

Radiation Calculations for the ILC Cryomodule

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Abstract

The MARS15 radiation simulations were performed for the ILC cryomodule. The model assumes a uniform beam loss intensity of 1 W/m of 750-MeV and 250-GeV electron along the inner surface of the beam pipe and the cavity iris of the 12-m cryomodule. Two-dimensional distributions of radiation dose in the module were obtained. Absorbed dose rate and energy spectra of electrons, photons, neutrons and protons were also obtained at the three cryogenic thermometers locations by filling with silicon material in the appropriate locations, and radiation hardness of the thermometers was discussed. From the obtained results, maximum absorbed dose of thermometers at the cooling pipe is 0.85mGy/sec (85 mRad/sec), that is 0.31 MGy (31 MRad) for 20 years.

1 Introduction

For the International Linear Collider project (ILC), a superconducting RF cryomodule of the main linac is being designed and its characteristics are tested at Fermilab. Estimation of energy deposition due to electro-magnetic and photo-neutron showers induced by electron beam loss is essential to evaluate the radiation hardness of the electronics devices. Irradiation behaviors of a cryogenic thermometers have been studied for neutrons and photons in Dubna [1, 2], and our thermometers should also be tested by experiment and simulation to clarify its characteristics.

Simulations of radiation and energy deposition by the MARS15 Monte Carlo code [3] were performed with a 250-GeV electron beam for the ILC project, and also with a 750-MeV electron beam for the ILC Test Area facility (ILCTA) planned to be built at Fermilab. From the calculated energy deposition distributions, absorbed dose rates for the cryogenic thermometers at various locations were obtained. Energy spectra of electrons, photons, neutrons and protons were also obtained and particle-dependent absorbed doses were clarified and discussed.

2 Cryomodule Geometry

A cryomodule geometry for the simulation was made by a simplified design of TESLA at DESY [4]. The main linac consists of many-chain cryomodules to accelerate an electron beam up to 250 GeV in ILC. In this work, simulations in one cryomodule region were carried out.

Figs.1, 2 and 3 show cross-sectional views of the MARS15 cryomodule geometry. One cryomodule structure is about 12-m long and has 8 cavities as shown in Fig.1(a). One cavity has 9 cells (8-9cell cavities) as shown in Fig.1(b). Cavity cells are made with 2.8-mm-thick niobium and are simplified in a rectangular shape as shown in Fig.1(c). Liquid-helium is flowing between the cavity and 5-mm-thick titanium vessel which is covered with 1-mm-thick mu-metal.

As shown in Fig.3, the cryomodule itself is covered with a carbon steel casing. A helium gas duct in the center is made of stainless steel. Several cylindrical pipes for a cooling pipe shield are made of aluminum or stainless steel. Aluminum thermal shields were simplified to be cylindrical or elliptical shapes.

Silicon material regions of the cryogenic thermometers should be large enough to get good statistics in a Monte Carlo calculation, but this regions should not disturb the radiation field because the actual thermometer size is on a few mm scale. Therefore, silicon material with air density are defined in the rectangular shape inside of the three cylindrical pipes of the cooling pipe shield in the region from 3 to 11 m in the beam line direction as shown in Fig. 2 to get maximum average absorbed dose.

3 Beam Loss

Electrons at a grazing angle of 1 mrad were impacted on the inner radius of the beam pipe uniformly in the circumference and uniformly in entire length of a cryomodule, as shown in Fig. 1(c). The results were normalized to 1 W/m beam loss intensity.

Dark current is generated due to an electron field in the wave guide, cavity, RF-gun cathode etc., and is not negligibly small. However, mechanisms of the dark current generation are complicated, condition-dependent and unclear. In order to simplify the issue in this work, it is assumed that dark current produced from a cathode at RF-gun is dominant and that energy and direction of the dark current electron are equivalent to those of the electron of the primary beam.

4 Prompt and Absorbed Dose Rate

A side view of prompt-dose distribution is shown in Fig. 4 for the 250 GeV case. The upper figure shows the entire region of up to 12 m, while the lower figure shows the first 2.8 m. The absolute values were normalized to 1 W/m beam loss.

Although, the beam loss is distributed uniformly along 12 m, the prompt dose rate profile seems to build up in the upstream region (the first 2-m region) because of secondary-particle forwardness is visible in the simulation with one cryomodule. In reality, since several cryomodules are continuously located, dose rate distribution is expected to be almost uniform.

In order to estimate maximum absorbed dose in the thermometers, the region from 3 m to 11 m was taken into account (see Fig. 2) so that the maximum average prompt and absorbed dose rates were obtained in the cross sectional view shown in Fig. 5(a) and (b), respectively. Detailed numerical values of the absorbed dose rates at three thermometers regions are discussed in Section 6.

5 Energy Spectra

Particle energy spectra of photons, electrons, neutrons and protons were scored in the three thermometers regions, and are shown in Fig. 6 for both 750 MeV and 250 GeV electron beams at the thermometer-2 where the radiation level is the highest of the three. It can be found that spectra shapes and absolute fluences of each particles due to the different beam energies are almost identical in the lower energy region (below ~ 500 MeV) when simulation results were normalized to the unit W/m beam loss.

Mean energies $\langle E \rangle$ of each spectrum are also shown in Fig. 6. Since fluxes in the low energy region are dominant, the mean energies are all about several MeV except for protons.

6 Relation Between Energy Spectrum and Absorbed Dose

The real thermometer is about 1-mm thick (0.234 g/cm^3), and 234-cm thick equivalent in air density (10^3 g/cm^3). In the simulation, the thermometer regions were around 2-cm thickness of air density and much thinner than 234 cm. Therefore, flux-to-absorbed-dose conversion factors for each particle were calculated separately by MARS15 in a simple geometry with a 234-cm thick silicon using the energy spectra at the thermometer-2 for the 750 MeV cryomodule in Fig.6. The spectra at the thermometer-1 and 3 were similar and the same conversion factors were assumed. (The difference from those for 250 GeV are negligible, as mentioned in the previous section.) Table 1 gives the obtained conversion factors.

Using the fluxes at three thermister regions in the cryomodule simulations, partial absorbed dose rates by electrons, photons, neutrons and protons for 750 MeV were obtained and are given in Table 2. Although photon flux is highest for all thermometers, absorbed dose by electron is dominant (60-80%). The maximum absorbed dose rate is about 0.85 mGy/sec (85 mRad/sec) at thermometer-2, and a 20-year integrated absorbed dose is 0.31 MGy (31 MRad) when 5000-hr annual operation is assumed.

Conversion factors were obtained by the simple geometry calculation also for mono-energetic electrons, photons and neutrons, and fission neutrons whose mean energies are close to those of the spectra at the cryomodule. The values are given also in Table 1. Ratios of these conversion factors to those of the spectra at the cryomodule were obtained, and these ratios are useful for a practical irradiation measurement to investigate the radiation hardness of the thermometer devices prior to the cryomodule operation.

7 Conclusions

The MARS15 simulations were performed for the ILC cryomodule with 750 MeV and 250 GeV electron beam losses. From the simulation results, in the same beam-loss power, the dominant part of energy spectra of particles, prompt dose and absorbed dose are independent of beam energy. The maximum absorbed dose of the cryogenic thermometers at the cooling pipe is 0.85 mGy/sec (85 mRad/sec), that is 0.31 MGy (31 MRad) for 20 years. Mean energies of electrons, photons and neutrons are around 2-5 MeV, and mono-energetic sources with those energies can be useful for irradiation tests with slight correction factors.

The MARS15 input files created for this study are given in Appendix.

8 Acknowledgement

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References

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- [2] Y.P. Filippov, V.V.Golikov, E.N.Kulagin, V.M.Miklayev and A.K.Sukhanova, “In-situ- and Post Irradiation Behaviour of Cryogenic Temperature Sensors Under Fast Neutron Fluence”, *Advances in Cryogenic Engineering*, Vol.47B, p.1700-1707 (2002).
- [3] N.V. Mokhov, “The MARS Code System User’s Guide”, Fermilab-FN-628 (1995); N.V. Mokhov et al, Fermilab-Conf-04/053 (2004); [http : //www – ap.fnl.gov/MARS/](http://www-ap.fnl.gov/MARS/).
- [4] TESLA Technical Design Report-Report, PART-II:TheAccelerator, March (2001)

Table 1: Flux-to-Absorbed-Dose conversion factors of electrons, photons, neutrons and protons for the energy spectra at the thermometer-2 in 250 GeV electron beam simulation in Fig.6 and comparisons with those of various energy spectra.

Particle	Energy spectrum	Mean Energy [MeV]	Flux-to-Absorbed-Dose conversion factor [Gy cm ²] (Error%)		Ratio
e	ILC Cryomodule by 250 GeV e	11.6	2.85E-10	0.13	1.00
	5 MeV mono-energy	5	2.77E-10	0.08	0.97
	40 MeV mono-energy	40	3.56E-10	0.16	1.25
γ	ILC Cryomodule by 250 GeV e	2.6	1.65E-12	1.72	1.00
	Co-60 γ	1.25	1.69E-12	0.67	1.02
	Cs-137 γ	0.664	1.84E-12	1.8	1.12
n	ILC Cryomodule by 250 GeV e	6.4	4.46E-12	1.6	1.00
	Cf-252 fission neutron	2.13	2.78E-12	1.8	0.56
	5 MeV mono-energy	5	6.30E-12	1.8	1.27
	2 MeV mono-energy	2	1.32E-12	0.90	0.27
p	ILC Cryomodule by 250 GeV e	207.5	1.41E-09	0.14	1.00

Table 2: Partial and total absorbed dose rates by electrons, photons, neutrons and protons with energy spectra for 250 GeV in three thermometers. Total absorbed doses for 20 years (5000 hr/yr operation) are also shown. Conversion factors for the energy spectra for the thermometer-2 were used for all cases.

		Mean Energy [MeV]	Conversion Factor [Gy cm ⁻²]	Total Flux* [cm ⁻² sec ⁻¹]	Absorbed Dose [Gy sec ⁻¹]	Ratio [%]
Thermometer-1	e	8.6	2.85E-10	5.34E+05	1.52E-04	63.2
	γ	2.2	1.65E-12	5.35E+07	8.82E-05	36.6
	n	5.0	4.46E-12	5.28E+04	2.35E-07	0.098
	p	214.7	1.41E-09	2.19E+02	3.09E-07	0.12
		Total Absorbed dose 20-year			2.41E-04 8.68E+04	(0.24 mGy/sec) (0.087 MGy)
Thermometer-2	e	11.6	2.85E-10	2.36E+06	6.74E-04	79.1
	γ	2.6	1.65E-12	1.07E+08	1.77E-04	20.7
	n	6.4	4.46E-12	9.88E+04	4.41E-07	0.052
	p	207.5	1.41E-09	6.66E+02	9.38E-07	0.11
		Total Absorbed dose 20-year			8.52E-04 3.07E+05	(0.85 mGy/sec) (0.31 MGy)
Thermometer-3	e	9.8	2.85E-10	5.18E+05	1.48E-04	63.0
	γ	2.3	1.65E-12	5.22E+07	8.60E-05	36.7
	n	5.1	4.46E-12	5.24E+04	2.34E-07	0.10
	p	193.3	1.41E-09	2.53E+02	3.57E-07	0.15
		Total Absorbed dose 20-year			2.34E-04 8.44E+04	(0.23 mGy/sec) (0.084 MGy)

* 1 W/m beam loss

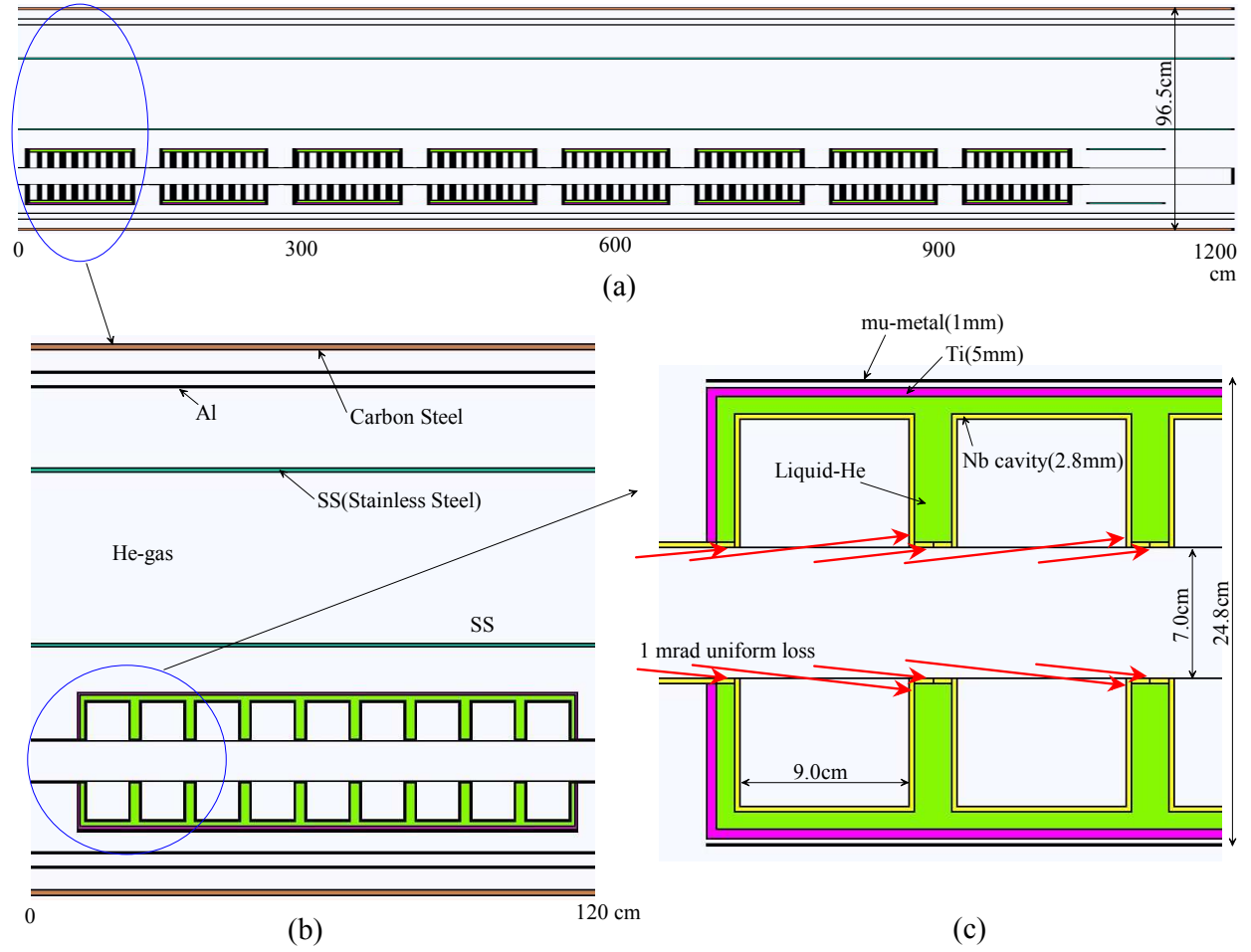


Figure 1: Side view of cryomodule geometry in vertical plane at A-A' in Fig 3. (a) 12-m whole region, (b) first cavity region and (c) a first few cells of cavity. Sketch of the beam loss image is also shown in (c).

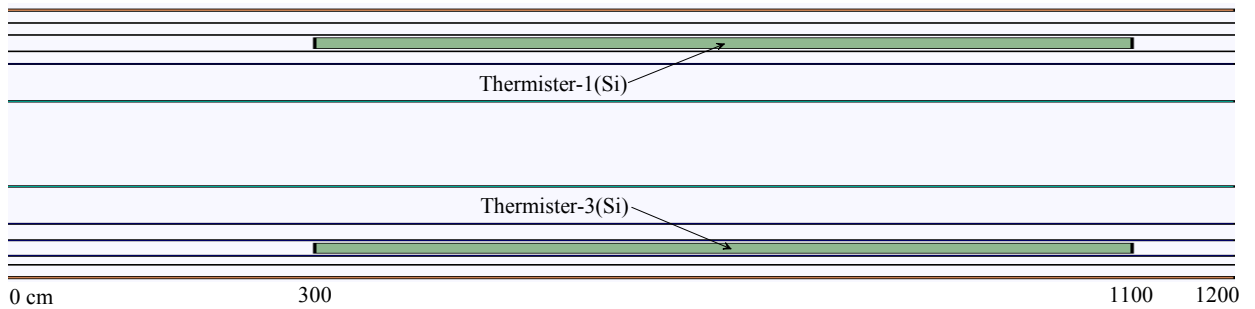


Figure 2: Top view of cryomodule geometry of 12-m whole region in horizontal plane at B-B' in Fig 3.

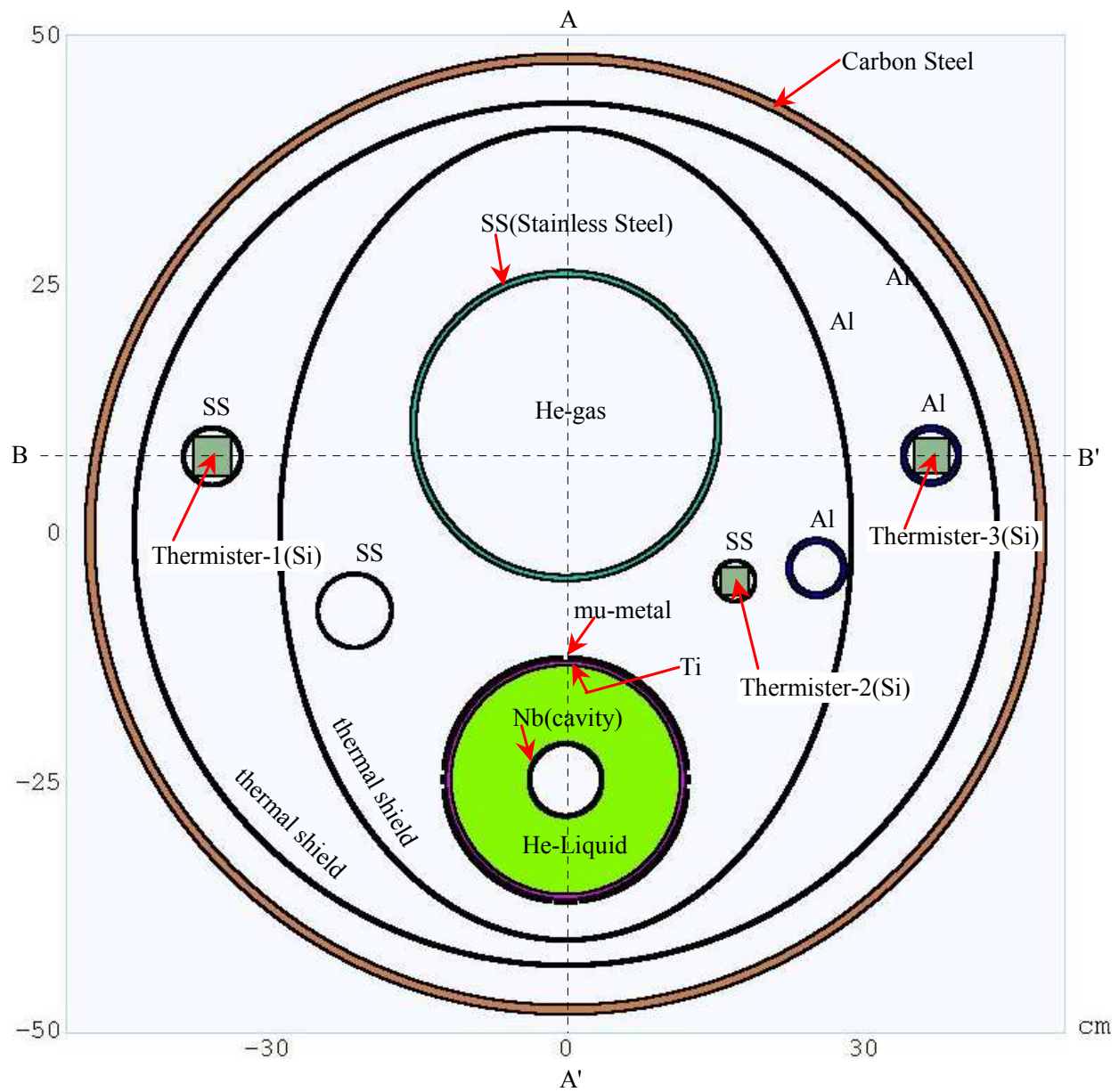


Figure 3: Vertical cross-sectional view of cryomodule geometry at middle part. Vertical A-A' and horizontal B-B' cross-sectional plane views are given in Figs. 1 and 2, respectively.

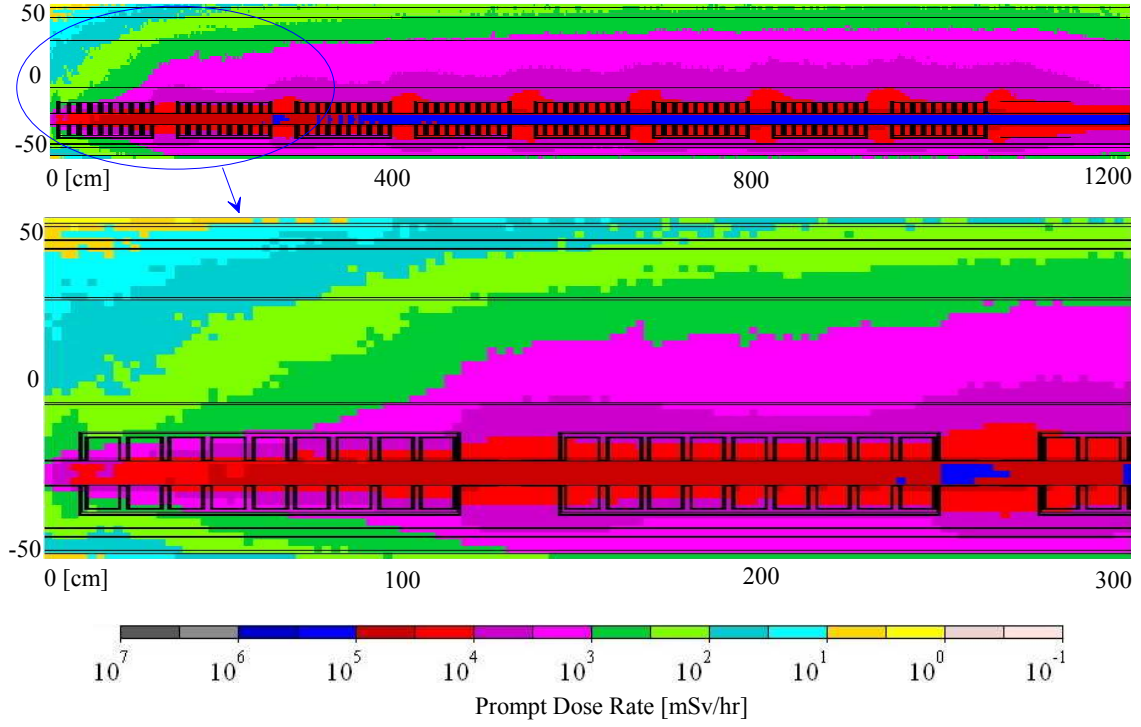


Figure 4: Side view of prompt dose rate distribution in 250 GeV case for the entire region up to 12-m (upper) and the first 2.8-m (lower).

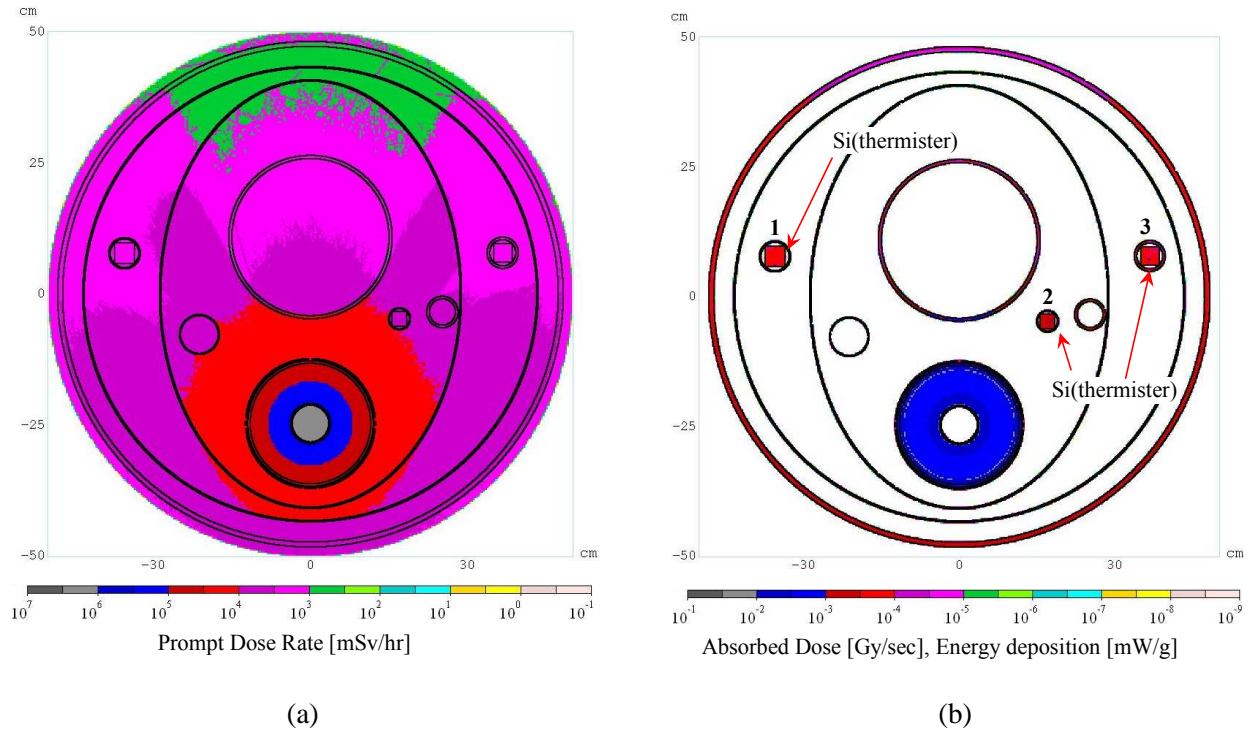


Figure 5: Cross sectional views of prompt and absorbed dose rates averaged in the region from 3- to 11-m in beam axis.

Energy Spectra at Thermister-2 of ILC Cryomodule

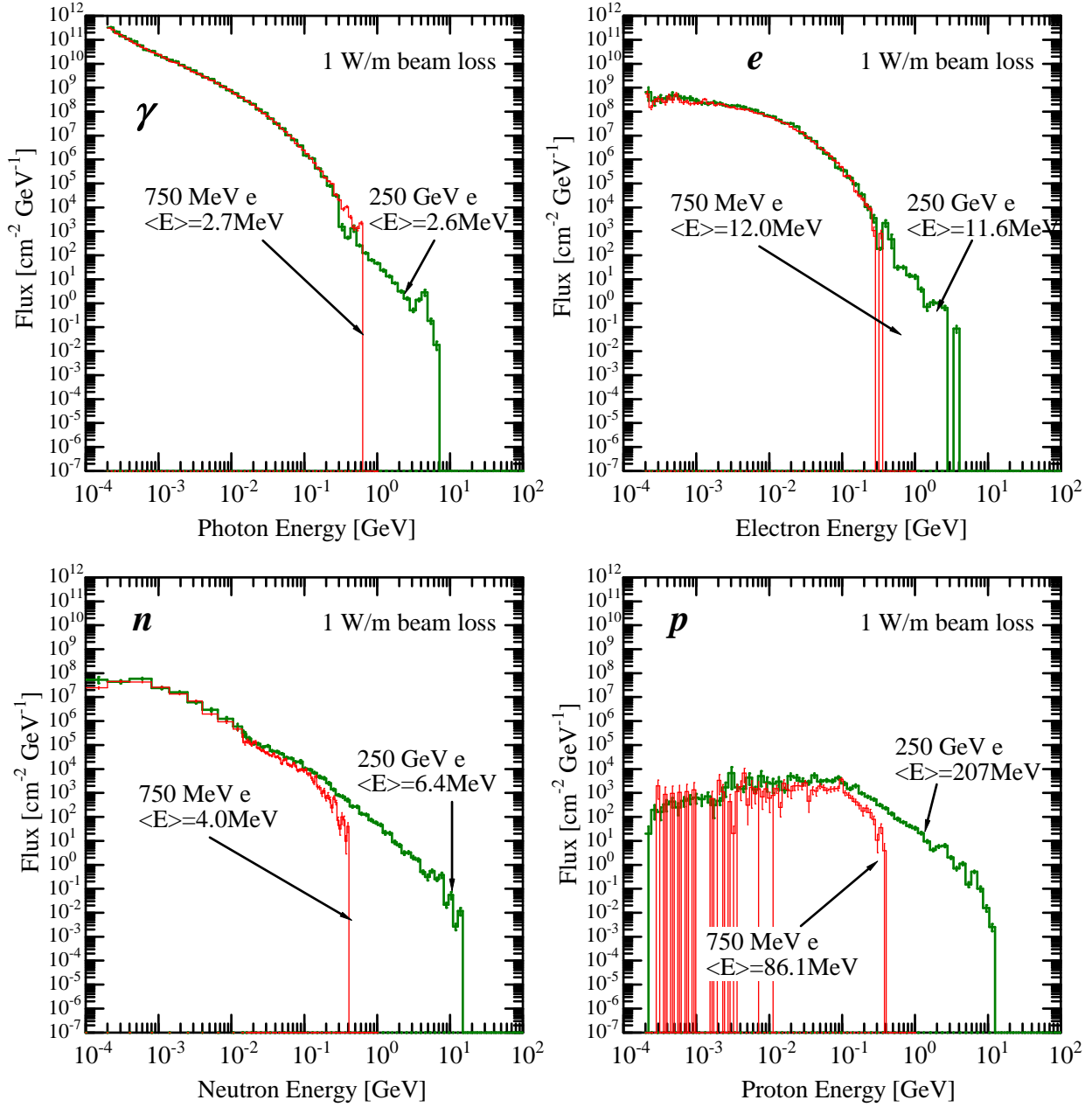


Figure 6: Energy spectra of photons, electrons, neutron and protons at the thermometer-2 location for 1 W/m beam loss of 750 MeV and 250 GeV electrons. Mean energies $\langle E \rangle$ of spectra are also shown in the figure.

APPENDIX

MARS.INP

```
ILC Cryomodule  N.Nakao    May 20,2006
/home/mokhov/restricted/mars15/dat
CTRL 0
NEVT 200
INDX 2=T T 5=T
ENRG 250.
IPIB 10
```

```
c 250 GeV  1W/m
INIT 7=3.E8
```

```
c 750 MeV   1W/m
c INIT 7=9.96E10
```

```
VARs 4=1.0
SMIN 0.01 3.
ZSEC 1210.      2501=0
RSEC 50.
NMAT 8
MATR 'AL' 'STST' 'NB' 'TI' 'NI' 'STCA' 'SI' 'LHE'
MTDN 7=1.0E-3
NHBK 1
STOP
```

```
*MCNP START
m1 13027 1.0 cond=1
m2 24000 -0.190 25055 -0.010 26000 -0.700 28000 -0.100 cond=1
m3 41093 1.0 cond=1
m4 20000 1.0 cond=1
m5 28000 1.0 cond=1
m6 26000 1.0 cond=1
m7 14000 1.0 cond=1
m8 2004 1.0
*MCNP END
```

beg1.f

User subroutine 'beg1'. Beam loss location is uniformly sampled along r- and z-coordinate. Energy is uniformly sampled in the defined enrgy range. Data is read from SRC.DAT

```
      SUBROUTINE BEG1(JJ,W,E,X,Y,Z,DCX,DCY,DCZ,TOFF,INTA,NREG1)
C     REVISION: 01-DEC-2005
C.....
      IMPLICIT DOUBLE PRECISION (A-H,O-Z), INTEGER (I-N)
      LOGICAL IND
      INCLUDE 'azwmat.inc'
      INCLUDE 'biount.inc'
      INCLUDE 'blregl.inc'
      INCLUDE 'cmasnsg.inc'
      INCLUDE 'tally2.inc'
      COMMON/MATINT/IM
      : /LOGIND/IND(20)
      : /BG/E0,ELEAK(3),ELGA,ELEN,ELEAMU,ENEUNO,ALIO(3),BLEAK(3,2)
      : /BLTOFF/TOFMIN,TOFMAX,TOFSHF
      : /SELEC2/CS,SS,CH,SH
      : /HIST/NI,NSTOP,NUPRI,NHIPR
      PARAMETER (PI=3.141592653589793227D+00)
C- - - - -
C+++ INSERT YOUR SOURCE TERM HERE +++
      SAVE NENTER
      DATA NENTER/0/
      DATA z1,z2/0.0, 1200.0/
      save zbegin,zend,SRCr,xcavity,alpha,Ene1,Ene2

      *** Source term N.Nakao(May 23, 2006)
      *** uniform beam loss at SRCr radius from cavity center
      *** uniform beam loss along z direction
      *** emmition angle is alpha(rad) from Z-coordinate
      IF(NENTER.EQ.0) THEN
        NENTER=1
        alpha=1.0D-3      ! 1.0mrad angle injection
        alpha=60 *PI/180. ! 60 degree angle injection
C
        open(20,file='SRC.DAT')
        read(20,*) xcavity      ! X of cavitycenter'
        read(20,*) zbegin,zend ! zbegin,zend
        read(20,*) SRCr        ! source location in radius
        write(*,*) xcavity,'    ! X of cavitycenter'
        write(*,*) zbegin,zend,' ! zbegin,zend'
        write(*,*) SRCr,'      ! source location in radius'
        read(20,*) Ene1        ! Kinetic Energy of entrance of cryomodule
        read(20,*) Ene2        ! Kinetic Energy of exit of cryomodule
        close(20)
        write(*,*) Ene1,' ! Kinetic Energy of entrance of cryomodule'
        write(*,*) Ene2,' ! Kinetic Energy of exit of cryomodule'
```

ENDIF

```
      theta=2.0d0*pi*rand()
      z=(zend-zbegin)*rand() + zbegin
      x=SRCr*sin(theta) + xcavity
      y=SRCr*cos(theta)
      dcx=sin(theta)*sin(alpha)
      dcy=cos(theta)*sin(alpha)
      dcz=sqrt(1-dcx**2-dcy**2)
      E= (Ene2-Ene1)/(z2-z1)*(z-z1) + Ene1 ! electron energy
C+++++
      RETURN
      END
```

SRC.DAT

Data file of beam loss location and energy range for beg1 subroutine.

```
-24.69      ! X of cavitycenter
0.00 1200.00 ! zbegin,zend,
3.50      ! inner radius of cavity
250.      ! Kinetic Energy of entrance of cryomodule
250.      ! Kinetic Energy of exit of cryomodule
```

geom.f

Fortran program to make GEOM.INP easily.

```

*** ILC cylinder geometry for GEOM.INP
*** by Noriaki Nakao (May 2006)
***
      character TIT*70
      COMMON /A/VNAM,NT,NTR,IM,XR,YR,ZR,C1,C2,C3,xref,yref,zref,TIT
      COMMON /B/C3e,C4e
      COMMON /C/NREG
      PARAMETER (PI=3.141592653589793227)
      character VNAM*8
      real inch
      data ft,inch/30.48, 2.54/ ! feet, inch --> cm
****
* material 'AL' 'STST' 'Nb' 'TI' 'mu-metal' 'STCA' 'SI' 'LHE'
  data mal, mstst, mnb, mti, mmu, mstca, msi, mlhe
  & / 1, 2, 3, 4, 5, 6, 7, 8/
*reference point
* coordinate(xref,yref,zref) is (0,0,0) in MARS calculation
  xref= 19.0*inch
  yref= 0.0
  zref= 0.0
*** parameter
  xcenter_cavity=9.281*inch
  write(20,100) xcenter_cavity - xref
100 format(0pf10.2,' ! X of cavitycenter')
  zbegin = 0.0
  zend =1200.0
  write(20,101) zbegin,zend
101 format(0p2f10.2,' ! zbegin,zend,')
  C4e=-1.0

** start geometry *****
*** Comment
  write(10,*) 'ILC cylindrical geometry'
  write(10,*)
c    write(10,*) 'OPT'

***common data
  NTR =0 ! rotation for target
*** Thermister
***
  NT =1 ! box
  IM = msi ! Si
  z1= 300.
  z2=1100.

  TIT='Thermister1'
  VNAM='therm1'
  XR = 22.071*inch
  YR = -13.976*inch
  ZR = z1
  C3 = z2 - z1
  C2 = 2.150/2.0*inch ! outer radii
  XYH=C2/sqrt(2.0)
  C1=XYH
  C2=XYH
  call geo
  vol = C1*C2*C3*4
  write(31,*) ' VOLUME(' ,NREG,')=' ,vol
  write(30,300) XR-XYH-XREF,XR+XYH-XREF,YR-XYH,YR+XYH,z1,z2,VNAM
300 format('XYZ ',0p3f8.2,1x,0p3f8.2,' 1 1 1 ! ',a8)

  TIT='Thermister2'
  VNAM='therm2'
  XR = 17.150*inch
  YR = 6.693*inch
  C2 = 1.530/2.0*inch ! outer radii
  XYH=C2/sqrt(2.0)
  C1=XYH
  C2=XYH
  call geo
  vol = C1*C2*C3*4
  write(31,*) ' VOLUME(' ,NREG,')=' ,vol
  write(30,300) XR-XYH-XREF,XR+XYH-XREF,YR-XYH,YR+XYH,z1,z2,VNAM

  TIT='Thermister3'
  VNAM='therm3'
  XR = 22.110*inch
  YR = 14.449*inch
  C2 = 1.965/2.0*inch ! outer radii
  XYH=C2/sqrt(2.0)
  C1=XYH
  C2=XYH
  call geo
  vol = C1*C2*C3*4
  write(31,*) ' VOLUME(' ,NREG,')=' ,vol
  write(30,300) XR-XYH-XREF,XR+XYH-XREF,YR-XYH,YR+XYH,z1,z2,VNAM
  C3 = zend ! z length
  ZR = 0.

***
  TIT='Cylinder outside'
  VNAM='Cyl-out'
  NT =2 ! cylinder
  IM = mstca ! carbon steel
  XR = 19.0*inch
  YR = 0.0
  C1 = 37.25/2.0*inch ! inner radii
  C2 = 38.00/2.0*inch ! outer radii
  call geo

***
  TIT='Cylinder inside'
  VNAM='Cyl-in'
  NT =2 ! cylinder
  IM = mal ! al
  C1 = 34.00/2.0*inch ! inner radii
  C2 = C1+0.3 ! outer radii
  call geo

***
  TIT='Elliptical Tube'
  VNAM='Elliptic'
  NT =6 ! Elliptical Tube
  IM = mal ! Al
  C1 = 32.0/2.0*inch ! inner radii of x-zxis
  C2 = 22.5/2.0*inch ! inner radii of y-zxis
  C3e = 0.3 ! tube wall thickness
  C4e = zend ! tube z-length
  call geo

***
  TIT='Cylinder center'
  VNAM='Cyl-cnt'
  NT =2 ! cylinder
  IM = mstst ! STST stainless steel
  XR = 23.291*inch
  YR = 0.0
  C1 = 11.811/2.0*inch ! inner radii
  C2 = 12.283/2.0*inch ! outer radii
  call geo

***
  TIT='pipel for thermister-1'
  VNAM='Cyl-pl'
  NT =2 ! cylinder
  IM = mstst ! STST stainless steel
  XR = 22.071*inch
  YR = -13.976*inch
  C1 = 2.156/2.0*inch ! inner radii
  C2 = 2.374/2.0*inch ! outer radii
  call geo

***
  TIT='pipe'
  VNAM='Cyl-p'
  NT =2 ! cylinder
  IM = mstst ! STST stainless steel
  XR = 15.974*inch
  YR = -8.347*inch
  C1 = 2.839/2.0*inch ! inner radii
  C2 = 2.996/2.0*inch ! outer radii
  call geo

***
  TIT='pipe2 for thermister-2'
  VNAM='Cyl-p2'
  NT =2 ! cylinder
  IM = mstst ! STST stainless steel
  XR = 17.150*inch
  YR = 6.693*inch
  C1 = 1.531/2.0*inch ! inner radii
  C2 = 1.661/2.0*inch ! outer radii
  call geo

***
  TIT='Al pipe for thermister-3'
  VNAM='ALpip3'
  NT =2 ! cylinder
  IM = mal ! AL aluminum
  XR = 17.662*inch
  YR = 9.923*inch
  C1 = 1.968/2.0*inch ! inner radii
  C2 = 2.362/2.0*inch ! outer radii
  call geo

***
  TIT='Al pipe'
  VNAM='ALpip'
  NT =2 ! cylinder
  IM = mal ! AL aluminum
  XR = 22.110*inch
  YR = 14.449*inch
  C1 = 1.969/2.0*inch ! inner radii
  C2 = 2.362/2.0*inch ! outer radii
  call geo

*****
*** cavity ***
*****

```

```

XR = xcenter_cavity
YR = 0.0 *inch
NT = 2 ! cylinder
thick=0.28 ! 2.8mm thickness of Nb shell of cavity
zcell=11.54 ! length of one cell
zsmall=1.0 ! length of narrow region at front and back
zlarge=zcell-zsmall*2-thick*2
dz = thick+length1+length2*2
rlarge= 20.6/2.
rsmall= 7.0/2.
write(20,102) rsmall
102 format(0pf10.2,' ! inner radius of cavity')
zHOM=10.56
zgap=7.18 ! gap between previous HOM and next HOM
***
TIT='Vacuum inside the cavity and HOM'
VNAME='Vacuum'
IM = 0 ! vacuum
C1 = 0.0 ! inner radii
C2 = rsmall ! outer radii
call geo
*** Niobium cell
ZR3 = 0.0
do j=1,8 ! 8 cavities in a Cryomodule

ZR = ZR3
TIT='HOM coupler'
VNAME='HOM'
IM = mnb ! Nb
C1 = rsmall ! inner radii
C2 = rsmall+thick ! outer radii
c3 = zHOM
call geo

ZR1=ZR+c3
do i=1,9 ! 9 cells in a cavity
* narrow
ZR = ZR + c3
if (ZR.gt.zend) goto 200
TIT='Nb cavity inside narrow Iris'
VNAME='Nb-Iris'
IM = mnb ! Nb
C1 = 0.0 ! inner radii
C2 = rsmall+thick ! outer radii
c3 = zsmall
call geo
* wide vacuum
ZR = ZR + c3 + thick
TIT='Vacuum inside the cavity'
VNAME='Vacuum'
IM = 0 ! vacuum
C1 = 0.0 ! inner radii
C2 = rlarge ! outer radii
c3 = zlarge
call geo
* wide
ZR = ZR - thick
if (ZR.gt.zend) goto 200
TIT='Nb cavity inside wide'
VNAME='Nb-cavi2'
IM = mnb ! Nb
C1 = 0.0 ! inner radii
C2 = rlarge+thick ! outer radii
c3 = zlarge+thick*2
call geo
* narrow
ZR = ZR + c3
if (ZR.gt.zend) goto 200
TIT='Nb cavity inside narrow Iris'
VNAME='Nb-Iris'
IM = mnb ! Nb
C1 = 0.0 ! inner radii
C2 = rsmall+thick ! outer radii
c3 = zsmall
call geo
enddo

ZR = ZR + c3
ZR2 = ZR
TIT='HOM coupler'
VNAME='HOM'
C1 = rsmall ! inner radii
C2 = rsmall+thick ! outer radii
c3 = zHOM
call geo

ZR = ZR + c3
TIT='gap between previous HOM and next HOM'
VNAME='HgapH'
C1 = rsmall ! inner radii
C2 = rsmall+thick/2 (!?) ! outer radii

c3 = zgap ! no-pipe
call geo
ZR3= ZR +c3
***
TIT='LHE Liquid He'
VNAME='Liq-He'
IM = mlhe ! LHE
C1 = 0.0 ! inner radii
C2LHE = 9.055/2.0*inch ! outer radii
C2 = C2LHE
C3 = ZR2-ZR1
ZR = ZR1
call geo
***
TIT='Ti outside cover of cavity'
VNAME='Ti-cavi'
IM = mti ! Ti
C1 = 0.0 ! inner radii
C2 = 9.449/2.0*inch ! outer radii
thick_Ti = C2 - C2LHE
ZR = ZR1-thick_Ti
C3 = ZR2-ZR1+thick_Ti*2
call geo
***
TIT='mu metal outside cover of cavity'
VNAME='mu-cavi'
IM = mmu ! Mu metal
C1 = 9.685/2.0*inch ! inner radii
C2 = 9.764/2.0*inch ! outer radii
call geo

enddo
200 continue
ZR = ZR3
TIT='Yellow Beamline equipment after 8 9-cell cavity'
VNAME='Yellow'
IM = mstst
C1 = 9.0/2*inch ! CHECK!! ! inner radii
C2 = C1+0.2*inch ! CHECK!! ! outer radii
c3 = 74.73
call geo
** stop geometry *****
write(10,*) 'STOP' ! GEOM.INP
stop
END
*****
SUBROUTINE GEO
character VNAME*8
character TIT*70
COMMON /A/VNAME,NT,NTR,IM,XR,YR,ZR,C1,C2,C3,xref,yref,zref,TIT
COMMON /B/C3e,C4e
COMMON /C/NREG
DATA NSTD/1/ ! number of standard region
DATA NEXG/0/
SAVE NEXG
XR1=XR-xref ! coordinate(xref,yref) is (0,0) in MARS calculation
YR1=YR-yref !
ZR1=ZR-zref !
NEXG=NEXG+1
NREG=NEXG+NSTD
write(10,50) NREG,NEXG,tit
50 FORMAT('! (NREG=',i3,', NEXG=',i3,',)',lx,a55)
if (C4e.lt.0.0) then
write(10,51) VNAME,NT,NTR,IM,XR1,YR1,ZR1,C1,C2,C3,NREG
51 FORMAT(A8,3I2,0P3F8.2,1X,0P3F8.2,' ! NREG=',I3)
else
write(10,52) VNAME,NT,NTR,IM,XR1,YR1,ZR1,C1,C2,C3e,C4e,NREG
52 FORMAT(A8,3I2,0P3F8.2,1X,0P4F8.2,' ! NREG=',I3)
C4e=-1.0
endif
return
END

```

GEOM.INP

ILC cylindrical geometry

```

! (NREG= 2, NEXG= 1) Thermister1
therm1 1 0 7 7.80 -35.50 300.00 1.93 1.93 800.00 ! NREG= 2

! (NREG= 3, NEXG= 2) Thermister2
therm2 1 0 7 -4.70 17.00 300.00 1.37 1.37 800.00 ! NREG= 3

! (NREG= 4, NEXG= 3) Thermister3
therm3 1 0 7 7.90 36.70 300.00 1.76 1.76 800.00 ! NREG= 4

! (NREG= 5, NEXG= 4) Cylinder outside
Cyl-out 2 0 6 0.00 0.00 0.00 47.31 48.26 1200.00 ! NREG= 5

! (NREG= 6, NEXG= 5) Cylinder inside
Cyl-in 2 0 1 0.00 0.00 0.00 43.18 43.48 1200.00 ! NREG= 6

! (NREG= 7, NEXG= 6) Elliptical Tube
Elliptic 6 0 1 0.00 0.00 0.00 40.64 28.57 0.30 1200.00 ! NREG= 7

! (NREG= 8, NEXG= 7) Cylinder center
Cyl-cnt 2 0 2 10.90 0.00 0.00 15.00 15.60 1200.00 ! NREG= 8

! (NREG= 9, NEXG= 8) pipel for thermister-1
Cyl-pl 2 0 2 7.80 -35.50 0.00 2.74 3.01 1200.00 ! NREG= 9

! (NREG= 10, NEXG= 9) pipe
Cyl-p 2 0 2 -7.69 -21.20 0.00 3.61 3.80 1200.00 ! NREG= 10

! (NREG= 11, NEXG= 10) pipe2 for thermister-2
Cyl-p2 2 0 2 -4.70 17.00 0.00 1.94 2.11 1200.00 ! NREG= 11

! (NREG= 12, NEXG= 11) Al pipe for thermister-3
Alpip3 2 0 1 -3.40 25.20 0.00 2.50 3.00 1200.00 ! NREG= 12

! (NREG= 13, NEXG= 12) Al pipe
Alpip 2 0 1 7.90 36.70 0.00 2.50 3.00 1200.00 ! NREG= 13

! (NREG= 14, NEXG= 13) Vacuum inside the cavity and HOM
Vacuum 2 0 0 -24.69 0.00 0.00 0.00 3.50 1200.00 ! NREG= 14

! (NREG= 15, NEXG= 14) HOM coupler
HOM 2 0 3 -24.69 0.00 0.00 3.50 3.78 10.56 ! NREG= 15

! (NREG= 16, NEXG= 15) Nb cavity inside narrow Iris
Nb-Iris 2 0 3 -24.69 0.00 10.56 0.00 3.78 1.00 ! NREG= 16

! (NREG= 17, NEXG= 16) Vacuum inside the cavity
Vacuum 2 0 0 -24.69 0.00 11.84 0.00 10.30 8.98 ! NREG= 17

! (NREG= 18, NEXG= 17) Nb cavity inside wide
Nb-cavi2 2 0 3 -24.69 0.00 11.56 0.00 10.58 9.54 ! NREG= 18

! (NREG= 19, NEXG= 18) Nb cavity inside narrow Iris
Nb-Iris 2 0 3 -24.69 0.00 21.10 0.00 3.78 1.00 ! NREG= 19

! (NREG= 20, NEXG= 19) Nb cavity inside narrow Iris
Nb-Iris 2 0 3 -24.69 0.00 22.10 0.00 3.78 1.00 ! NREG= 20

! (NREG= 21, NEXG= 20) Vacuum inside the cavity
Vacuum 2 0 0 -24.69 0.00 23.38 0.00 10.30 8.98 ! NREG= 21

! (NREG= 22, NEXG= 21) Nb cavity inside wide
Nb-cavi2 2 0 3 -24.69 0.00 23.10 0.00 10.58 9.54 ! NREG= 22

! (NREG= 23, NEXG= 22) Nb cavity inside narrow Iris
Nb-Iris 2 0 3 -24.69 0.00 32.64 0.00 3.78 1.00 ! NREG= 23

! (NREG= 24, NEXG= 23) Nb cavity inside narrow Iris
Nb-Iris 2 0 3 -24.69 0.00 33.64 0.00 3.78 1.00 ! NREG= 24

! (NREG= 25, NEXG= 24) Vacuum inside the cavity
Vacuum 2 0 0 -24.69 0.00 34.92 0.00 10.30 8.98 ! NREG= 25

! (NREG= 26, NEXG= 25) Nb cavity inside wide
Nb-cavi2 2 0 3 -24.69 0.00 34.64 0.00 10.58 9.54 ! NREG= 26

! (NREG= 27, NEXG= 26) Nb cavity inside narrow Iris
Nb-Iris 2 0 3 -24.69 0.00 44.18 0.00 3.78 1.00 ! NREG= 27

! (NREG= 28, NEXG= 27) Nb cavity inside narrow Iris
Nb-Iris 2 0 3 -24.69 0.00 45.18 0.00 3.78 1.00 ! NREG= 28

! (NREG= 29, NEXG= 28) Vacuum inside the cavity
Vacuum 2 0 0 -24.69 0.00 46.46 0.00 10.30 8.98 ! NREG= 29

! (NREG= 30, NEXG= 29) Nb cavity inside wide
Nb-cavi2 2 0 3 -24.69 0.00 46.18 0.00 10.58 9.54 ! NREG= 30

! (NREG= 31, NEXG= 30) Nb cavity inside narrow Iris
Nb-Iris 2 0 3 -24.69 0.00 55.72 0.00 3.78 1.00 ! NREG= 31

! (NREG= 32, NEXG= 31) Nb cavity inside narrow Iris
Nb-Iris 2 0 3 -24.69 0.00 56.72 0.00 3.78 1.00 ! NREG= 32

! (NREG= 33, NEXG= 32) Vacuum inside the cavity
Vacuum 2 0 0 -24.69 0.00 58.00 0.00 10.30 8.98 ! NREG= 33

! (NREG= 34, NEXG= 33) Nb cavity inside wide
Nb-cavi2 2 0 3 -24.69 0.00 57.72 0.00 10.58 9.54 ! NREG= 34

! (NREG= 35, NEXG= 34) Nb cavity inside narrow Iris
Nb-Iris 2 0 3 -24.69 0.00 67.26 0.00 3.78 1.00 ! NREG= 35

! (NREG= 36, NEXG= 35) Nb cavity inside narrow Iris
Nb-Iris 2 0 3 -24.69 0.00 68.26 0.00 3.78 1.00 ! NREG= 36

! (NREG= 37, NEXG= 36) Vacuum inside the cavity
Vacuum 2 0 0 -24.69 0.00 69.54 0.00 10.30 8.98 ! NREG= 37

! (NREG= 38, NEXG= 37) Nb cavity inside wide
Nb-cavi2 2 0 3 -24.69 0.00 69.26 0.00 10.58 9.54 ! NREG= 38

! (NREG= 39, NEXG= 38) Nb cavity inside narrow Iris
Nb-Iris 2 0 3 -24.69 0.00 78.80 0.00 3.78 1.00 ! NREG= 39

! (NREG= 40, NEXG= 39) Nb cavity inside narrow Iris
Nb-Iris 2 0 3 -24.69 0.00 79.80 0.00 3.78 1.00 ! NREG= 40

! (NREG= 41, NEXG= 40) Vacuum inside the cavity
Vacuum 2 0 0 -24.69 0.00 81.08 0.00 10.30 8.98 ! NREG= 41

! (NREG= 42, NEXG= 41) Nb cavity inside wide
Nb-cavi2 2 0 3 -24.69 0.00 80.80 0.00 10.58 9.54 ! NREG= 42

! (NREG= 43, NEXG= 42) Nb cavity inside narrow Iris
Nb-Iris 2 0 3 -24.69 0.00 90.34 0.00 3.78 1.00 ! NREG= 43

! (NREG= 44, NEXG= 43) Nb cavity inside narrow Iris
Nb-Iris 2 0 3 -24.69 0.00 91.34 0.00 3.78 1.00 ! NREG= 44

! (NREG= 45, NEXG= 44) Vacuum inside the cavity
Vacuum 2 0 0 -24.69 0.00 92.62 0.00 10.30 8.98 ! NREG= 45

! (NREG= 46, NEXG= 45) Nb cavity inside wide
Nb-cavi2 2 0 3 -24.69 0.00 92.34 0.00 10.58 9.54 ! NREG= 46

! (NREG= 47, NEXG= 46) Nb cavity inside narrow Iris
Nb-Iris 2 0 3 -24.69 0.00 101.88 0.00 3.78 1.00 ! NREG= 47

! (NREG= 48, NEXG= 47) Nb cavity inside narrow Iris
Nb-Iris 2 0 3 -24.69 0.00 102.88 0.00 3.78 1.00 ! NREG= 48

! (NREG= 49, NEXG= 48) Vacuum inside the cavity
Vacuum 2 0 0 -24.69 0.00 104.16 0.00 10.30 8.98 ! NREG= 49

! (NREG= 50, NEXG= 49) Nb cavity inside wide
Nb-cavi2 2 0 3 -24.69 0.00 103.88 0.00 10.58 9.54 ! NREG= 50

! (NREG= 51, NEXG= 50) Nb cavity inside narrow Iris
Nb-Iris 2 0 3 -24.69 0.00 113.42 0.00 3.78 1.00 ! NREG= 51

! (NREG= 52, NEXG= 51) HOM coupler
HOM 2 0 3 -24.69 0.00 114.42 3.50 3.78 10.56 ! NREG= 52

! (NREG= 53, NEXG= 52) gap between previous HOM and next HOM
HgapH 2 0 3 -24.69 0.00 124.98 3.50 3.64 7.18 ! NREG= 53

! (NREG= 54, NEXG= 53) LHE Liquid He
Liq-He 2 0 8 -24.69 0.00 10.56 0.00 11.50 103.86 ! NREG= 54

! (NREG= 55, NEXG= 54) Ti outside cover of cavity
Ti-cavi 2 0 4 -24.69 0.00 10.06 0.00 12.00 104.86 ! NREG= 55

! (NREG= 56, NEXG= 55) mu metal outside cover of cavity
mu-cavi 2 0 5 -24.69 0.00 10.06 12.30 12.40 104.86 ! NREG= 56

;
; NREG=15*56 is repeated 8 times with different z-coordinate
;

! (NREG=350, NEXG=349) mu metal outside cover of cavity
mu-cavi 2 0 5 -24.69 0.00 935.18 12.30 12.40 104.86 ! NREG=350

! (NREG=351, NEXG=350) Yellow Beamline equipment after 8 9-cell cavity
Yellow 2 0 2 -24.69 0.00 1057.28 11.43 11.94 74.73 ! NREG=351
STOP

```