Fermilab

Particle Physics Division 12-01-01

Mechanical Department Engineering Note

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Project: ANU NuMI Upgrades R&D

Project Internal Reference: UID 1581

Title: Horn1 Stripline Air Cooling- ANU 700 kW Study

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Reviewer(s): Salman Tariq

Key Words: ANU Stripline FEA thermal horn1 cooling upgrades

Abstract/Summary: 3D FEA results for cooling the Horn1 stripline under 700 kW load conditions. As of 1/16/08, this note has not been reviewed, nor have the results presented herein been discussed with the collaboration. Due to revocation of NOvA funding, work has been suspended at this time.

Applicable Codes:

1. Introduction

This analysis was performed because of proposed upgrades to the NuMI accelerator complex. These upgrades (ANU) are part of the NOvA experiment. An energy upgrade from 400kW to 700kW makes it necessary to analyze beam line components for increased heat loading. This task was concerned with a finite-element thermal analysis of the Horn1 stripline. Specifically the analysis should have provided enough information to determine what/if cooling upgrades are necessary for operating at 700kW.

2. Results

2.1. Figure 1 shows the results of the upper estimate for stripline temperatures. The deltaT is 100K, with a minimum value of 316.9K (43.8°C) and maximum of 416.9K (143.8°C). This is conservative, as it assumes no forced air over the stripline. This condition would be similar to operating without the blower unit in the chase.

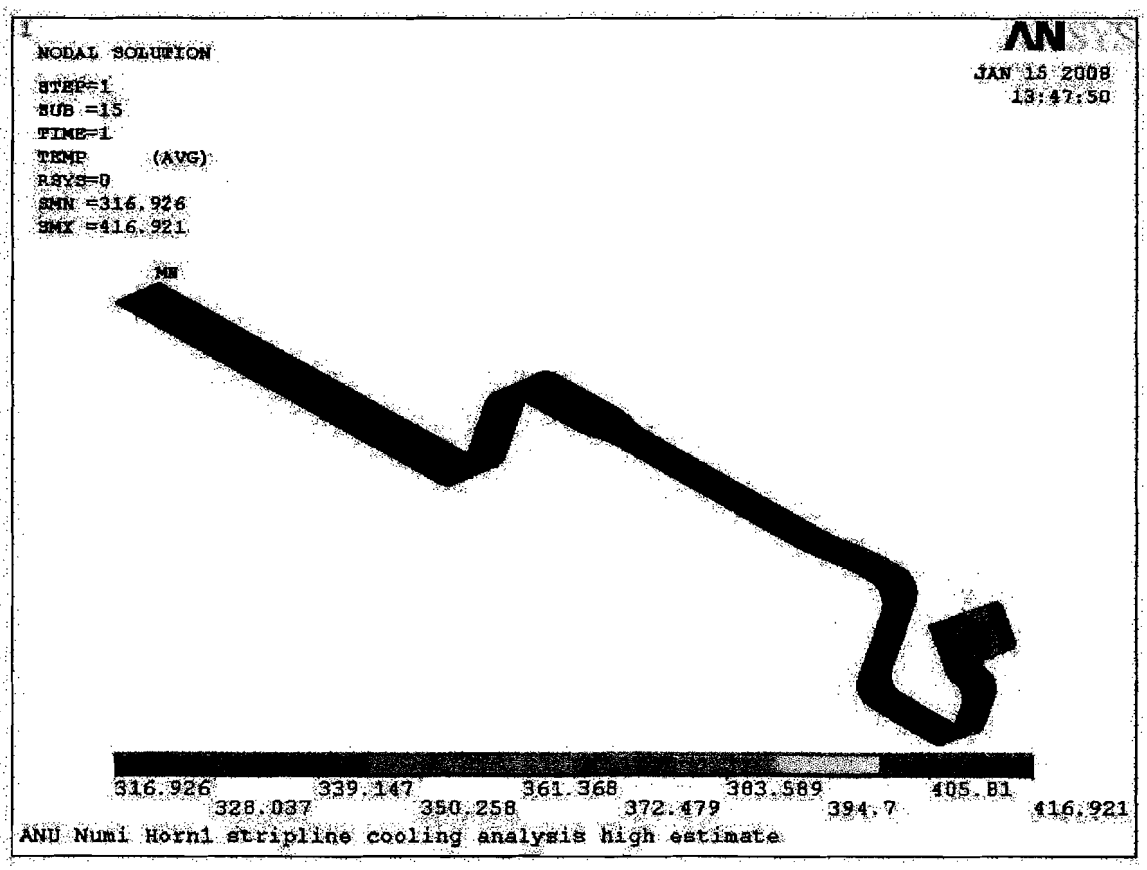

Figure 1. Maximum stripline temperature of 416.9K (143.8°C). Assumes no forced air, only natural convection cooling.

2.2. Figure 2 shows the results of the lower temperature estimate for the stripline. The deltaT is 66.7K, with a minimum value of 312.6K (39.5°C) and maximum of 379.3K (106.2°C).

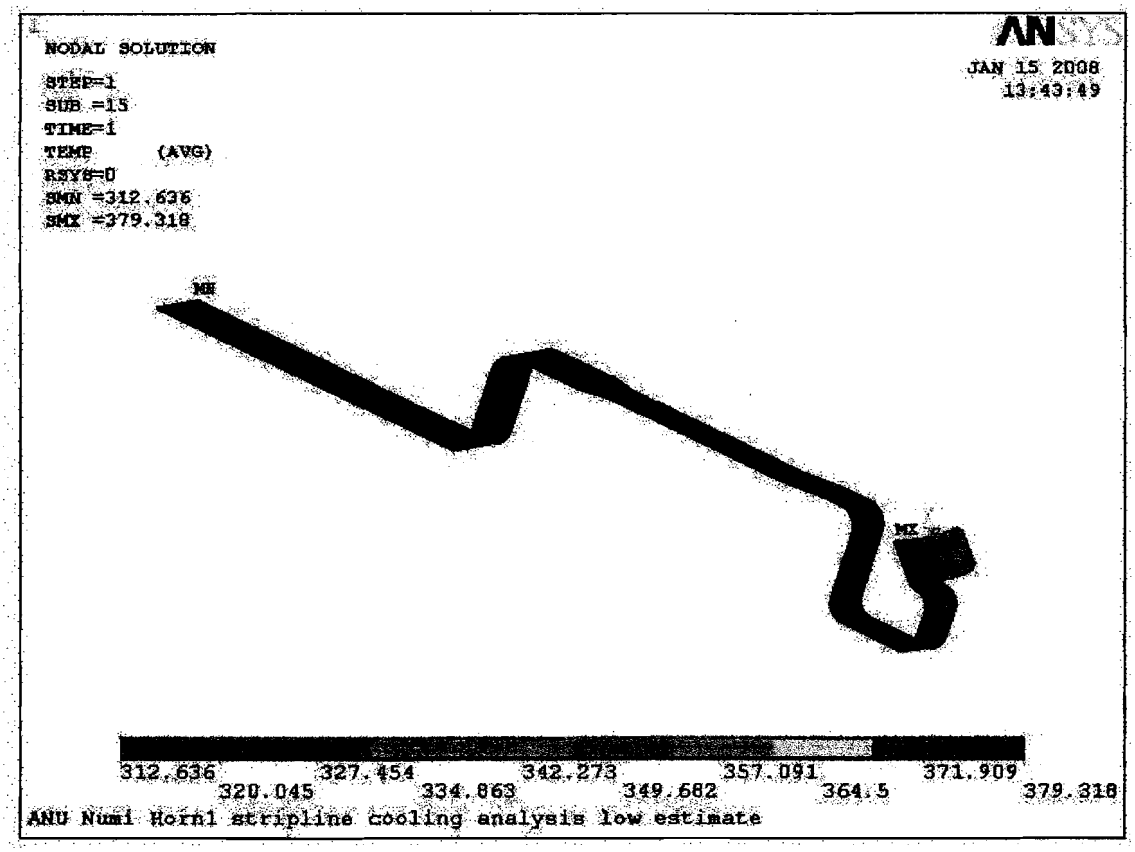

Figure 2. Maximum stripline temperature of 379.3K (106.2°C). Uses convection values close to those calculated from empirical data.

3. Methodology

Two analyses are presented here. They are intended to provide high and low estimates for stripline temperatures.

3.1. Analysis 1 (Attachment 1), uses a very conservative convection coefficient. Essentially assumes no air flow in the target chase, only cooling by natural convection.

3.2. Analysis 2 (Attachment 2), uses higher convection coefficients and assumes more heat is carried away by cooled air, forced through the chase. These cooling values have some basis from velocity measurements made on a test fixture. See attachment#x for a summary of this testing and sample cooling calculations.

3.3. The original analysis was done by Andy Steffanik (7.2). His FEA work was for the 400kW NuMI loads in 2003. He was asked in 2006 to update this model for the 700kW load conditions. The results of his latest model showed temperatures higher than desired, and prompted additional studies. A simple mathematical model by Pat Hurh in early 2007 (7.1) indicated an error in Andy's FEA loading. Another concern was that cooling conditions assumed in the model were

unnecessarily conservative. On the basis of these finding and concerns, the decision was made to:

3.3.1. Empirically investigate stripline cooling and

3.3.2. Create a new 3D thermal FEA with revised loading. This note summarizes the work done on a new 3D thermal FEA, and uses input from the cooling investigation.

3.4. The analysis' loading conditions presented here are based heavily on work done by Andy Steffanik and Pat Hurh. (Refer. 7.1, 7.2) Additionally, the technical aspects of the FEA input file are similar to ones compiled in ANSYS by Salman Tariq.

4. Design loads

4.1. Figure 3 shows the stripline broken down into zones. The loads were applied to the model by zone.

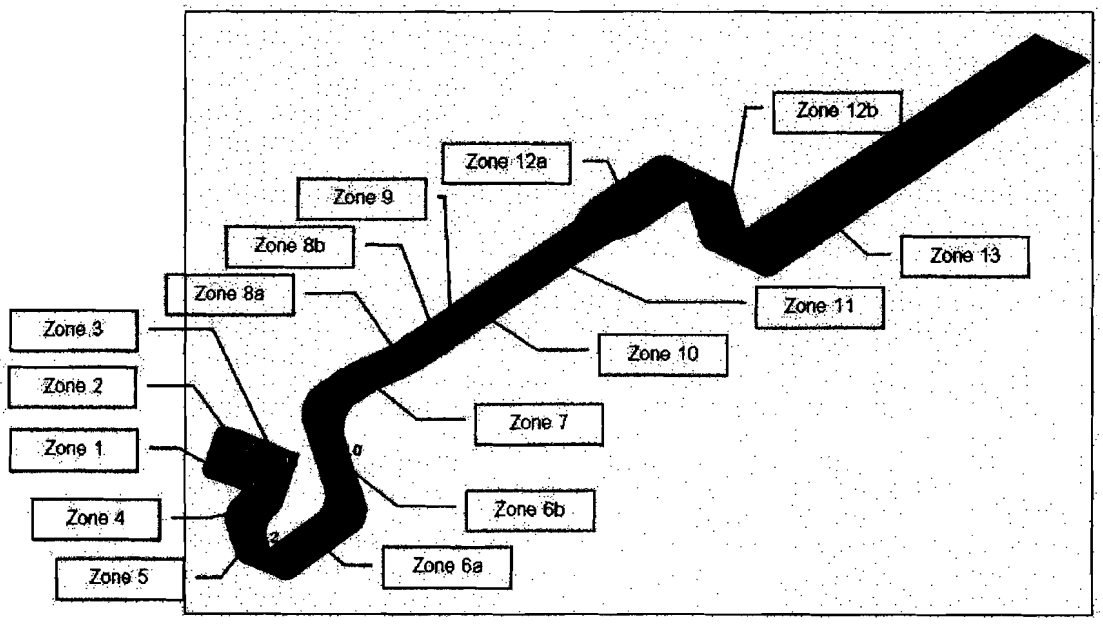

Figure 3. Read in conjunction with loading in Tables 1 & 2.

4.2. Table 1 summarizes thermal loads used for the high temperature estimate FEA model.

	Beam Heating W/m^3	Joule Heating W/m^3	**Total (Beam+Joule)** W/m^3	Zone Volumes m^3	**Heat input** W	Inner face of stripline: Convection coefficient W/m^{2}K	Inner face of stripline: Air Temp Kelvin	Outer face of stripline: Convection coefficient W/m^{2}K	Outer face of stripline: Air Temp Kelvin
Zone 1	167000	29300	**196300**	8.4E-05	**16.45**	Conduct	340	1	288
Zone 2	232000	29300	**261300**	2.3E-04	**59.13**	4	288	4	288
Zone 3	232000	29300	**261300**	3.2E-04	**83.69**	4	288	4	288
Zone 4	232000	29300	**261300**	2.8E-04	**73.16**	4	288	4	288
Zone 5	113000	29300	**142300**	2.2E-04	**30.74**	4	288	4	288
Zone 6a	67500	29300	**96800**	7.5E-04	**72.27**	4	288	4	288
Zone 6b	67500	29300	**96800**	9.8E-04	**95.34**	4	288	4	288
Zone 7	48600	29300	**77900**	3.6E-04	**27.68**	4	288	4	288
Zone 8	48600	29300	**77900**	5.0E-04	**38.56**	4	288	4	288
Zone 9	48600	29300	**77900**	2.0E-04	**15.32**	4	288	4	288
Zone 10	6210	29300	**35510**	2.0E-04	**6.98**	4	308	4	308
Zone 11	6210	29300	**35510**	7.6E-04	**26.87**	4	308	4	308
Zone 12	675	10500	**11175**	2.7E-03	**30.72**	4	308	4	308
Zone 13	675	10500	**11175**	4.1E-03	**45.45**	4	303	4	303
					622.36				

Table 1. High temperature estimate load conditions, note 4W/m^{2}K convection coefficients. Read in conjunction with Figure 3. below.

4.3. Table 2 thermal loads used for the low temperature estimate FEA model.

	Beam Heating W/m^3	Joule Heating W/m^3	**Total (Beam+Joule)** W/m^3	Zone Volumes m^3	**Heat input** W	Inner face of stripline: Convection coefficient W/m^{2}K	Inner face of stripline: Air Temp Kelvin	Outer face of stripline: Convection coefficient W/m^{2}K	Outer face of stripline: Air Temp Kelvin
Zone 1	167000	29300	**196300**	8.4E-05	**16.45**	Conduct	340	8	288
Zone 2	232000	29300	**261300**	2.3E-04	**59.13**	8	288	8	288
Zone 3	232000	29300	**261300**	3.2E-04	**83.69**	10	288	10	288
Zone 4	232000	29300	**261300**	2.8E-04	**73.16**	10	288	10	288
Zone 5	113000	29300	**142300**	2.2E-04	**30.74**	10	288	10	288
Zone 6a	67500	29300	**96800**	7.5E-04	**72.27**	10	288	10	288
Zone 6b	67500	29300	**96800**	9.8E-04	**95.34**	10	288	10	288
Zone 7	48600	29300	**77900**	3.6E-04	**27.68**	10	288	10	288
Zone 8	48600	29300	**77900**	5.0E-04	**38.56**	5.67	288	5.67	288
Zone 9	48600	29300	**77900**	2.0E-04	**15.32**	5.67	288	5.67	288
Zone 10	6210	29300	**35510**	2.0E-04	**6.98**	5.67	308	5.67	308
Zone 11	6210	29300	**35510**	7.6E-04	**26.87**	5.67	308	5.67	308
Zone 12	675	10500	**11175**	2.7E-03	**30.72**	5.67	308	5.67	308
Zone 13	675	10500	**11175**	4.1E-03	**45.45**	5.67	303	5.67	303
					622.36				

Table 2. Low temperature estimate load condition, note convection coefficients on the inner and outer surfaces. Read in conjunction with Figure 3. below.

5. Assumptions

5.1. Single conductor
5.2. Neglected edges
5.3. No radiation from other striplines
5.4. No radiation from clamp or surrounding components
5.5. No conduction through ceramic spacers
5.6. No contact resistance between flag/horn
5.7. Temperature at flag/horn contact at 67C, see e-mail from P. Hurh (attachment# 6.3)
5.8. Chase air temperature at 15C
5.9. Applied heat generation as piece-wise function, rather than smooth. Data as received from Byron Lundberg's MARS analysis (attachment# 6.4).
5.10. High temperature estimate (attachment 6.1) assumes a convection coefficient of [10 W/m^2K] over exposed sections of the stripline. Assumes natural convection [5.67 W/m^2K] within the stripline block. See reference 7.3.
5.11. Low temperature estimate (attachment 6.2) assumes a uniform convection coefficient of [4 W/m^2K] over the entire length of the stripline. Same as

6. Attachments

6.1. High temperature estimate input file
6.2. Low temperature estimate input file
6.3. E-mails, input file revision and flag/horn contact.
6.4. "Energy Deposition Horn 1 Outer Conductor / Stripline," Byron Lundberg

7. References

7.1. "Summary of NuMI Horn1 stripline/stripline block cooling concerns for 700 kW beam operation (ANU)," Pat Hurh, 2/12/2007 (Nova-Doc-1787)
7.2. MD-ENG-042 Section 34.0- "Horn1 Stripline Air Cooling – Shielding Block and Chase" Andy Steffanik, 4/23/2003
7.3. "Horn1 Stripline Air Velocity Measurements and Chase Mockup" Matt Slabaugh, 1/16/2008

Attachment 6.1

```
!*************************************************
!*******anu_horn1_stripline_cool_700******
!*************************************************
!M.Slabaugh   12/11/2007
!1. Added MARS data from Byron, updated. Increased values by about 20%. Also
corrected Joule heating from 26900 to 29300 kW/m^3
!*************************************************
!*******anu_horn1_stripline_cool_700******
!*************************************************
!M.Slabaugh   11/30/2007
!1. Uses updated beam and joule heating (MARS) (11/30)
!2. Horn temp at 67C (obtained from Pat Hurh's model minimum)
!3. Used Pat Hurh's more conservative transfer co-eff of 4 (old 5.67)
!4. Changed uniform temperature to 25C
!*************************************************
!*******anu_horn1_stripline_cool_700******
!*************************************************
!M.Slabaugh   09/05/2007
!1. Corrected thermal loads from Andy Stefanik, 700kW case, halved joule heating
!2. Horn temp at 25C
!*************************************************
!*******anu_horn1_stripline_cool_700******
!*************************************************
!M.Slabaugh   08/14/2007
!1. Thermal loads from Andy Stefanik, 700kW
!2. Element type: Plane90, 3d 20 node element, thermal solid
!3. Film coefficients and volumetric heat generation applied to 13 zones of
stripline
!4. Units  m, sec, K

/filname,anu_horn1_stripline_700_v8
/TITLE,ANU Numi Horn1 stripline cooling analysis high temp estimate

!Import geometry from IGES file
!=======================
/aux15
ioptn,iges,faceted
ioptn,merge,yes
ioptn,solid,yes
ioptn,small,yes
ioptn,gtoler,1e-2


!igesin,'LAYER1_RIGHT_STRIPLINE','igs'
!igesin,'LAYER2_RIGHT_STRIPLINE','igs'
igesin,'LAYER3_RIGHT_STRIPLINE','igs'
!igesin,'LAYER4_RIGHT_STRIPLINE','igs'



!vplot
!allsel
!save

!Create
!------------------------------
/prep7



kwplan,,34,39,33
vsel,s,volu,,1
```

```
vsbw,all

kwplan,,69,62,70
vsel,s,volu,,1
vsbw,all

wpoffs,,,.4572
vsel,s,volu,,3
vsbw,all

wpoffs,,,.4064
vsel,s,volu,,4
vsbw,all

wpoffs,,,.1016
vsel,s,volu,,5
vsbw,all

wpoffs,,,.1016
vsel,s,volu,,6
vsbw,all

kwplan,,96,81,79
vsel,s,volu,,7
vsbw,all

kwplan,,95,82,30
vsel,s,volu,,8
vsbw,all

kwplan,,90,85,91
vsel,s,volu,,9
vsbw,all

kwplan,,129,130,26
vsel,s,volu,,10
vsbw,all

kwplan,,23,22,138
vsel,s,volu,,11
vsbw,all

kwplan,,24,21,139
vsel,s,volu,,12
vsbw,all

kwplan,,19,18,16
vsel,s,volu,,13
vsbw,all

kwplan,,146,147,16
vsel,s,volu,,14
vsbw,all

kwplan,,3,11,4
vsel,s,volu,,14
vsbw,all


!Material Property
!===================
!Material 1: 6101 T61 Aluminum
!-----------------------------------------------
```

```
mptemp
mptemp,1,293            ! RT (293K) mechanical properties


mpdata,ex,1,,1.227e2    ! Elastic modulus (N/m^2)
mpdata,kxx,1,,222       ! Electrical conductivity (W/m-K)
mpdata,prxy,1,,0.33     ! Poisson's ratio



!=========================
!Element Selection & Creation
!=========================
et,1,solid90            ! 3d 20 node element, Thermal solid

!Meshing
!========
!First assign materials to areas
vsel,s,volu,,1,16
vatt,1,,1                       !assign material 1


allsel
vplot

!Mesh areas
!------------------

smrtsize,6
mshape,1,3D
mshkey,0
!esz1=.375              ! element sizes
!lesize,all,esz1
vsel,s,volu,,1,16
aslv,s
vmesh,all               ! mesh volumes

allsel
save

!==================================
!Apply boundary conditions & loads
!==================================
tunif,298                       !uniform temperature

!A.Heat transfer coefficients
!=====================
!##Zone 1 film coefficient simulating flag contact to horn (inner side)##
!h_1is=10000                    !inner side film coefficient (W/m2 K)
tb_1is=340                      !bulk (ambient) temperature (K)
asel,s,area,,2
!sfa,all,,conv,h_1is,tb_1is
da,all,temp,tb_1is

h_1os=1                         !outer side film coefficient (W/m2 K)
tb_1os=288                      !bulk (ambient) temperature (K)
asel,s,area,,4
sfa,all,,conv,h_1os,tb_1os


!##Zone 2 film coefficients##
h_2is=4                         ! inner side film coefficient (W/m2 K)
```

```
tb_2is=288                      ! bulk (ambient) temperature (K)
asel,s,area,,11
asel,a,area,,113
sfa,all,,conv,h_2is,tb_2is      ! Apply film coefficient to inner side of zone 2

h_2os=4                         ! outer side film coefficient (W/m2 K)
tb_2os=288                      ! bulk (ambient) temperature (K)
asel,s,area,,117
asel,a,area,,151
sfa,all,,conv,h_2os,tb_2os      ! Apply film coefficient to outer side of zone 2


!##Zone 3 film coefficients##
h_3is=4                         ! inner side film coefficient (W/m2 K)
tb_3is=288                      ! bulk (ambient) temperature (K)
asel,s,area,,145
sfa,all,,conv,h_3is,tb_3is      ! Apply film coefficient to inner side of zone 3

h_3os=4                         ! outer side film coefficient (W/m2 K)
tb_3os=288                      ! bulk (ambient) temperature (K)
asel,s,area,,15,20,5
sfa,all,,conv,h_3os,tb_3os      ! Apply film coefficient to outer side of zone 3


!##Zone 4 film coefficients##
h_4is=4                         ! inner side film coefficient (W/m2 K)
tb_4is=288                      ! bulk (ambient) temperature (K)
asel,s,area,,145
sfa,all,,conv,h_4is,tb_4is      ! Apply film coefficient to inner side of zone 4

h_4os=4                         ! outer side film coefficient (W/m2 K)
tb_4os=288                      ! bulk (ambient) temperature (K)
asel,s,area,,17,22,5
sfa,all,,conv,h_4os,tb_4os      ! Apply film coefficient to outer side of zone 4


!##Zone 5 film coefficients##
h_5is=4                         ! inner side film coefficient (W/m2 K)
tb_5is=288                      ! bulk (ambient) temperature (K)
asel,s,area,,25
sfa,all,,conv,h_5is,tb_5is      ! Apply film coefficient to inner side of zone 5

h_5os=4                         ! outer side film coefficient (W/m2 K)
tb_5os=288                      ! bulk (ambient) temperature (K)
asel,s,area,,23
sfa,all,,conv,h_5os,tb_5os      ! Apply film coefficient to outer side of zone 5


!##Zone 6 film coefficients##
h_6is=4                         ! inner side film coefficient (W/m2 K)
tb_6is=288                      ! bulk (ambient) temperature (K)
asel,s,area,,31,32,
asel,a,area,,38,43,5
asel,a,area,,73
sfa,all,,conv,h_6is,tb_6is      ! Apply film coefficient to inner side of zone 6

h_6os=4                         ! outer side film coefficient (W/m2 K)
tb_6os=288                      ! bulk (ambient) temperature (K)
asel,s,area,,29,34,5
```

```
asel,a,area,,40,41
asel,a,area,,71
sfa,all,,conv,h_6os,tb_6os      ! Apply film coefficient to outer side of zone 6


!##Zone 7 film coefficients##
h_7is=4                 ! inner side film coefficient (W/m2 K)
tb_7is=288                      ! bulk (ambient) temperature (K)
asel,s,area,,47,48
sfa,all,,conv,h_7is,tb_7is      ! Apply film coefficient to inner side of zone 7

h_7os=4                 ! outer side film coefficient (W/m2 K)
tb_7os=288                      ! bulk (ambient) temperature (K)
asel,s,area,,50,70,20
sfa,all,,conv,h_7os,tb_7os      ! Apply film coefficient to outer side of zone 7

!##Zone 8 film coefficients##
h_8is=4                 ! inner side film coefficient (W/m2 K)
tb_8is=288                      ! bulk (ambient) temperature (K)
asel,s,area,,74,124,50
sfa,all,,conv,h_8is,tb_8is      ! Apply film coefficient to inner side of zone 8

h_8os=4                 ! outer side film coefficient (W/m2 K)
tb_8os=288                      ! bulk (ambient) temperature (K)
asel,s,area,,54,135,81
sfa,all,,conv,h_8os,tb_8os      ! Apply film coefficient to outer side of zone 8


!##Zone 9 film coefficients##
h_9is=4                 ! inner side film coefficient (W/m2 K)
tb_9is=288                      ! bulk (ambient) temperature (K)
asel,s,area,,138
sfa,all,,conv,h_9is,tb_9is      ! Apply film coefficient to inner side of zone 9

h_9os=4                 ! outer side film coefficient (W/m2 K)
tb_9os=288                      ! bulk (ambient) temperature (K)
asel,s,area,,130
sfa,all,,conv,h_9os,tb_9os      ! Apply film coefficient to outer side of zone 9


!##Zone 10 film coefficients##
h_10is=4                        ! inner side film coefficient (W/m2 K)
tb_10is=308                     ! bulk (ambient) temperature (K)
asel,s,area,,133
sfa,all,,conv,h_10is,tb_10is    ! Apply film coefficient to inner side of zone 10

h_10os=4                        ! outer side film coefficient (W/m2 K)
tb_10os=308                     ! bulk (ambient) temperature (K)
asel,s,area,,125
sfa,all,,conv,h_10os,tb_10os    ! Apply film coefficient to outer side of zone 10


!##Zone 11 film coefficients##
h_11is=4                        ! inner side film coefficient (W/m2 K)
tb_11is=308                     ! bulk (ambient) temperature (K)
asel,s,area,,128
sfa,all,,conv,h_11is,tb_11is    ! Apply film coefficient to inner side of zone 11

h_11os=4                        ! outer side film coefficient (W/m2 K)
tb_11os=308                     ! bulk (ambient) temperature (K)
```

```
asel,s,area,,118
sfa,all,,conv,h_11os,tb_11os    ! Apply film coefficient to outer side of zone 11


!##Zone 12 film coefficients##
h_12is=4                        ! inner side film coefficient (W/m2 K)
tb_12is=308                     ! bulk (ambient) temperature (K)
asel,s,area,,57,93,36
asel,a,area,,87,88
sfa,all,,conv,h_12is,tb_12is    ! Apply film coefficient to inner side of zone 12

h_12os=4                        ! outer side film coefficient (W/m2 K)
tb_12os=308                     ! bulk (ambient) temperature (K)
asel,s,area,,55,82,27
asel,a,area,,90,95,5
sfa,all,,conv,h_12os,tb_12os    ! Apply film coefficient to outer side of zone 12


!##Zone 13 film coefficients##
h_13is=4                        ! inner side film coefficient (W/m2 K)
tb_13is=303                     ! bulk (ambient) temperature (K)
asel,s,area,,98
sfa,all,,conv,h_13is,tb_13is    ! Apply film coefficient to inner side of zone 13

h_13os=4                        ! outer side film coefficient (W/m2 K)
tb_13os=303                     ! bulk (ambient) temperature (K)
asel,s,area,,96
sfa,all,,conv,h_13os,tb_13os    ! Apply film coefficient to outer side of zone 13


! B. Apply internal heat generation rates to volumes
hg_1=196300
vsel,s,volu,,14
bfv,all,hgen,hg_1               !Apply internal heat gen rate to Zone 1

hg_2=261300
vsel,s,volu,,16
bfv,all,hgen,hg_2               !Apply internal heat gen rate to Zone 2

hg_3=261300
vsel,s,volu,,15
bfv,all,hgen,hg_3               !Apply internal heat gen rate to Zone 3

hg_4=261300
vsel,s,volu,,13
bfv,all,hgen,hg_4               !Apply internal heat gen rate to Zone 4

hg_5=142300
vsel,s,volu,,12
bfv,all,hgen,hg_5               !Apply internal heat gen rate to Zone 5

hg_6=96800
vsel,s,volu,,10,11
bfv,all,hgen,hg_6               !Apply internal heat gen rate to Zone 6

hg_7=77900
vsel,s,volu,,9
bfv,all,hgen,hg_7               !Apply internal heat gen rate to Zone 7

hg_8=77900
```

```
vsel,s,volu,,7,8
bfv,all,hgen,hg_8                !Apply internal heat gen rate to Zone 8

hg_9=77900
vsel,s,volu,,6
bfv,all,hgen,hg_9                !Apply internal heat gen rate to Zone 9

hg_10=35510
vsel,s,volu,,5
bfv,all,hgen,hg_10               !Apply internal heat gen rate to Zone 10

hg_11=35510
vsel,s,volu,,4
bfv,all,hgen,hg_11               !Apply internal heat gen rate to Zone 11

hg_12=11175
vsel,s,volu,,1,3,2
bfv,all,hgen,hg_12               !Apply internal heat gen rate to Zone 12

hg_13=11175
vsel,s,volu,,2
bfv,all,hgen,hg_13               !Apply internal heat gen rate to Zone 13

allsel
save


!Solve
!=======
/solu
time,1
nsubst,15,,5
outres,all,last

solve
save
finish


!/exit,solu


!save

!==================================================
finish
!/exit,solu
```

Attachment 6.2

```
!*************************************************
!*******anu_horn1_stripline_cool_700******
!*************************************************
!M.Slabaugh   12/11/2007
!1. Added MARS data from Byron, updated. Increased values by about 20%. Also
corrected Joule heating from 26900 to 29300 kW/m^3
!*************************************************
!*******anu_horn1_stripline_cool_700******
!*************************************************
!M.Slabaugh   11/28/2007
!1. Used convection co-effs calculated from velocity measurements
!2. Changed Horn1 temp to 67C, reflects Pat's work
!3. Added convection in clamp areas
!*************************************************
!*******anu_horn1_stripline_cool_700******
!*************************************************
!M.Slabaugh   10/31/2007
!1. Corrected the Corrected thermal loads from Andy Stefanik, 700kW case, halved
joule heating
!2. Used beam heating information supplied by MARS analysis (10/24/07)
!3. Horn temp at 25C, conservative value from cooling tests performed in June 2001
(Vladimir Sidorov)
!*************************************************
!*******anu_horn1_stripline_cool_700******
!*************************************************
!M.Slabaugh   09/05/2007
!1. Corrected thermal loads from Andy Stefanik, 700kW case, halved joule heating
!2. Horn temp at 25C
!*************************************************
!*******anu_horn1_stripline_cool_700******
!*************************************************
!M.Slabaugh   08/14/2007
!1. Thermal loads from Andy Stefanik, 700kW
!2. Element type: Plane90, 3d 20 node element, thermal solid
!3. Film coefficients and volumetric heat generation applied to 13 zones of
stripline
!4. Units  m, sec, K

/filname,anu_horn1_stripline_700_v7
/TITLE,ANU Numi Horn1 stripline cooling analysis low temp estimate

!Import geometry from IGES file
!=========================
/aux15
ioptn,iges,faceted
ioptn,merge,yes
ioptn,solid,yes
ioptn,small,yes
ioptn,gtoler,1e-2


!igesin,'LAYER1_RIGHT_STRIPLINE','igs'
!igesin,'LAYER2_RIGHT_STRIPLINE','igs'
igesin,'LAYER3_RIGHT_STRIPLINE','igs'
!igesin,'LAYER4_RIGHT_STRIPLINE','igs'



vplot
allsel
save

!Create
```

```
!-------------------------------
/prep7

kwplan,,34,39,33
vsel,s,volu,,1
vsbw,all

kwplan,,69,62,70
vsel,s,volu,,1
vsbw,all

wpoffs,,,.4572
vsel,s,volu,,3
vsbw,all

wpoffs,,,.4064
vsel,s,volu,,4
vsbw,all

wpoffs,,,.1016
vsel,s,volu,,5
vsbw,all

wpoffs,,,.1016
vsel,s,volu,,6
vsbw,all

kwplan,,96,81,79
vsel,s,volu,,7
vsbw,all

kwplan,,95,82,30
vsel,s,volu,,8
vsbw,all

kwplan,,90,85,91
vsel,s,volu,,9
vsbw,all

kwplan,,129,130,26
vsel,s,volu,,10
vsbw,all

kwplan,,23,22,138
vsel,s,volu,,11
vsbw,all

kwplan,,24,21,139
vsel,s,volu,,12
vsbw,all

kwplan,,19,18,16
vsel,s,volu,,13
vsbw,all

kwplan,,146,147,16
vsel,s,volu,,14
vsbw,all

kwplan,,3,11,4
vsel,s,volu,,14
vsbw,all
```

```
!Material Property
!===================
!Material 1: 6101 T61 Aluminum
!-----------------------------------------------
mptemp
mptemp,1,293            ! RT (293K) mechanical properties


mpdata,ex,1,,1.227e2    ! Elastic modulus (N/m^2)
mpdata,kxx,1,,222       ! Electrical conductivity (W/m-K)
mpdata,prxy,1,,0.33     ! Poisson's ratio



!========================
!Element Selection & Creation
!========================
et,1,solid90            ! 3d 20 node element, Thermal solid

!Meshing
!========
!First assign materials to areas
vsel,s,volu,,1,16
vatt,1,,1                       !assign material 1


allsel
vplot

!Mesh areas
!------------------

smrtsize,6
mshape,1,3D
mshkey,0
!esz1=.375              ! element sizes
!lesize,all,esz1
vsel,s,volu,,1,16
aslv,s
vmesh,all               ! mesh volumes

allsel
save

!==================================
!Apply boundary conditions & loads
!==================================
tunif,295                       !uniform temperature

!A.Heat transfer coefficients
!=====================
!##Zone 1 film coefficient simulating flag contact to horn (inner side)##
h_1is=10000                     !inner side film coefficient (W/m2 K)
tb_1is=340                      !bulk (ambient) temperature (K)
asel,s,area,,2
sfa,all,,conv,h_1is,tb_1is

h_1os=8                         !outer side film coefficient (W/m2 K)
tb_1os=288                      !bulk (ambient) temperature (K)
asel,s,area,,4
sfa,all,,conv,h_1os,tb_1os
```

```
!##Zone 2 film coefficients##
h_2is=8                          ! inner side film coefficient (W/m2 K)
tb_2is=288                       ! bulk (ambient) temperature (K)
asel,s,area,,11
asel,a,area,,113
sfa,all,,conv,h_2is,tb_2is       ! Apply film coefficient to inner side of zone 2

h_2os=8                          ! outer side film coefficient (W/m2 K)
tb_2os=288                       ! bulk (ambient) temperature (K)
asel,s,area,,117
asel,a,area,,151
sfa,all,,conv,h_2os,tb_2os       ! Apply film coefficient to outer side of zone 2


!##Zone 3 film coefficients##
h_3is=10                                 ! inner side film coefficient (W/m2 K)
tb_3is=288                       ! bulk (ambient) temperature (K)
asel,s,area,,145
sfa,all,,conv,h_3is,tb_3is       ! Apply film coefficient to inner side of zone 3

h_3os=10                                 ! outer side film coefficient (W/m2 K)
tb_3os=288                       ! bulk (ambient) temperature (K)
asel,s,area,,15,20,5
sfa,all,,conv,h_3os,tb_3os       ! Apply film coefficient to outer side of zone 3


!##Zone 4 film coefficients##
h_4is=10                                 ! inner side film coefficient (W/m2 K)
tb_4is=288                       ! bulk (ambient) temperature (K)
asel,s,area,,145
sfa,all,,conv,h_4is,tb_4is       ! Apply film coefficient to inner side of zone 4

h_4os=10                                 ! outer side film coefficient (W/m2 K)
tb_4os=288                       ! bulk (ambient) temperature (K)
asel,s,area,,17,22,5
sfa,all,,conv,h_4os,tb_4os       ! Apply film coefficient to outer side of zone 4


!##Zone 5 film coefficients##
h_5is=10                                 ! inner side film coefficient (W/m2 K)
tb_5is=288                       ! bulk (ambient) temperature (K)
asel,s,area,,25
sfa,all,,conv,h_5is,tb_5is       ! Apply film coefficient to inner side of zone 5

h_5os=10                                 ! outer side film coefficient (W/m2 K)
tb_5os=288                       ! bulk (ambient) temperature (K)
asel,s,area,,23
sfa,all,,conv,h_5os,tb_5os       ! Apply film coefficient to outer side of zone 5


!##Zone 6 film coefficients##
h_6is=10                                 ! inner side film coefficient (W/m2 K)
tb_6is=288                       ! bulk (ambient) temperature (K)
asel,s,area,,31,32,
asel,a,area,,38,43,5
asel,a,area,,73
sfa,all,,conv,h_6is,tb_6is       ! Apply film coefficient to inner side of zone 6
```

```
h_6os=10                                  ! outer side film coefficient (W/m2 K)
tb_6os=288                          ! bulk (ambient) temperature (K)
asel,s,area,,29,34,5
asel,a,area,,40,41
asel,a,area,,71
sfa,all,,conv,h_6os,tb_6os          ! Apply film coefficient to outer side of zone 6


!##Zone 7 film coefficients##
h_7is=10                            ! inner side film coefficient (W/m2 K)
tb_7is=288                          ! bulk (ambient) temperature (K)
asel,s,area,,47,48
sfa,all,,conv,h_7is,tb_7is          ! Apply film coefficient to inner side of zone 7

h_7os=10                            ! outer side film coefficient (W/m2 K)
tb_7os=288                          ! bulk (ambient) temperature (K)
asel,s,area,,50,70,20
sfa,all,,conv,h_7os,tb_7os          ! Apply film coefficient to outer side of zone 7


!##Zone 8 film coefficients##
h_8is=5.67                          ! inner side film coefficient (W/m2 K)
tb_8is=288                          ! bulk (ambient) temperature (K)
asel,s,area,,74,124,50
sfa,all,,conv,h_8is,tb_8is          ! Apply film coefficient to inner side of zone 8

h_8os=5.67                          ! outer side film coefficient (W/m2 K)
tb_8os=288                          ! bulk (ambient) temperature (K)
asel,s,area,,54,135,81
sfa,all,,conv,h_8os,tb_8os          ! Apply film coefficient to outer side of zone 8


!##Zone 9 film coefficients##
h_9is=5.67                          ! inner side film coefficient (W/m2 K)
tb_9is=288                          ! bulk (ambient) temperature (K)
asel,s,area,,138
sfa,all,,conv,h_9is,tb_9is          ! Apply film coefficient to inner side of zone 9

h_9os=5.67                          ! outer side film coefficient (W/m2 K)
tb_9os=288                          ! bulk (ambient) temperature (K)
asel,s,area,,130
sfa,all,,conv,h_9os,tb_9os          ! Apply film coefficient to outer side of zone 9


!##Zone 10 film coefficients##
h_10is=5.67                         ! inner side film coefficient (W/m2 K)
tb_10is=308                         ! bulk (ambient) temperature (K)
asel,s,area,,133
sfa,all,,conv,h_10is,tb_10is        ! Apply film coefficient to inner side of zone 10

h_10os=5.67                         ! outer side film coefficient (W/m2 K)
tb_10os=308                         ! bulk (ambient) temperature (K)
asel,s,area,,125
sfa,all,,conv,h_10os,tb_10os        ! Apply film coefficient to outer side of zone 10


!##Zone 11 film coefficients##
h_11is=5.67                         ! inner side film coefficient (W/m2 K)
tb_11is=308                         ! bulk (ambient) temperature (K)
```

```
asel,s,area,,128
sfa,all,,conv,h_11is,tb_11is    ! Apply film coefficient to inner side of zone 11

h_11os=5.67                     ! outer side film coefficient (W/m2 K)
tb_11os=308                     ! bulk (ambient) temperature (K)
asel,s,area,,118
sfa,all,,conv,h_11os,tb_11os    ! Apply film coefficient to outer side of zone 11


!##Zone 12 film coefficients##
h_12is=5.67                     ! inner side film coefficient (W/m2 K)
tb_12is=308                     ! bulk (ambient) temperature (K)
asel,s,area,,57,93,36
asel,a,area,,87,88
sfa,all,,conv,h_12is,tb_12is    ! Apply film coefficient to inner side of zone 12

h_12os=5.67                     ! outer side film coefficient (W/m2 K)
tb_12os=308                     ! bulk (ambient) temperature (K)
asel,s,area,,55,82,27
asel,a,area,,90,95,5
sfa,all,,conv,h_12os,tb_12os    ! Apply film coefficient to outer side of zone 12


!##Zone 13 film coefficients##
h_13is=5.67                     ! inner side film coefficient (W/m2 K)
tb_13is=303                     ! bulk (ambient) temperature (K)
asel,s,area,,98
sfa,all,,conv,h_13is,tb_13is    ! Apply film coefficient to inner side of zone 13

h_13os=5.67                     ! outer side film coefficient (W/m2 K)
tb_13os=303                     ! bulk (ambient) temperature (K)
asel,s,area,,96
sfa,all,,conv,h_13os,tb_13os    ! Apply film coefficient to outer side of zone 13


! B. Apply internal heat generation rates to volumes
hg_1=196300
vsel,s,volu,,14
bfv,all,hgen,hg_1               !Apply internal heat gen rate to Zone 1

hg_2=261300
vsel,s,volu,,16
bfv,all,hgen,hg_2               !Apply internal heat gen rate to Zone 2

hg_3=261300
vsel,s,volu,,15
bfv,all,hgen,hg_3               !Apply internal heat gen rate to Zone 3

hg_4=261300
vsel,s,volu,,13
bfv,all,hgen,hg_4               !Apply internal heat gen rate to Zone 4

hg_5=142300
vsel,s,volu,,12
bfv,all,hgen,hg_5               !Apply internal heat gen rate to Zone 5

hg_6=96800
vsel,s,volu,,10,11
bfv,all,hgen,hg_6               !Apply internal heat gen rate to Zone 6
```

```
hg_7=77900
vsel,s,volu,,9
bfv,all,hgen,hg_7                !Apply internal heat gen rate to Zone 7

hg_8=77900
vsel,s,volu,,7,8
bfv,all,hgen,hg_8                !Apply internal heat gen rate to Zone 8

hg_9=77900
vsel,s,volu,,6
bfv,all,hgen,hg_9                !Apply internal heat gen rate to Zone 9

hg_10=35510
vsel,s,volu,,5
bfv,all,hgen,hg_10               !Apply internal heat gen rate to Zone 10

hg_11=35510
vsel,s,volu,,4
bfv,all,hgen,hg_11               !Apply internal heat gen rate to Zone 11

hg_12=11175
vsel,s,volu,,1,3,2
bfv,all,hgen,hg_12               !Apply internal heat gen rate to Zone 12

hg_13=11175
vsel,s,volu,,2
bfv,all,hgen,hg_13               !Apply internal heat gen rate to Zone 13

allsel
save


!Solve
!=======
/solu
time,1
nsubst,15,,5
outres,all,last

solve
save
finish


!/exit,solu


!save

!==================================================
finish
!/exit,solu
```

Attachment 6.3

Subject: H1 stripline cooling calculations
From: Patrick Hurh <hurh@fnal.gov>
Date: Thu, 29 Nov 2007 17:39:58 -0600
To: Kris Anderson <kander@fnal.gov>, James Hylen <hylen@fnal.gov>, Mike Martens <martens@fnal.gov>, Matt Slabaugh <slabaugh@fnal.gov>, Andy Stefanik <stefanik@fnal.gov>, Salman Tariq <tariq@fnal.gov>, "Elaine G. Mccluskey" <mccluskey@fnal.gov>

Hello,

After our morning meeting, Matt dropped off my old calculations on the Horn 1 DS stripline flags. I spent a couple of hours going through them and comparing them with Matt's results and Andy's results. I think I may have found something that makes all the calculations relatively consistent.

Andy's 400 kW analysis shows a model with a flag that is shaped like a top inner conductor, but with a total flag length of an outer conductor. Basically the inner conductor has a very short length (about 10") compared to the outer conductor (about 16"). Since conduction to the horn dominates the thermal analysis, this can make a big difference.

So, I took my "model" in mathpad (which simply treats the flag as a 1 dimensional conduction path with internal heat generation and accounts for heat removal by convection as well) and changed the outer conductor heat inputs to roughly match the heat input used by Andy in his FEA (scaled by 7/4). This yielded a hot temp of 163 C and a cold temp of 51 C. This compares to Andy's results of 166 C and 45 C respectively. Not too bad...

Next I took my mathpad "model" and changed the inner conductor heat inputs to roughly match the heat input used by Matt in his recent FEA. This yielded a hot temp of 116 C and a cold temp of 67 C. This should be compared to Matt's results of 100 C and 45 C. Now, remember that my cold temperature is dependent upon the inner conductor cooling path back to the sprayed surface and Matt's is not. Matt set his temp to 45 C. So, it is really the temp difference that should be compared. In this case my "model" predicts 49 C temp diff and Matt's predicts 55 C. Again not too bad...

So, my take is that all the analyses are consistent (if one assumes that Andy was given the geometry for the OC). One should note that Matt's results scale roughly (within 20%) from Andy's with the input power. If we are to believe the new beam heating results I would take my results as being conservatively high (if we confirm the inner conductor flange cooling) at 116 C.

Finally, I think it odd that zone 1 in Matt's analysis which is about an inch closer to beam ctr than zone 2 has significantly less beam heating than zone 2. I would have thought it the other way around.

--patrick.

Subject: Stripline calcs revisited
From: Byron Lundberg <lundberg@fnal.gov>
Date: Tue, 11 Dec 2007 10:27:59 -0600
To: Matt Slabaugh <slabaugh@fnal.gov>

Matt,

I have attached a new version of the note listing the energy (and power) densities for the stripline components.
Changes include

- A new MARS run with 3x better statistics
- Better volume boundary testing
- default energy thresholds
- energy dep. is approx. 20% higher on avg with these new numbers

The inner/outer ear concern is probably the result of re-interactions in the outer conductor (5/8 inch). Therefore, the energy deposition will not be a smooth function with the radius, but have a bump near the OC.

Byron

H1_ED_detail_v2.pdf	**Content-Type:** application/pdf **Content-Encoding:** BASE64

Subject: Re: H1 stripline cooling calculations
From: Patrick Hurh <hurh@fnal.gov>
Date: Thu, 13 Dec 2007 10:47:41 -0600
To: Matt Slabaugh <slabaugh@fnal.gov>
CC: Salman Tariq <tariq@fnal.gov>, James Hylen <hylen@fnal.gov>, Mike Martens <martens@fnal.gov>, Kris Anderson <kander@fnal.gov>

Hi Matt,

See below:

On Dec 13, 2007, at 10:27 AM, Matt Slabaugh wrote:

> Hello Pat,
>
> Here are some questions and responses to your e-mail a couple of weeks ago. I didn't respond right away because I had nothing to add at the time...
>
> Patrick Hurh wrote:
>
> > Next I took my mathpad "model" and changed the inner conductor heat inputs to roughly match the heat input used by Matt in his recent FEA. This yielded a hot temp of 116 C and a cold temp of 67 C. This should be compared to Matt's results of 100 C and 45 C. Now, remember that my cold temperature is dependent upon the inner conductor cooling path back to the sprayed surface and Matt's is not. Matt set his temp to 45 C. So, it is really the temp difference that should be compared. In this case my "model" predicts 49 C temp diff and Matt's predicts 55 C. Again not too bad...
>
> Your cold temp of 67°C- would you consider that valid to use as a Horn temperature in my model? I'm assuming your minimum temperature would be located at the Horn/flag interface.

As good a guess as any at this point. Re-design of the stripline connection "bosses" will bring it down some and better analysis is required. I believe Kris Anderson is asking Zhijing to look at that area sometime in the future.

> > Finally, I think it odd that zone 1 in Matt's analysis which is about an inch closer to beam ctr than zone 2 has significantly less beam heating than zone 2. I would have thought it the other way around.
>
> I met with Byron Lundberg last week for several reasons. One of which was the issue above (Zone1<Zone2). He didn't have a good answer why the MARS model predicted lower energy deposition in smaller radius (closer) flag. However, he was willing to refine and rerun his model. He sent me those results on Tuesday.
>
> Byron's second run predicted energies about 20% higher overall than previously reported. Using these numbers, the max temp in the stripline increased ~10%. However, Zone1<Zone2. Here is what he wrote me about this phenomena: "The inner/outer ear concern is probably the result of re-interactions in the outer conductor (5/8 inch). Therefore, the energy deposition will not be a smooth function with the radius, but have a bump near the O[uter]C[onductor]."

OK. on the zone1<zone2 issue. However, what is the explanation for 20% higher deposited energy? Is this latest run more trustworthy than past runs? This is probably a question that needs to be looked at by Hylen/Martens.

Thanks,
--patrick.

Attachment 6.4

Energy Deposition Horn 1 Outer Conductor / Stripline

Summary

The Horn 1 outer conductor (OC), strip line and strip support pieces were modeled in MARS and energy deposition values were recorded.

The OC was 5/8" thick. The simulated strip line includes a simplified geometry for the conductors, the connection bosses and inner and outer conductor terminal connections. Also included are the fixed and swinging plates (stainless steel) that receive the aluminum conductors as they extend into the slot in the steel shielding. Included was the insulating ceramic ring, separating the OC from the inner conductor, as well as one ceramic insulator near the horn connection. See the figures for the modeling of these parts.

The energy depositions and input power were calculated for 5.0×10^{13} 120 GeV protons every 1.33s or 726kW beam power.

The detailed energy depositions for annuli in the OC are included in an Excel spreadsheet. The depositions in the strip line segments, stainless plates and ceramics are given in Table 1.

The displacements per atom (DPA), as an indication of radiation damage, are also listed.

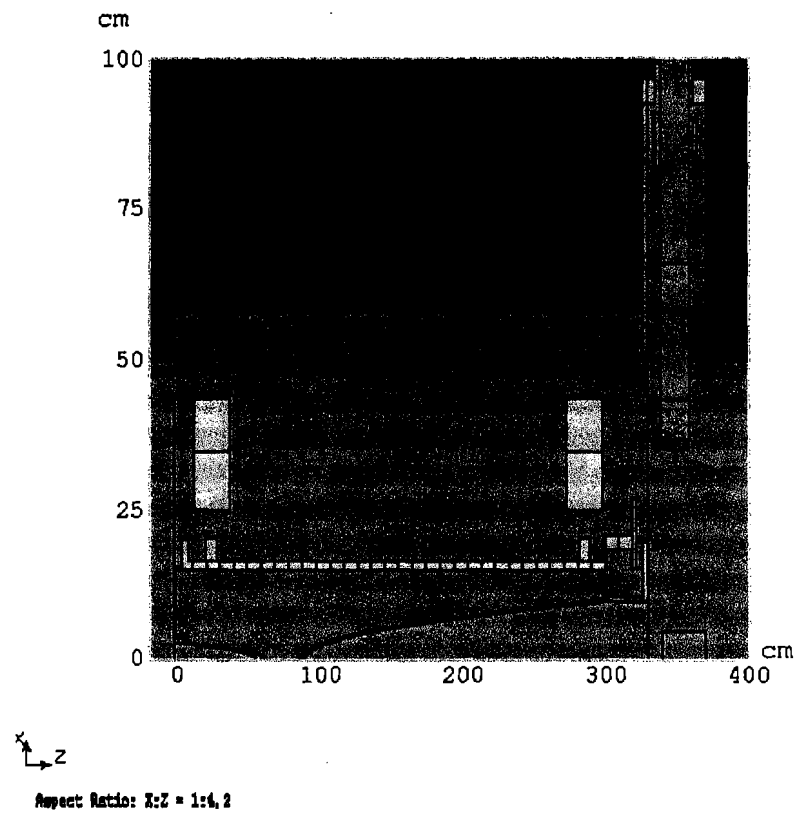

Figure 1. Horn1 and environs as modeled in MARS, elevation view. Materials are colored: *Yellow* - aluminum, *Dark green* - steel shielding, *Magenta* - Aluminum strip line, *Gray* - stainless steel, *Cyan* - air.

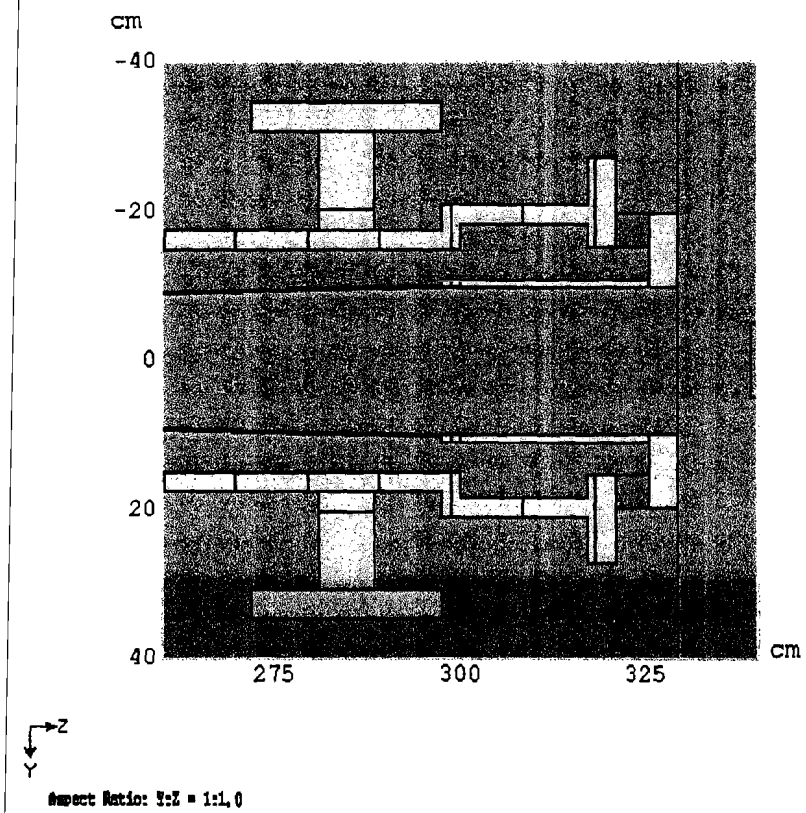

Figure 2. Downstream end of Horn 1, plan view. The greenish volume is the ceramic ring.

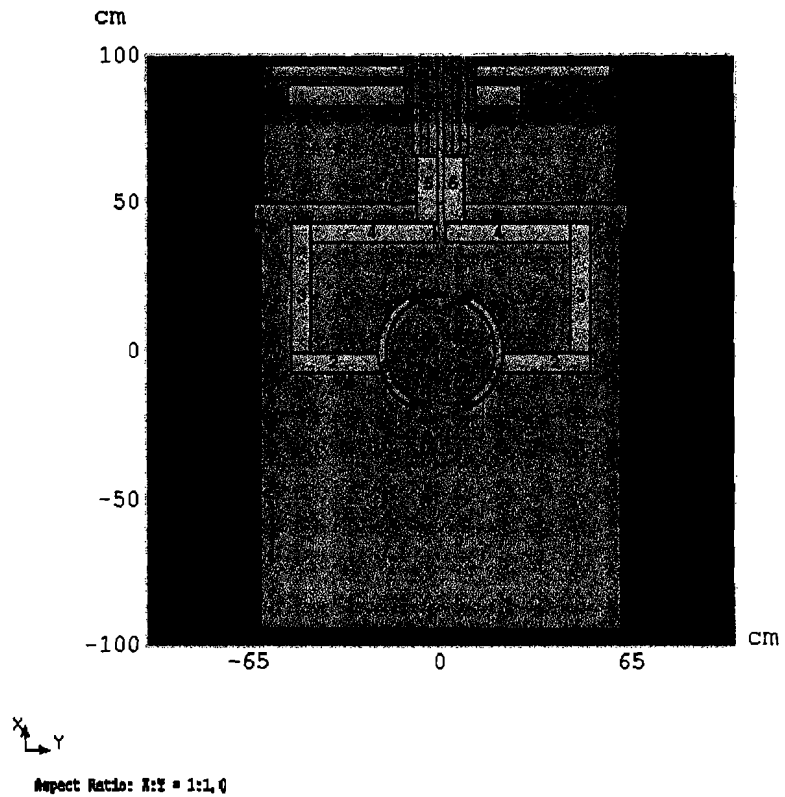

Figure 3. Strip line penetration and configuration just upstream of Horn 1. The density of each region compensates for the lack of detail (e.g. two or four conductors shown as single volume). The numbered regions correspond to the number in the first column of the table. The "ears" are not shown in this view.

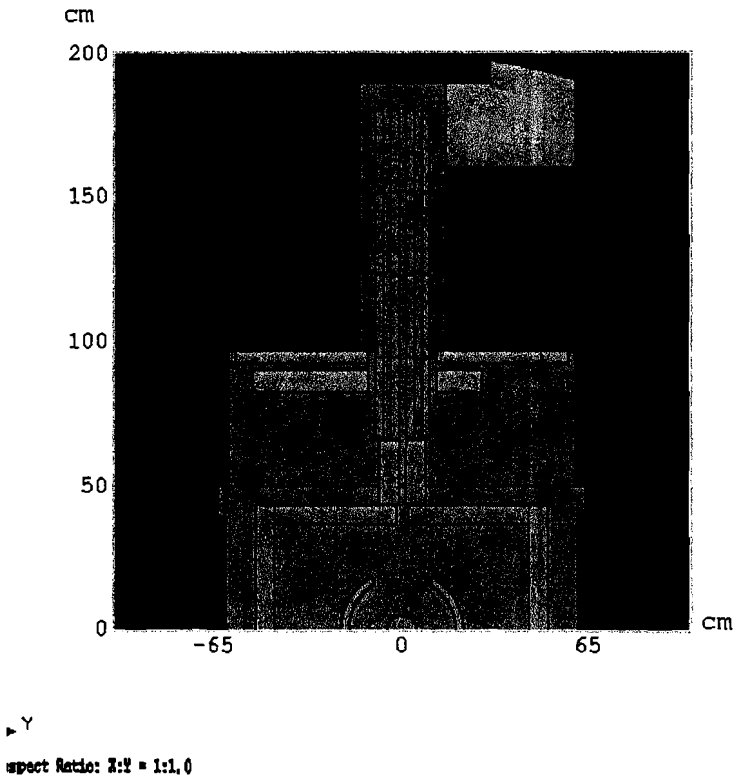

Figure 4. Upper part of the stripline volumes within the penetration. For recording energy deposition, the stripline is divided into 4 equal sections, 28.5cm long. The density is set to 2/3 the density of aluminum. The lower sections are 4/7 the density of aluminum.

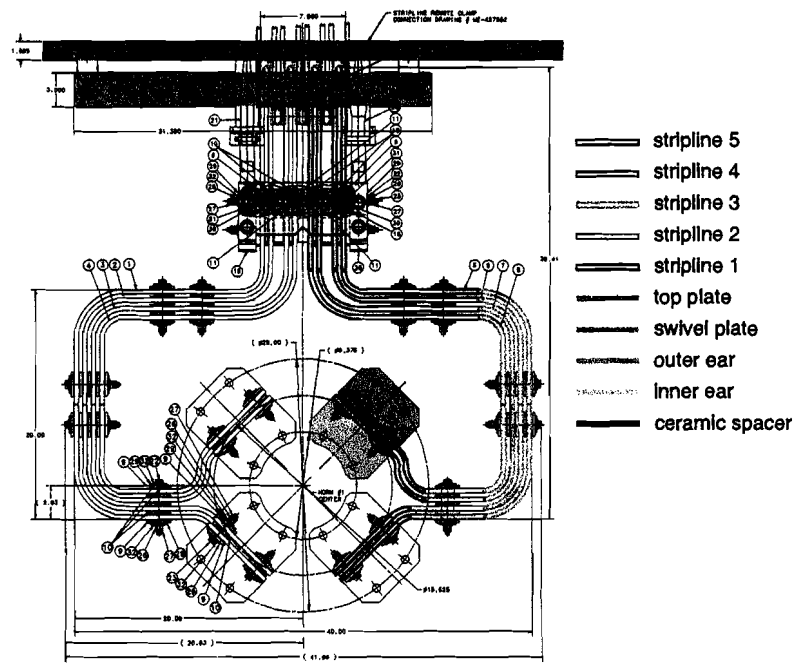

Figure 5. Stripline MARS volumes realized approximately with the true design.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
strip line 1	4580.	1.43×10^{-5}	0.086	5.9×10^{-25}
strip line 2	8480.	7.0×10^{-6}	0.042	4.2×10^{-25}
strip line 3	11880.	3.8×10^{-6}	0.023	3.2×10^{-25}
strip line 4	11320.	4.1×10^{-6}	0.025	3.3×10^{-25}
strip line 5	6100.	3.0×10^{-6}	0.018	2.2×10^{-25}
strip line 6a	6680.	3.8×10^{-7}	2.3×10^{-3}	8×10^{-26}
strip line 6b	6680.	4.1×10^{-8}	2.5×10^{-4}	3×10^{-26}
strip line 6c	6680.	7×10^{-9}	4×10^{-5}	7×10^{-27}
strip line 6d	6680.	2×10^{-9}	1×10^{-5}	3×10^{-27}
inner ear	692.	1.03×10^{-5}	0.062	3.1×10^{-25}
outer ear	1480.	1.13×10^{-6}	0.068	4.4×10^{-25}
boss	192.	2.7×10^{-5}	0.16	1.4×10^{-24}
H1 ceramic	2200.	3.05×10^{-5}	0.184	1.31×10^{-24}
cer. spacer	22.5	5×10^{-6}	0.03	1.6×10^{-25}
Top plate	16930.	5.5×10^{-8}	3.3×10^{-4}	3.4×10^{-26}
Swivel plate	59500.	1.1×10^{-7}	6.7×10^{-4}	5.7×10^{-26}

Table 1. Energy deposition, power density and DPA estimates for the stripline. For volume definitions, see Figs. 3, 4.