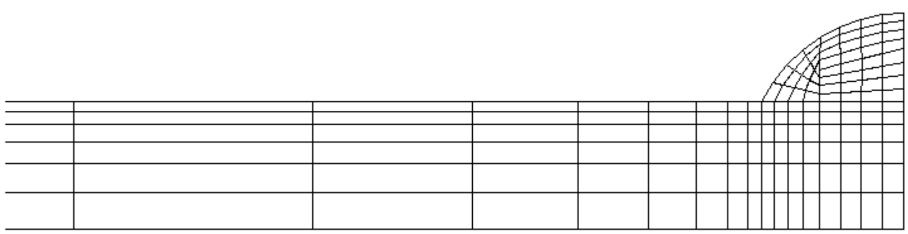


Figure 10. Illustration of Bead-on-Pipe Weld Geometry

The Pipe Joint data input panel also contains a push button labeled Max. Hardness that, when selected, activates a Base Metal Chemistry input panel, which is shown in Figure 11. This input is only required if the user requires HAZ hardness predictions calculated using the Yurioka algorithm, the use of which is described in Section 7. If base metal chemistry is entered, hardness predictions will appear in tabular form on the printed report after running the finite element solver and as part of the enhanced heat input selection curves which are also described in Section 7.

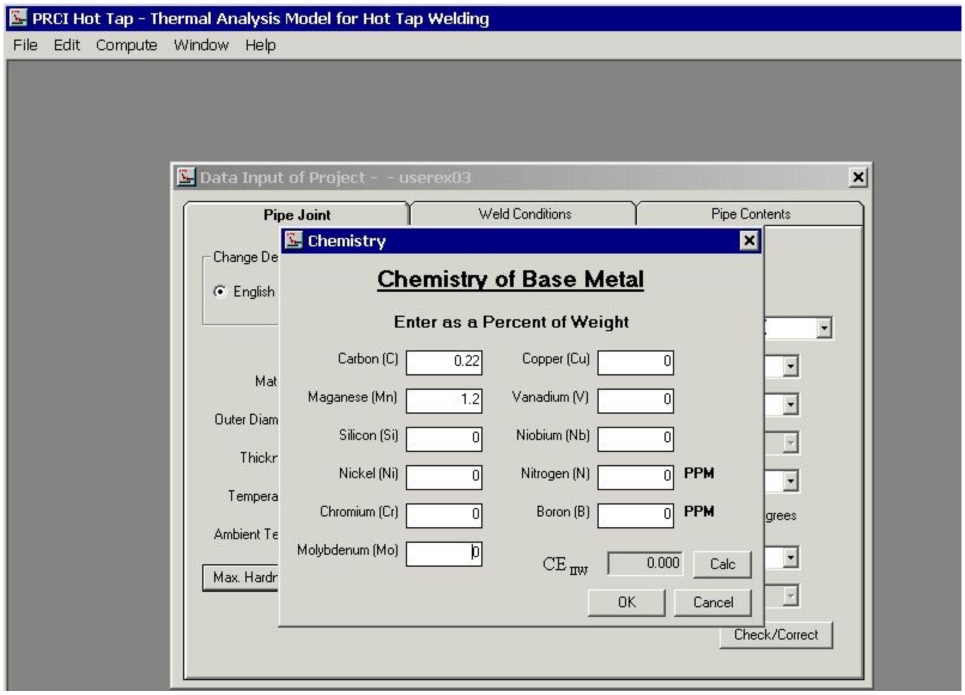


Figure 11. **Base Metal Chemistry Input Panel**

The remaining feature on the Pipe Joint data input panel is push button links to the other two data input panels.

4.2 Weld or Heating Conditions

The second data input panel is Weld Conditions for Sleeve, Branch, and Bead-on-Pipe cases, or Heating Conditions for Heat-Sink Capacity cases.

The Weld Conditions data input panel contains fields for entering details pertaining to the welding parameters. This input panel, which allows multiple cases to be run from a single input file, is shown in Figure 12. After entering an optional weld description, options for entering the welding parameters include Enter Weld Parameters or Enter Heat Input. Selecting Enter Weld Parameters allows specific values for welding current, voltage, and travel speed to be entered. Selecting Enter Heat Input requires that only a value for the resulting heat input is entered - the software selects specific values for welding current, voltage, and travel speed according to a preset algorithm. These specific values are shown as a function of heat input in Figures 13 and 14.

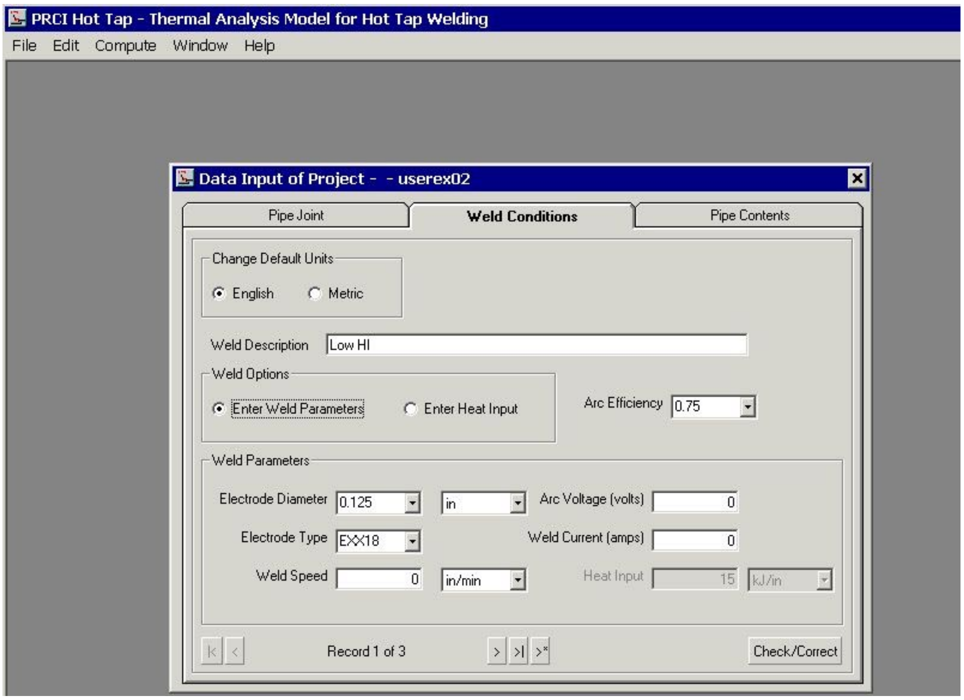


Figure 12. Weld Conditions Data Input Panel

For cases where Enter Welding Parameters is selected, the fields pertaining to the welding parameters include Electrode Type, Electrode Diameter, Weld Speed, Arc Voltage, and Weld Current. For cases where Enter Heat input is selected, the fields pertaining to the welding parameters are the same except Heat Input replaces Weld Speed, Arc Voltage, and Weld Current.

A field for entering the arc efficiency of the welding process is also provided on the Weld Conditions data input panel. A pull-down menu containing arc efficiency for common welding processes is provided. A user-defined value for arc efficiency can also be entered.

The counter at the bottom of the Weld Conditions data input panel tells the user what case is currently being displayed. To enter another case, the user can simply toggle to the next unused Weld Conditions data input panel, or use the Edit feature on the Menu Bar. Selecting the Edit feature will generate a pull-down menu as shown in Figure 5. The Edit menu options are: **Duplicate Weld Condition** and **Delete Weld Condition**. Selecting Duplicate Weld Condition will duplicate the weld condition that is currently displayed. Changes can then be made to the duplicated weld condition. Selecting Delete Weld Condition deletes the weld condition that is currently displayed.

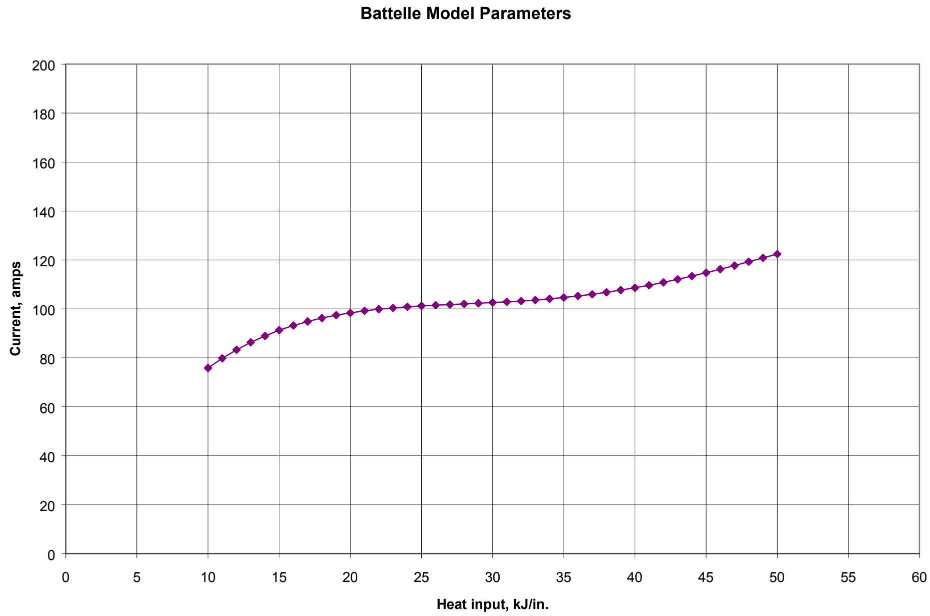


Figure 13. Welding Current Used when Enter Heat Input Option is Specified

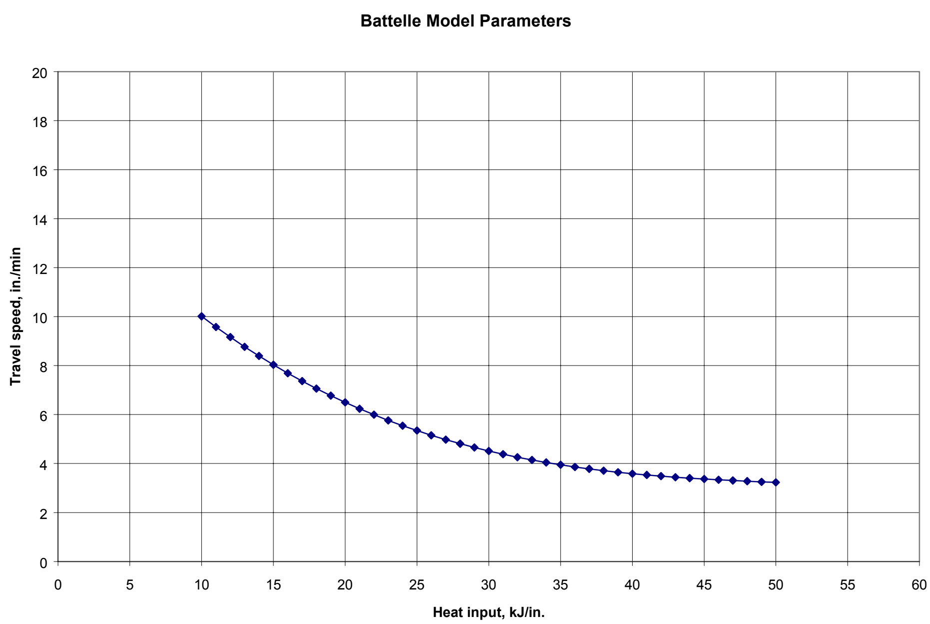


Figure 14. Travel Speed Used when Enter Heat Input Option is Specified

The Heating Conditions data input panel for Heat-Sink Capacity cases is shown in Figure 15. This panel is similar to the Weld Conditions data input panel except that it contains fields for entering data pertaining to torch heating conditions. The Enter Heating Parameters option is inactive at this time. The ability to run cases using the Enter Heating Parameters option will be included in a future release of the software. To obtain heat-sink capacity predictions that are consistent with the procedure used in previous programs at EWI,[6] a Heating Rate value of 3.272 BTU/sec should be used. The EWI heat-sink capacity measurement procedure is given in Appendix B.

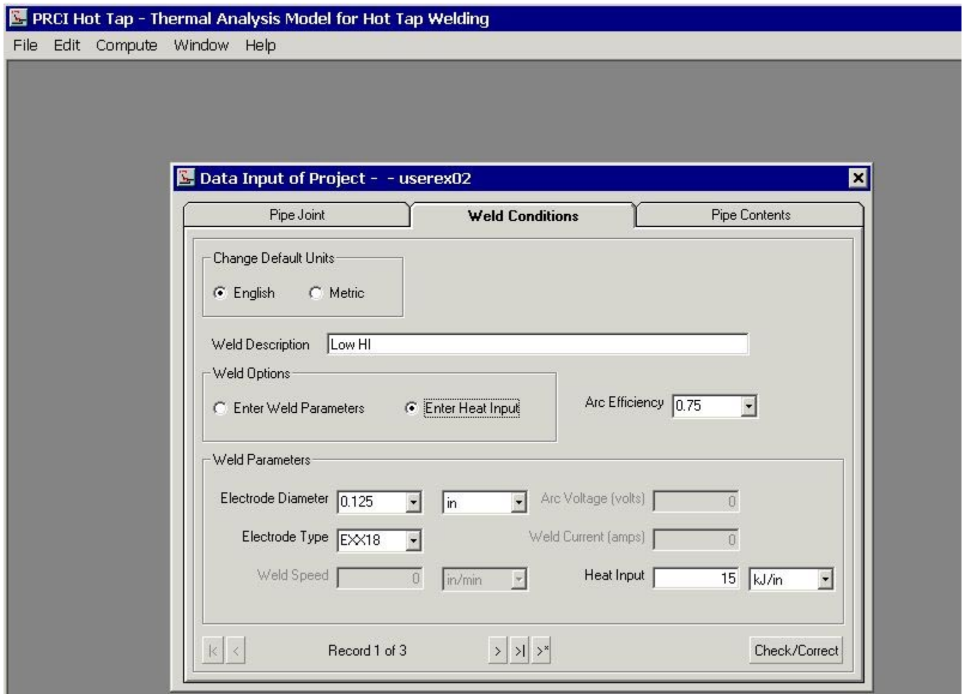


Figure 15. Heating Conditions Data Input Panel

4.3 Pipe Contents

The Pipe Contents data input panel contains fields for entering details pertaining to the pipe contents. This input panel is shown in Figure 16 for a gas pipeline contents example. Options for entering the flow rate include Linear Flow Rate or Volumetric Flow Rate. Fields pertaining to the Pipe Contents include Gas (or Liquid) Type, Linear (or Volumetric) Flow Rate, Temperature, and Pressure. For cases involving gas pipeline contents, a pull-down menu containing a list of common gases is provided. For cases involving liquid pipeline contents, a pull-down menu containing a list of common liquids is provided.

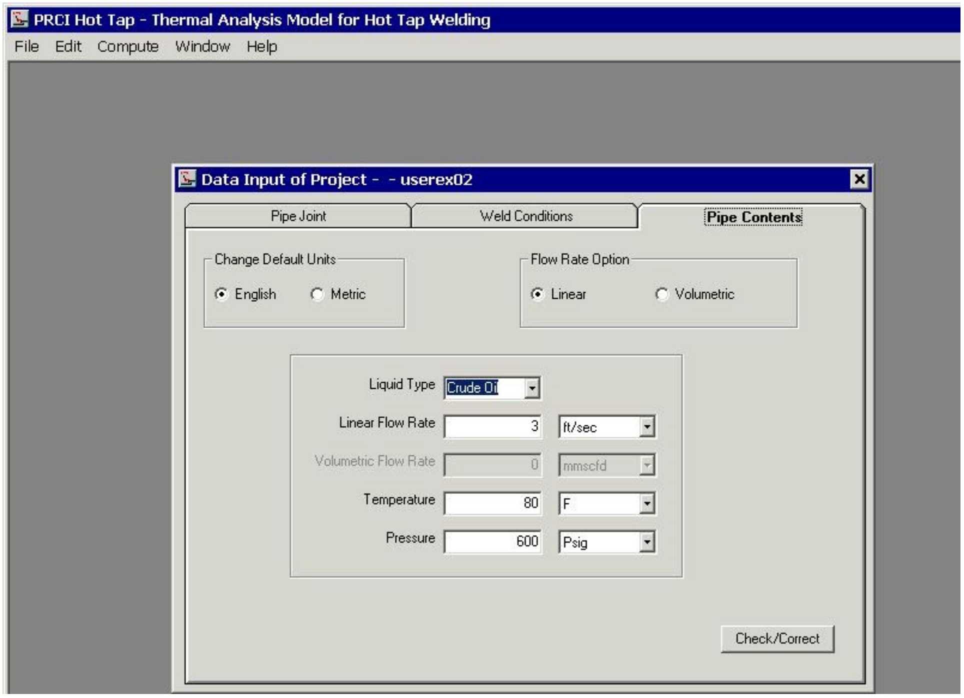


Figure 16. Pipe Contents Data Input Panel

5.0 Modifying Previously-Entered Data

Previously entered data sets can be modified either by simply opening the data file and making changes, whereby the previous version of data file will be lost, or by using the Duplicate Project feature under the File option on the Menu Bar, which allows a previously-entered data set to be duplicated under a different file name. Selecting the Duplicate Project feature will activate the Duplicate Project panel, as shown in Figure 17. The pointing device can be used to select a file from the list of existing files; clicking on a file name will cause it to be highlighted. To duplicate a project, enter a unique Project ID (file name), and an optional Title (description). Clicking on the OK push button will duplicate the file.

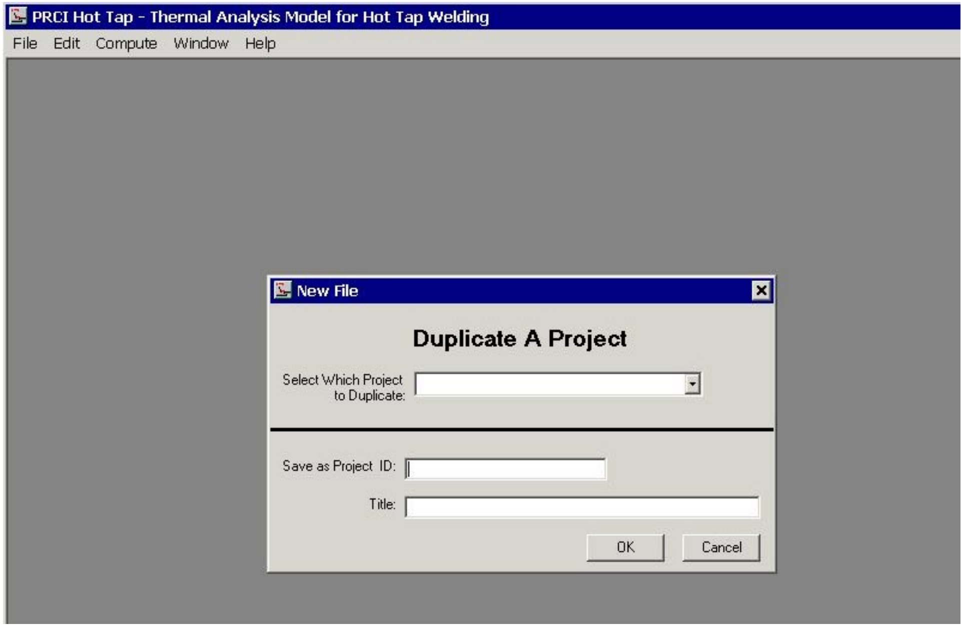


Figure 17. Duplicate Project Panel

This feature allows the user to begin with parameters from a previously entered data set and is particularly useful for cases that involve the same welding conditions but different flow parameters, for example. After the file is duplicated, the new file can be opened, as described above, and changes can then be made to any of the fields in the three data input screens, without loosing the data set that was duplicated.

6.0 Running the Program

After a data set has been entered, closing any of the three data input panels will cause the data that was entered to be saved. To run the finite-element solver, select the Analyze option from the pull-down menu under Compute on the Menu Bar, which will activate the Start Analysis file selection panel as shown in Figure 18. Select a file from the list of existing files; double clicking on the file name, or clicking on the OK push button will run the finite element solver and generate results for the file selected. While the program is running, a DOS screen will appear, as shown in Figure 19, on which the progress of the program can be monitored. Once the program has completed running the selected file, the results can be viewed in tabular form by clicking on the OK button. _Note_: *clicking on the OK button before the program has completed running the selected file will result in an error*.

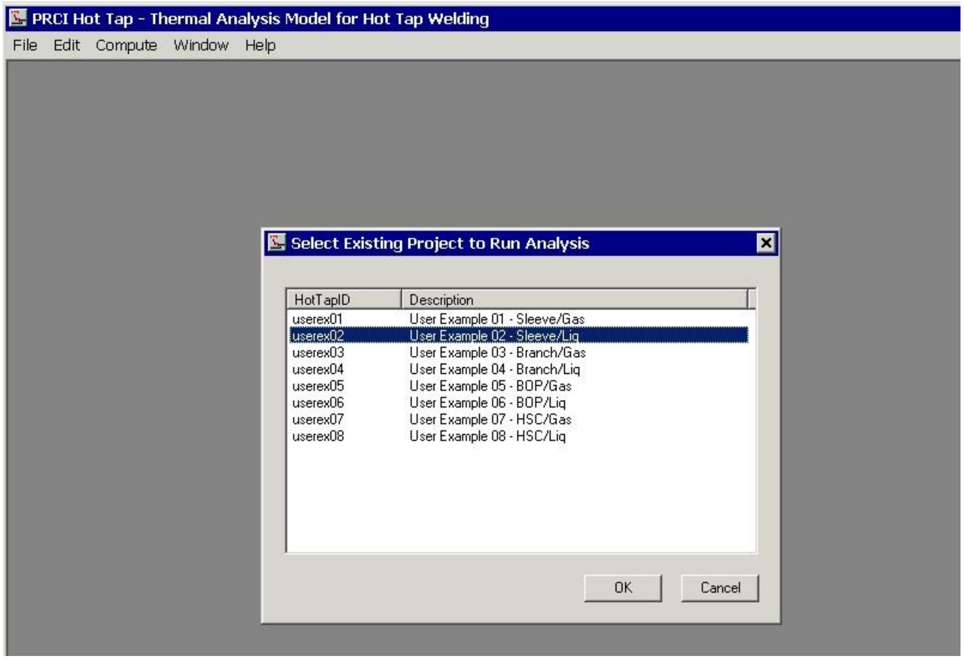


Figure 18. Start Analysis File Selection Panel

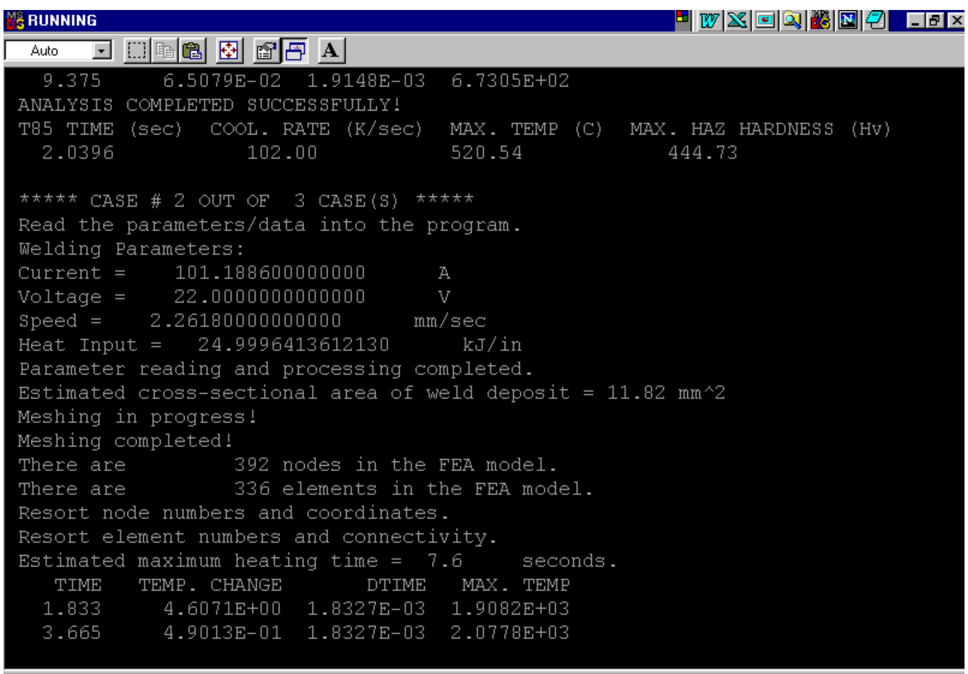


Figure 19. DOS Screen for Finite-Element Solver

7.0 Using the Results

7.1 Controlling Burnthrough Risk

The inside surface temperature predictions are used to control the risk of burnthrough. Safe parameters are defined as those which produce an inside surface temperature of less than 1800°F (982°C) when using low-hydrogen electrodes or [less than 1400°F (760°C) when using cellulosic-coated electrodes]. In a series of previously conducted experiments,(2) Battelle observed that burnthrough tended to occur when the inside surface temperature exceeded 2300°F (1260°C). The 500°F (278°C) temperature difference between this and the 1800°F (982°C) limit was introduced as a margin for safety. For individual cases that result in an inside surface temperature greater than the limits established by Battelle, an asterisk is provided adjacent to the inside surface temperature prediction on the printed report.

7.2 Controlling Hydrogen Cracking Risk

The weld cooling rate and cooling time between 800 and 500°C ($\Delta t_{8\text{-}5}$) predictions are used to control the risk of hydrogen cracking. Hydrogen cracking susceptibility tends to increase with increasing hardness and hardness tends to increase with faster weld cooling rates (or shorter $\Delta t_{8\text{-}5}$ times). There are two ways to use the results to control the risk of hydrogen cracking: the chemical composition method and the carbon equivalent method. The use of the latter is less precise but requires fewer details of the pipe material chemical composition.

7.2.1 Chemical Composition Method

Knowing the predicted $\Delta t_{8\text{-}5}$ time and the chemical composition of the pipe material, a previously developed algorithm, such as the one built into the software that was developed by Yurioka,(3) can be used to predict the HAZ hardness. The hardness level above which hydrogen cracking can be expected to occur, or the critical hardness level, depends on the carbon equivalent level of the materials and on the hydrogen level of the welding process. The critical hardness level for in-service welds is shown as a function of carbon equivalent level and weld hydrogen level in Figure 20. This criteria, which is a modification of previous work by Matharu and Hart,(4) was developed for welds made under simulated in-service conditions during earlier work at EWI.(5)

If base metal chemical composition is entered using the push button labeled Max. Hardness on the Pipe Joint data input panel, hardness predictions will appear in tabular form on the printed report after running the finite-element solver. The solver predicts HAZ hardness using the Yurioka algorithm and the predicted $\Delta t_{8\text{-}5}$ time. To evaluate the risk of hydrogen cracking, the user can compare the predicted hardness to those shown in Figure 20. Alternatively, an enhanced heat input selection curve can be plotted from which the required heat input can be determined.

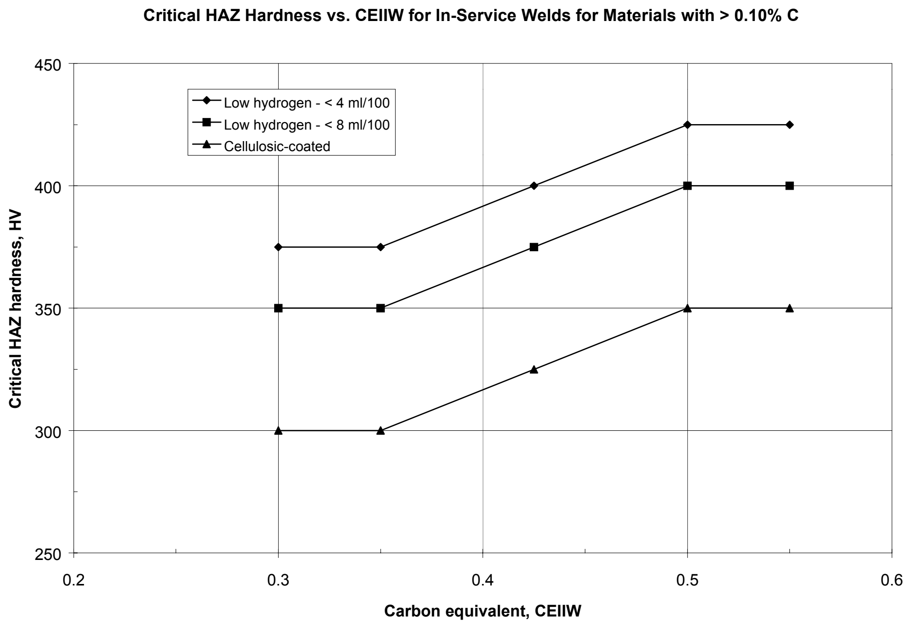


Figure 20. Critical Hardness for In-Service Welds vs. Carbon Equivalent and Weld Hydrogen Level

To plot an enhanced heat input selection curve, select the Graph Results option from the pull-down menu under Compute on the Menu Bar, which will activate the Chart Data file selection panel as shown in Figure 21. Select a file from the list of existing files; double clicking on the file name, or clicking on the OK push button will export the results to a MS Excel spreadsheet and automatically graph the results. <u>Note</u>: *after MS Excel launches, Enable Macros must be selected*.

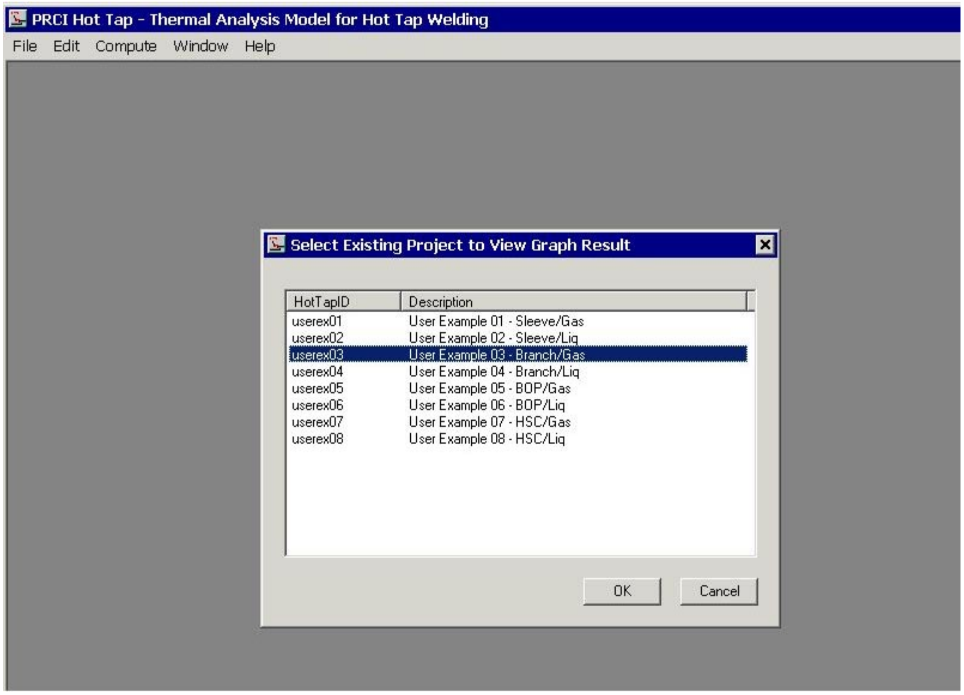


Figure 21. Graph Results File Selection Panel

An example of an enhanced heat input selection curve is shown in Figure 22. The required heat input is determined by selecting the critical hardness for the carbon equivalent level and weld hydrogen level of interest from Figure 20, selecting the corresponding Δt_{8-5} time from the Yurioka predictions from the bottom part of the graph, and then using the heat input selection curve in the top part of the graph to determine the required heat input level.

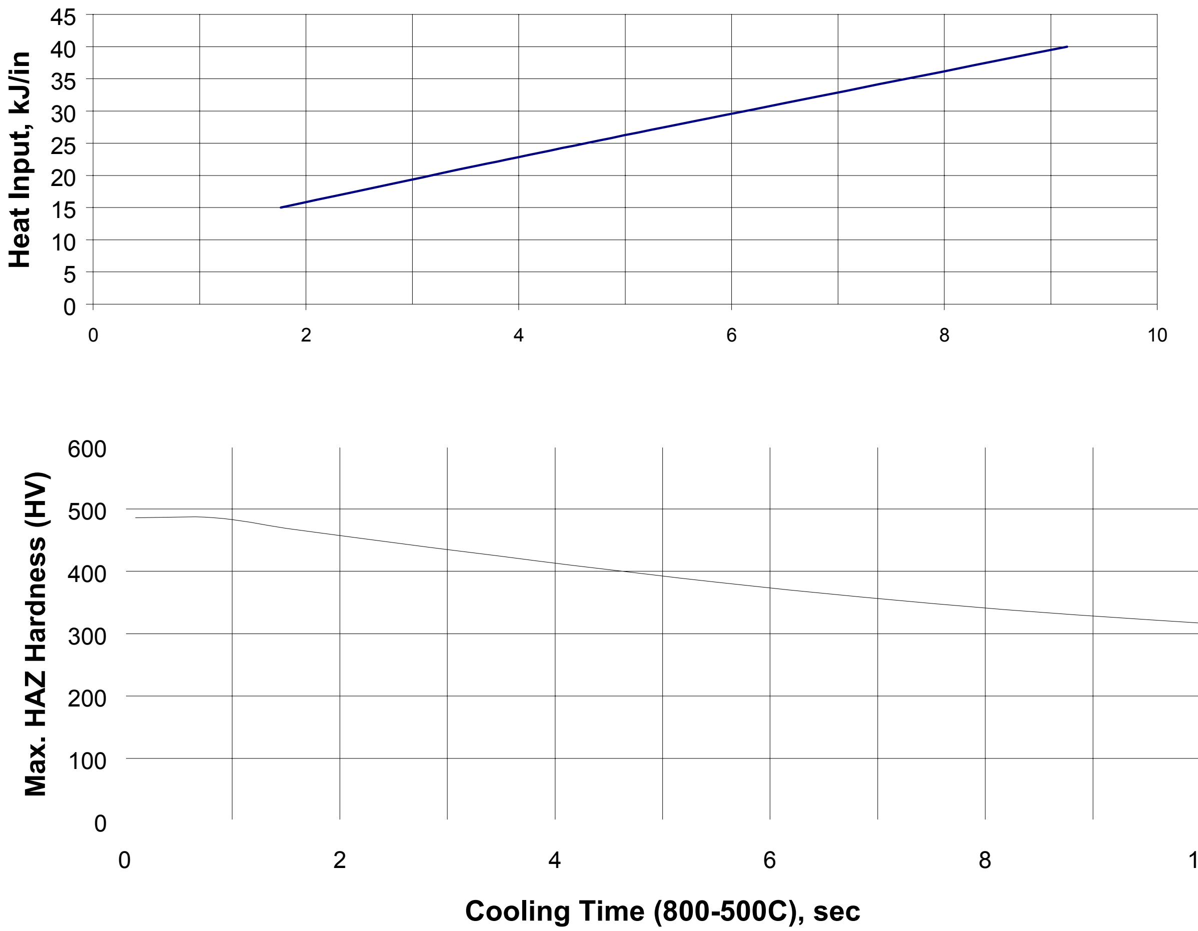


Figure 22. Example of Enhanced Heat Input Selection Curve

7.2.2 Carbon Equivalent Method

Limits on weld cooling rates and $\Delta t_{8\text{-}5}$ times used in previous work by Battelle(6) are shown in Table 2 for materials with different carbon equivalent levels. These limits, which are a modification of previous work by Graville and Read,(7) are intended to avoid a HAZ hardness greater than 350 HV. According to this criteria, safe parameters are defined as those that produce weld cooling rates less than those shown in Table 2 (or $\Delta t_{8\text{-}5}$ times greater than those shown in Table 2). To evaluate the risk of hydrogen cracking, the user can compare the predicted weld cooling rates and $\Delta t_{8\text{-}5}$ times to those shown in Table 2. Alternatively, a standard heat input selection curve can be plotted from which the required heat input can be determined.

To plot a standard heat input selection curve, select the Graph Results option from the pull-down menu under Compute on the Menu Bar, which will activate the Chart Data file selection panel as shown in Figure 21. Select a file from the list of existing files; double clicking on the file name, or clicking on the OK push button will export the results to a MS Excel spreadsheet and automatically graph the results. *<u>Note</u>: after MS Excel launches, Enable Macros must be selected*.

Table 2. Limits on Weld Cooling Rates and $\Delta t_{8\text{-}5}$ Times vs. Carbon Equivalent

Carbon Equivalent, CE_{IIW}	Cooling parameter	
	Cooling rate at 1000°F (538°C), deg F/sec, above which 350 HV is expected	800 to 500°C (1473 to 932°F) weld cooling time ($\Delta t_{8\text{-}5}$), sec, below which 350 HV is expected
0.50	31	13
0.45	43	9
0.40	56	7
0.35	74	5
0.30	94	3
0.25	120	2

An example of a standard heat input selection curve is shown in Figure 23. The required heat input is determined by selecting the corresponding $\Delta t_{8\text{-}5}$ time for the material of interest from Table 2 and then using the heat input selection curve to determine the required heat input level.

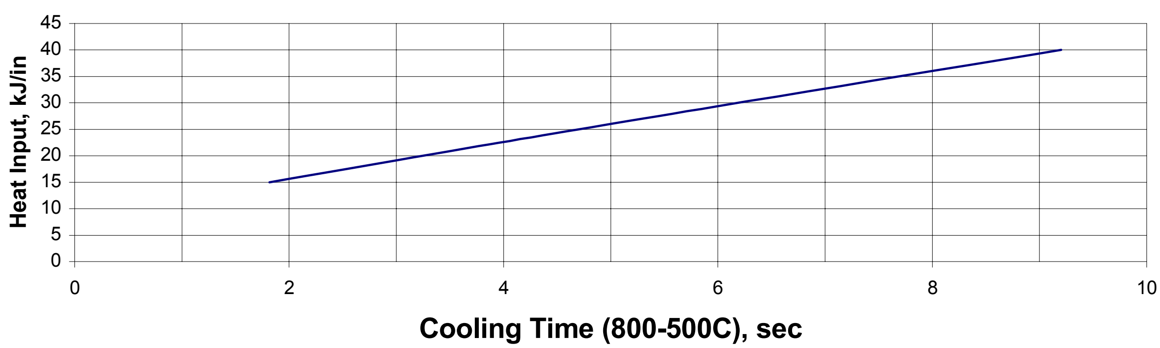


Figure 23. Example of Standard Heat Input Selection Curve

7.3 Heat-Sink Capacity Prediction

Once the required welding parameters for the conditions of interest have been determined, the heat-sink capacity for those conditions can be predicted and used in the field to verify that the flow conditions that exist are close to those used for the predictions.

7.4 Precautions/Limitations

The following is a partial list of precautions and/or limitations for the use of the model:

- Using the Enter Heat Input option to model a case where the actual welding current level will be higher than that shown in Figure 13 (e.g., higher that that used by the algorithm) can result in non-conservative inside surface temperature predictions.
- An entered heat input value of less than 10 kJ/in. (0.4 kJ/mm), which is the minimum value shown in Table 1, will default to 10 kJ/in. (0.4 kJ/mm).
- Discontinuous heat input selection curves will results unless step-wise increases in heat input are made.
- If the chemical composition of the sleeve or branch material is less-favorable than that of the pipe material (e.g., if the carbon equivalent is higher), non-conservative predictions for the heat input required to avoid hydrogen cracking can result.
- The only extensive validation trials that have been conducted to date are Δt_{8-5} predictions for sleeve-fillet welds with methane gas as the pipe contents. Inside surface temperature predictions were validated against Battelle model predictions for sleeve-fillet welds with methane gas as the pipe contents. A summary of these validation exercises is given in Appendix C.
- The use of this model is not a substitute for procedure qualification. The model provides guidance for establishing safe parameters, but provides no means for demonstrating that these parameters are practical under field conditions. To demonstrate that the parameters are practical, a welding procedure based on these predictions should be qualified under simulated conditions.[1]

Additional precautions and/or limitations may be added to this list in future versions of this users manual.

8.0 Example

The following examples are intended to demonstrate the use of the model. For these examples, fillet welds at the ends of a full-encirclement repair sleeve are required on a 16-in. (406-mm) diameter by 0.250-in. (6.4-mm) -thick pipeline composed of API Grade 5L X52 line pipe. The chemical composition of the pipe material is assumed to be that shown in Table 3. The sleeve material is assumed to be the same as the pipe material. The pipeline is transporting natural gas (consisting mostly of methane) at 600 psi (4.14 mPa), 10 ft/sec (3.0 m/sec), and 80°F (27°C). A qualified welding procedure is available for this application which uses low-hydrogen electrodes and covers a range of heat input levels.

Table 3. Pipe Material Chemical Composition for User Example 01

Element	Composition, wt %
	N5
C	0.21
Mn	1.20
P	0.011
S	0.009
Si	0.20
Cu	0.010
Ni	0.020
Cr	0.030
Mo	0.010
Al	0.054
V	0.000
Nb	0.000
N	0.000
B	0.000
CE_{IIW}	0.42

8.1 Chemical Composition Method Example

For this chemical composition method example, assume that details of the pipe material chemical composition are known or can be determined.

Begin by selecting New Project from the File pull down menu on the Menu Bar. Type a file name in the Project ID field, “userex01” for this example, and an optional description in the Title field, “User Example 01” for this example. Select Sleeve for the Geometry option and Gas for the Pipe Contents option. Click on the OK push button.

In the Pipe Joint data input panel, enter the parameters of interest, including the pipe material chemical composition shown in Table 3 by activating the push button labeled Max. Hardness. Closing the input panels by clicking on the OK push button will cause the data that was entered to be saved. When the required parameters on the Pipe Joint data input panel have been entered, click on the push button labeled “✔” to check that the value for each parameter entered falls within pre-defined limits. Click on the push button labeled Weld Conditions to proceed to the next data input panel.

In the Weld Conditions data input panel, enter the welding parameters for the cases of interest. For this example, assume that qualified welding procedure covers heat input levels ranging from 15 to 40 kJ/in. (0.6 to 1.6 kJ/mm), and that the welding parameters of interest include heat input levels of 15, 25, and 40 kJ/in. Begin by entering the welding parameters for a heat input of 15 kJ/in. Type a description of the weld in the Weld Description field, "Low HI" for this case. For this example, select Enter Heat Input as the Weld Options option. In the Welding Parameter section, enter the required parameters for a heat input of 15 kJ/in. For the second heat input levels in this example, select Duplicate Weld Condition from the Edit pull-down menu on the Menu Bar. Repeat this procedure for the third heat input level. Use the counter at the bottom of the panel to select the second case and change the description of the weld in the Weld Description field to "Medium HI" and the heat input to 25 kJ/in. in the Welding Parameter section. Repeat this process for the third case by changing the description of the weld to "High HI" and the heat input to 40 kJ/in. As an alternative to this duplicate-and-change procedure, the parameters for each individual case could have been entered individually. Click on the push button labeled "✔" for each case to check that the value for each parameter entered falls within pre-defined limits. Click on the push button labeled Pipe Contents to proceed to the next data input panel.

In the Pipe Contents data input panel, enter the parameters of interest. When the required parameters have been entered, click on the push button labeled "✔" to check that the value for each parameter entered falls within pre-defined limits. Closing any of the data input panels by clicking on the "✕" in the upper right-hand corner will cause the data that was entered to be saved.

To run the example, select the Analyze option from the pull-down menu under Compute on the Menu Bar. Select the file name userex01 from the list of existing files and click on the OK push button. A DOS screen will appear while the program is running, after which the results can be viewed in tabular form by clicking on the push button labeled OK. To evaluate the risk of burnthrough, the predicted inside surface temperatures can be compared to the limits described in Section 7.1. To evaluate the risk of hydrogen cracking, the resulting HAZ hardness can be compared to the critical hardness level shown in Figure 19, or an enhanced heat input selection curve can be plotted from which the required heat input can be determined.

To plot an enhanced heat input selection curve, select the Graph Results option from the pull-down menu under Compute on the Menu Bar. Select the file name userex01 from the list of existing files and click on the OK push button. The results will be exported to a MS Excel spreadsheet and graphed automatically. The resulting enhanced heat input selection curve for this example is shown in Figure 24. To determine the required heat input level, the critical hardness level for this material and a weld hydrogen level of < 4 ml/100 gm of deposited weld metal (properly treated low-hydrogen electrodes) is determined from Figure 19, which in this example is 400 HV. A corresponding Δt_{8-5} time is then determined from the Yurioka predictions for this material by constructing a horizontal line through this hardness level in the bottom part of the graph (4 sec). A vertical line is then constructed through the intersection of this line and the Yurioka prediction. A second horizontal line is then constructed through the intersection of this line and the heat input selection curve in the top part of the graph indicating the required heat input level (22 kJ/in.).

If the burnthrough risk for the required heat input is in question, another run of the model for this specific heat input level can be made to check burnthrough risk. Another run of the model can also be made for the flow conditions of interest to determine the predicted heat-sink capacity. The predicted heat-sink capacity can be used in the field to verify that the flow conditions that exist are close to those used for the predictions.

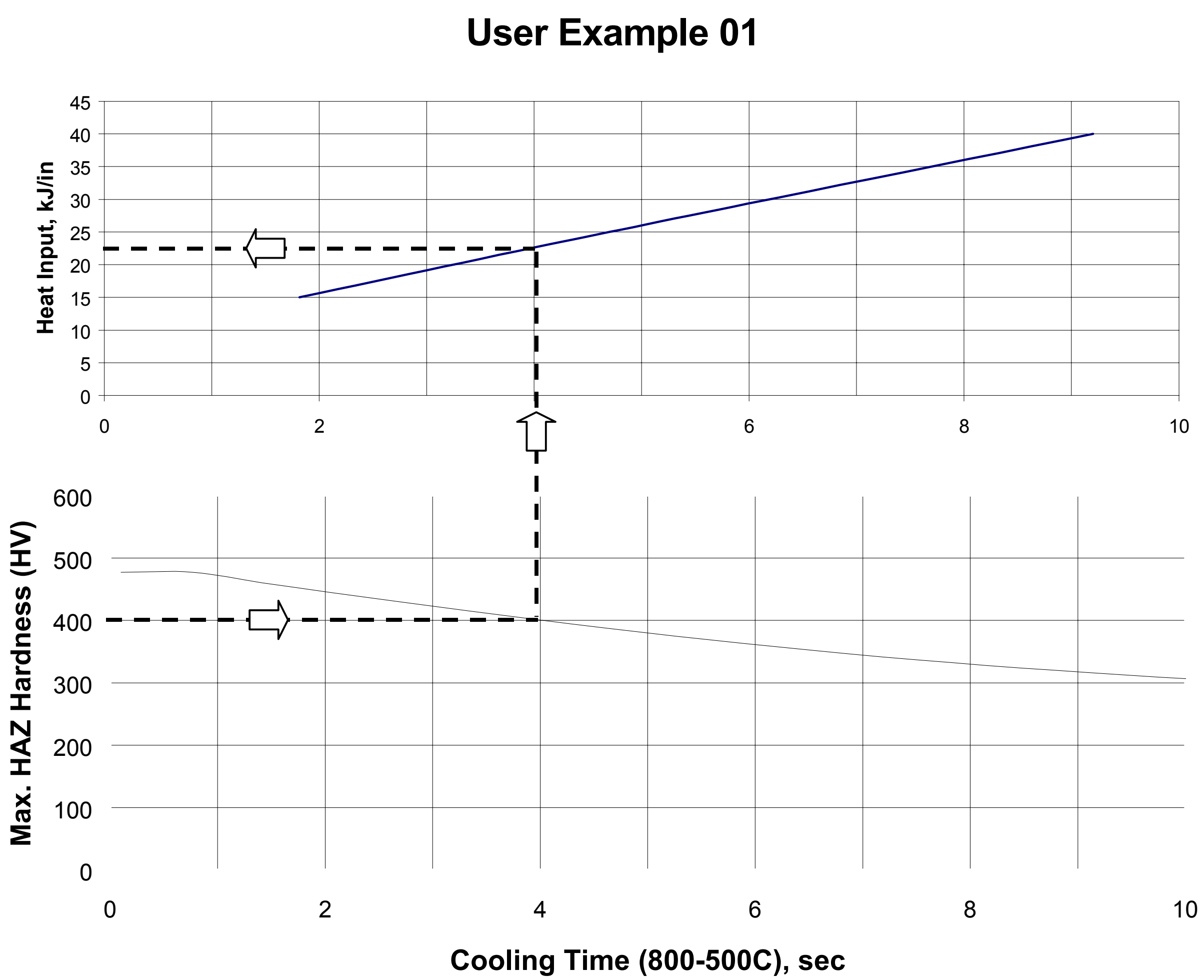


Figure 24. Enhanced Heat Input Selection Curve for User Example 01

8.2 Carbon Equivalent Method Example

For this carbon equivalent method example, assume that only the carbon equivalent of the pipe material is known or can be estimated, 0.42 CE_{IIW} in this case, and that details of the pipe material chemical composition are not known.

Data is entered exactly the same as it is for the Chemical Composition Method example except that, since details of the pipe material chemical composition are not known, there is no need to activate the push button labeled Max. Hardness on the Pipe Joint data input panel.

Running the model is also exactly the same as it is for the Chemical Composition Method example except that hardness predictions will not appear on the printed report. As with the Chemical Composition Method example, to evaluate the risk of burnthrough, the predicted inside surface temperatures can be compared to the limits described in Section 7.1. To evaluate the risk of hydrogen cracking, the predicted weld cooling rates and Δt_{8-5} times can be compared to those shown in Table 2, or a standard heat input selection curve can be plotted from which the required heat input can be determined.

Plotting the results are also exactly the same as it is for the Chemical Composition Method example except that Yurioka predictions will not appear in the heat input selection curve. The resulting standard heat input selection curve for this example is shown in Figure 25. To determine the required heat input level, the Δt_{8-5} time corresponding to the material of interest is determined from Table 2 (8 sec). A vertical line is then constructed through this Δt_{8-5} time. A horizontal line is then constructed through the intersection of this line and the heat input selection curve indicating the required heat input level (36 kJ/in.). As with the Chemical Composition Method example, if the burnthrough risk for this heat input is in question, another run of the model for this specific heat input level can be made.

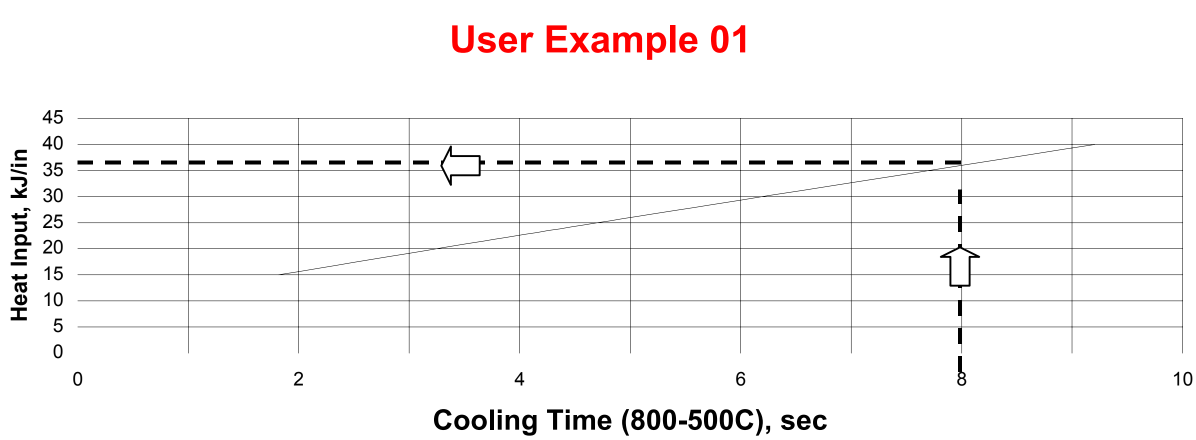


Figure 25. Standard Heat Input Selection Curve for User Example 01

The difference between the required heat input predicted by the chemical composition method (22 kJ/in.) and the carbon equivalent method (36 kJ/in.) results from the chemical composition method allowing higher hardness than the carbon equivalent method (400 vs. 350 HV) and the Yurioka algorithm being less conservative than Graville and Read criteria.

9.0 References

1. Bruce, W. A. and Threadgill, P. L., "Effect of Procedure Qualification Variables for Welding onto In-Service Pipelines," Final Report to A.G.A. Welding Supervisory Committee, Project PR-185-9329, EWI, Columbus, OH, July 21, 1994.

2. Kiefner, J. F. and Fischer, R. D., "Repair and Hot-Tap Welding on Pressurized Pipelines," Symposium during 11th Annual Energy Sources Technology Conference and Exhibition, New Orleans, LA, January 10-13, 1988.

3. Yurioka, N., "*Weldability of Offshore Structure Steels*", Evalmat '89, International Conference, Kobe, Japan, ISIJ, November 20-23, 1989.

4. Hart, P.H.M. and Matharu, I. S., "HAZ (HAZ) Hydrogen Cracking Behaviour of Low Carbon Equivalent C-Mn Structural Steels, TWI Research Report No. 290/1985, November 1985.

5. Bruce, W. A., "Qualification and Selection of Procedures for Welding onto In-Service Pipelines and Piping Systems," EWI Project No. J6176 to an international group of sponsors, Edison Welding Institute, Columbus, OH, January 1996.

6. Cola, M. J., Kiefner, J. F., Fischer, R. D., Jones, D. J., and Bruce, W. A., "Development of Simplified Weld Cooling Rate Models for In-Service Gas Pipelines," Project Report No. J7134 to A.G.A. Pipeline Research Committee, Edison Welding Institute, Kiefner and Associates and Battelle Columbus Division, Columbus, OH, July 1992.

7. Graville, B. A. and Read, J. A., *"Optimization of Fillet Weld Sizes"*, Welding Research Supplement, Welding Journal, April 1974.

Appendix A

History of Cooling Rate Prediction Methods for Welds Made onto In-Service Pipelines

History of Cooling Rate Prediction Methods for Welds Made onto In-Service Pipelines

A1.0 Existing Battelle Model

A major advancement in in-service welding technology was the development of a thermal analysis model for predicting burnthrough and hydrogen cracking risk for welds made onto in-service pipelines.[A-1] The model, which was developed by Battelle beginning in the late 1970s, uses two-dimensional numerical solutions of heat-transfer equations to predict inside surface temperatures and cooling rates for single-pass fillet welds at the end of a sleeve or a branch-to-carrier pipe groove weld. The model allows burnthrough risk to be controlled by limiting inside surface temperature and hydrogen cracking risk to be controlled by limiting weld cooling rates.

The original Battelle model was developed for main-frame computers and was implemented by only a handful of companies. Delivery of the original Battelle model was either by reel-to-reel magnetic tape or three boxes of computer cards. To simplify the use of the original model, Columbia Gas developed a compendium of results in the form of tables and graphs.[A-2] Beginning in 1989, Battelle and EWI worked together to further develop the Battelle model.[A-3] This further development included refinement, further validation, and adapting the model so that it could be used on a personal computer (PC).

Some significant results were generated from this early work at Battelle. Regarding the risk of burnthrough, use of the Battelle model was able to show that burnthrough is unlikely if the wall thickness is 0.250 in. (6.4 mm) or greater, provided that low-hydrogen electrodes and normal welding practices are used,[A-4] and that the effect of pressure on burnthrough risk is secondary, since the size of the heated area is small. Regarding the risk of hydrogen cracking, the Battelle model allowed welding parameters (i.e., required heat input levels) to be chosen based on anticipated weld cooling rates. Experiments by Battelle were also able to draw attention to the fact that the use of low-hydrogen electrodes significantly reduces hydrogen cracking risk. Prior to this, it was common for cellulosic-coated electrodes to be used for in-service welding, and a number of significant incidents occurred as a result.[A-5-A-6]

2.0 Heat-Sink Capacity Method

A second method for predicting required heat input levels was developed concurrently at EWI[A-7] and involves measuring the ability of the flowing contents to remove heat from the pipe wall using a simple field test (Figure A1). This test involves quickly heating a 2-in. (50-mm) - diameter area on the pipeline with an oxy-fuel torch to between 300 and 325°C. The time required for the area to cool from 250 to 100°C is then measured using a digital contact thermometer and a stopwatch. Six heat-sink capacity measurement trials are made and the average calculated. The average value is referred to as the heat-sink capacity of the pipeline. The heat-sink capacity value is used to predict the weld cooling rates using empirical relationships that were developed from data generated in the field and in the laboratory for a wide range of conditions.

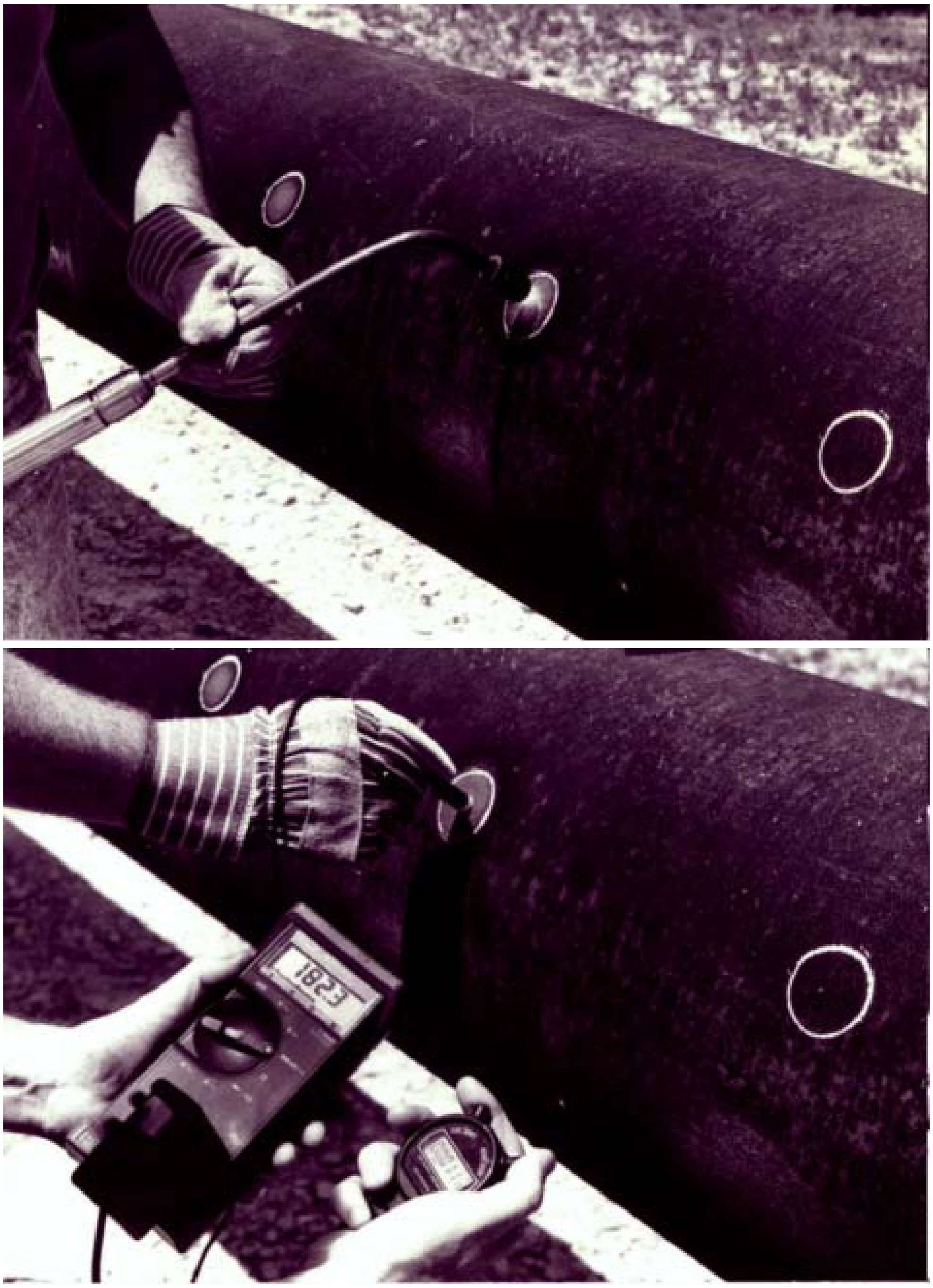


Figure A1. **Heat-Sink Capacity Measurement**

With both of these methods, the predicted weld cooling rate is reported as a function of heat input for a given set of pipeline operating conditions (Figure A2). Limits on the weld cooling rates are established based on the maximum tolerable HAZ hardness predicted using previously-established empirical correlations(A-8) and the anticipated carbon equivalent of the pipe material. Both of these methods allow welding parameters (i.e., heat input levels) to be selected based on anticipated weld cooling rates.

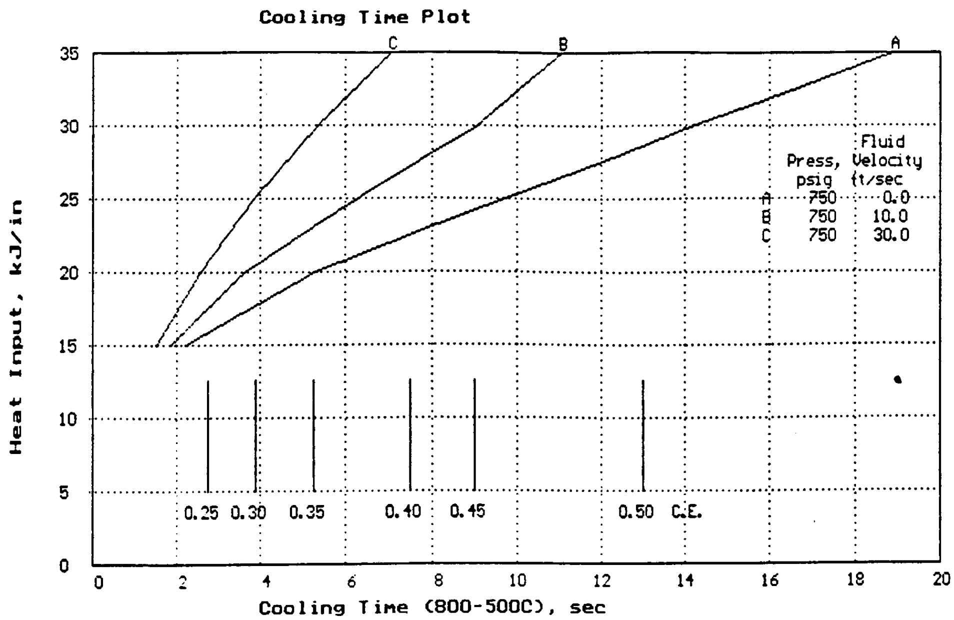


Figure A2. Example of Battelle Model-Produced Heat Input Selection Curve

A3.0 Shortcomings of Existing Methods

The Battelle model, while having served the industry well, has a number of shortcomings. First, the finite-element meshes that are used by the model have a fixed number of elements, so when the thickness of the materials of interest increases, the mesh becomes unacceptably coarse. This effect begins to occur at thicknesses of about 0.5 in. (12.7 mm) or so. Since burnthrough risk is negligible for pipe wall thickness of 0.25 in. (6.4 mm) and greater, this does not affect the burnthrough risk prediction capabilities of the model. In terms of weld cooling rates, however, an unacceptably coarse finite-element mesh produces results that are very conservative with regard to hydrogen cracking risk.(A-9)

The second shortcoming of the Battelle model is the way in which hydrogen cracking risk is predicted from weld cooling rate predictions. For an individual run, the model uses the predicted weld cooling rate to identify a material carbon equivalent for which welds made under the conditions of interest will have a HAZ hardness less than a fixed value of 350 HV. This may be very conservative for some applications and non-conservative for others. The third shortcoming of the Battelle model is that its user friendliness leaves a lot to be desired.

A4.0 PRCI Thermal Analysis Model for Hot-Tap Welding

The PRCI Thermal Analysis Model for Hot-Tap Welding[A-10] is Windows-based and takes advantage of advancements in PC hardware technology (e.g., processor speed, user friendliness, etc.). The model uses a proprietary finite-element solver that was developed at EWI. Mesh generation capabilities include sleeve, branch, and bead-on-pipe geometries (the latter for buttering layers and weld deposition repairs). Heat-sink capacity values can also be predicted for comparison with field-measured values. The user interface uses Microsoft Access and allows multiple cases to be run and heat input selection curves to be generated. The model runs individual cases in about 20 sec on a PC with a Pentium II, 350 MHz processor.

A5.0 References

A1. Kiefner, J. F., Fischer, R. D., and Mishler, H. W., "Development of Guidelines for Repair and Hot-Tap Welding on Pressurized Pipelines," Final Report - Phase 1, to Repair and Hot-Tap Welding Group, Battelle Columbus Division, Columbus, OH, September 1981.

A2. Shapiro, D. E., “Guidelines for Hot Tapping Pressurized Pipelines,” Research Report, Columbia Gas System Service Corporation Research Department, Columbus, OH, April 1984.

A3. Bubenik, T. A., Fischer, R. D., Whitacre, G. R., Jones, D. J., Kiefner, J. F., Cola, M. J., and Bruce, W. A., "Investigation and Prediction of Cooling Rates During Pipeline Maintenance Welding," Final Report to American Petroleum Institute, December 1991.

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A5. National Energy Board (Canada), "In the Matter of an Accident on 19 February 1985 near Camrose, Alberta, on the Pipeline System of Interprovincial Pipe Line Limited," National Energy Board Report, June 1986.

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A7. Cola, M. J., Kiefner, J. F., Fischer, R. D., Jones, D. J., and Bruce, W. A., "Development of Simplified Weld Cooling Rate Models for In-Service Gas Pipelines," Project Report No. J7134 to A.G.A. Pipeline Research Committee, Edison Welding Institute, Kiefner and Associates and Battelle Columbus Division, Columbus, OH, July 1992.

A8. Graville, B. A. and Read, J. A., "*Optimization of Fillet Weld Sizes*," Welding Research Supplement, Welding Journal, April 1974.

A9. Kiefner, J. F. and Fischer, R. D., "*Models Aid Pipeline Repair Welding Procedure*," Oil & Gas Journal, March 7, 1988.

A10. Bruce, W. A., Li, V., Citterberg, R., Wang, Y.-Y., and Chen, Y., "Improved Cooling Rate Model for Welding on In-Service Pipelines," PRCI Contract No. PR-185-9633, EWI Project No. 42508CAP, Edison Welding Institute, Columbus, OH.

Appendix B

Heat-Sink Capacity Measurement Procedure

Heat-Sink-Capacity Measurement Procedure

Equipment Required:

- Chalk or soap stone
- Oxy-acetylene torch with "rosebud" tip
- Digital contact thermometer
- Stopwatch.

Procedure:

1. Determine the direction of fluid flow.

2. Using chalk or soap stone, scribe three 2-in.-diameter circles (approximately 12-in. apart) on both sides of the pipe.

3. Starting with the downstream circle, use the gas torch to quickly heat the entire region to 300°C (572°F) using a circular motion. The maximum temperature should not exceed 325°C (617°F).

4. After attaining a temperature of between 300 and 325°C (572 and 617°F), remove the torch and apply the contact thermometer to the center of the circle.

5. While holding the thermometer in contact with the pipe, using a stopwatch, measure and record the time required to cool from 250 to 100°C (482 to 212°F).

6. Repeat Steps 3, 4, and 5 on the next untested upstream circle on the opposite side of the pipe. If the pipe is still warm from the previous measurements, wait until normal temperatures are restored.

Once the measurements are complete, calculate an average time from the recorded readings.

Appendix C

Validation Data for PRCI Thermal Analysis Model for Hot-Tap Welding

Validation Data for PRCI Thermal Analysis Model for Hot-Tap Welding

C1.0 Introduction

The PRCI Thermal Analysis Model for Hot-Tap Welding was validated my comparing model predictions to experimental data generated during a previous PRCI-sponsored program at EWI and to predictions made using the existing Battelle model.(C-1) Examples from this validation exercise are given in the following sections.

C2.0 Validation Data

C2.1 Cooling Rate Prediction Capability

The cooling rate prediction capability of the PRCI model was validated using data generated during a previous PRCI-sponsored program at EWI.(C-2) During this program, weld cooling rate data was collected over a wide range of wall thicknesses, natural gas flow rates, and welding heat inputs. This data was compared to predictions made using the PRCI model and the existing Battelle model. Examples of the results are shown in Figures 1 through 4. The results indicate that Battelle model predictions tend to be non-conservative for thin-wall materials, particularly at low flow rates, and very conservative for thick-wall materials. The PRCI model predictions tend to be relatively accurate, with a consistent level of conservatism across wall thickness range.

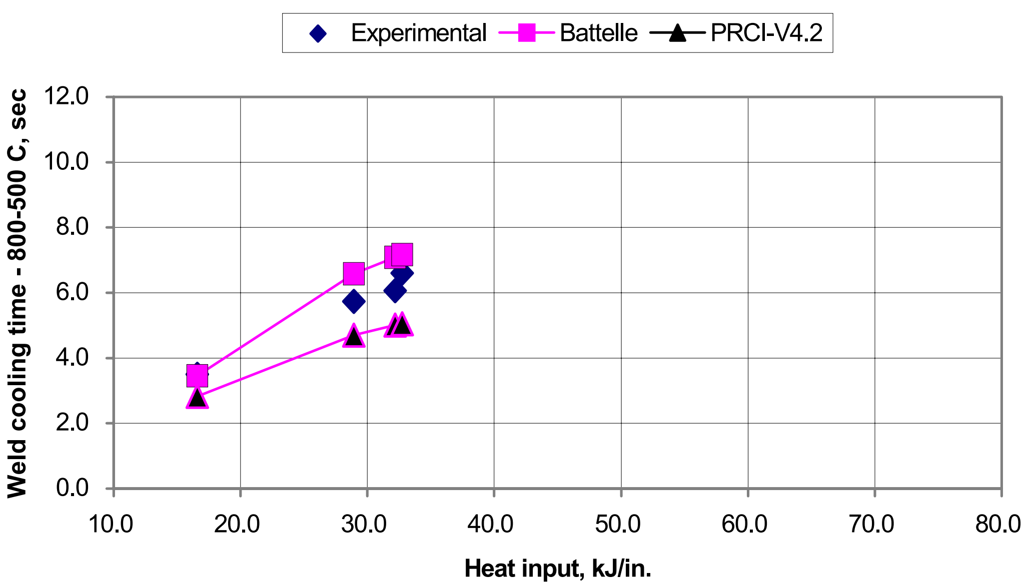

Figure C1. Example of Validation Data for PRCI and Battelle Model Cooling Rate Prediction Capibility for 0.188-in. (4.8-mm) -Thick Sleeve-Fillet Welds

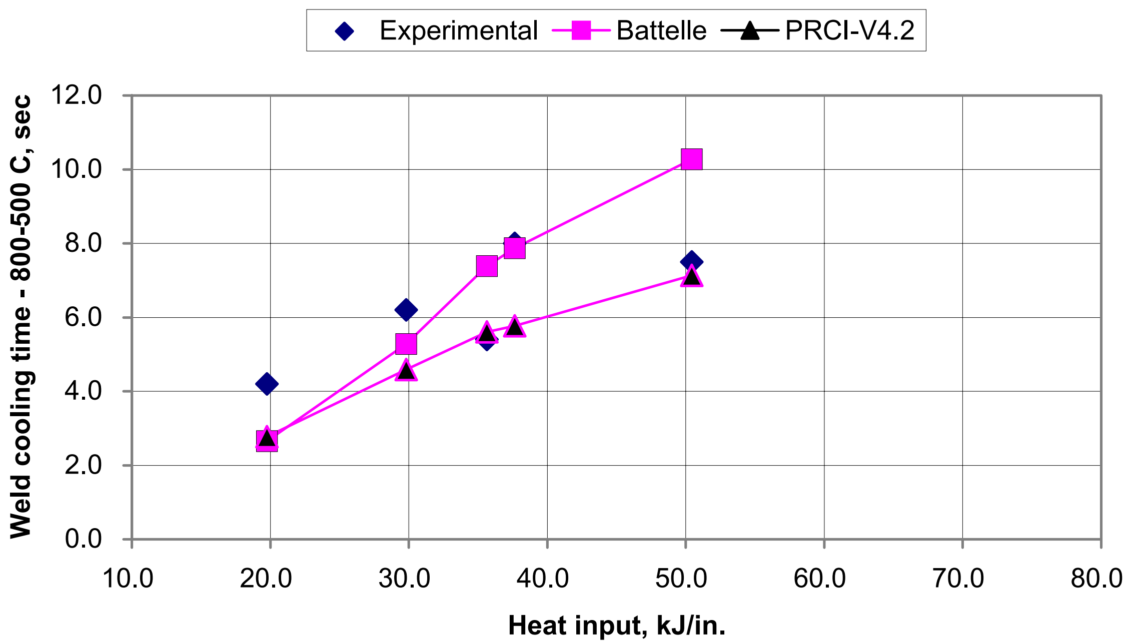

Figure C2. **Example of Validation Data for PRCI and Battelle Model Cooling Rate Prediction Capibility for 0.250-in. (6.4-mm) -Thick Sleeve-Fillet Welds**

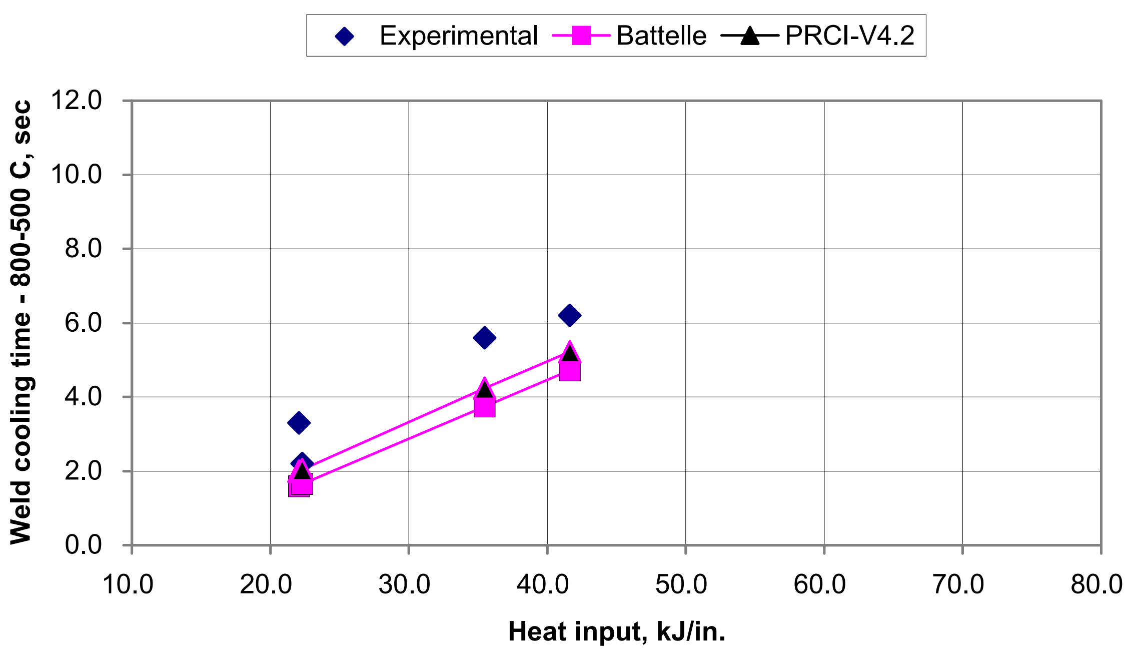

Figure C3. **Example of Validation Data for PRCI and Battelle Model Cooling Rate Prediction Capibility for 0.365-in. (9.3-mm) -Thick Sleeve-Fillet Welds**

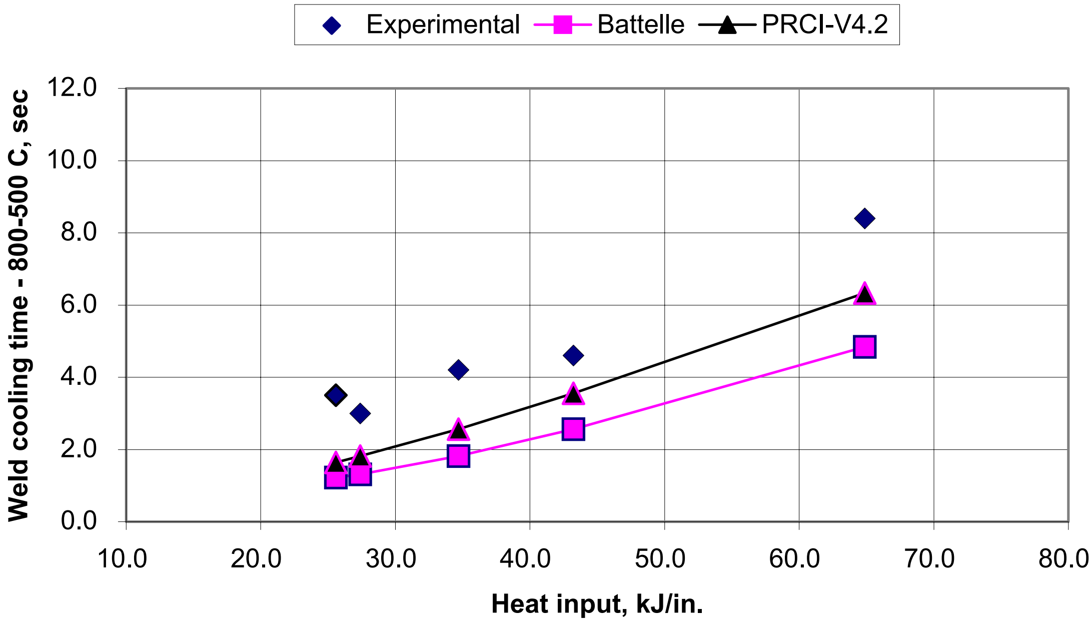

Figure C4. Example of Validation Data for PRCI and Battelle Model Cooling Rate Prediction Capibility for 0.594-in. (15.1-mm) -Thick Sleeve-Fillet Welds

C2.2 Burnthrough Prediction Capability

Since there is no comprehensive validation data for inside surface temperature, PRCI model predictions were compared to predictions made using the existing Battelle model for the conditions described above. Examples of the results are shown in Figures C5 through C8. The results indicate that, provided that the user enters a value for heat input only (i.e., allows the software select specific values for welding current, voltage, and travel speed according to the preset algorithm), the PRCI model predictions are nearly the same as Battelle model predictions. For thin-wall materials, the PRCI model predicts slightly higher inside surface temperatures than the Battelle model. If the user enters specific values for welding current, voltage, and travel speed, the PRCI model is be able to predict the effect of current level (electrode size) on burnthrough risk that was discovered during another previous PRCI-sponsored program at EWI.(15)

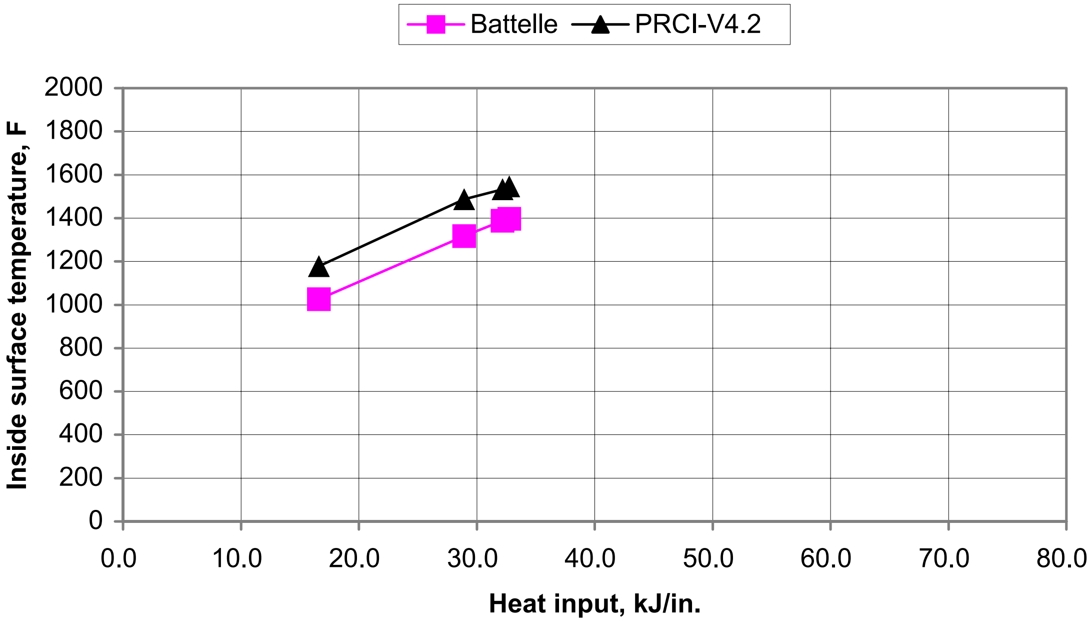

Figure C5. Example of Comparison Between PRCI and Battelle Model Inside Surface Temperature Prediction Capibility for 0.188-in. (4.8-mm) -Thick Sleeve-Fillet Welds

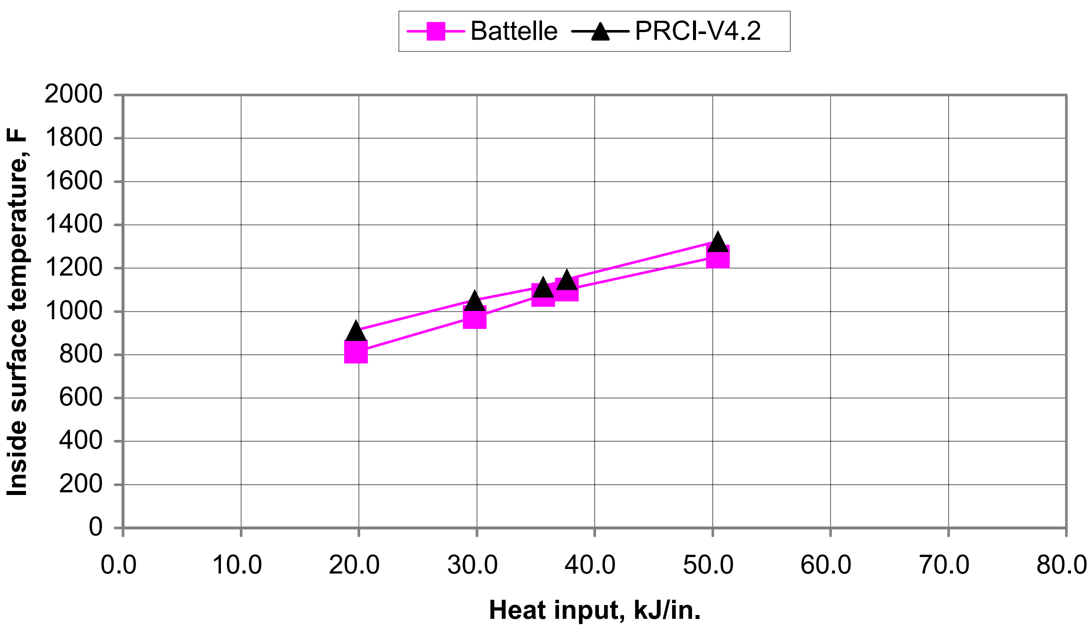

Figure C6. Example of Comparison Between PRCI and Battelle Model Inside Surface Temperature Prediction Capibility for 0.250-in. (6.4-mm) -Thick Sleeve-Fillet Welds

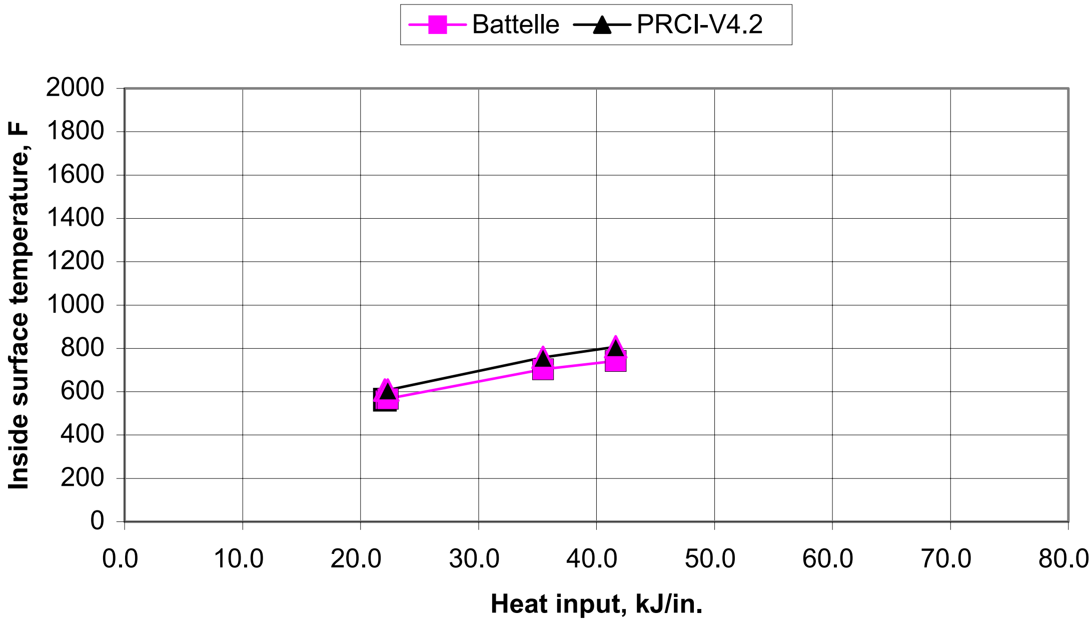

Figure C7. **Example of Comparison Between PRCI and Battelle Model Inside Surface Temperature Prediction Capibility for 0.365-in. (9.3-mm) -Thick Sleeve-Fillet Welds**

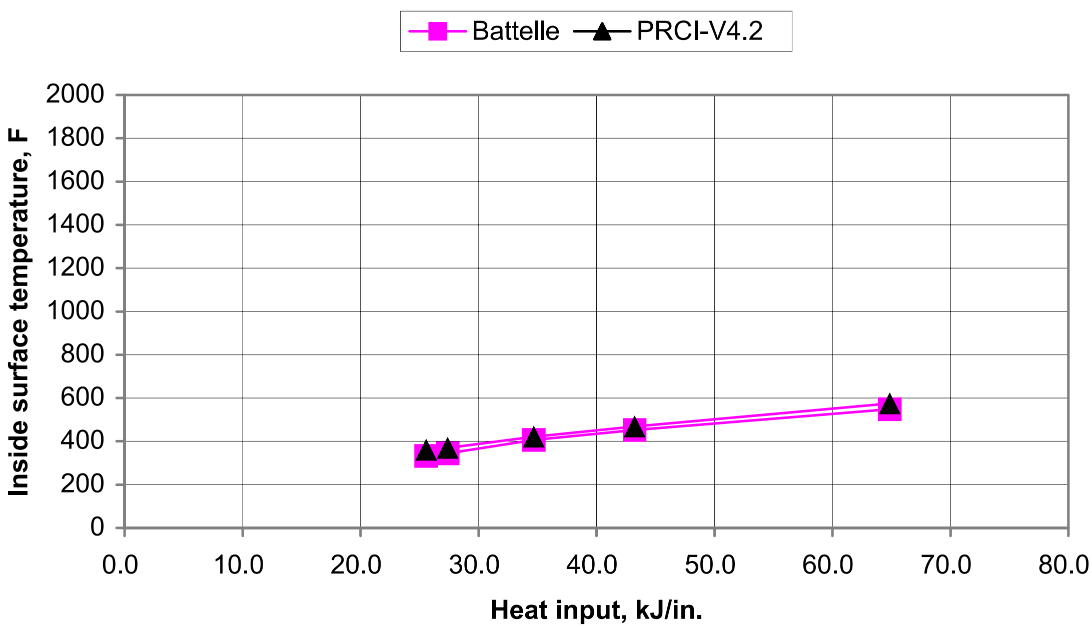

Figure C8. **Example of Comparison Between PRCI and Battelle Model Inside Surface Temperature Prediction Capibility for 0.594-in. (15.1-mm) -Thick Sleeve-Fillet Welds**

C3.0 References

C-1. Cola, M. J., Kiefner, J. F., Fischer, R. D., Jones, D. J., and Bruce, W. A., "Development of Simplified Weld Cooling Rate Models for In-Service Gas Pipelines," Project Report No. J7134 to A.G.A. Pipeline Research Committee, Edison Welding Institute, Kiefner and Associates and Battelle Columbus Division, Columbus, OH, July 1992.

C-2. Bruce, W. A. and Threadgill, P. L., "Evaluation of the Effect of Procedure Qualification Variables for Welding onto In-Service Pipelines," Final Report to A.G.A. Pipeline Research Committee for PR-185-9329, EWI Project No. J7141, Edison Welding Institute, Columbus, OH, July 1994.