Nuclear Weapons 101

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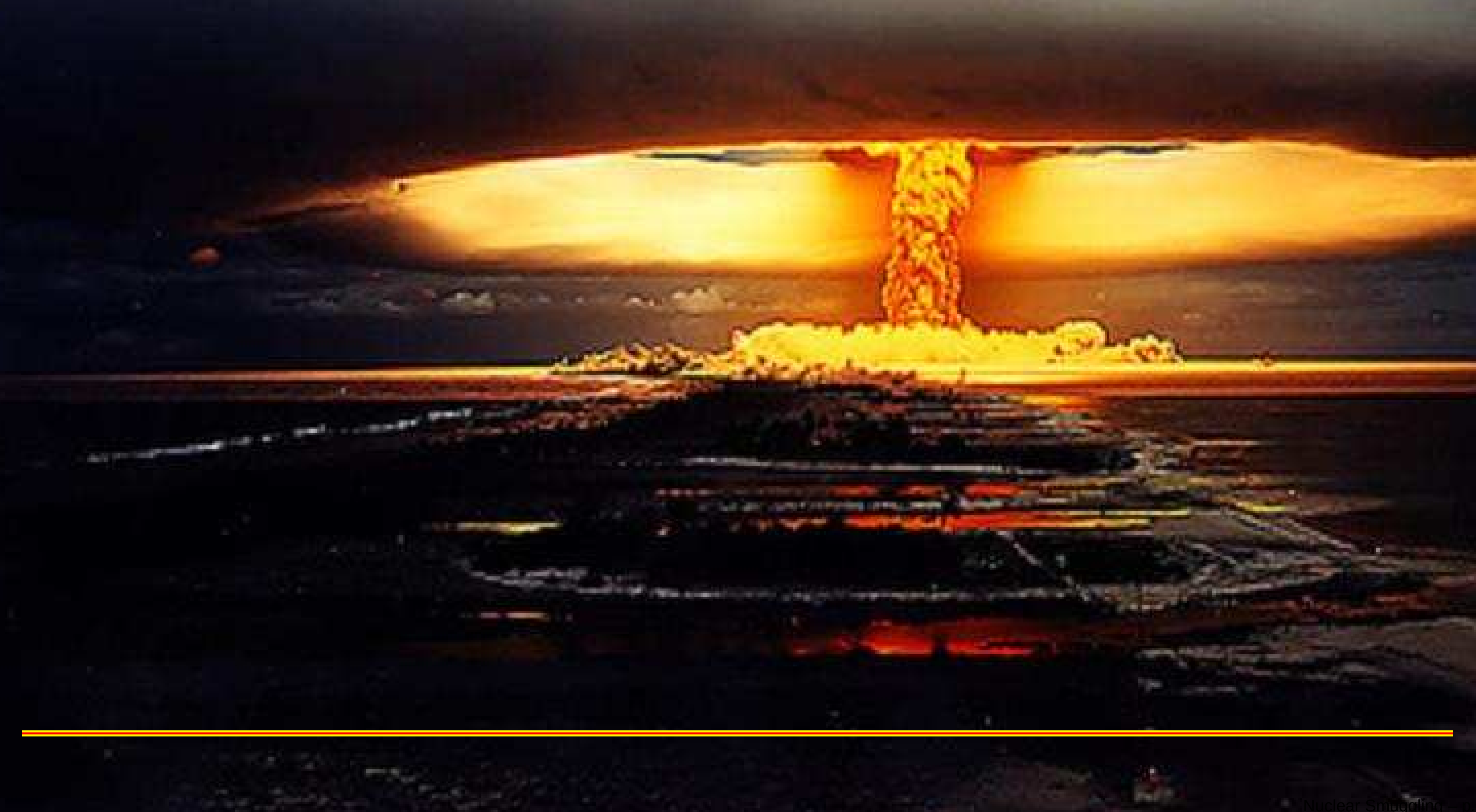
- Fissile materials (^{235}U, ^{233}U, ^{239}Pu) are used to make weapons of devastating power.



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- Fissile materials (^{235}U, ^{233}U, ^{239}Pu) are used to make weapons of devastating power.
- As each nucleus fissions, it emits 2 or so neutrons plus lots of energy.

$$^{235}\mathrm{U} + \mathrm{n} \rightarrow {}^{236}\ \mathrm{U}^{*} \rightarrow {}^{140}\ \mathrm{Xe}\ +\ {}^{94}\mathrm{Sr}\ +\ 2\mathrm{n}\ +\ \approx 200\ \mathrm{MeV}$$

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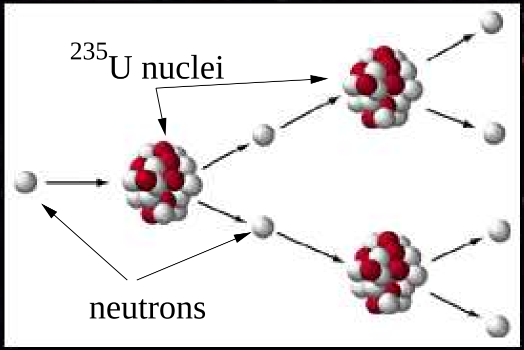
A Chain Reaction



Nuclear Weapons 101

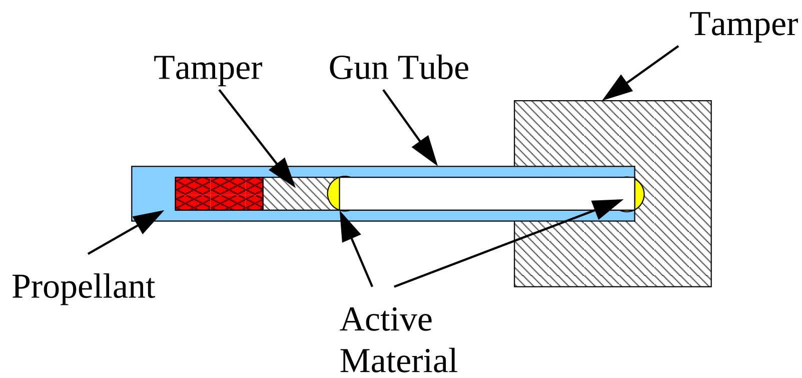
- Uranium, gun-type nuclear weapon -

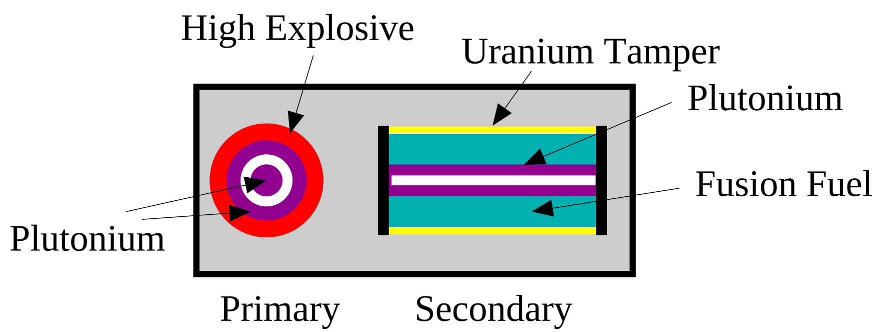
  High explosive detonates pushing highly-enriched uranium at high speed into another piece of active material.

- Two-stage, thermonuclear weapon -

  (1) Spherically-shaped high explosive detonates crushing the plutonium primary to a critical density.

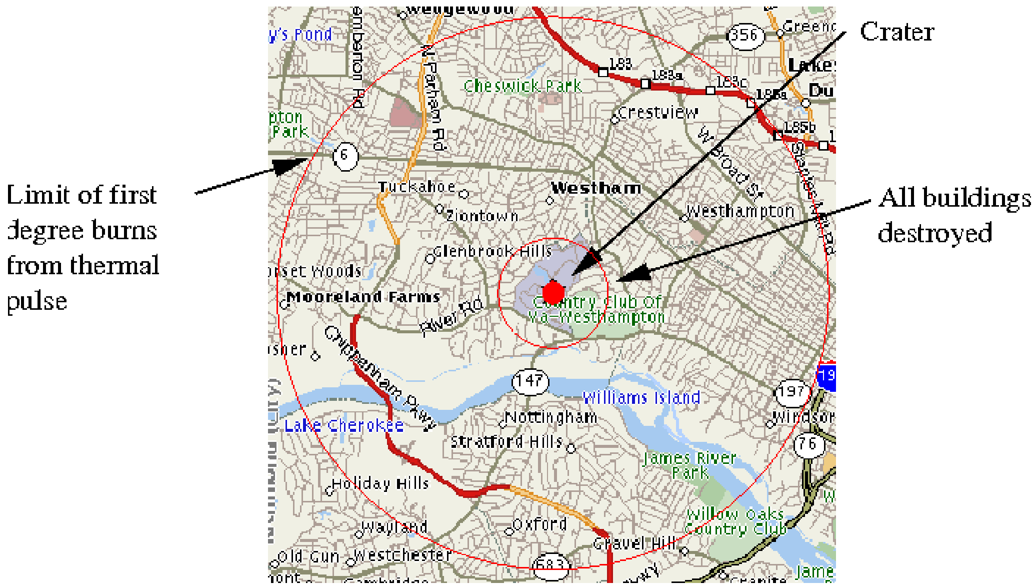
  (2)The uranium and plutonium in the secondary burn and increase the temperature until fusion starts. The energy released by the fusion reaction raises the temperature even higher and burns more of the fission fuel.





Nuclear Weapons 101 - Effects

- Energy released in the form of light, heat and blast.
- Blast ≈40-50% of total energy.
- Thermal radiation ≈30-50% of total energy.
- Ionizing radiation ≈5% of total energy.
- Residual radiation ≈5-10% of total energy.
- Figure shows effect of a 15 kiloton bomb (about the size of the Hiroshima bomb) exploded over the .



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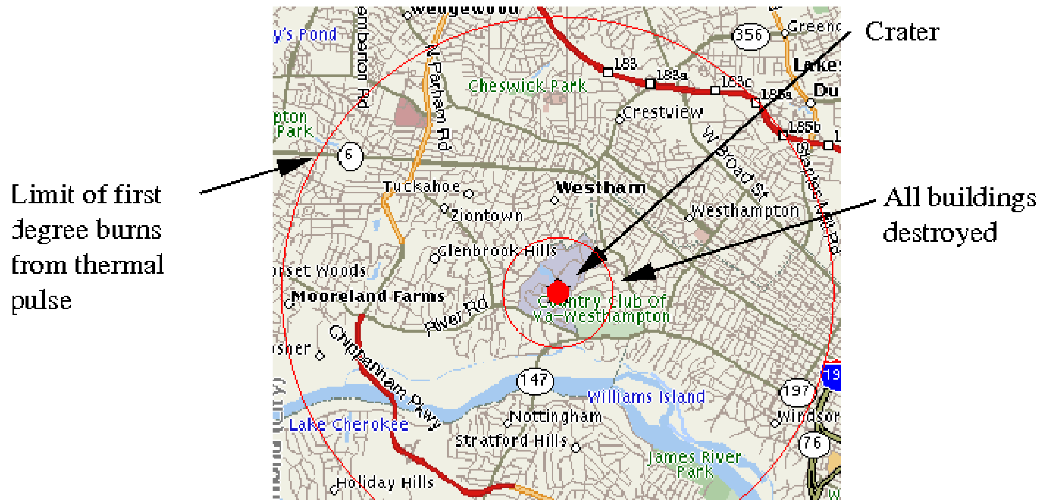

Nuclear Weapons 101 - Why Should You Care?

Nuclear Smuggling (Scientific American, April, 2008)

- Existing and future radiation portal monitors cannot cost-effectively detect weapons-grade uranium hidden inside shipping containers.
- The U.S. should spend more resources rounding up nuclear smugglers, securing HEU, and blending down this material to low-enriched uranium, which cannot be fashioned into a bomb.

Uranium in a haystack

- 20 feet - length of a typical shipping container (TEU).
- 297 million - Number of TEUs shipped worldwide in 2005.
- 42 million - TEUs entering U.S. ports that same year.
- 6,500 - TEUs arriving at the Port of New York and New Jersey on a light day; up to 13,000 on a busy day.

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Uranium and plutonium detection is a key physics issue.

Who is the Hottest?

Consider two nuclear weapon 'pits', one made of $^{235}\mathrm{U}$ with $m_U = 24\ kg$ and the other made of $^{239}\mathrm{Pu}$ with $m_{Pu} = 8\ kg$. Their radioactive decay is described by the differential equation

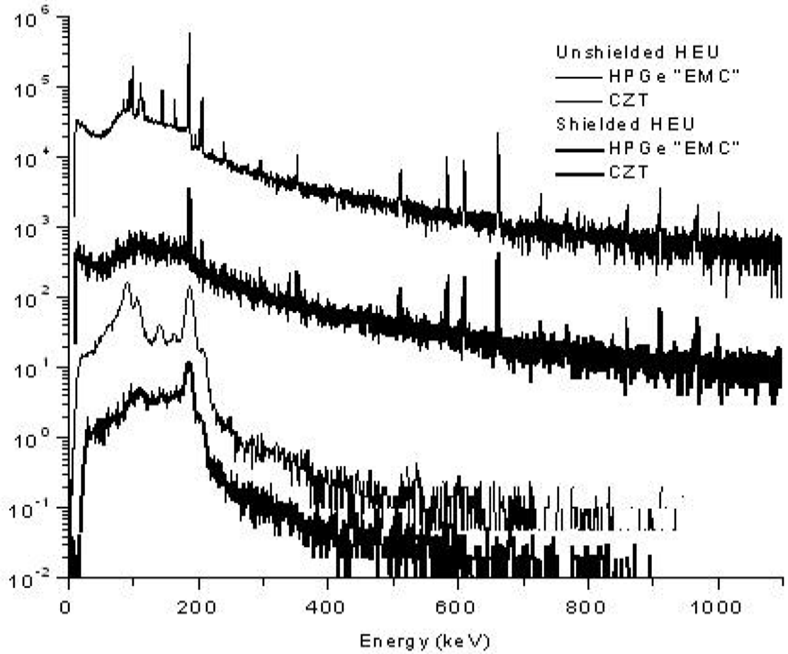
$$\frac{dN}{dt} = -\lambda N$$

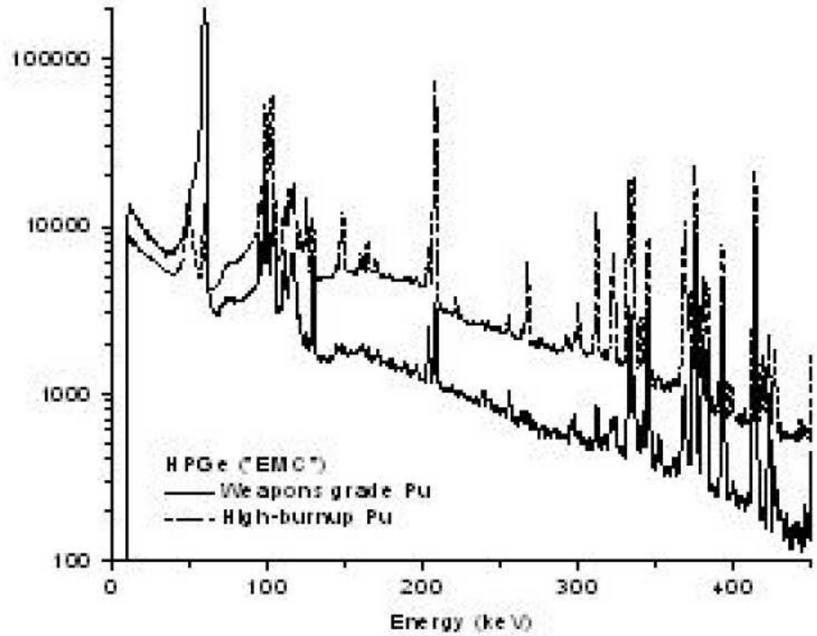
where N is the number of nuclei, t is time, and λ is the decay constant. This equation has the following solution.

$$N = N_0 e^{-\lambda t}$$

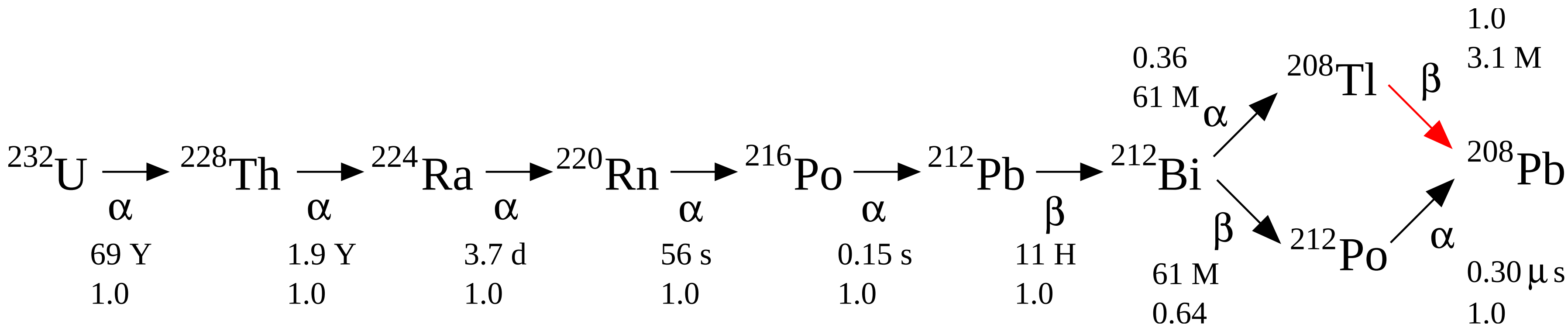
1. What is the half-life of each isotope? Use the website here.
2. How is the half-life related to the decay constant?
3. Which one decays fastest?
4. What radiation actually comes out?

Gamma Rays from Uranium and Plutonium

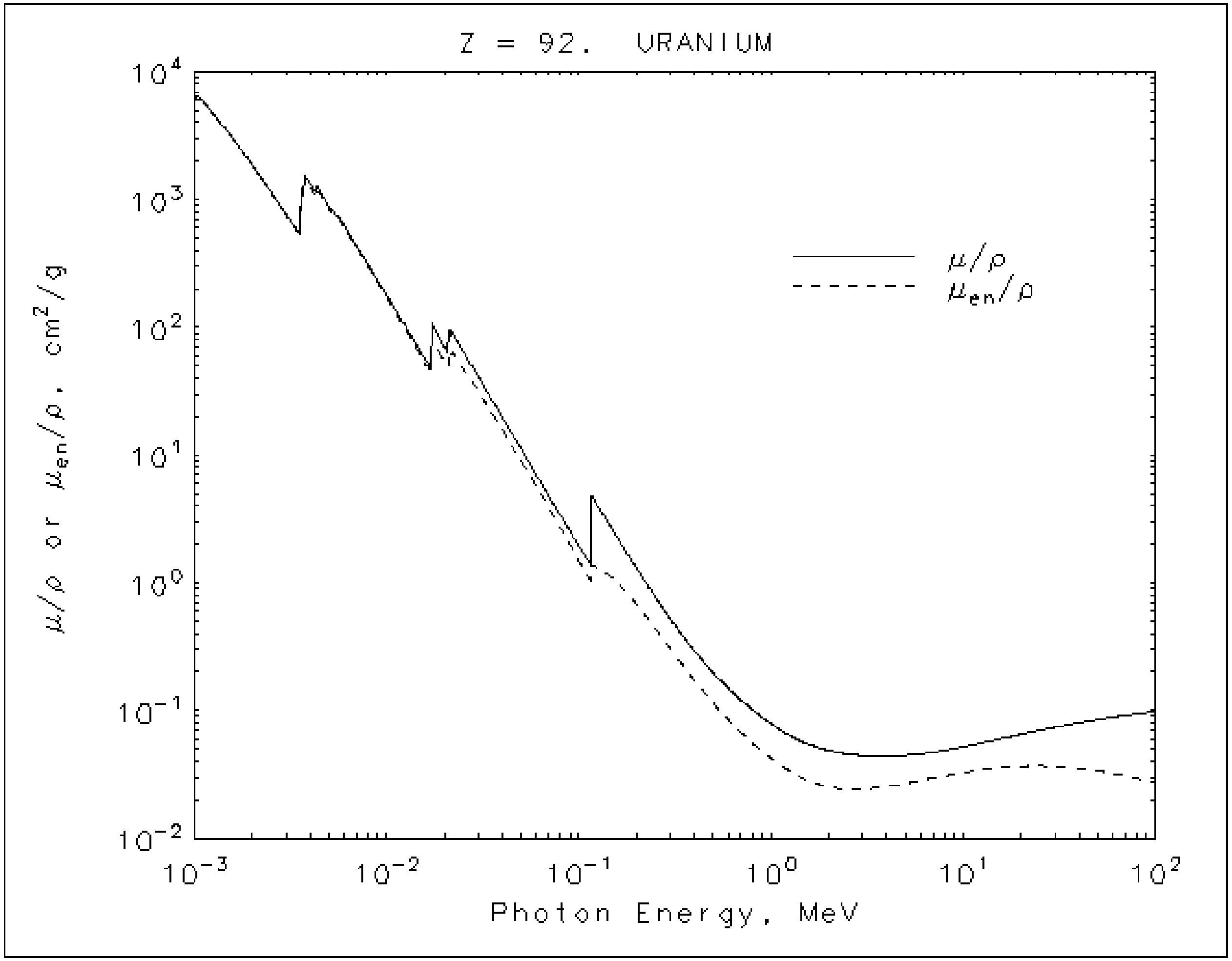




The ^{232}U Decay Scheme



Stopping Power of Gamma-Rays in Uranium

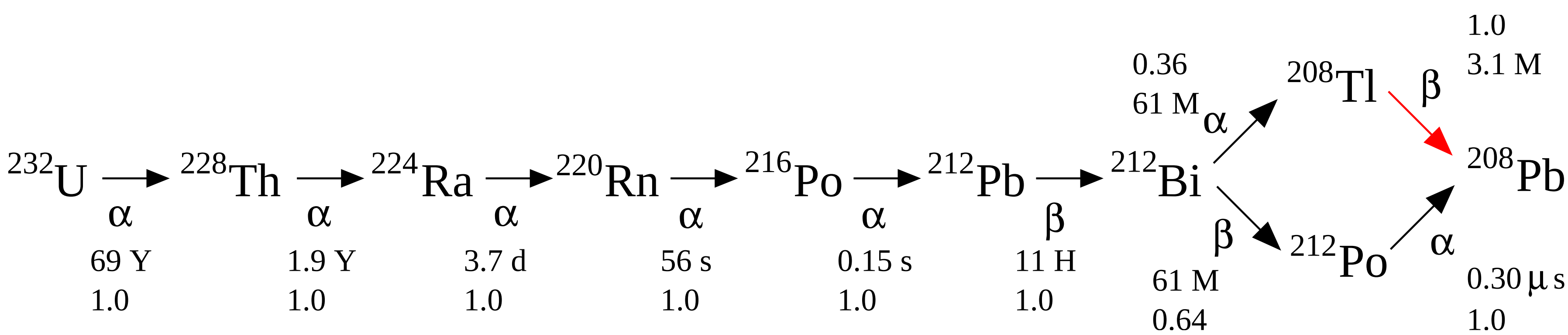


Source:

`http://physics.nist.gov/PhysRefData/XrayMassCoef/ElemTab/z92.html`

Penetrating Radiation

Consider an HEU (highly-enriched uranium) pit with $m_U = 24\ kg$ with a small amount, $1\ ppt$, of $^{232}\mathrm{U}$ mixed uniformly throughout the volume. If one of the $^{232}\mathrm{U}$ nuclei at the center of the pit goes through its decay chain (shown below) a 2.6-MeV gamma ray will eventually be emitted from the decay of the $^{208}\mathrm{Pb}$ daughter/son/child nucleus. Will that gamma ray get out of the pit? The stopping power of 2.6-MeV gammas in uranium is $\mu/\rho = 0.046\ g/cm^2$. The density of uranium is $\rho = 19.05\ g/cm^3$.



Nuclear Decay Monte Carlo

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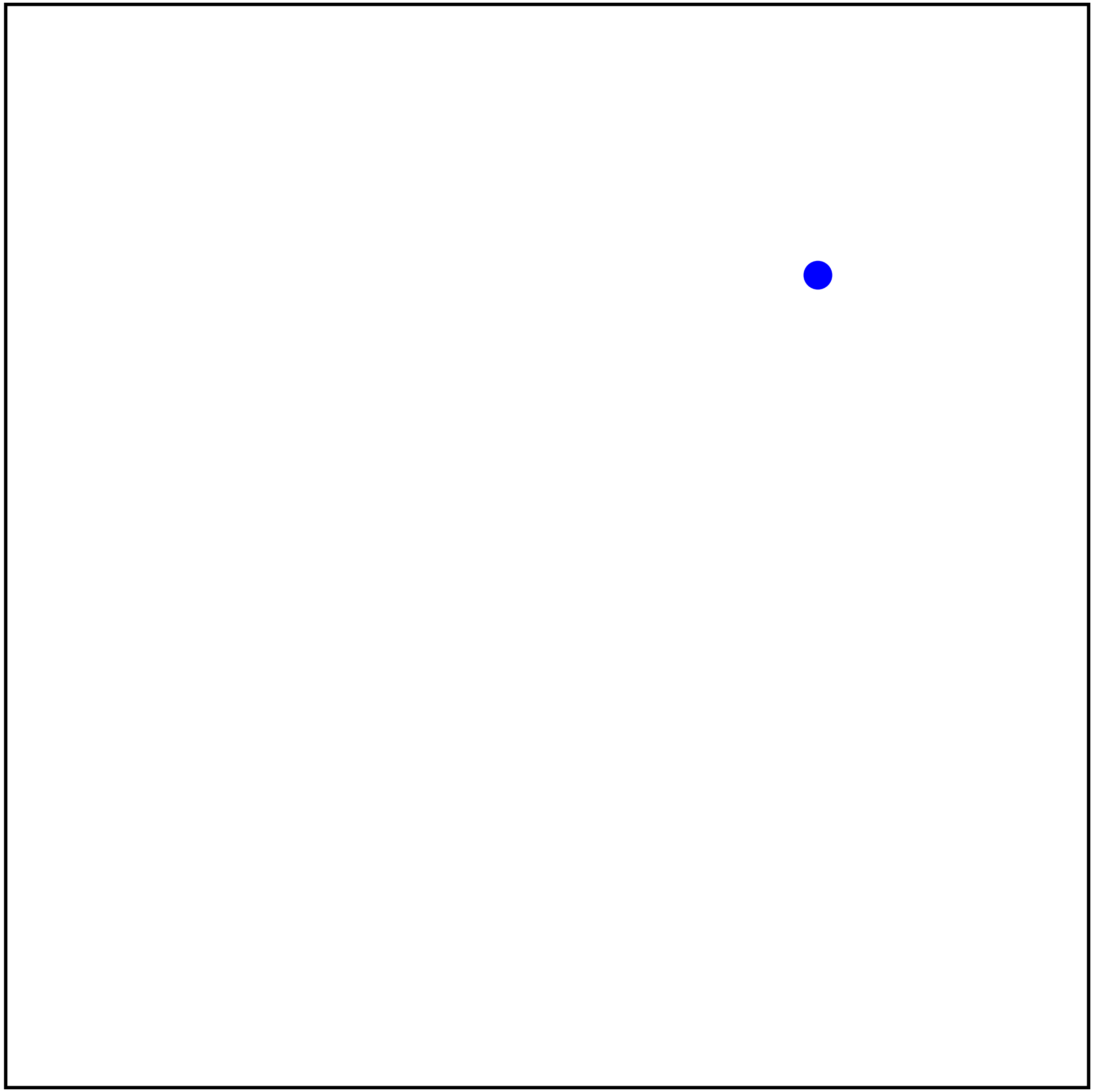

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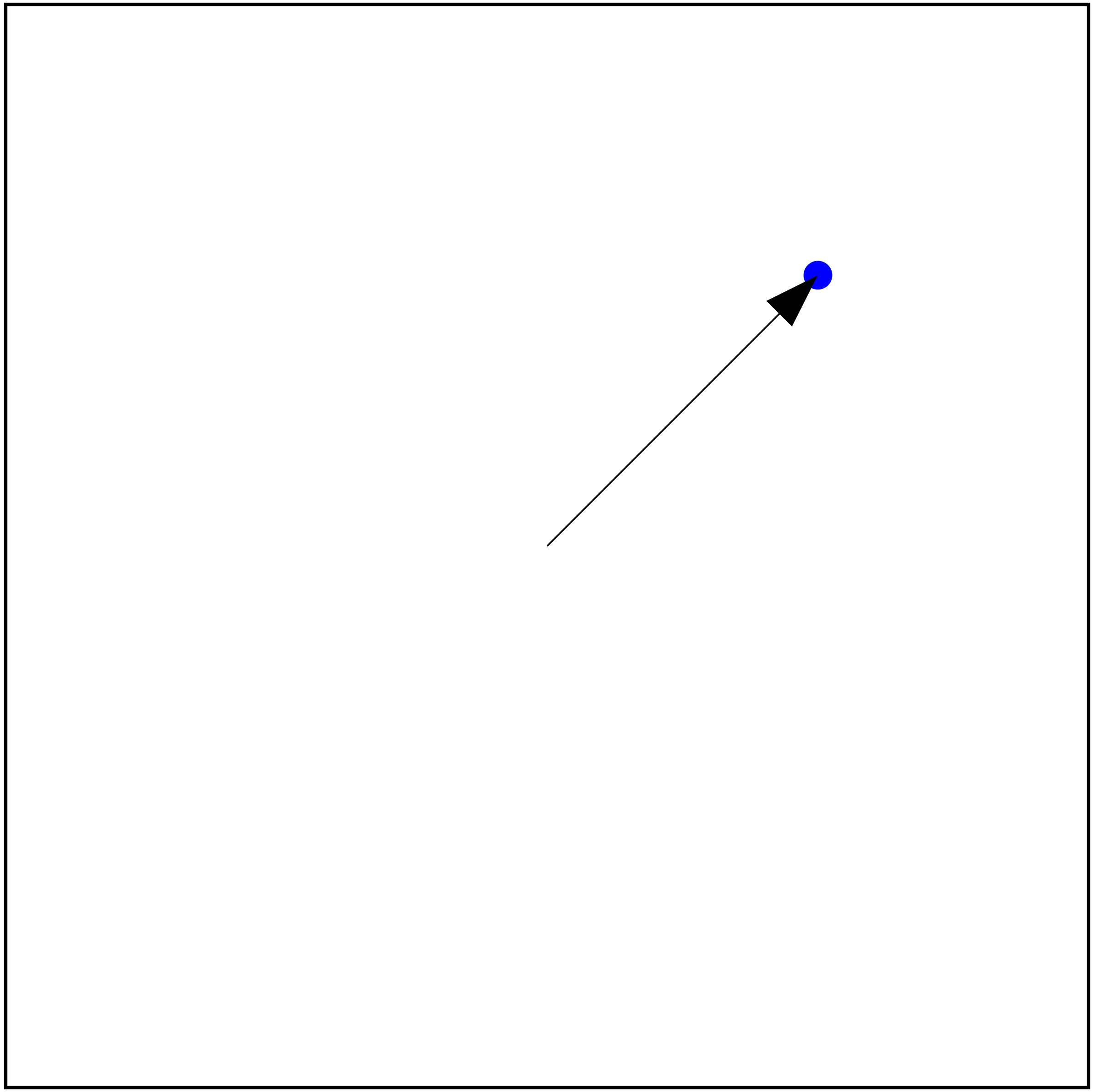

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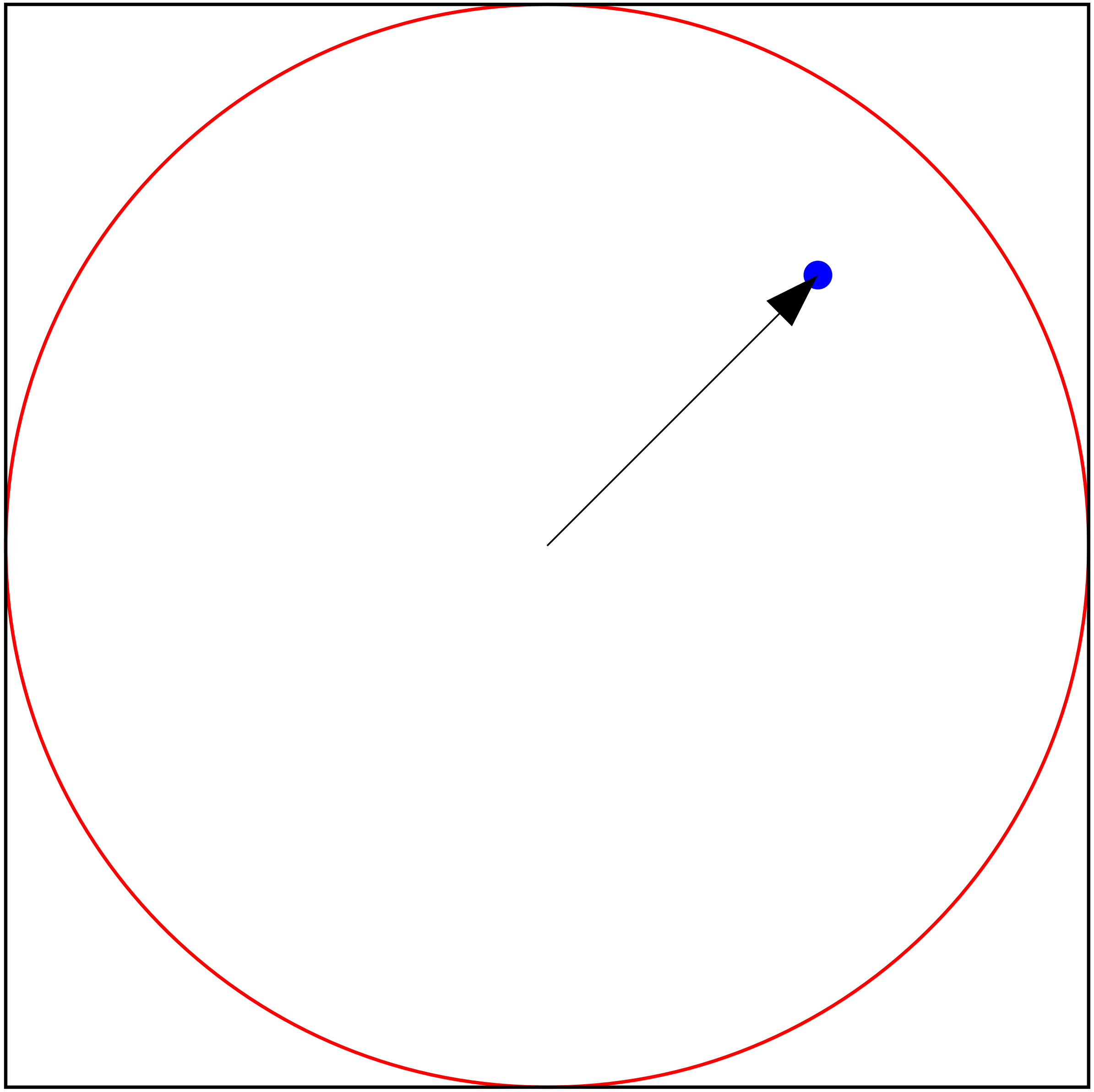

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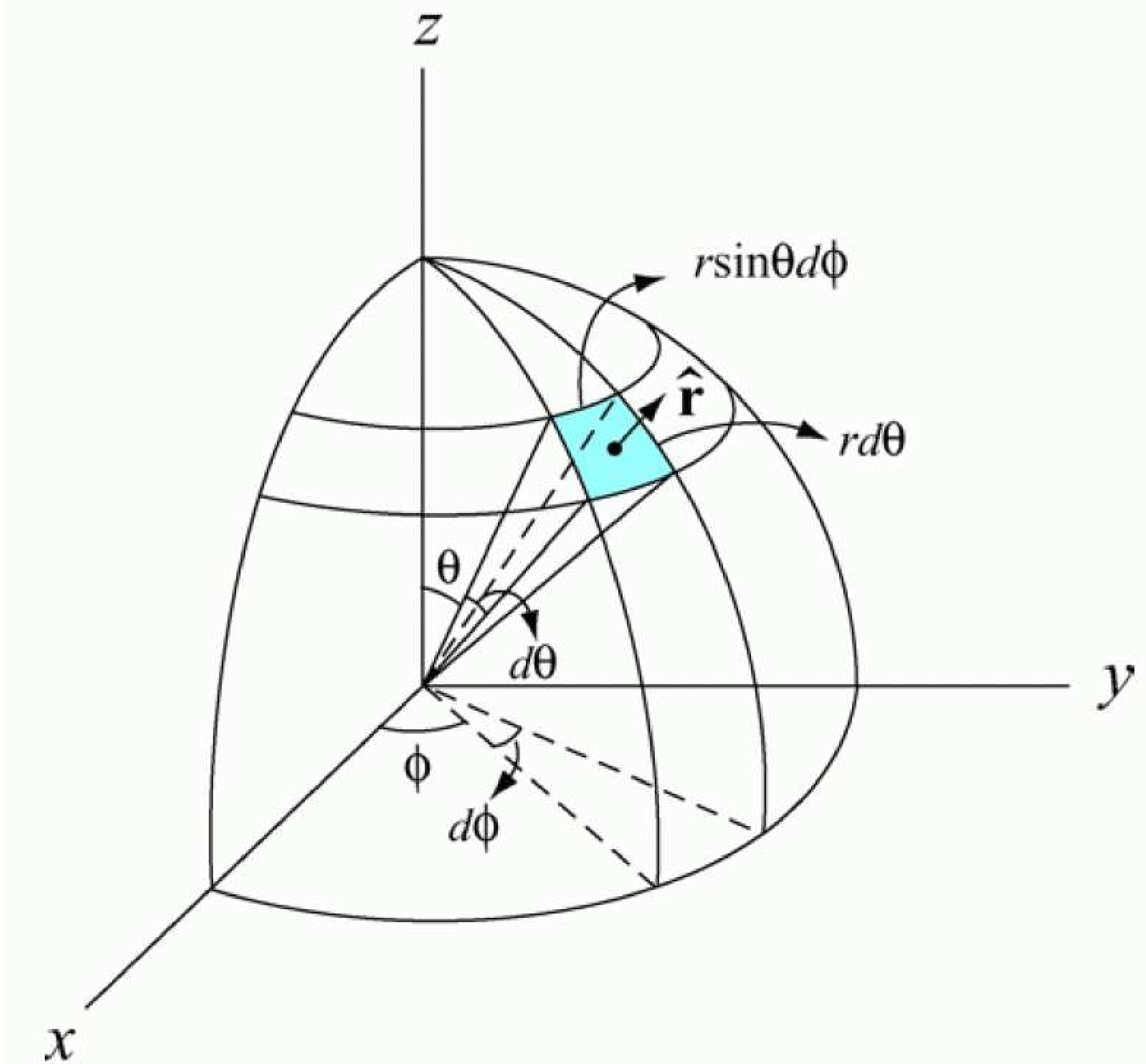

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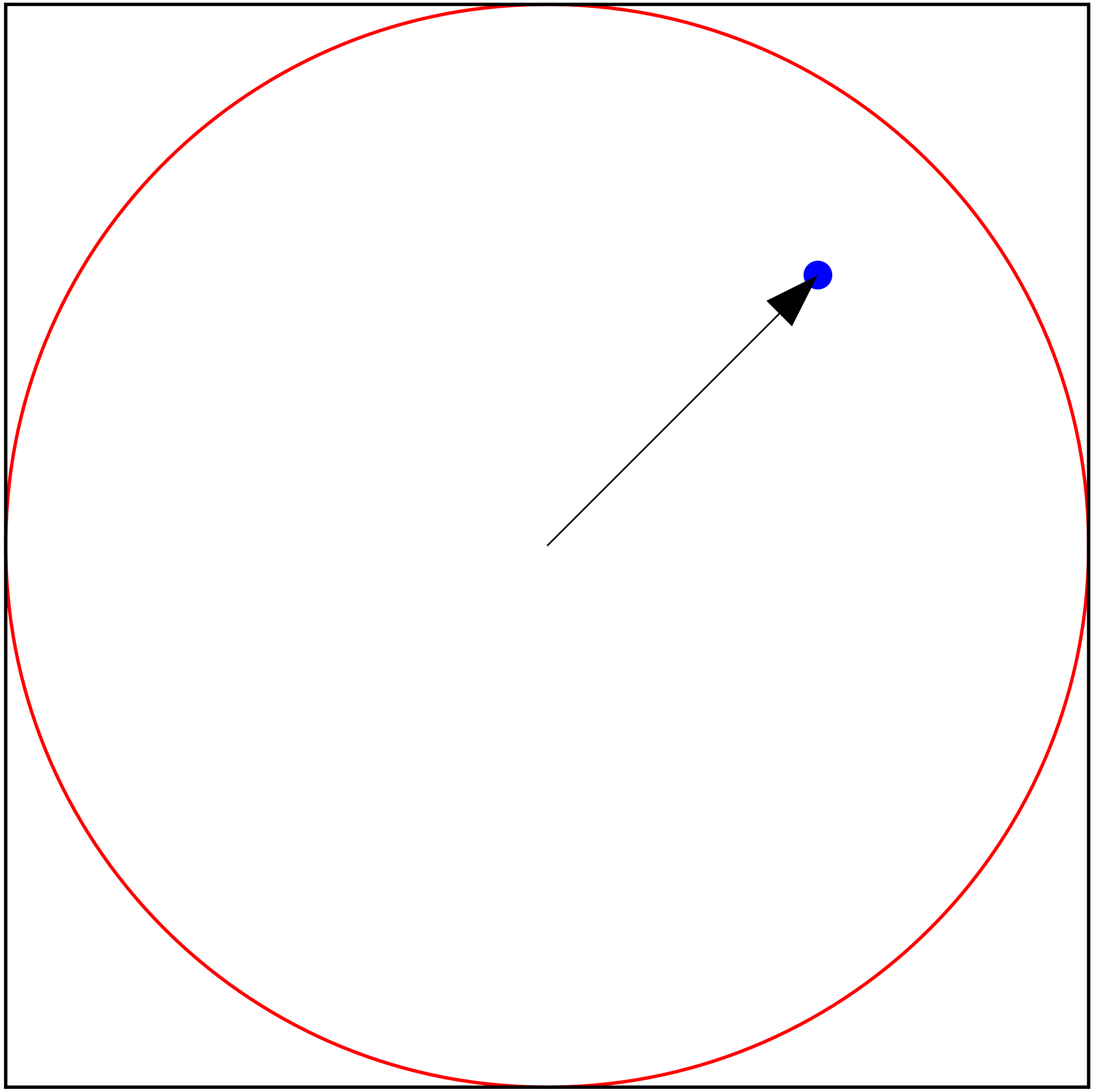

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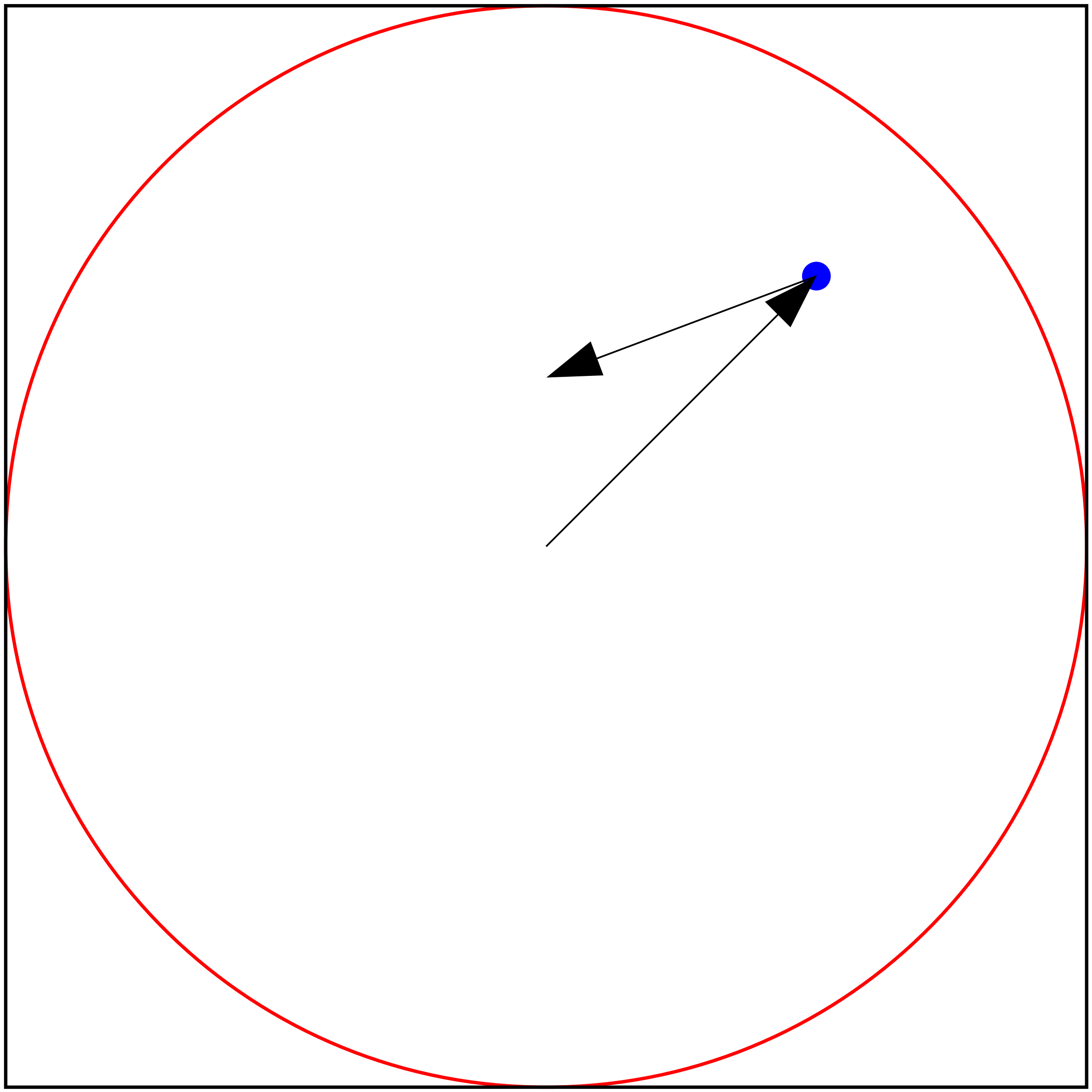

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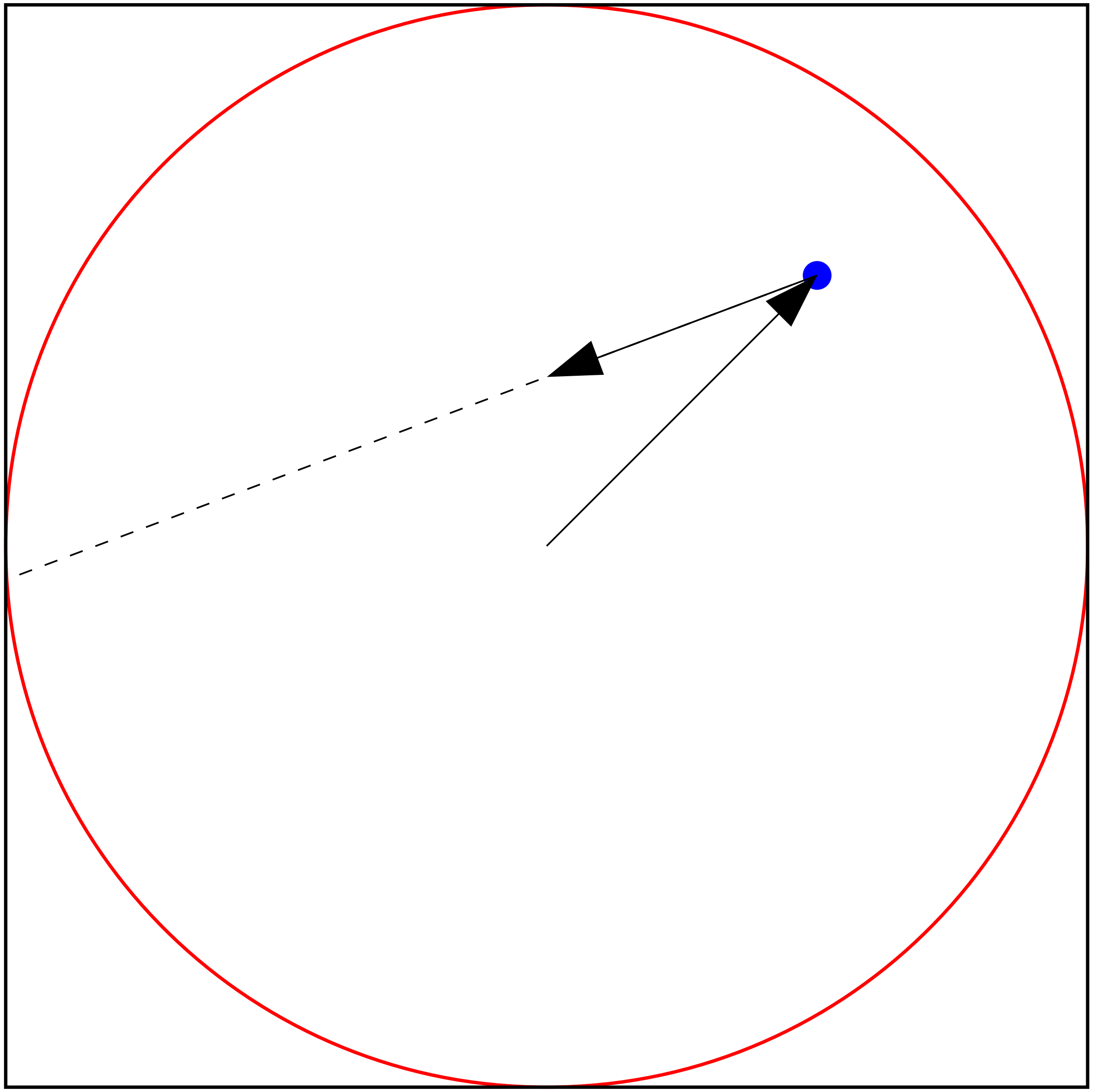
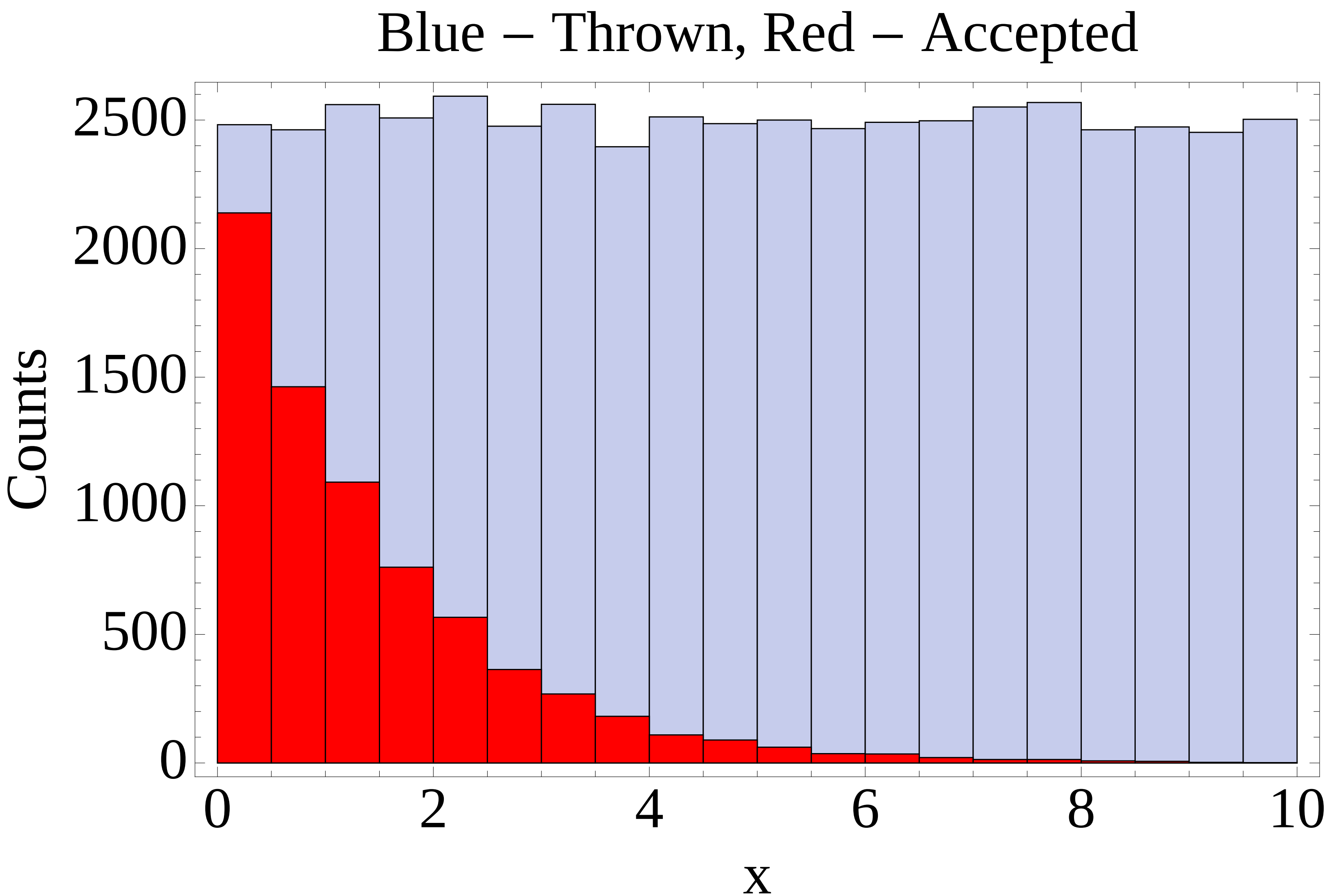
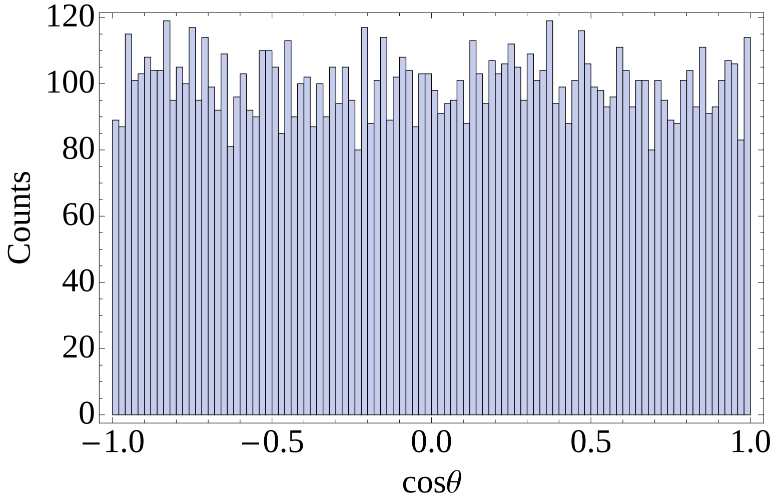
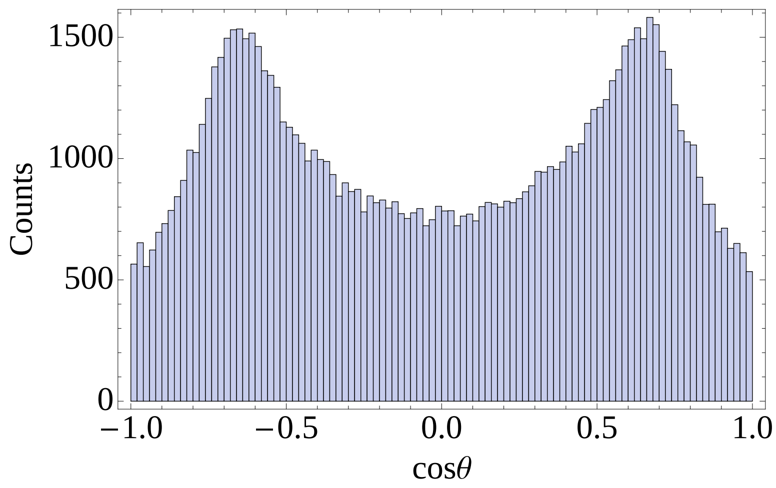


Acceptance-Rejection Method to Select Monte Carlo Events



Isotropic Decay





Monte Carlo for Self-Attenuation - 1

```
(* parameters *)
nthrows = 1000;
ndecays = 0;
ngammas = 0;
rstep = 0.01‘;
mU = 25000.‘;
rhoU = 19.05‘;
muoverrhoU = 0.046‘;
mu = muoverrhoU*rhoU;
rU = ((3 mU)/(4 \[Pi] rhoU))ˆ(1/3);

(* event loop. *)
Do[x0 = RandomReal[{-rU, +rU}];
 y0 = RandomReal[{-rU, +rU}];
 z0 = RandomReal[{-rU, +rU}];
 r0 = Sqrt[x0ˆ2 + y0ˆ2 + z0ˆ2];
 rgamma = 0.‘;
 distance = 0.‘;
```

Monte Carlo for Self-Attenuation - 2

```
(* see if we're in the sphere, then do the decay. *)
If[r0 < rU,
 ndecays = ndecays + 1; (* get a random direction. *)
 zcosine = RandomReal[{-1, 1}];
 zsine = Sqrt[1 - zcosine^2];
 phi = RandomReal[{0, 2 \[Pi]}];

 (* step along the path of the gamma until we leave the sphere. *)
 While[distance < rU,
  rgamma = rgamma + rstep;
  xgamma = rgamma zsine Cos[phi] + x0;
  ygamma = rgamma zsine Sin[phi] + y0;
  zgamma = rgamma zcosine + z0;
  distance = Sqrt[xgamma^2 + ygamma^2 + zgamma^2];
  ]; (* end of while loop to get photon out of the sphere. *)
  Pemission = \[ExponentialE]^(-mu*rgamma);
  Ptest = RandomReal[{0, 1}];
  If[Ptest < Pemission, ngammas = ngammas + 1] (* photon got out? *)
 ] (* end of If test on being inside sphere. *),
 {i, 1, nthrows}]; (* End of event loop. *)
```

Uncertainty in Monte Carlo Calculations