Modeling Nuclear Fallout Design Review

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Phys 305

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Introduction

Accidents happen:

Fukushima - 2011

Chernobyl – 1986

How are the isotopes spread?

What is the impact on the region?

How long are the effects noticeable?

Problem Statement

- Provide a program that will model atmospheric dispersion of radioactive particles from an event and provide ground level concentrations as well as estimated increase in radiation levels from calculated concentrations
- Base line
  - Fire in RAM of one isotope, immediate dispersion and dose
- Expansion
  - Time factor, account for decay to estimate concentrations and exposure-15y, 60y, 150y, 300y.
  - More violent source, i.e. – explosion vs. fire

Dispersion

$$C(x, y, 0, H) = \frac{Q}{\pi \sigma_y \sigma_z u} e^{\frac{-y^2}{2\sigma_y^2}} e^{\frac{-H^2}{2\sigma_z^2}}$$

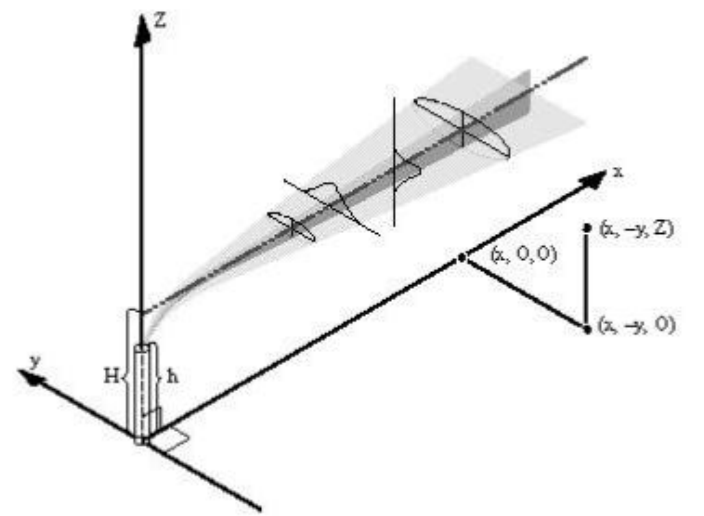
C = concentration at point (x,y) (kg/m^3) or (Ci/m^3)

Q = mass flow of contaminates from source (kg/s) or (Ci/s)

H = effective height of emissions (m)

u = wind speed (m/s)

$\sigma_y \sigma_z$ = standard deviation of plume concentration in y or z plane (m)



http://www.faa.gov/regulations_policies/policy_guidance/envir_policy/airquality_handbook/media/App_I.PDF

Atmospheric Considerations

TABLE 1. Key to P-G stability categories using objective and conventional Turner methods.

Surface wind speed (10 m) ($m\ s^{-1}$)	Day: Incoming solar radiation ($W\ m^{-2}$) Strong (>700)	Day: Moderate (350–700)	Day: Slight (70–350)	Night: Thinly overcast or more than 1/2 low clouds ($-\Delta T$)*	Night: Clear or less than 1/2 clouds ($+\Delta T$)*
<2	A	A	B	E	F
2–3	A	B	C	E	F
3–5	B	B	C	D	E
5–6	C	C	D	D	D
>6	C	D	D	D	D

* ΔT is change in temperature with height, such as 2–10 m AGL. Negative ΔT indicates cooling with height; positive ΔT indicates warming with height.

Bowen, *Brent Evaluation and Comparison of Several Methods to Determine Dispersion Coefficients*, 1994

Atmospheric Considerations

TABLE 2. Formulas recommended by Briggs (1973) for sigma y and sigma z. Equations are valid for downwind distances (x) from 100 m to 10 km.

P–G category	σ_y (m)	σ_z (m)
Open-country conditions		
A	$0.22x(1 + 0.0001x)^{-1/2}$	$0.20x$
B	$0.16x(1 + 0.0001x)^{-1/2}$	$0.12x$
C	$0.11x(1 + 0.0001x)^{-1/2}$	$0.08x(1 + 0.0002x)^{-1/2}$
D	$0.08x(1 + 0.0001x)^{-1/2}$	$0.06x(1 + 0.0015x)^{-1/2}$
E	$0.06x(1 + 0.0001x)^{-1/2}$	$0.03x(1 + 0.0003x)^{-1}$
F	$0.04x(1 + 0.0001x)^{-1/2}$	$0.016x(1 + 0.0003x)^{-1}$
Urban conditions		
A–B	$0.32x(1 + 0.0004x)^{-1/2}$	$0.24x(1 + 0.001x)^{1/2}$
C	$0.22x(1 + 0.0004x)^{-1/2}$	$0.20x$
D	$0.16x(1 + 0.0004x)^{-1/2}$	$0.14x(1 + 0.0003x)^{-1/2}$
E–F	$0.11x(1 + 0.0004x)^{-1/2}$	$0.08x(1 + 0.00015x)^{-1/2}$

Bowen, *Brent Evaluation and Comparison of Several Methods to Determine Dispersion Coefficients*, 1994

Source

$$\Delta T_c = \left(\frac{T_\infty}{g C_p^2 \rho_\infty^2}\right)^{1/3} \dot{Q}_c^{\ 2/3} (z - z_0)^{-5/3}, \qquad U_c = \left(\frac{g}{C_p \rho_\infty T_\infty}\right)^{1/3} \dot{Q}_c^{\ 1/3} (z - z_0)^{-1/3}$$

ΔT_c = centerline mean temperature difference (K)

T_∞ = ambient temperature (K)

g = acceleration of gravity (m/s^2)

C_p =specific heat of air at constant pressure [(kJ/kg)/K]

ρ_∞ =ambient air density (kg/m^3)

$\dot{Q}_c$ = convective heat release rate (kJ/s) or (kW)

z = elevation above fuel source (m)

z_0 = elevation of fuel source (m)

U_c= centerline mean velocity (m/s)

Budnik, Edward *Simplified Fire Growth Calculations*, 1997

Plume Rise Height

```
switch (sta){
            case 1:
            case 2:
            case 3:
            case 4:
            case 5:
                  ds=0.02;
                  break;
            case 6:
                  ds=0.035;
                  break;
            default:
                   ds=0.0;
            }
double s= g/Ta*(ds);
double F= g*U*pow(D,2)/4*(1-Ta/T);
switch (sta){
            case 1:
            case 2:
            case 3:
            case 4:
                  if(F>=55){
                           dt=0.00575*T*pow(U,2.0/3.0)/pow(D,1.0/3.0);
                           if((T-Ta)<=dt){Dh=3*D*U/u;}
                           else{
                                xst=34*pow(F,2.0/5.0);
                                xf=3.5*xst;
                                if(x>=xf){Dh=1.6*pow(F,1.0/3.0)*pow(xst,2.0/3.0)/u; break;}
                                else{Dh=1.6*pow(F,1.0/3.0)*pow(x,2.0/3.0)/u;}
                                }
                           }
                  else {
                       dt=0.0297*T*pow(U,1.0/3.0)/pow(D,2.0/3.0);
                       if((T-Ta)<=dt){Dh=3*D*U/u;}
                       else{
                           xst=14*pow(F,5.0/8.0);
                           xf=3.5*xst;
                           if(x>=xf){Dh=1.6*pow(F,1.0/3.0)*pow(xst,2.0/3.0)/u; break;}
                           else{Dh=1.6*pow(F,1.0/3.0)*pow(x,2.0/3.0)/u;}
                           }
                       } break;
            case 5:
            case 6:
                  dt=0.01958*Ta*U*pow(s,0.5);
                  if((T-Ta)<=dt){Dh=1.5*pow(pow(U,2)*pow(D,2)*Ta/(4*T*u),1.0/3.0)*pow(s,-1.0/6.0);}
                  else{
                       xf=2.07*u/pow(s,0.5);
                       if(x>=xf){Dh=2.6*pow(F/(u*s),1.0/3.0); break;}
                       else{Dh=2.6*pow(F/(u*s),1.0/3.0);}
                       } break;
            }
return Dh;
}
```

Bowen, *Brent Evaluation and Comparison of Several Methods to Determine Dispersion Coefficients*, 1994

Exposure

$$\dot{X} = 5.263\ x\ 10^{-6}\ \frac{AyE(\mu_{en}/\rho)}{r^2}$$

$\dot{X}$ = exposure (mR/h)

A = activity (Bq)

y = number of photons emitted

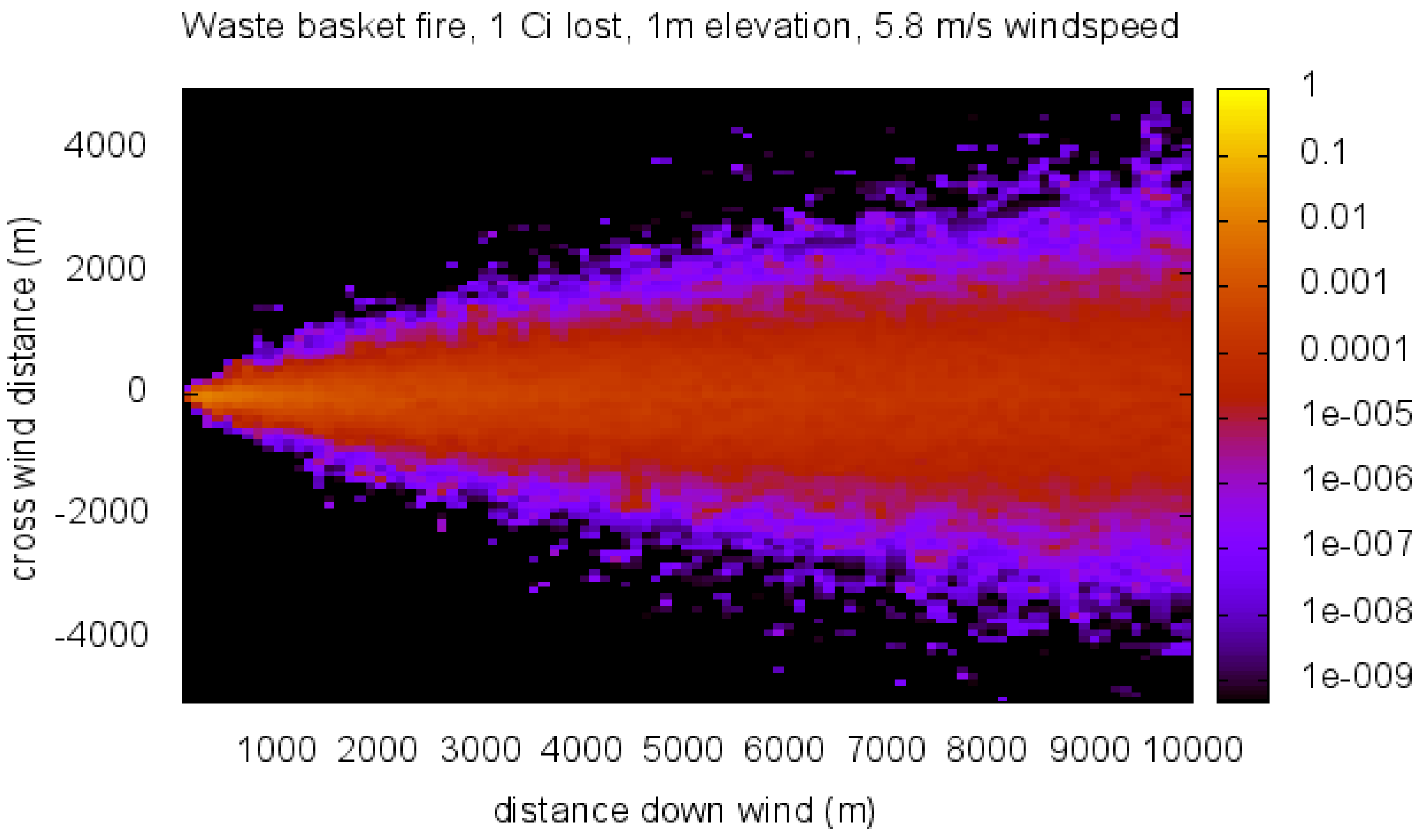
E= energy of photons (MeV)

μ_{en}/ρ = mass energy absorption coefficient (m^2/kg)

r = distance from point (m)

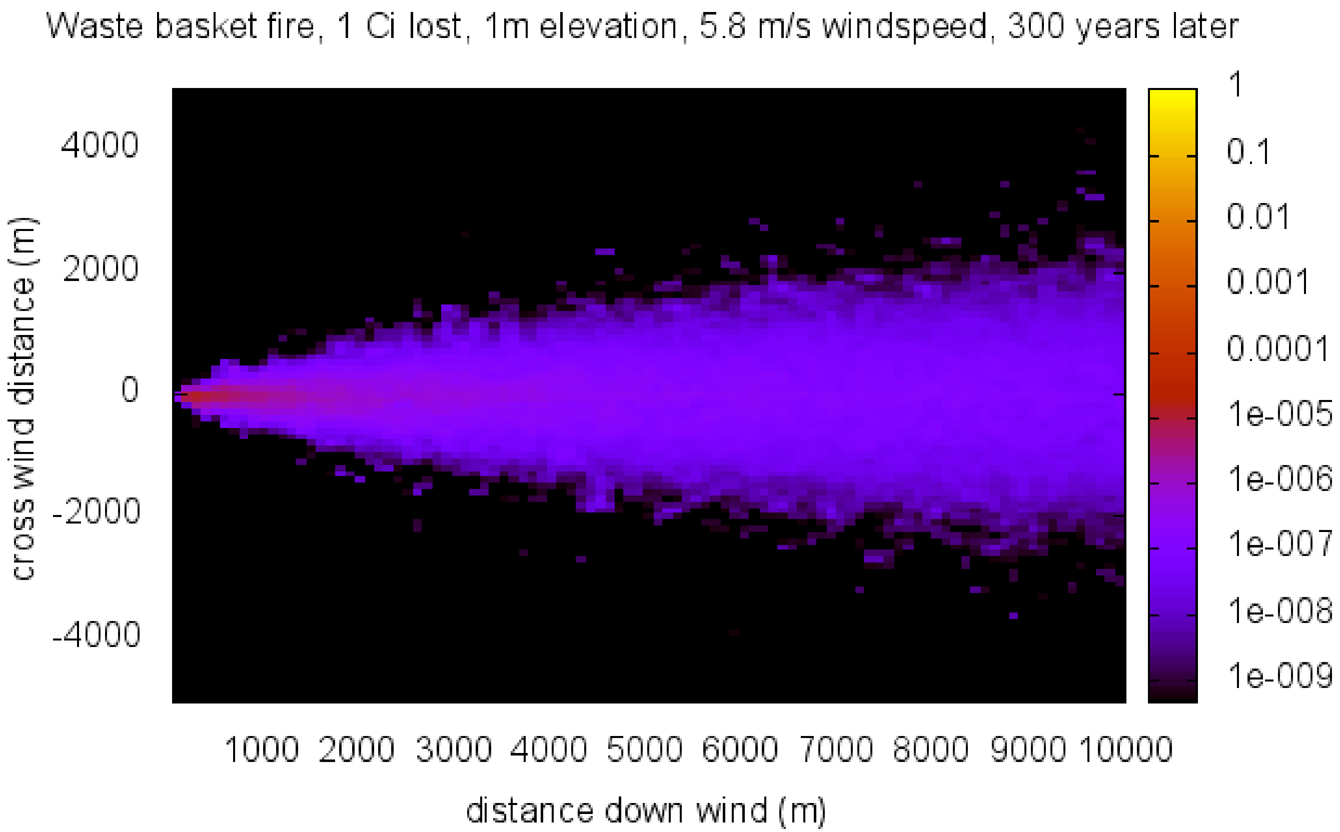
Chabot, George *Relationship Between Radionuclide Gamma Emission and Exposure Rate, http://hps.org/publicinformation/ate/faqs/gammaandexposure.html, Aug 27,2011*

Results



Scale is in Ci/100 cm^2

Results



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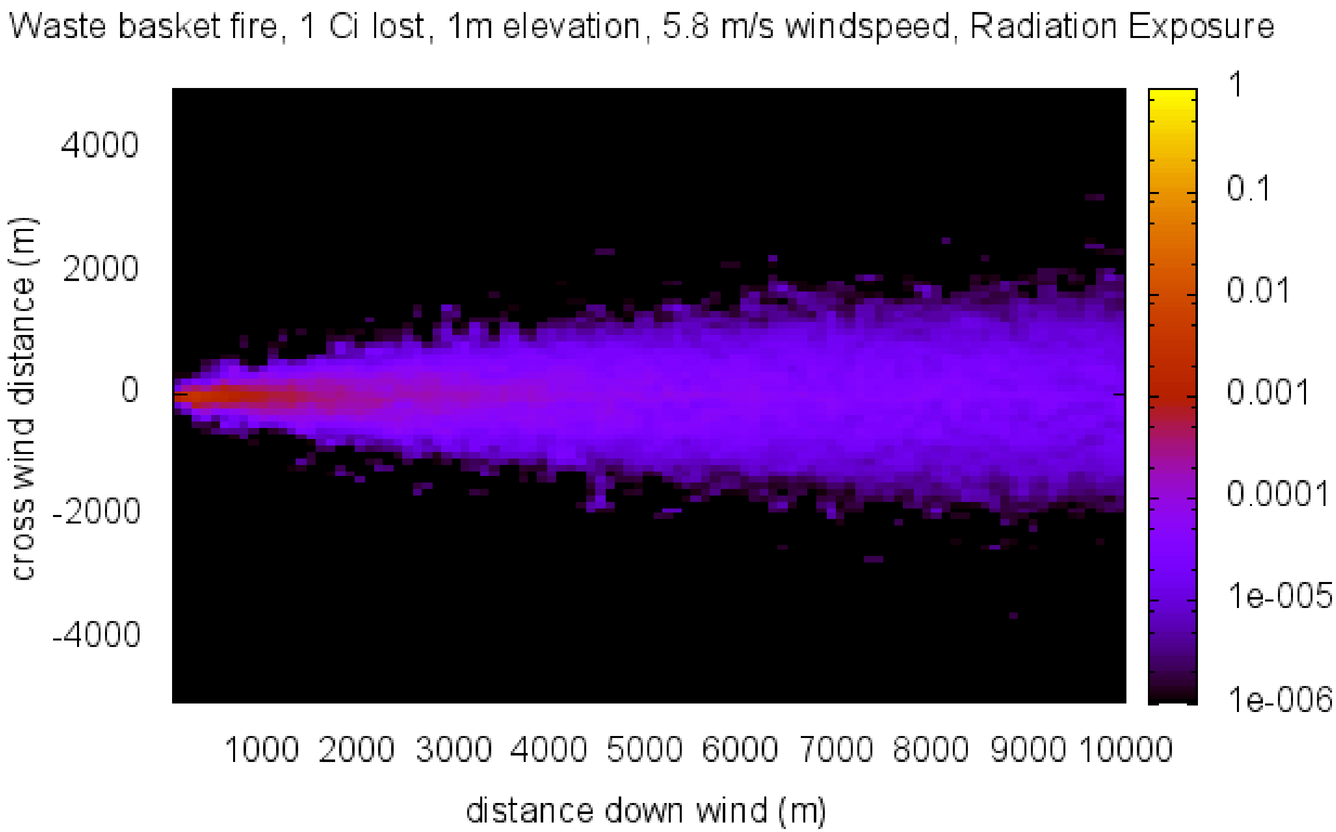
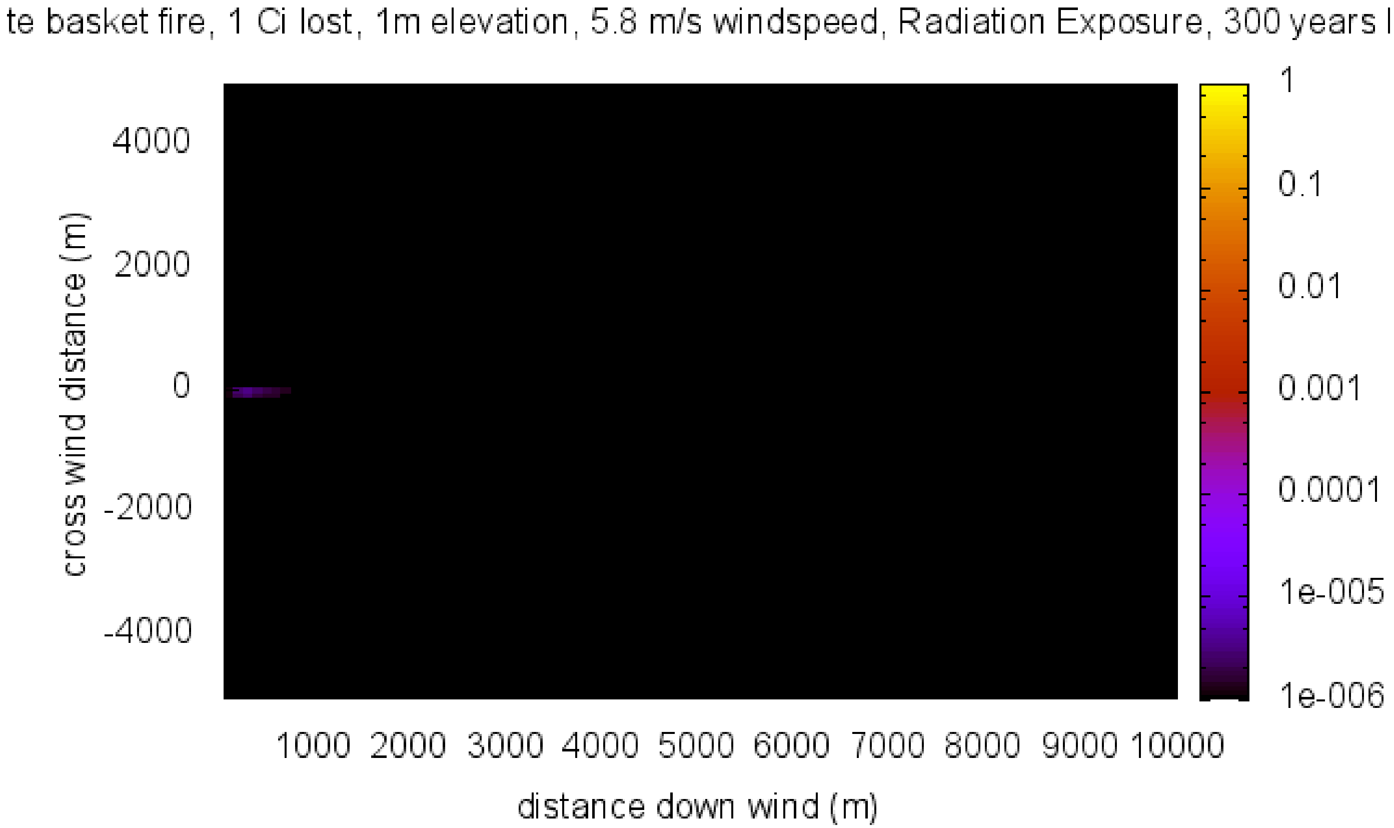
Results



Scale is in mR/hr

Results



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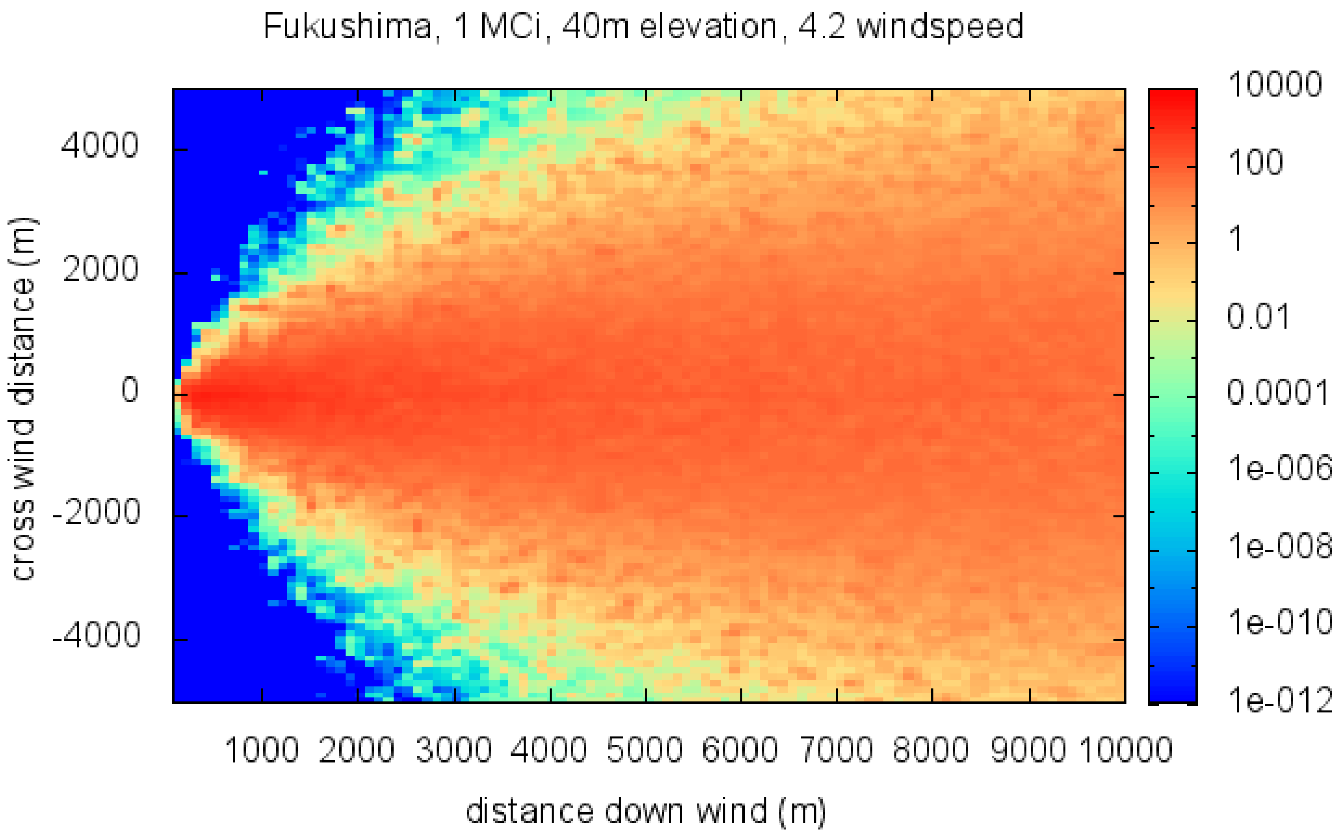

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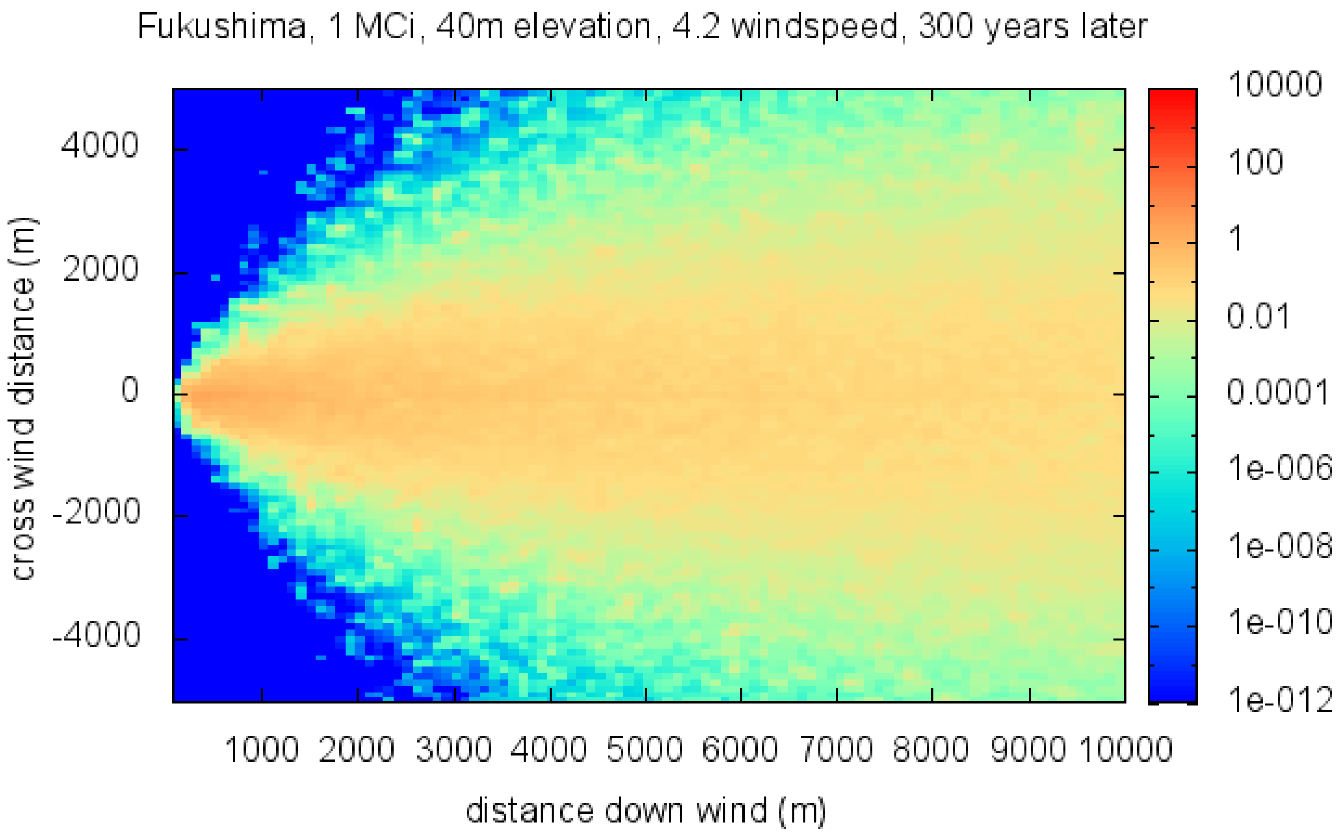

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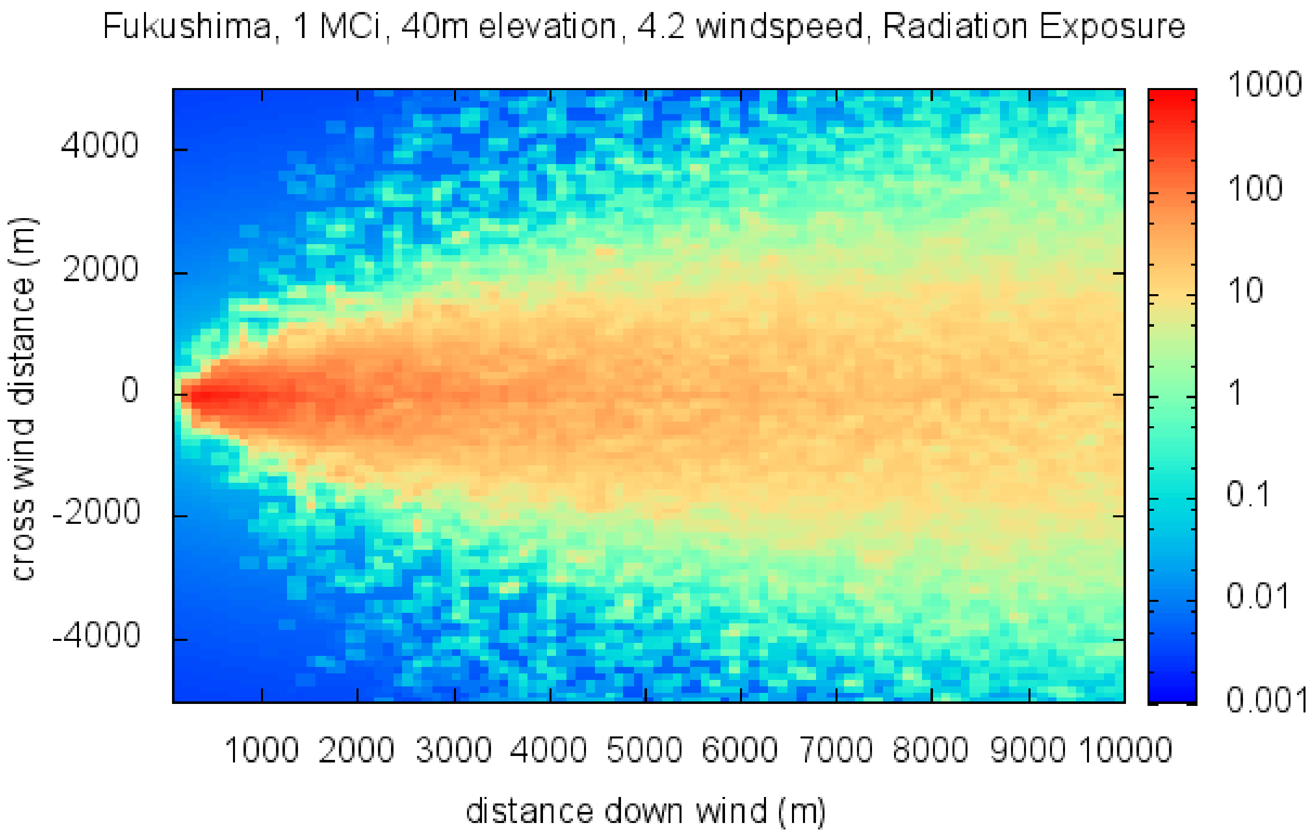
Results



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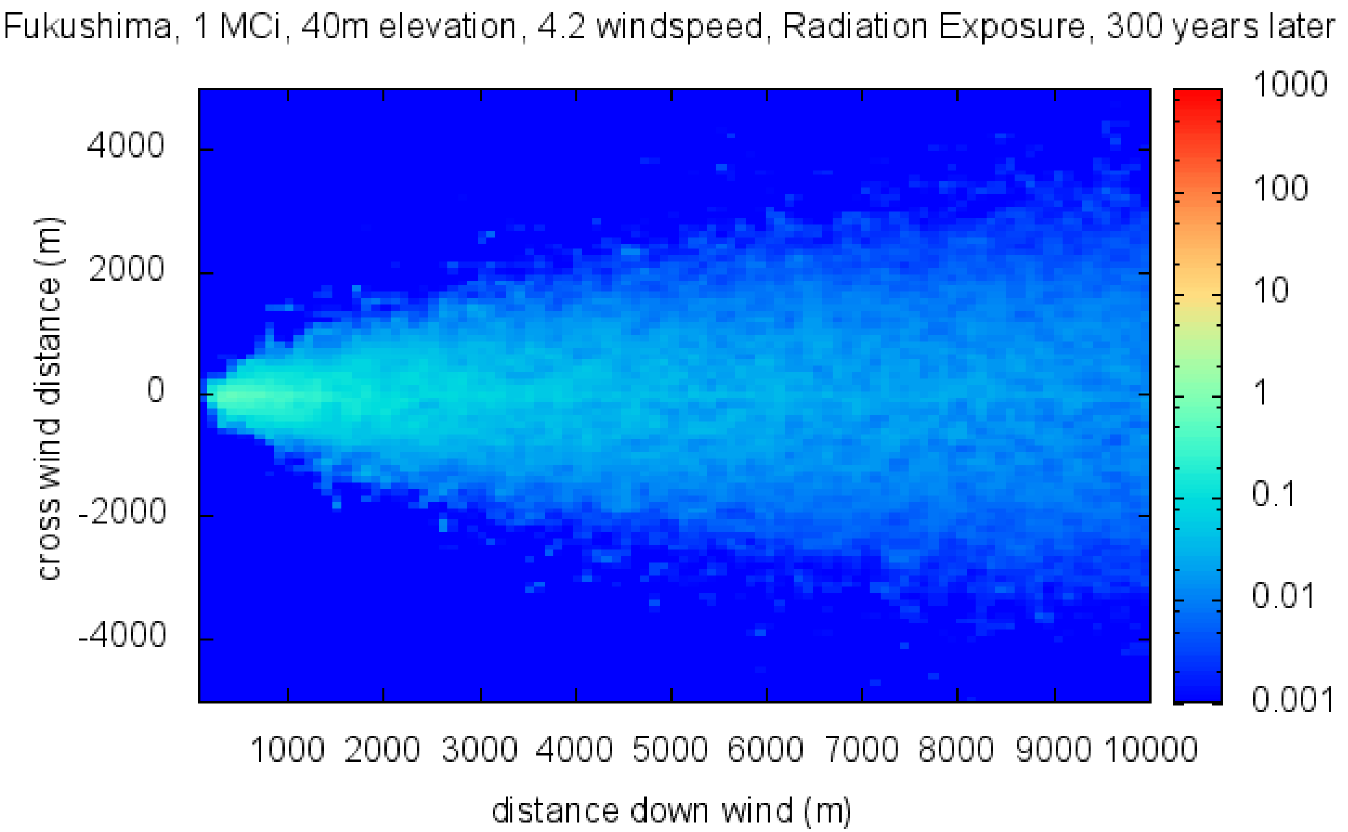

Scale is in mR/hr

Actual Fukushima Distribution