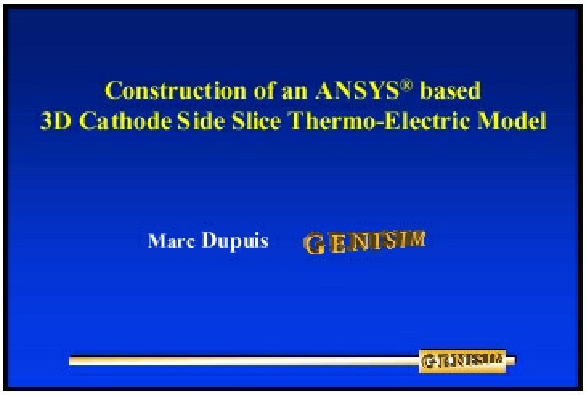
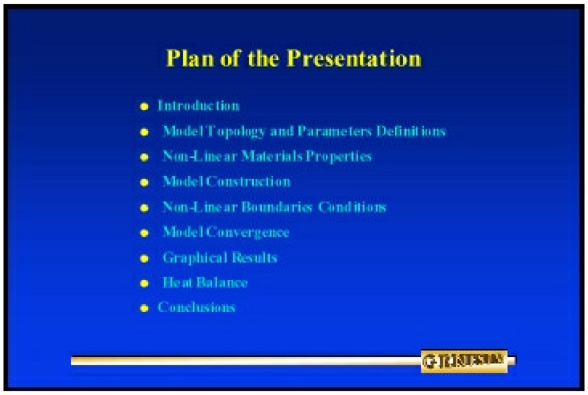


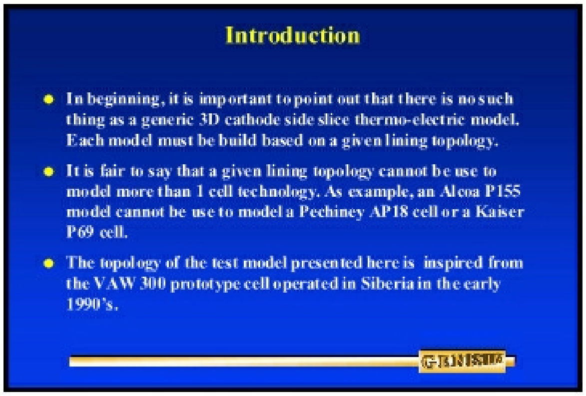
Construction of an ANSYS® based 3D Cathode Side Slice Thermo-Electric Model

Marc Dupuis



Plan of the Presentation

- Introduction
- Model Topology and Parameters Definitions
- Non-Linear Materials Properties
- Model Construction
- Non-Linear Boundaries Conditions
- Model Convergence
- Graphical Results
- Heat Balance
- Conclusions

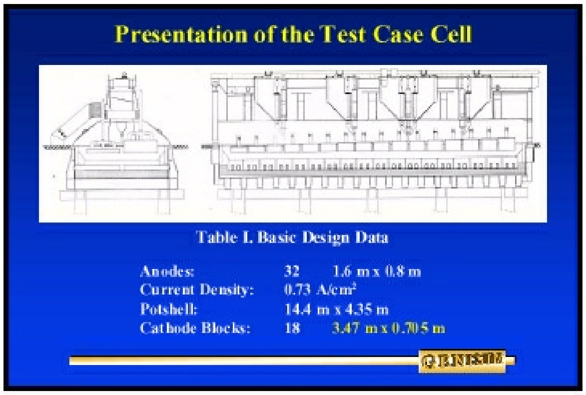


Introduction

- In beginning, it is important to point out that there is no such thing as a generic 3D cathode side slice thermo-electric model. Each model must be build based on a given lining topology.
- It is fair to say that a given lining topology cannot be use to model more than 1 cell technology. As example, an Alcoa P155 model cannot be use to model a Pechiney AP18 cell or a Kaiser P69 cell.
- The topology of the test model presented here is inspired from the VAW 300 prototype cell operated in Siberia in the early 1990's.

Presentation of the Test Case Cell

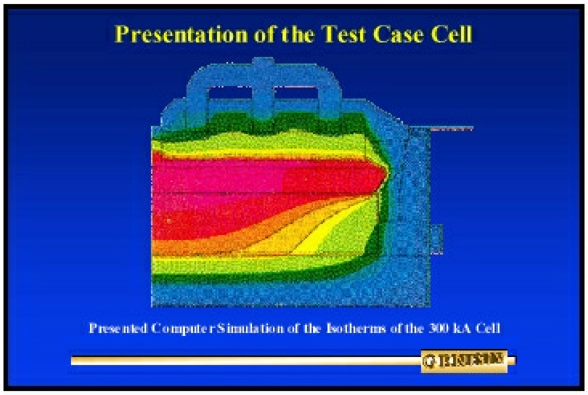
VAW's 300 kA Experimental Cell in Operation in Sayanogorsk Siberia in 1993



Presentation of the Test Case Cell

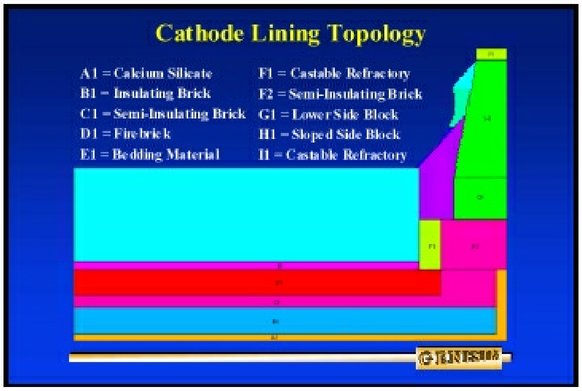
Table I. Basic Design Data

Anodes:	32	1.6 m x 0.8 m
Current Density:	0.73 A/cm²	
Potshell:	14.4 m x 4.35 m	
Cathode Blocks:	18	3.47 m x 0.705 m



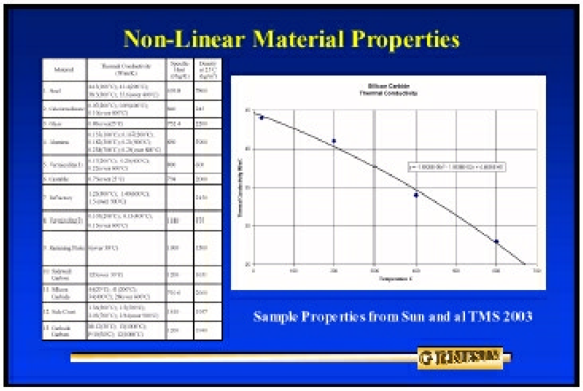
Presentation of the Test Case Cell

Presented Computer Simulation of the Isotherms of the 300 kA Cell



Cathode Lining Topology

A1 = Calcium Silicate
B1 = Insulating Brick
C1 = Semi-Insulating Brick
D1 = Firebrick
E1 = Bedding Material
F1 = Castable Refractory
F2 = Semi-Insulating Brick
G1 = Lower Side Block
H1 = Sloped Side Block
I1 = Castable Refractory



Non-Linear Material Properties

Sample Properties from Sun and al TMS 2003

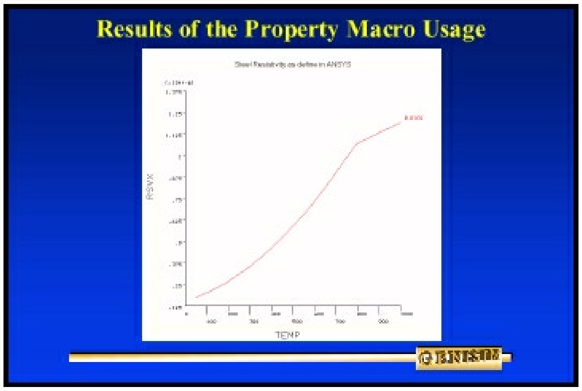
Implementation of Non-Linear Properties Data in a Material Property Library

```
!   KXX FOR SILICON CARBIDE

*if,arg2,eq,3,then
 mp,kxx,arg1,44.635,-0.018536,-1.5926E-5
*endif
```

Syntax of Material Property Library Macro Usage

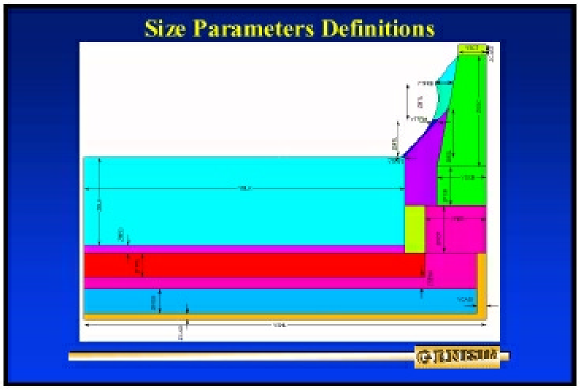
```
prop,1,2                   ! SEMI-GRAPHITE (CATHODE BLOCK)
prop,2,10                  ! ARAI TAMPING MIX (MONO MIX)
prop,3,15                  ! ARAI FIRE BLICK (FIRE BLICK)
prop,4,16                  ! ARAI INSULATING BR. (MOLAR BLICK)
prop,5,14                  ! SEMI-INSULATING BLICK (SEMI-INSULATING BLICK)
prop,6,2                   ! SEMI-GRAPHITE (SIDE BLOCK)
prop,7,13,6,600            ! SKAMOL SUPER-1100 (CALCIUM SILICATE SLAB)
prop,8,36,50,650,50        ! FENG/HAUPIN ALUMINA CRUST (ALUMINA BEDDING)
prop,9,18                  ! ARAI CASTABLE (CEMENT)
prop,10,45,15              ! HAUPIN LEDGE (FREEZE METAL 15%)
prop,11,45,5               ! HAUPIN LEDGE (FREEZE BATH 5%)
prop,12,36,20,600,100      ! FENG/HAUPIN ALUMINA CRUST (CRUST)
prop,13,40                 ! SORLIE STEEL (COLLECTOR BAR)
prop,14,20                 ! ARAI SOLID ALUMINUM (FLEX)
prop,15,40                 ! SORLIE STEEL (STEEL SHELL)
prop,16,42,ver,xei,1       ! CAST IRON CR= ver THK= xei DIR= x
prop,17,42,her,zei,3       ! CAST IRON CR= her THK= zei DIR= z
prop,18,40                 ! SORLIE STEEL (STEEL CRADLE)
```



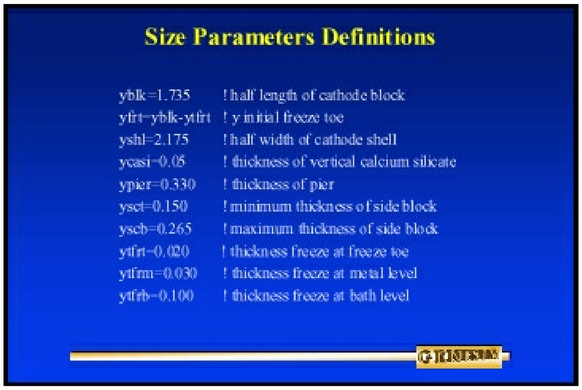
Results of the Property Macro Usage

Syntax of Areas Material Assignment

```
A1 = 7      ! Calcium Silicate
B1 = 4      ! Insulating Brick
C1 = 5      ! Semi-Insulating Brick
D1 = 3      ! Firebrick
E1 = 8      ! Bedding Material
F1 = 9      ! Castable Refractory
F2 = 5      ! Semi-Insulating Brick
G1 = 6      ! Lower Side Block
H1 = 6      ! Sloped Side Block
I1 = 9      ! Castable Refractory
```

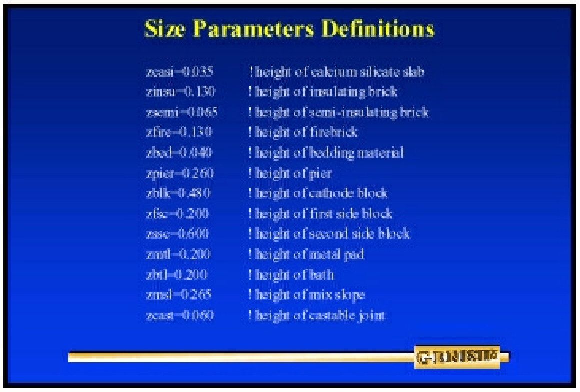


Size Parameters Definitions



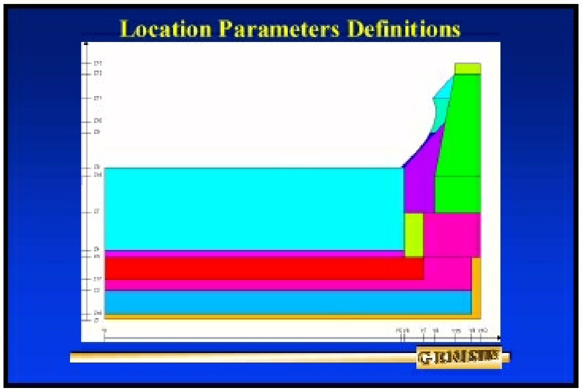
Size Parameters Definitions

```
yblk=1.735          ! half length of cathode block
yfrt=yblk-ytfrt     ! y initial freeze toe
yshl=2.175          ! half width of cathode shell
ycasi=0.05          ! thickness of vertical calcium silicate
ypier=0.330         ! thickness of pier
ysct=0.150          ! minimum thickness of side block
yscb=0.265          ! maximum thickness of side block
ytfrt=0.020         ! thickness freeze at freeze toe
ytfrm=0.030         ! thickness freeze at metal level
ytfrb=0.100         ! thickness freeze at bath level
```

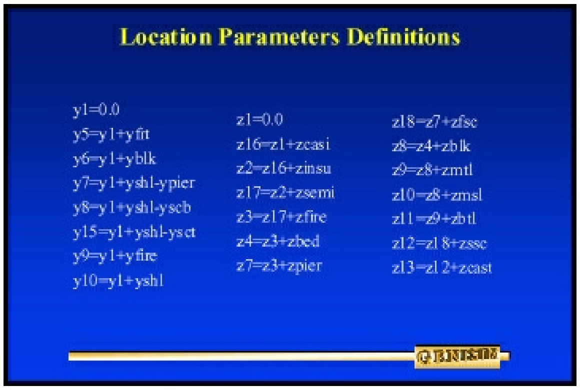


Size Parameters Definitions

```
zcasi=0.035      ! height of calcium silicate slab
zinsu=0.130      ! height of insulating brick
zsemi=0.065      ! height of semi-insulating brick
zfire=0.130      ! height of firebrick
zbed=0.040       ! height of bedding material
zpier=0.260      ! height of pier
zblk=0.480       ! height of cathode block
zfsc=0.200       ! height of first side block
zssc=0.600       ! height of second side block
zmtl=0.200       ! height of metal pad
zbtl=0.200       ! height of bath
zmsl=0.265       ! height of mix slope
zcast=0.060      ! height of castable joint
```



Location Parameters Definitions

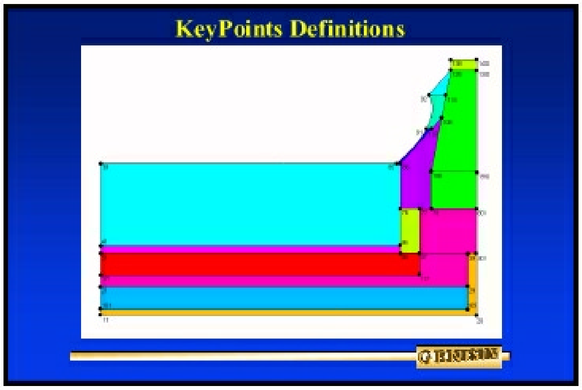


Location Parameters Definitions

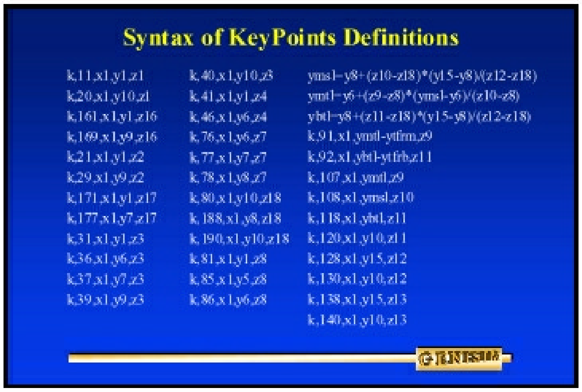
```
y1=0.0
y5=y1+yfrt
y6=y1+yblk
y7=y1+yshl-ypier
y8=y1+yshl-yscb
y15=y1+yshl-ysct
y9=y1+yfire
y10=y1+yshl

z1=0.0
z16=z1+zcasi
z2=z16+zinsu
z17=z2+zsemi
z3=z17+zfire
z4=z3+zbed
z7=z3+zpier

z18=z7+zfsc
z8=z4+zblk
z9=z8+zmtl
z10=z8+zmsl
z11=z9+zbtl
z12=z18+zssc
z13=z12+zcast
```



KeyPoints Definitions

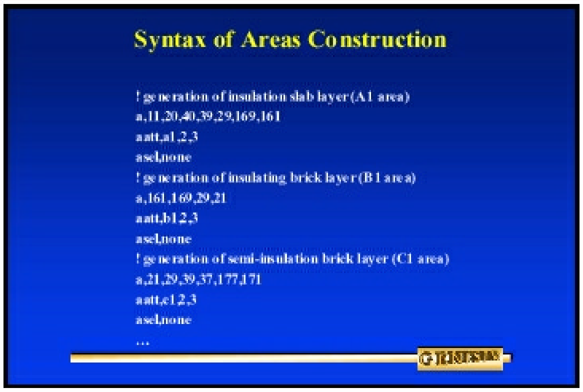


Syntax of KeyPoints Definitions

```
k,11,x1,y1,z1
k,20,x1,y10,z1
k,161,x1,y1,z16
k,169,x1,y9,z16
k,21,x1,y1,z2
k,29,x1,y9,z2
k,171,x1,y1,z17
k,177,x1,y7,z17
k,31,x1,y1,z3
k,36,x1,y6,z3
k,37,x1,y7,z3
k,39,x1,y9,z3
```

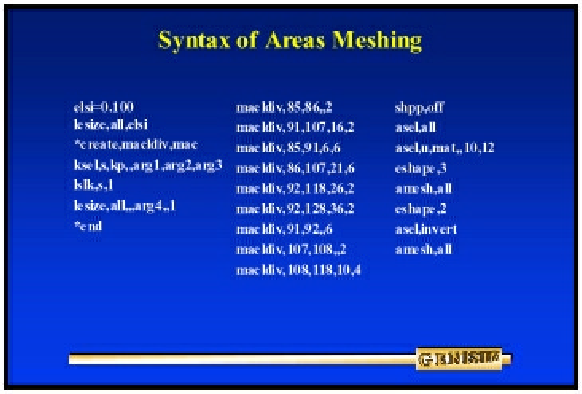
```
k,40,x1,y10,z3
k,41,x1,y1,z4
k,46,x1,y6,z4
k,76,x1,y6,z7
k,77,x1,y7,z7
k,78,x1,y8,z7
k,80,x1,y10,z18
k,188,x1,y8,z18
k,190,x1,y10,z18
k,81,x1,y1,z8
k,85,x1,y5,z8
k,86,x1,y6,z8
```

```
ymsl=y8+(z10-z18)*(y15-y8)/(z12-z18)
ymtl=y6+(z9-z8)*(ymsl-y6)/(z10-z8)
ybtl=y8+(z11-z18)*(y15-y8)/(z12-z18)
k,91,x1,ymtl-ytfrm,z9
k,92,x1,ybtl-ytfrb,z11
k,107,x1,ymtl,z9
k,108,x1,ymsl,z10
k,118,x1,ybtl,z11
k,120,x1,y10,z11
k,128,x1,y15,z12
k,130,x1,y10,z12
k,138,x1,y15,z13
k,140,x1,y10,z13
```



Syntax of Areas Construction

```
! generation of insulation slab layer (A1 area)
a,11,20,40,39,29,169,161
aatt,a1,2,3
asel,none
! generation of insulating brick layer (B1 area)
a,161,169,29,21
aatt,b1,2,3
asel,none
! generation of semi-insulation brick layer (C1 area)
a,21,29,39,37,177,171
aatt,c1,2,3
asel,none
...
```

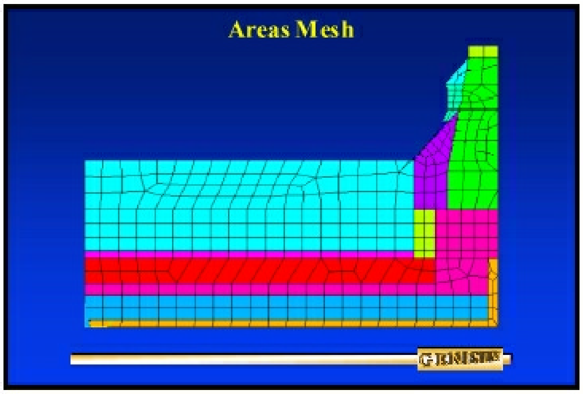


Syntax of Areas Meshing

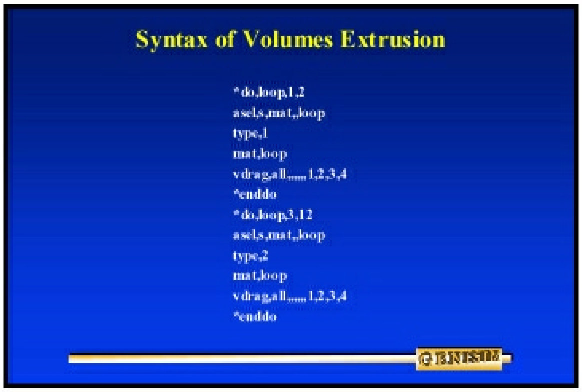
```
elsi=0.100
lesize,all,elsi
*create,macldiv,mac
ksel,s,kp,,arg1,arg2,arg3
lslk,s,1
lesize,all,,,arg4,,1
*end
```

```
macldiv,85,86,,2
macldiv,91,107,16,2
macldiv,85,91,6,6
macldiv,86,107,21,6
macldiv,92,118,26,2
macldiv,92,128,36,2
macldiv,91,92,,6
macldiv,107,108,,2
macldiv,108,118,10,4
```

```
shpp,off
asel,all
asel,u,mat,,10,12
eshape,3
amesh,all
eshape,2
asel,invert
amesh,all
```

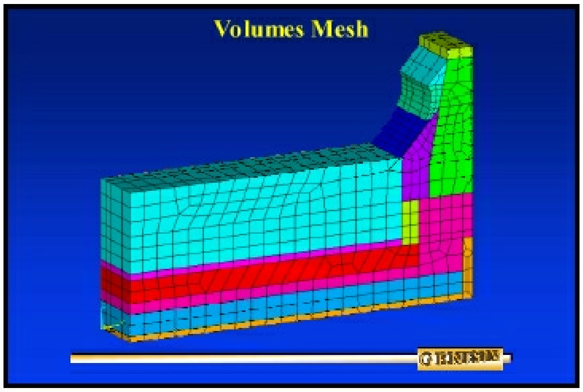


Areas Mesh

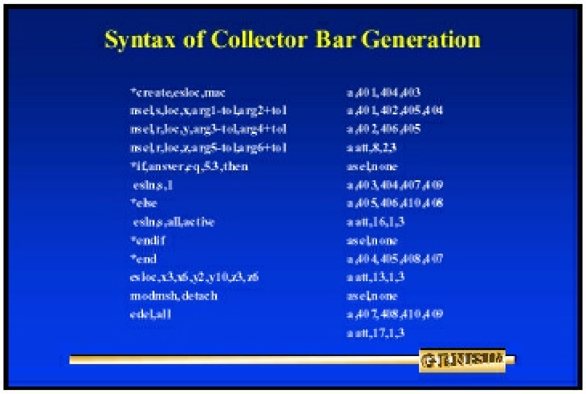


Syntax of Volumes Extrusion

```
*do,loop,1,2
asel,s,mat,,loop
type,1
mat,loop
vdrag,all,,,,,,1,2,3,4
*enddo
*do,loop,3,12
asel,s,mat,,loop
type,2
mat,loop
vdrag,all,,,,,,1,2,3,4
*enddo
```



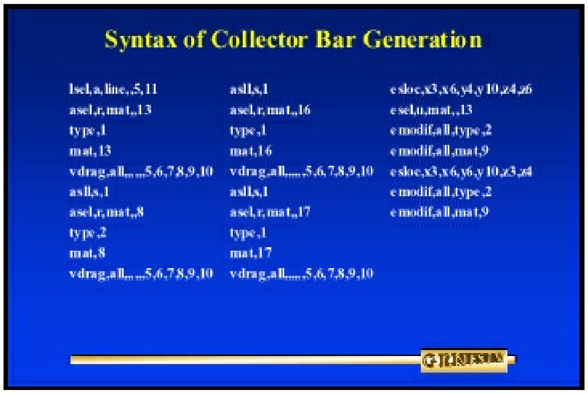
Volumes Mesh



Syntax of Collector Bar Generation

```
*create,esloc,mac
nsel,s,loc,x,arg1-tol,arg2+tol
nsel,r,loc,y,arg3-tol,arg4+tol
nsel,r,loc,z,arg5-tol,arg6+tol
*if,answer,eq,53,then
 esln,s,1
*else
 esln,s,all,active
*endif
*end
esloc,x3,x6,y2,y10,z3,z6
modmsh,detach
edel,all
```

```
a,401,404,403
a,401,402,405,404
a,402,406,405
aatt,8,2,3
asel,none
a,403,404,407,409
a,405,406,410,408
aatt,16,1,3
asel,none
a,404,405,408,407
aatt,13,1,3
asel,none
a,407,408,410,409
aatt,17,1,3
```

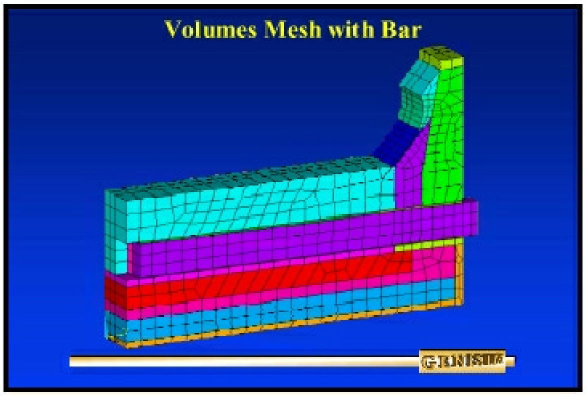


Syntax of Collector Bar Generation

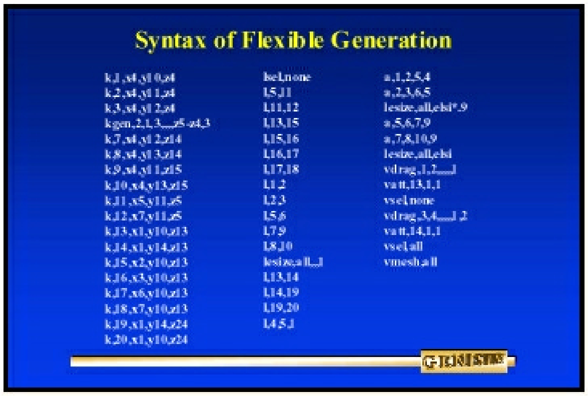
```
lsel,a,line,,5,11
asel,r,mat,,13
type,1
mat,13
vdrag,all,,,,,5,6,7,8,9,10
asll,s,1
asel,r,mat,,8
type,2
mat,8
vdrag,all,,,,,5,6,7,8,9,10
```

```
asll,s,1
asel,r,mat,,16
type,1
mat,16
vdrag,all,,,,,5,6,7,8,9,10
asll,s,1
asel,r,mat,,17
type,1
mat,17
vdrag,all,,,,,5,6,7,8,9,10
```

```
esloc,x3,x6,y4,y10,z4,z6
esel,u,mat,,13
emodif,all,type,2
emodif,all,mat,9
esloc,x3,x6,y6,y10,z3,z4
emodif,all,type,2
emodif,all,mat,9
```



Volumes Mesh with Bar

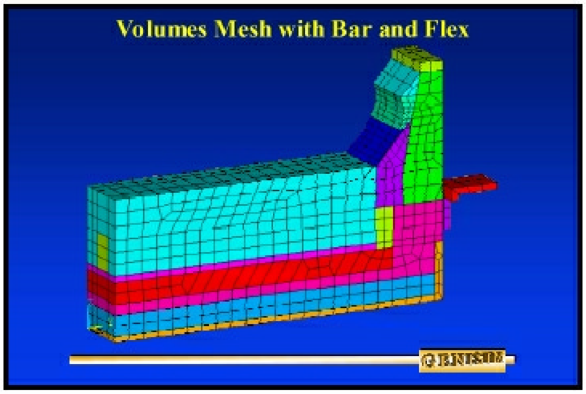


Syntax of Flexible Generation

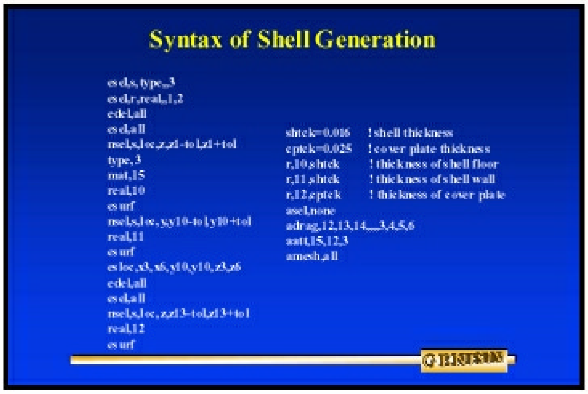
```
k,1,x4,y10,z4
k,2,x4,y11,z4
k,3,x4,y12,z4
kgen,2,1,3,,,,z5-z4,3
k,7,x4,y12,z14
k,8,x4,y13,z14
k,9,x4,y11,z15
k,10,x4,y13,z15
k,11,x5,y11,z5
k,12,x7,y11,z5
k,13,x1,y10,z13
k,14,x1,y14,z13
k,15,x2,y10,z13
k,16,x3,y10,z13
k,17,x6,y10,z13
k,18,x7,y10,z13
k,19,x1,y14,z24
k,20,x1,y10,z24
```

```
ksel,none
l,5,11
l,11,12
l,13,15
l,15,16
l,16,17
l,17,18
l,1,2
l,2,3
l,5,6
l,7,9
l,8,10
lesize,all,,,1
l,13,14
l,14,19
l,19,20
l,4,5,1
```

```
a,1,2,5,4
a,2,3,6,5
lesize,all,ebi*.9
a,5,6,7,9
a,7,8,10,9
lesize,all,ebi
vdrag,1,2,,,,,1
vatt,13,1,1
vsel,none
vdrag,3,4,,,,,1,2
vatt,14,1,1
vsel,all
vmesh,all
```



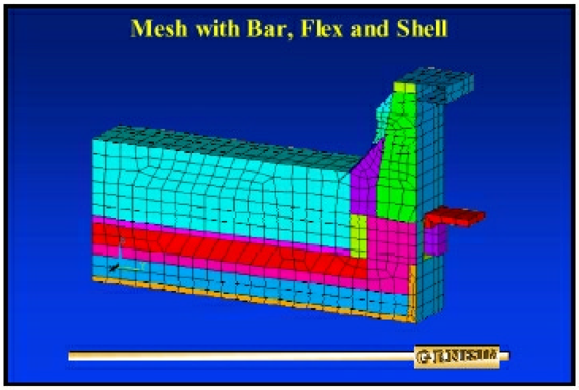
Volumes Mesh with Bar and Flex



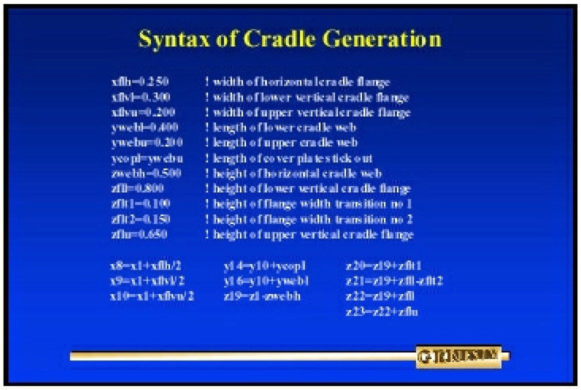
Syntax of Shell Generation

```
esel,s,type,,3
esel,r,real,,1,2
edel,all
esel,all
nsel,s,loc,z,z1-tol,z1+tol
type,3
mat,15
real,10
esurf
nsel,s,loc,y,y10-tol,y10+tol
real,11
esurf
esloc,x3,x6,y10,y10,z3,z6
edel,all
esel,all
nsel,s,loc,z,z13-tol,z13+tol
real,12
esurf
```

```
shtek=0.016     ! shell thickness
cptek=0.025     ! cover plate thickness
r,10,shtek      ! thickness of shell floor
r,11,shtek      ! thickness of shell wall
r,12,cptek      ! thickness of cover plate
asel,none
adrag,12,13,14,,,,3,4,5,6
aatt,15,12,3
amesh,all
```



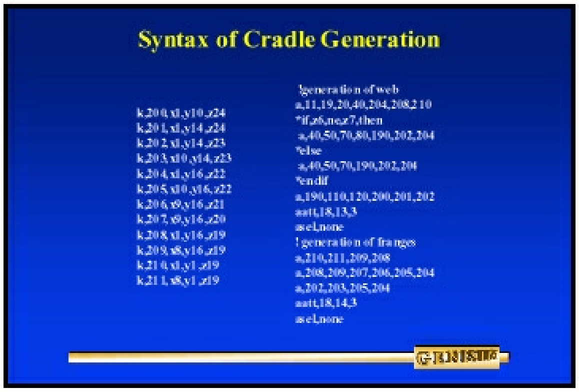
Mesh with Bar, Flex and Shell



Syntax of Cradle Generation

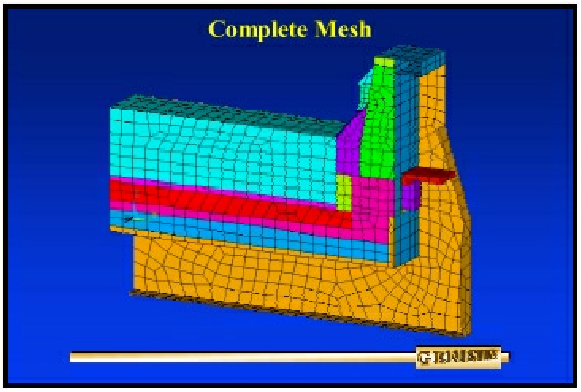
```
xflh=0.250       ! width of horizontal cradle flange
xflvl=0.300      ! width of lower vertical cradle flange
xflvu=0.200      ! width of upper vertical cradle flange
ywebl=0.400      ! length of lower cradle web
ywebu=0.200      ! length of upper cradle web
ycopl=ywebu      ! length of cover plate stick out
zwebh=0.500      ! height of horizontal cradle web
zfll=0.800       ! height of lower vertical cradle flange
zflt1=0.100      ! height of flange width transition no 1
zflt2=0.150      ! height of flange width transition no 2
zflu=0.650       ! height of upper vertical cradle flange

x8=x1+xflh/2       y14=y10+ycopl      z20=z19+zflt1
x9=x1+xflvl/2      y16=y10+ywebl      z21=z19+zfll-zflt2
x10=x1+xflvu/2     z19=z1-zwebh       z22=z19+zfll
                                      z23=z22+zflu
```

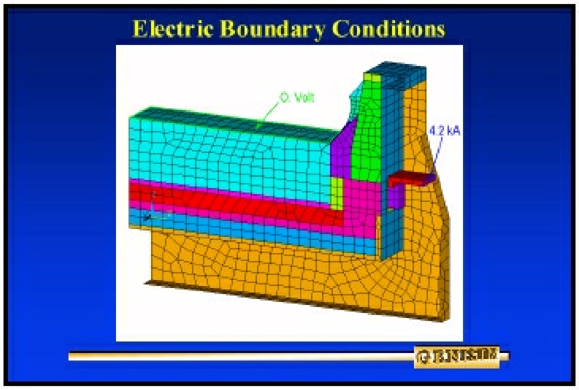


Syntax of Cradle Generation

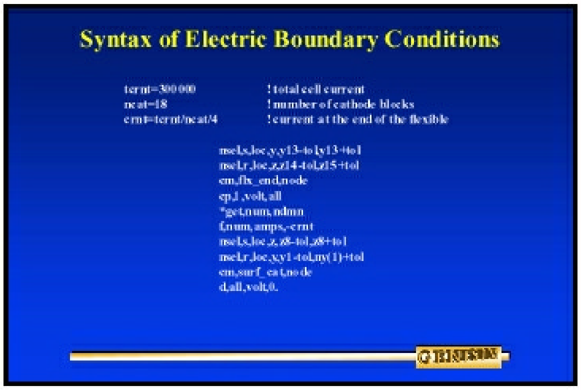
```
                          !generation of web
                          a,11,19,20,40,204,208,210
k,200,x1,y10,z24          *if,z6,ne,z7,then
k,201,x1,y14,z24           a,40,50,70,80,190,202,204
k,202,x1,y14,z23          *else
k,203,x10,y14,z23          a,40,50,70,190,202,204
k,204,x1,y16,z22          *endif
k,205,x10,y16,z22         a,190,110,120,200,201,202
k,206,x9,y16,z21          aatt,18,13,3
k,207,x9,y16,z20          asel,none
k,208,x1,y16,z19          ! generation of franges
k,209,x8,y16,z19          a,210,211,209,208
k,210,x1,y1,z19           a,208,209,207,206,205,204
k,211,x8,y1,z19           a,202,203,205,204
                          aatt,18,14,3
                          asel,none
```



Complete Mesh



Electric Boundary Conditions



Syntax of Electric Boundary Conditions

```
tcrnt=300000              ! total cell current
ncat=18                   ! number of cathode blocks
crnt=tcrnt/ncat/4         ! current at the end of the flexible

            nsel,s,loc,y,y13-tol,y13+tol
            nsel,r,loc,z,z14-tol,z15+tol
            cm,flx_end,node
            cp,1,volt,all
            *get,num,ndmn
            f,num,amps,-crnt
            nsel,s,loc,z,z8-tol,z8+tol
            nsel,r,loc,x,y1-tol,ny(1)+tol
            cm,surf_cat,node
            d,all,volt,0.
```

Natural Convection Boundary Conditions

$$T_{f} = \frac{(T_s + T_{\blacksquare})}{2}$$

Vertical surfaces:

$$Nu = 0.59\,Ra^{1/4} \text{ for } 10^4 \le Ra \le 10^9$$

$$Nu = 0.105\,Ra^{\blacksquare} \text{ for } 10^9 \le Ra \le 10^{12}$$

Horizontal surfaces facing up:

$$Nu = 0.54\,Ra^{1/4} \text{ for } 10^5 \le Ra \le 2\times10^7$$

$$Nu = 0.141\,Ra^{\blacksquare} \text{ for } 10^7 \le Ra \le 10^{11}$$

Horizontal surfaces facing down:

$$Nu = 0.27\,Ra^{1/4} \text{ for } 3\times10^5 \le Ra \le 3\times10^{10}$$

Natural Convection Boundary Conditions

Where:

$Nu = \frac{h_c L}{k}$; is the Nusselt number

$Ra = Gr \cdot \Pr$; is the Rayleigh number

$Gr = \frac{g\beta L^3 (T_s - T_b)}{\upsilon^2}$; is the Grashof number

$\Pr = \frac{Cp \cdot \rho \cdot \upsilon}{k}$; is the Prandtl number

Natural Convection Boundary Conditions

Property values of air at atmospheric pressure

T (°C)	ρ (kg/m3)	Cp (kJ/kg °C)	k (W/m °C)	ν (m2/s)	Pr
27	1.1774	1.0057	0.02624	1.57E-05	0.70757863
77	0.998	1.009	0.03003	2.08E-05	0.69613541
127	0.8826	1.014	0.03365	2.59E-05	0.68863717
177	0.7833	1.0207	0.03707	3.17E-05	0.68081149
227	0.7048	1.0295	0.04038	3.79E-05	0.68102827
277	0.6423	1.0392	0.0436	4.43E-05	0.67880692
327	0.5879	1.0551	0.04659	5.13E-05	0.68353418
377	0.543	1.0635	0.04953	5.85E-05	0.68218011
427	0.503	1.0752	0.0523	6.63E-05	0.68608023
477	0.4709	1.0856	0.05509	7.39E-05	0.6858497
527	0.4405	1.0978	0.05779	8.23E-05	0.68859443
577	0.4149	1.1095	0.06028	9.08E-05	0.69301738
627	0.3925	1.1212	0.06279	9.93E-05	0.69595557
677	0.3716	1.1321	0.06525	1.08E-04	0.69760123
727	0.3524	1.1417	0.06752	1.18E-04	0.70194124
827	0.3204	1.16	0.0732	1.39E-04	0.70372446
927	0.2947	1.179	0.0782	[illegible]	[illegible]
1027	0.2707	1.197	0.0837	1.82E-04	0.70498383

Natural Convection Boundary Conditions

The evolution of those properties with temperature
can be approximated by using polynomial fits

$$k = 2.014E-15\times T_{\blacksquare}^{\blacksquare} + 1.68E-11\times T_{\blacksquare}^{\blacksquare} - 4.118E-8\times T_{\blacksquare}^{\blacksquare} + 8.051E-5\times T_{\blacksquare} + 0.02407$$

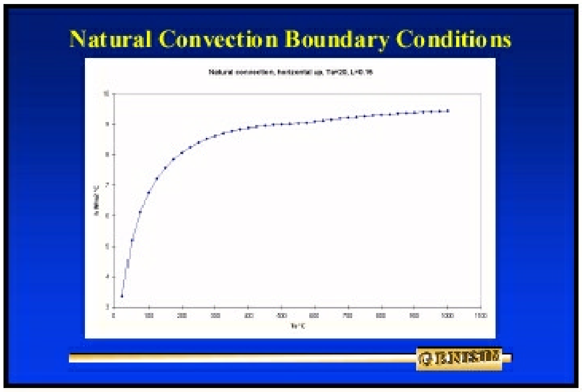
$$\upsilon = 1.438E-17\times T_{\blacksquare}^{\blacksquare} - 3.25E-14\times T_{\blacksquare}^{\blacksquare} + 9.095E-11\times T_{\blacksquare}^{\blacksquare} + 8.977E-8\times T_{\blacksquare} + 1.32E-5$$

$$Cp = 2.866E-13\times T_{\blacksquare}^{\blacksquare} - 7.631E-10\times T_{\blacksquare}^{\blacksquare} + 6.688E-7\times T_{\blacksquare}^{\blacksquare} - 5.714E-6\times T_{\blacksquare} + 1.005$$

$$\rho = 2.258E-12\times T_{\blacksquare}^{\blacksquare} - 6.282E-9\times T_{\blacksquare}^{\blacksquare} + 6.71E-6\times T_{\blacksquare}^{\blacksquare} - 3.669E-3\times T_{\blacksquare} + 1.258$$

$$\Pr = 1.937E-13\times T_{\blacksquare}^{\blacksquare} - 6.581E-10\times T_{\blacksquare}^{\blacksquare} + 7.349E-7\times T_{\blacksquare}^{\blacksquare} - 2.788E-4\times T_{\blacksquare} + 0.714$$

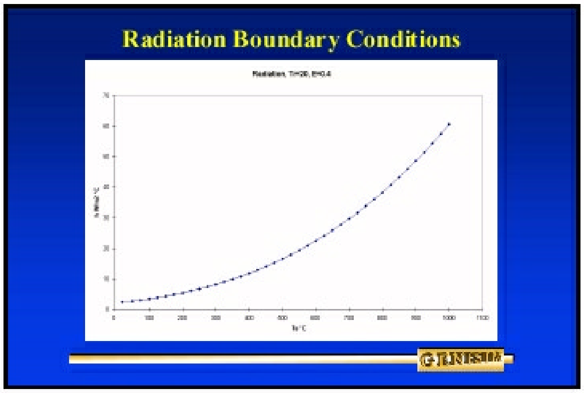
Natural Convection Boundary Conditions



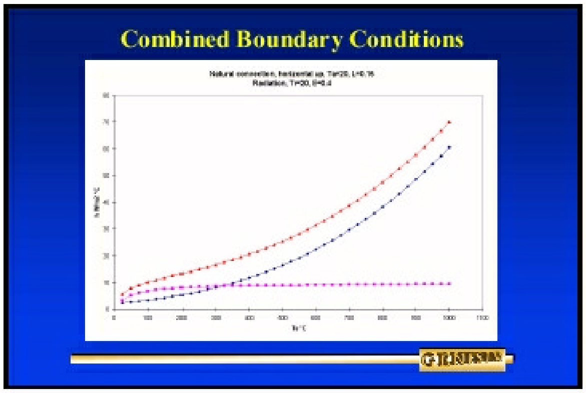
Radiation Boundary Conditions

$$h_r = \frac{\varepsilon\sigma\left(T_s^4 - T_o^4\right)}{\left(T_s - T_b\right)}$$

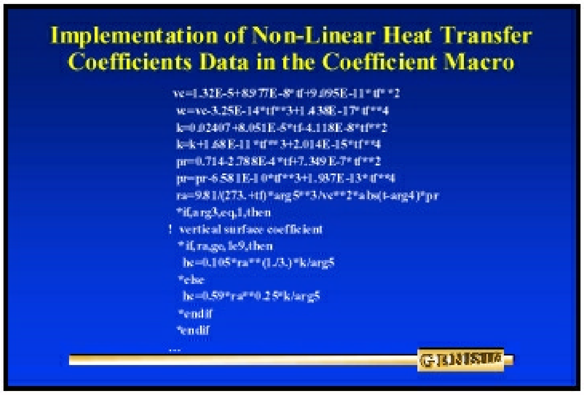
Where $T_{\blacksquare}$ is the temperature of the 'surrounding black box' in k.
Notice also that $T_{\blacksquare}$ is different than $T_{\blacksquare}$ the air bulk temperature



Radiation Boundary Conditions

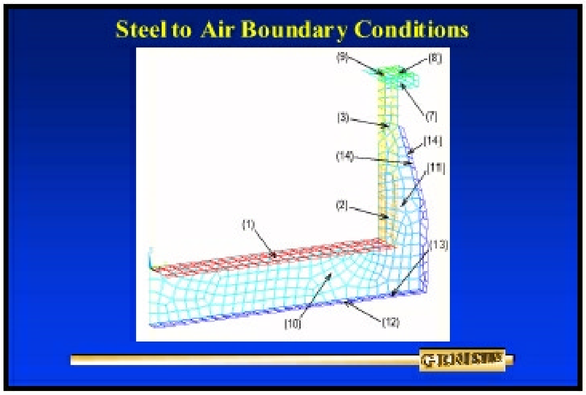


Combined Boundary Conditions

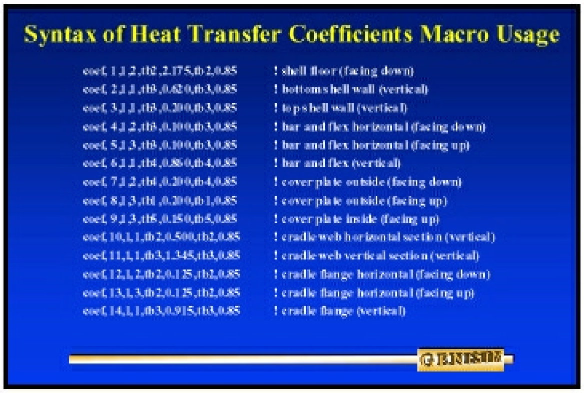


Implementation of Non-Linear Heat Transfer Coefficients Data in the Coefficient Macro

```
 ve=1.32E-5+8.977E-8*tf+9.095E-11*tf**2
  ve=ve-3.25E-14*tf**3+1.438E-17*tf**4
  k=0.02407+8.051E-5*tf-4.118E-8*tf**2
  k=k+1.68E-11*tf**3+2.014E-15*tf**4
  pr=0.714-2.788E-4*tf+7.349E-7*tf**2
  pr=pr-6.581E-10*tf**3+1.937E-13*tf**4
  ra=9.81/(273.+tf)*arg5**3/ve**2*abs(t-arg4)*pr
  *if,arg3,eq,1,then
!  vertical surface coefficient
   *if,ra,ge,1e9,then
    hc=0.105*ra**(1./3.)*k/arg5
   *else
    hc=0.59*ra**0.25*k/arg5
   *endif
  *endif
...
```

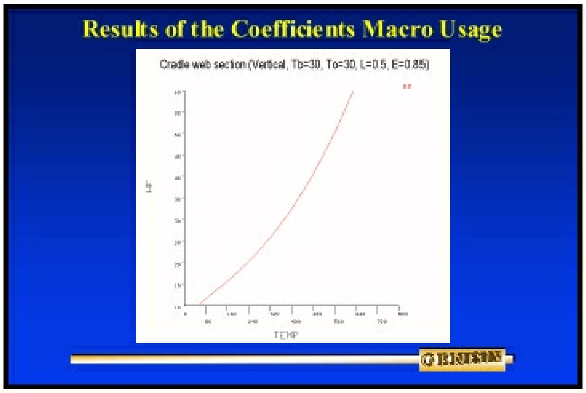


Steel to Air Boundary Conditions

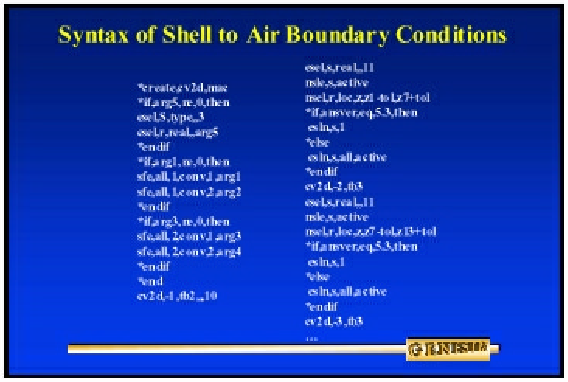


Syntax of Heat Transfer Coefficients Macro Usage

```
coef, 1,1,2,tb2,2.175,tb2,0.85        ! shell floor (facing down)
coef, 2,1,1,tb3,0.620,tb3,0.85        ! bottom shell wall (vertical)
coef, 3,1,1,tb3,0.200,tb3,0.85        ! top shell wall (vertical)
coef, 4,1,2,tb3,0.100,tb3,0.85        ! bar and flex horizontal (facing down)
coef, 5,1,3,tb3,0.100,tb3,0.85        ! bar and flex horizontal (facing up)
coef, 6,1,1,tb4,0.860,tb4,0.85        ! bar and flex (vertical)
coef, 7,1,2,tb1,0.200,tb4,0.85        ! cover plate outside (facing down)
coef, 8,1,3,tb1,0.200,tb1,0.85        ! cover plate outside (facing up)
coef, 9,1,3,tb5,0.150,tb5,0.85        ! cover plate inside (facing up)
coef, 10,1,1,tb2,0.500,tb2,0.85       ! cradle web horizontal section (vertical)
coef, 11,1,1,tb3,1.345,tb3,0.85       ! cradle web vertical section (vertical)
coef, 12,1,2,tb2,0.125,tb2,0.85       ! cradle flange horizontal (facing down)
coef, 13,1,3,tb2,0.125,tb2,0.85       ! cradle flange horizontal (facing up)
coef, 14,1,1,tb3,0.915,tb3,0.85       ! cradle flange (vertical)
```



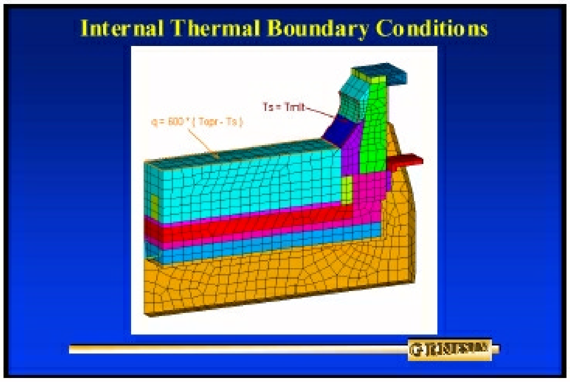
Results of the Coefficients Macro Usage



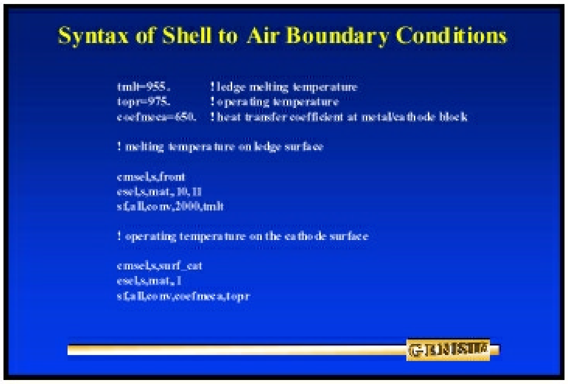
Syntax of Shell to Air Boundary Conditions

```
*create,cv2d,mac
*if,arg5,ne,0,then
esel,S,type,,3
esel,r,real,,arg5
*endif
*if,arg1,ne,0,then
sfe,all,1,conv,1,arg1
sfe,all,1,conv,2,arg2
*endif
*if,arg3,ne,0,then
sfe,all,2,conv,1,arg3
sfe,all,2,conv,2,arg4
*endif
*end
cv2d,-1,tb2,,,10
```

```
esel,s,real,,11
nsle,s,active
nsel,r,loc,z,z1-tol,z7+tol
*if,ansver,eq,5.3,then
 esln,s,1
*else
 esln,s,all,active
*endif
cv2d,-2,,tb3
esel,s,real,,11
nsle,s,active
nsel,r,loc,z,z7-tol,z13+tol
*if,ansver,eq,5.3,then
 esln,s,1
*else
 esln,s,all,active
*endif
cv2d,-3,,tb3
...
```



Internal Thermal Boundary Conditions



Syntax of Shell to Air Boundary Conditions

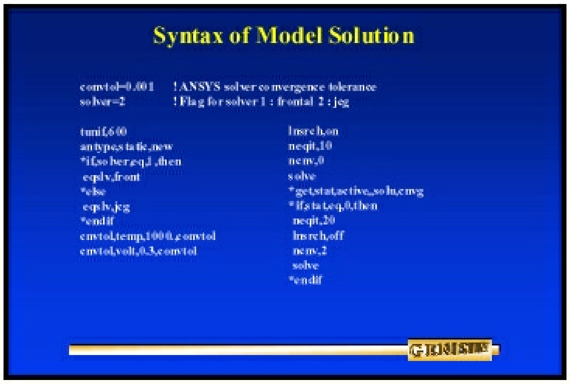
```
tmlt=955.        ! ledge melting temperature
topr=975.        ! operating temperature
coefmeca=650.    ! heat transfer coefficient at metal/cathode block

! melting temperature on ledge surface

cmsel,s,front
esel,s,mat,,10,11
sf,all,conv,2000,tmlt

! operating temperature on the cathode surface

cmsel,s,surf_cat
esel,s,mat,,1
sf,all,conv,coefmeca,topr
```

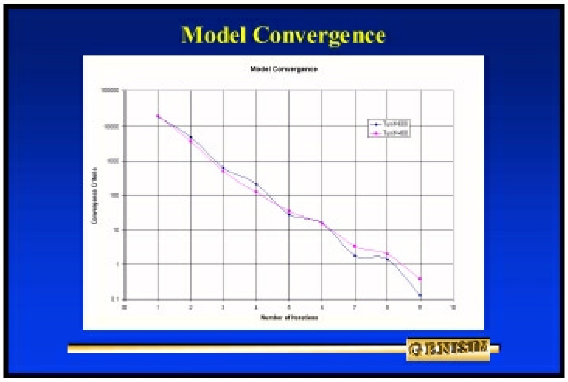


Syntax of Model Solution

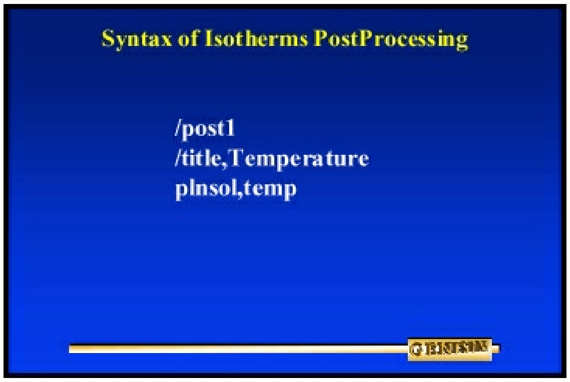
```
convtol=0.001     ! ANSYS solver convergence tolerance
solver=2          ! Flag for solver 1 : frontal  2 : jcg

tunif,600
antype,static,new
*if,solver,eq,1,then
 eqslv,front
*else
 eqslv,jcg
*endif
cnvtol,temp,1000,,convtol
cnvtol,volt,0.3,,convtol
```

```
lnsrch,on
neqit,10
nenv,0
solve
*get,stat,active,,solu,cnvg
*if,stat,eq,0,then
 neqit,20
 lnsrch,off
 nenv,2
 solve
*endif
```

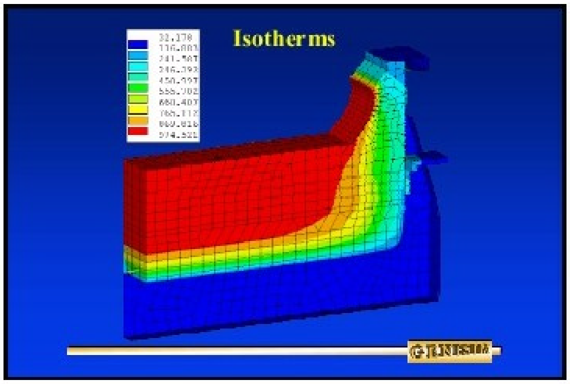


Model Convergence

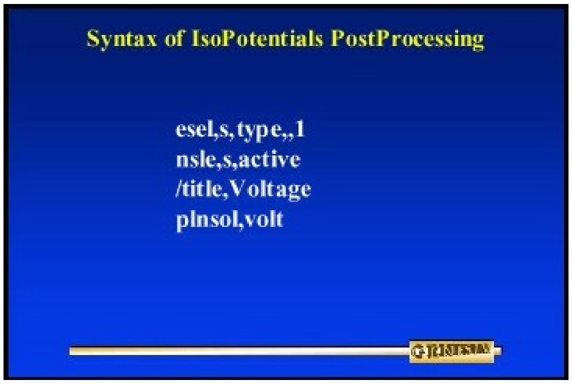


Syntax of Isotherms PostProcessing

```
/post1
/title,Temperature
plnsol,temp
```

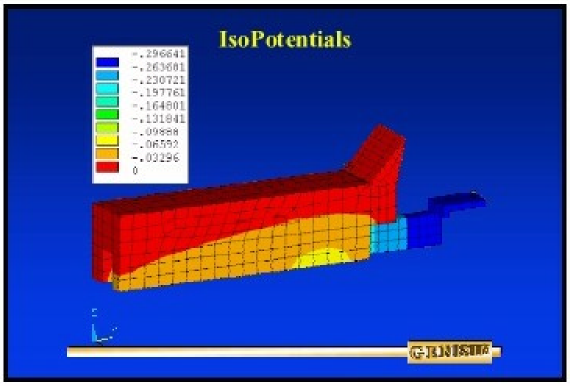


Isotherms

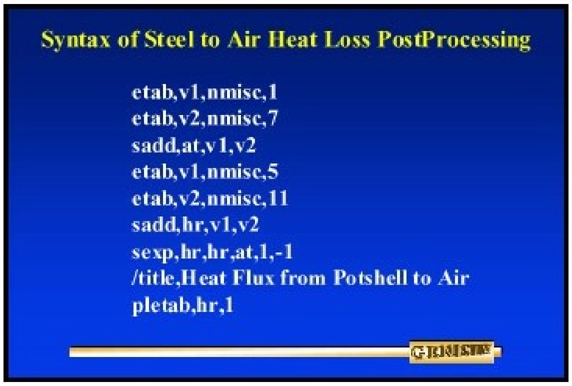


Syntax of IsoPotentials PostProcessing

```
esel,s,type,,1
nsle,s,active
/title,Voltage
plnsol,volt
```

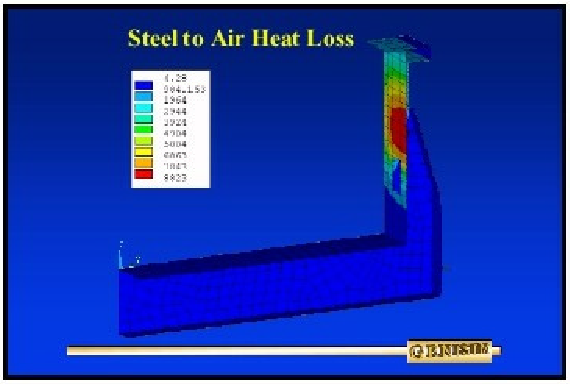


IsoPotentials

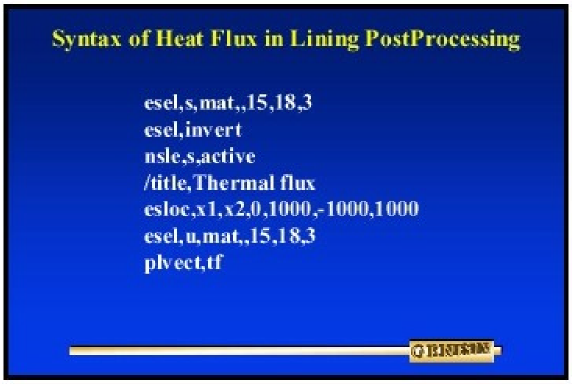


Syntax of Steel to Air Heat Loss PostProcessing

```
etab,v1,nmisc,1
etab,v2,nmisc,7
sadd,at,v1,v2
etab,v1,nmisc,5
etab,v2,nmisc,11
sadd,hr,v1,v2
sexp,hr,hr,at,1,-1
/title,Heat Flux from Potshell to Air
pletab,hr,1
```

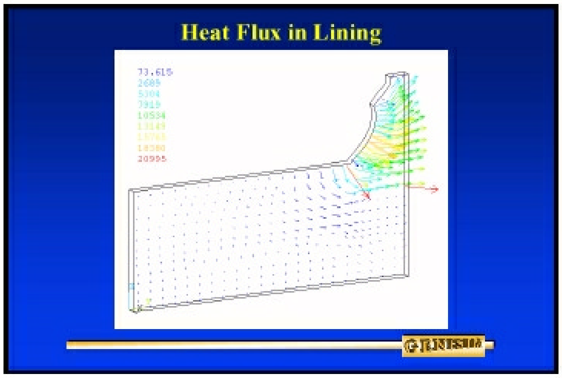


Steel to Air Heat Loss

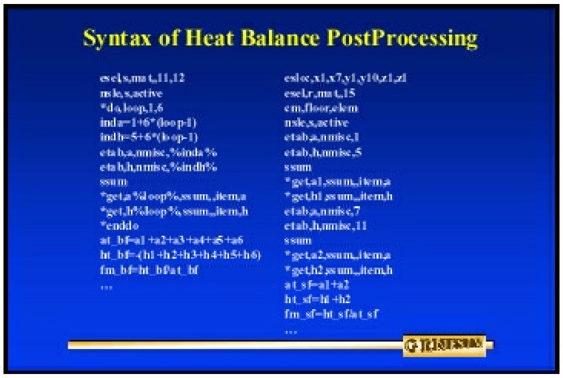


Syntax of Heat Flux in Lining PostProcessing

```
esel,s,mat,,15,18,3
esel,invert
nsle,s,active
/title,Thermal flux
esloc,x1,x2,0,1000,-1000,1000
esel,u,mat,,15,18,3
plvect,tf
```



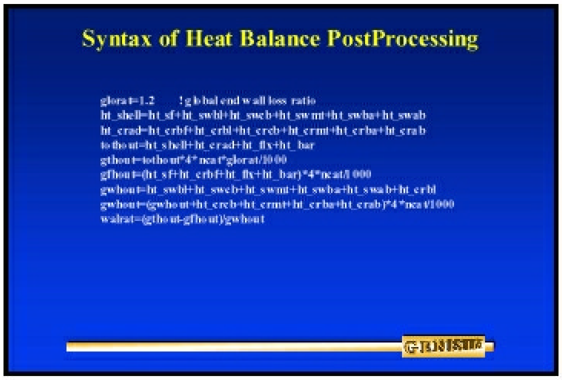
Heat Flux in Lining



Syntax of Heat Balance PostProcessing

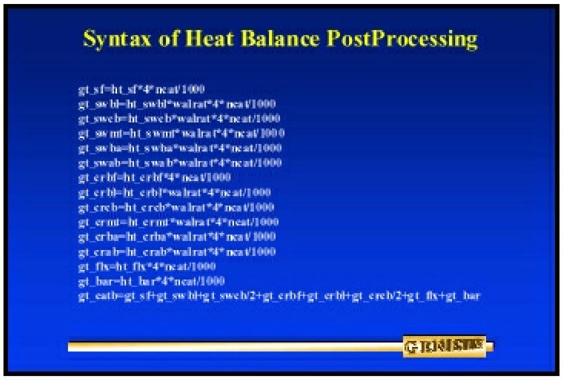
```
esel,s,mat,,11,12
nsle,s,active
*do,loop,1,6
inda=1+6*(loop-1)
indh=5+6*(loop-1)
etab,a,nmisc,%inda%
etab,h,nmisc,%indh%
ssum
*get,a%loop%,ssum,,item,a
*get,h%loop%,ssum,,item,h
*enddo
at_bf=a1+a2+a3+a4+a5+a6
ht_bf=-(h1+h2+h3+h4+h5+h6)
fm_bf=ht_bf/at_bf
...
```

```
esloc,x1,x7,y1,y10,z1,zl
esel,r,mat,,15
em,floor,elem
nsle,s,active
etab,a,nmisc,1
etab,h,nmisc,5
ssum
*get,a1,ssum,,item,a
*get,h1,ssum,,item,h
etab,a,nmisc,7
etab,h,nmisc,11
ssum
*get,a2,ssum,,item,a
*get,h2,ssum,,item,h
at_sf=a1+a2
ht_sf=h1+h2
fm_sf=ht_sf/at_sf
...
```



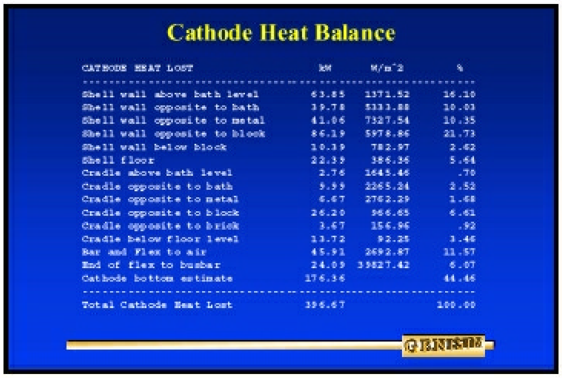
Syntax of Heat Balance PostProcessing

```
glorat=1.2     !global end wall loss ratio
ht_shell=ht_sf+ht_swbl+ht_sweb+ht_swmt+ht_swba+ht_swab
ht_crad=ht_crbf+ht_crbl+ht_creb+ht_crmt+ht_crba+ht_crab
tothout=ht_shell+ht_crad+ht_flx+ht_bar
gthout=tothout*4*ncat*glorat/1000
gfhout=(ht_sf+ht_crbf+ht_flx+ht_bar)*4*ncat/1000
gwhout=ht_swbl+ht_sweb+ht_swmt+ht_swba+ht_swab+ht_crbl
gwhout=(gwhout+ht_creb+ht_crmt+ht_crba+ht_crab)*4*ncat/1000
walrat=(gthout-gfhout)/gwhout
```



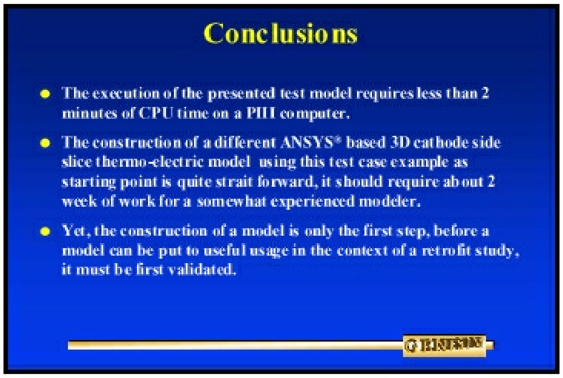
Syntax of Heat Balance PostProcessing

```
gt_sf=ht_sf*4*ncat/1000
gt_swbl=ht_swbl*walrat*4*ncat/1000
gt_sweb=ht_sweb*walrat*4*ncat/1000
gt_swmt=ht_swmt*walrat*4*ncat/1000
gt_swba=ht_swba*walrat*4*ncat/1000
gt_swab=ht_swab*walrat*4*ncat/1000
gt_crbf=ht_crbf*4*ncat/1000
gt_crbl=ht_crbl*walrat*4*ncat/1000
gt_creb=ht_creb*walrat*4*ncat/1000
gt_crmt=ht_crmt*walrat*4*ncat/1000
gt_crba=ht_crba*walrat*4*ncat/1000
gt_crab=ht_crab*walrat*4*ncat/1000
gt_flx=ht_flx*4*ncat/1000
gt_bar=ht_bar*4*ncat/1000
gt_catb=gt_sf+gt_swbl+gt_sweb/2+gt_crbf+gt_crbl+gt_creb/2+gt_flx+gt_bar
```



Cathode Heat Balance

```
CATHODE HEAT LOST                        kW      W/m^2        %
-----------------------------------------------------------------
Shell wall above bath level           63.85   1371.52     16.10
Shell wall opposite to bath           39.78   5333.88     10.03
Shell wall opposite to metal          41.06   7327.54     10.35
Shell wall opposite to block          86.19   5978.86     21.73
Shell wall below block                10.39    782.97      2.62
Shell floor                           22.39    386.36      5.64
Cradle above bath level                2.76   1645.46       .70
Cradle opposite to bath                9.99   2265.24      2.52
Cradle opposite to metal               6.67   2762.29      1.68
Cradle opposite to block              26.20    966.65      6.61
Cradle opposite to brick               3.67    156.96       .92
Cradle below floor level              13.72     92.25      3.46
Bar and Flex to air                   45.91   2692.87     11.57
End of flex to busbar                 24.09  33827.42      6.07
Cathode bottom estimate              176.36               44.46
-----------------------------------------------------------------
Total Cathode Heat Lost              396.67              100.00
```



Conclusions

- The execution of the presented test model requires less than 2 minutes of CPU time on a PIII computer.
- The construction of a different ANSYS® based 3D cathode side slice thermo-electric model using this test case example as starting point is quite strait forward, it should require about 2 week of work for a somewhat experienced modeler.
- Yet, the construction of a model is only the first step, before a model can be put to useful usage in the context of a retrofit study, it must be first validated.