Intakes of Plutonium Produce One-Fourth the Risk when Human Susceptibility Data Are Used for Risk Assessment

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Abstract

Cancer is a family of diseases, and it should be obvious that different tissues would have different susceptibility to radiation-induced cancer. Current radiation risk models assume that, while various organs and tissues may have different radiosensitivities, all follow a linear, nonthreshold (LNT) dose-response relationship. A more accurate (if more complicated) risk assessment would account for different shaped dose-response relationships for each cancer type. Since the most compelling risk estimates for radiation carcinogenesis come from human data, we examined the human data for bone cancer and liver cancer caused by intakes of radioactive materials. Excess bone cancer has been seen in radium workers (primarily female dial-painters at the beginning of the 20th century) and plutonium workers at Mayak. Excess liver cancer has been seen in patients administered the radioactive thorium compound Thorotrast for x-ray studies, and also in plutonium workers at Mayak. In each case, there is evidence for, or at least a suggestion of, a threshold dose or dose rate below which there is no excess disease. Since intakes of plutonium produce dose primarily to bone and liver, a threshold in the dose-response relationship for these cancers would directly impact cleanup standards for DOE sites, and radiation protection standards for workers exposed to plutonium. Using state-of-the-art computer codes developed at Pacific Northwest National Laboratory, we show that current cleanup standards for Pu are too *low* by a factor of 4, and worker protection standards are too low by a factor of 13. This work shows that application of radiation-detriment models that incorporate human data for each individual endpoint should be used in radiation risk estimates and standards-setting.

Introduction

- Cancer is a family of diseases
  - different tissues have different susceptibility to radiation
- *Current* radiation risk models assume
  - various organs and tissues may have different radiosensitivities
  - all follow a linear, nonthreshold (LNT) dose-response relationship
- *Future* radiation risk models
  - more complicated
  - more accurate
  - account for different shaped dose-response relationships for each cancer type
  - some LNT, others nonlinear, still others have thresholds
- Human data are most compelling

The General Linear Model

$$P(n > 0 \mid b, k, D, D_0) = 1 - e^{-(k[D - D_0] + b)}$$

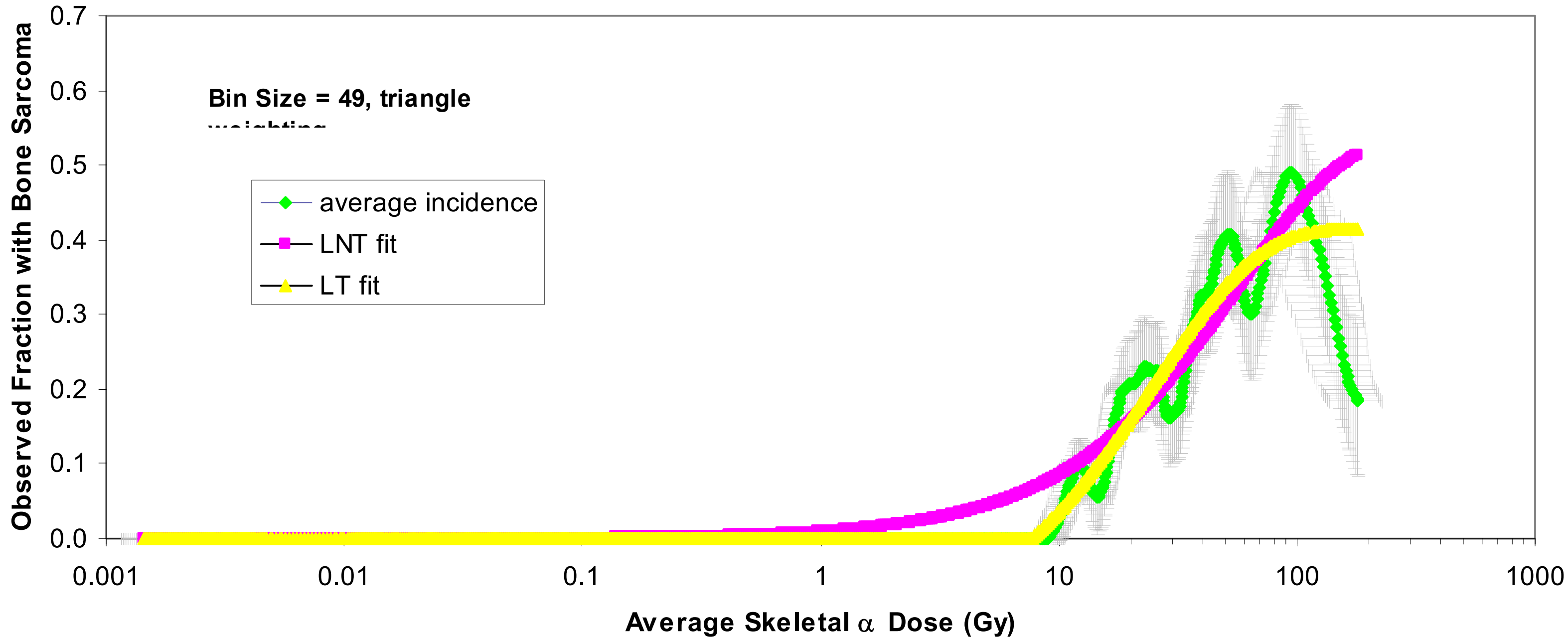
- where
  - P is the probability of occurrence
  - n is the number of tumors in an individual
  - b is the background incidence rate
  - k is the risk per unit dose (Gy^{-1})
  - D is the dose (Gy)
  - D_0 is the threshold dose (Gy)
    - if D_0 is 0, then there's no threshold

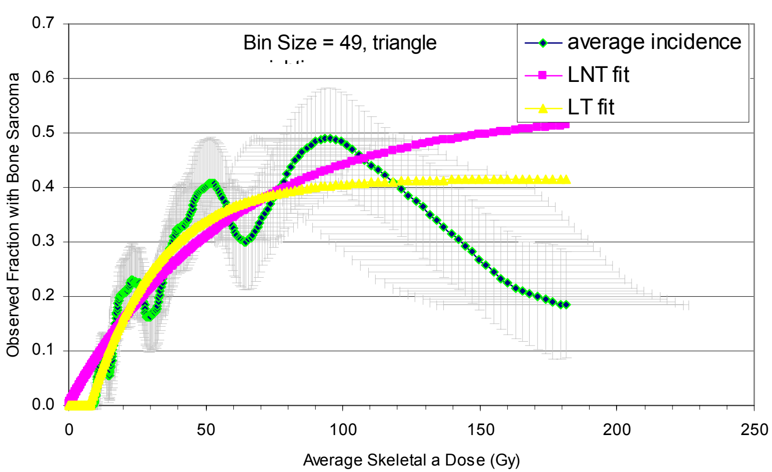
Probable Thresholds

- Human data suggest *dose* & *dose rate* thresholds for
  - Osteosarcoma
    - in Ra dial painters ($D_0 \sim 8$ Gy)
    - in Pu-exposed Mayak workers
  - Liver cancer
    - in Thorotrast patients
    - in Pu-exposed Mayak workers

Model-free data visualization using rolling, weighted averages

2403 Radium Workers

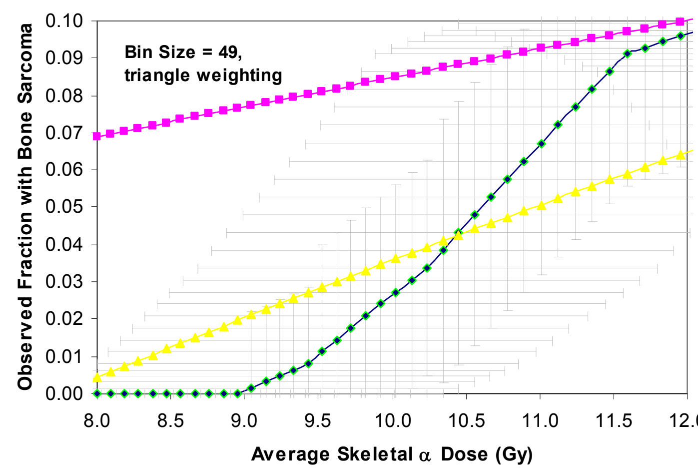




Uncertainty bars:

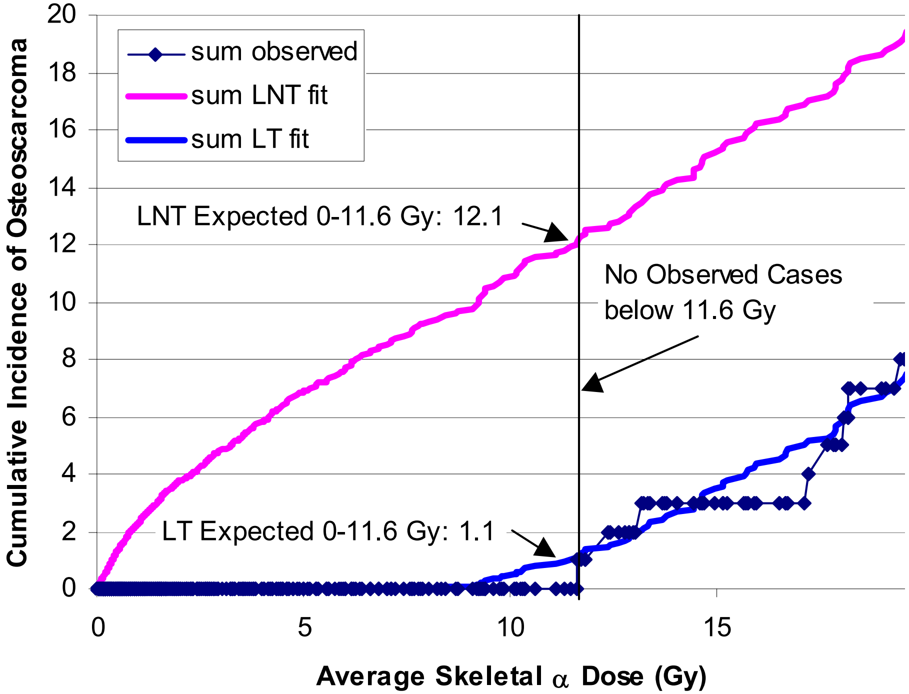
± 1 S.D.

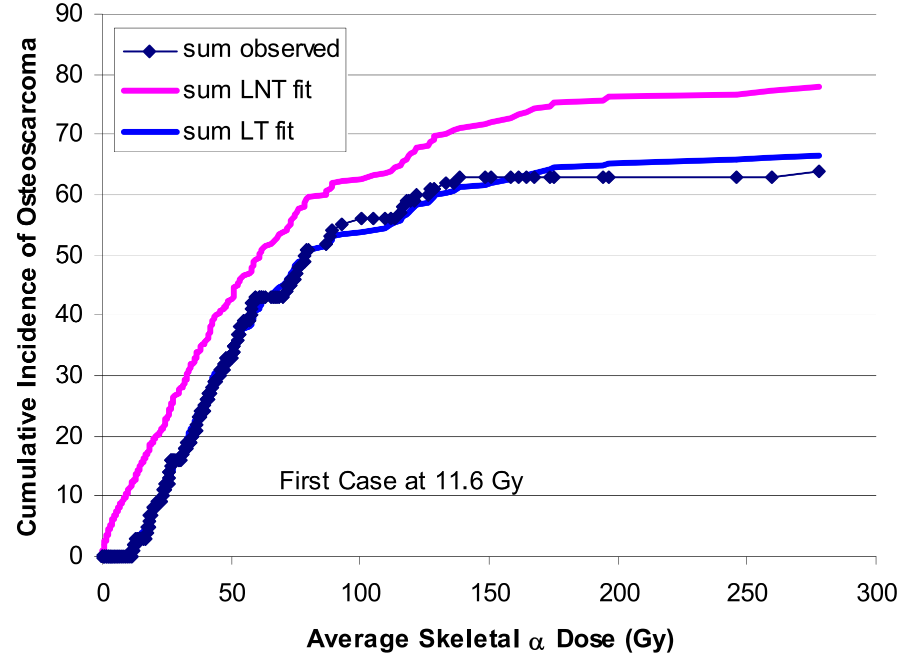
D_0 for LT = 7.73 Gy



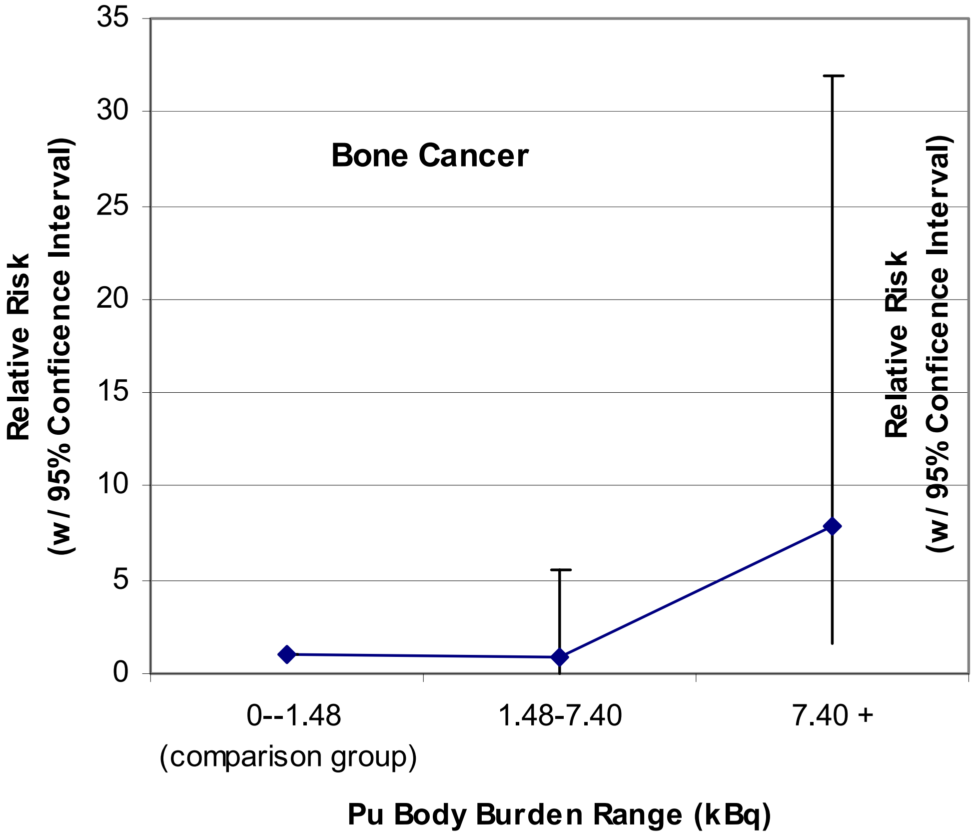
Threshold Likely in Radium Workers

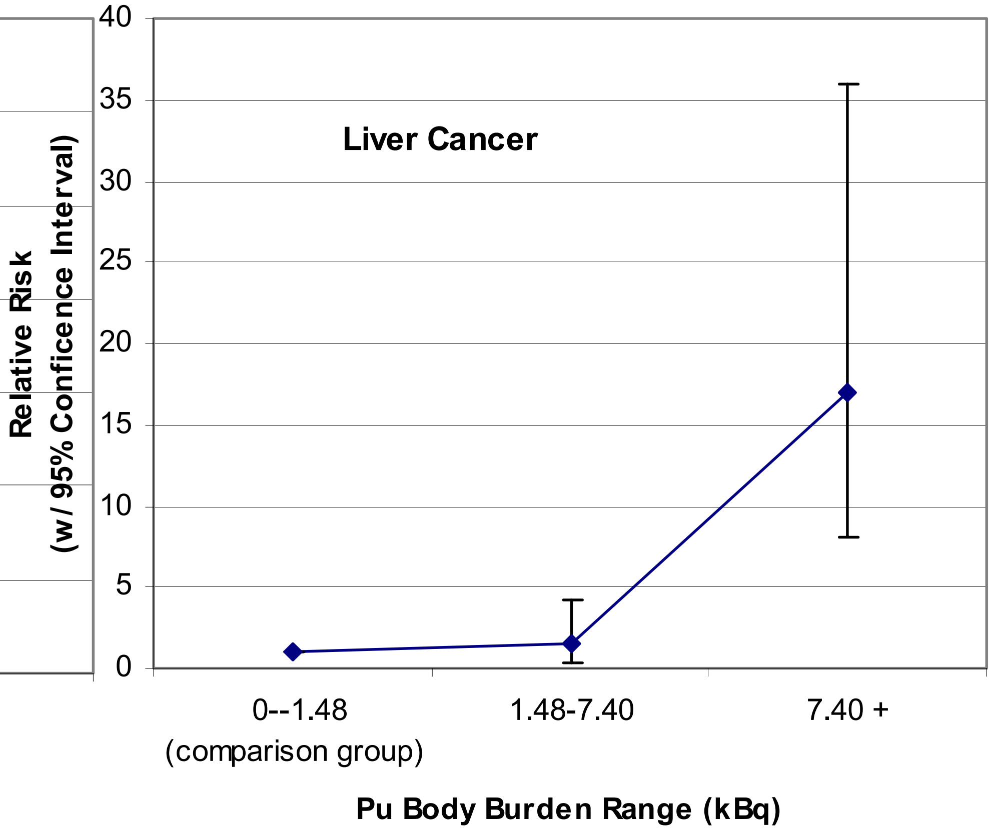
- LNT model predicts 12 cases when 1 is observed
- LNT is not likely to be correct; LT is likely correct



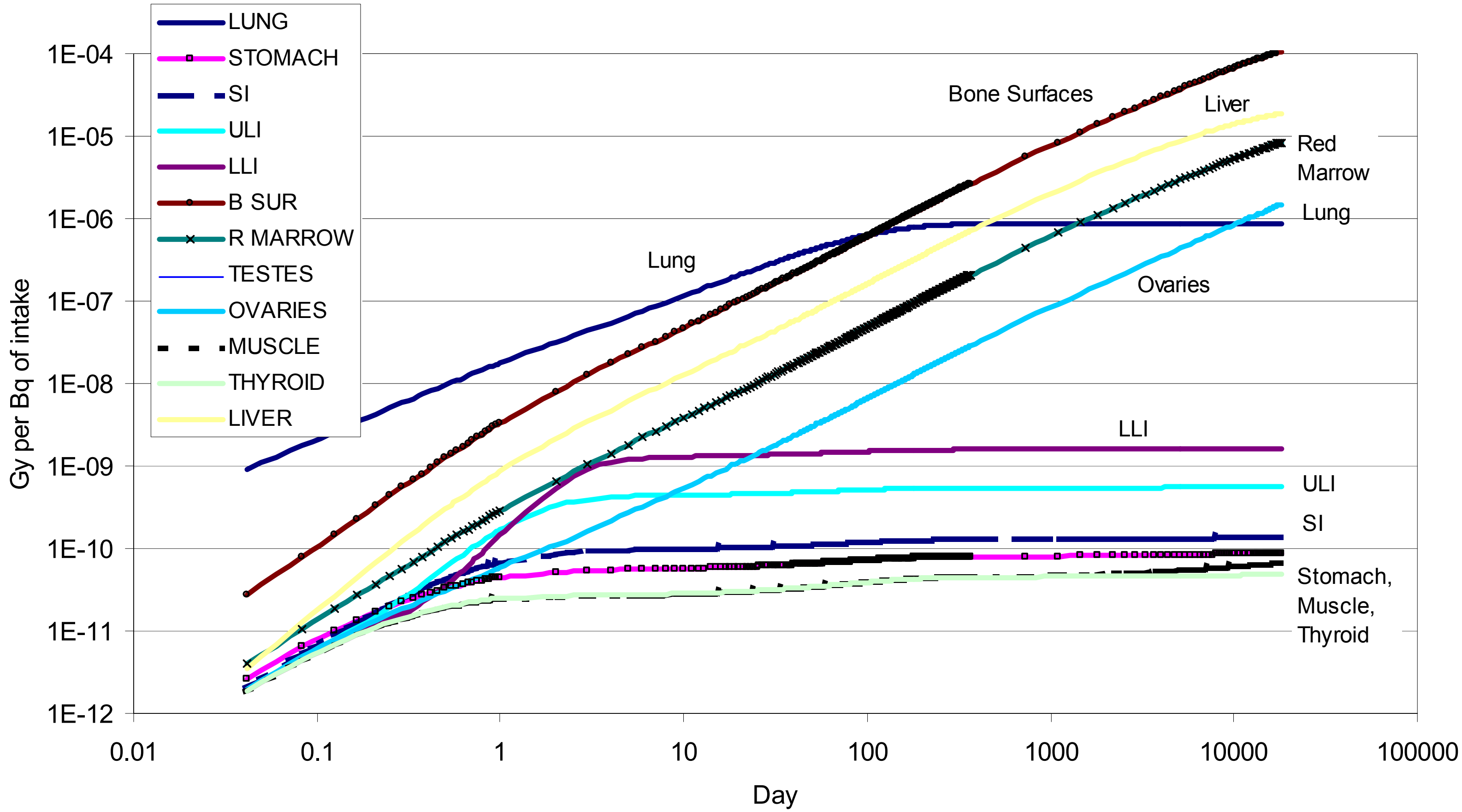


Mayak Workers

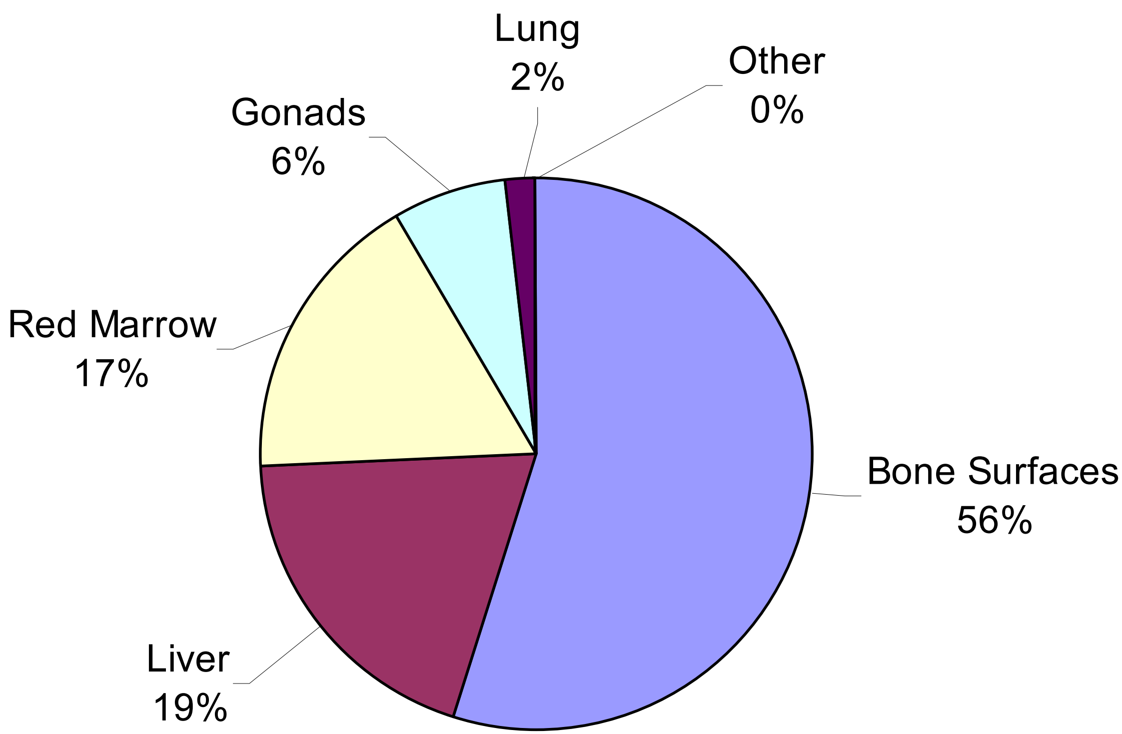




^{239}Pu Organ **Cumulative** Doses, Acute Inhalation, Class W, $f_1 = 0.001$



Fraction of *Effective* Dose to Various Tissues from Inhalation of Plutonium



- bone surfaces and liver account for 75% of *effective* dose
- if there's a threshold, only red marrow, gonads, lung, and "other" matter

Example: Plutonium

- Internal Pu primarily irradiates bone and liver
- If thresholds exist, then only the irradiation that occurs above a certain *dose rate* matters
- Dose, especially committed dose, *alone* does not predict risk in this case
- Must model entire time course of irradiation in each tissue
- There's nothing "linear" about it

Result: Standards for Human Intakes of Plutonium Increase for *Same Risk*

- Cleanup standards *increase* by a factor of 4
  - environmental standards are based on stochastic effects, i.e., limiting 50-year committed effective dose to 0.05 Sv
- Occupational exposure standards *increase* by a factor of 13
  - occupational standards are based on deterministic effects, i.e., limiting 50-year committed dose to bone surfaces to 0.5 Sv (0.025 Gy for a-particles)
- Higher values for cleanup standards result in
  - less cleanup
  - lower cost

Conclusions

- Different cancer endpoints require different dose-response models
- Human data show that cancer dose-response relationships may be
  - LNT (Linear-Nonthreshold)
  - LQ (Linear-Quadratic)
  - LT (Linear-Threshold)
- Using cancer-specific dose-response models can result in more accurate risk estimates
- For plutonium, dramatic savings in cleanup can be realized from using the correct models based on human data

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