Photon Mapping Superluminal Particles

Gustaf Waldemarson   Michael Doggett
Arm, Lund University

Who Am I?

- Industrial PhD Student at the Lund University Graphics Group
- Employed by Arm Sweden

Lighting Phenomena
From A to Z

The Aurora Borealis

Zodiacal Light

LUND UNIVERSITY

Inspiration

Chernobyl

“The air is glowing!”

“The Cherenkov effect – it’s a completely normal phenomenon, it can happen with minimal radiation.”

“Look at that glow! That’s radiation ionizing the air!”

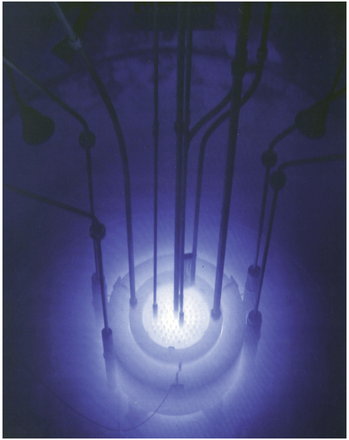
– Quotes from “Chernobyl” Episode 1-2 © HBO

Inspiration
Chernobyl

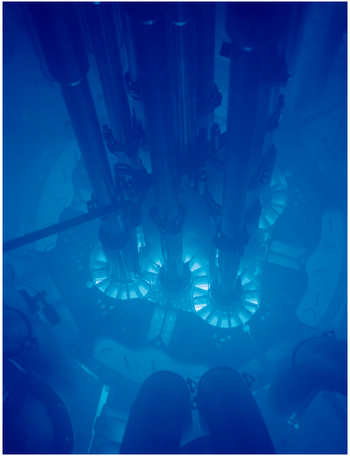

– Images from “Chernobyl” Episode 1-2 © HBO

Inspiration

Nuclear Reactors



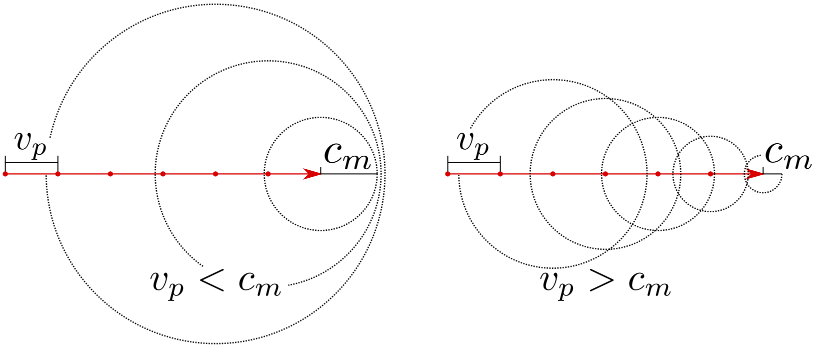
Reed Research Reactor



Advanced Test Reactor

The Phenomenon

The Cherenkov Effect



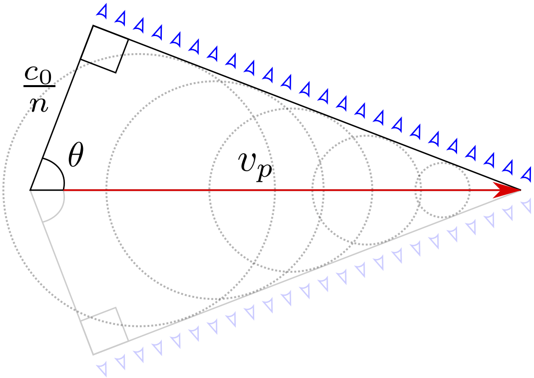
v_p – Particle velocity

c_0 – Speed of light

n – Index of refraction

$c_m = \frac{c_0}{n}$ – Medium phase velocity

Cherenkov Emission Angle



$$\cos(\theta) = \frac{c_0}{v_p n}$$

The Frank-Tamm Equation

$$\frac{d^2E}{dxd\omega} = \frac{q^2}{4\pi}\mu(\omega)\omega\left(1 - \frac{c_0^2}{v_p^2 n^2(\omega)}\right)$$

ω – Angular frequency

q – Electrical charge

$n(\omega)$ – Index of refraction

$\frac{d^2N}{dxd\omega}$ – Energy per length x and ω

The Frank-Tamm Equation

$$\frac{d^2E}{dxd\omega} = \frac{q^2}{4\pi}\mu(\omega)\omega\left(1 - \frac{c_0^2}{v_p^2 n^2(\omega)}\right)$$

$$\Rightarrow$$

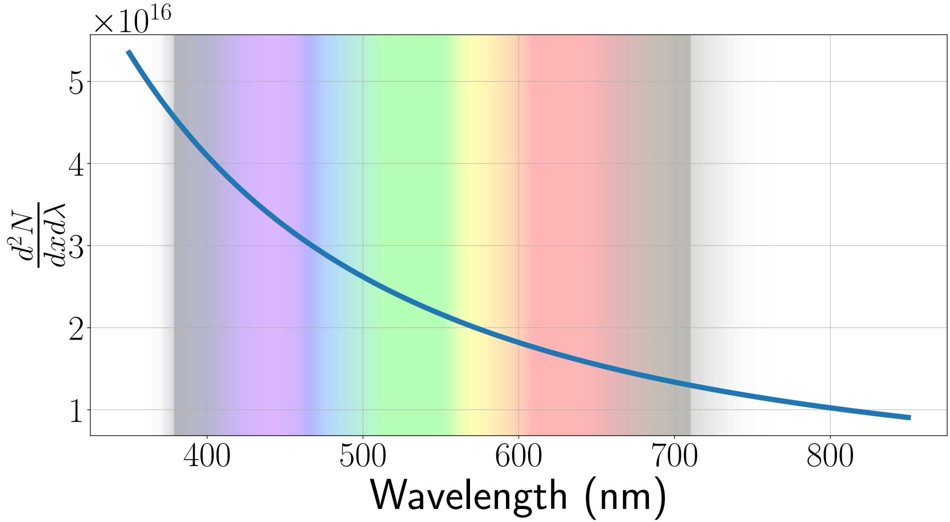
$$\frac{d^2N}{dxd\lambda} = -\frac{2\pi\alpha\mu(\lambda)}{\lambda^2}\left(1 - \frac{c_0^2}{v_p^2 n^2(\lambda)}\right)$$

λ – wavelength

N – # photons

α – Free structure constant

Cherenkov Radiation Spectrum

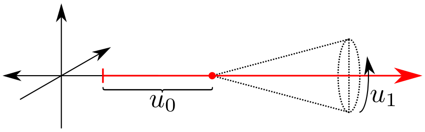


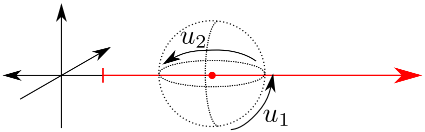
Our Algorithm

1. Choose a point along the particle path (u_0)
2. Find the particle velocity and refractive index at the point
3. If *superluminal* at the point

   Set the photon direction to somewhere in the Cherenkov direction (u_1)
4. Otherwise

   Set the photon direction to a random direction (u_1, u_2)
5. Use the Frank-Tamm spectrum for the particle as photon color
6. Trace the photon as usual in SPPM





Photon Density Distributions

- Probability Density Functions
  - Importance sampling
- Photon Density Distribution
  - Photon Origin (o)
  - Photon Direction (ω)

$$p(o, \omega) = p(o) \cdot p(\omega)$$

$$p(o) = \frac{1}{\text{total particle length}}$$

Photon Density Distributions

$$p(\omega) = Pr(S)p_c(\omega) + (1 - Pr(S))p_s(\omega)$$

Lund University

Photon Density Distributions

$$p(\omega) = Pr(S)p_c(\omega) + (1 - Pr(S))p_s(\omega)$$

$$p(\omega) = \frac{Pr(S)}{2\pi} + \frac{1 - Pr(S)}{4\pi} = \frac{1 + Pr(S)}{4\pi}$$

Photon Density Distributions

$$p(\omega) = Pr(S)p_c(\omega) + (1 - Pr(S))p_s(\omega)$$

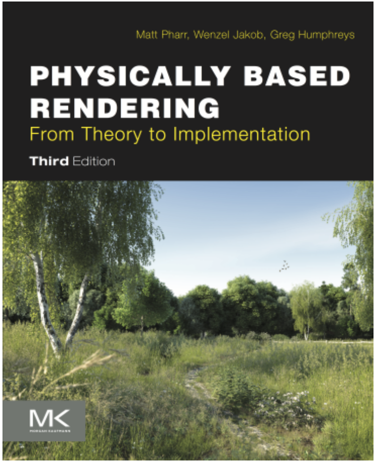
$$p(\omega) = \frac{Pr(S)}{2\pi} + \frac{1 - Pr(S)}{4\pi} = \frac{1 + Pr(S)}{4\pi}$$

$$Pr(S) = \frac{\text{superluminal path length}}{\text{total path length}}$$

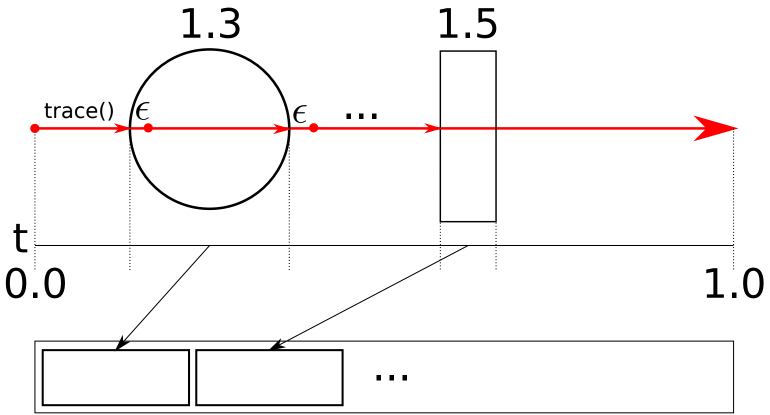
PBRT Implementation

- Implemented in a PBRT (v3)

https://github.com/Xaldew/pbrt-v3



PBRT Implementation



PBRT Implementation

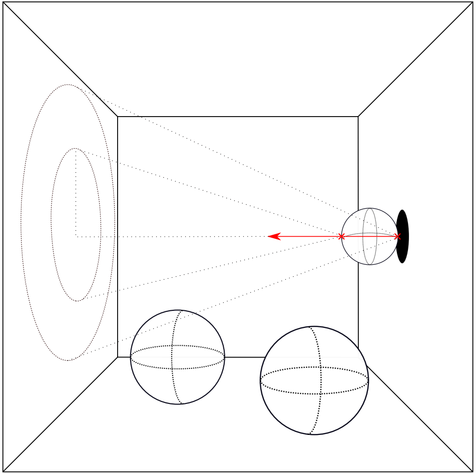
- PBRT *particle* arealight
  - The particle velocity
  - The number of particles
  - . . .

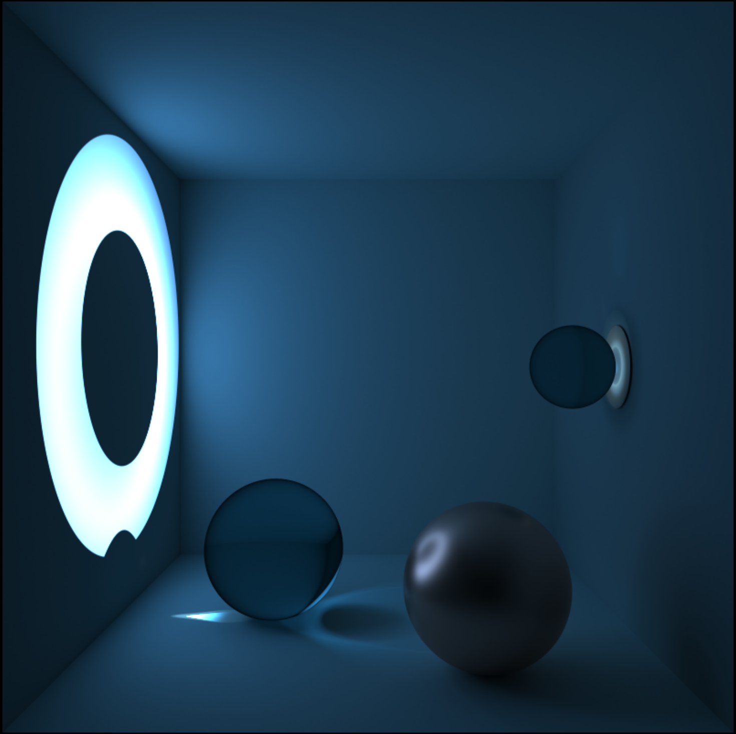
```
AttributeBegin
    AreaLightSource "particle"
                    "float velocity" 0.8
                    "integer nparticles" 1
    Translate 59.5 60 0
    Rotate -90 0 1 0
    Rotate 90 0 0 1
    Shape "disk" "float radius" 10
AttributeEnd
```

Cornell Box

Results

- Simple Cornell Box
  - Particle light on the right
  - Optically dense object
  - No colors on the walls

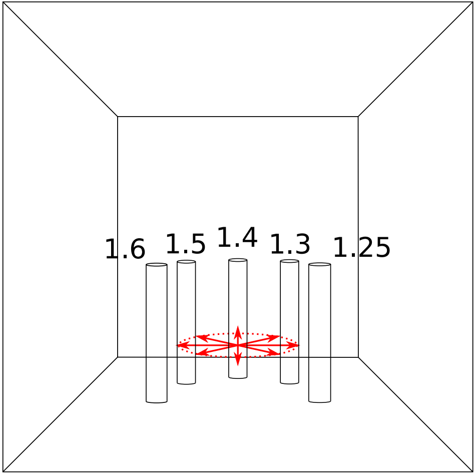


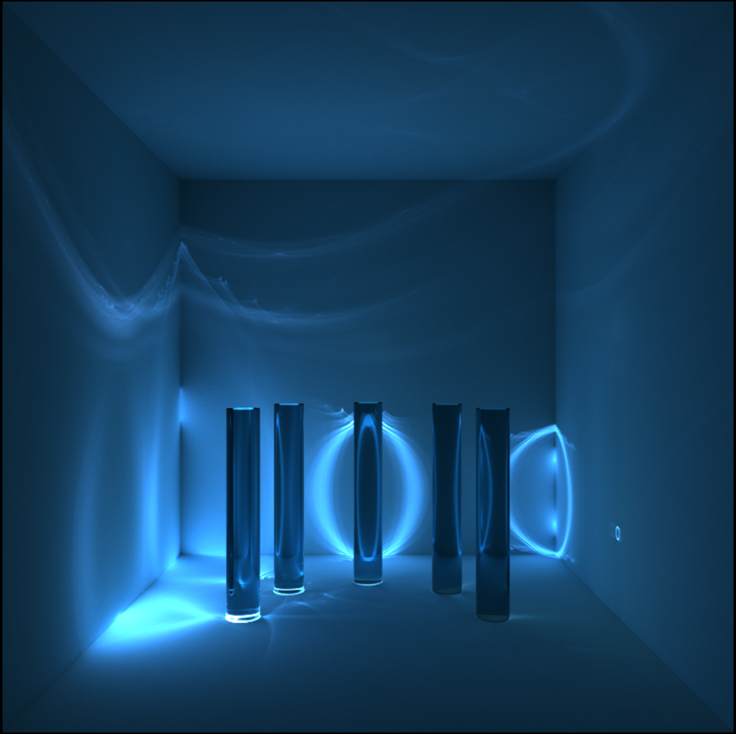


LUND
UNIVERSITY

Cornell Box - Cylinders
Results

- Cornell Box with Cylinders
  - Particle light in center
  - Several optically dense objects with varying refractive indices



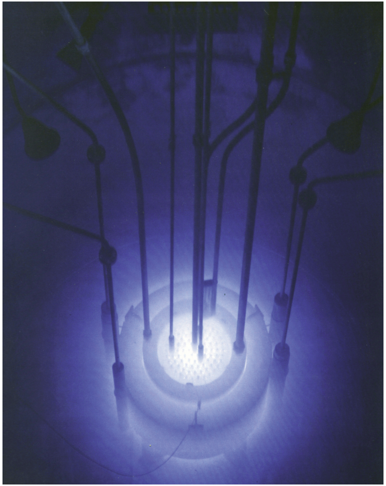


Lund University

Reactor

Results

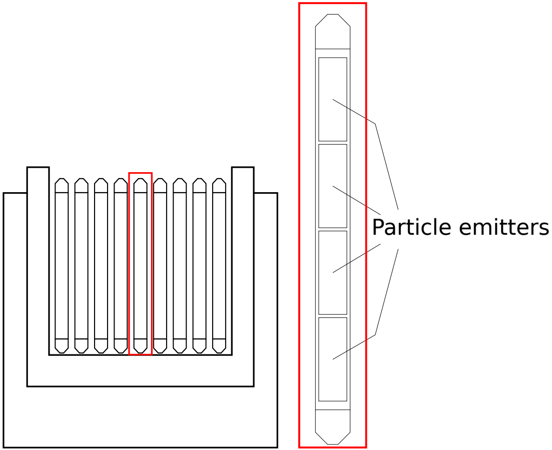
- Nuclear Reactor Model
  - Based on this photograph from the Reed research reactor
  - Try to connect the geometrical representation of the Cherenkov radiation with the the real world appearance



Reactor

Results

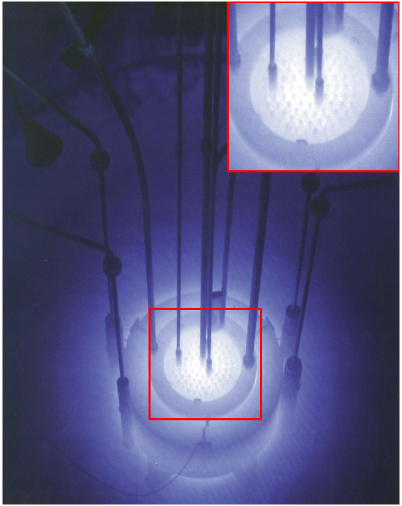
- Nuclear Reactor Model
  - Based on this photograph from the Reed research reactor
  - Try to connect the geometrical representation of the Cherenkov radiation with the the real world appearance

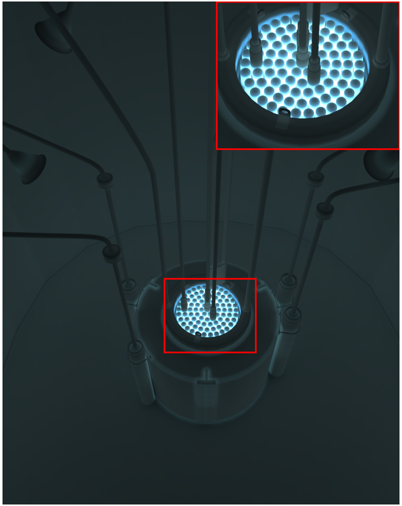


LUND
UNIVERSITY

Reactor

Results





Applications

Limitations or Possibilities

- Easily faked with conventional light-sources
  - . . . but we may want references images anyways
  - Simulate placement of Radioactivity detectors
  - Medical applications

Future Work

- Straight line vs. Random walk?
- Other phenomena?
- Volumetric rendering

Conclusions

- Extension to Photon Mapping: *Charged Particle Lights*
- Used to simulate the Cherenkov Effect
  - Implemented in PBRT (v3)
- Possible applications in nuclear physics or medicine

Thanks for Listening

Questions

- Thanks for listening!
- Questions and Answers

?

Photon Mapping Superluminal Particles

Gustaf Waldemarson   Michael Doggett

This work was partially supported by the Wallenberg AI, Autonomous Systems and Software Program (WASP) funded by the Knut and Alice Wallenberg Foundation.

- Special thanks to...
  - Pierre Moreau @ LUGG
  - Simone Pellegrini @ Arm

The End