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User Manual for SPLASH (Single Panel Lamp and Shroud Helper)

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Abstract

The radiant heat test facility develops test sets providing well-characterized thermal environments, often representing fires. Many of the components and procedures have become standardized to such an extent that the development of a specialized design tool to determine optimal configurations for radiant heat experiments was appropriate. SPLASH (Single Panel Lamp and Shroud Helper) is that tool. SPLASH is implemented as a user-friendly, Windows-based program that allows a designer to describe a test setup in terms of parameters such as number of lamps, power, position, and separation distance. This document is a user manual for that software. Any incidental descriptions of theory are only for the purpose of defining the model inputs. The theory for the underlying model is described in SAND2005-2947 (Ref. [1]).

SPLASH provides a graphical user interface to define lamp panel and shroud designs parametrically, solves the resulting radiation enclosure problem for up to 2500 surfaces, and provides post-processing to facilitate understanding and documentation of analyzed designs.

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Nomenclature

$e(t)$	Temperature control error
C_p	Specific heat (J/kg/K)
F	Fraction of available heater power applied
GUI	Graphical User Interface
k	Thermal conductivity (W/m/K)
PID	Proportional Integral Differential
P,**I**,**D**	Constants weighting relative importance of conditioned error indicators in PID algorithm
rms	Root mean square
t	Time (s)
T	Temperature (K)
x, y, z	Directions in 3-space. In SPLASH z is perpendicular to the shroud, x runs parallel to lamps, and y is parallel to the length of the lamp panel.
Windows	An operating system ©Microsoft Corporation.
ε	emissivity

1 Introduction

1.1 Background

Sandia's Radiant Heat Facility makes extensive use of high power lamps to generate fire-simulating, controlled boundary conditions for thermally challenging tests. A particular panel design (Ref. [2]), accommodates up to 63 lamps. A test configuration utilizing the panel is shown in Figure 1. The panel can be configured with any subset of the lamp slots occupied to tailor a desired heating effect. Since all of the lamps in a panel are energized by the same electrical bus, each operates at the same power level. An inconel shroud is usually used between the lamps and the test object. In these cases the goal is to provide a uniform (or least well characterized) shroud temperature which is "seen" by the test object and understood by modelers so that analysis methods can be developed and validated. The panel is versatile and has been used at the facility in many different test configurations. In some large test configurations it is necessary to utilize multiple panels. However, many experimental arrangements are accommodated using a single panel. As many of the components and implementation practices have become standardized, it was desirable and practical to develop an easy-to-use model to approximately predict expected performance for proposed lamp and shroud geometries. SPLASH (Single Panel Lamp and Shroud Helper) is the resultant model.

The SPLASH software is a Windows application with a Graphical User Interface (GUI). SPLASH's GUI provides error checking and contemporary GUI widgets to facilitate the accurate and complete specification of component properties needed to define a lamp and panel test set up. In addition to guiding model quantitative input, SPLASH renders graphical views of the test setup and resulting predictions.

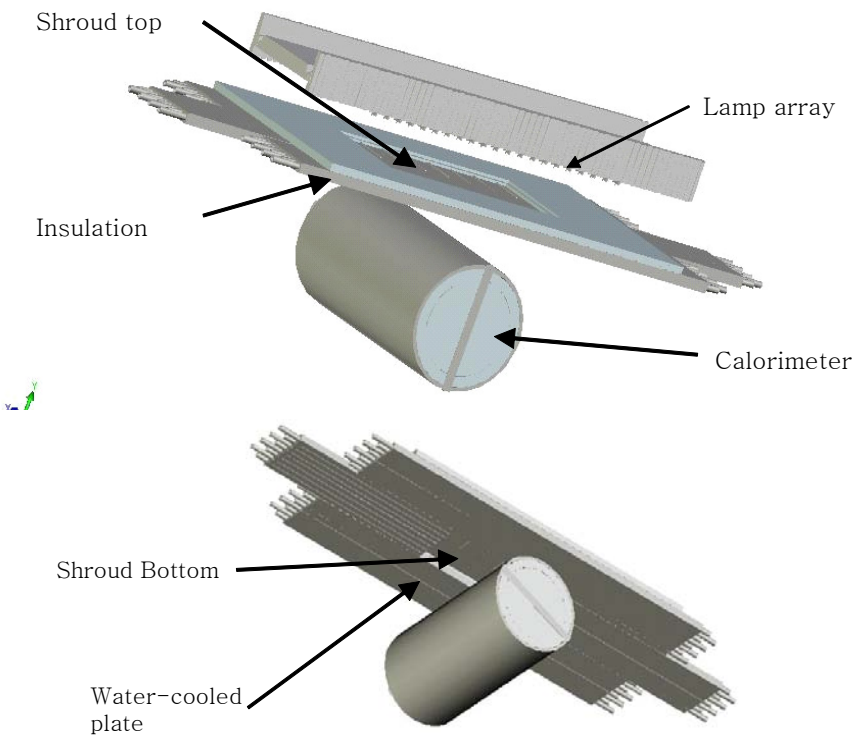


Figure 1: Schematic views of a typical single panel lamp and shroud test set.

Figure 2 shows a schematic view describing differences between the actual hardware and the geometry modeled in SPLASH for a system including a shroud. The left part of the figure is representative of a section through the middle of the test set and perpendicular to the quartz lamps (circular lamp cross-sections are shown). In actual systems the upper cooled plate is the lamp panel. The lower cooled plate supporting insulation and the shroud may have a circular or rectangular opening defining the hot spot that irradiates the test object.

The right hand side of Figure 2 shows the geometry idealizations that are accepted to facilitate the model implementation. As shown, the lamps are replaced by flat strips in the same plane as the bottom of the cooling plate. Also shown on the right hand side of Figure 2 are symbols representing the most important physical properties of the system. $T(t)$ represents a ramp-up-and-hold temperature schedule that is a model input.

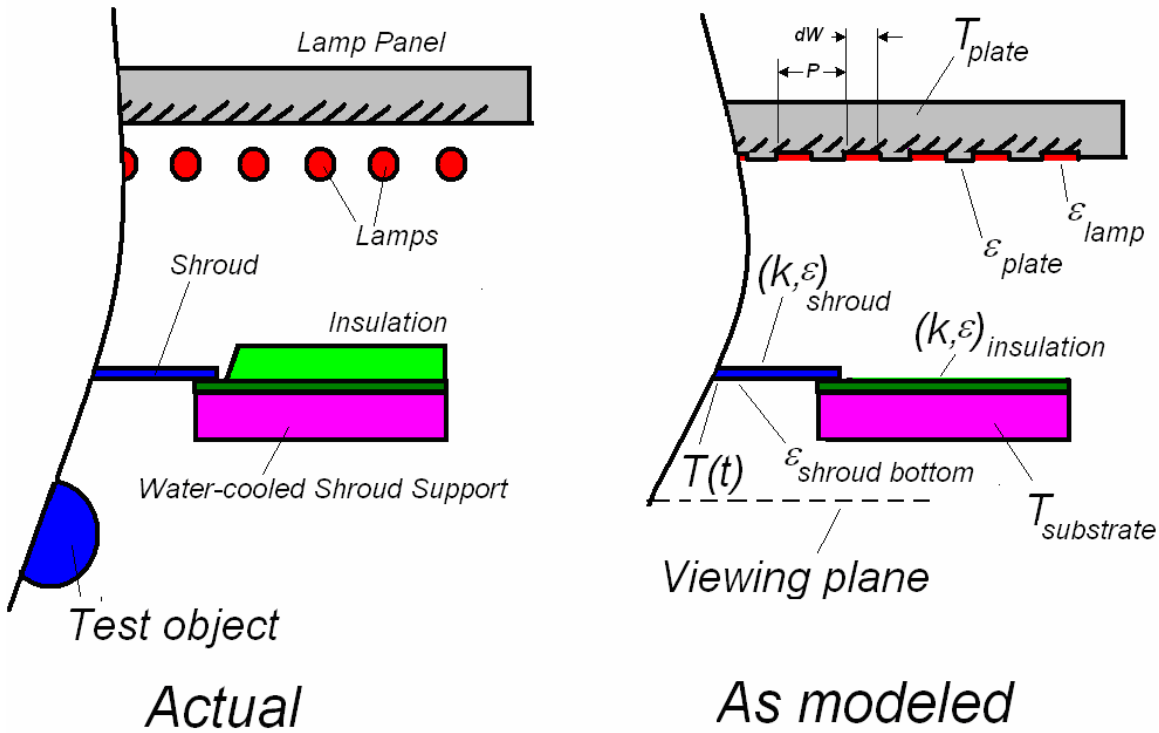


Figure 2: SPLASH schematic representation.

1.2 How this Manual is Organized

This document describes use of the software. Readers interested in the underlying theory are referred to SAND2005-2947 (Ref. [1]). **SPLASH** supports two primary modes of operation: 1) **Shroud Mode**; the nominal setup as shown in Figure 1 in which a defined series of lamps illuminates the backside of a shroud and 2) **Aperture Mode**; which is a no-**Shroud Mode** of operation. Many of the same features and model components are present in both modes. **Shroud Mode** was the first development, is the richest in terms of required inputs, and the default mode which is presumed to be **SPLASH**'s primary mode of use. The following section follows through the use of **SPLASH** from problem specification to post-processing in **Shroud Mode**. Section 3 parallels the next section describing differences in operation associated with **Aperture Mode**.

While this is not a theory manual, in presenting the GUI controls, technical guidance that is expected to be useful is presented in context as each user interface component is discussed. Text in the **SPLASH** application is in the **Arial Font**. From this section forward this document's references to keywords found in the application are presented in bold **Arial Font**.

1.3 Installing and Starting SPLASH

SPLASH is simple in the sense of being part of a Windows-based computing platform. The entire program is contained within the `SPLASH.EXE` file. No modifications are made to the Windows registry. Installing is as simple as copying `SPLASH.EXE` to the computer. Thereafter, the program can executed as any Windows executable.

2 SPLASH in Shroud Mode

2.1 SPLASH Overview, Shroud Mode

SPLASH provides a graphical user interface to facilitate the following activities:

- **Case editing:** Editable fields are the most common control and the means used to communicate numerical values specifying the problem definition. Other controls that provide discrete choices are sometimes used.
- **Input screening:** When edit fields are read by the program to determine problem specification the associated values are screened in varying levels. When input is not decipherable as a numerical value or the value is out of range, the problem is identified for the user.
- **Numerical solution:** When a suitable problem specification exists, the code will render numerical solutions. Solution progress is monitored and the process can be interrupted by the user.
- **Post-processing and documentation**: **SPLASH** integrates graphical interpretation of the system specified and resulting temperature distributions. Text output is also available. Case files can be saved, reloaded and edited to facilitate project development.

SPLASH was programmed in the DELPHI programming language (Ref. [3]) which provides a range of GUI components familiar to Windows users. The application is a single document interface—it always runs within a single window. It is probably possible to crash **SPLASH**, but the code is fairly robust. since it does a fair amount input screening.

Figure 3 shows **SPLASH**'s opening screen. Seven main level tabs are presented which are labeled **Geometry**, **Temps/Props**, **Text Output**, **Visualizer**, **Plot**, **Notes**, and **About**. These tabs are ordered logically so that an analysis might be accomplished by working through the tabs from left to right. Generally, these tabs expose controls appropriate to their corresponding activities.

The following subsections describe the features and use of each of the main tabs, in order, for use in **Shroud Mode**. The next major section of this manual includes parallel sub-sections addressing differences that occur when operating in **Aperture Mode**.

One control to be discussed before describing the tabs is the **File** menu. The **File** menu presents familiar **Open** and **Save** options. The **File** menu is accessible with any of the tabs active. Executing **File|Save** provides a Windows-familiar **SaveAs** dialogue and writes the current state of all editable **SPLASH** controls to a file. This includes the property of page control, indicating which page is currently active. That is, if **File|Save** is executed from the **About** tab, **File|Open**ing that same file will populate all of the editable features and open **SPLASH** to the **About** tab. **SPLASH** files have a SPL extension by default but this can be overridden by explicitly typing another extension. The file's content is a superset of the necessary content for either **Shroud Mode** or **Aperture Mode**. Calculated results are not saved in this manner but may be recalculated from the documented state of **SPLASH**.

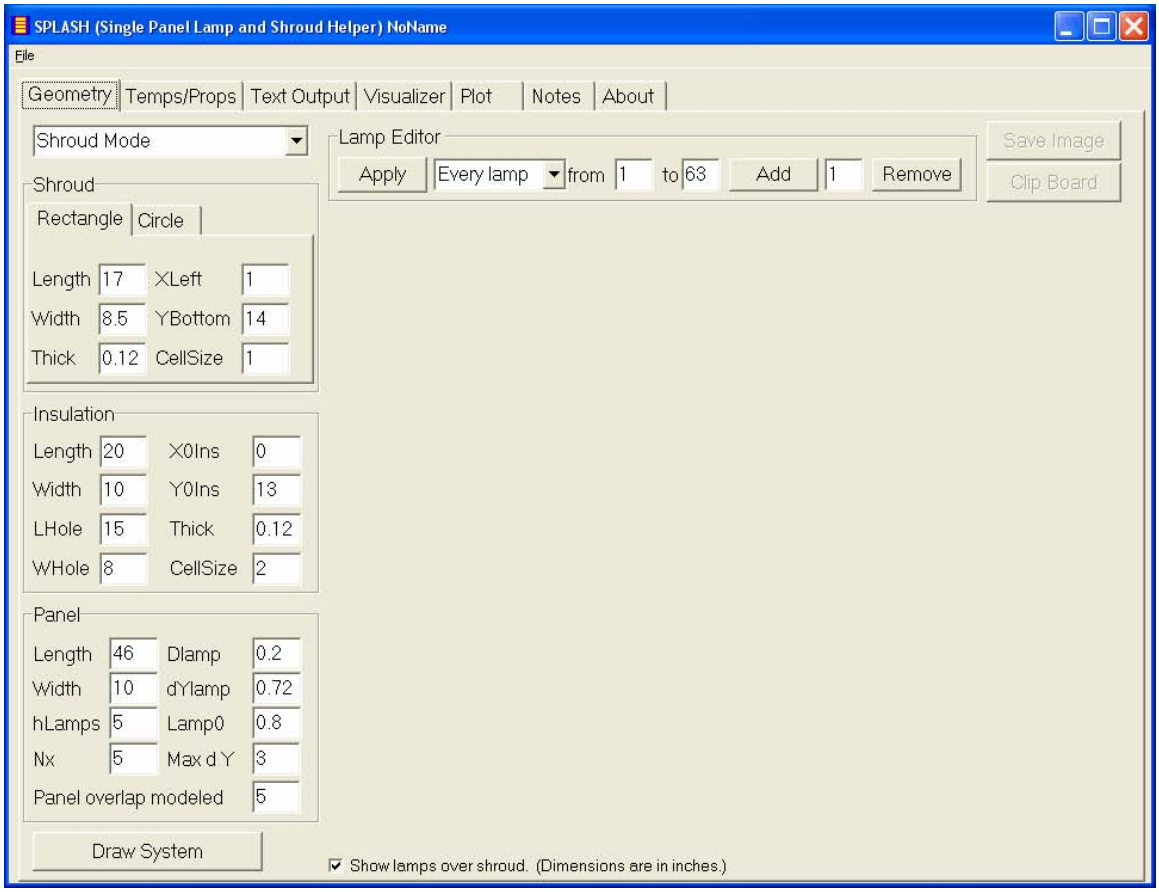


Figure 3: SPLASH's opening view (Geometry tab).

2.2 Geometry

The **Geometry** tab panel is shown for **SHROUD MODE** in Figure 3. Regions of that input screen are discussed in the following minor sections. All of the dimensions specified on the **Geometry** tab are in inches. The calculated quantities reported later will be in SI units. These mixed units are purposefully retained as the units most prevalent in the activities of test set up (inches) and subsequent analyses (SI). After these inputs are described the behaviors of the panel's buttons and resulting graphics are discussed. Figure 4 is a composite sketch produced by choosing elements of the **Geometry** tab schematics for rectangular and circular shroud geometries. Several key features are labeled for reference in the following descriptions.

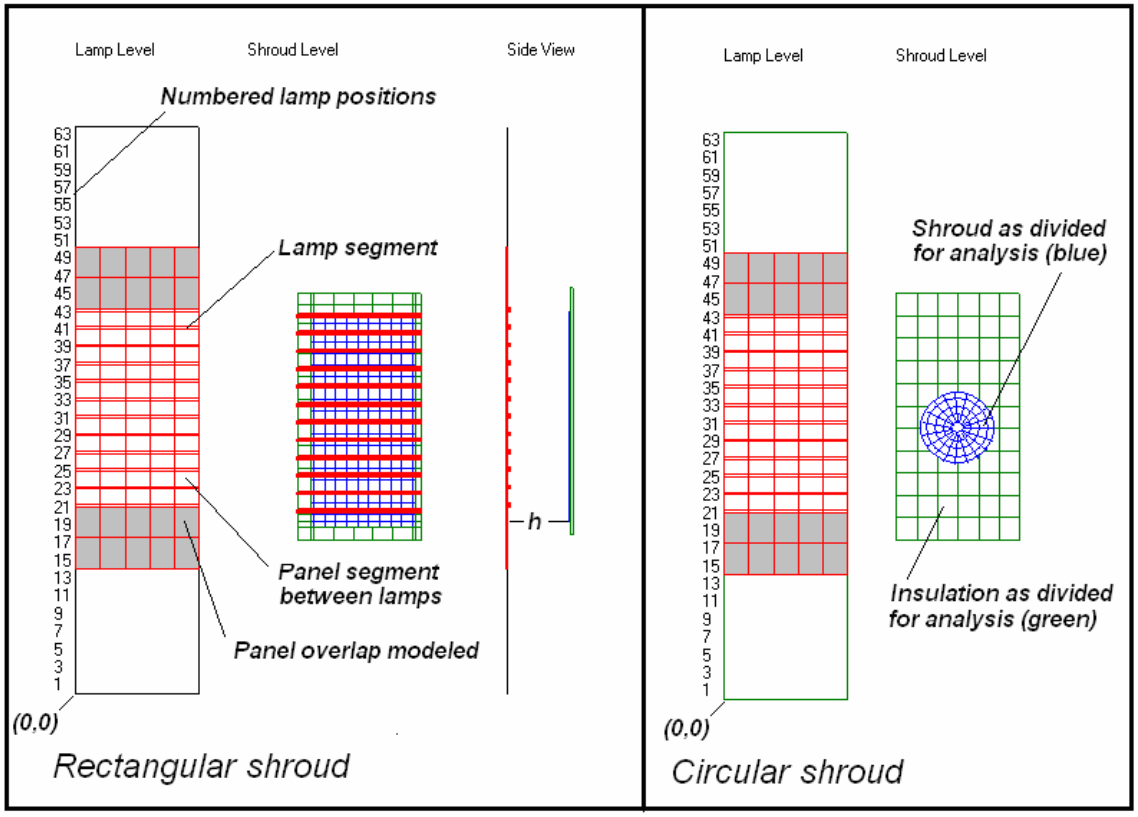
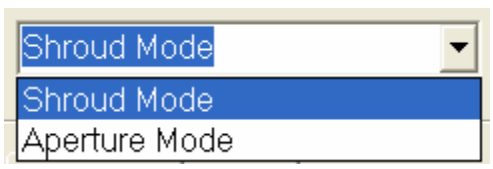


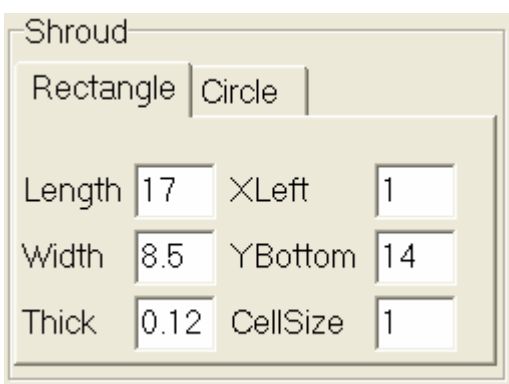
Figure 4: Embellished composite sketch produced on Geometry tab.

2.2.1 Mode selection



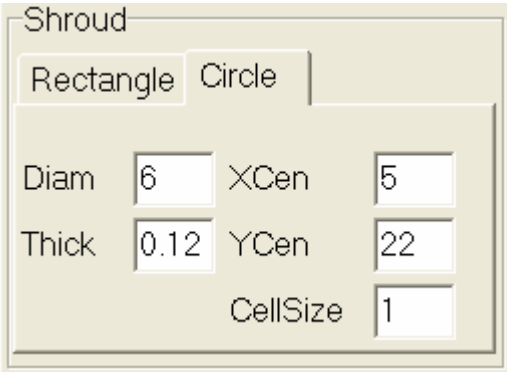
The mode selection combination box defaults to **Shroud Mode**. Mode selection should be the first choice made for a new case because it modifies the GUI to solicit subsequent inputs for the mode of analysis chosen. For example, on the **Geometry** tab the field for shroud thickness disappears if **Aperture Mode** has been selected.

2.2.2 Shroud



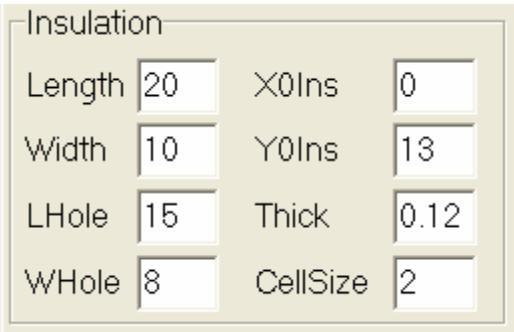
The **Shroud** group includes a tab control to choose whether the shroud is rectangular or circular. At left the rectangular tab is active. There are six dimensions associated which correspond to the length, width, and thickness of the shroud; the x- and y-coordinates of the bottom left corner of the shroud relative to (0,0) which is the bottom left corner of the lamp panel (as presented in plan view); and a cell size. The cell size is the maximum dimension allowed for the sub-elements that will

represent the shroud in the analysis. In Figure 4, the grid for the shroud interior is chosen with the smallest number of cells in each direction that result in cells not larger than the specification on this panel. **SPLASH** requires that the shroud be at least large enough to wholly cover the hole specified for the insulation. The shroud is always centered over that hole and the analysis defines elements in both the shroud and the insulation in the overlapping area. Consequently, regardless the value of cell size, there is always at least one row of elements around the perimeter of the shroud representing this area. In Figure 4 this row (and/or column) of elements is apparent as high aspect ratio elements around the rectangular shroud perimeter.

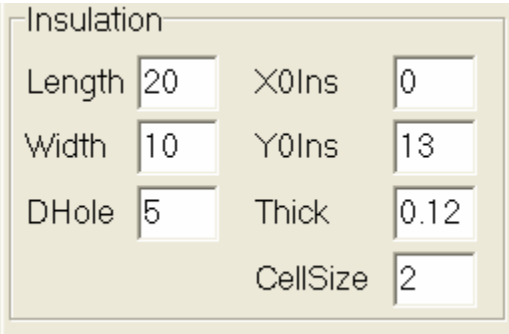


At left the **Shroud** group is shown with the Circular shroud selected. There are five dimensions associated which correspond to the diameter and thickness of the shroud; the x- and y-coordinates of the center of the shroud relative to (0,0) which is the bottom left corner of the lamp panel; and a cell-size. The circular shroud is always gridded with a round element in its center. The number of radial and azimuthal divisions are chosen to avoid exceeding the cell size limit. As with the rectangular geometry, the shroud is centered over the hole through the insulation and there is always at least one ring of elements around the perimeter of the shroud that describe the area of shroud and insulation overlap.

2.2.3 Insulation



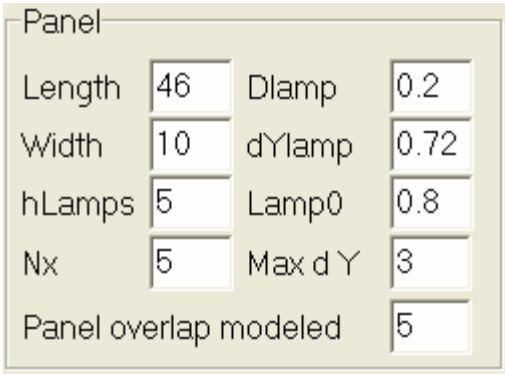
The **Insulation** group shown at left corresponds to the rectangular geometry. There are eight dimensions associated which correspond to the length, width, and thickness of the insulation; the x- and y-coordinates of the bottom left corner of the insulation relative to (0,0), which is the bottom left corner of the lamp panel; a cell-size; and the length and width of the rectangular hole centered under the shroud. The cell size is the maximum dimension allowed for the sub-elements that will represent the insulation in the analysis. As discussed in the shroud geometry, at least one row of elements around the perimeter of the shroud describes the area where the shroud and insulation overlap.



The **Insulation** group shown at left corresponds to the circular geometry. There are seven dimensions associated which correspond to the length, width, and thickness of the insulation; the x- and y-coordinates of the bottom left corner of the insulation relative to (0,0), which is the bottom left corner of the lamp panel; a cell size; and the diameter of the circular hole centered under the

shroud. The cell size is the maximum dimension allowed for the sub-elements that will represent the insulation in the analysis. As discussed in the shroud geometry, at least one ring of elements around the perimeter of the shroud describes the area where the shroud and insulation overlap.

2.2.4 Panel

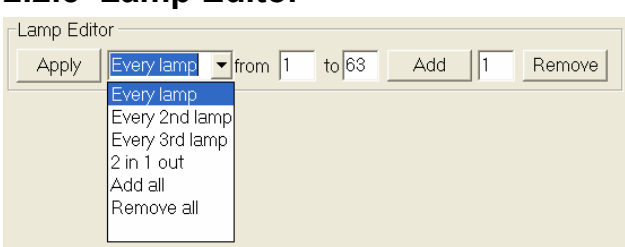


The **Panel** group is independent of the shroud geometry choices. There are eight dimensions and a specification for the number of elements into which the panel width will be divided. Default values of **Length**, **Width**, **dYlamp** and **Lamp0** reflect the panel design described in Ref. [2] and commonly used at the Radiant Heat Facility, although panels of other dimensions can be considered. **dYlamp** is the pitch between available lamp sites (labeled **P** on the right side of Figure 2) and **Lamp0** is the displacement from the plan-view-bottom of the panel to the first lamp site. **Dlamp** is the width of the strip used in the idealized representation of a lamp (labeled **dw** on the right side of Figure 2). Only the lamp temperatures (which are generally not of interest) are sensitive to the choice of **Dlamp**—the default of 0.2" is appropriate. **hLamps** (labeled h Figure 4 in the side view) is the distance between the plane of the lamp strips and the top of the shroud.

Nx is the number of width-wise divisions used to model the panel—the value of 5 shown is consistent with geometries depicted in Figure 4. **MaxdY** is the allowable panel interval for cells between lamps or in the modeled portion of the panel extending beyond the lamps. For example, if **MaxdY**=3 inches and some intervals between populated lamp sites are greater than 3 inches, those intervals will be divided until this dimension is not exceeded. It has the same function as cell size for shroud or insulation, but cell size is not used on the panel because relatively long and narrow cells may be acceptable on this surface.

Panel Overlap Modeled is the panel distance included in the **SPLASH** model beyond the populated lamp sites on either end (provided such space exists). In Figure 4, this is shown as 5 inches while **MaxdY**=3 inches. Consequently, two rows of panel elements are added to the model on each end of the lamped region. In Figure 4, the regions specified by this parameter have been shaded gray.

2.2.5 Lamp Editor



The lamp editor, shown left, is used to add or delete lamps from the system. The editor consists of a pull-down menu, 3 editable integers and three buttons. The pull-down menu choices are exposed at left. The first four choices are uniform lamp densities to be applied over the interval specified in the first two edit boxes. After one of these lamp densities is chosen and the interval is specified, pressing the **Apply** button will populate the specified interval of lamp

positions accordingly. The last two choices **Add all** and **Remove all** apply to the entire panel (without regard to what is in the range boxes). The action is not performed until the **Apply** button is pressed.

The **Add** and **Remove** buttons operate on the single position specified in the edit box located between these two buttons. This feature can be used adjust lamping that does not conform to one of the uniform density rules.

2.2.6 Draw Button Interactions

A large button resides on the **Geometry** tab in the lower left corner. When the program is started or a case is loaded it appears with the label **Draw NEEDED** (as shown above). Pressing this button results in:

- Parsing of all the input fields on the left of the tab (everything but the lamp editor).
- Verification of inputs; for example, a shroud must be large enough to cover the hole in the insulation and at least one lamp must be in the system.
- A schematic rendering of the current system specification.
- Enabling of the view factor calculation button on the **Temps/Props** tab.

Figure 5 is an example of an error dialogue created by entering an invalid value for shroud thickness. All edit fields that are used to input real values have this sort of check performed at the point that the parsing occurs. On the **Geometry** tab parsing occurs when **Draw NEEDED** is pressed.

Figure 5: Error dialogue generated by bad shroud thickness input.

Beyond qualifying the individual fields to required ranges in the manner of Figure 5, **SPLASH** performs some additional tests on geometry. By rule, the shroud is always centered over the hole specified in the insulation group. The right, top, left, and bottom limits of the shroud must lie within the horizontal extent of the insulation. If one of these rules is violated, **SPLASH** generates a dialogue similar to that shown in Figure 6.

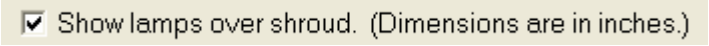
Figure 6: Error dialogue generated by non-conforming geometry.

If there are no problems with the input parsing or the **Geometry** specification the label on the button will change to "**Drawing Up-to-date**."

If numbers affecting the **Geometry** are edited on the **Geometry** tab the button reverts to the "**Draw NEEDED**" label and view factor calculation button on the Temps/Props Tab is disabled until this button is pressed again.

The foregoing behavior is logical because only changes in **Geometry** on this screen result in the need for view factor recalculation. Figure 4 includes (embellished) examples of the schematics drawn by use of the Draw Button. The drawing includes plan views at the lamp and shroud levels and a side view. The lamp level has numbered lamp slots so that it is easy to see which specific lamps are present in the system.

A checkbox at the very bottom of the screen appears as follows:



When this box is checked the lamps are superimposed on top of the shroud level plan view. This can be convenient for seeing the relative horizontal displacement between lamps and the shroud and insulation. It is also convenient to choose not to display the lamps when studying the gridding of the shroud and insulation. Consequently, this feature is controllable. In Figure 4, the left part of the figure shows the lamps on the shroud level and the right part of the figure illustrates the option of leaving them off.

2.2.7 Save Image / Clip Board Buttons

These buttons are enabled only when the drawing is up to date. Pressing **Save Image** presents a standard Windows **SaveAs** dialogue box to the user. Upon definition of a file name and completion of that dialogue, the current image in the drawing space is saved to the file in bitmap format. The **Clip Board** button results in the current image being placed in the Windows clipboard. This button is the most convenient way to get an image from **SPLASH** into any other Windows application that can accept the pasting of an image from the clipboard.

2.3 Temps/Props

The Temps/Props tab is the second tab and is shown in Figure 7. Regions of that input screen include thermal properties, control properties, and numerical computation parameters. These are discussed in the following minor sections. The thermal properties on this screen are all in

SI units (W,J,s,K,kg,m). Computation of view factors and system analyses are initiated on this panel. After these inputs are discussed the behaviors of the panel's buttons are discussed.

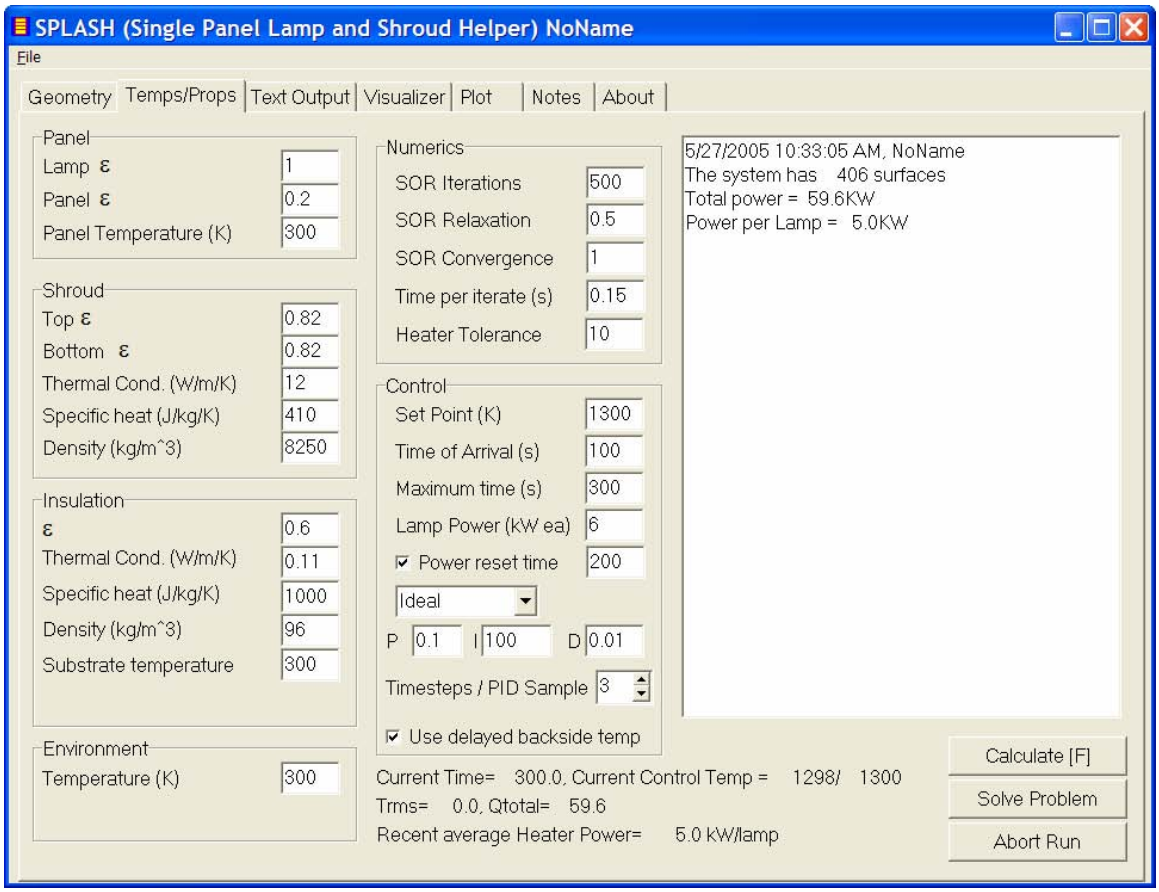


Figure 7: SPLASH's Temps/Prop tab.

2.3.1 Thermal Properties

Groups corresponding to the panel, shroud, insulation and the environment form a left-hand column on the **Temps/Props** tab.

Panel	
Lamp ε	1
Panel ε	0.2
Panel Temperature (K)	300

The panel group has emissivities associated with the lamps and with the material between lamps. The **Panel Temperature** is specified for the material between the lamps. The panel emissivity represents the shiny aluminum construction of Ref. [2] and should generally be a lower value like its default of 0.2. The lamp emissivity defaults to 1.0. Only the lamp temperatures should be sensitive to this choice and will little effect on temperatures and flux distributions on the shroud.

Shroud	
Top ε	0.82
Bottom ε	0.82
Thermal Cond. (W/m/K)	12
Specific heat (J/kg/K)	410
Density (kg/m^3)	8250

The shroud has distinct emissivities for the top and the bottom. Thermal conductivity, specific heat, and density of the shroud are also specified in this group and the defaults correspond to inconel.

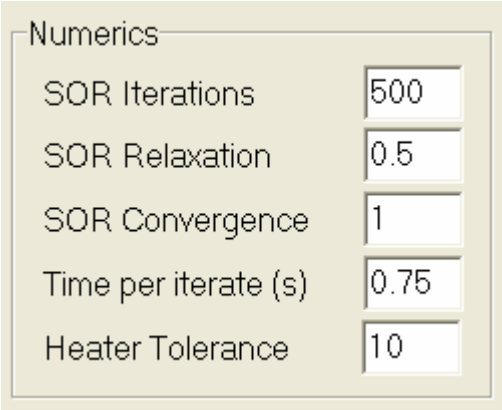
Insulation	
ε	0.6
Thermal Cond. (W/m/K)	0.11
Specific heat (J/kg/K)	1000
Density (kg/m^3)	96
Substrate temperature	300

Insulation emissivity, thermal conductivity, specific heat, and density are specified in the next group. The defaults correspond to an insulation that was in use at the radiant heat facility at the time **SPLASH** was developed. (The constant property assumption in the model is probably particularly poor for the insulation but unimportant so long as an insulation layer is present and of very much greater thermal impedance than the shroud.)

Environment	
Temperature (K)	300

Finally, a background temperature for the environment (which is uniform and temporally constant in the analysis) is specified.

2.3.2 Numerics



There are five user-defined parameters that affect the solution numerics. The Successive Over Relaxation (**SOR**) method is used to find the surface radiosities for the enclosure analysis. For most reasonable problem definitions the SOR method converges rapidly and the default values of these parameters will be sufficient. **SOR Iterations** defines how many loops through the method will be attempted. If convergence is not achieved within this limit the program is interrupted and the user is presented with the following dialogue:

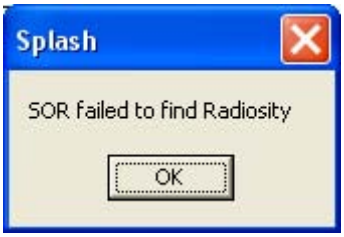


Figure 8: SOR convergence failure dialogue.

Merely increasing the number of iterations is not likely to help if this dialogue has been received. The second SOR-related parameter, **SOR relaxation**, sets how aggressively the solution is pursued. The relaxation factor must be greater than zero and less than two. Very small values (like 0.001, not at all aggressive) may nurse a solution out of a difficult problem, but it is highly unlikely that a very small value is required with systems that are well-suited for analysis with **SPLASH**. The default value of **SOR Relaxation** =0.5 should usually be acceptable. For a well-behaved system a value larger than one may succeed. If a system known to be of good behavior is analyzed repeatedly, the user may save time by setting somewhat more aggressive SOR parameters, but generally the defaults should serve.

The last parameter **SOR Convergence** sets how precise a solution must be to be accepted. The default of 1 is quite tight in that it is a measure of radiosity error and typical values of radiosity are 10 to 100 thousand.

Time per iterate is a value that the user is fairly likely to need to adjust. The transient solution is advanced using simple forward difference approximation for the time derivative of the system temperatures that vary. Too large a time step is certain to yield numerical instability. Generally, if the **Use Delayed Backside Temperature** option (to be discussed further shortly) is not selected, time steps smaller than about 1 second will result in convergence. (It appears that small time steps, ~0.1s, are needed to succeed at modeling control of the heater.) Physically small features limit the time step so that finer grids or thinner layers (insulation and/or shroud) can require a reduction of the time step taken. The most probable ill effect of using too large a time step is numerical instability that will lead to a step at which the SOR will no longer converge and the user is presented the dialogue of Figure 8. When the **Use Delayed Backside Temperature** is elected it is very probable that the

time-step-limiting feature of the model is associated with the short length scale between zones placed across the shroud thickness. Consequently, the user receives more specific counsel on time step when the delay is selected. For example, for the default shroud (1/8th-inch inconel), if the delay is checked and an arbitrarily large time step has been specified, the following dialogue will be generated:

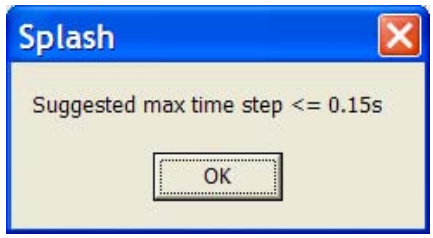


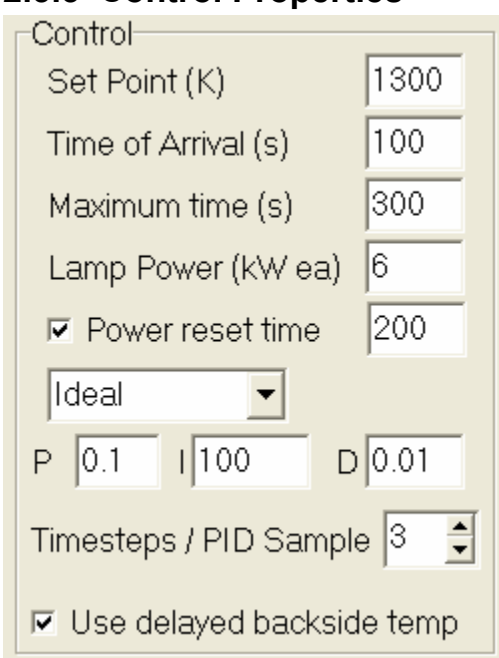
Figure 9: Time step too big dialogue.

SPLASH will not allow the user to continue until a complying time step is specified.

The only practical downside to using arbitrarily small time steps is that it will take longer to run the calculation. In the **Control Properties**, to be discussed next, an option exists to specify an integer number of analysis time steps between control algorithm time samples. The time step must be coordinated with that choice to achieve a specific, fixed sampling period in the numerical modeling of the control.

Finally, **Heater Tolerance** specifies how well the heat flux distribution in the lamps must match the uniform distribution of power that is assumed. As with the SOR Convergence, this quantity is the measure of a number that is large (about an order of magnitude larger than most of the radiosities in the system). Hence the default value will generally be demanding enough. Lowering this quantity requires tighter numerical convergence.

2.3.3 Control Properties



The control group consists of eight editable fields, a pull-down menu, a spin edit field, and two check boxes. The first edit box is the control **Set Point** temperature. This temperature is the desired temperature at the shroud bottom center location. The system always starts at the environment temperature (described earlier) and seeks to ramp the shroud up to the set point temperature at the **Time of Arrival** which is specified in the second edit box. After that time, power is adjusted with the goal of holding the temperature at the set point with analysis ending at **Maximum Time**, the third edit box of this group. If the **Power reset time** is used, it should be set to a value between **Time of Arrival** and **Maximum Time.** The **Power reset time** is a time at which the modeling of the control system is taken out of **SPLASH**'s model and a constant power level is imposed for the lamps. The power level used is

the average power level for the last 100 time steps taken (this imposes a further requirement that the reset time generally not be too close to the time of arrival).

Figure 10 is graph that is produced on the **Plot** tab which will be discussed later. It is embellished with labels identified in the control group. For this particular case the control parameters have led a to a fairly smooth temperature history. Immediately after the time of arrival a little oscillation is present as the heater power fluctuates (this can be much more pronounced for other conditions).

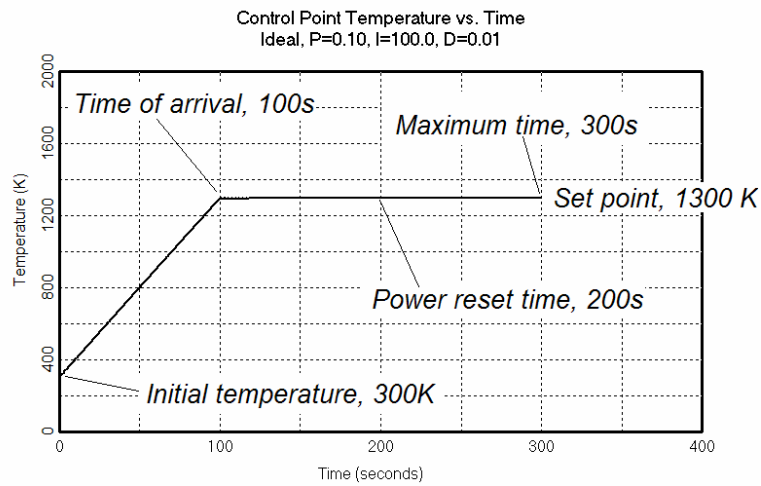


Figure 10: Temperature vs. time plot illustrating control constants.

The fourth edit box sets **Lamp Power**, which imposes a maximum power dissipation for each lamp in the system. If a model has been assembled for which the maximum power is not sufficient, the heaters will be maintained at this power, and the set point temperature will not be reached.

The pull-down menu in the controls group allows the user to select **Ideal**, **Parallel**, or **Series** PID control algorithms. Editable fields allow the setting of the proportional, integral, and differential multipliers used in the control. **P** needs to be greater than zero or no power is indicated. The control algorithms implemented in **SPLASH** (Ref. [4]) are:

$$\text{Ideal:} \quad F = P\left\{e(t) + \frac{1}{I}\int e(t)dt + D\frac{de(t)}{dt}\right\} \tag{1}$$

$$\text{Parallel:} \quad F = Pe(t) + \frac{1}{I}\int e(t)dt + D\frac{de(t)}{dt} \tag{2}$$

$$\text{Series:} \quad F = P\left\{e(t) + \frac{1}{I}\int e(t)dt\right\}\left\{1 + D\frac{de(t)}{dt}\right\} \tag{3}$$

where F is the fraction of power output ($0 \le F \le 1$) and $e(t)$ is the amount by which the desired temperature exceeds the system temperature at the control point (always the middle,

bottom of the shroud). $e(t)$ is filtered as described in Ref. [1]. Notice that the integral term is multiplied by the proportional constant in the **Ideal** and **Series** algorithms.

The spin edit field of this group sets a whole number multiple of simulation steps between control sample steps. If a specific control sampling interval is to be simulated, the product of this setting and the **Time per Iterate** must equal that interval.

The **Use delayed backside temp** checkbox causes the model to invoke an approximate model to resolve the temperature distribution through the thickness of the shroud. As discussed earlier use of this feature will constrain the timestep that can be taken.

Figure 11 shows curves generated on the Plot Tab that illustrate contributions of the individual terms on the RHS of Eq. (1, 2, or 3). The two plots compare the effect of using the delayed backside temperature feature for the default **SPLASH** case. The top left and top right plots are for a case not selecting **Use delayed backside temp** while the bottom plots show the effect of using the delay on this same case. For this case it appears that the delay is not beneficial.

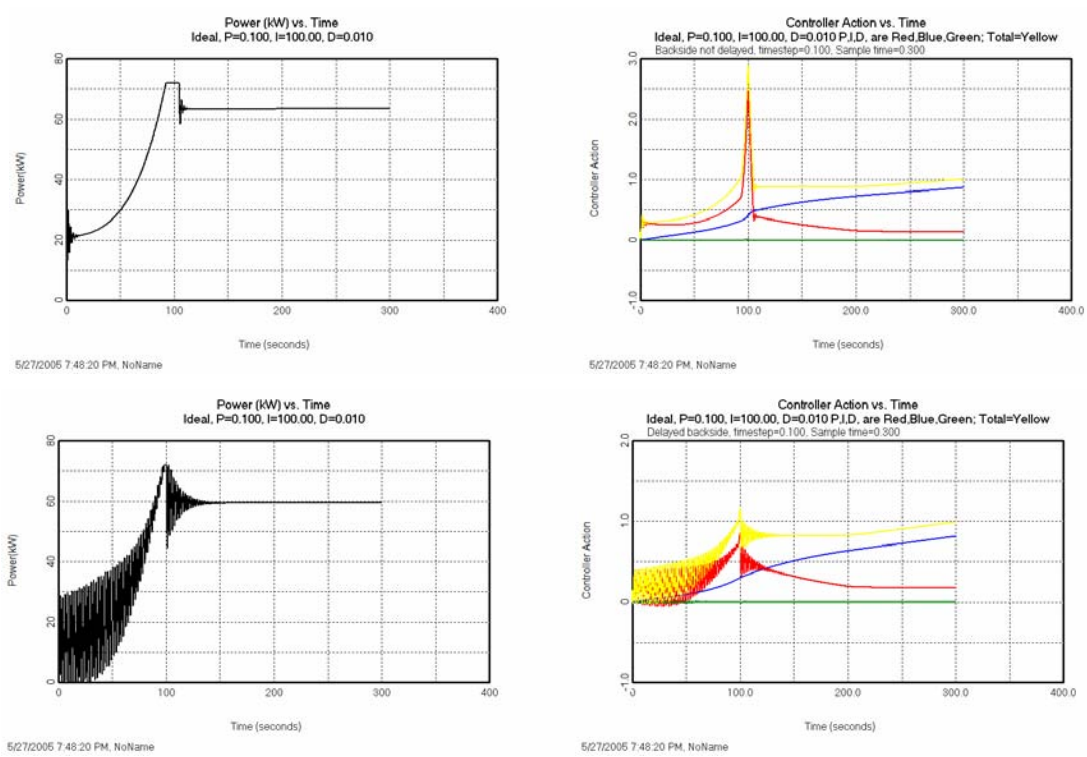
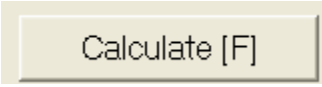


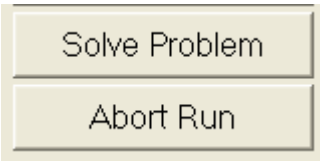
Figure 11: PID Controller Action and Power Plots.

2.3.4 Calculate [F]

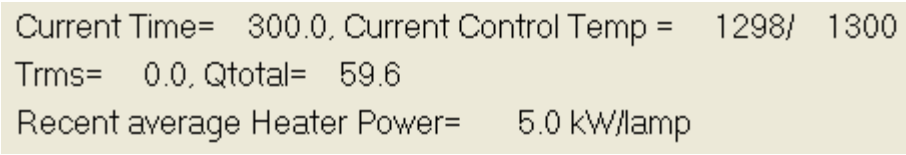


The **Calculate [F]** button is pressed to compute the system's view factors. This button is disabled until the **Draw System** button has been used on the **Geometry** tab. The view factors of the system depend only on contents on the **Geometry** tab. Consequently, when the **Geometry** is satisfactory this calculation can be completed and need not be repeated until the **Geometry** has been edited. For rectangular shroud **Geometry**, all of the view factors are calculated from closed form expressions so the delay to complete this calculation is small even when there are a large number of surfaces. For circular shroud geometries some of the view factors require numerical integration and the delay associated with completing the **Calculate [F]** function may be several seconds (depending upon the size of the problem and the speed of the computer).

2.3.5 Solve Problem / Abort Run



The **Solve Problem** button initiates the transient calculation. The **Abort Run** button interupts the solution process. These buttons are enabled and disabled appropriately so that they are available only when applicable. During the solution process, three labels left of these buttons are continuously updated to give progress information.



The first of these lines gives the current time (counting up in seconds) and the current calculated value and scheduled value for the control temperature. The **Trms** field on the second line indicates rms temperature change at each time step (every transient temperature in the system being equally weighted). For late time, particularly if the power level has been set to a constant value, **Trms** will fall steadily to (or near) zero as the steady operating condition is found. **Qtotal** is the current total lamp power (kW) in the system. Depending on the stability of the control scheme, this quantity may move steadily or erratically. Generally, the power "rings" wildly to start up the ramp, then settles into a consistent growth as the required power grows with increasing system temperature.

Recent average Heater Power indicates per lamp power level. This quantity is the average of the power levels for the most recent 100 time steps. Consequently, this line does not show up until 100 time steps into the solution. If an adequate interval is provided between **Power reset time** and **Maximum time** (and the power reset feature is used) the **Recent average Heater Power** will always settle to a constant value to allow a steady condition to be found.

Finally, the **Temps/Props** tab has a text box. At the conclusion of a run (simulation time reaches **Maximum Time**) a brief summary is written including a timestamp corresponding to the initiation of the analysis, the file name (or "**NoName**" if not yet assigned), surface count, total lamp power at the end of the analysis, and power per lamp. Information can be highlighted and copied (control-C) to be pasted (control-V) into other Windows applications.

2.4 Text Output

Figure 12 shows **SPLASH** with the **Text Output** tab selected following the completion of an analysis. The **Text Output** tab hosts a set of three sub-tabs each of which contains a text box. At the initiation of an analysis these text boxes are cleared and the timestamp is written to the first line. On completion of an analysis, information documenting the final state of the enclosure system is written to the first two sub-tabs. Those tabs are labeled **Shroud Temperatures** and **All Temperatures**. Output to these text boxes is not written to an output file by **SPLASH**. However, if these details are of interest to the analyst they can be selected and copied to other Windows applications.

Shroud Temperatures will contain a line for each area element in the shroud giving **SPLASH**'s ID number and material type for the element, x- and y-coordinates of the element, the temperature on the top side of the shroud, the local radiation flux (from the enclosure calculation), and the bottom temperature of the shroud.

All Temperatures will contain a line for each area element in the enclosure analysis, including the shroud locations on the previous tab. Each line gives **SPLASH**'s ID number and material type for the element, x- and y-coordinates of the element, the temperature of the enclosing surface, and the local radiation flux (from the enclosure calculation). For the insulation and shroud the flux given is approximately that corresponding to the temperature drop through the material thickness times the constant thermal conductivity divided by thickness. It is not identically so because of lateral conduction in these materials. The material type is one of **Lamp**, **Panel**, **Shroud**, **Frame**, or **Insul**. The **Lamp** elements will have the highest temperatures and large negative values for heat flux. The **Panel** temperatures are the specified value and the fluxes will be positive. The **Shroud** temperatures are generally the objective of the calculation and should be around the specified end temperature. **Frame** temperatures correspond to the top side of the shroud at locations where it overlaps insulation. **Frame** temperatures are usually hotter than **Shroud** neighbors, but for thin insulation the effect should be reversed. **Insul** temperatures near the shroud should generally be hotter than the shroud.

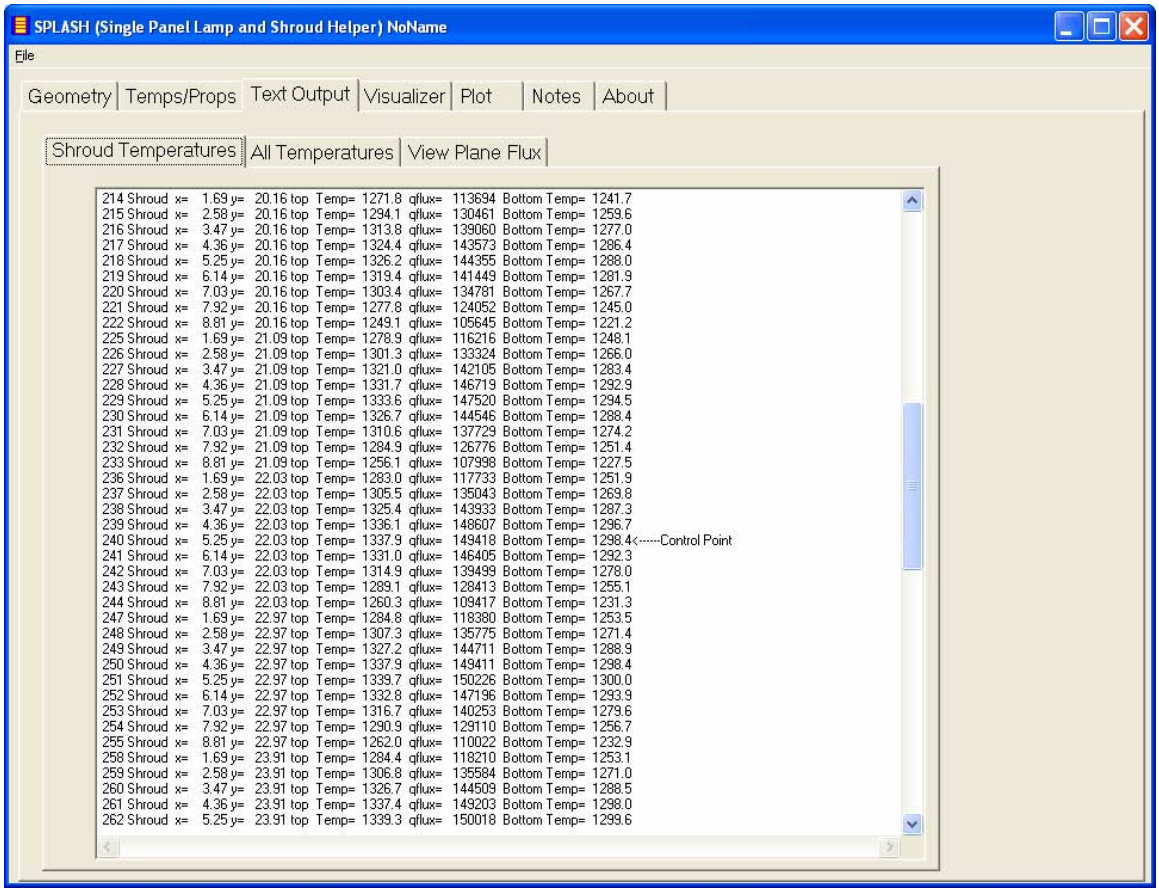


Figure 12: SPLASH's Text Output tab.

While the first two tabs are populated with information on the end enclosure state at the conclusion of the calculation, the last tab, **View Plane Flux**, will not contain information until that calculation has been initiated on the **Visualizer** tab which is discussed in the next section. Information in the text boxs can be highlighted and copied (control-C) to be pasted (control-V) into other Windows applications.

2.5 Visualizer

2.5.1 Vizualizer Overview

The **Visualizer** tab provides numerous graphical post-processing views of the end state of the system. Figure 13 shows **SPLASH** with the **Visualizer** tab exposed and presenting a representation of the enclosure analysis temperatures. The features of this tab are only available in post-processing. That is, because the available views all represent system end-states, the transient analysis must be completed before rendering these views.

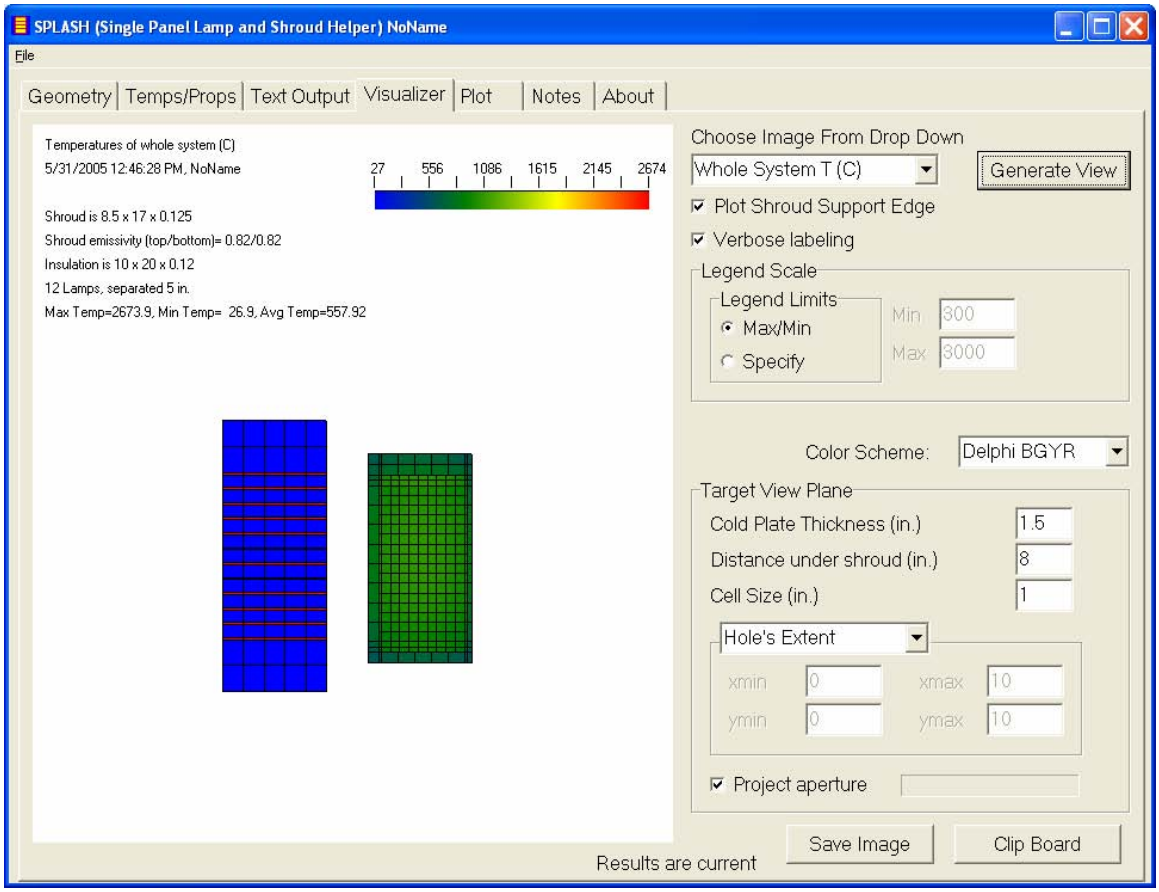
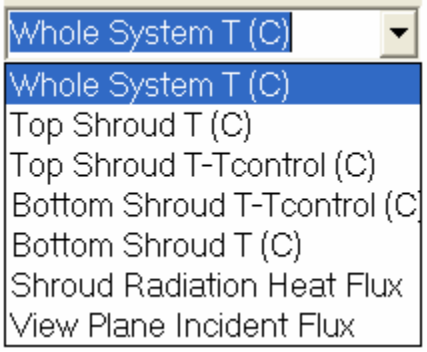


Figure 13: SPLASH's Visualizer tab.

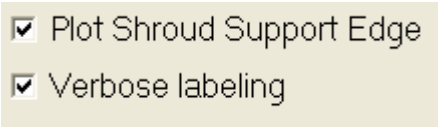
2.5.2 Whole System View

The graphic at left is an image of the upper right corner of the **Visualizer** tab. The pull-down menu presents the user a list of choices which are the available graphical views. The selected view is generated when the user has completed any other pertinent choices and presses the **Generate View** button. The **Whole System T (C)** choice is shown highlighted and the result is consistent with that shown in Figure 13. The color graphics of this view consist of a temperature legend and schematics of both the lamp level and the shroud/insulation level. Text output upon the view consists of an identifying label (**Temperatures of the whole system (C)**) , the time stamp, and summary information including shroud dimensions, insulation dimensions, lamp count, and max and min temperatures.

2.5.3 View Selector and Common Controls

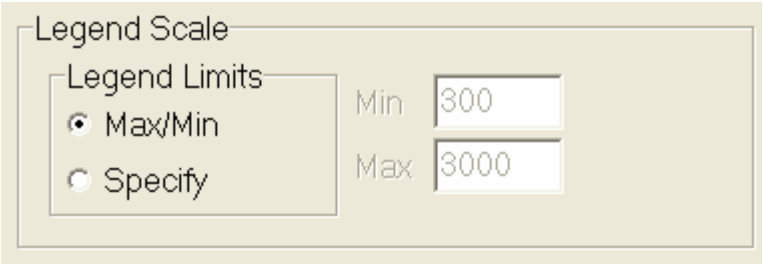


The graphic at left shows all of the choices available in the view selector pull-down menu. Temperature distributions can be plotted for the whole system, as already discussed; and for the top of the shroud and the bottom of the shroud. Flux distributions are available to show the net radiation flux to the shroud and the irradiance on a plane defined beneath the shroud. Each of these views will be discussed below. First, however, other controls on the **Visualizer** tab will be described here because their influence is often common to several of these available views.



Two checkboxes are positioned immediately beneath the view selector. **Plot Shroud Edge** applies to the top shroud views. If it is selected the whole shroud is shown in the graphic. If it is not selected only the shroud over top of the whole through the insulation is shown. Depending upon the geometry and system setup, the **Frame** of material that is backed by insulation beneath it may be appreciably hotter than the rest of the shroud. In that case, it can be useful to leave this material out of the view so that the temperature legend represents only the temperatures of the portion of the shroud lined up with the hole through the insulation, which will usually be of primary interest.

The second checkbox, **Verbose labeling**, determines how much text output is placed on the graphic. If it is not selected the text output is minimal. An optional line of text entered into an edit box on the Notes tab (to be discussed later, see Figure 15) is always presented on the plot if it has been defined (irrespective of **Verbose labeling** selection).



The next group controls the extent of the legend. By default, when a view is rendered, the information is scanned for its minimum and maximum values and these are used to define the range of the legend. This behavior maximizes the use of color resolution to describe the current field of values but leads to odd and varying bounding values. If the user wishes to control the legend, the **Specify** option is chosen and the **Min** and **Max** values are entered. This feature is desirable when the range of presented values is known and it is particularly helpful if graphics from multiple systems are to be compared.

Following the legend control is a pull-down menu that allows the user to choose the color scheme used for color graphics rendering. Four choices are available and their names and examples of their resulting color schemes are presented in Figure 14.

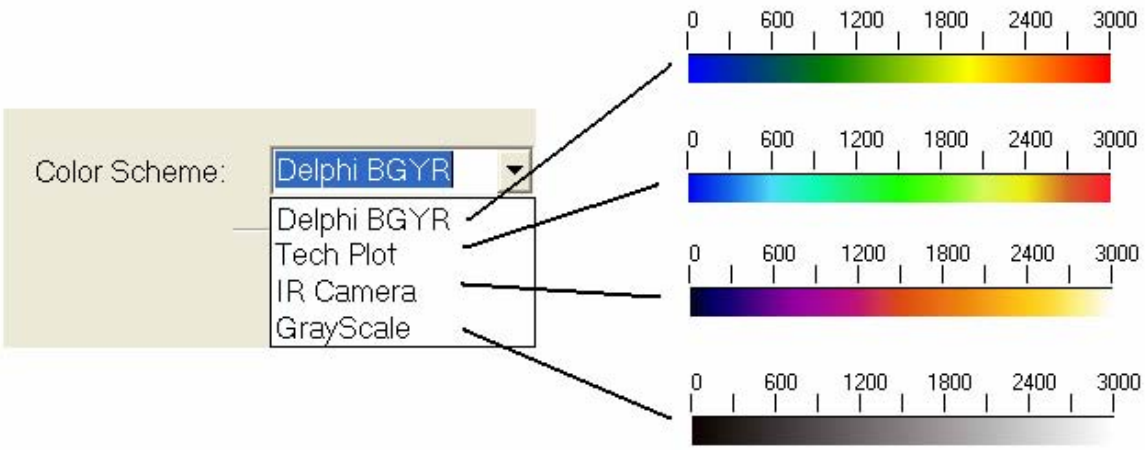


Figure 14: SPLASH's color schemes.

The next group of controls, **Target View Plane**, only pertains to the **View Plane Incident Flux** viewing mode, so its use will be discussed shortly along with the view it helps to generate.

The bottom right corner of the tab includes a label (showing **Results are current** above and in Figure 13) and two buttons. The label informs the user if analysis results have changed since the view was last rendered, in which case that label reads **Results not current**. The **Save Image** and **Clip Board** buttons operate as the ones described earlier for the **Geometry** tab. **Save Image** produces a Windows dialogue to name a file into which a bitmap graphic will be saved that contains whatever is currently displayed. The **Clip Board** button puts whatever is currently displayed into the Windows buffer so that it can be pasted into other applications.[1]

2.5.4 Top Shroud Views

The second (**Top Shroud T (C)**) and third (**Top Shroud T – Tcontrol (C)**) viewing modes display temperature fields of the top of the shroud. Figure 15 includes an example of each of these two views including a rectangular geometry and circular geometry. Note that the left side of the figure was generated with the **Plot Shroud Support Edge** and **Verbose labeling** options selected and that on the right with both deselected. Note the hot edges included around the rectangular shroud and the absence of the outside ring of elements on the right shroud corresponding to their respective settings. Only the plot title and timestamp are included on the right. The third line of text output on the left graphic is the content of an editable field on the **Notes** tab and it is included without regard for whether **Verbose labeling** is selected. It does not occur on the right part of the figure because the field was empty when that example was generated.

[1] Provided the application can handle a graphic image. For example, Windows NOTEPAD can not hold a graphics image, whereas MS WORD and WORDPAD do accommodate such images.

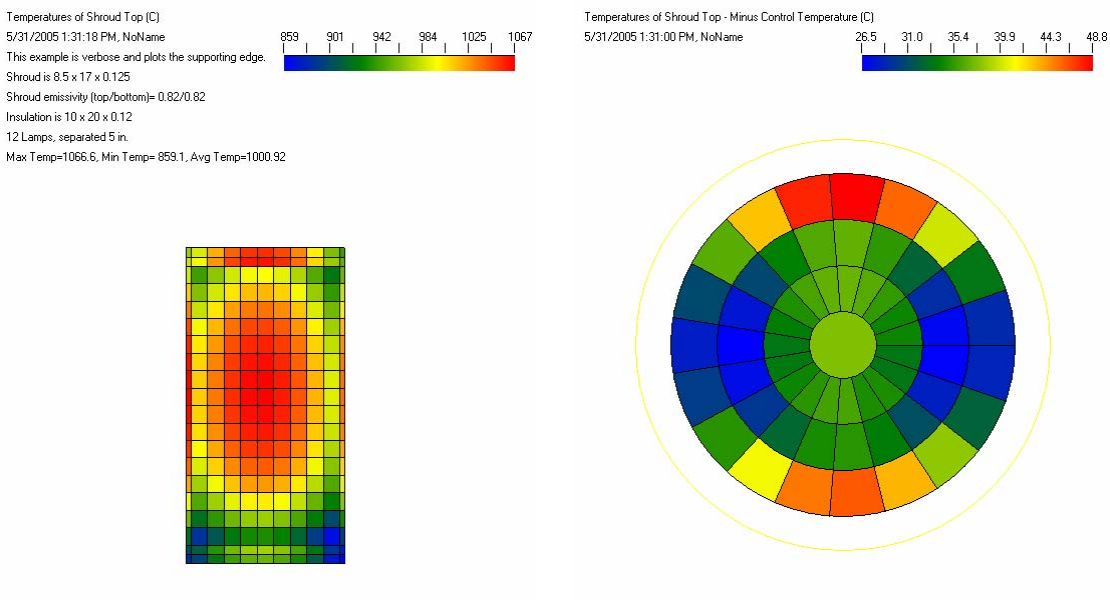


Figure 15: Rectangular (T) and circular (T-Tcontrol) Top Shroud views.

2.5.5 Bottom Shroud Views

The next two views are (**Bottom Shroud T (C)**) and third (**Bottom Shroud T – Tcontrol (C)**) and examples are shown in Figure 16. The state of the **Plot Shroud Support Edge** and **Verbose labeling** options have been reversed as compared to the results in Figure 15. For these particular cases the bottom temperatures are about 40°C less than the top temperatures. Correspondingly, the center of the right hand figure (temperature minus control temperature) is very nearly zero.

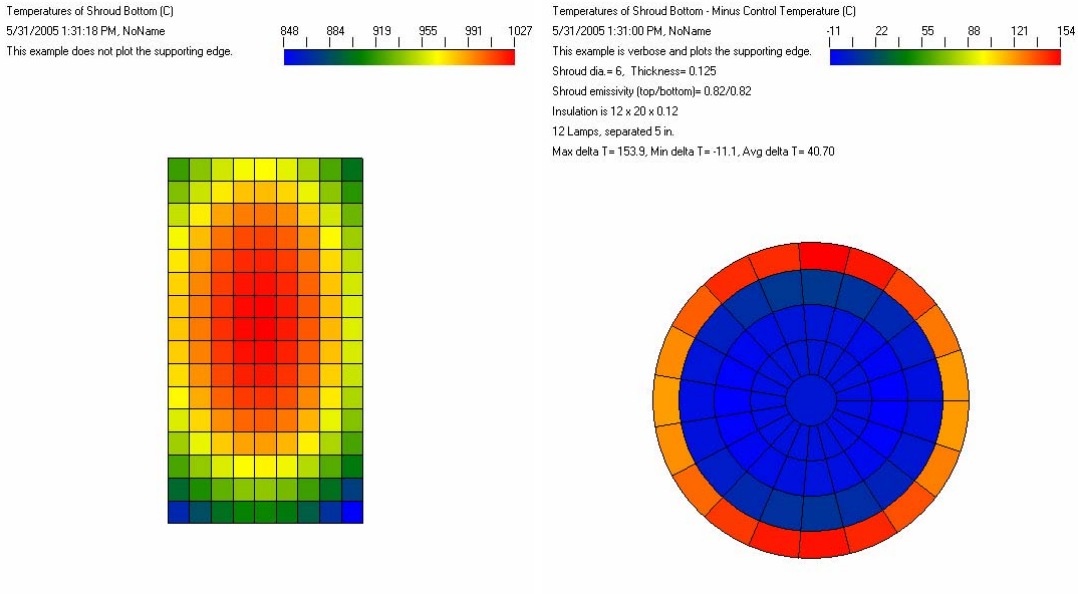


Figure 16: Rectangular (T) and circular (T-Tcontrol) Bottom Shroud views.

2.5.6 Shroud Radiation Heat Flux View

The **Shroud Radiation Heat Flux** view shows the radiation heat fluxes to the shroud at the end of the analysis. An example is shown in Figure 17. In this example the legend is labeled with nice round numbers because the **Legend Scale|Legend Limits|Specify** option was selected. When the legend extent is not specified it is always the case that the whole legend scale is present somewhere in the field. When values to be displayed lie outside of the limits of the legend, the color saturates at that corresponding to the near end of the legend.

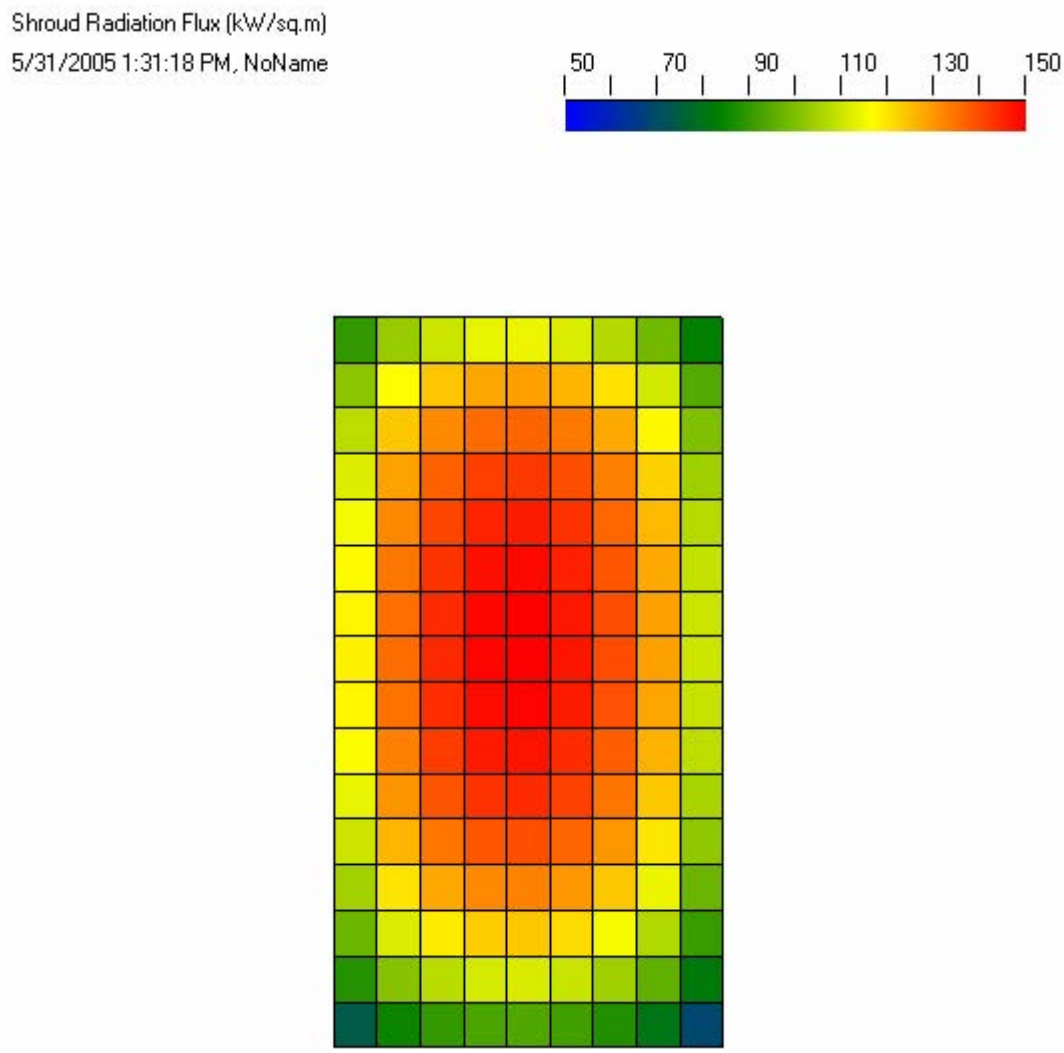
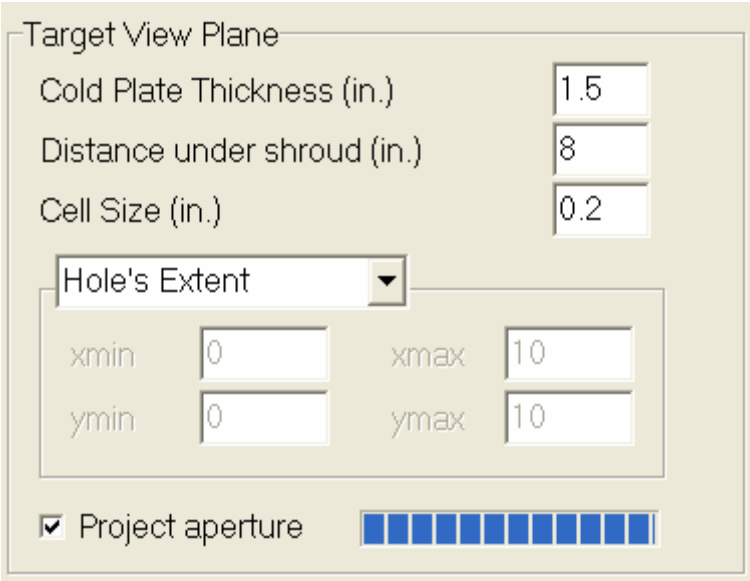


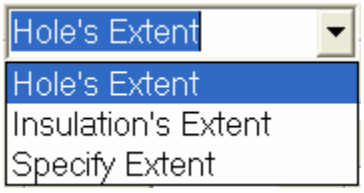
Figure 17: Shroud Radiation Heat Flux Example.

2.5.7 View Plane Incident Flux

The **View Plane Incident Flux** is the irradiance predicted for a plane parallel to and beneath the shroud. The user must define the location and extent of this plane. This view differs from all of the others in that the quantity displayed is calculated on demand. All the views previously discussed only render numbers already present in program memory by virtue of having completed the analysis. In this view the displayed quantity can only be calculated after the properties of the view plane are set.



The **Target View Plane** group provides the means to define the view plane. The first quantity specified is the thickness of the water-cooled plate that supports the shroud. This dimension is important because it affects shadowing that occurs. At least some shadowing will occur if the extent of the view plane is greater than that of the hole through the water-cooled substrate. Shadowing will be increasingly significant when the extent of the view plane increases and its separation from the shroud decreases. The second number in this group is the distance from the bottom of the shroud to the view plane. **SPLASH** requires this to be greater than the **Cold Plate Thickness**. The third quantity is a cell size. The view plane is broken into sub-areas not larger than the cell size. The resulting array can be at most 100 cells by 100 cells. The cell size set here and that set for the shroud on the **Geometry** tab affect the integration that occurs in that it determines the number of finite areas considered. However, within **SPLASH** the spatial integration is limited to not exceed 0.25 inch steps. Consequently, the size of the calculation here depends primarily on the extent of the shroud and the view plane (and not their cell sizes).



The pull-down menu in this group provides three selection options for specifying the horizontal extent of the view plane. **Hole's Extent** corresponds to specifying a view plane of the same dimensions as the hole specified on the **Geometry** tab and centered under the shroud. **Insulation's Extent** corresponds to specifying a view plane of the same dimensions as the as the insulation specified on the **Geometry** tab and positioned the same as the insulation relative to the shroud. Finally, **Specify Extent**, allows the user to specify the horizontal extent independent of other features in the system. The coordinate system is the same as that on the **Geometry** tab (i.e., the lower left corner of the panel corresponds to (0,0)).

The **Project aperture** selection tells **SPLASH** to draw an outline of the shroud on top of the view plane result. The segmented bar is a progress bar. It fills from left to right as the view plane calculation is completed. If the view planes are large this calculation can be lengthy enough that this feedback is reassuring to the user.

Figure 18 shows examples of view plane irradiance. On both the right and the left the extent of the view plane has been chosen as the system's insulation extent. Both have the **Project aperture** selected. The view on the left places the plane 8 inches under the shroud while that on the right puts it at 3 inches and exhibits the expected sharpening of the aperture definition due to the closer proximity.

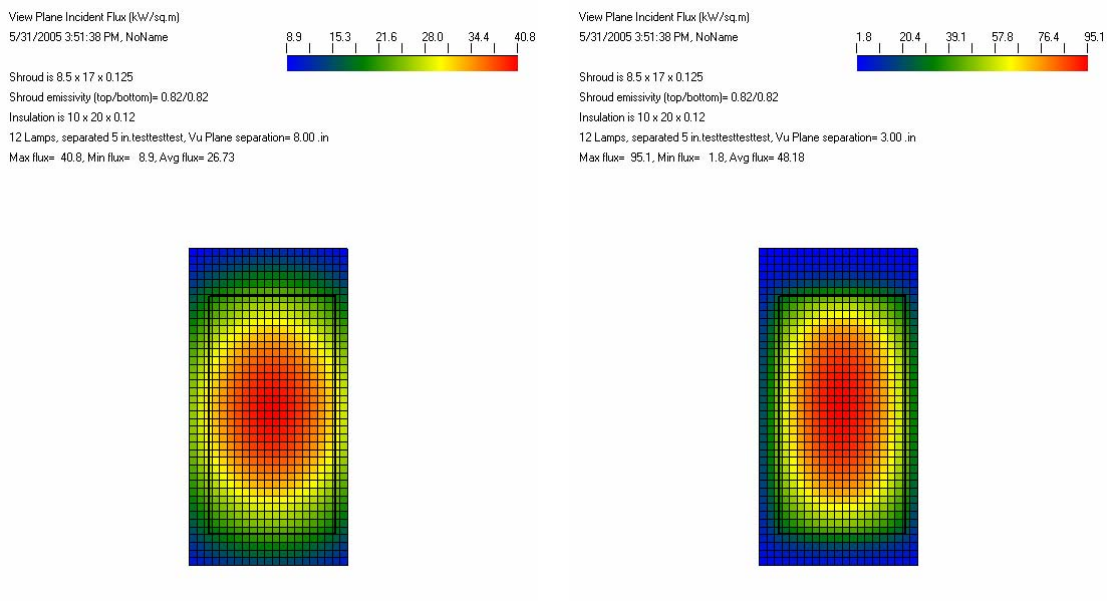


Figure 18: View plane irradiance examples.

2.6 Plot

Figure 19 shows **SPLASH**'s **Plot** tab. This tab provides transient plots of the modeled control point temperature, the total heater power, and the PID controller action. Examples of the control temperature and PID action plots (Figure 10 and Figure 11) were shown previously in discussing the effects of the PID control constants on the **Temps/Props** tab. Figure 19 shows an example of the total heater power plot that is available.

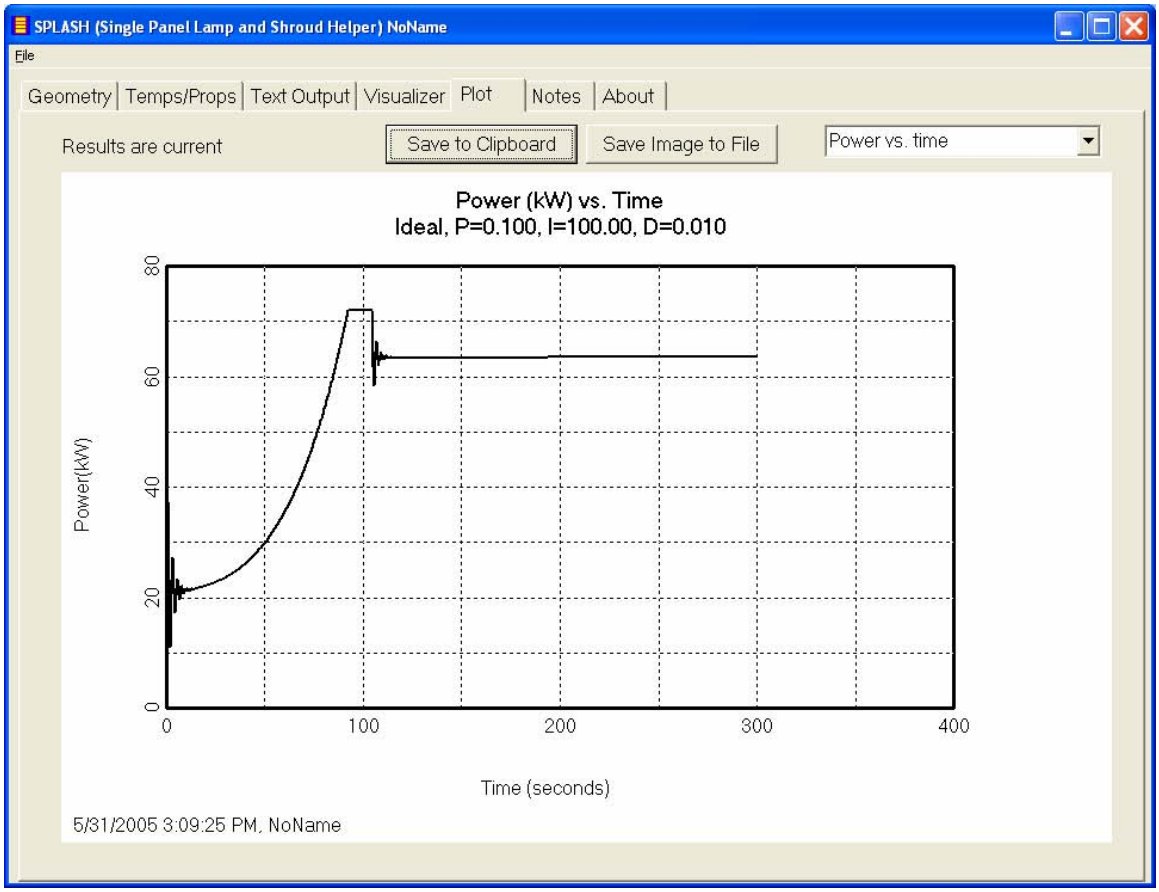
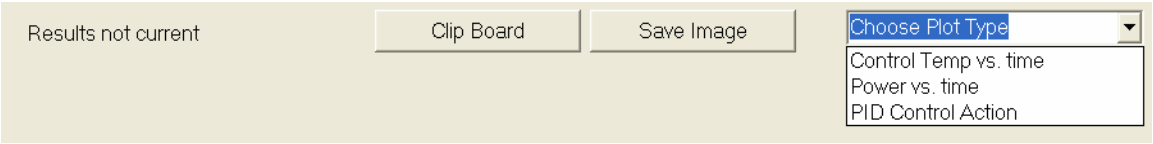


Figure 19: The Plot tab with a power plot showing.

Shown below are all of the controls associated with the **Plot** tab. The **Results Not Current** label advises whether the case has changed since a plot was last generated. An interesting behavior of the **Plot** tab is that it can be used "on the fly." The user does not need to wait for a transient analysis to complete to generate the requested plot up to the current time. Note that the label applies only to status of problem definition. That is, it will read **not current** with a plot displayed only if the problem has been edited (so if the last plot generated occurred before the end of the transient analysis, it does not indicate that there are additional transient results to plot). The **Save Image** and **Clip Board** buttons operate as the ones described earlier for the earlier tabs.



The pull-down menu in the upper right corner provides the options of **Control Temp vs. time**, **Power vs. time**, and **PID Control Action**. As there are no other settings on this tab, the effect of making a selection is immediate and the available plot is generated.

2.7 Notes

The **Notes** tab is to facilitate documentation. An example is shown in Figure 20. The tab's two prominent features are a single-line edit box and a large memo box. If the user has placed content in the edit box it will be displayed as the third line of text output on any view produced on the **Visualizer** tab. The effect was shown on Figure 15 and Figure 16. The text box is more general than others in **SPLASH** in that text can be pasted into the notes memo. If formatted text is pasted into the memo, the font style and size will be showing when it is pasted. However, if the project is saved and reloaded, formatting information is lost. For example a symbol such as: "σ" can be pasted into the window (owing to use of the Symbol font set on Windows), but upon reloading in the simple Arial font it will be returned as "s."

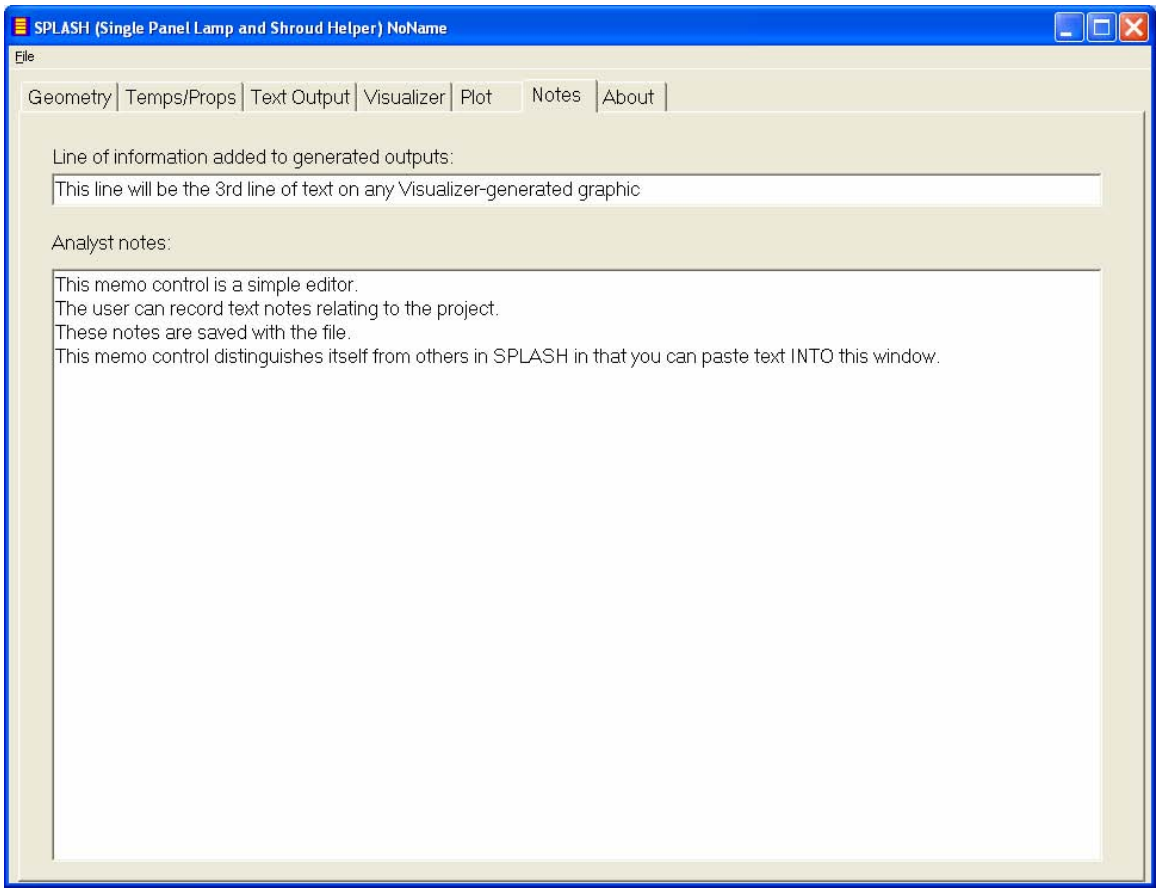


Figure 20: SPLASH with Notes tab example exposed.

2.8 About

The **About** tab provides version and contact information for **SPLASH**.

3 SPLASH in Aperture Mode

3.1 SPLASH Overview, Aperture Mode

As described in Section 1.2, Section 2 provides detailed descriptions of all the controls for **SPLASH** in **Shroud Mode**. This section parallels the **Shroud Mode** section and describes differences as they pertain to **Aperture Mode**. Consequently, this section does not stand entirely alone and reference to the **Shroud Mode** section is required for features that operate the same in both modes.

3.2 Geometry

There are no changes on the **Geometry** tab as a result of operating in **Aperture Mode** other than having selected that mode from the pull-down menu. In **Aperture Mode**, shroud temperatures are not calculated but the shroud is represented as cold (set to the environment temperature) and black $(\varepsilon = 1)$ in the calculation. This has the effect of the shroud's area returning negligible energy to the enclosure, i.e., mimicking the hole. Consequently, the analyst should use an arbitrarily thin value for shroud thickness and the horizontal dimensions of the shroud should be chosen just slightly greater than the dimensions for the hole in the insulation.

3.3 Temps/Props

The **Temps/Props** tab exhibits more change than any other tab in changing modes between **Shroud Mode** and **Aperture Mode**. An example of the Temps/Props tab in **Aperture Mode** at the completion of the solution is shown in Figure 21. Several features shown in Figure 7, the corresponding **Shroud Mode** view, are hidden and one new checkbox control is added. A discussion paralleling that for this tab in **Shroud Mode** follows.

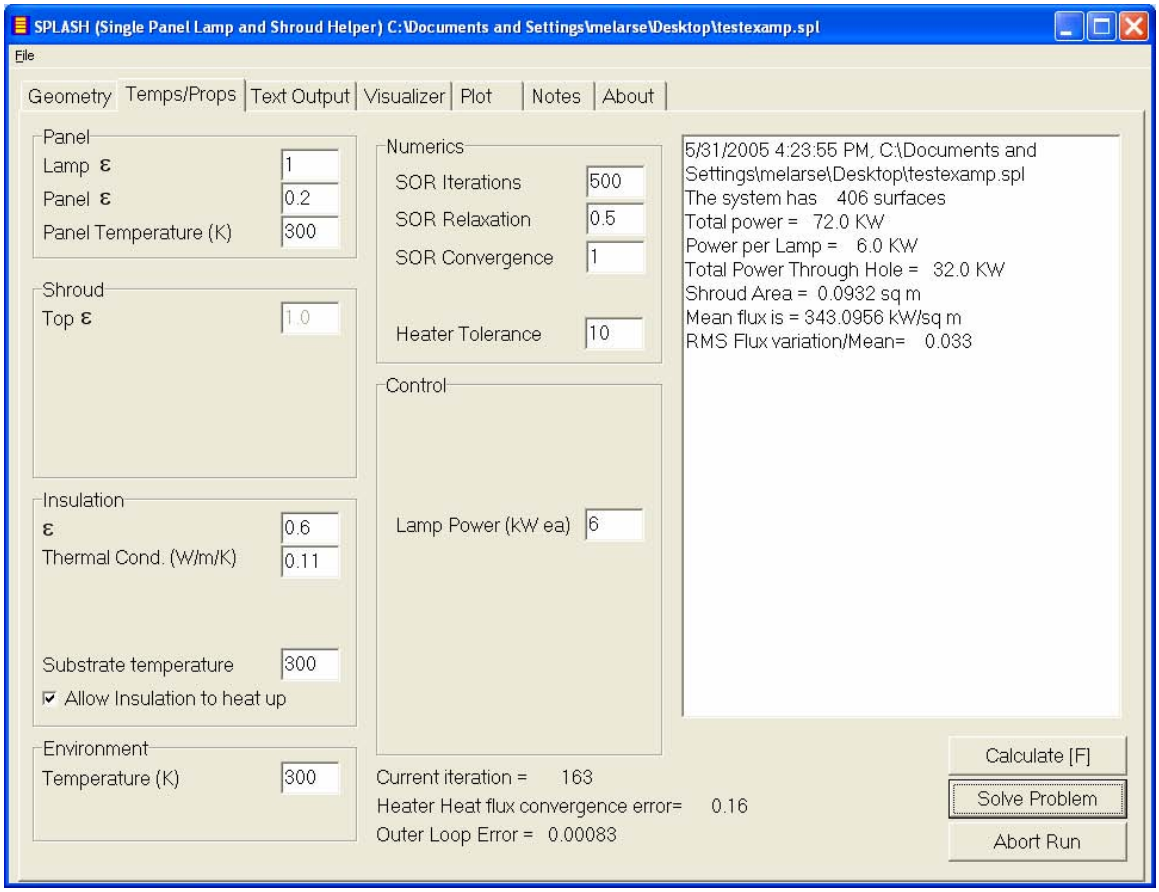


Figure 21: The Temps/Props tab in Aperture Mode.

3.3.1 Thermal Properties

The **Panel** group of properties remains unchanged. Lamp and panel emissivities and the panel temperature are specified as before.

The Shroud group has no editable information. The emissivity of the shroud is unity in **Aperture Mode** and that is displayed in the editbox control but the editbox has been disabled and changing the emissivity is not an option. None of the other shroud properties affect the calculation and they have hidden to take them out of consideration.[2]

The Insulation group retains editable emissivity, thermal conductivity, and substrate (cooled plate) temperature. Specific heat and density are not in play and the corresponding controls have been hidden. A checkbox, labeled **Allow Insulation to heat up**, is visible that is not present in **Shroud Mode.** If this option is not selected the insulation surfaces presented to the enclosure analysis are at the specified temperature and there is no conduction present in the system so that the solution is trivial. **Allow Insulation to heat up** is checked by default and generally should remain checked.

Environment temperature is specified as just as it is in **Shroud Mode**.

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[2] Associated variables still exist in **SPLASH** because they are allocated for the **Shroud Mode** of operation. The corresponding GUI controls are made invisible to eliminate confusion.

3.3.2 Numerics

In the **Numerics** group the **Time per iterate** is not relevant for **Aperture Mode** and it is hidden. No transient information is preserved in **Aperture Mode**. The solution method uses the same SOR routines and relaxation to find enclosure radiosities and lamp temperatures. As described in Ref. [1] a pseudo-transient method is used to find the solution to the non-linear equations in which a "time-step" is modified along the way to stay stable but no requirement for transient solution accuracy exists.

The solution method should be robust for reasonable system specifications. If there are problems finding the solution the dialogue of Figure 8 will probably be displayed. It may be helpful to reduce the **SOR Relaxation** at that point.

3.3.3 Control Properties

The only relevant control in the **Control** group is the **Lamp Power** specification. In contrast to **Shroud Mode**, where this field is the maximum power available, the **Lamp Power** is imposed (and not throttled back by a PID control system) in **Aperture Mode**.

3.3.4 Calculate [F]

Refer to 2.3.4, operation of the **Calculate [F]** button is the same as in **Shroud Mode**.

3.3.5 Solve Problem / Abort Run

Refer to 2.3.5, operation of the **Solve Problem** and **Abort Run** buttons is the same as in **Shroud Mode**.

The three dynamically updated labels left of these buttons change to the content shown in Figure 21. **Current Iteration** is the count of pseudo time steps taken. **Heater Heat flux convergence error** is rms error between the imposed lamp strip heat flux and that calculated with the current set of temperatures. **The Outer Loop Error** is the rms relative emissive power change between iterates.

At the conclusion of a run (**Outer Loop Error**<0.001), a brief summary is written the **Temps/Props** tab text box. The summary includes a timestamp corresponding to the initiation of the analysis, the file name (or "**NoName**" if not yet assigned), surface count, total lamp power at the end of the analysis, the power per lamp, the power through the hole, the shroud area, the corresponding mean flux, and the rms variation in incident flux on the hole.

3.4 Text Output

The content of the **Text Output** tab is the same as in **Shroud Mode**.

3.5 Visualizer

Since the **Visualizer** tab only reflects end states in **Shroud Mode**, its operation in **Aperture Mode** is substantially the same. However, some of the views no longer make any sense. If the user selects (**Top Shroud T – Tcontrol (C)**), (**Bottom Shroud T – Tcontrol (C)**), or (**Bottom Shroud T (C)**) views, the dialogue of Figure 22 is produced.

Figure 22: Dialogue indicating Invalid view for Aperture Mode.

The differences between **Aperture Mode** and **Shroud Mode** have been described in detail in Ref. [1] and the rest of this document. Nonetheless, visual examples, pertinent to the discussion at hand, may further improve user insight. To that end, Figure 23 shows the **Geometry** tab rendering of a simple system. This system is not likely to be of interest to radiant heat testing but it illustrates the behavior of **SPLASH** in **Aperture Mode**. Four lamps in an asymmetric pattern are positioned over a "shroud" that is a narrow slit running parallel to the lamps. This same geometry will be calculated in **Aperture Mode** and in **Shroud Mode**. Switching modes requires no value editing but the system must be redrawn between the two solutions to initialize variables correctly (**SPLASH** enforces this redraw by disabling the **Solve Problem** button until redraw occurs).

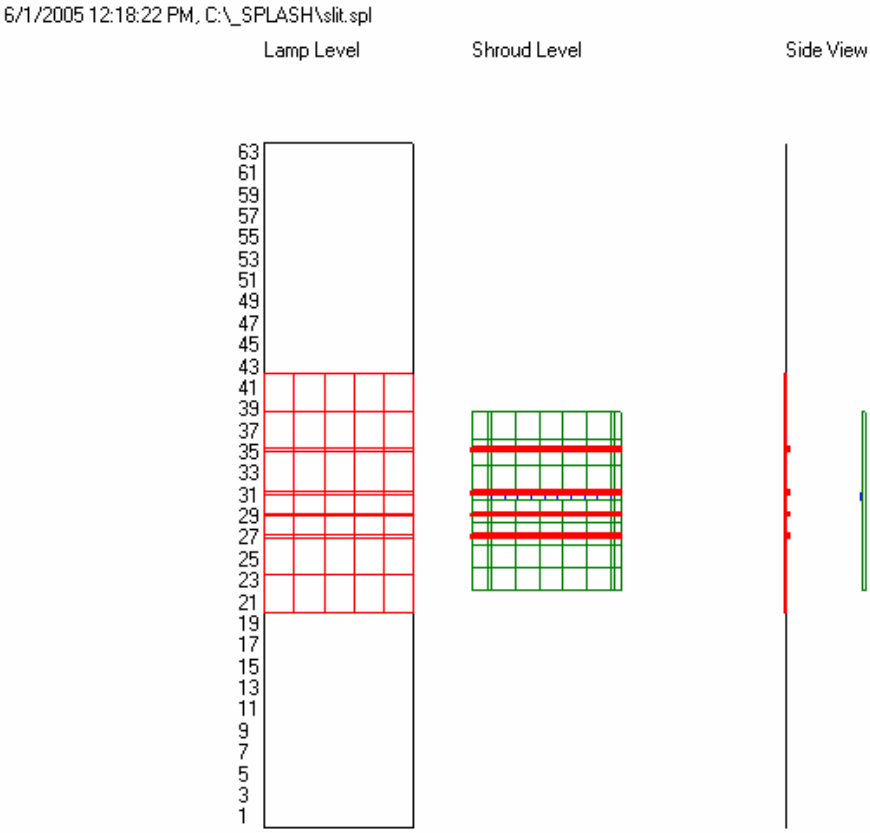

Figure 23: Geometry tab graphical representation of Aperture Mode example.

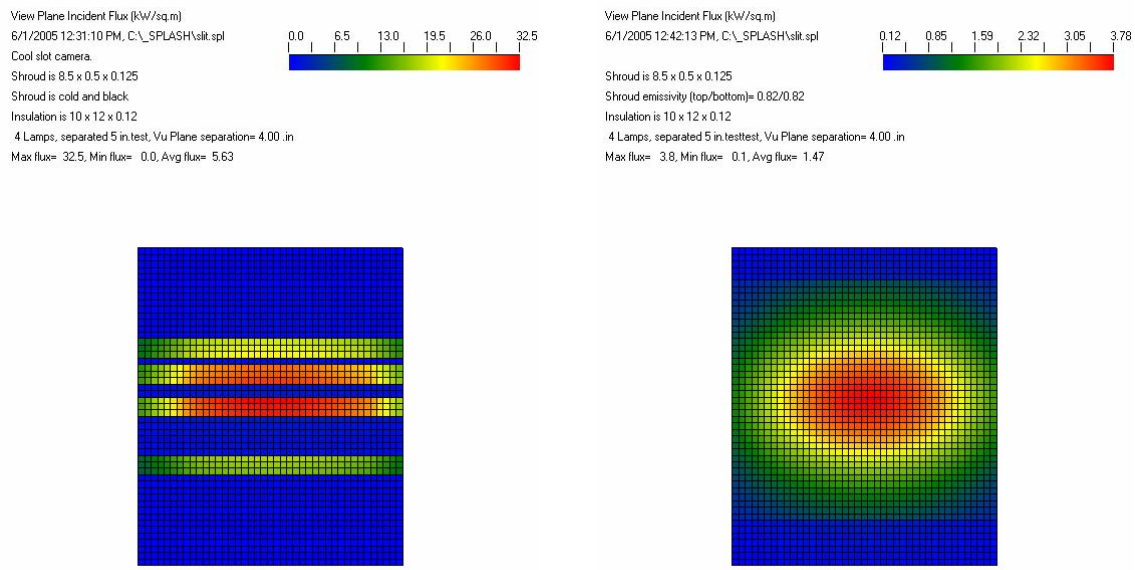

Figure 24: Figure 23 system results in Aperture Mode and Shroud Mode.

Figure 24 includes **View Plane Incident Flux** results for this geometry for both modes of operation. For both analyses the **Lamp Power** was set at 6kW per lamp. For the **Shroud Mode** result the control temperature was placed at a temperature beyond what can reached at the maximum lamp power which results in its 4 lamps running at full power as they do in **Aperture Mode**. "Images" of the lamps can be seen on the view plane on the left. The lamps have far greater radiosity than the panel intervals between them and projection of these intervals through the slot are seen on the viewing plane. In the **Shroud Mode** result on the right the irradiance is due to emission from the shroud which equilibrated (power maxed out at 6 kW per lamp) at approximately 1200K.

3.6 Plot

The **Plot** tab only displays transient information. Attempting to generate a plot in **Aperture Mode** produces the dialogue of Figure 25.

Figure 25: Dialogue indicating plots not applicable to Aperture Mode.

3.7 Notes

The **Notes** tab operates the same in **Shroud Mode** and **Aperture Mode**.

3.8 About

The **About** tab is the same in **Shroud Mode** and **Aperture Mode**.

4 References

1) Larsen, M.E., and J.M. Porter, Theory and Experimental Validation of SPLASH (Single Panel Lamp and Shroud Helper), Sandia National Laboratories, SAND2005-2947, Unlimited Release, Printed May 2005.

2) R.I. Controls, Drawing number D49083, *Modular Heater Assembly*, May, 1986.

3) BORLAND DELPHI Professional Version 7.0, Borland Software Corporation, Copyright 1983-2002.

4) National Instruments, BridgeView and LabView PID Control Toolkit for G Reference Manual, Part Number 320563B-01, January, 1998.

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