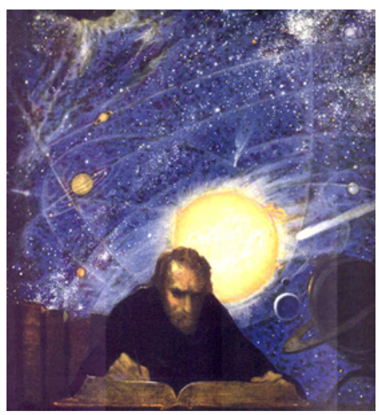
RADICAL

The Radiometric Calculator

Manual



Virial, Inc.
Gaitherthburg, MD
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www.virial.com

CONTENT

1. INTRODUCTION

RadiCal (RADIometric CALculator) is the program for calculating radiation characteristics of a gray thermal radiation source with uniform temperature as well as radiation fluxes falling onto a detector from such a source. It is supposed that radiation heat transfer takes place in vacuum, i.e., without refraction, scattering, and absorption.

RADICAL is intended for researcher working in optical radiometry, radiation thermometry, and adjacent areas. RADICAL can also be used for educational purposes.

RADICAL works on PC with operating system MS Windows from 2000 to 8 (in compatibility mode). Screen resolution should be at least 1280×800 pixels.

2. MAIN FEATURES

RADICAL performs calculations of the following radiation characteristics of gray thermal sources:

- spectral radiance and radiance temperatures as a function of spectral variable
- position and value of spectral radiance curve maximum
- in-band radiance and in-band radiance temperature for a detector with the rectangular or Gaussian spectral responsivity shape
- radiant exitance, radiance, and radiation temperature
- irradiance distributions in the plane perpendicular to the axis of circular radiation source
- radiant flux emerged from the source
- radiant flux falling onto the circular detector which lies in the plane perpendicular to the axis of circular radiation source and co-axial with it

RADICAL allows working with three spectral scales:

- wavelength in µm
- wavenumber in cm^{-1}
- frequency in THz

RADICAL allows working with three temperature scales:

- absolute (Kelvin) in K
- Celsius in ºC
- Fahrenheit in ºF

RADICAL provides a possibility to take into account the background radiation.

RADICAL presents results of calculations in form of tables and graphs. Numerical results can be saved in text files, XLS-files (MS Excel spreadsheets), as XML and HTML tables. Graphs are fully editable and can be saved or exported as bitmaps (*.bmp) or Windows metafiles (*.wmf).

RADICAL has the mode of automatic selection of spectral range for graphs plotting.

3. BASIC DEFINITIONS AND EQUATIONS

3.1. Temperature scale

In all formulae below, temperature T is the absolute (thermodynamic) temperature measured in Kelvins (K); however, **RADICAL** allows using alternative temperature scales: Celsius (t_C) and Fahrenheit (t_F). Relationships between these scales and the thermodynamic scale are the following:

$$t_C[^\circ\mathrm{C}] = T[\mathrm{K}] - 273.15, \quad (1)$$

$$t_F[^\circ\mathrm{F}] = \tfrac{9}{5}T[\mathrm{K}] - 459.67, \quad (2)$$

3.2. Spectral scale

Electromagnetic radiation transfers energy in the form of electromagnetic waves with the associated photons. In the physical optics, the spectral scale can be represented by frequency, or wavelength, or wavenumber.

Frequency (f) is the number of oscillation cycles of an electromagnetic wave per unit of time. In optical spectral range, frequency is usually measured in THz (1 THz = 10^{12} Hz).

Wavelength (λ) is the distance in the direction of propagation of an electromagnetic wave between two successive points at which the phase is same (e. g., between two successive maxima), $\lambda = \frac{c}{f}$, where c is the speed of light in vacuum (see numerical value in the next Section). In the optical spectral range, wavelength is usually measured in μm (1 μm = 10^{-6} m) or nm (1 nm = 10^{-9} m).

Wavenumber (ν) is the reciprocal of the wavelength, $\nu = \frac{1}{\lambda}$. In the optical spectral range, wavenumber is measured in cm^{-1}.

Optical radiation is electromagnetic radiation of spectral range between the region of transition to X-rays ($\lambda \approx 1$ nm) and the region of transition to radio waves ($\lambda \approx 1$ mm).

3.3. Physical constants

Table 1 shows the most important physical constants [1] used in definition of physical quantities and equations of fundamental physical laws employed in **RADICAL**. The International System of Units (SI) is used everywhere.

Table 1

Constant	Symbol	Value	Unit
Speed of light in vacuum	c	299 792 458	$\mathrm{m \cdot s^{-1}}$
Planck constant	h	6.626 068 96×10^{-34}	$\mathrm{J \cdot s}$
Boltzmann constant	k	1.380 6504×10^{-23}	$\mathrm{J \cdot K^{-1}}$
Stefan-Boltzmann constant	σ	5.670 400×10^{-8}	$\mathrm{W \cdot m^{-2} \cdot K^{-4}}$
First radiation constant for spectral radiance (wavelength scale)	c_{1L}	1.191 042 759×10^{-16}	$\mathrm{W \cdot m^{2} \cdot sr^{-1}}$
Second radiation constant (wavelength scale)	c_2	1.438 7752×10^{-2}	$\mathrm{m \cdot K}$
Wien displacement law constant (wavelength scale)	b	2.897 7685×10^{-3}	$\mathrm{m \cdot K}$
Wien displacement law constant (frequency scale)	b'	5.878 933×10^{10}	$\mathrm{Hz \cdot K^{-1}}$

Since **RADICAL** uses three spectral scales (wavelength, wavenumber, and frequency), it is convenient to introduce five additional constants that can be calculated using the data presented in Table 1. These auxiliary constants are shown in Table 2 to be used in Planck's law and the Wien displacement law.

Table 2

Constant	Symbol	Value	Unit
First radiation constant for spectral radiance (frequency scale)	c'_{1L}	1.474 199 952×10^{-14}	$\mathrm{W \cdot m^{-2} \cdot sr^{-1} \cdot Hz^{-1}}$
Second radiation constant (frequency scale)	c'_2	4.799 237×10^{-11}	$\mathrm{Hz^{-1} \cdot K}$
First radiation constant for spectral radiance (wavenumber scale)	c''_{1L}	1.191 042 758×10^{-8}	$\mathrm{W \cdot m^{-2} \cdot sr^{-1} \cdot cm}$
Second radiation constant (wavenumber scale)	c''_2	1.438 7752	$\mathrm{cm \cdot K}$
Wien displacement law constant (wavenumber scale)	b''	1.961 0009	$\mathrm{cm^{-1} \cdot K^{-1}}$

3.4. Basic definitions and equations for principal quantities

In this Section, we'll hold (as far as possible) standard terminology recommended in [2 – 4].

Perfect blackbody is the ideal thermal radiator that absorbs completely all incident radiation, whatever the wavelength, the direction of incidence or the polarization. This radiator has, for any wavelength and any direction, the maximum spectral radiance for a thermal radiator in thermal equilibrium at a given temperature.

Thermal radiation source is the source emitting thermal radiation, i.e. the electromagnetic radiation emitted due to the thermal agitation of the particles of matter such as atoms, molecules, ions.

Background radiation is the thermal radiation of structural elements of a radiometric system, environment, and objects within the detector's field-of-view registered together with the radiation of the source. Usually, background radiation is considered as the radiation of a perfect blackbody at temperature T_{bg}.

Radiant flux (Φ_e , measured in W) is the power emitted, transmitted or received in the form of radiation.

Spectral radiant flux ($\Phi_{ef}, \Phi_{e\lambda}, \Phi_{e\nu}$) is the ratio of the radiant flux taken over an elementary spectral interval containing the frequency f (or wavelength λ , or wavenumber ν) to that interval:

$$\Phi_{ef} = \frac{d\Phi_e(f)}{df} \quad \left[\frac{\mathrm{W}}{\mathrm{Hz}}\right], \tag{3}$$

$$\Phi_{e\lambda} = \frac{d\Phi(\lambda)}{d\lambda} \quad \left[\frac{\mathrm{W}}{\mathrm{m}}\right], \tag{4}$$

$$\Phi_{e\nu} = \frac{d\Phi(\nu)}{d\nu} \quad \left[\frac{\mathrm{W}}{\mathrm{cm}^{-1}}\right]. \tag{5}$$

Radiant exitance (M_e , measured in $\mathrm{W/m^2}$) is the quotient of the radiant flux $d\Phi_e$ leaving an element of the surface containing the point, by the area dA of that element:

$$M_e = \frac{d\Phi_e}{dA}. \tag{6}$$

Radiant intensity (I_e ,measured in W/sr) is the quotient of the radiant flux $d\Phi_e$ leaving the source and propagated in the element of solid angle $d\Omega$ containing the given direction, by the element of solid angle:

$$I_e = \frac{d\Phi_e}{d\Omega}. \tag{7}$$

Spectral radiant intensity ($I_{ef}, I_{e\lambda}, I_{e\nu}$) is the quantity defined by formulae

$$I_{ef} = \frac{d\Phi}{d\Omega \cdot df} \quad \left[\frac{\mathrm{W}}{\mathrm{sr \cdot Hz}}\right], \tag{8}$$

$$I_{e\lambda} = \frac{d\Phi}{d\Omega \cdot d\lambda} \quad \left[\frac{\mathrm{W}}{\mathrm{sr \cdot m}}\right], \tag{9}$$

$$I_{e\nu} = \frac{d\Phi}{d\Omega \cdot d\nu} \quad \left[\frac{\mathrm{W}}{\mathrm{sr \cdot cm^{-1}}}\right]. \tag{10}$$

Radiance (L_e , measured in $\mathrm{W}/\left(\mathrm{m^2 sr}\right)$) is the quantity defined by formula

$$L_e = \frac{d\Phi}{dA \cdot \cos\theta \cdot d\Omega}, \tag{11}$$

where $d\Phi$ is the radiant flux transmitted by an elementary beam passing though the given point and propagating in the solid angle $d\Omega$ containing the given direction; dA is the area of a section of that beam containing the given point; θ is the angle between the normal to that section and the direction of the beam.

Spectral radiance ($L_{ef}, L_{e\lambda}, L_{e\nu}$) is the quantity defined by formulae

$$L_{ef} = \frac{d\Phi}{dA \cdot \cos\theta \cdot d\Omega \cdot df} \quad \left[\frac{\mathrm{W}}{\mathrm{m^2 sr \cdot Hz}}\right], \tag{12}$$

$$L_{e\lambda} = \frac{d\Phi}{dA \cdot \cos\theta \cdot d\Omega \cdot d\lambda} \quad \left[\frac{\mathrm{W}}{\mathrm{m^3 sr}}\right], \tag{13}$$

$$L_{e\nu} = \frac{d\Phi}{dA \cdot \cos\theta \cdot d\Omega \cdot d\nu} \quad \left[\frac{\mathrm{W}}{\mathrm{m^2 sr \cdot cm^{-1}}}\right], \tag{14}$$

where $d\Phi$ is the radiant flux transmitted by an elementary beam passing though the given point and propagating in the solid angle $d\Omega$ containing the given direction; dA is the area of a section of that beam containing the given point; θ is the angle between the normal to that section and the direction of the beam; $df, d\lambda,$ and $d\nu$ are the elementary spectral intervals in frequency, wavelength, and wavenumber scale, respectively.

The radiance is related to the spectral radiance by the following equations:

$$L_e = \int_0^\infty L_{ef}(f)df\ , \tag{15}$$

$$L_e = \int_0^\infty L_{e\lambda}(\lambda)d\lambda\ , \tag{16}$$

$$L_e = \int_0^\infty L_{e\nu}(\nu)d\nu\ , \tag{17}$$

Relative spectral responsivity ($S(f), S(\lambda), S(\nu)$) is the quotient of the detector output (signal) by its input at given frequency, wavelength, or wavenumber (e.g., spectral radiant flux). Relative spectral responsivity is expressed in arbitrary units.

In-band radiance ($L_{e,ib}$, measured in $\mathrm{W}/(\mathrm{m^2 sr})$)

$$L_{e,ib} = \frac{\int_0^\infty S(f)L_{ef}(f)df}{\int_0^\infty S(f)df} = \frac{\int_0^\infty S(\lambda)L_{e\lambda}(\lambda)d\lambda}{\int_0^\infty S(\lambda)d\lambda} = \frac{\int_0^\infty S(\nu)L_{e\nu}(\nu)d\nu}{\int_0^\infty S(\nu)d\nu}\ . \tag{18}$$

Planck's law is expressed the spectral radiance of a perfect blackbody as a function of spectral variable (frequency, wavelength or wavenumber) and temperature:

$$L_{ef,bb}(f,T) = \frac{c'_{1L} f^3}{\exp\left(\frac{c'_2 f}{T}\right) - 1}\ , \tag{19}$$

$$L_{e\lambda,bb}(\lambda,T)=\frac{c_{1L}}{\lambda^5}\frac{1}{\exp\left(\frac{c_{2,\lambda}}{\lambda T}\right)-1}, \tag{20}$$

$$L_{e\nu,bb}(\nu,T)=\frac{c''_{1L}\nu^3}{\exp\left(\frac{c''_2\nu}{T}\right)-1}. \tag{21}$$

Wien's displacement law states that the dependences of spectral radiance of a perfect blackbody on wavelength have similar shape at any temperature; the position of distribution's maximum (peak frequency, wavelength, or wavenumber) is inversely proportional to temperature:

$$f_{peak}=b'T, \tag{22}$$

$$\lambda_{peak}=\frac{b}{T}, \tag{23}$$

$$\nu_{peak}=b''T. \tag{24}$$

The maximum of spectral radiation curve has different positions in different spectral scales [5, 6].

Stefan-Boltzmann law is the relationship between the radiant exitance of a perfect blackbody and its temperature:

$$M_e=\sigma T^4. \tag{25}$$

Lambert's law states that for a surface element whose radiance is the same in all directions of the hemisphere above the surface:

$$I_e(\theta)=I_n\cos\theta, \tag{26}$$

where $I_e(\theta)$ and I_n are the radiant intensities of the surface element in a direction at an angle θ from the normal to the surface and in the direction of that normal, respectively.

Lambert's law is often called "*cosine law*"; surface for which Lambert's law is fulfilled is often called "Lambertian", "*perfectly diffuse*" or simply "*diffuse*". Perfect blackbody obeys Lambert's law. For a diffuse radiation source

$$M_e = \pi \cdot L_e . \quad (27)$$

Spectral emissivity (a.k.a. *spectral emittance*) is the ratio of the spectral radiance of the thermal radiator at a given wavelength (frequency or wavenumber) and temperature and in a given direction to the spectral radiance of a perfect blackbody at the same wavelength and temperature. For diffuse radiation sources, spectral radiance does not depend on direction; therefore spectral emissivity is also direction-independent.

Gray source (graybody) is the thermal radiation source whose emissivity does not depend on spectral variable (frequency, wavelength, or wavenumber).

View factor ($F_{A_1-A_2}$) between the two Lambertian surfaces A_1 and A_2 is the ratio of radiant flux leaving A_1 and intercepted by A_2 to the total radiant flux emitted by A_1 .

$$F_{A_1-A_2} = \frac{1}{A_1}\int_{A_1}\int_{A_2} \frac{\cos\theta_1 \cos\theta_2}{\pi d^2} dA_1 dA_2 , \quad (28)$$

where dA_1 and dA_2 are the elements of areas A_1 and A_2, respectively; d is the distance between them; θ_1 and θ_2 are the angles between the line connecting dA_1 and dA_2 and normals to these surfaces (see Fig. 1).

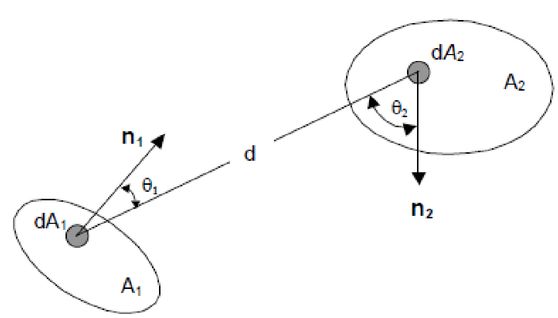


Fig. 1. To the definition of the view factor.

Synonyms of view factor are "*angle factor*", "*form factor*", "*shape factor*", and "*configuration factor*".

Radiance temperature ($T_S(f), T_S(\lambda), T_S(\nu)$) is the perfect blackbody temperature, for which the spectral radiance at the specified frequency, (or wavelength, or wavenumber) has the same value as for the thermal radiation source considered:

$$T_S(f) = \frac{c_2' f}{\ln\left[1 + \frac{c_{1L}' f^3}{L_{ef}(f)}\right]}, \tag{29}$$

$$T_S(\lambda) = \frac{c_{2,\lambda}}{\lambda \ln\left[1 + \frac{c_{1L,\lambda}}{\lambda^5 L_{e\lambda}(\lambda)}\right]}, \tag{30}$$

$$T_S(\nu) = \frac{c_2'' \nu}{\ln\left[1 + \frac{c_{1L,\nu} \nu^3}{L_{ef}(\nu)}\right]}. \tag{31}$$

Radiance temperature is often called "*brightness temperature*".

Radiation temperature (T_R) is the temperature of the perfect blackbody for which the radiance has the same value as for the thermal radiator considered. For the graybody,

$$T_R = T \cdot \sqrt[4]{\varepsilon}. \tag{32}$$

Radiation temperature is sometimes called "*total radiance temperature*".

In-band radiance temperature ($T_{S,ib}$) is the temperature of the perfect blackbody for which in-band radiance has the same value as for thermal radiator considered. For the graybody, $T_{S,ib}$ can be found from one of the following equivalent equations:

$$\int_0^\infty \varepsilon\, S(f) L_{ef,bb}(f,T)\, df = \int_0^\infty S(f) L_{ef,bb}(f,T_{S,ib})\, df, \tag{33}$$

$$\int_0^\infty \varepsilon\, S(\lambda) L_{e\lambda,bb}(\lambda,T)\, d\lambda = \int_0^\infty S(\lambda) L_{e\lambda,bb}(\lambda,T_{S,ib})\, d\lambda, \tag{34}$$

$$\int_0^\infty \varepsilon\, S(\nu) L_{e\nu,bb}(\nu,T)\, d\lambda = \int_0^\infty S(\nu) L_{e\nu,bb}(\nu,T_{S,ib})\, d\nu. \tag{35}$$

Irradiance (E_e , measured in $\mathrm{W/m^2}$) is the quotient of the radiant flux $d\Phi_e$ incident on an element of the surface containing the point, by the area dA of that element.

3.5. Effect of background radiation

In Eqs. (32) – (35) it was supposed that the background radiation is negligible. However, if background radiation falling onto a detector is comparable with the radiation delivered from the source these equations needed in corrections.

The radiance of a diffuse gray source in the presence of background radiation consists of radiation emitted by the source and background radiation reflected by the source:

$$L_e = \frac{\sigma}{\pi}\left[\varepsilon \cdot T^4 + (1-\varepsilon)T_{bg}^4\right], \tag{36}$$

where T_{bg} is the temperature assigned to background.

For the in-band radiance of the thermal radiation source in the presence of background radiation, we obtain:

$$L_{e,ib} = \frac{\int_0^\infty S(f)\left[\varepsilon \cdot L_{ef,bb}(f,T) + (1-\varepsilon)L_{ef,bb}(f,T_{bg})\right]df}{\int_0^\infty S(f)df} = \frac{\int_0^\infty S(\lambda)\left[\varepsilon \cdot L_{e\lambda,bb}(\lambda,T) + (1-\varepsilon)L_{e\lambda,bb}(\lambda,T_{bg})\right]d\lambda}{\int_0^\infty S(\lambda)d\lambda} = \frac{\int_0^\infty S(\nu)\left[\varepsilon \cdot L_{e\nu,bb}(\nu,T) + (1-\varepsilon)L_{e\nu,bb}(\nu,T_{bg})\right]d\nu}{\int_0^\infty S(\nu)d\nu}. \tag{37}$$

Expression for radiation temperature with the account of background radiation has to be re-written in form:

$$T_R = \sqrt[4]{\varepsilon \cdot T^4 + (1-\varepsilon)T_{bg}^4} \,. \tag{38}$$

In different spectral scales, we obtain the following equivalent equations for the in-band radiance temperature:

$$\int_0^\infty S(f)\left[\varepsilon\, L_{ef,bb}(f,T) + (1-\varepsilon)L_{ef,bb}\left(f,T_{bg}\right)\right]df = \int_0^\infty S(f)L_{ef,bb}\left(f,T_{S,ib}\right)df \,, \tag{39}$$

$$\int_0^\infty S(\lambda)\left[\varepsilon\, L_{e\lambda,bb}(\lambda,T) + (1-\varepsilon)L_{e\lambda,bb}\left(\lambda,T_{bg}\right)\right]d\lambda = \int_0^\infty S(\lambda)L_{e\lambda,bb}\left(\lambda,T_{S,ib}\right)d\lambda \,, \tag{40}$$

$$\int_0^\infty S(\nu)\left[\varepsilon\, L_{e\nu,bb}(\nu,T) + (1-\varepsilon)L_{e\nu,bb}\left(\nu,T_{bg}\right)\right]d\nu = \int_0^\infty S(\nu)L_{e\nu,bb}\left(\nu,T_{S,ib}\right)d\nu \,. \tag{41}$$

For in-depth studying of optical radiometry, radiation thermometry, and radiative heat transfer we recommend books [7 - 18].

4. WORKING WITH RADICAL

4.1. Installation of RADICAL

RADICAL does not require special efforts for installation. Simply download the Evaluation version of the program from www.virial.com, unzip radical.zip to any place of the hard drive, and run radical.exe. The following window will appear:

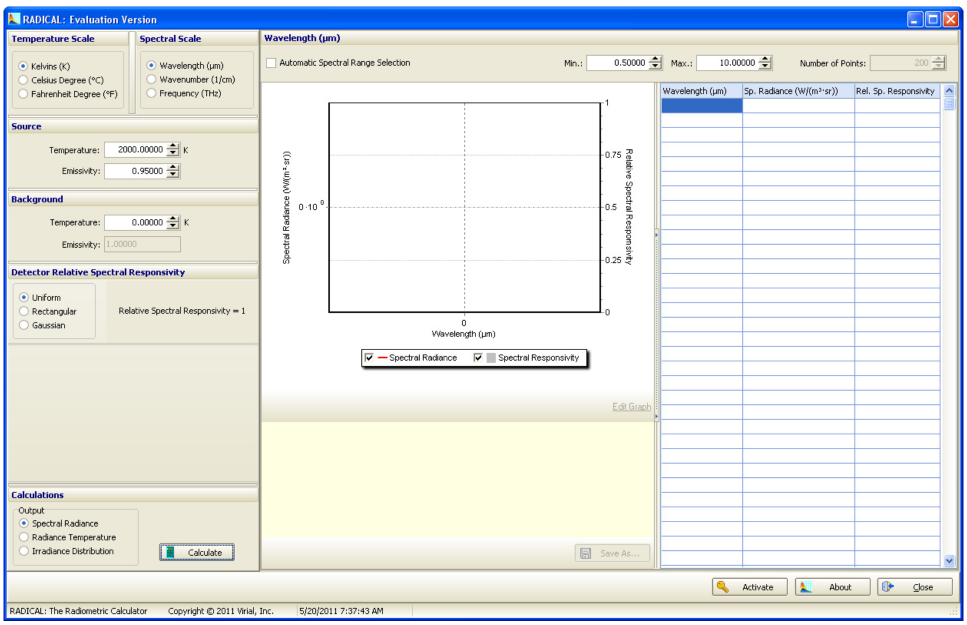


Fig. 2. **RADICAL** before activation (Evaluation Version)

Press 

; the Activation window will appear:

Fig. 3. Activation window

Enter the activation key then press 

. This turns Evaluation version into full-functioned program:

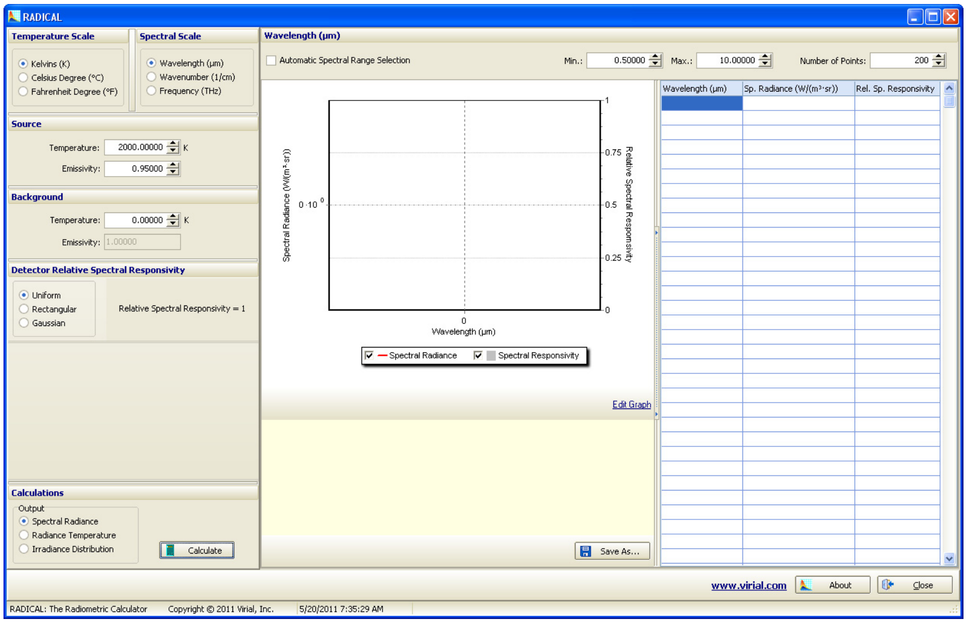


Fig. 4. **RADICAL** after activation (full-functioned program)

4.2. Calculations with RADICAL

RADICAL provides work in three modes for calculation Spectral Radiance, Radiance Temperature, and Irradiance Distribution, respectively (see Fig. 5).

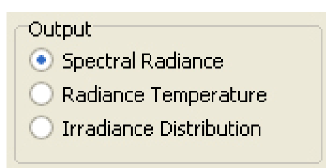
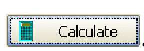


Fig. 5. Selector of output quantities

Calculations are performed after pressing 

. For any calculation mode, it is necessary:

1. Choose the temperature scale (see Fig. 6):

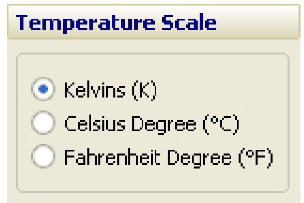


Fig. 6. Temperature Scale Selector

2. Enter temperature and emissivity of the thermal radiation source (see Fig. 7):

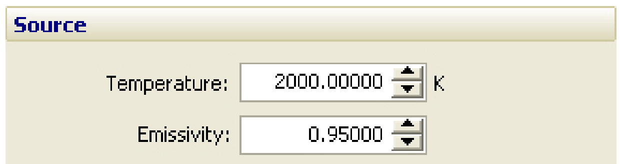


Fig. 7. Source Parameters input fields

3. Enter temperature of background (it is supposed that emissivity of background equals 1; see Fig. 8):

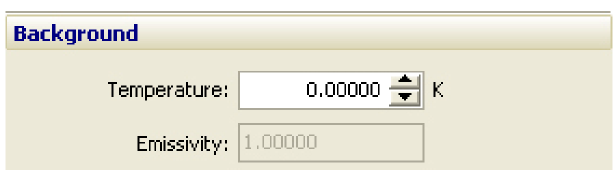


Fig. 8. Background Temperature input field

4.2.1. Calculation of spectral radiance and radiance temperature

For calculation of spectral radiance and radiance temperature values that will be used for graph plotting and filling the table you have to enter the number of points and can use automatic (see Fig. 9) or manual entering mode for left and right bounds of the spectral interval. In the case of automatic selection of the spectral range (Fig. 9), the value of Threshold chosen from the dropdown list determines the left and the right bounds of the spectral range at which spectral radiance decreases down to Threshold value relative to its maximum value.

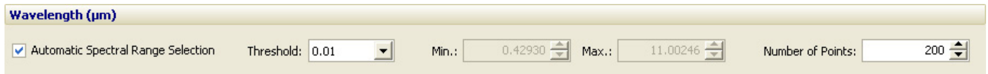
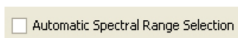


Fig. 9. Automatic selection of the spectral range; wavelength scale; checkbox is checked

If the checkbox 

is unchecked, you have to enter bounds of the spectral scale manually.

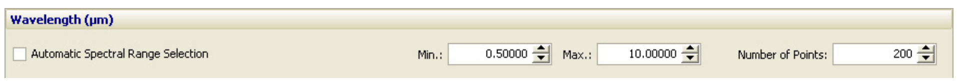


Fig. 10. Manual selection of the spectral range; wavelength scale; checkbox is unchecked

Increment of the spectral scale is determines by formulae:

$$\Delta f = (f_{\max} - f_{\min})/(n-1), \quad (42)$$

$$\Delta \lambda = (\lambda_{\max} - \lambda_{\min})/(n-1), \quad (43)$$

$$\Delta \nu = (\nu_{\max} - \nu_{\min})/(n-1), \quad (44)$$

where n is the number of spectral points.

For the spectral radiance and the radiance temperature calculation you can also choose the shape of the detector relative spectral responsivity shape. If “Uniform” is selected (see Fig. 11), in-band values won’t be computed.

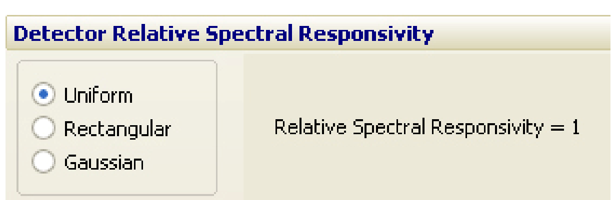


Fig. 11. Detector Relative Spectral Responsivity selector

For rectangular shape of the detector relative spectral responsivity, the mean value and the width of the detector's responsivity band have to be entered (see Fig. 12).

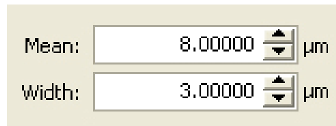


Fig. 12. Fields for entering the mean value and the band width of the detector relative spectral responsivity with rectangular shape

In such a case the detector relative spectral responsivity is expressed as

$$S(Z) = \begin{cases} 0, & if \ 0 < Z < Z_{mean} - \frac{1}{2} \cdot w_Z \\ 1, & if \ Z_{mean} - \frac{1}{2} \cdot w_Z \le Z \le Z_{mean} + \frac{1}{2} \cdot w_Z \\ 0, & if \ Z_{mean} + \frac{1}{2} \cdot w_Z < Z < \infty \end{cases}, \tag{45}$$

where Z is the spectral variable ($f, \lambda,$ or ν), Z_{mean} is the position of the center of the detector spectral responsivity band, w_Z is its width.

For Gaussian shape of the detector relative spectral responsivity, the mean value and the FWHM (Full Width at Half Maximum) of the detector's responsivity band have to be entered (see Fig. 13).

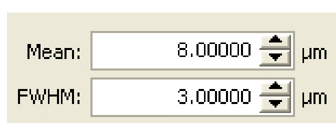


Fig. 13. Fields for entering the mean value and the FWHM of the detector relative spectral responsivity with Gaussian shape

Gaussian relative spectral responsivity can be written in form:

$$S(Z)=\begin{cases}0, & if\ Z\le 0\\ \exp\left[-\left(\dfrac{Z-Z_{mean}}{s_Z\sqrt{2}}\right)^2\right], & if\ Z>0,\end{cases} \qquad (45)$$

where Z is the spectral variable ($f,\lambda,\text{or }\nu$), Z_{mean} is the position of the mean value (position of the center) of the Gaussian spectral responsivity curve, s_Z is its standard deviation; $\text{FWHM}=s_Z 2\sqrt{2\ln 2}\approx 2.354\,820\,045\cdot \text{s}_Z$.

Figures 14 – 16 show calculation results for the spectral radiance; the initial data and results of numerical integration are shown below the graphs.

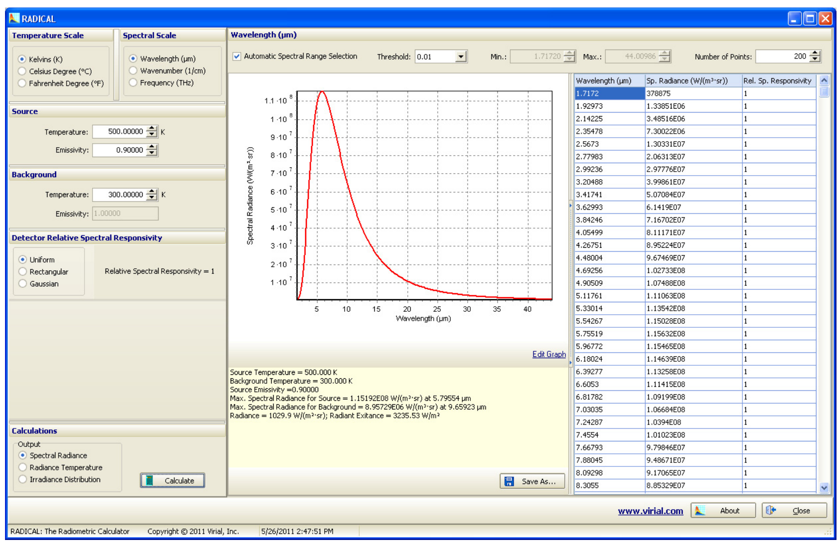


Fig. 14. Calculation results for the spectral radiance; detector has the uniform spectral responsivity (integration over the spectral range from 0 to ∞)

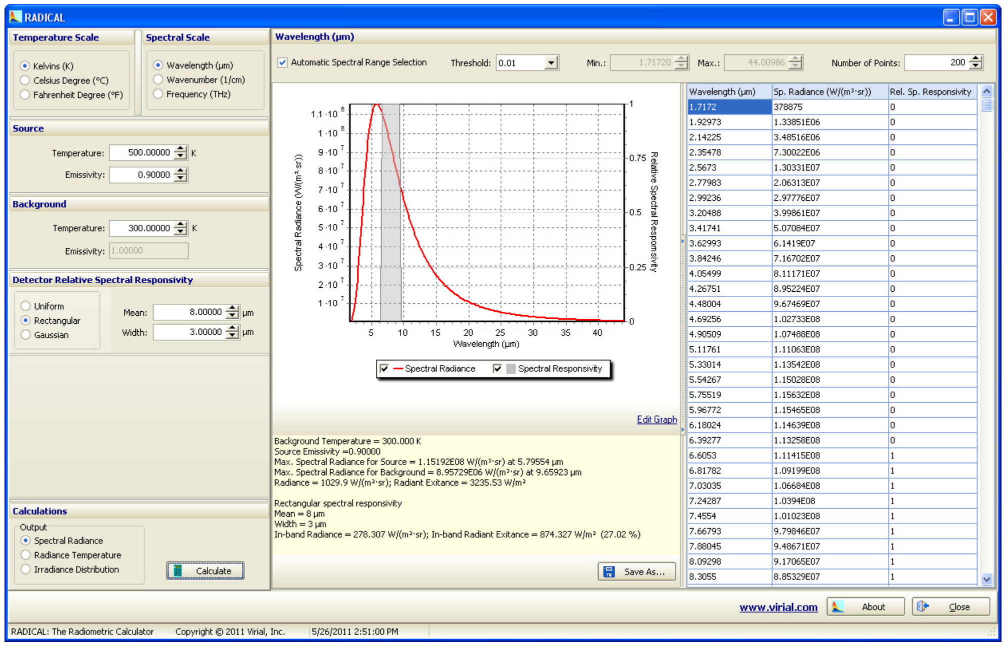


Fig. 15. Calculation results for the spectral radiance; detector has the rectangular spectral responsivity

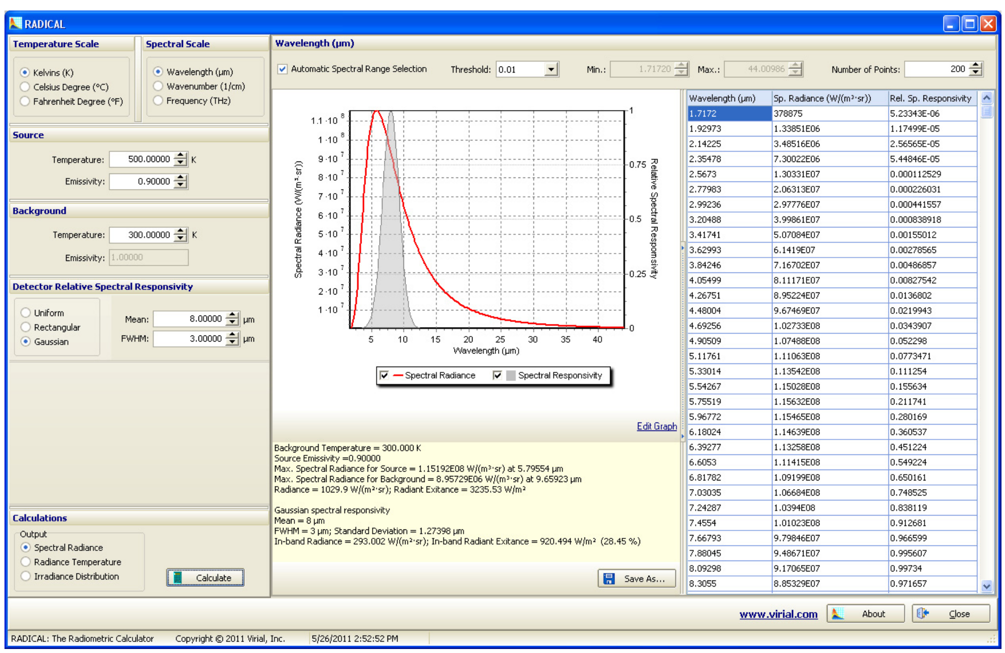
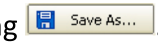


Fig. 16. Calculation results for the spectral radiance; detector has the Gaussian spectral responsivity

All initial data and calculation results can be saved in the text file after pressing 

. The text (ASCII) file saved will contain the text, and example of which is shown below:

Source Temperature = 2000.000 K
Background Temperature = 0.000 K
Source Emissivity =0.95000
Max. Spectral Radiance = 1.24509E11 W/(m^3·sr) at 1.44888 µm
Radiance = 274352 W/(m^2·sr); Radiant Exitance = 861901 W/m^2

Gaussian spectral responsivity
Mean = 4.75 µm
FWHM = 0.95 µm; Standard Deviation = 0.403428 µm
In-band Radiance = 13903.4 W/(m^2·sr); In-band Radiant Exitance = 43678.7 W/m^2 (5.07 %)

WL (µm)	SR (W/(m^3·sr))	Rel. Resp.
0.5	2.0430542E09	7.9601781E-25
0.54773869	4.5379458E09	2.7496307E-24
0.59547739	8.5640336E09	9.3657961E-24
0.64321608	1.4276559E10	3.1458192E-23
0.69095477	2.1615171E10	1.0419373E-22
……………………		
4.1281407	2.0027849E10	0.30482526
4.1758794	1.9372131E10	0.36326766
4.2236181	1.8741776E10	0.4268952
4.2713568	1.8135697E10	0.4946916
4.3190955	1.7552852E10	0.56528381
4.3668342	1.6992245E10	0.63696753
4.4145729	1.6452927E10	0.70776125
4.4623116	1.5933989E10	0.77548787
4.5100503	1.5434566E10	0.83788029
……………………		
9.7613065	1.1717609E09	3.1178337E-34
9.8090452	1.1514293E09	7.1193443E-35
9.8567839	1.1315345E09	1.6030453E-35
9.9045226	1.1120654E09	3.5593469E-36
9.9522613	1.093011E09	7.7931599E-37
10	1.074361E09	1.6825795E-37

You can also (if you wish) to collapse or expand again the table with the calculation results as it is shown in Figs. 17 and 18.

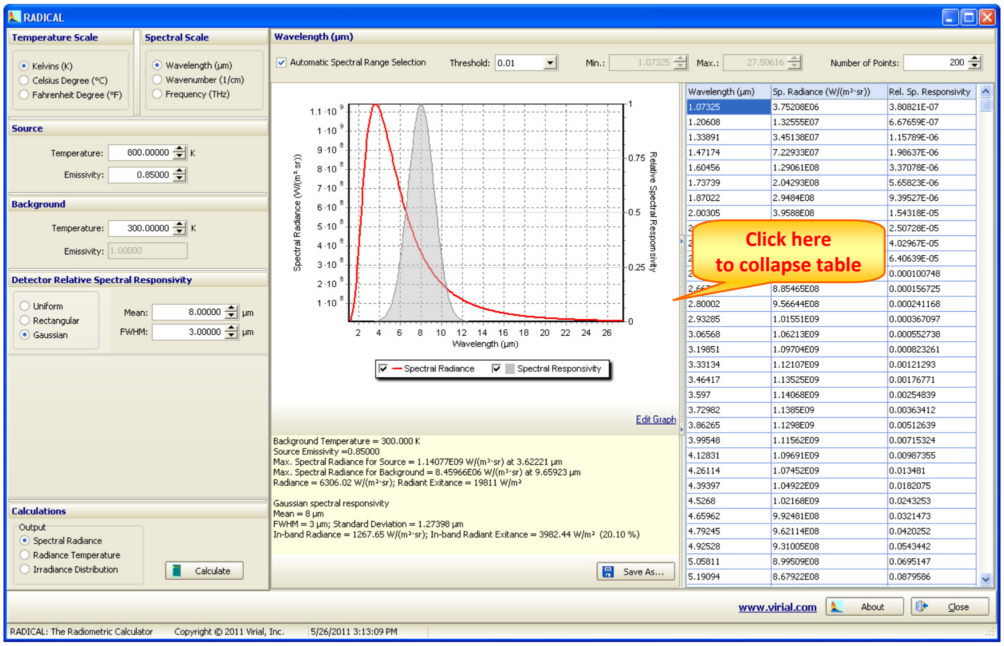


Fig. 17. How to collapse the table

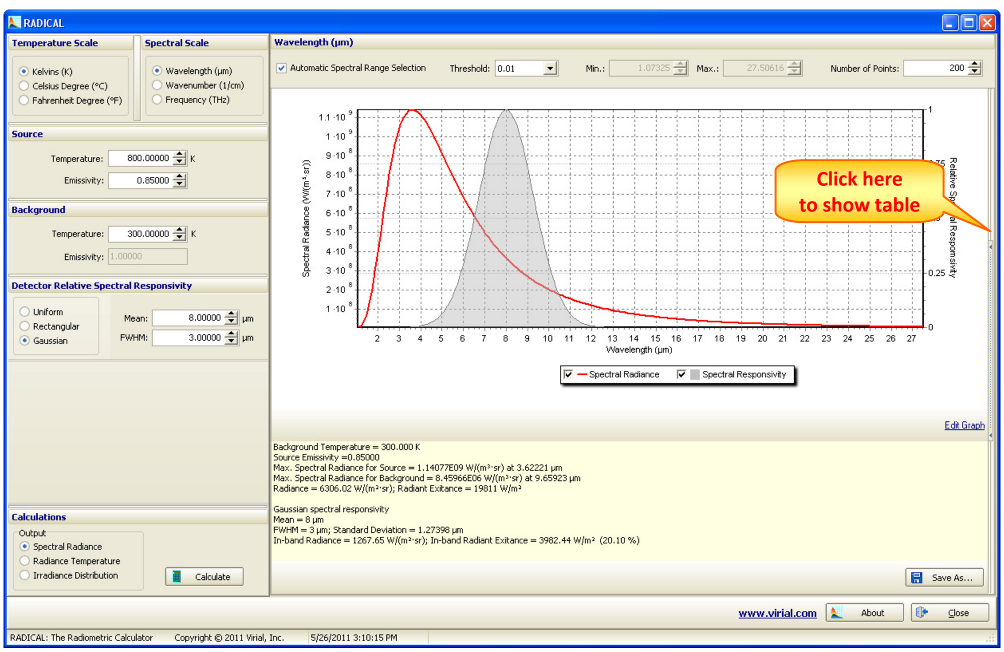


Fig. 18. How to restore the table after collapsing

An example of the radiance temperature calculations is shown in Fig. 19.

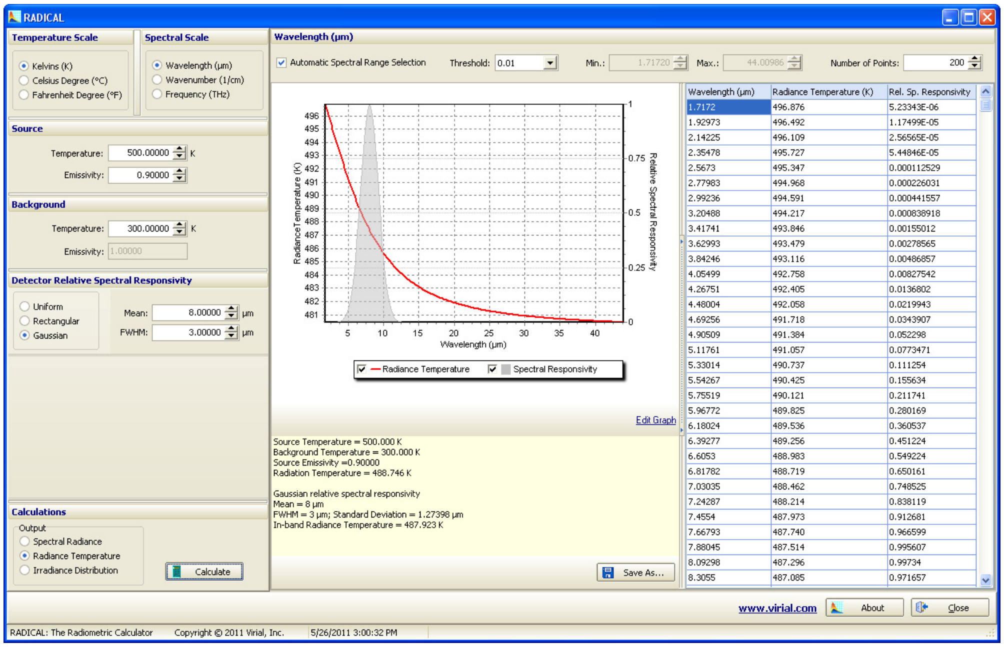


Fig. 19. An example of the radiance temperature calculations

The initial data and results saved in text file for this case will look like:

Source Temperature = 500.000 K
Background Temperature = 300.000 K
Source Emissivity = 0.90000
Radiation Temperature = 488.746 K

Gaussian relative spectral responsivity
Mean = 8 µm
FWHM = 3 µm; Standard Deviation = 1.27398 µm
In-band Radiance Temperature = 487.923 K

WL (µm)	RT (K)	Rel. Resp.
1.7172	496.87595	5.233431E-06
1.9297259	496.49215	1.1749917E-05
2.1422519	496.10916	2.5656484E-05
2.3547778	495.7272	5.4484568E-05
…………		
7.0303482	488.4622	0.74852501
7.2428742	488.21359	0.83811893
7.4554001	487.97276	0.91268103
7.667926	487.7396	0.96659921
7.880452	487.51396	0.99560689
8.0929779	487.29569	0.99734035
8.3055038	487.08462	0.97165688
8.5180297	486.88059	0.92065414
8.7305557	486.68341	0.84838725

8.9430816	486.49289	0.76033643
9.1556075	486.30884	0.66272217
9.3681335	486.13107	0.56178644
………………………		
43.372282	480.44582	3.9882751E-168
43.584808	480.4416	3.8298832E-170
43.797334	480.43745	3.576844E-172
44.00986	480.43334	3.2488414E-174

4.2.2. Calculation of irradiance distribution

Before calculation of irradiance distribution and radiant flux falling onto the detector, you have to enter geometrical parameters as it is shown in Fig. 20. Number of point, N defines the increment $\Delta X = X_{\max}/(N-1)$ which will be used for filling the table and graph plotting from $X = 0$ to $X = X_{\max}$. Geometry of the system is depicted schematically in Fig. 21.

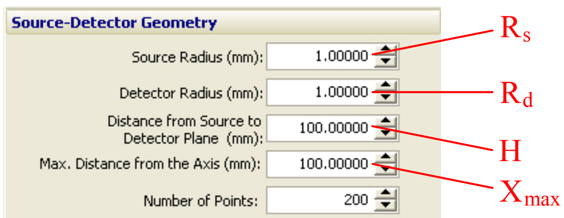


Fig. 20. Fields for entering the geometrical parameters

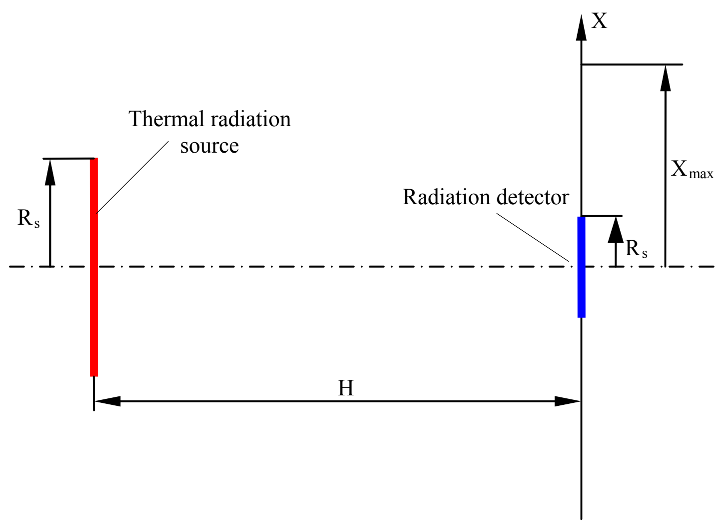


Fig. 21. Source-detector geometry schematic

Two examples of irradiance calculation are shown in Figs. 22 (Kelvin temperature scale) and 23 (Celsius temperature scale, background temperature is −273.15ºC, i.e. $T_{bg} = 0\,\mathrm{K}$). Since irradiation produced by the background is uniform, it is convenient to hold "Irradiance from Background" checkbox in the graph legend unchecked.

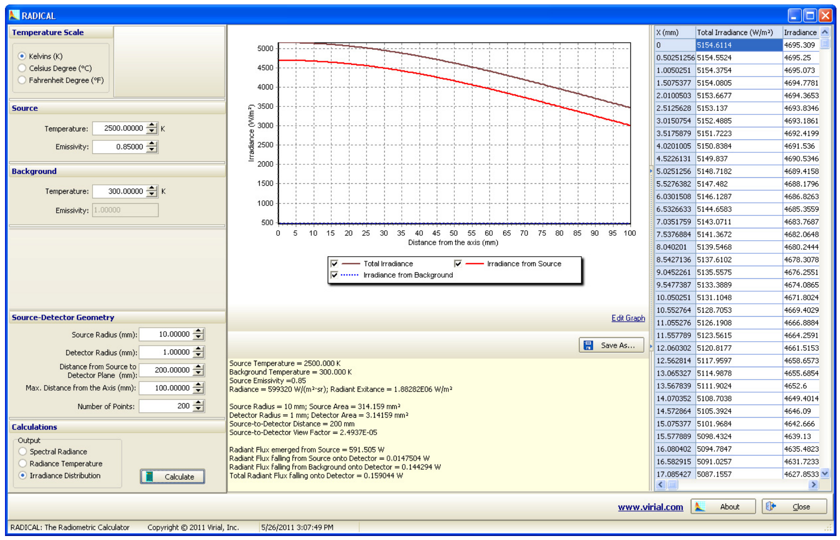


Fig. 22. Examples of irradiance calculation; irradiation from background is constant; the appropriate checkbox in the graph legend is checked

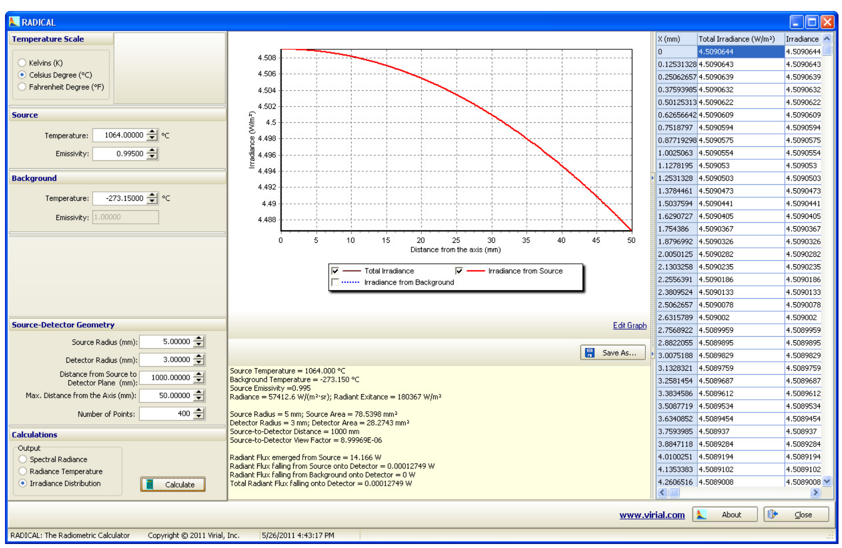


Fig. 23. Examples of irradiance calculation; irradiation from background is zero; the appropriate checkbox in the graph legend is unchecked

A fragment of the text file contained the initial data and results of the irradiance distribution calculation is presented below:

Source Temperature = 2500.000 K
Background Temperature = 300.000 K
Source Emissivity = 0.85
Radiance = 599320 W/(m²·sr); Radiant Exitance = 1.88282E06 W/m²

Source Radius = 10 mm; Source Area = 314.159 mm²
Detector Radius = 1 mm; Detector Area = 3.14159 mm²
Source-to-Detector Distance = 200 mm
Source-to-Detector View Factor = 2.4937E-05

Radiant Flux emerged from Source = 591.505 W
Radiant Flux falling from Source onto Detector = 0.0147504 W
Radiant Flux falling from Background onto Detector = 0.144294 W
Total Radiant Flux falling onto Detector = 0.159044 W

X (mm)	IRsource (W/m²)	IRbg (W/m²)	IR (W/m²)
0	4695.309	459.3024	5154.6114
0.50251256	4695.25	459.3024	5154.5524
1.0050251	4695.073	459.3024	5154.3754
1.5075377	4694.7781	459.3024	5154.0805
2.0100503	4694.3653	459.3024	5153.6677
2.5125628	4693.8346	459.3024	5153.137
3.0150754	4693.1861	459.3024	5152.4885
3.5175879	4692.4199	459.3024	5151.7223
4.0201005	4691.536	459.3024	5150.8384
4.5226131	4690.5346	459.3024	5149.837
5.0251256	4689.4158	459.3024	5148.7182
5.5276382	4688.1796	459.3024	5147.482
6.0301508	4686.8263	459.3024	5146.1287
6.5326633	4685.3559	459.3024	5144.6583

……

4.3. Working with graphs

RADICAL allows plotting a magnified fragment of the graph: holding left mouse button depressed, drag the cursor right and downwards to zoom (see Fig. 24) and left and upwards to unzoom.

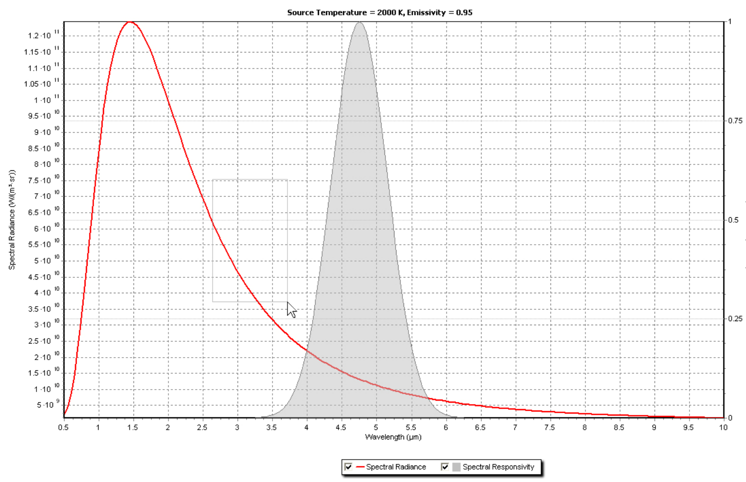
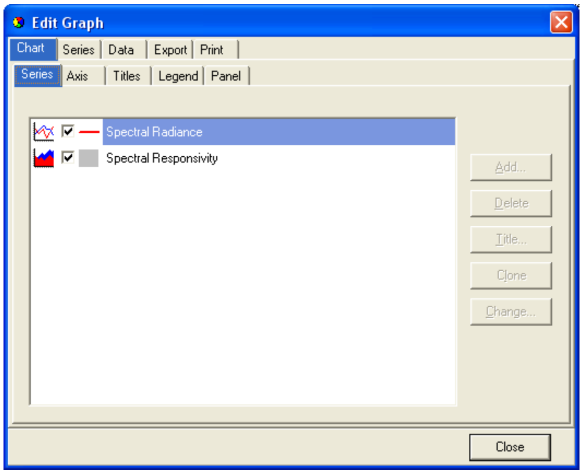


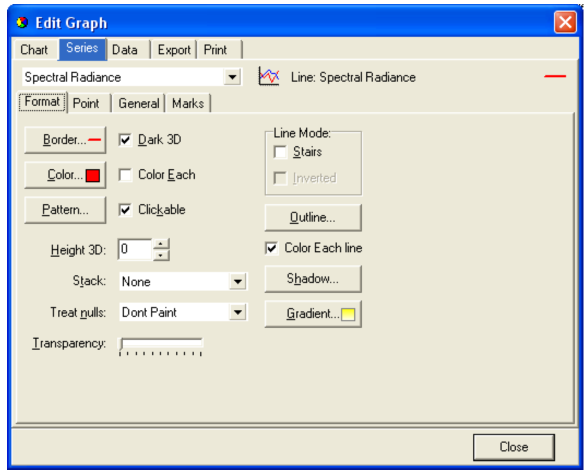
Fig. 24. Use of zoom

To displace curves relative to graph axes, hold the left mouse button depressed and move cursor. To restore graph original position, draw a rectangle of arbitrary size by moving from the bottom right corner to the top left one while left mouse button remains pressed.

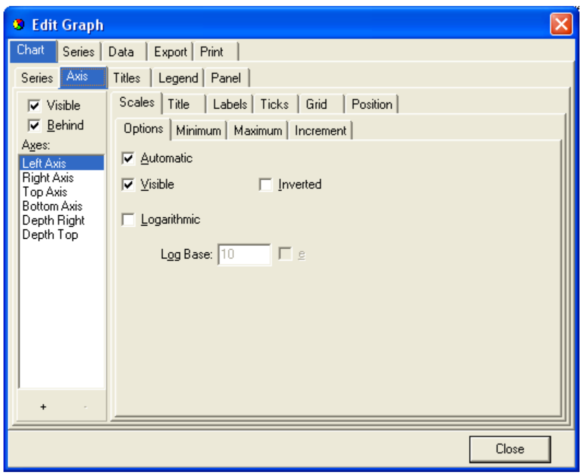
Click the link Edit Graph below the graph which should be edited to call the Graph Editor that has intuitive interface and provides comprehensive access to the most of the editable properties of each graph (see Figs. 25A and 25B).



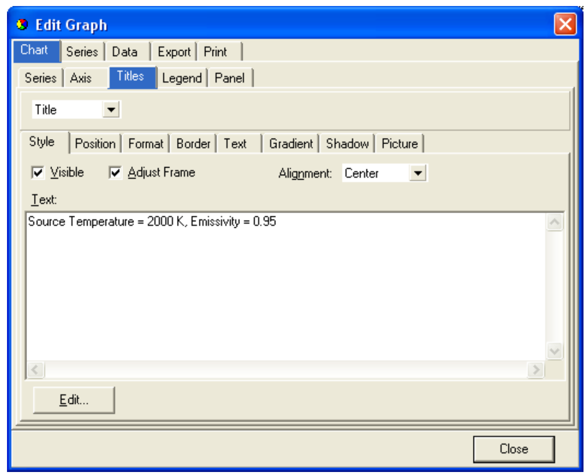
Access to individual series (curves)



Formatting the series



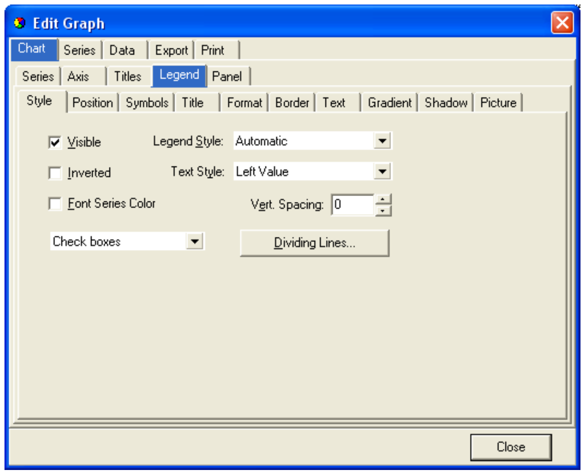
Editing the graph axes



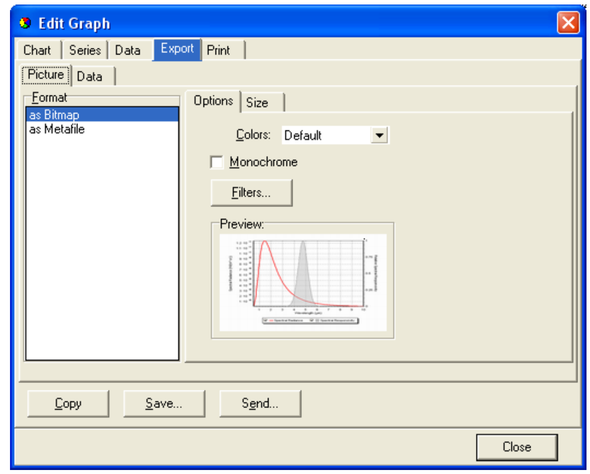
Editing the title

Fig. 25A. Screenshots that demonstrate general possibilities of the Graph Editor

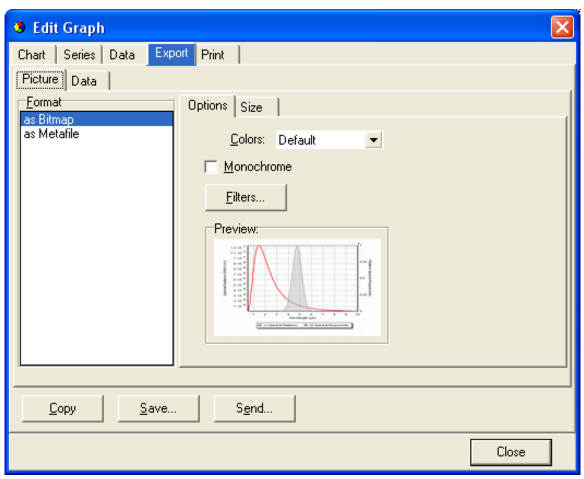
Graph Editor provides access to individual curves (series) allowing to edit all elements of the graph (points, axes, legend, title, etc.) and adjust their properties. The Graph Editor gives the possibility of copying to clipboard, saving in the file, and printing graphs, as well as exporting series values in formats of text (ASCII) file, MS Excel spreadsheet, HTML and XML tables.



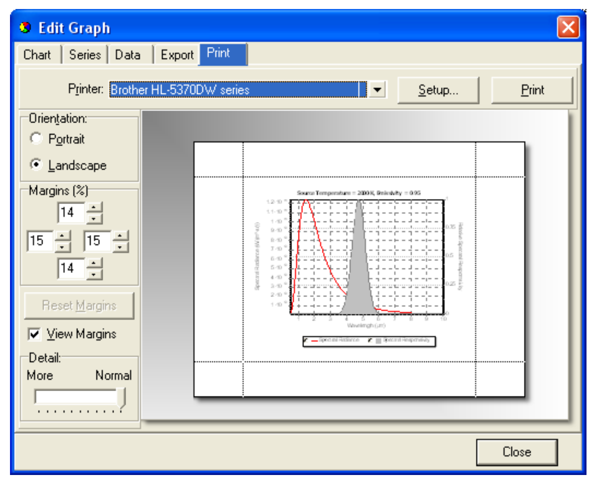
Formatting the graph legend



Data Export



Graph copying and saving



Graph printing

Fig. 25B. Screenshots that demonstrate general possibilities of the Graph Editor

5. EVALUATION VERSION VS. FULL-FUNCTIONED PROGRAM

RADICAL will work in Evaluation mode until you activated it by entering activation key you'll obtain as soon as the license will be purchased. Evaluation Version of **RADICAL** uses the same computational procedures as the full-functioned program but has several restrictions:

1. Evaluation version doesn't allow entering initial values using keyboard; they can be changed only using spinners that have fixed increments.
2. Content of tables and auxiliary information cannot be saved in text files.
3. Graphs cannot be edited.

Procedure of activation **RADICAL** is described in Section 4.1.

6. REFERENCES

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