Validation of Methodology to Simulate Gamma Doses from Historical Weapons Tests

Thomas M. Miller
Bruce W. Patton

Nuclear Security and Isotope Technology Division

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Outline

- Introduction and motivation
- Review 2 validation simulations
  - Ranger Fox – gamma dose versus distance
  - Buster-Jangle Sugar – gamma dose rate versus time and distance
  - Review analysis methodology for both
- Conclusions

Introduction and Motivation

- If a nuclear or radiological device was detonated in the USA, how accurately could we calculate the dose received by the public?
- Answer this question with another question:
  - How accurately can we simulate the doses measured during US aboveground testing?
- Some context about gamma doses from a nuclear detonation
  - Up to ~5% of the dose comes from prompt fission
  - ~55-85% of the dose comes from neutron interactions outside the device (inelastic scattering, capture, activation)
  - The rest comes from fission and activation products within the device

Introduction and Motivation (cont.)

- All the dose from a radiological device comes from fission and/or activation products, obviously
- Plan to simulate these different sources of dose
  - Prompt fission gammas – ignore since the contribution is usually less than 5%
  - (n,γ) reactions
    - Need neutron leakage source from device
    - Need dose data measured as a function of distance
  - Fission and activation product decay gammas
    - Need to burn some fissile material
    - Need dose data measured as a function of time and distance

Validation Case: Ranger Fox

Gamma Dose vs Distance

- Ranger Fox (WT-201)
  - February 6, 1951, Nevada Test Site
  - Yield 22 kt (NV-209)
  - HOB 1435 ft (~437 m)
  - All dose measurements made with film badges collected within a few hours of detonation
  - Film badges on the ground along two directions, 90° apart, at 100 yd (91.44 m) increments from point of detonation – 41 film badges along each direction

Validation Case: Ranger Fox
Gamma Dose vs Distance

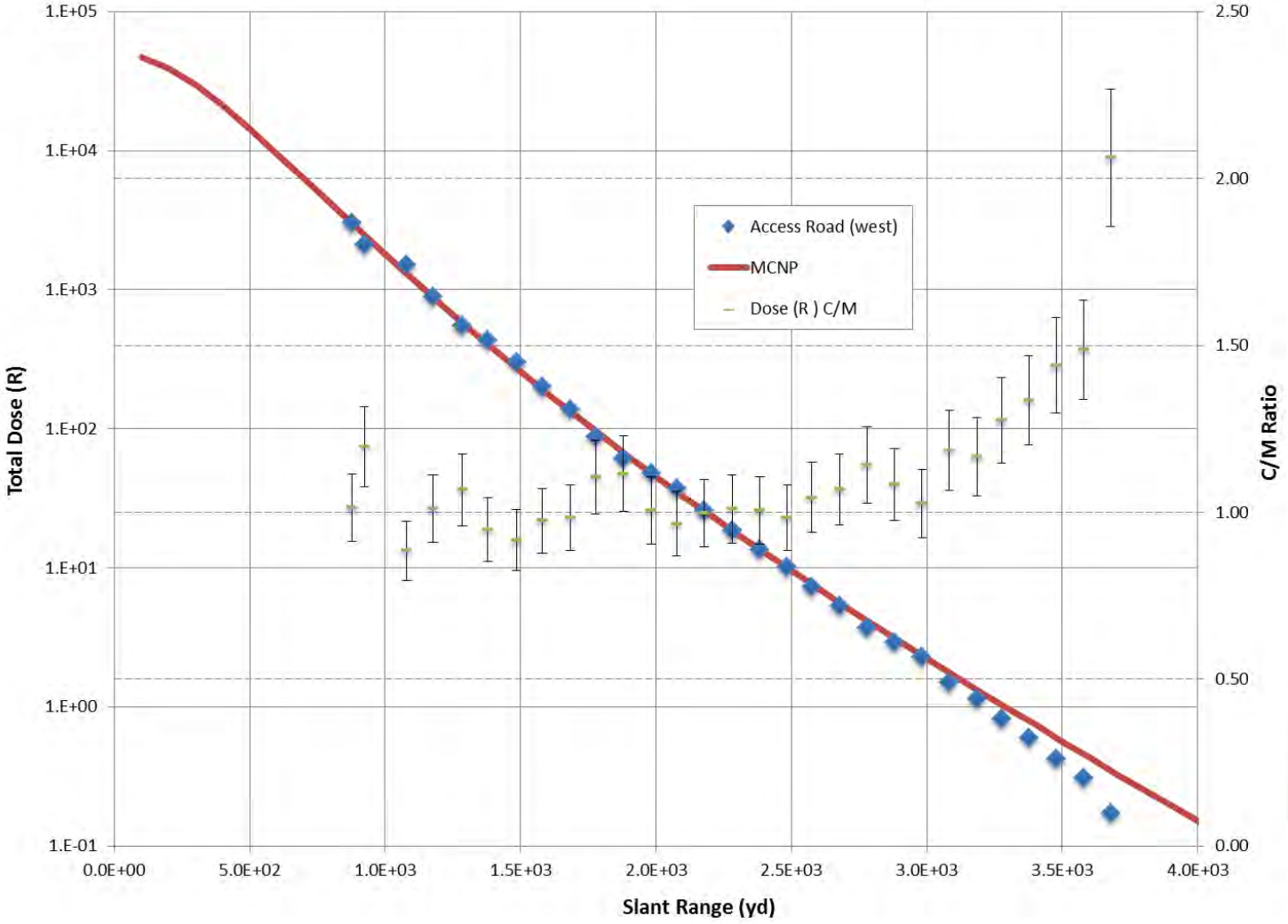
- MCNP model
  - Source
    - Neutron leakage spectrum and number of neutrons (EM-1), treated as a point at the HOB
    - Fission product decay photons also transported, but insignificant contribution to total dose – more details later for this type of source
  - Geometry
    - 5 m of “average US soil” (PNNL-15870)
    - 101 layers of air with these conditions on the ground (WT-201): 6°C, 87.415 kPa, and 45% relative humidity
    - Naval Research Laboratory (NRL) model used to determine conditions within different layers / altitude

Validation Case: Ranger Fox
Gamma Dose vs Distance

- MCNP model (cont.)
  - Tallies
    - F6 with conversion from MeV/cm^3 to roentgen (see paper)
    - Cells were large cuboids of air, 16 m on a side
  - Variance reduction
    - ADVANTG used to calculate space and energy dependent weight windows and source energy biasing parameters
    - The cell tallies reduce tally fluctuations observed by point detector tallies or cell tallies used with a DXTRAN sphere, but likely require more histories to sample the cell volumes
    - In hindsight, the (n,γ) doses could have been calculated using a ring / cylindrical shell for the tallies – this is not the case for the fission product gammas

Ranger Fox Comparison

Errors: MCNP < 1%, measurement assumed ~10%



OAK RIDGE National Laboratory

Validation Case: Buster-Jangle Sugar

Gamma Dose Rate vs Time and Distance

- Buster-Jangle Sugar (WT-329)
  - November 19, 1951, Nevada Test Site
  - Yield 1.2 kt (NV-209)
  - HOB 3.5 ft (~1.1 m)
  - Scintillation detectors triggered at 0.1 and 10 s after detonation
  - Time dependent dose rate measured at several locations
    - We will focus on detectors at 2000, 4000, and 6000 ft (609.6, 1219.2, and 1818.8 m)
    - The detectors we are using are opposite the direction the cloud was blown / drifted so as to minimize fallout landing directly on the detectors (however, this could not be completely avoided)

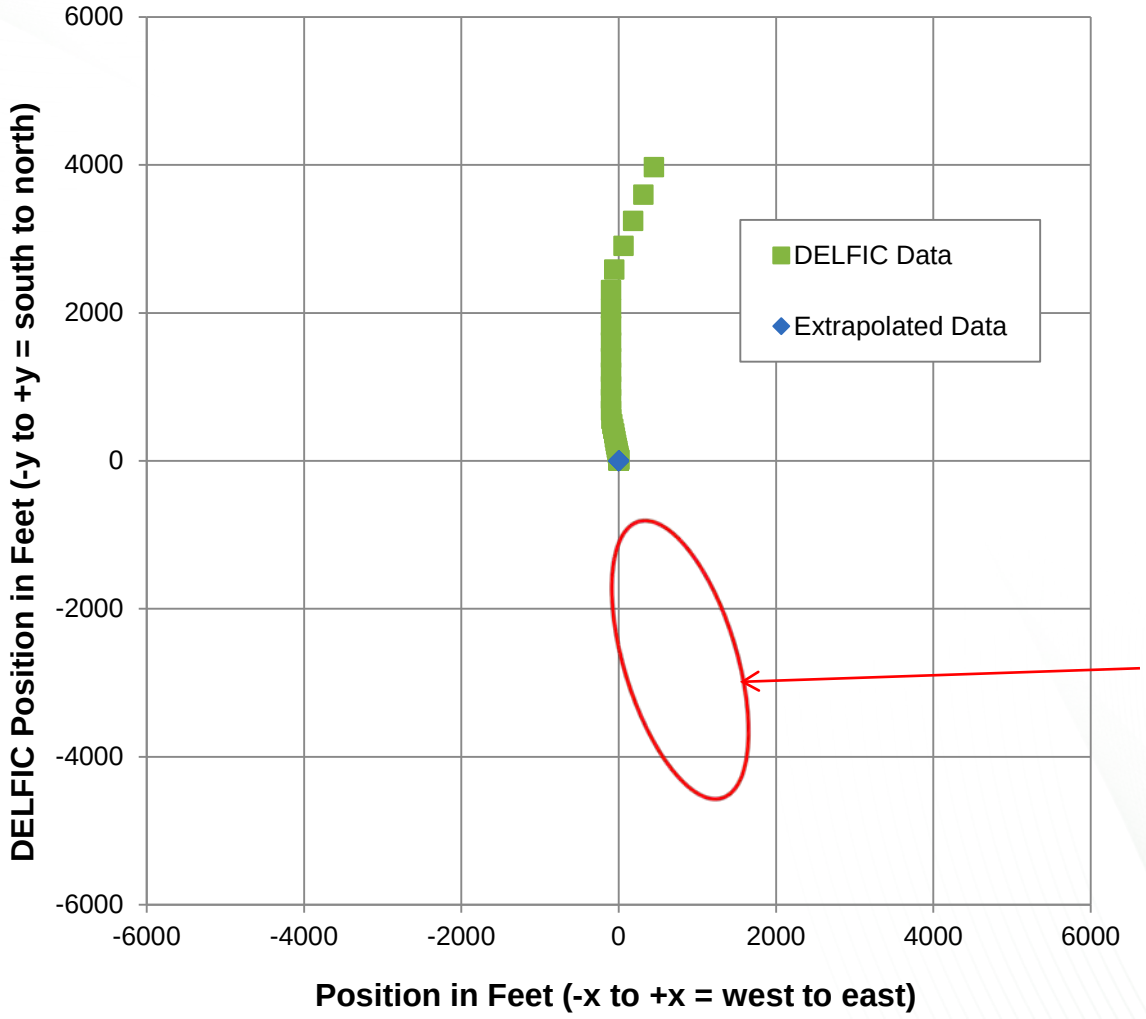
Validation Case: Buster-Jangle Sugar
Gamma Dose Rate vs Time and Distance

- MCNP model
  - Source
    - ORIGEN used to simulate 1.74e23 fissions (1.2 kt × 1.45e23 fissions / kt) in 25 kg of ^{235}U – neutron energy watt fission spectrum [energy dependence]
    - DELFIC, using measured weather conditions as input, simulated the location and size of the cloud containing the fission products [spatial dependence]
      - Unfortunately, DELFIC does not tell you where the fission products are within the cloud and roughly approximates what else was picked up from the ground
      - Assume soil and fission products are evenly distributed within the cloud
      - Also, DELFIC does not provide data before the fireball reaches pressure equilibrium with the surrounding atmosphere, which was ~2 sec in this case
      - Use Glasstone and Dolan approximation before 2 sec ($R = 90*W^{0.4}$) at 1 ms and linearly interpolate between these times
    - Neutron leakage spectrum also transported, but insignificant contribution to dose rates at the times considered in this analysis – see Ranger Fox

Validation Case: Buster-Jangle Sugar

Gamma Dose Rate vs Time and Distance

- DELFIC results of cloud position projected on the ground (x,y) plane

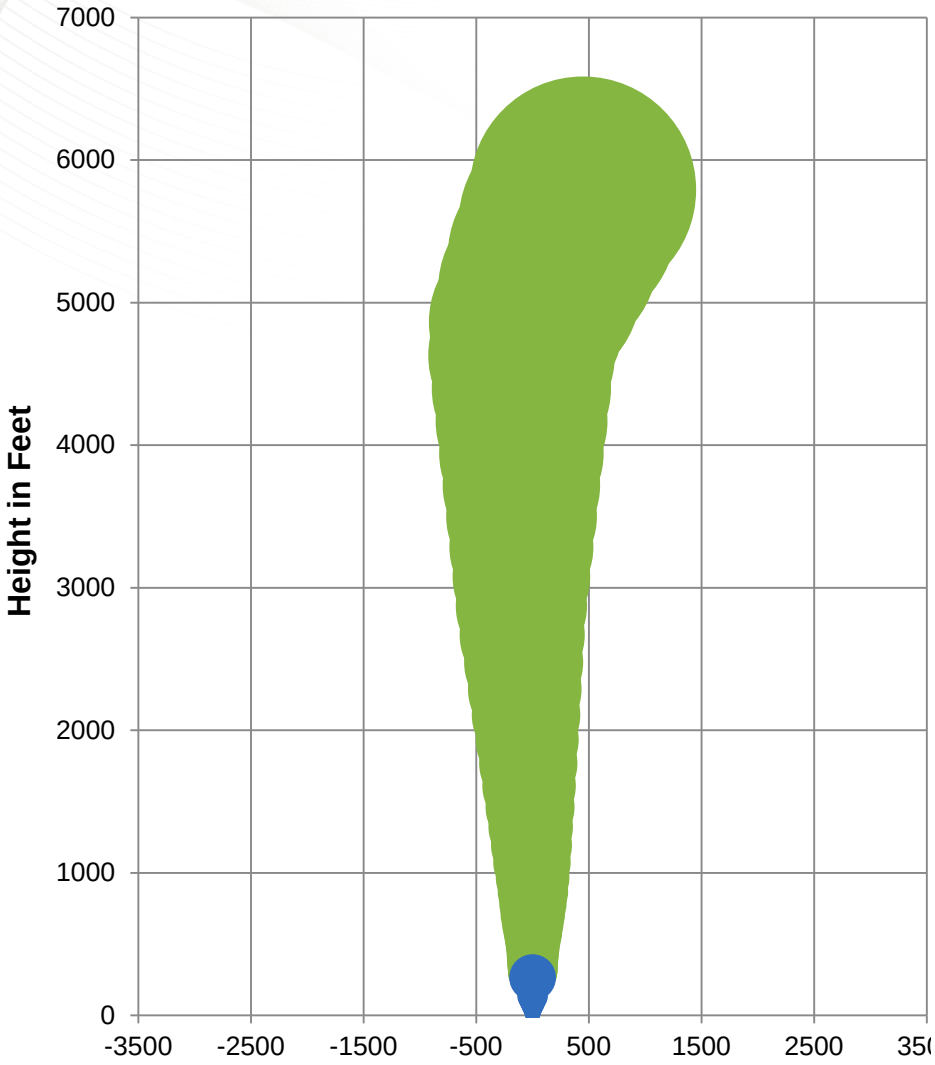


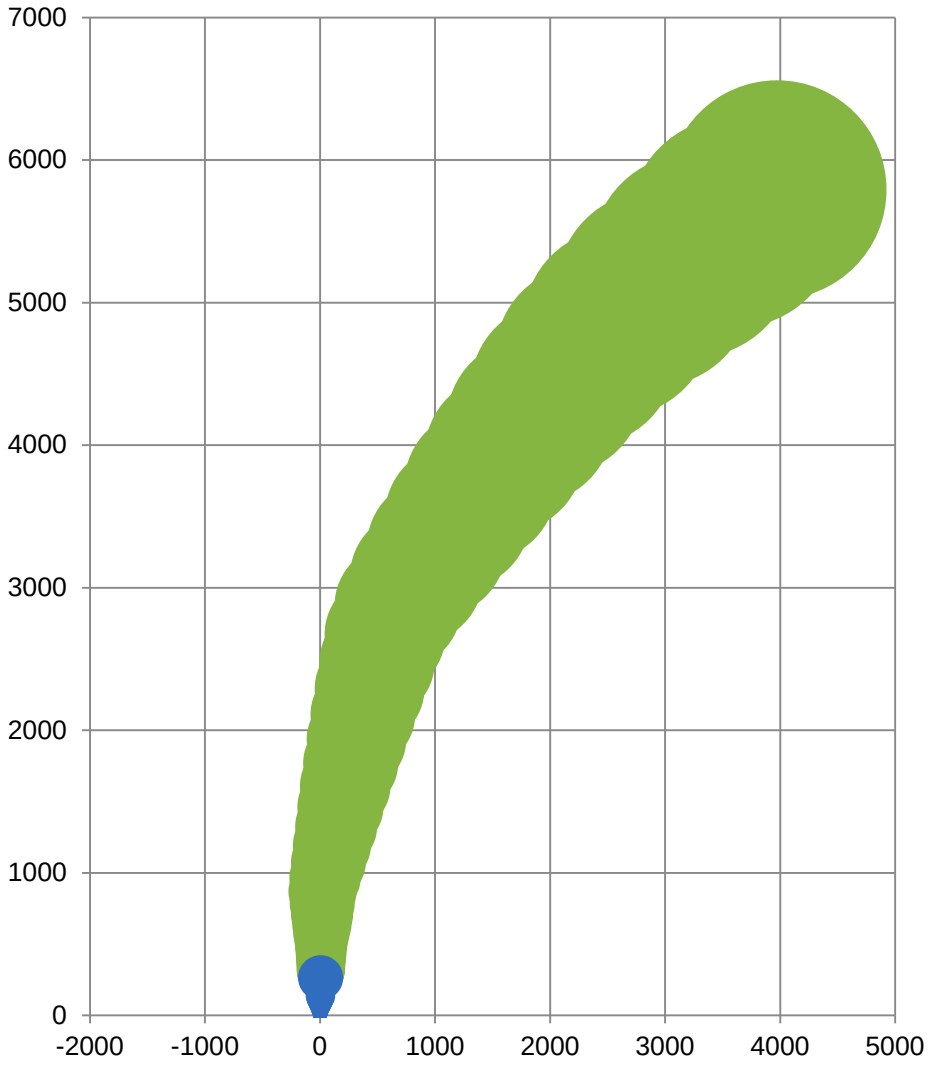
Detector locations in this general area

Validation Case: Buster-Jangle Sugar

Gamma Dose Rate vs Time and Distance

- DELFIC results of cloud height and radius (DELFIC=green, extrapolation=blue)



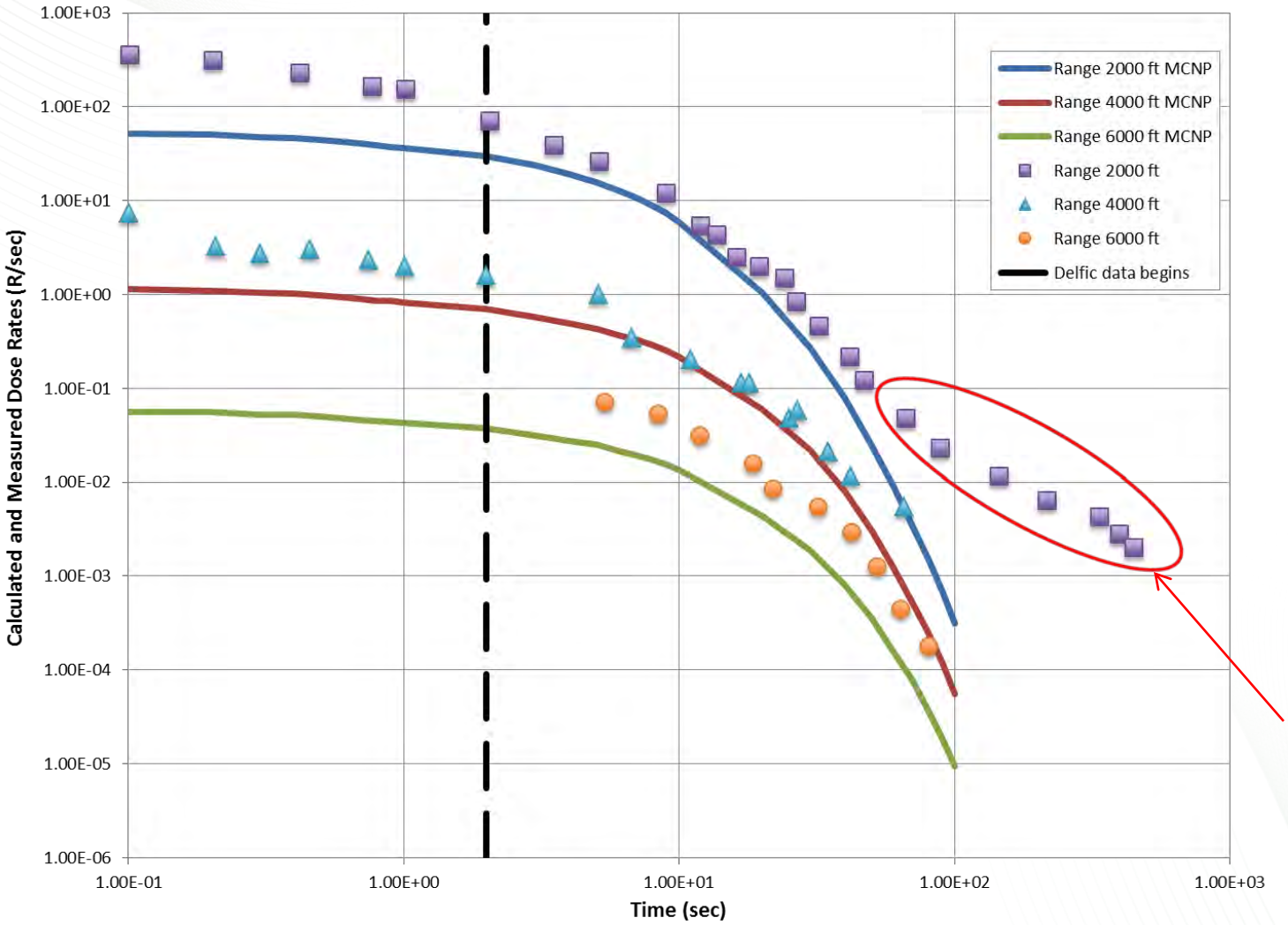


Validation Case: Buster-Jangle Sugar
Gamma Dose Rate vs Time and Distance

- MCNP model (cont.)
  - Geometry
    - 5 m of “average US soil” (PNNL-15870)
    - 17 layers of air with conditions measured by a weather balloon up to ~6000 m
    - NRL model used to determine conditions from ~6000 m to ~9000 m
  - Tallies
    - F5 / point detectors 28 in. (71.12 cm) above the ground with tally multiplier from flux to roentgen
    - Exclusion sphere around point detectors, 71 cm radius
  - Variance reduction
    - ADVANTG used to calculate space and energy dependent weight windows and source energy biasing parameters
    - Care must be taken to converge these tallies, pay attention to the variance of the variance (VOV)

Buster-Jangle Sugar Comparison

Errors: MCNP < 1%, measurement estimated ~12.5%



Fallout landing on detector?

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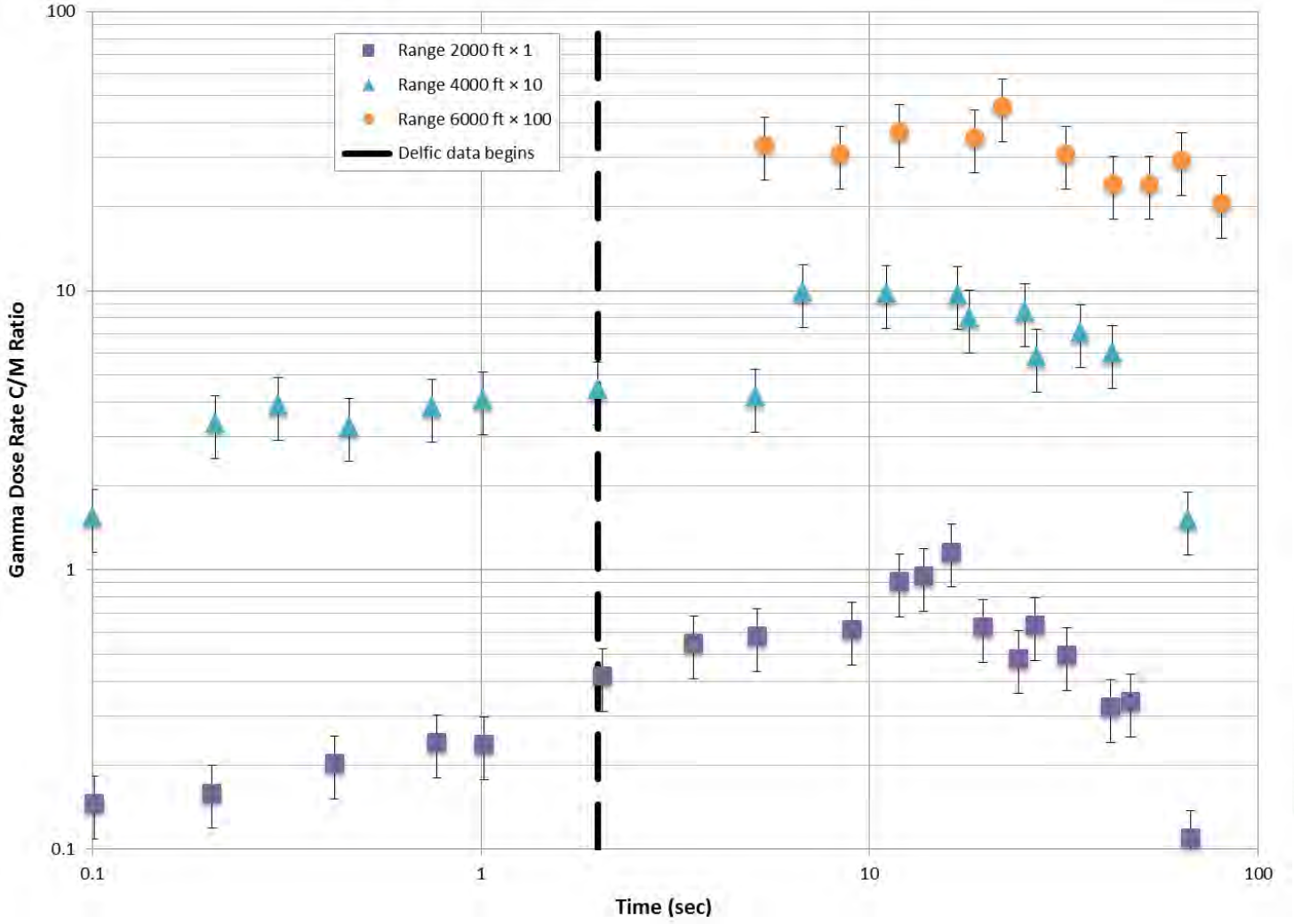
Buster-Jangle Sugar C/E Ratios



Conclusions

- Ranger Fox (dose vs distance)
  - The calculated and measured results compare well
  - However, this is just one data point (hopefully we did not just get lucky)
- Buster-Jangle Sugar (dose rate vs time and distance)
  - The calculated and measure results are within a factor of 2
  - A lot of assumptions have been made that impact the fission product source
  - A more detailed model than what is currently in DELFIC is needed
- Considering the lack of information about the actual devices, the computational estimates seem acceptable
- Additional work is needed to fully investigate these types of simulations in a city or urban center