Modeling Radiation Sources in MCNP

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Every Radiation Source has:

- **Location**
  - Point, surface, or volume
- **Direction**
  - Isotropic, beam like, or angular distribution
- **Energy**
  - Single energy, multiple discrete lines, distribution
- **Particle type**
  - Neutrons, photons, electrons, or positrons (MCNP5)
  - 34 elementary particles + heavy ions (MCNPX)
- **Time distribution**
  - Constant, radioactive decay

MCNP Particles

IPT	Name	Symbol
1	neutron (n)	n
1	anti-neutron	-n
2	photon (g)	p
3	electron (e-)	e
3	positron (e+)	-e
4	muon- (m-)	l
4	anti-muon- (m+)	-l
6	electron neutrino	u
6	anti-electron neut.	-u
9	proton	h
9	anti-proton	-h

IPT	Name	Symbol
20	pion+ (p+)	/
20	pion- (p-)	-/
21	neutral pion (p0)	z
22	Kaon+ (K+)	k
22	Kaon- (K-)	-k
23	K0 short	%
24	K0 long	^
31	Deuteron	d
32	Triton	t
33	Helium-3	s
34	Helium-4 (a)	a
35	Heavy ion	#

MCNPX only

Both MCNPX & MCNP5

MCNP Sources

MCNP can model the previous physical descriptions in one of four source data cards:

• General	SDEF	[This Lecture]
• Criticality	KSRC	
• Surface	SSW / SSR	

- User-Supplied (Fortran Routine)

For SDEF source types, can use source distribution functions to provide details:

- **SIn** **information** **about the variable**
- **SPn** **probability** **of choosing a particular value**

- **SBn** **probability biasing**

- **DSn** **dependent source distribution**

(More on these later.)

MCNP Sources

In this lecture, we will use the SDEF card to work the following examples:

- A ^{99m}Tc (monoenergetic) point γ source in lung
- A ^{99m}Tc spherical γ source in Pb shield
- A ^{60}Co spherical γ source in Pb shield [optional]
- Two point gamma sources: ^{99m}Tc bottom, ^{38}S top
- Two spherical gamma sources: ^{99m}Tc bottom, ^{38}S top
- A neutron beam source [optional]

General Source: SDEF Data Card

Form: **SDEF** **source_variable=specification .....**

Source Variable is an abbreviation for a physical description:

- erg   energy (MeV)
- pos   position (location)
- dir   cosine of angle
- vec   reference vector (direction) for DIR
- rad   radial distance of the position
- ext   extents (distance or angle)
- axs   reference vector for EXT and RAD
- cel   cell
- others

SDEF Data Card (cont.)

Specification is a value or distribution, in one of three forms:

1. explicit value: SDEF ERG=2.0

   [default values + source energy = 2.0 MeV]

2. distribution number: SDEF ERG=D1

   [default values + source energy is a distribution ("D1" notation is explained later)]

3. as a function of another variable:

   SDEF POS=D1 ERG=FPOS=D2

   [default values + src position is a distribution + src energy depends on which position]

SDEF Source

When a physical description is omitted from the SDEF card, a default is assumed

Defaults:

Energy	[erg]	14.0 MeV
Position	[pos]	0.0 0.0 0.0
Direction	[vec]	Isotropic
Time	[tme]	0.0
Particle Type	[par]	neutrons if mode n, mode n p, or mode n p e photons if mode p or mode p e electrons if mode e or mode e f

The mode data card is a listing of all particles to be used in the simulation.

SDEF Source Scalar Variables

Explicit Value Only:

`WGT    EFF    NRM`

Explicit Value or Distribution:

`SUR    TME    CCC    ARA    TR    X    Y    Z`

`CEL    ERG    DIR    RAD    EXT    PAR`

DIR cosine of angle between reference vector VEC and u,v,w.
azimuthal angle always sampled uniformly from 0 to 360.

NRM sign of surface normal

RAD radial distance of the position from POS or AXS vector

EXT cell case: distance from POS along AXS
surface case: cosine of angle from AXS

SDEF Source Vector Variables

Each vector variable has 3 entries: the x,y,z component.

VEC	reference vector for DIR
POS	reference point for sampling position
AXS	reference vector for EXT and RAD

EXAMPLE PROBLEMS

Problem source1

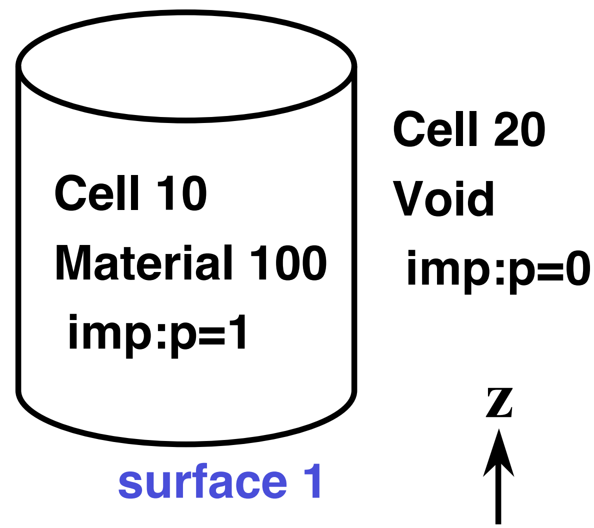
Tc-99m point source in lung

(Source variables are values)

Tc99m in lung -- using SDEF Sources

- **Bare cylinder of (almost) ICRU lung, ρ = 1.06 g/cm3**
- **Tc99m emits one 0.14 MeV γ per decay**
- **Tc99m is not a material in the geometry**
- **Nuclide / Mass-fraction / ZAID**

Nuclide	Mass-fraction	ZAID
Hydrogen	.103	1001
Carbon	.105	6000
Nitrogen-14	.03	7014
Oxygen-16	.749	8016



(1) Copy file “lung“ to file “source1”

(2) Use macrobodies, with center at (0.0, 0.0, 5.0) height = 10.0 rad=5.0

cylinder: RCC V_x V_y V_z H_x H_y H_z R (see next slide)

(3) Add these data cards:

SDEF (**Add a point source of photons at center of cylinder**)

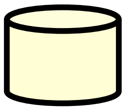
mode p $ for photon transport, mode p e for photon and electron transport

nps 100

print 10 110 170

RCC Macrobody

Right Circular Cylinder



RCC Vx Vy Vz Hx Hy Hz R

Vx Vy Vz = center of base

Hx Hy Hz = axis of cylinder, magnitude = height

R = radius

Checking the Source

WHAT SHOULD YOU DO?

1) Examine Print Tables in the output file

Table 10	**source input information**
Table 110	**info about 1st 50 source particles** **x y z cell surface u v w time wgt erg**
Table 170	**source distribution frequency after run**

2) Examine the summary tables in the output file

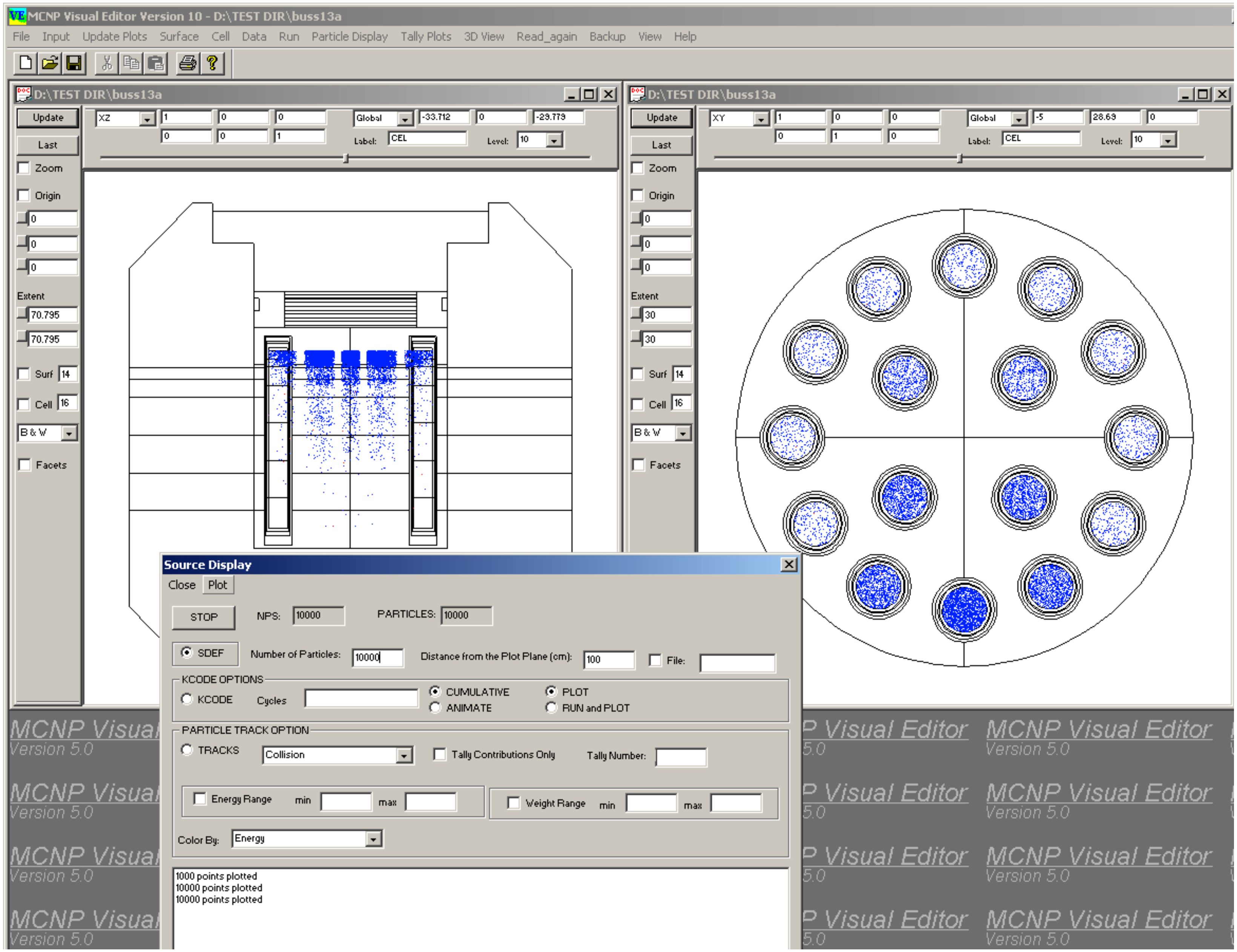
weight started should be ~total source strength

energy started should be ~average source energy

3) [OPTIONAL] Use Visual Editor to plot source points (under particle display)

But for a point source, plot is not interesting.

Visual Editor



SI, SP, SB, and DS Cards

Often, source variables are not single values.

The following cards are used in conjunction with the SDEF card to describe distributions in location, direction, energy, etc.

SI **information about the variable**
bins, discrete values, distribution numbers

SP **probability of choosing particular value**
true probabilities, built-in functions

SB **biased probabilities**

DS **dependent distribution**
values, distribution numbers

SI (source information) Card

FORM: `SIn option entries`

blank

or

- **H** entries are <u>histogram</u> bin boundaries (default)
- **L** entries are <u>discrete</u> <u>values</u>
- **A** entries are <u>points</u> where probability density distribution is defined
- **S** entries are <u>distribution numbers</u>

SI Card Examples

SDEF ERG=D1

SI1 H .01 .1 1.0 3.0 14.0 $ bins

SDEF POS=D1

SI1 L 0. 0. 0. 10. 0. 0. $ xyz values

SDEF ERG=D1

SI1 S 3 4 5 $ other distributions #

⋮

SP (source probability) Card
SB (source bias) Card

FORM: SPn option entries

OR SPn F a b

SBn same form as SPn

blank or

- **D** entries are bin probabilities (default)
- **C** entries are cumulative bin probabilities
- **V** entries are probability proportional to volume

- **F** built-in function
- **a, b** parameters for function

SP Card Examples

```
SDEF   ERG=D1
SI1    .01   0.1   1.0   3.0    14.0
SP1     0    2.    1.    1.      6.      (bin probabilities)
  OR
SP1 C   0    .2    .3     .4     1.0      (cumulative)
```

```
SDEF   POS=0 1 0   RAD=D2   CEL=D1
SI2    H    0    3
SP2    -21   2
SI1    L    30    40             (proportional to volume)
SP1    V                         (special case for CEL)
```

(see input file “svol1”)

Cartesian Volume

point:	**SDEF**	**X=5**	**Y=3**	**Z=6**	
line:	**SDEF**	**X=D1**	**Y=3**	**Z=6**	
	SI1 H	**-50**	**50**		
	SP1	**0**	**1**		
area:	**SDEF**	**X=D1**	**Y=D2**	**Z=6**	
	SI2 H	**0**	**10**		
	SP2	**0**	**1**		
volume:	**SDEF**	**X=D1**	**Y=D2**	**Z=D3**	**CEL=5**

Cell Rejection: if x,y,z are not in cell 5, then reject and sample x,y,z again

SP and SB General Example

```
SDEF   ERG=D1    POS=x y z
SI1    H   E_1   E_2 … E_k
SP1    D   0     P_2 … P_k        $ bin probabilities
SB1    D   0     B_2 … B_k        $ bin probabilities
```

Biasing some energy bins at the expense of others.
(think variance reduction)

Problem source2

Photon Sources in Lead Shield

(Volumetric Source)

Pb Shield -- SDEF Volumetric Source

1) **Copy file shield to source2**

2) **Change SDEF card to be a spatial distribution in xyz to surround bottom sphere.**

3) **Run. Look at starting cell locations in Table 110**

4) **Add "cell=40" to sdef card for cell acceptance – source particles will only be in bottom sphere**

5) **Run. Look at starting cell locations in Table 110**

HINT: See slide #23

Visual Editor Source plots

Without SDEF Cell=40

With SDEF Cell=40

Problem source3

^{60}Co Photon Sources in Lead Shield

(Multiple Discrete Energies)

(OPTIONAL)

Pb Shield – SDEF ^{60}Co Source

1) **Copy file source2 to source3**

2) **Make the source a ^{60}Co source:**
   – ^{60}Co emits 2 photons per decay, 1.173 and 1.332 MeV
   – Make the distribution in energy equally probable

3) **Run the problem**

4) **Look at the energies in Table 110**

More about SDEF Distributions

- So far, each distribution has been independent and fully defined by the user.
- SDEF Distributions can also be built in functions.
- SDEF Distribution can also depend on previous distributions on the SDEF card.

SDEF Built–in Functions

Some distributions already built into MCNP, mostly used for energy distributions of neutron sources

Example:

```
SDEF    ERG=D1
SP1   -3          $  Watt fission; default a and b
```

Example:

```
SDEF    ERG=D1
SP1   -4          $ Gaussian fusion spectrum; default a and b
```

Built-in Functions for Source Probability and Bias Specification

Source Variable	Function No. and Input Parameters	Description
ERG	-2 *a*	Maxwell fission spectrum
ERG	-3 *a b*	Watt fission spectrum
ERG	-4 *a b*	Gaussion fusion spectrum
ERG	-5 *a*	Evaporation spectrum
ERG	-6 *a b*	Muir velocity Gaussian fusion spectrum
ERG	-7 *a b*	Spare
DIR, RAD, or EXT	-21 *a*	Power law: $p(x)=c\|x\|^a$
DIR or EXT	-31 *a*	Exponential: $p(\mu)=ce^{a\mu}$
TME, X, Y, Z	-41 *a b*	Gaussian distribution of time or position

CAUTION: Some defaults depend on which Source Variable.

Dependent Source Distributions

Want to make the energy emitted a function of location?

1) **Use <u>FUNCTION</u> of preceding Source Variable on SDEF card.**
   - Example: SDEF Y=D20 ERG = FY = D45

2) **Change its source information card (SI) to dependent source card (DS).**
   - Example: DS45 L 0.14 1.88

3) **Remove SP card for the dependant source, since the probability of something is now correlated to the preceding source variable.**

4) **Must match number of selections on SI and DS cards.**

DS (dependent source) Card

FORM: **DSn** **option** **entries**

blank or

- **H** **continuous distribution values (default)**
- **L** **discrete values**
- **S** **distribution numbers**

Other choices for option exist. See the MCNP manual for more detail.

Example Problem source4

^{99m}Tc and ^{38}S point sources in shield

(Source variables are functions of other source variables)

Dependant γ sources in Pb Shield

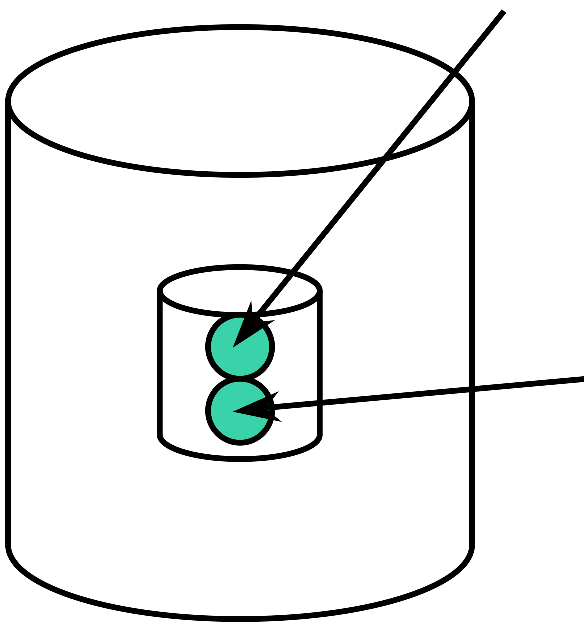
1) Copy shield to source4

2) Delete the SDEF, SI and SP cards.

3) Create a new SDEF:

2 point sources, each in the middle of the two spheres.

- Make the y=2 point emit 1.88 MeV photons (^{38}S) and the y=0 point emit 0.14 MeV photons (^{99m}Tc)
- Hint: Y should be a distribution with two discrete values.
- Hint: ERG is a dependant distribution of Y, and has two discrete values



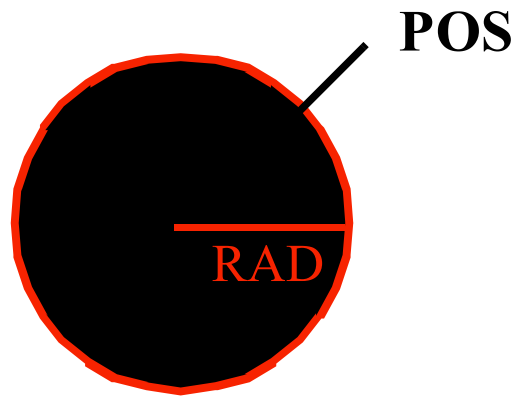
More Dependent Source Examples

```
SDEF   POS=D1      ERG=FPOS=D2
SI1  L    0.0  0.0  0.0     10.0  0.0  0.0
SP1            1                  1
DS2  S    3    4             $ other distributions
SI3  H  2.0  10.0  14.0      $ below 2, 2-10, 10-14
SP3  D    0     0.5   0.5    $ prob: 0,  1/2,   1/2
SP4  -5                      $ evaporative spectrum
```

```
SDEF   RAD=D1    POS    FRAD    D4
SI1   S     2    3
•
•
•
DS4   L    0.0  0.0  0.0      10.0  0.0  0.0
```

Spherical Volume Sources

uniform in volume:



SDEF RAD=D1 POS = 2 0 5

SI1 H 0 3

SP1 -21 2 $ density proportional to R^2 (default)

can source bias with a function

SB1 -21 1.5 $ density proportional to $R^{1.5}$

Uniform Spherical Volume

SP -21 2

WHY R^2 ???

Want p(r) $\propto$ incremental volume

$$\frac{dV}{dr} = \frac{d(4/3\,\pi\, r^3)}{dr} = 4\pi r^2$$

Prob of choosing radius r

$$p(r) \propto r^2$$

Spherical Volume Source Example

Uniform in a spherical shell:

```
SDEF  RAD=D1     POS     0     0     0
SI1        2       3
SP1     -21        2         $ default
```

Clipped Sphere and Shell Example

```
10     100   -11.4     -1    imp:p=1
30     200   -1.12     +1    imp:p=1

1   PX   2.0


SDEF   RAD=D1    POS FRAD D5    CEL FRAD D6
SI1    S      2      4               $   dist #2 & #4
SP1    D      1      1
SI2    H      0           3          $   solid
SI4    H      2           3          $   shell
DS5    L   0  0   0     4   0   0
DS6    L     10          30          $   cell acceptance
```

(see file “clip1”)

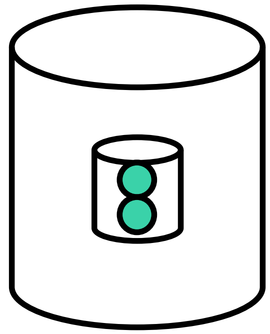
Problem source5

^{99m}Tc and ^{38}S spherical sources in shield

(Source functions and spherical sources)

(OPTIONAL)

E sources in Pb Shield – using Spherical Sources



1) Copy source4 to source5

2) Make both sources into spherical sources homogeneously filling their geometric spheres. Use RAD

   HINT: Must use POS, not X Y Z

3) Run the problem

4) Change the source into a thin shell covering the two spheres, like surface contamination. (OPTIONAL)

Visual Editor slices (XY plane @ origin), source particles colored by energy

CAUTION:

If the source starting location is always going to be on an MCNP defined surface, must add SUR to SDEF card. Otherwise particles could get lost.

Alternatively, change particle starting locations (rad, pos, or x y z) to start them in a cell, not on a surface (see file source5b).

Example:

```
SDEF   RAD=1.0   SUR=1
```

or

```
SDEF   RAD=0.999
```

Source5 Comments (cont.)

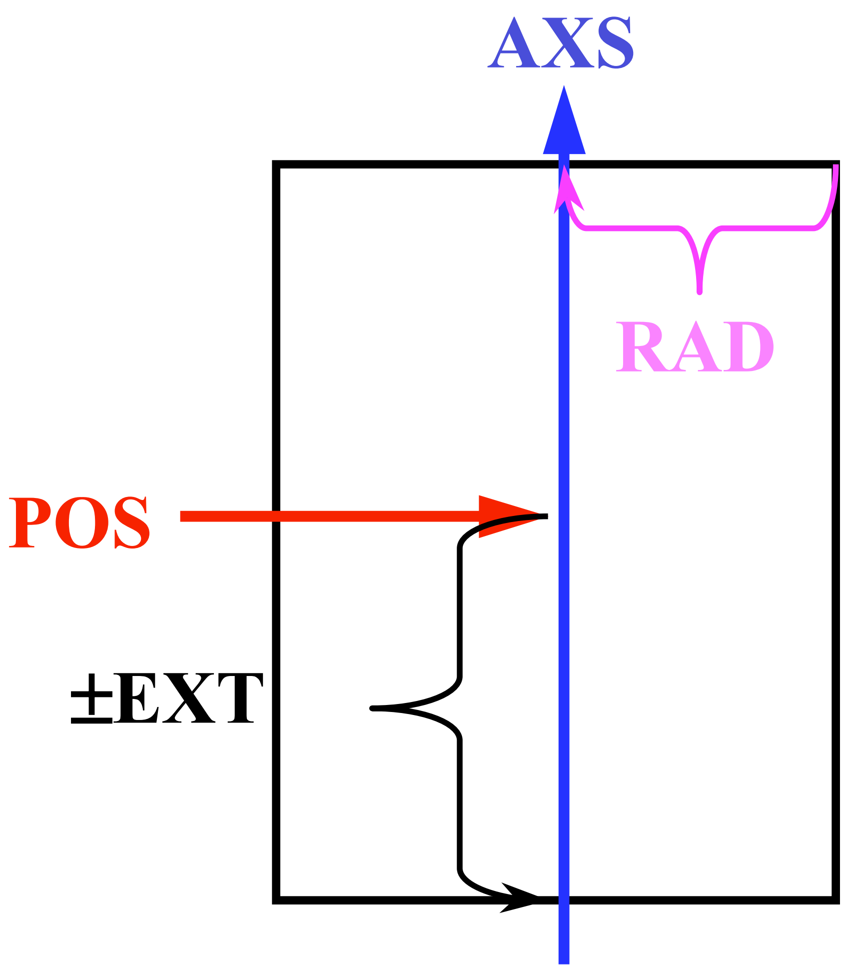
For previous example with two spheres, SUR must be a distribution.

- For better efficiency, use a dependent distribution
- SUR can NOT depend on POS
- SDEF changed so both POS and SUR depend on energy (see file source5c)

Cylindrical Volume Sources

- A cylindrical volume source is created by adding the AXS (Axis) vector variable to the SDEF card
- The RAD keyword now only applies orthogonally to the AXS vector
- The EXT (Extent) keyword applies along the AXS vector, and defines how far along the axis from POS will be sampled.

Cylindrical Volume Sources



AXS vector u v w

POS vector x y z

RAD distribution Dn

EXT distribution Dn

Cylindrical Volume (cont)

```
SDEF   POS    0   0   0   RAD=D1   EXT=D2   AXS   0   1   0
SI1   H    0        5.6       $  inner and outer radii
SP1        -21      1         $  default density proportional to R
SI2 H     -7        7         $  height
SP2        -21      0         $  default density constant with Y
```

Add cell acceptance/rejection:

```
SDEF   POS   0   0   0   RAD=D1   EXT=D2   AXS   0   1   0    CEL 5
```

If the cell acceptance rate is too low, the problem is terminated for inefficiency.   (EFF   Default < 1 in 100)

Source Efficiency = 0.6149 in Cell 5

Uniform Cylindrical Volume

SP -21 1

WHY R^1 ???

p(r) ∝ incremental volume

$$\frac{dV}{dr} = \frac{d(\pi r^2 h)}{dr} = 2\pi rh$$

Prob of choosing radius r

$$p(r) \propto r^1$$

Non-Isotropic Sources

- A non-isotropic source is created by adding the VEC vector variable to the SDEF card, and the distribution from this vector with the variable DIR

- DIR is the cosine of the angle, 1=forward, along direction of VEC, -1 is opposite direction of VEC.

- The default for DIR is equiprobable in cosine, which results in an isotropic source.

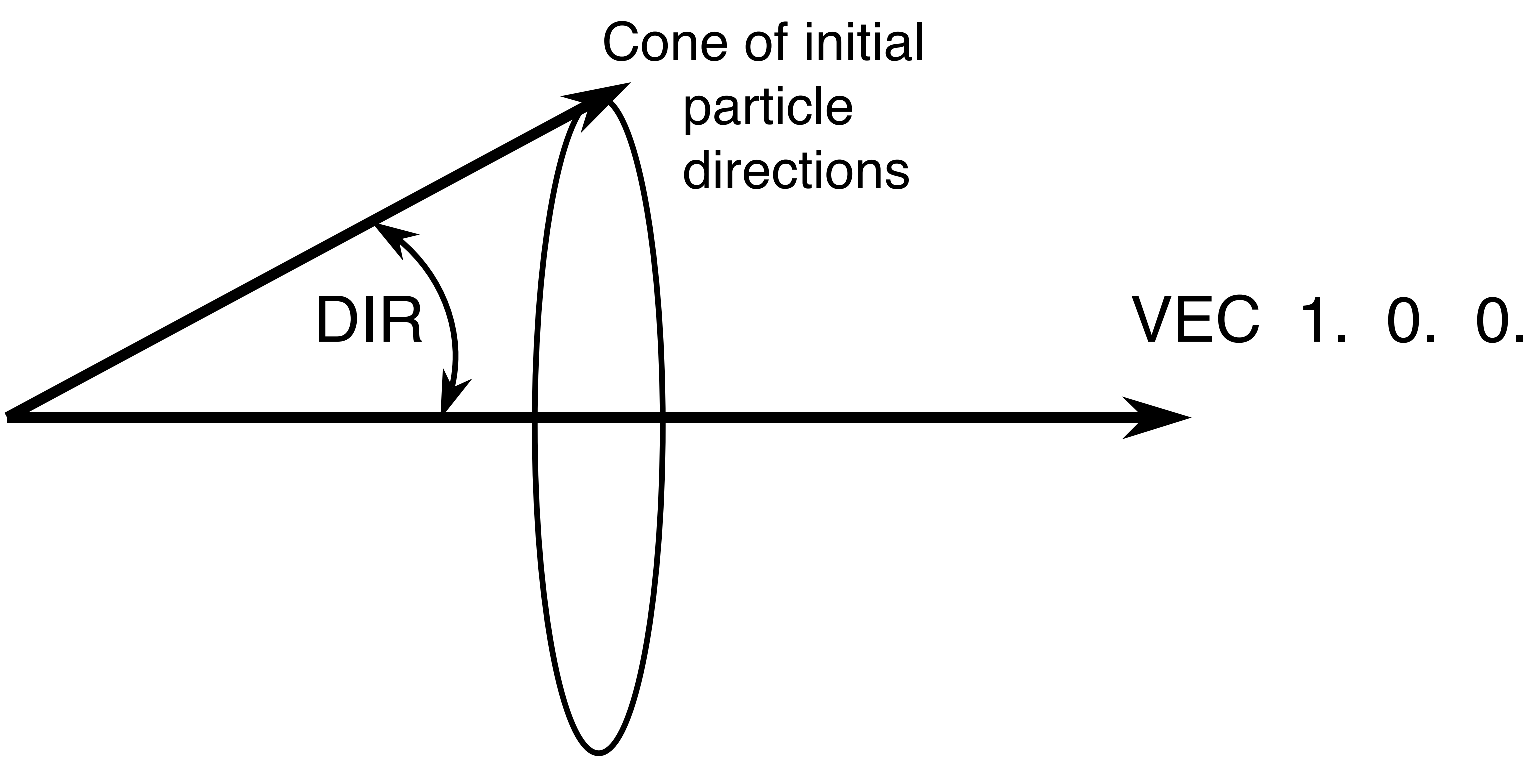
- Setting DIR = value results in particles being emitted in a cone.

- Remember, particle starting location and direction are separate (independent) variables

Non-Isotropic Sources

- **A non-isotropic source is created by adding the VEC vector variable to the SDEF card, and the distribution from this vector with the variable DIR**

- **DIR is the cosine of the angle, 1.0=foreward, along direction of VEC.**



Problem nbeam

Neutron beam source

(Cylindrical source, w/ direction)

(OPTIONAL)

Example - Neutron Beam Source

1) Create a new file – nbeam
2) Make 1 cell – a large box
3) Create a disk neutron beam source:

    Particle Starting Locations:

    Disk at X=2.0, radius 2.5 cm

    Disk facing along Y axis

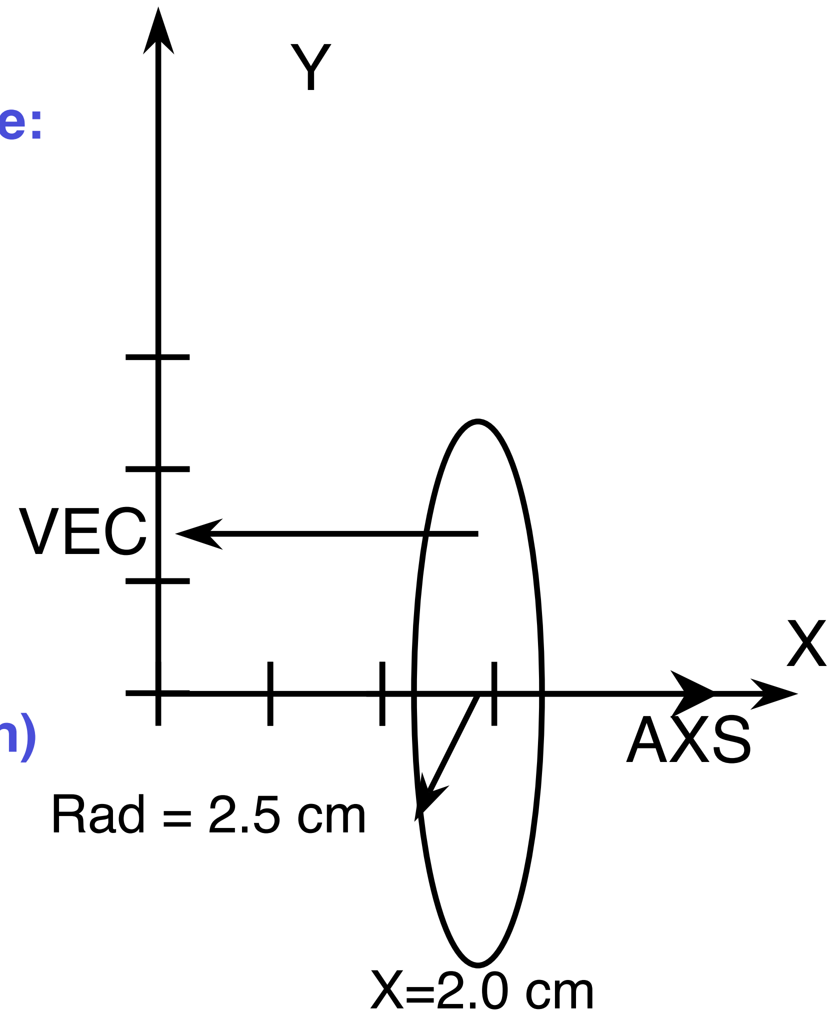
    Particle starting Directions:

    VEC along -X

    μ = 1.0

(start in VEC direction, no distribution)

4) Run Problem
5) Look at table 110



problem nbeam

```
Foreward Directed Neutron Disk Beam (Cylinder w/ Extent = 0.0)
100  0          -10      imp:n=1
102  0           10      imp:n=0

10 RPP -10.0 10.0   -10.0   10.0   -10.0 10.0

mode n
sdef pos  2. 0.  0.  rad=d4    $ Starting position, radius for disk
     axs  1. 0.  0.  $ What happens if no axs? - spherical source
     ext=0.0      $ A disk source is a cylinder source w/ 0.0 extent
     vec  -1. .0  0.     $ Starting direction for particles
     dir=1.0             $ What happens if no dir? [isotropic source]
     erg=1.0             $ Monoenergetic neutrons at 1 MeV
si4 H 0.0  2.5           $ Disk from zero to 2.5 cm
sp4  -21    1            $ Power Law, power=1 for disk (area) source
nps 100
print 10  110  170
```