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Title: Implementation of Cerenkov Radiation and Reflection/Refraction into MCNP6

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Implementation of Cerenkov Radiation and Reflection/Refraction into MCNP6

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Abstract

This is a summary report on implementation of Cerenkov Emission and Reflection/Refraction in MCNP6 [1]. Both of these mechanisms depend on the refractive index of a material. An interface has been written which allows these to be specified by material. The physics of both have been implemented for optical light photons (200 to 800 nm). Examples of results using these new physics capabilities are shown. Some issues which could be addressed in follow-on development in the future are discussed.

Introduction

Since MCNP6 has extended the lower energy limit of photon transport down to 1eV, it is now possible to transport visible light photons. This opens the way to adding Cerenkov production to the charged particle transport.

Initially, a routine was added which uses the Frank-Tallman equation out of Evans' "The Atomic Nucleus" to sample the Yield and energy dependence of Cerenkov radiation.. The Cerenkov radiation was sampled over wavelengths of 200 to 800 nm.

$$\frac{1}{h\bar{\nu}}\left(\frac{dT}{ds}\right)_{Cer} = \frac{4\pi^2 z^2 e^2}{hc^2}\,(\nu_2 - \nu_1)\,\left(1 - \frac{1}{\beta^2 n^2}\right) \qquad \text{Equation 1.}$$

The user can specify the refractive index for a given material either a constant refractive index with the "refi" keyword or they can specify a dispersive refractive index with a Cauchy formulation using the "refc" keyword and four entries, some of which may be zero or by using the "refs" keyword with six coefficient using a Sellmeier equation (some of which can also be zero).

REFI = A

Ex. M1 1001 2   8016 1 REFI=1.3199 $ Water with constant Ref. Index = 1.3199

REFC= A B C D

$$n(\lambda) = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4} + \frac{D}{\lambda^6} \qquad \text{Equation 2}$$

Ex. M1 1001 2 8016 1 REFC= 1.3199 6.878e-2 1.132e-3 1.11e-4 $ Water with Ref Index specified by coefficients for 4th order CAUCHY expression. The coefficients are in units of micrometers.

REFS = B_1 C_1 B_2 C_2 B_3 C_3

$$n(\lambda) = 1 + \frac{B_1\lambda^2}{\lambda^2 - C_1} + \frac{B_2\lambda^2}{\lambda^2 - C_2} + \frac{B_3\lambda^2}{\lambda^2 - C_3} \qquad \text{Equation 3.}$$

Ex. M1 14028 1 8016 2 REFS = 1.0396 6e-3 0.2318 2.0018e-2 1.0104 1.0356e2 $ Borosilicate crown glass with Ref Index specified by coefficients for Sellmeier equation. Note that Sellmeier coefficients are applied directly and are not squared.

Figure 1 shows the results from 4 Mev electrons in water with a constant refractive index. The tally results of photon crossings compare the base version of MCNP6 with no Cerenkov photon production with the new capability.

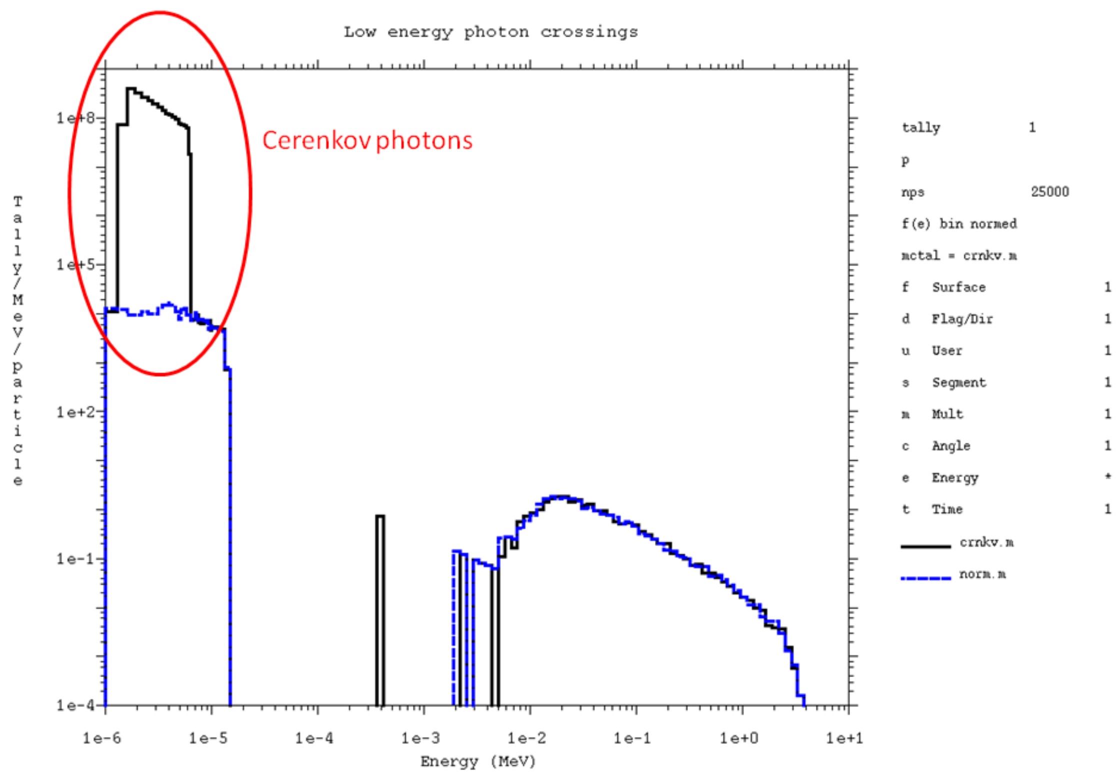

Figure 1. Plot of low-energy photons showing Cerenkov photon production.

Figure 2. shows a mesh tally of the Cerenkov photons illustrating the characristic “cone” from the specific angular emission of Cerenkov radiation.

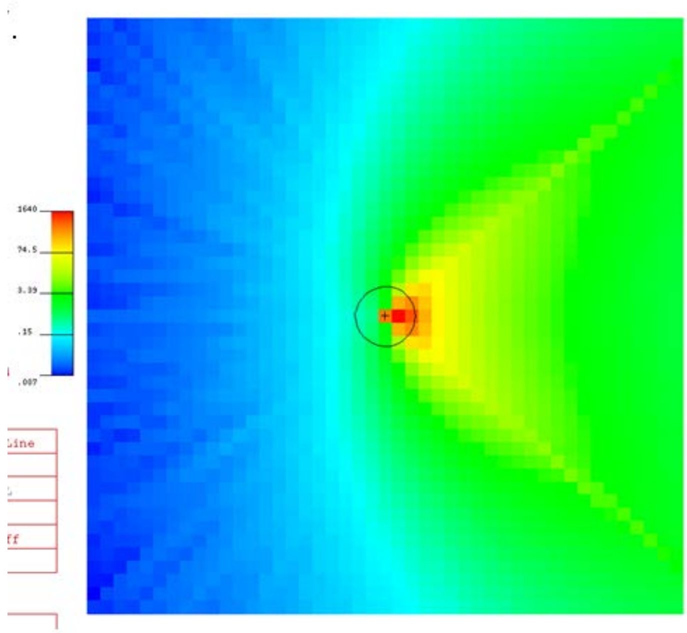

Figure 2. Mesh tally plot of low-energy photons with Cerenkov cone.

Reaction TAG option 7 can be used to identify Cerenkov photons. A TAG for Cerenkov photons in cell 4 would look like 40000.00007.

Full threading can be used with Cerenkov physics and reflection/refraction physics.

The sixteenth entry on the phys:<pl> card (where <pl> is a charged particle) is ckvnum, a scaling parameter which can be applied to control the number of Cerenkov photons emitted from that particle. Values between 0 and 1 emit the fractional number of photons with an accordingly higher weight. A value of ckvnum=0 turns off Cerenkov emission.

Reflection/Refraction Example:

A prism is specified with a frequency-dependent index of refraction and a beam of white light is directed from one side. Note that the refraction at the two surfaces is not uniform and creates a separation in of the light into its components. Energy-dependent multipliers were used to create false color in the image.

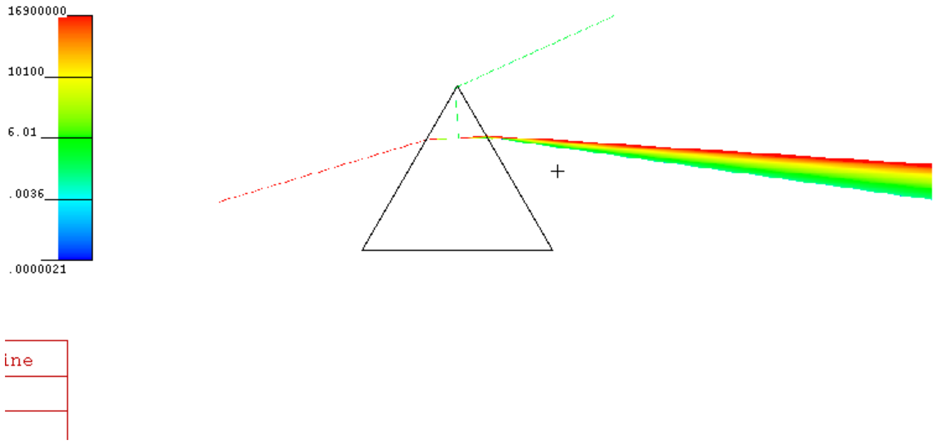

Figure 4: White light passing through a prism.

Testing

The features of Cerenkov photon production and reflection/refraction were tested using MPI parallelism and threading. Both reproduce the serial results. Further review and testing were conducted of the physics and are described in an accompanying document [2].

Future Work:

Point detectors do not score direct Cerenkov contribution because of the highly anisotropic nature of the emission. Also, point detectors will not work for reflected/refracted light. The code will issue a warning when F5 detectors are present.

References

1. MCNP6 Users Manual Version 1.0, LA-CP-13-00634.

2. “Cerenkov Radiation Feature Verification”, Durkee, Joe W. Jr., LA-UR-13-25416'

Appendix A.

Input file for Cerenkov photon production.

```
Cerenkov emission from electrons in water, constant Ref Index
1  1 -1    -1       imp:p=1
2  0        1 -2 #3 imp:p=1
3  0       -3       imp:p=1
99  0       2 imp:p=0

1 so 1
2 so 50
3 s  10 0 10 1

m1 1001.12p 2 8016.12p 1 refi=1.3199
sdef par=e erg=4 vec= 0 0 1 dir=1
cut:p j 1e-6
cut:e j 1e-3
phys:p j
phys:e 15j 1e-3  $ ckvnum = 1e-3
mode p e
fc14 Low energy photon tracks
f14:p 1
e14 1e-6 99ilog 4e-6
fc1 Low energy photon crossings
f1:p 1
e1 1e-6 29i 1e-5 99ilog 10
c
nps 150000
f6:p 1
sd6 1
f16:e 1
sd16 1
+f26 1
sd26 1
prdmp 2j -1
```