LTH
FACULTY OF
ENGINEERING

Photon Mapping Superluminal Particles

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Who Am I?

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

arm

Lighting Phenomena
From A to Z

The Aurora Borealis

Zodiacal Light

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!"

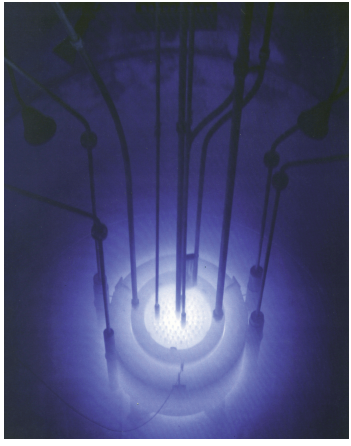
– Quotes from "Chernobyl" Episode 1-2 © HBO

Inspiration
Chernobyl

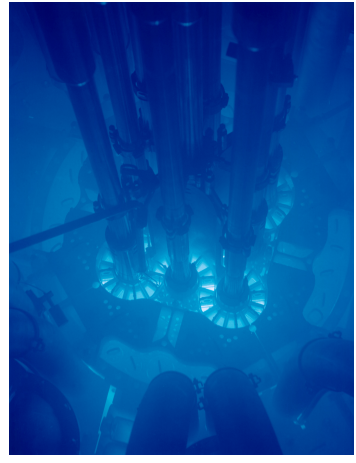
– Images from “Chernobyl” Episode 1-2 © HBO

Inspiration

Nuclear Reactors



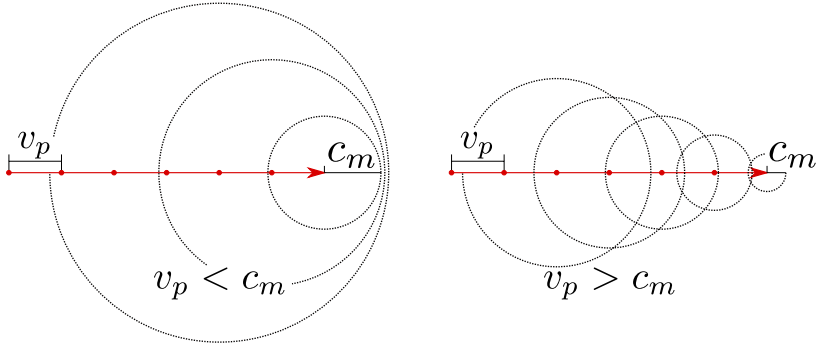
Reed Research Reactor



Advanced Test Reactor

The Phenomenon

The Cherenkov Effect



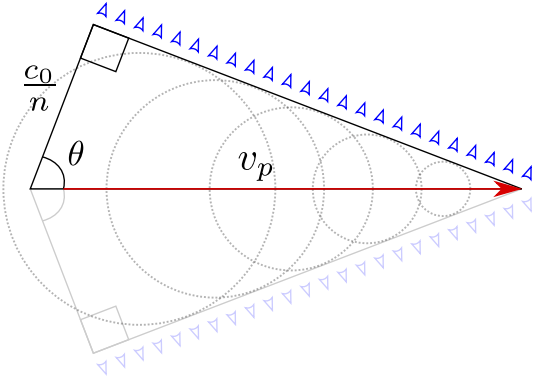
v_p – Particle velocity

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

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

$$\Rightarrow$$

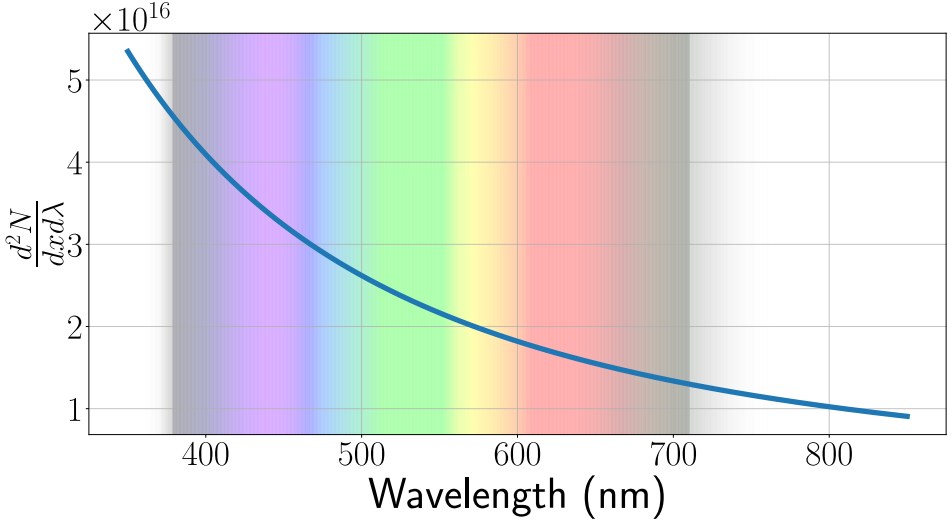
$$\frac{d^2N}{dxd\lambda} = -\frac{2\pi\alpha\mu(\lambda)}{\lambda^2}\left(1 - \frac{c_0^2}{v_p^2 n^2(\lambda)}\right)$$

λ – wavelength

N – # photons

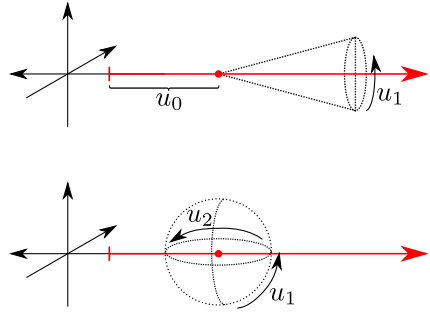
α – Free structure constant

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

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

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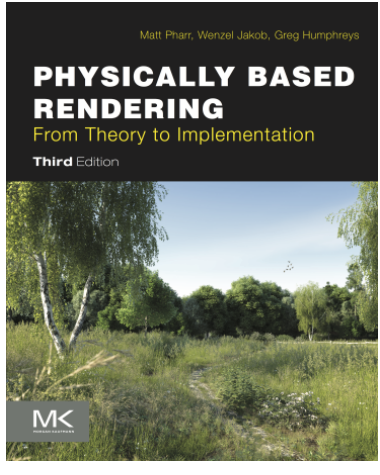
$$Pr(S) = \frac{\text{superluminal path length}}{\text{total path length}}$$

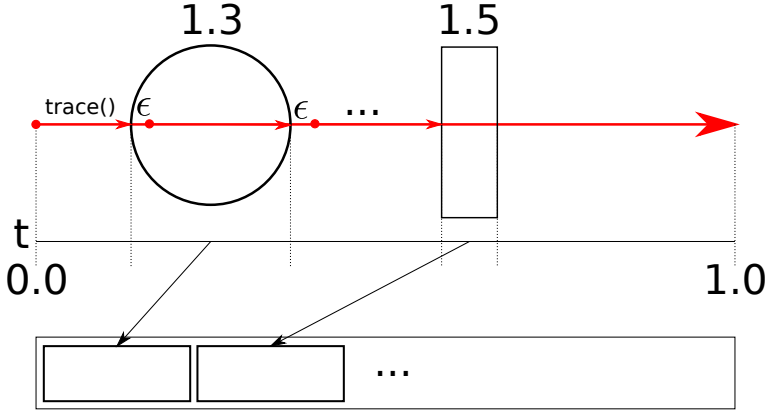
PBRT Implementation

- Implemented in a PBRT (v3)

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



PBRT Implementation



PBRT Implementation

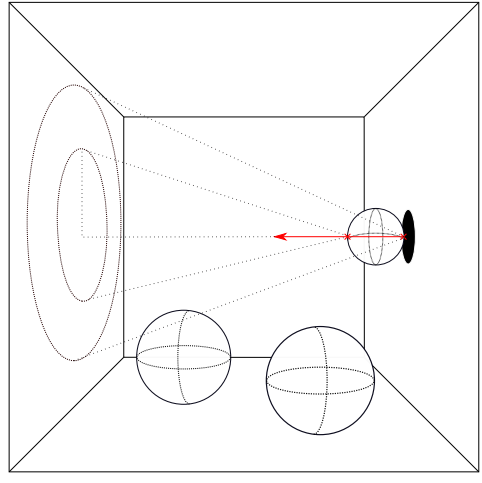
- PBRT *particle* arealight
  - The particle velocity
  - The number of particles
  - ...

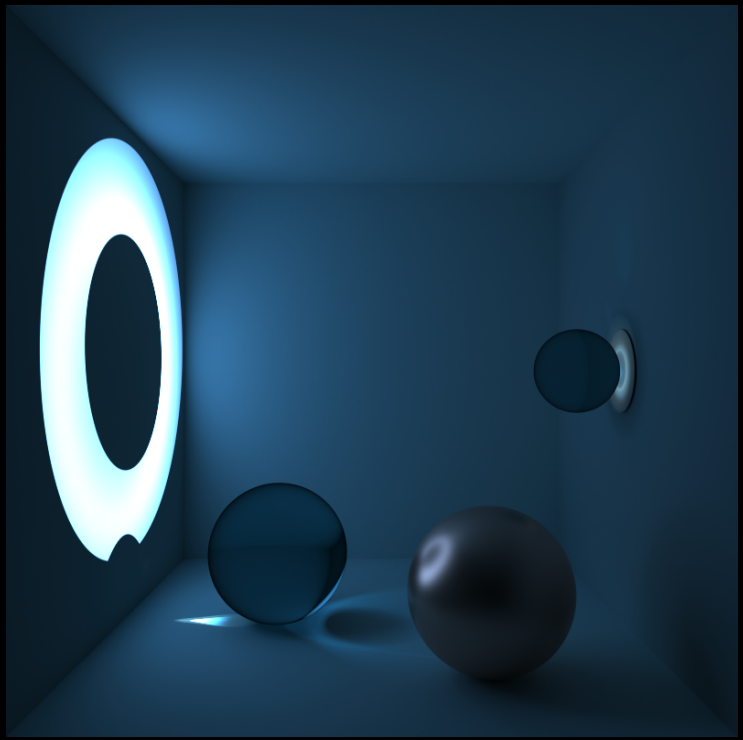
```
AttributeBegin
    AreaLightSource "particle"
                    "float velocity" 0.8
                    "integer nparticles" 1
    Translate 59.5 60 0
    Rotate -90 0 1 0
    Rotate 90 0 0 1
    Shape "disk" "float radius" 10
AttributeEnd
```

Cornell Box

Results

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

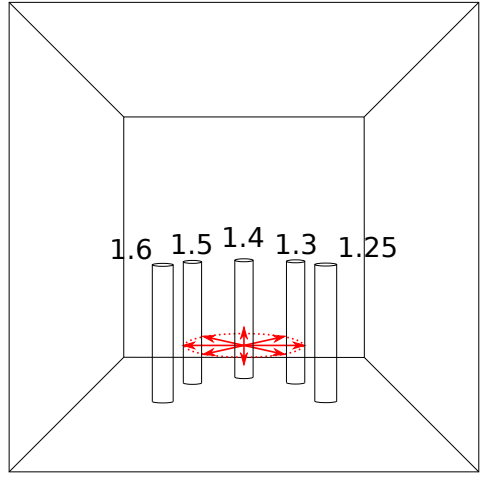


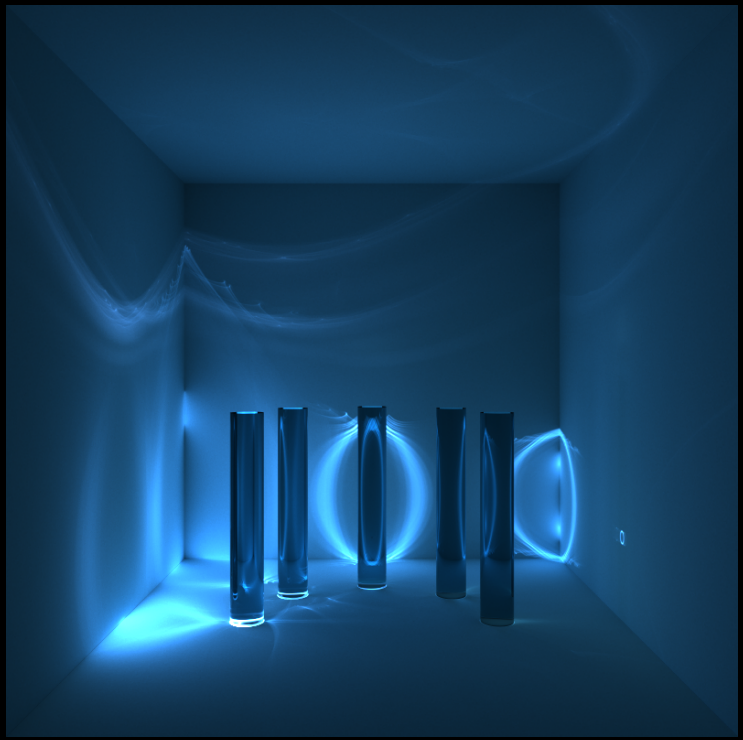


Cornell Box - Cylinders

Results

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

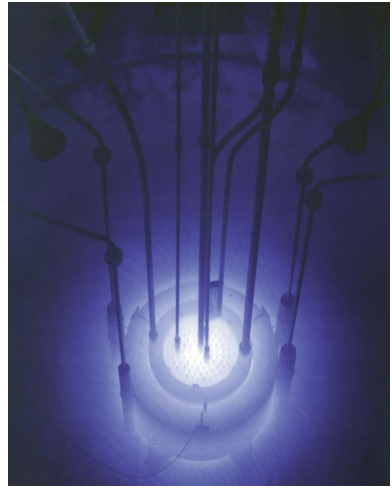




Reactor

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



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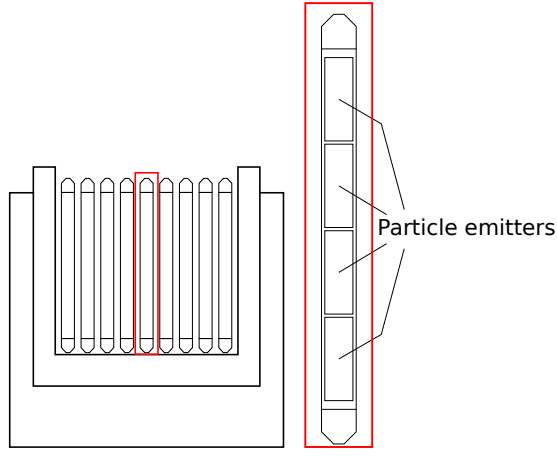

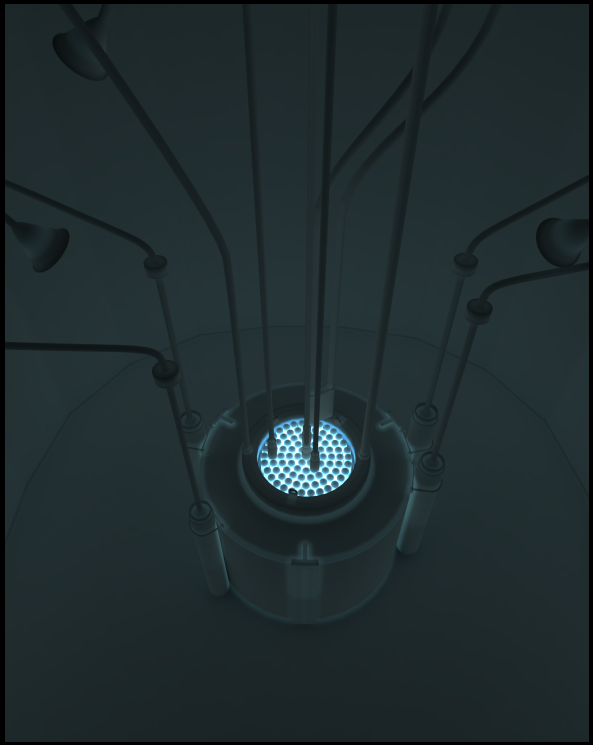

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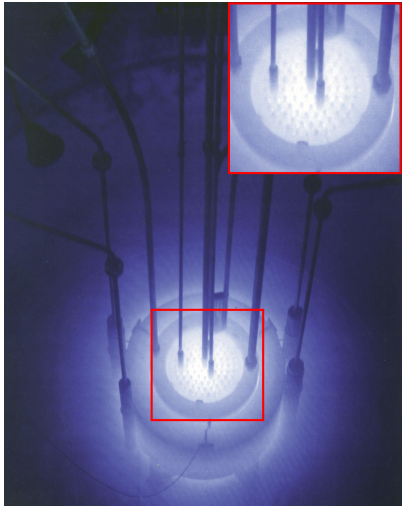
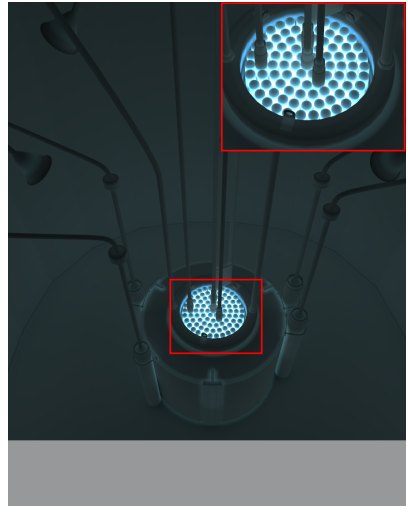
Reactor

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

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- Special thanks to. . .
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The End