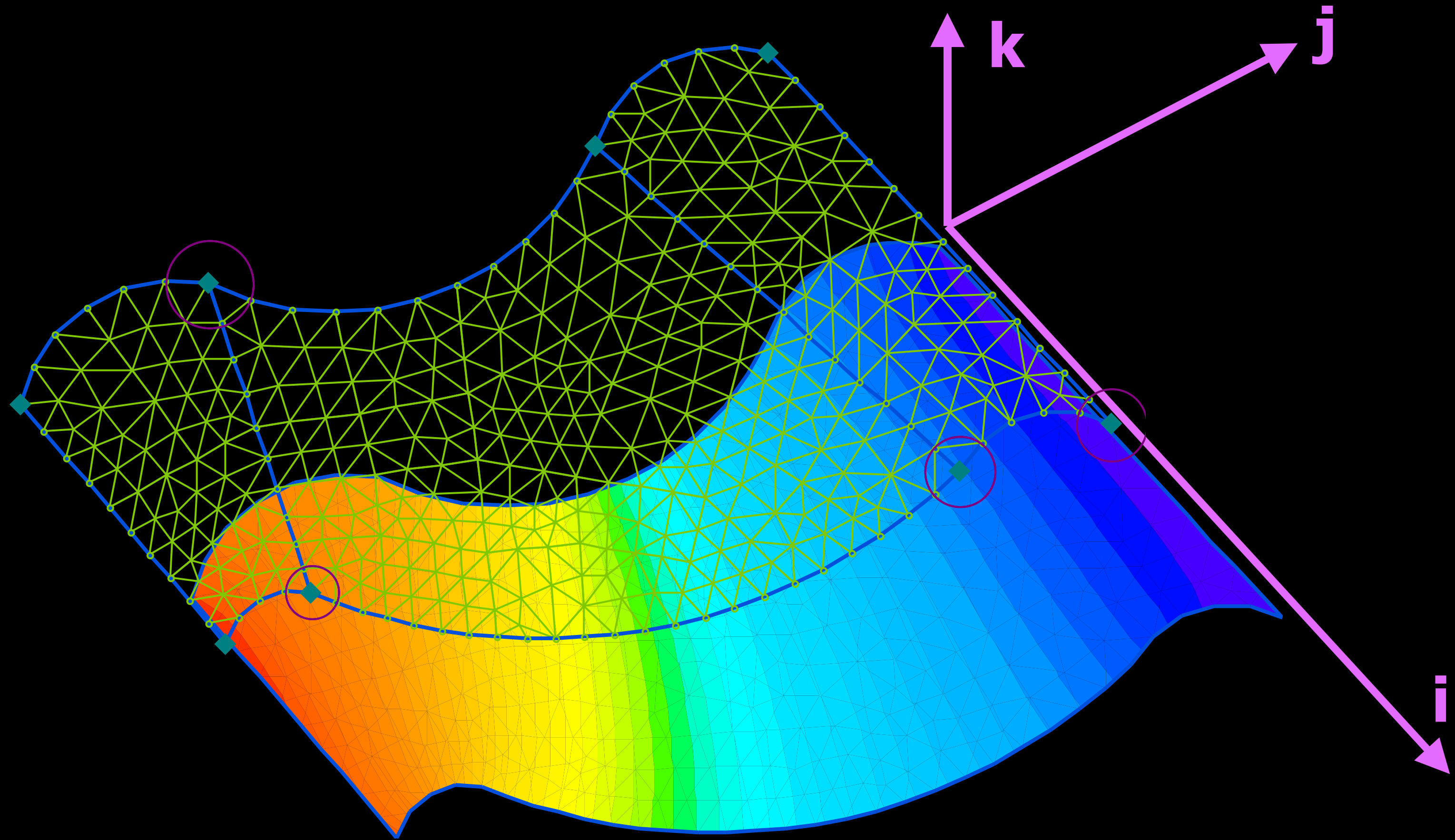
Application of QuickField Software to Heat Transfer Problems



By Dr. Evgeni Volpov

Basic Formulations for GIS HT model

Classical Heat Transfer Equations

Heat-transfer equation for linear problems is:

$$\frac{\partial}{\partial x}\left(\lambda_x \frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\lambda_y \frac{\partial T}{\partial y}\right)=-q-c\rho\frac{\partial T}{\partial t}$$ - planar case;

$$\frac{1}{r}\frac{\partial}{\partial r}\left(\lambda_r r \frac{\partial T}{\partial r}\right)+\frac{\partial}{\partial z}\left(\lambda_z \frac{\partial T}{\partial z}\right)=-q-c\rho\frac{\partial T}{\partial t}$$ - axisymmetric case;

for nonlinear problems:

$$\frac{\partial}{\partial x}\left(\lambda(T)\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\lambda(T)\frac{\partial T}{\partial y}\right)=-q(T)-c(T)\rho\frac{\partial T}{\partial t}$$ - planar case;

$$\frac{1}{r}\frac{\partial}{\partial r}\left(\lambda(T) r \frac{\partial T}{\partial r}\right)+\frac{\partial}{\partial z}\left(\lambda(T)\frac{\partial T}{\partial z}\right)=-q(T)-c(T)\rho\frac{\partial T}{\partial t}$$ - axisymmetric case;

where:

T - temperature;
t - time;
$\lambda_{x(y,r,z)}$ - components of heat conductivity tensor;
$\lambda(T)$ - heat conductivity as a function of temperature approximated by cubic spline (anisotropy is not supported in nonlinear case);
$q(T)$ - volume power of heat sources, in linear case - constant, in nonlinear case - function of temperature approximated by cubic spline;
$c(T)$ - specific heat, in nonlinear case - function of temperature approximated by cubic spline;
ρ - density of the substance.

In linear case all the parameters are constants within each block of the model.

Boundary Conditions

1. $T(S) = T_0$ Const Temperature

$T(S) = T_0 + k.S$ Linear Temp.

2. $F_n = -q_s$ Flux

$F_n(+) - F_n(-) = -q_s$

3. $F_n = a(T - T_0)$ Convection

a - film coefficient

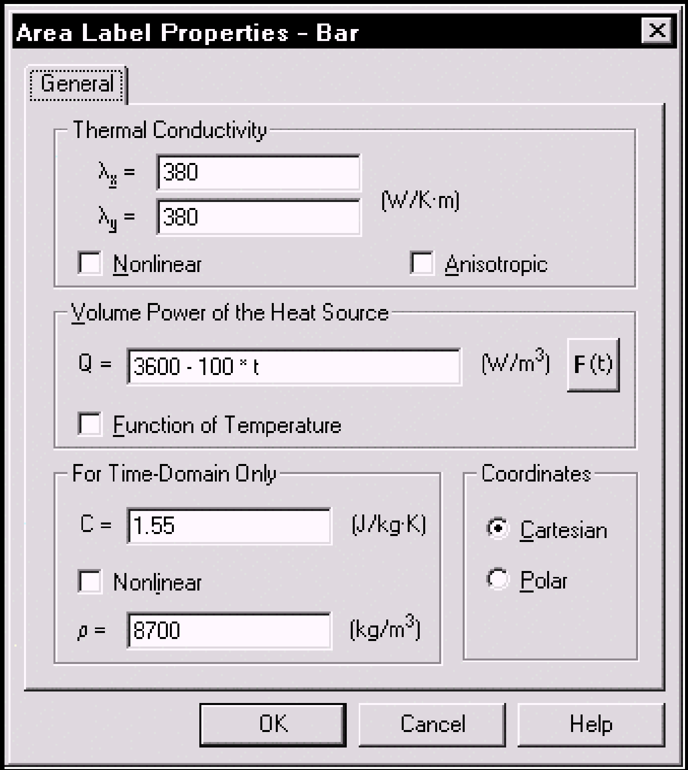
T_0 – temperature of contacting medium

4. $F_n = b.K_{sb}(T^4 - T_0^4)$ Radiation

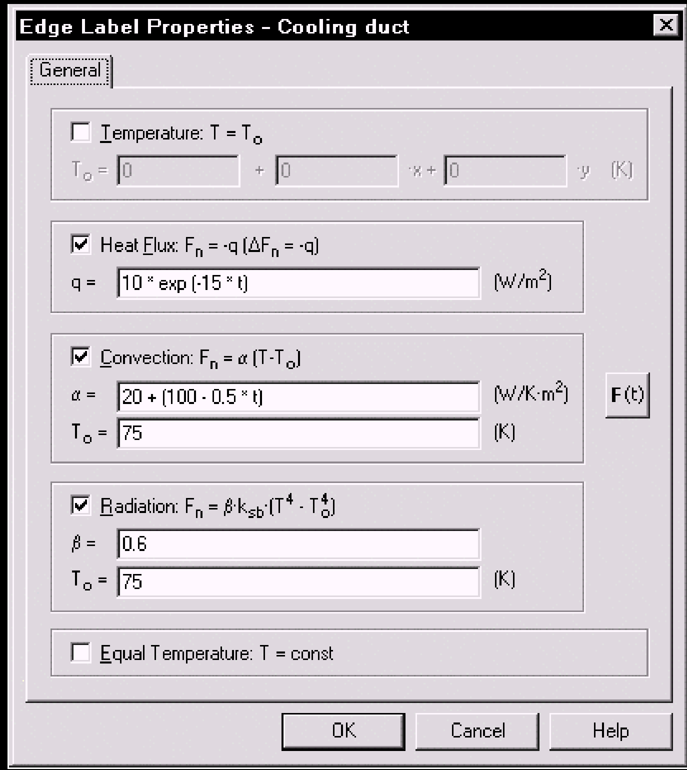
K_{sb} - Stephan-Boltzmann constant;

b - emissivity coefficient

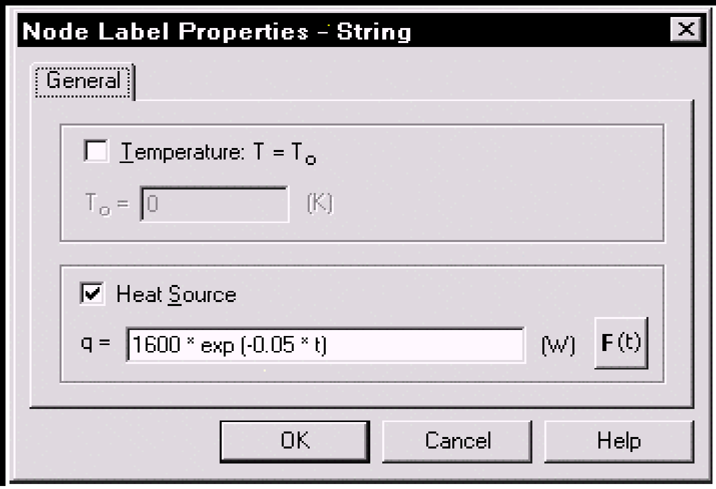
Boundary conditions & domain characterization



Volume element

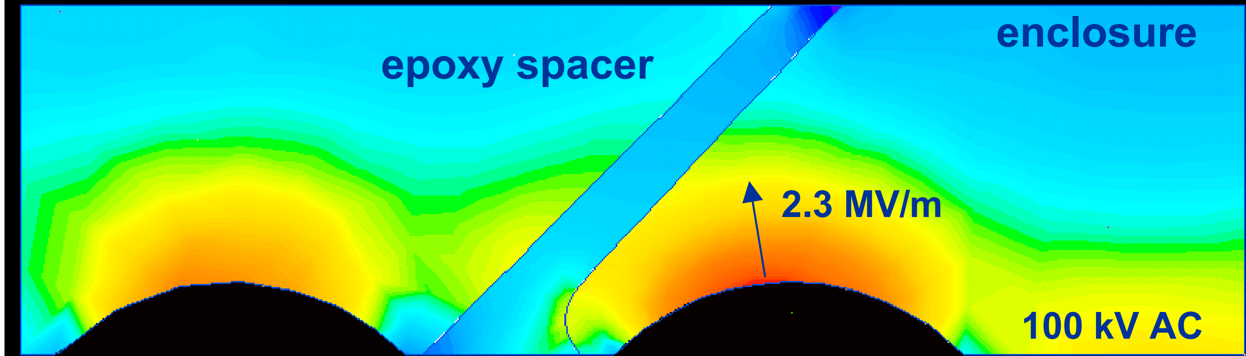


Surface element

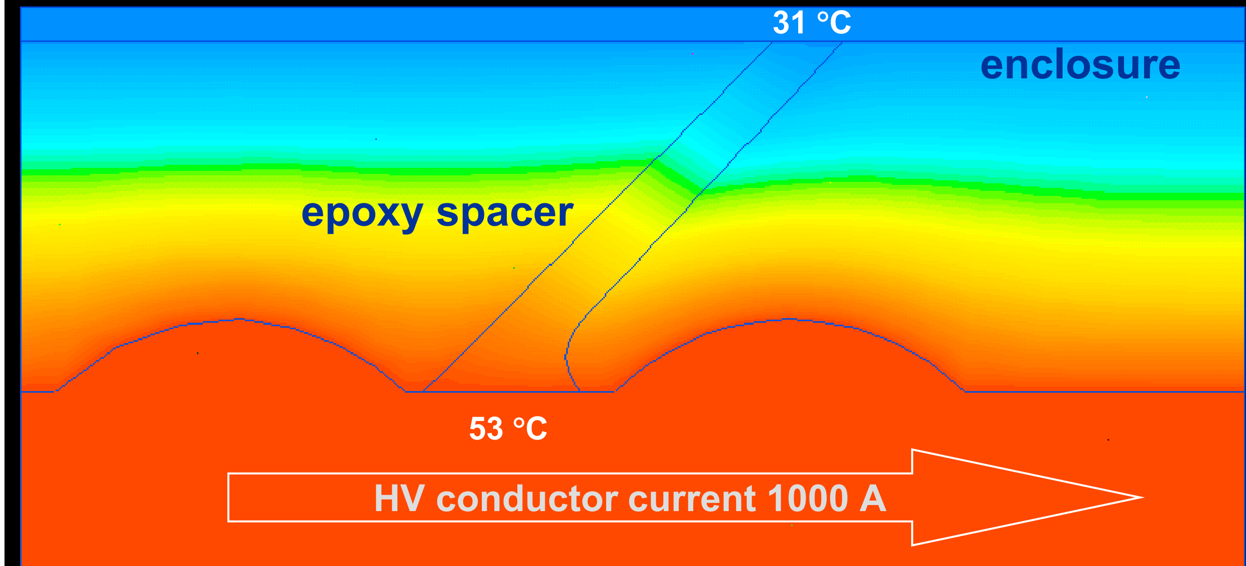


Point-Source element

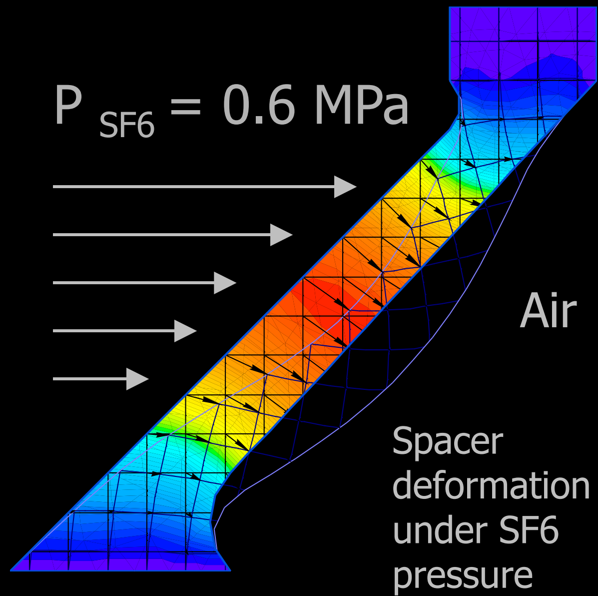
Coupling Problems solution for SF6 GIS 170 kV



Electric Field distribution in GIS compartment



Thermo-static field mapping in GIS compartment



SF6 GIS HT Model Parameters

1. SF6 Thermal Conductivity λ_g = 0.0136 W/m.K
2. Air Thermal Conductivity λ_a = 0.026 W/m.K
3. Epoxy Thermal Conductivity $\lambda_e \in$ (0.3-0.6) W/m.K
4. Aluminum Thermal Conductivity $\lambda_{al} \in$ (140-220) W/m.K
5. Copper Thermal Conductivity λ_{cu} = 380 W/m.K
6. Convection Parameters:

6.1. Internal SF6 space:

$$\varepsilon_k = 0.133(Gr.Pr)^{0.28} \in (1.2 - 6.0)$$

$10^3 < Gr.Pr < 10^6$ (for SF6 GIS)

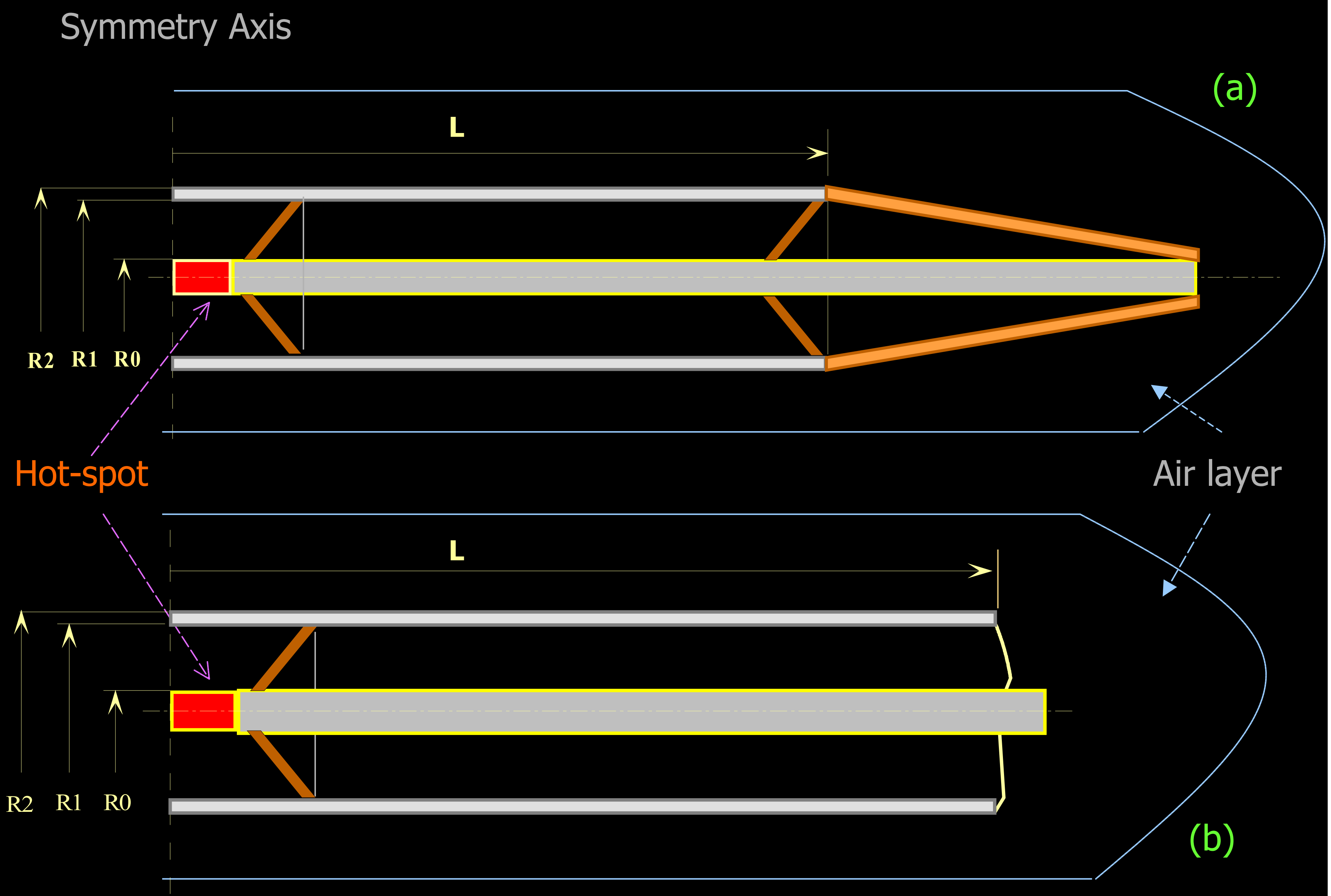
6.2. External Air space:

$$a_c \in (2\text{-}10)\ W/K.m^2\ ;\ T_0 \in (20\text{-}25^\circ C)$$

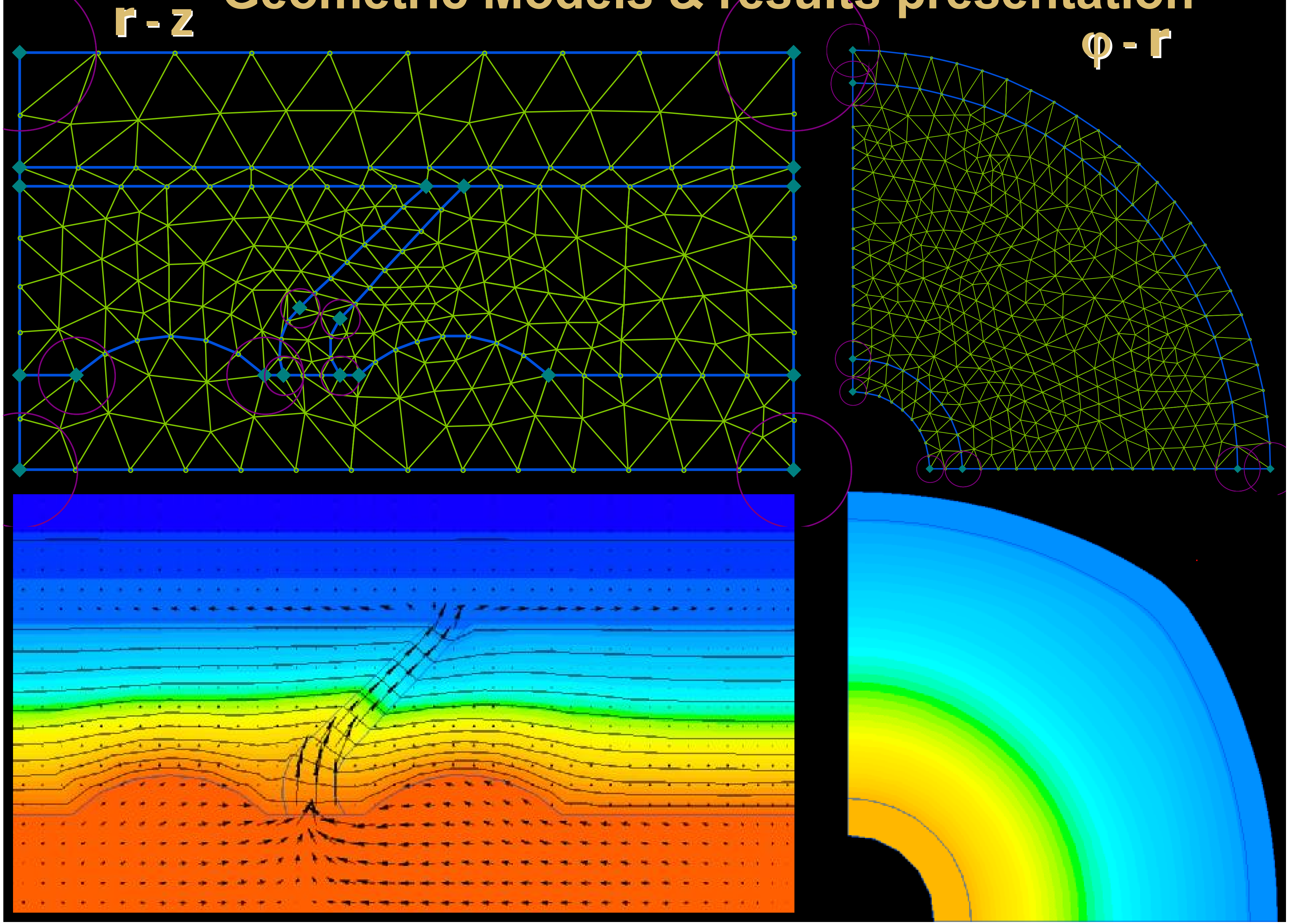
7. Radiation Parameters:

equivalent emissivity coefficient: $b_e \in (0.01 - 0.6)$

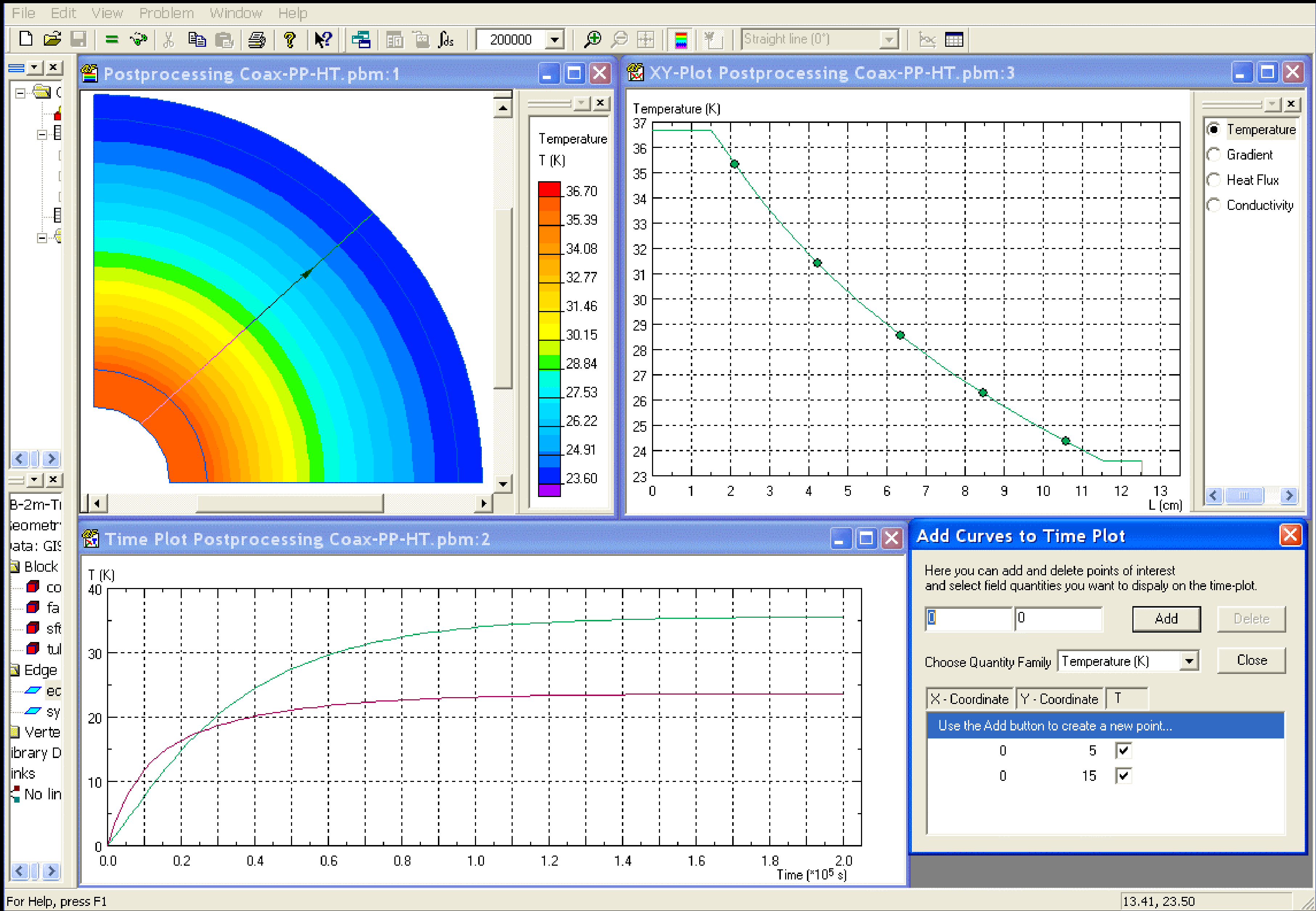
GIS Geometric Model examples



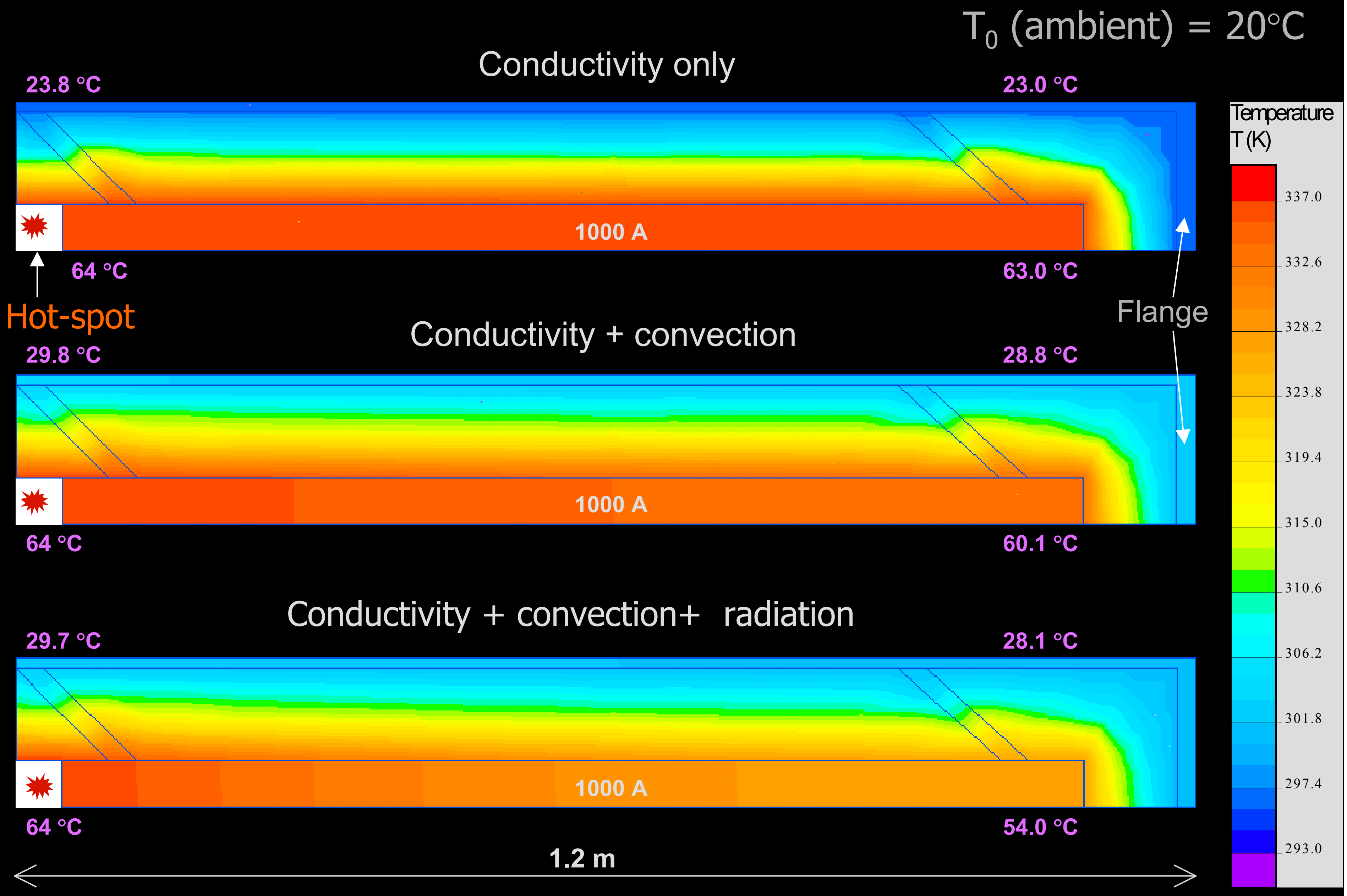
Geometric Models & results presentation

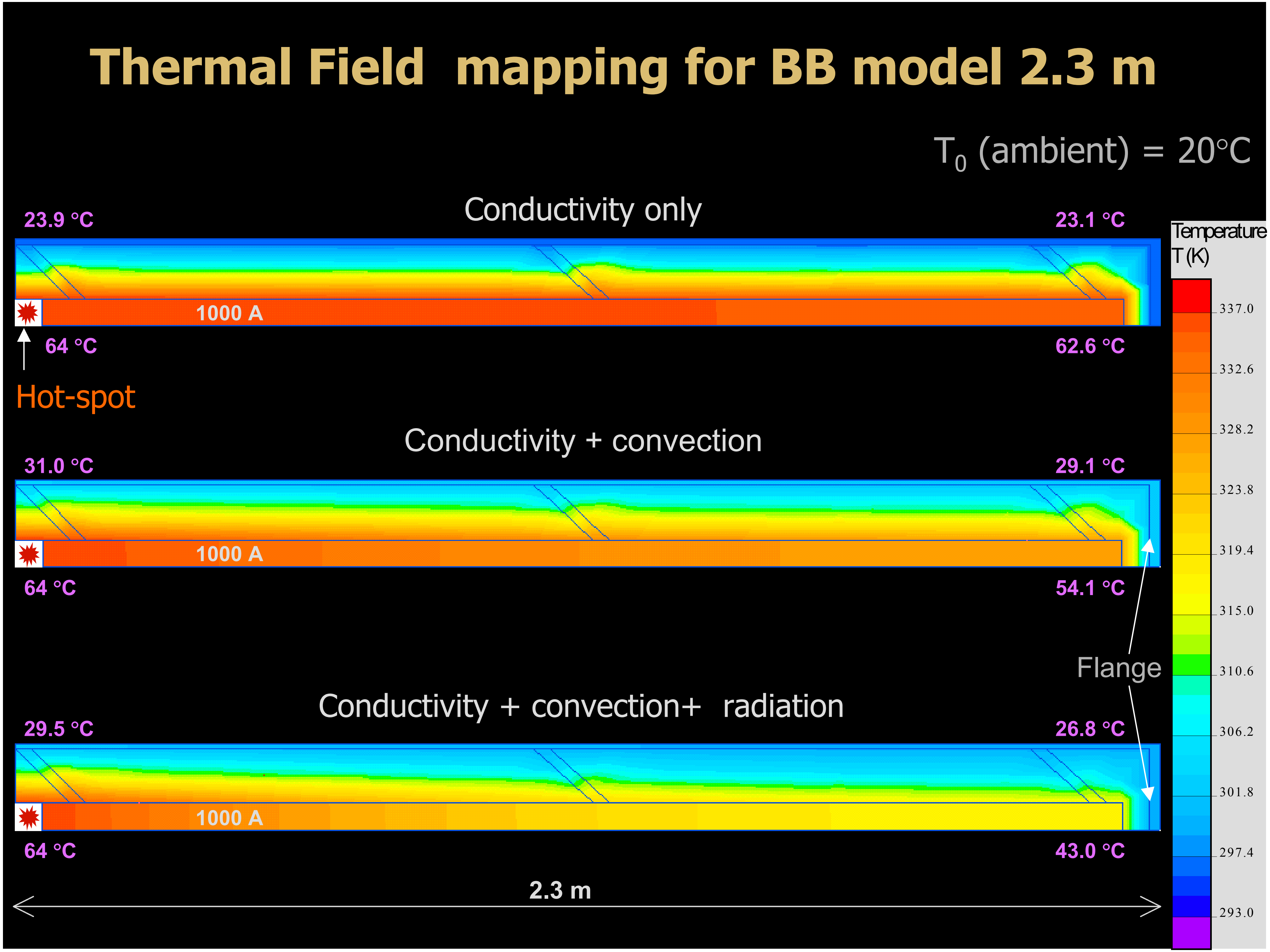


Geometric Models & results presentation

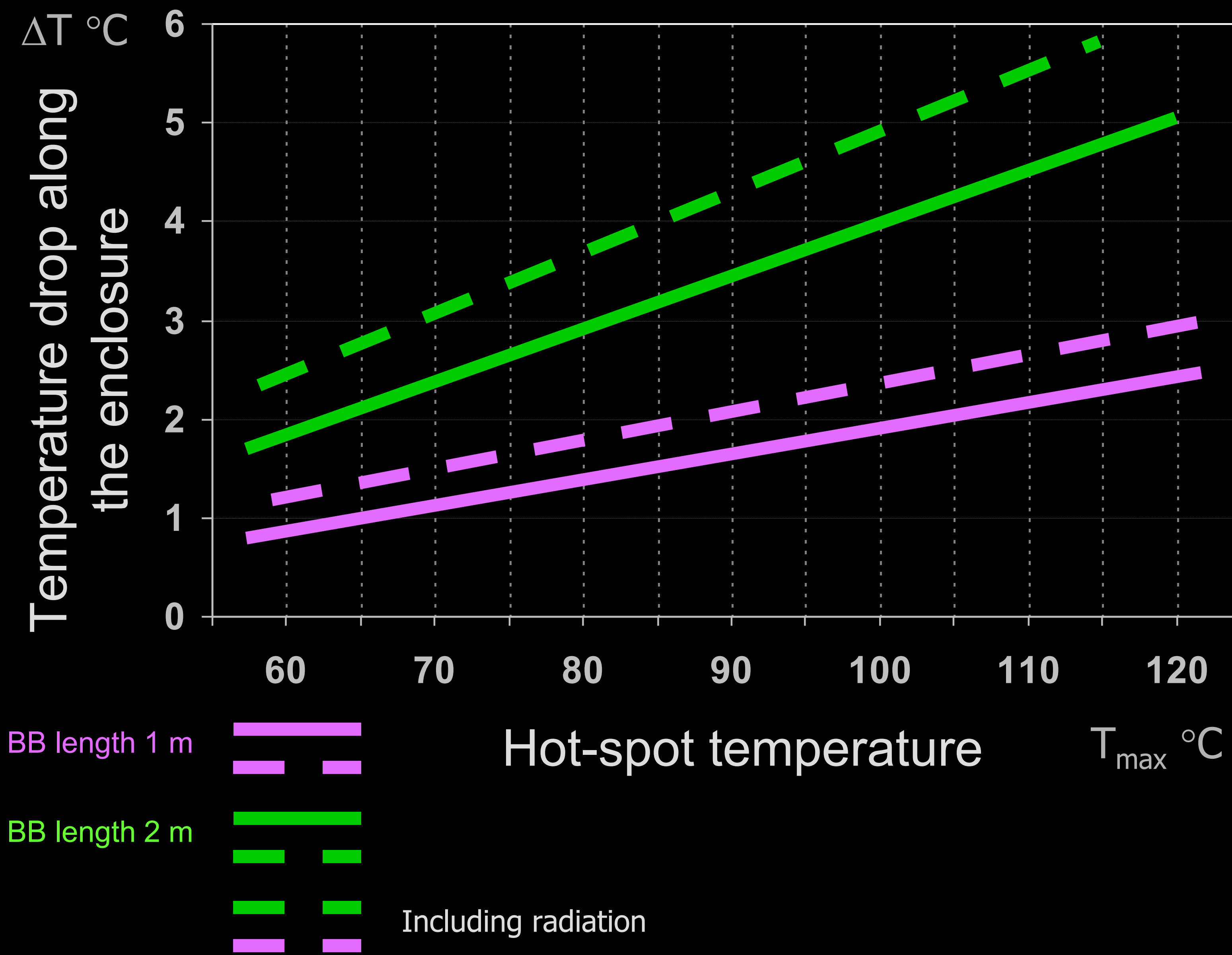


Thermal Field mapping for BB model 1.2 m

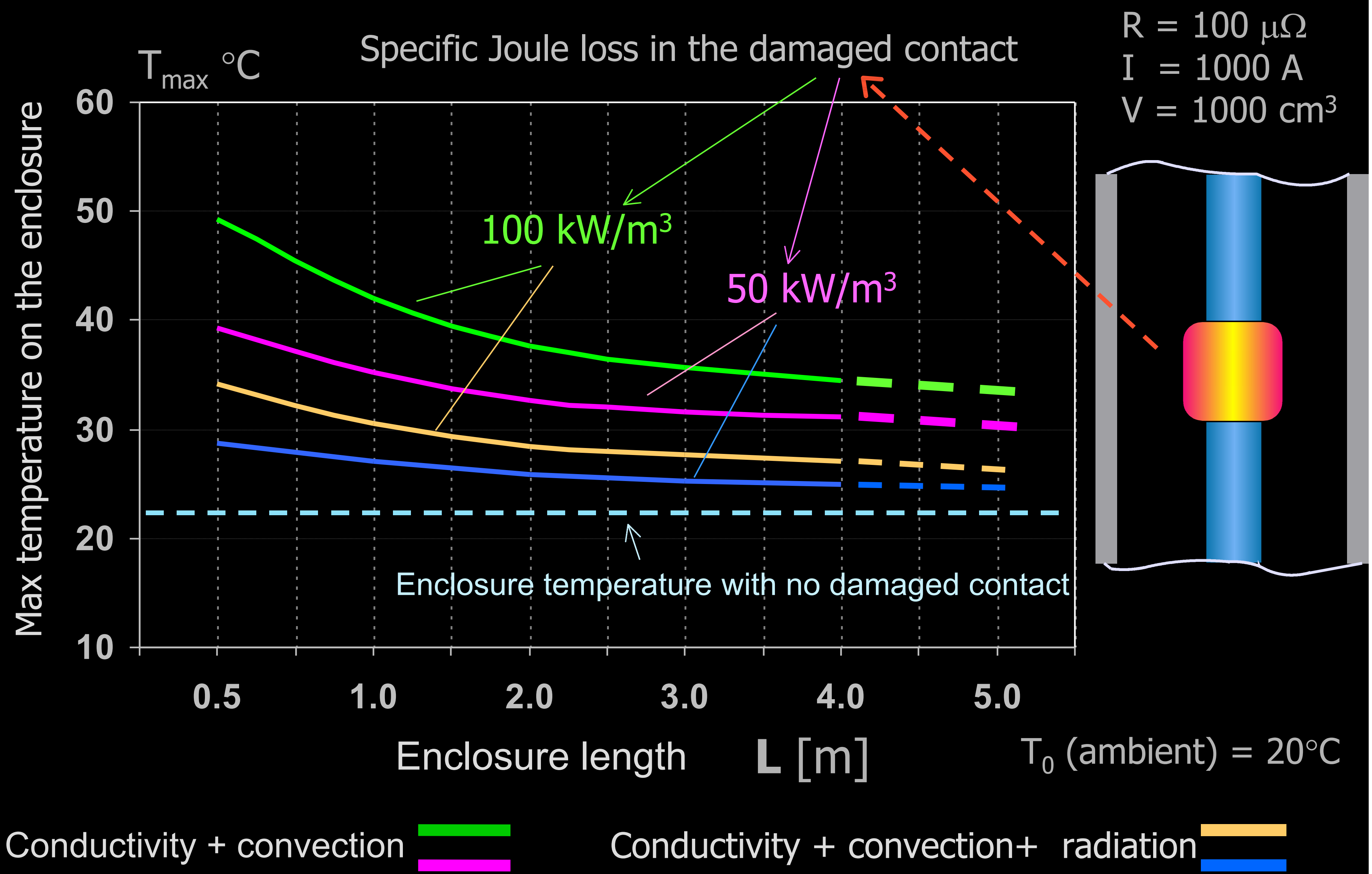


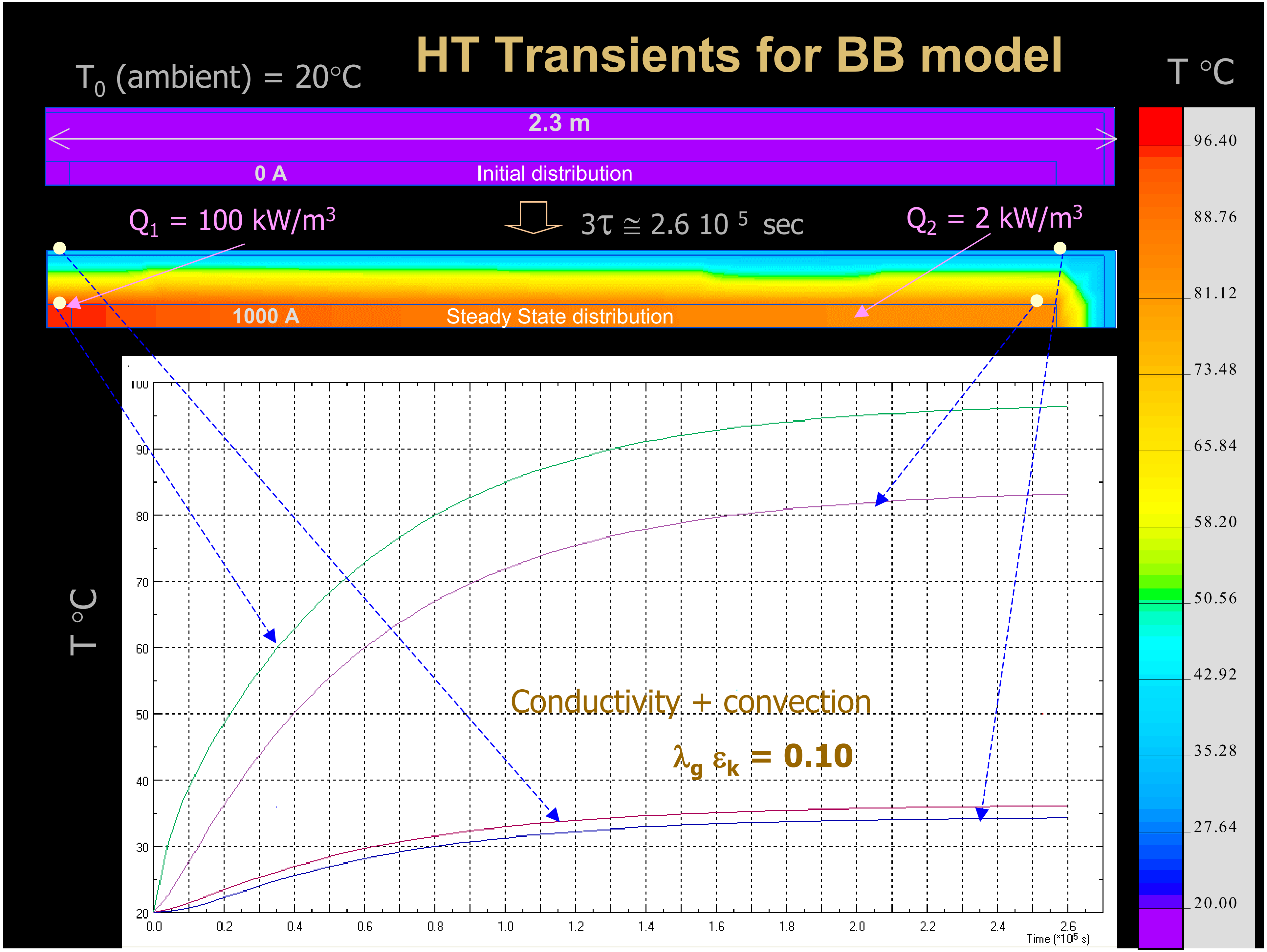

Thermal Field mapping for BB model 2.3 m
T0 (ambient) = 20°C
Conductivity only
23.9 °C
23.1 °C
1000 A
64 °C
62.6 °C
Hot-spot
Conductivity + convection
31.0 °C
29.1 °C
1000 A
64 °C
54.1 °C
Flange
Conductivity + convection+ radiation
29.5 °C
26.8 °C
1000 A
64 °C
43.0 °C
2.3 m
Temperature
T (K)
337.0
332.6
328.2
323.8
319.4
315.0
310.6
306.2
301.8
297.4
293.0

Enclosure overheating as a function of Hot-spot temperature



Enclosure overheating as a function of the BB length





HT Transients for BB model
T0 (ambient) = 20°C
T °C
2.3 m
0 A
Initial distribution
Q1 = 100 kW/m3
3τ ≅ 2.6 10 5 sec
Q2 = 2 kW/m3
1000 A
Steady State distribution
96.40
88.76
81.12
73.48
65.84
58.20
50.56
42.92
35.28
27.64
20.00
T °C
Conductivity + convection
λg εk = 0.10
100
90
80
70
60
50
40
30
20
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
Time (*10^5 s)