The Abdus Salam
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School on Physics, Technology and Applications of Accelerator Driven Systems (ADS)

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Background Information for P. SATYAMURTHY's talk on Thermal Hydraulics of Heavy Liquid Metal Target for ADS.

"Numerical Simulation of Flow and Heat Transfer near the Spallation Region of ADS Target" by Siddhartha PAL.

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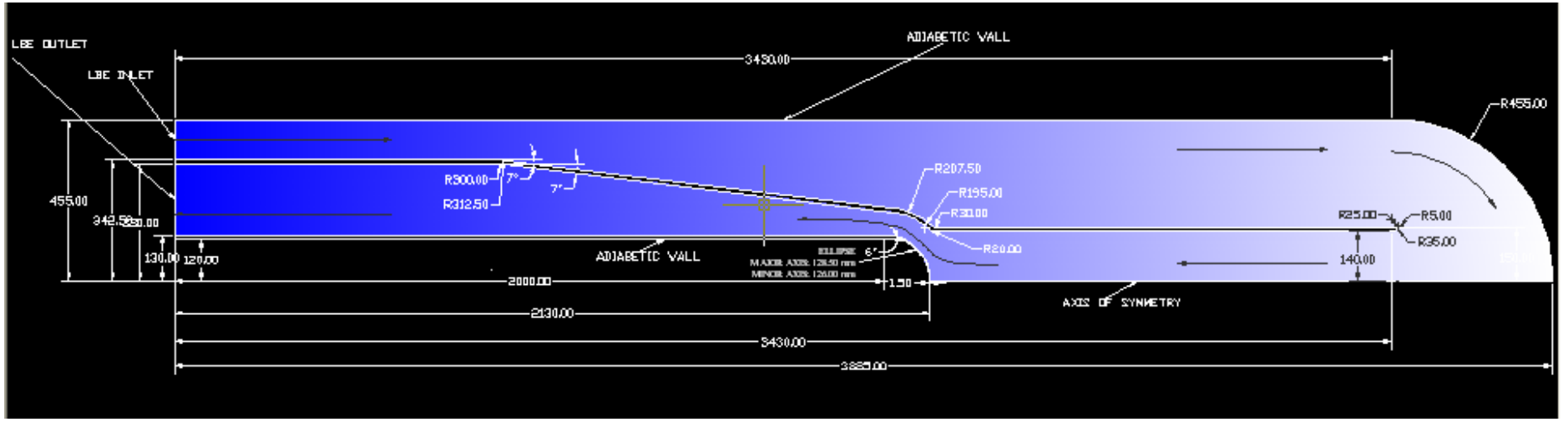
Numerical Simulation of Flow and Heat Transfer near the Spallation Region of ADS Target

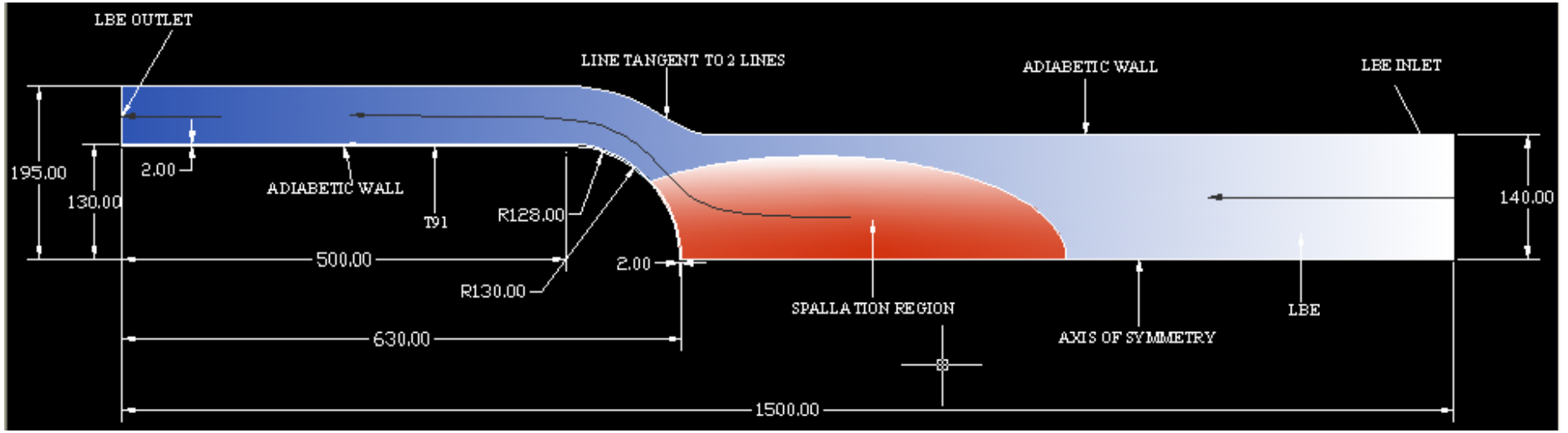
Siddhartha Pal

Bhabha Atomic Research Centre

Mumbai, India



Optimized Full Geometry

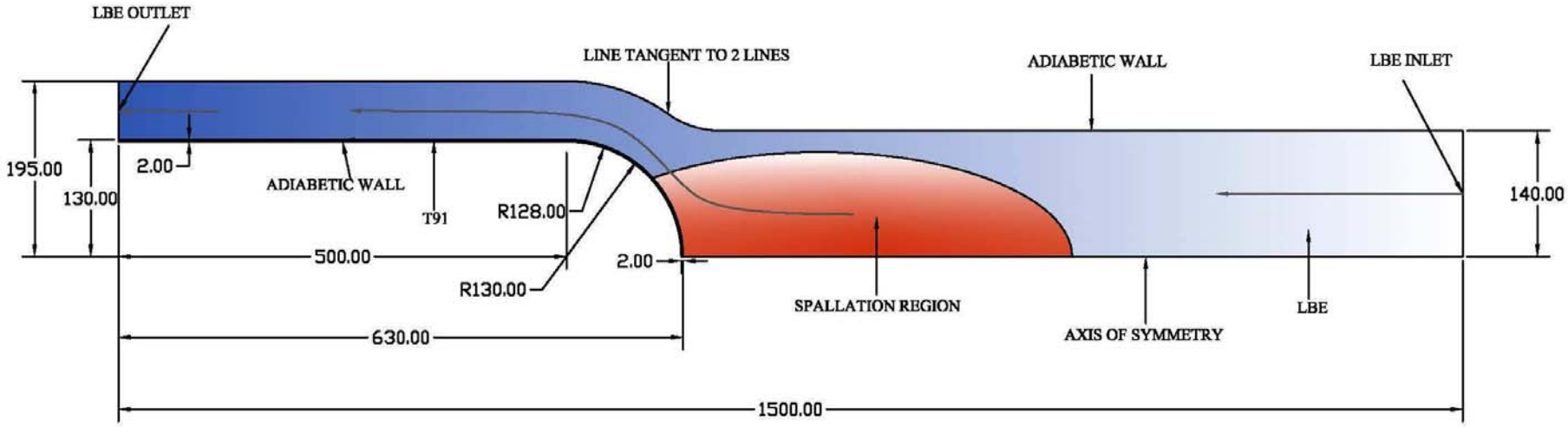


Simplified Geometry

Features of the Problem

- Simplified Geometry
- Geometry is Axisymmetric
- Swirl is Neglected
- 2D Model
- Turbulence: k-ε Model
- Conjugate Heat Transfer
- Volumetric Heat Generation

Problem Specification: Geometry



Problem Specification: Inlet Conditions

- Flow Rate: 600 kg/s
  Velocity (U) ~ 0.934 m/s
  (considering uniform profile,
  density ~ 10430 kg/m^3)

- Temperature: 523 K

Problem Specification: Inlet Conditions

- Turbulent Intensity, $I = 10\%$
- Turbulent Kinetic Energy, $k = 1.5I^2U^2 \sim 0.013$
- Turbulent Dissipation Rate, $\varepsilon = \frac{(C_\mu)^{3/4}(k)^{3/2}}{\lambda} \sim 0.0027$

Where $C_\mu = 0.09$, $\lambda = 0.09$

Boundary Conditions: Velocity

- Inlet: U = -0.934 m/s, V= 0
- Wall: $U = 0$, $V = 0$
- Symmetry: $\frac{\partial U}{\partial n} = 0$, $V = 0$
- Outlet: $\frac{\partial U}{\partial n} = 0$, $\frac{\partial V}{\partial n} = 0$

Boundary Conditions: Pressure

- Outlet: $p = 0$
- All other boundaries: $\frac{\partial p}{\partial n} = 0$

Boundary Conditions: Turbulence

- Inlet: $k = 0.013$, $\varepsilon = 0.0027$
- All other boundaries: $\dfrac{\partial k}{\partial n} = \dfrac{\partial \varepsilon}{\partial n} = 0$

Boundary Conditions: Thermal

- Inlet: T = 523K
- Adiabatic Wall: $\frac{\partial T}{\partial n} = 0$
- Symmetry: $\frac{\partial T}{\partial n} = 0$
- Outlet: $\frac{\partial T}{\partial n} = 0$

Steps to be followed

1. Build Geometry
2. Mesh Geometry
3. Specify Properties
4. Apply Boundary Conditions
5. Obtain the Solution
6. View Results

Customizing Heat Deposition Data from FLUKA

- Obtain Heat Deposition Data from FLUKA
- Customize the Data for Visualization in TECPLOT
- Customize the Data for ANSYS Simulation

Obtain Heat Deposition Data from FLUKA

```
*****   Sample problem for ictp                                         *****

        DATE: 11/ 6/ 7,  TIME: 12:31: 5

        Total number of particles followed       1000, for a total weight of  1.0000E+03

1
  R - Z     binning n.   1  "wndheat    " , generalized particle n.  208
     R coordinate: from  0.0000E+00 to  1.3000E+01 cm,   400 bins ( 3.2500E-02 cm wide)
     Z coordinate: from  1.0000E+01 to  2.3000E+01 cm,   400 bins ( 3.2500E-02 cm wide)
     axis coordinates: X = 0.0000E+00, Y =  0.0000E+00 cm
     Data follow in a matrix A(ir,iz), format (1(5x,1p,10(1x,e11.4)))

     accurate deposition along the tracks requested
      0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
      0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
      0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
      0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
      0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
      0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
      0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
      0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
      0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
```

```
4.3124E-05  4.1943E-05  1.7500E-04  5.9315E-05  1.1034E-05  3.4028E-05  3.0433E-05  9.0781E-05  2.0965E-04  6.4648E-05
6.0821E-05  8.5781E-05  1.0771E-04  9.4115E-05  8.1027E-05  2.3352E-05  6.4469E-05  1.6286E-05  1.2889E-05  7.3044E-05
8.7458E-05  8.1810E-05  6.4090E-05  6.4758E-05  7.9055E-05  8.9944E-05  6.1860E-05  6.9519E-05  4.0733E-05  8.7049E-05
1.5654E-05  6.0990E-05  4.6512E-05  5.7037E-05  3.9447E-05  6.5139E-05  2.6619E-05  3.8518E-05  4.6089E-05  6.4684E-05
2.3484E-05  4.7856E-05  1.9353E-04  9.5061E-05  2.2095E-05  6.0408E-05  6.7627E-05  3.6409E-05  2.5694E-05  3.1143E-05
4.0047E-05  4.9240E-05  1.0979E-05  2.5938E-05  4.7175E-05  2.7720E-05  0.0000E+00  2.8654E-05  2.7012E-05  1.8144E-05
3.4628E-05  1.5131E-05  4.5066E-05  3.2459E-05  1.2780E-05  2.5943E-05  3.4707E-05  5.4359E-05  3.0120E-05  2.7325E-05
4.9206E-05  1.5630E-05  2.9753E-05  2.0893E-05  2.1897E-05  4.0512E-05  1.9034E-05  4.4154E-05  5.9634E-05  3.8828E-05
7.1954E-05  3.9784E-05  4.4350E-05  4.4295E-05  2.4405E-05  4.4528E-05  7.9386E-05  1.0796E-04  8.0515E-05  1.8130E-05
4.7109E-05  4.1312E-05  9.2846E-05  1.1382E-04  5.3635E-05  3.9620E-05  5.7864E-05  2.8659E-05  3.1786E-05  3.5142E-05
1.0783E-04  4.9688E-05  5.4442E-05  5.8466E-05  3.5264E-05  3.1127E-05  5.9573E-05  3.1346E-05  2.1156E-05  3.4545E-05
2.9998E-05  0.0000E+00  5.6908E-05  4.2226E-05  4.5451E-05  3.2502E-05  2.8402E-05  2.4997E-05  4.2396E-05  6.9706E-05
2.7470E-05  5.2683E-05  2.0240E-05  1.1284E-04  4.1551E-05  3.4723E-05  1.3074E-04  1.4650E-05  3.0844E-05  1.5875E-04
2.4605E-05  3.9376E-05  3.3638E-05  9.7710E-05  5.0456E-05  4.2784E-05  7.1042E-05  2.0124E-05  3.2508E-05  4.0544E-05
2.4145E-05  2.0629E-05  3.7049E-05  3.3939E-05  4.5475E-05  3.0675E-05  1.4079E-05  1.1297E-05  1.6920E-05  1.0630E-05
2.8275E-05  1.5132E-05  1.7964E-05  2.5299E-05  1.2706E-05  8.8021E-07  1.5264E-05  0.0000E+00  1.7718E-05  1.3758E-05
1.2286E-05  2.4868E-05  1.2895E-05  9.6323E-06  7.3003E-06  5.4665E-06  1.6340E-05  1.0736E-05  2.9535E-05  2.9363E-05
1.1617E-05  1.6214E-05  7.1590E-06  7.1181E-06  7.0779E-06  5.9531E-06  2.0738E-05  6.2759E-06  1.2550E-05  0.0000E+00
5.7875E-07  1.0583E-07  0.0000E+00  0.0000E+00  0.0000E+00  1.1462E-05  8.4999E-08  0.0000E+00  0.0000E+00  1.4635E-06
3.0665E-06  9.0771E-06  2.8885E-06  0.0000E+00  0.0000E+00  0.0000E+00  9.9265E-06  1.6355E-07  1.1364E-05  1.8298E-05
```

```
      subroutine post( IDATA, IOUT, NRBIN, NZBIN, NEPL, dr, dz )
      implicit double precision ( a-h, o-z )
      dimension A(1:NRBIN,1:NZBIN)
      dimension B(1:NEPL)
      pi = 4.d0*atan(1.d0)
      do i = 1, NRBIN
         do j = 1, NZBIN
            A(i,j) = 0.d0
         enddo
      enddo
       do j = 1, NEPL
         B(j) = 0.d0
      enddo
      NTOT  = NRBIN*NZBIN
      NLEFT = mod(NTOT-1,NEPL) + 1
      NLINE = (NTOT - NLEFT)/NEPL + 1
      do i = 1, 15
         read(IDATA,*)
      enddo
      do i = 1, NLINE - 1
          read(IDATA,*) ( B(j), j = 1, NEPL )
           do k  = 1, NEPL
              n       = (i-1)*NEPL + k
              n2      = mod(n-1,NRBIN) + 1
              n1      = (n - n2)/NRBIN + 1
              A(n2,n1) = B(k)
          enddo
      enddo
      read(IDATA,*) ( B(j), j = 1, NLEFT )
        do k  = 1, NLEFT
          n       = (NLINE-1)*NEPL + k
          n2      = mod(n-1,NRBIN) + 1
          n1      = (n - n2)/NRBIN + 1
          A(n2,n1) = B(k)
      enddo
```

```
c       fluka data is in GeV/cm3/proton, output shall be in W/m3/mA
        cfac = 1.0e12
        write(IOUT,*) 'TITLE="HGEN"'
        write(IOUT,*) 'VARIABLES="r" "z" "q"'
        write(IOUT,*) 'ZONE I=',NRBIN, ' J=', NZBIN, ' F=POINT'
        sum1 = 0.d0
        sum2 = 0.d0
        do j = 1, NZBIN
            z = (j-0.5)*dz*1e-2
           do i = 1, NRBIN
               r = (i-0.5)*dr*1e-2
              write(IOUT,*) r, z, cfac*A(i,j)
              sum1 = sum1 + r*cfac*A(i,j)
c             if(z.gt.(0.1).and.r.lt.(0.13)) sum2 = sum2 + r*cfac*A(i,j)
              if(z.gt.(0.0)) then
                  rad=dsqrt(r**2+(z-0.0)**2)
                if(rad.lt.(0.13)) sum2 = sum2 + r*cfac*A(i,j)
              endif
           enddo
        enddo
        ht_tot =  2.d0*pi*sum1*dr*dz*1.0e-4/1.0e6
        ht_win =  2.d0*pi*sum2*dr*dz*1.0e-4/1.0e3
        write(*,*) sum2, sum1
         write(*,100) "Total Heat Deposited (in MW/mA) = ", ht_tot
c        write(*,100) "Heat Deposited in Window (in kW/mA) = ", ht_win
100     format(1x,a40,f10.2)
        return
        end
```

Code to Rearrange Data for TECPLOT

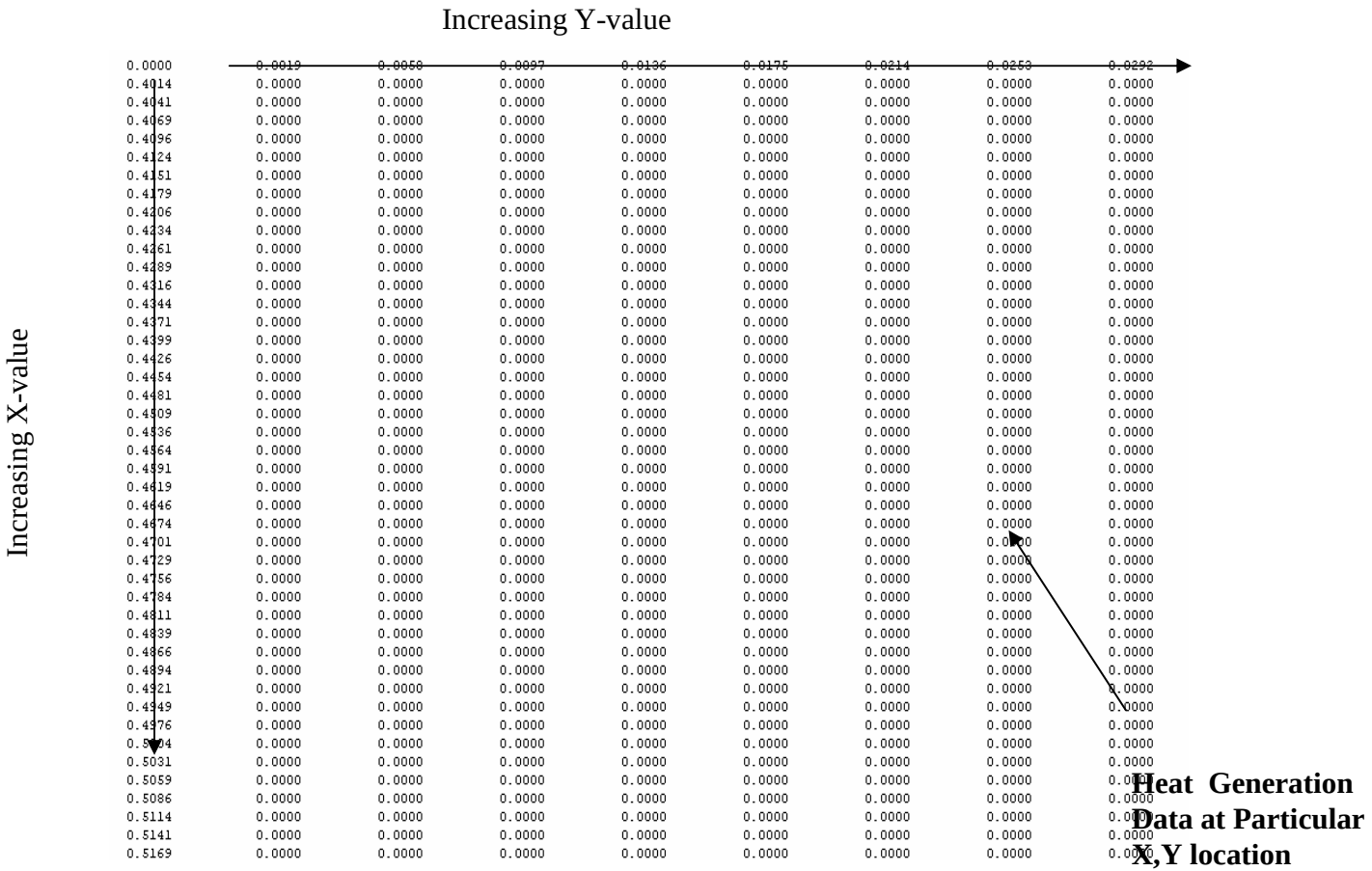
```
TITLE="HGEN"
VARIABLES="r" "z" "q"
ZONE I= 50 J= 400 F=POINT
 0.00194999996  0.00137499997  0.
 0.00584999987  0.00137499997  0.
 0.00974999978  0.00137499997  0.
 0.0136499997  0.00137499997  0.
 0.0175499996  0.00137499997  0.
 0.0214499995  0.00137499997  0.
 0.0253499994  0.00137499997  0.
 0.0292499993  0.00137499997  0.
 0.0331499993  0.00137499997  0.
 0.0370499992  0.00137499997  0.
 0.0409499991  0.00137499997  0.
 0.044849999  0.00137499997  0.
 0.0487499989  0.00137499997  0.
 0.0526499988  0.00137499997  0.
 0.0565499987  0.00137499997  0.
 0.0604499986  0.00137499997  0.
 0.0643499986  0.00137499997  0.
 0.0682499985  0.00137499997  0.
 0.0721499984  0.00137499997  0.
 0.0760499983  0.00137499997  0.
 0.0799499982  0.00137499997  0.
 0.0838499981  0.00137499997  0.
 0.087749998  0.00137499997  0.
 0.091649998  0.00137499997  0.
 0.0955499979  0.00137499997  0.
 0.0994499978  0.00137499997  0.
 0.103349998  0.00137499997  0.
 0.107249998  0.00137499997  0.
 0.111149998  0.00137499997  0.
 0.115049997  0.00137499997  0.
 0.118949997  0.00137499997  0.
 0.122849997  0.00137499997  0.
 0.126749997  0.00137499997  124259.999
 0.130649997  0.00137499997  451629.998
 0.134549997  0.00137499997  316489.999
 0.138449997  0.00137499997  223339.999
 0.142349997  0.00137499997  216029.999
 0.146249997  0.00137499997  145159.999
 0.150149997  0.00137499997  123389.999
 0.154049997  0.00137499997  104100.
 0.157949996  0.00137499997  84176.9997
```

Data Arranged for TECPLOT

Code to Rearrange Data for ANSYS

```
      program main

      implicit double precision (a-h,o-z)

      dimension A(1:50,1:400)
      dimension x(1:50)
      dimension y(1:400)

      open(10,file='hgen.dat',form='formatted')

      read(10,*)
      read(10,*)
      read(10,*)

      do j = 1, 400
            do i = 1,50
                  read(10,*) x(i), y(j), A(i,j)
            enddo
      enddo

      open(11,file='hgen',form='formatted')

      d = 0.00
      write(11,1000) d, (x(i), i = 1, 50 )
      do i = 1, 400
            write(11,1000) y(i)+ 0.4, ( A(j,i)*10.0, j = 1, 50 )
      enddo

1000  format(1x,f6.4,1x,50f16.4)

      close( 10 )
      close( 11 )

      end
```

Data Arranged for ANSYS



Fluid (LBE) Properties

- Density = 10430 kg/m^3
- Viscosity = 0.002 Pa-s
- Conductivity = 12 W/m.K
- Specific Heat = 146.5 J/kg.K

Solid (T91) Properties

- Density = 8230 kg/m^3
- Conductivity = 27 W/m.K
- Specific Heat = 530 J/kg.K

Further Exercises

- Turbulence Model
- Mesh Refining – Grid Independence Test
- Flow Rate
- Geometry
- Variation of properties with temperature