A New Look At Radiation Carcinogenesis

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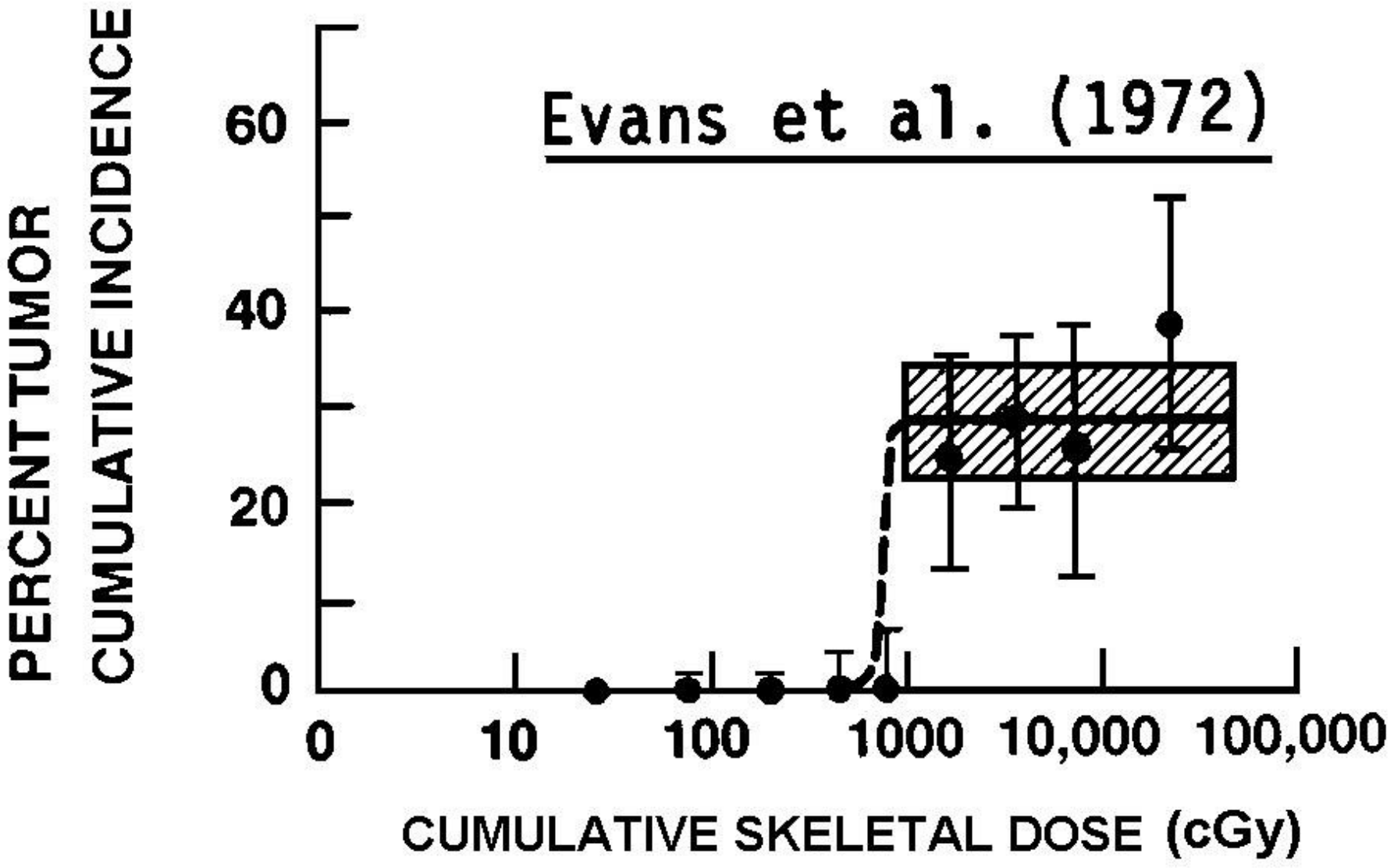
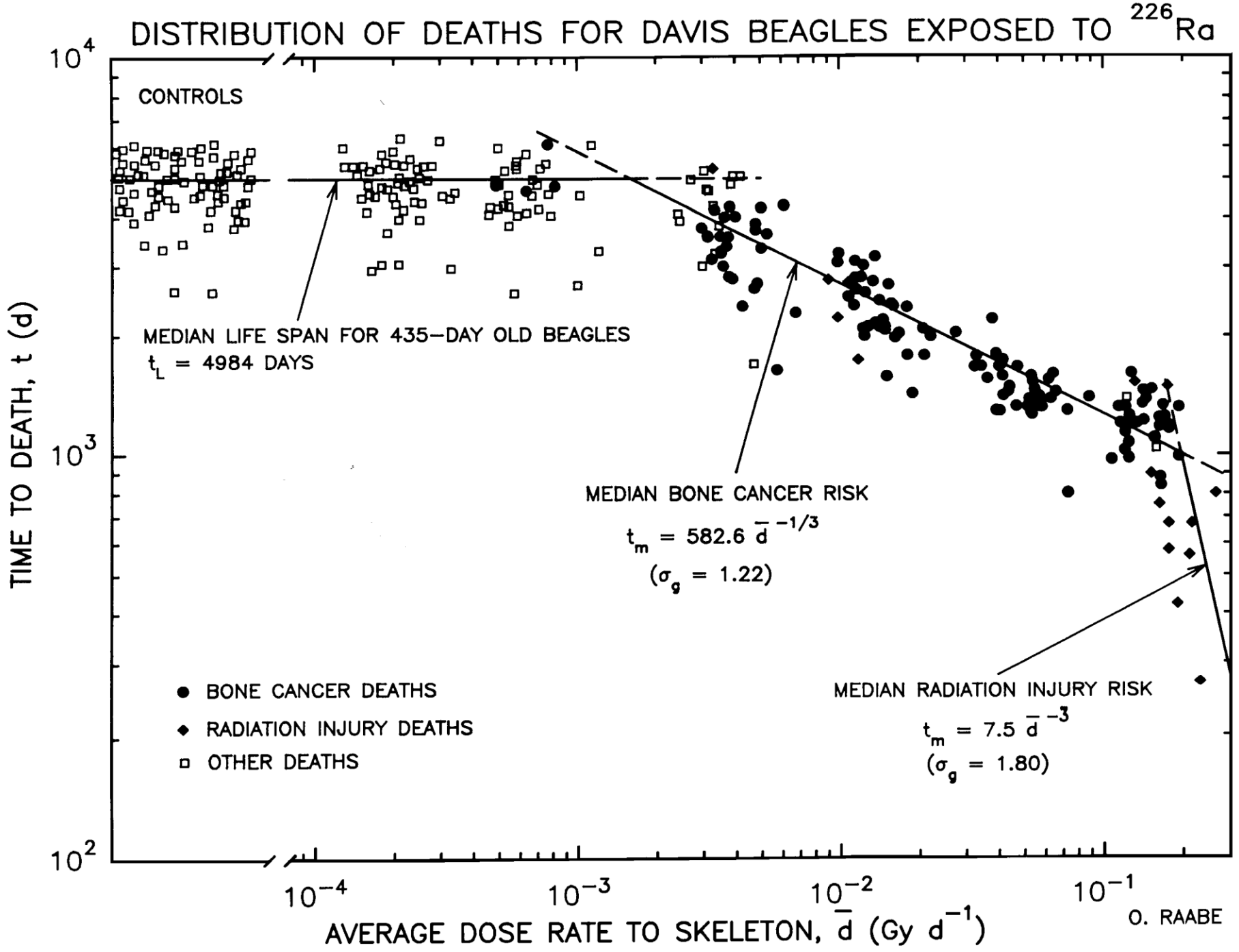
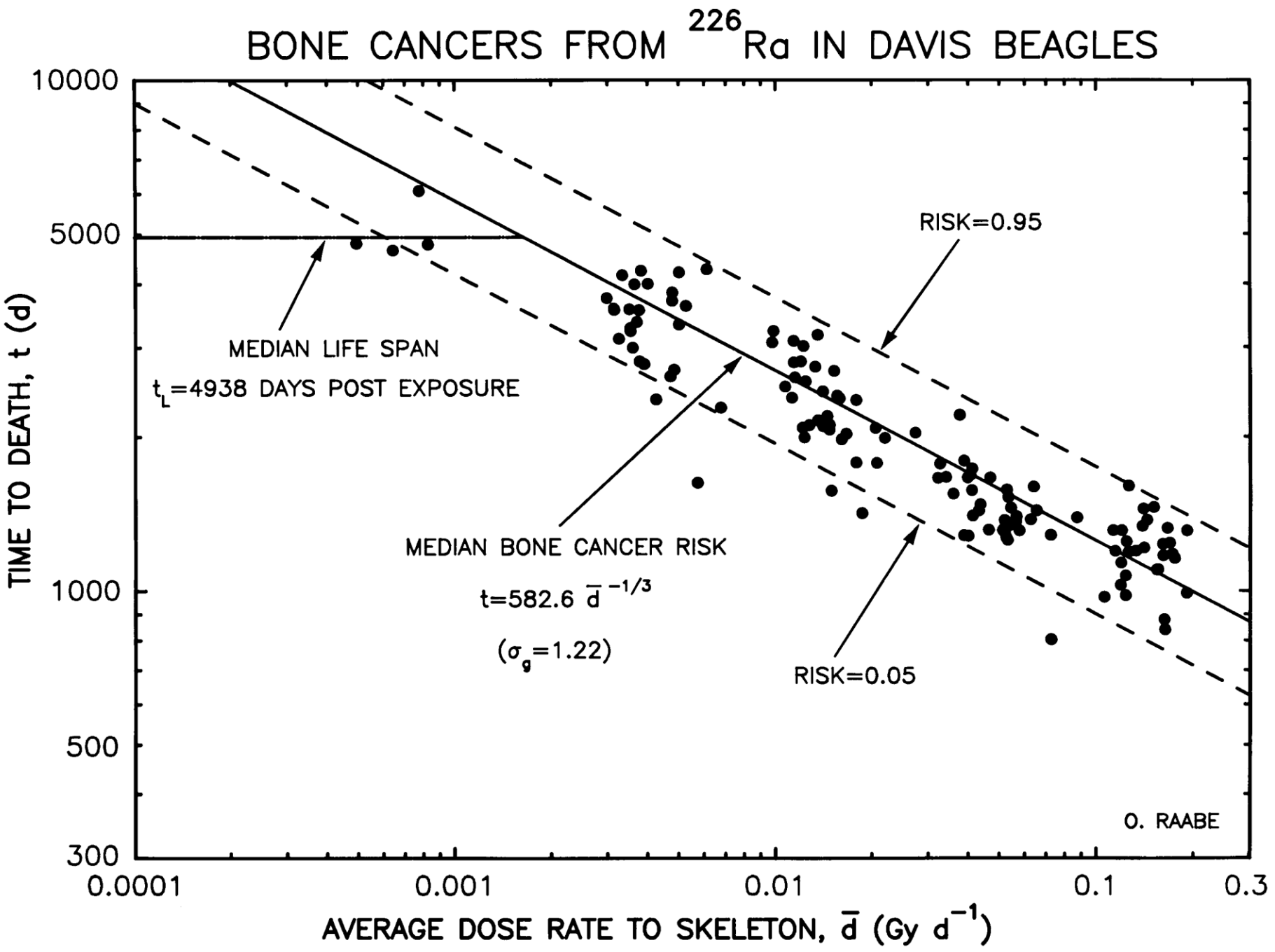
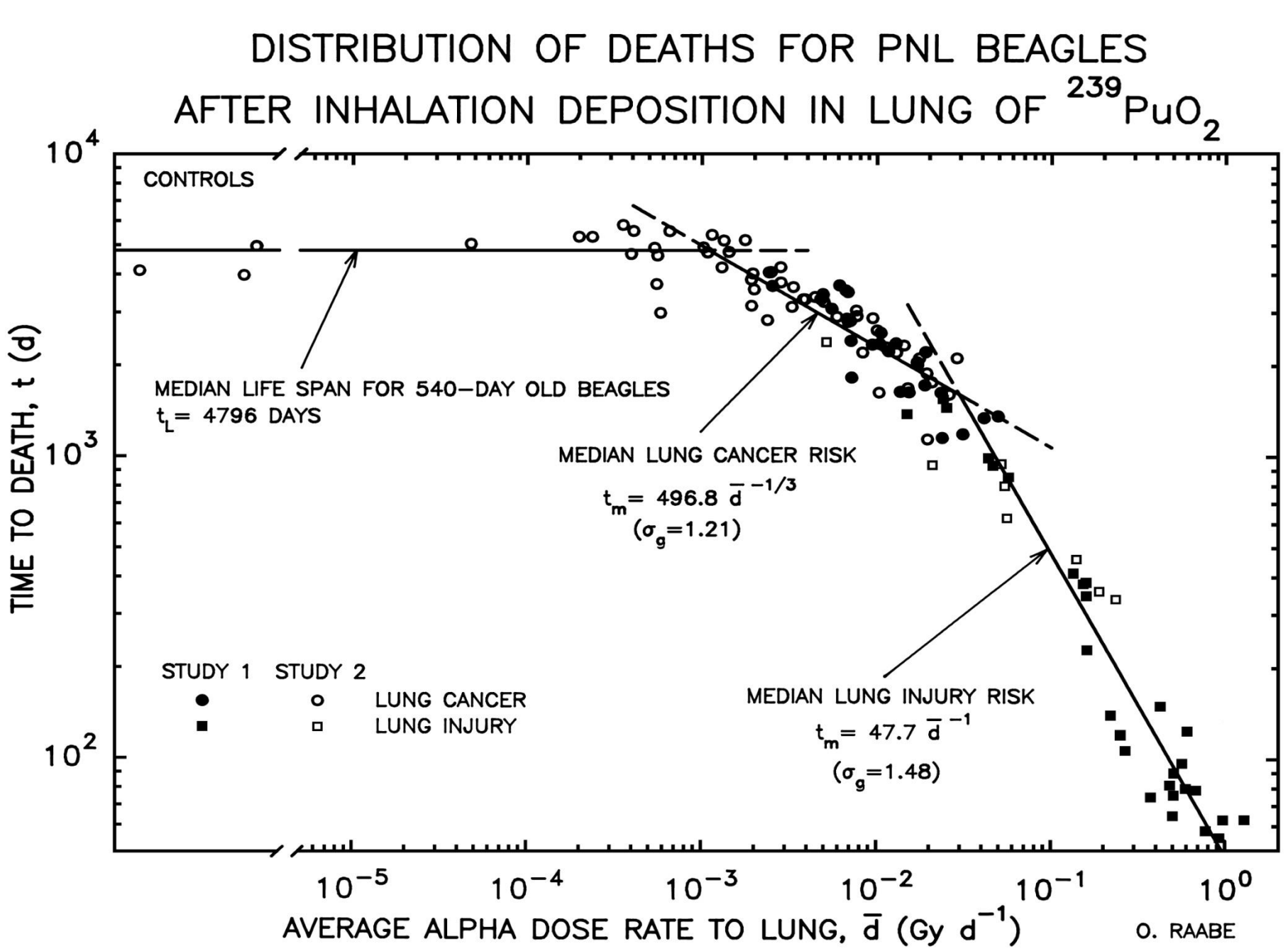
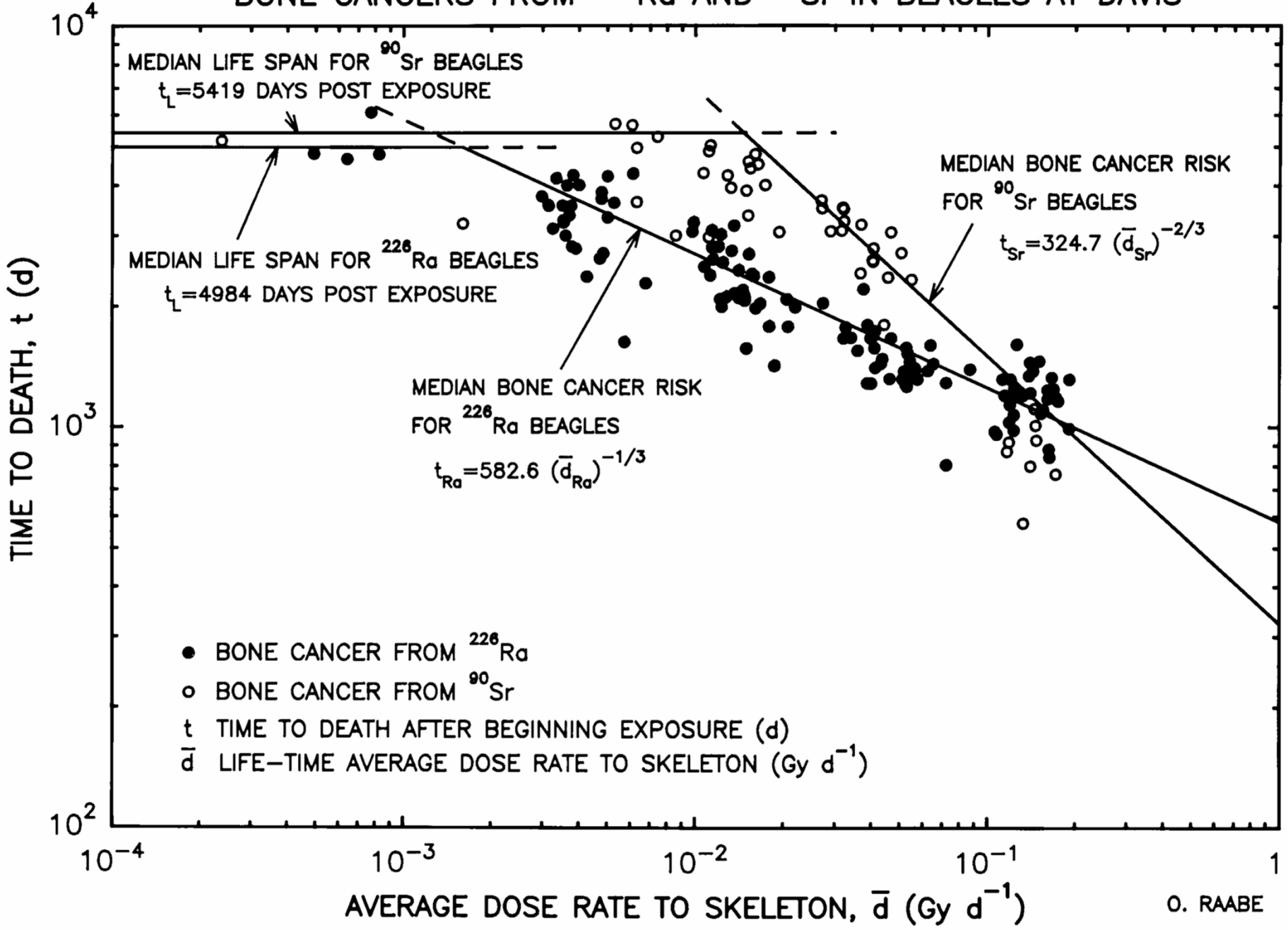
Protracted Exposures To Ionizing Radiation

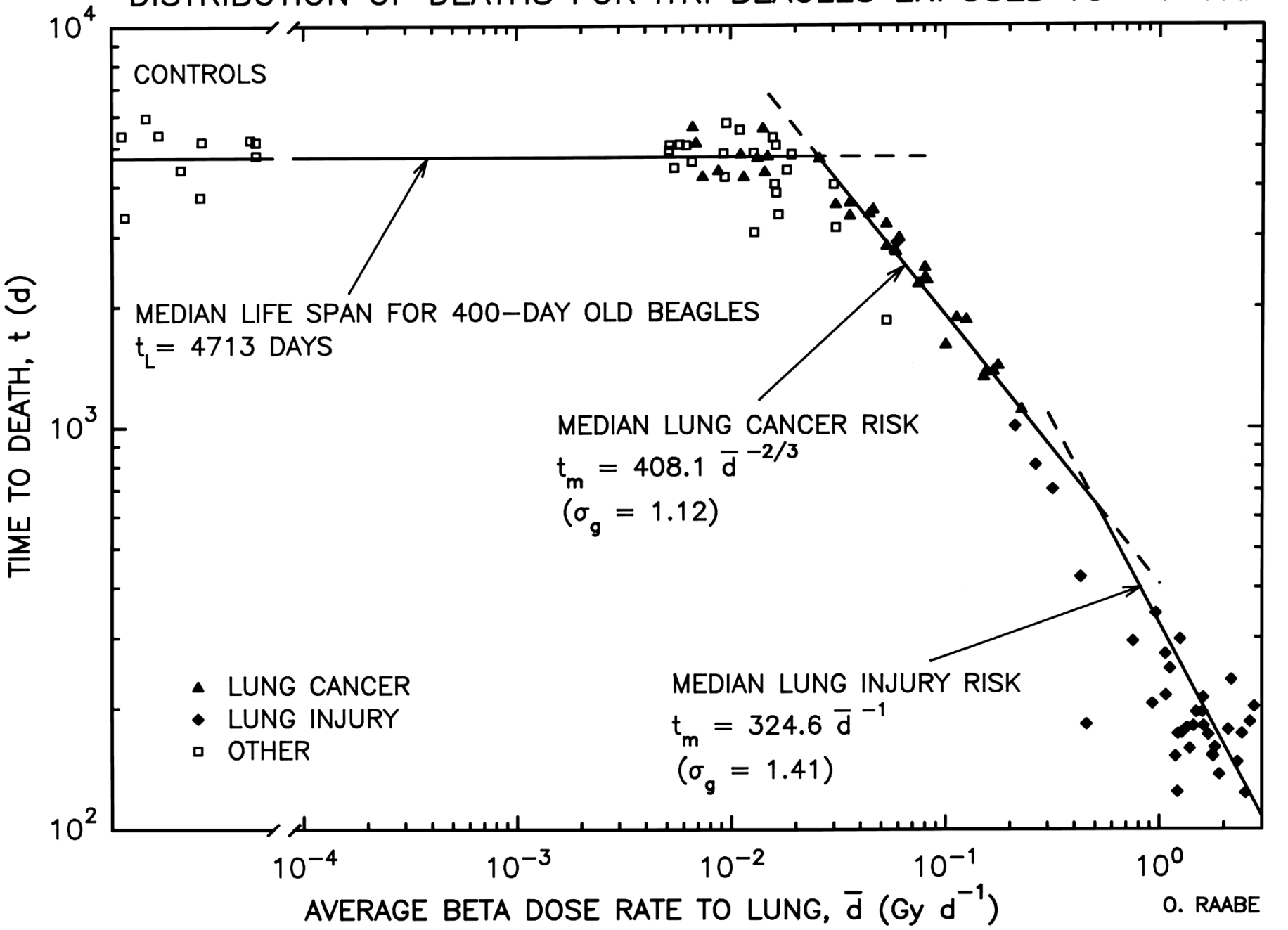

Evans et al. (1972)
PERCENT TUMOR
CUMULATIVE INCIDENCE
60
40
20
0
0
10
100
1000
10,000
100,000
CUMULATIVE SKELETAL DOSE (cGy)

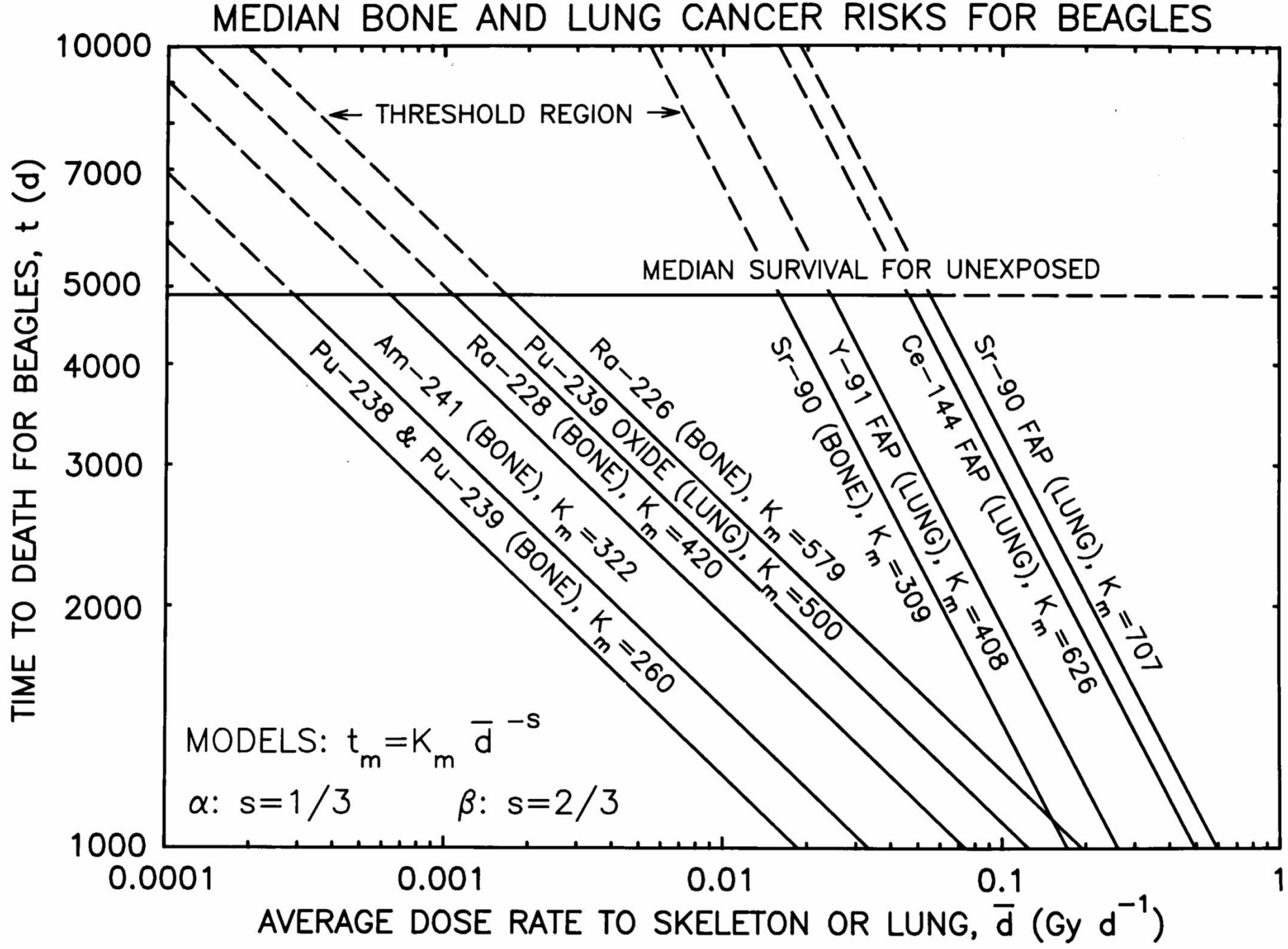

DISTRIBUTION OF DEATHS FOR DAVIS BEAGLES EXPOSED TO ^{226}Ra
CONTROLS
MEDIAN LIFE SPAN FOR 435-DAY OLD BEAGLES
t_L = 4984 DAYS
MEDIAN BONE CANCER RISK
$t_m = 582.6\ \bar{d}^{-1/3}$
(σ_g = 1.22)
MEDIAN RADIATION INJURY RISK
$t_m = 7.5\ \bar{d}^{-3}$
(σ_g = 1.80)
BONE CANCER DEATHS
RADIATION INJURY DEATHS
OTHER DEATHS
TIME TO DEATH, t (d)
10^4
10^3
10^2
10^{-4}
10^{-3}
10^{-2}
10^{-1}
AVERAGE DOSE RATE TO SKELETON, $\bar{d}$ (Gy d^{-1})
O. RAABE

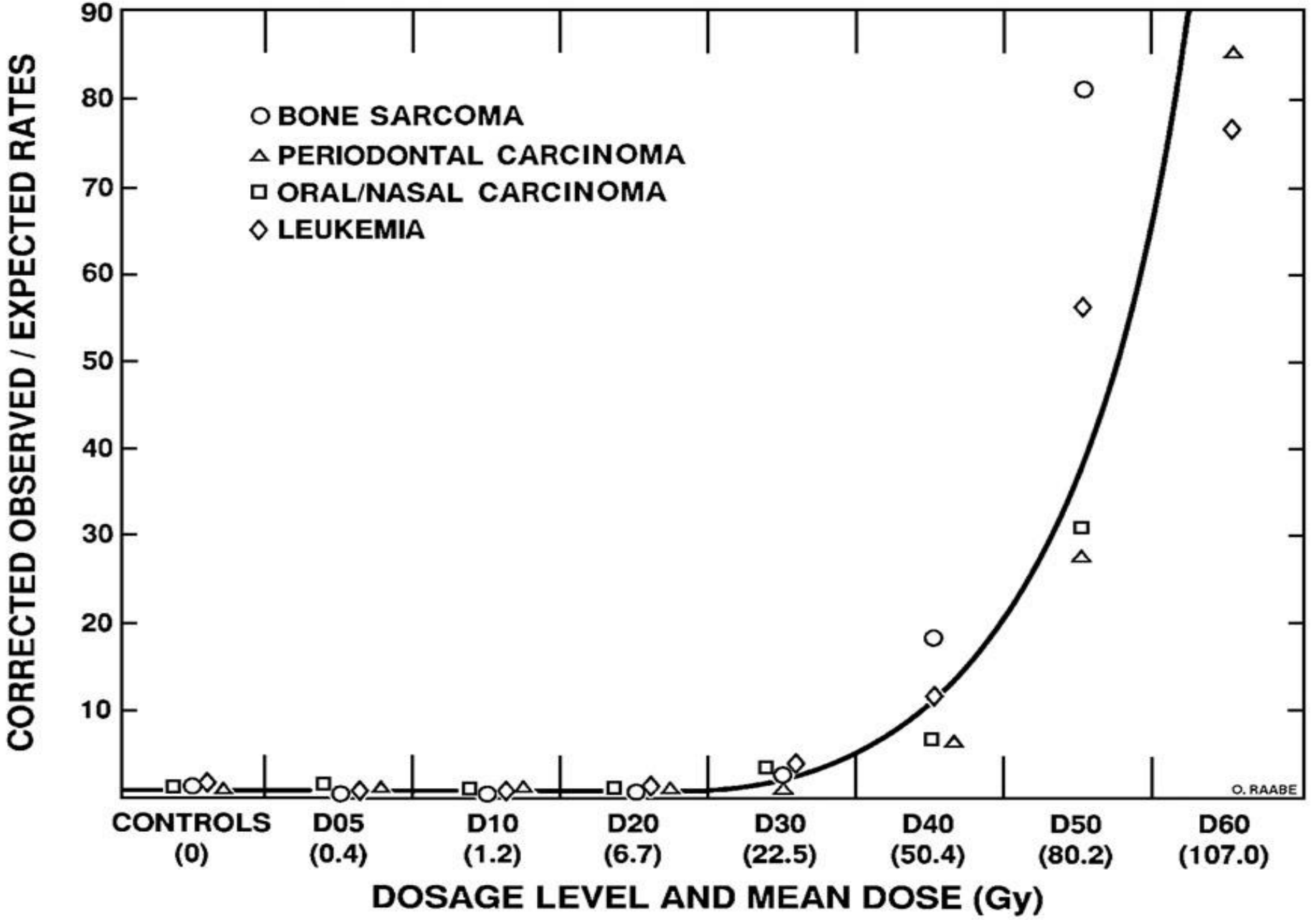

BONE CANCERS FROM ^{226}Ra IN DAVIS BEAGLES
10000
5000
1000
500
300
TIME TO DEATH, t (d)
RISK=0.95
MEDIAN LIFE SPAN
t_L=4938 DAYS POST EXPOSURE
MEDIAN BONE CANCER RISK
$t=582.6\ \bar{d}^{-1/3}$
(σ_g=1.22)
RISK=0.05
O. RAABE
0.0001
0.001
0.01
0.1
0.3
AVERAGE DOSE RATE TO SKELETON, $\bar{d}$ (Gy d^{-1})


DISTRIBUTION OF DEATHS FOR PNL BEAGLES
AFTER INHALATION DEPOSITION IN LUNG OF $^{239}PuO_2$
CONTROLS
MEDIAN LIFE SPAN FOR 540–DAY OLD BEAGLES
t_L = 4796 DAYS
MEDIAN LUNG CANCER RISK
$t_m = 496.8\ \bar{d}^{-1/3}$
(σ_g=1.21)
MEDIAN LUNG INJURY RISK
$t_m = 47.7\ \bar{d}^{-1}$
(σ_g=1.48)
STUDY 1 STUDY 2
LUNG CANCER
LUNG INJURY
TIME TO DEATH, t (d)
10^4
10^3
10^2
10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^0
AVERAGE ALPHA DOSE RATE TO LUNG, $\bar{d}$ (Gy d^{-1})
O. RAABE


BONE CANCERS FROM 226Ra AND 90Sr IN BEAGLES AT DAVIS
MEDIAN LIFE SPAN FOR 90Sr BEAGLES
tL=5419 DAYS POST EXPOSURE
MEDIAN LIFE SPAN FOR 226Ra BEAGLES
tL=4984 DAYS POST EXPOSURE
MEDIAN BONE CANCER RISK FOR 90Sr BEAGLES
tSr=324.7 (d̄Sr)−2/3
MEDIAN BONE CANCER RISK FOR 226Ra BEAGLES
tRa=582.6 (d̄Ra)−1/3
BONE CANCER FROM 226Ra
BONE CANCER FROM 90Sr
t TIME TO DEATH AFTER BEGINNING EXPOSURE (d)
d̄ LIFE–TIME AVERAGE DOSE RATE TO SKELETON (Gy d−1)
TIME TO DEATH, t (d)
AVERAGE DOSE RATE TO SKELETON, d̄ (Gy d−1)
O. RAABE


DISTRIBUTION OF DEATHS FOR ITRI BEAGLES EXPOSED TO ^{91}Y–FAP
CONTROLS
MEDIAN LIFE SPAN FOR 400–DAY OLD BEAGLES
t_L = 4713 DAYS
MEDIAN LUNG CANCER RISK
$t_m = 408.1\ \bar{d}^{-2/3}$
(σ_g = 1.12)
MEDIAN LUNG INJURY RISK
$t_m = 324.6\ \bar{d}^{-1}$
(σ_g = 1.41)
LUNG CANCER
LUNG INJURY
OTHER
TIME TO DEATH, t (d)
10^4
10^3
10^2
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^0
AVERAGE BETA DOSE RATE TO LUNG, $\bar{d}$ (Gy d^{-1})
O. RAABE


MEDIAN BONE AND LUNG CANCER RISKS FOR BEAGLES
THRESHOLD REGION
MEDIAN SURVIVAL FOR UNEXPOSED
Ra-226 (BONE), K_m=579
Pu-239 OXIDE (LUNG), K_m=500
Ra-228 (BONE), K_m=420
Am-241 (BONE), K_m=322
Pu-238 & Pu-239 (BONE), K_m=260
Sr-90 (BONE), K_m=309
Y-91 FAP (LUNG), K_m=408
Ce-144 FAP (LUNG), K_m=626
Sr-90 FAP (LUNG), K_m=707
MODELS: $t_m = K_m \bar{d}^{-s}$
α: s=1/3 β: s=2/3
TIME TO DEATH FOR BEAGLES, t (d)
10000
7000
5000
4000
3000
2000
1000
0.0001
0.001
0.01
0.1
1
AVERAGE DOSE RATE TO SKELETON OR LUNG, $\bar{d}$ (Gy d^{-1})


INCIDENCE OF FATAL CANCER IN BEAGLES FED 90Sr
CORRECTED OBSERVED / EXPECTED RATES
90
80
70
60
50
40
30
20
10
BONE SARCOMA
PERIODONTAL CARCINOMA
ORAL/NASAL CARCINOMA
LEUKEMIA
O. RAABE
CONTROLS (0)
D05 (0.4)
D10 (1.2)
D20 (6.7)
D30 (22.5)
D40 (50.4)
D50 (80.2)
D60 (107.0)
DOSAGE LEVEL AND MEAN DOSE (Gy)

RADIATION INDUCED CANCER

- Cancer Induction depends of lifetime average dose rate to the target organ.
- Cancer induction risk is not proportional to cumulative dose.
- Low dose rates yield a life span virtual threshold (cumulative doses <10 Sv).

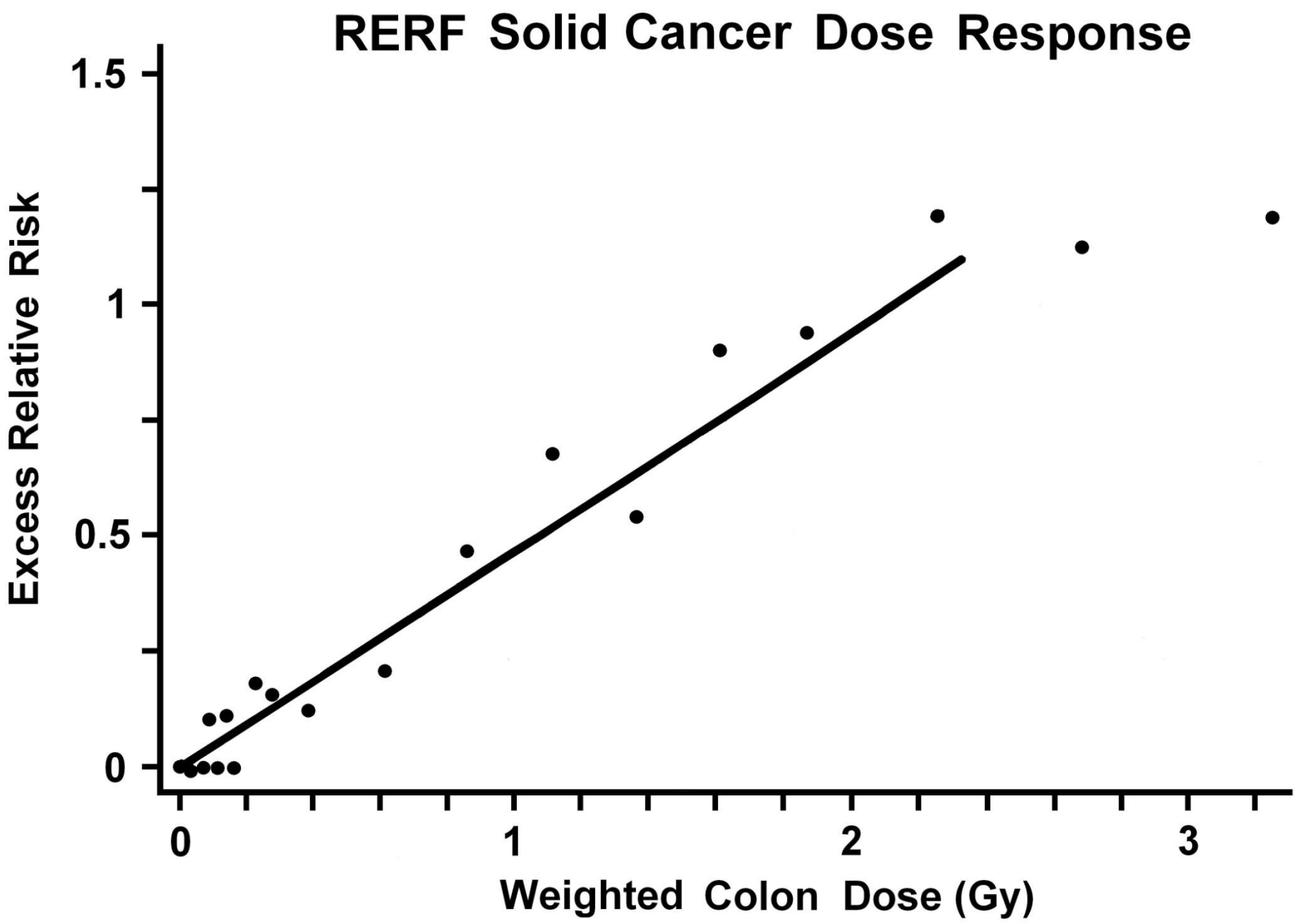
Acute Exposures To Ionizing Radiation

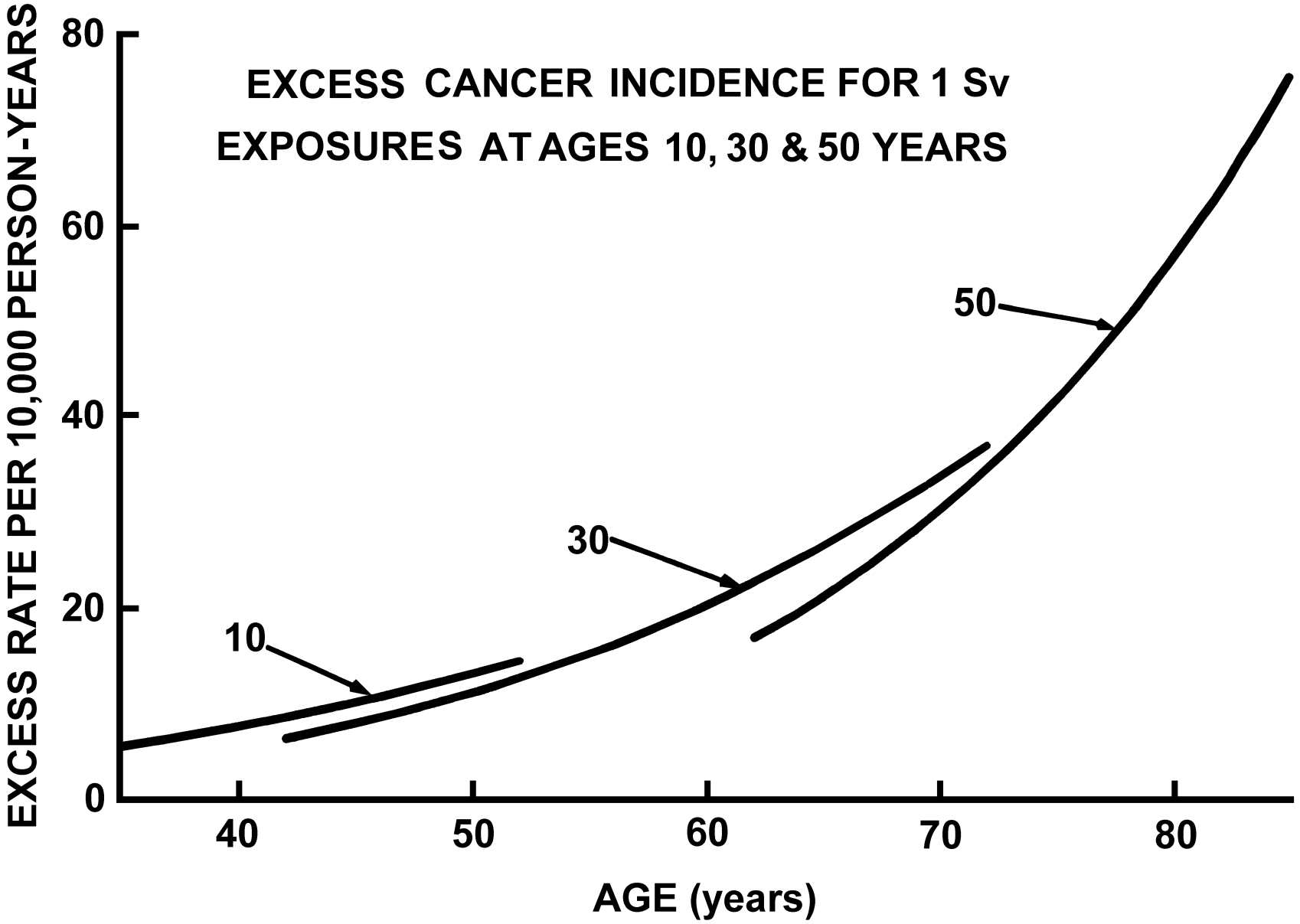
Atomic Bomb Survivor Studies

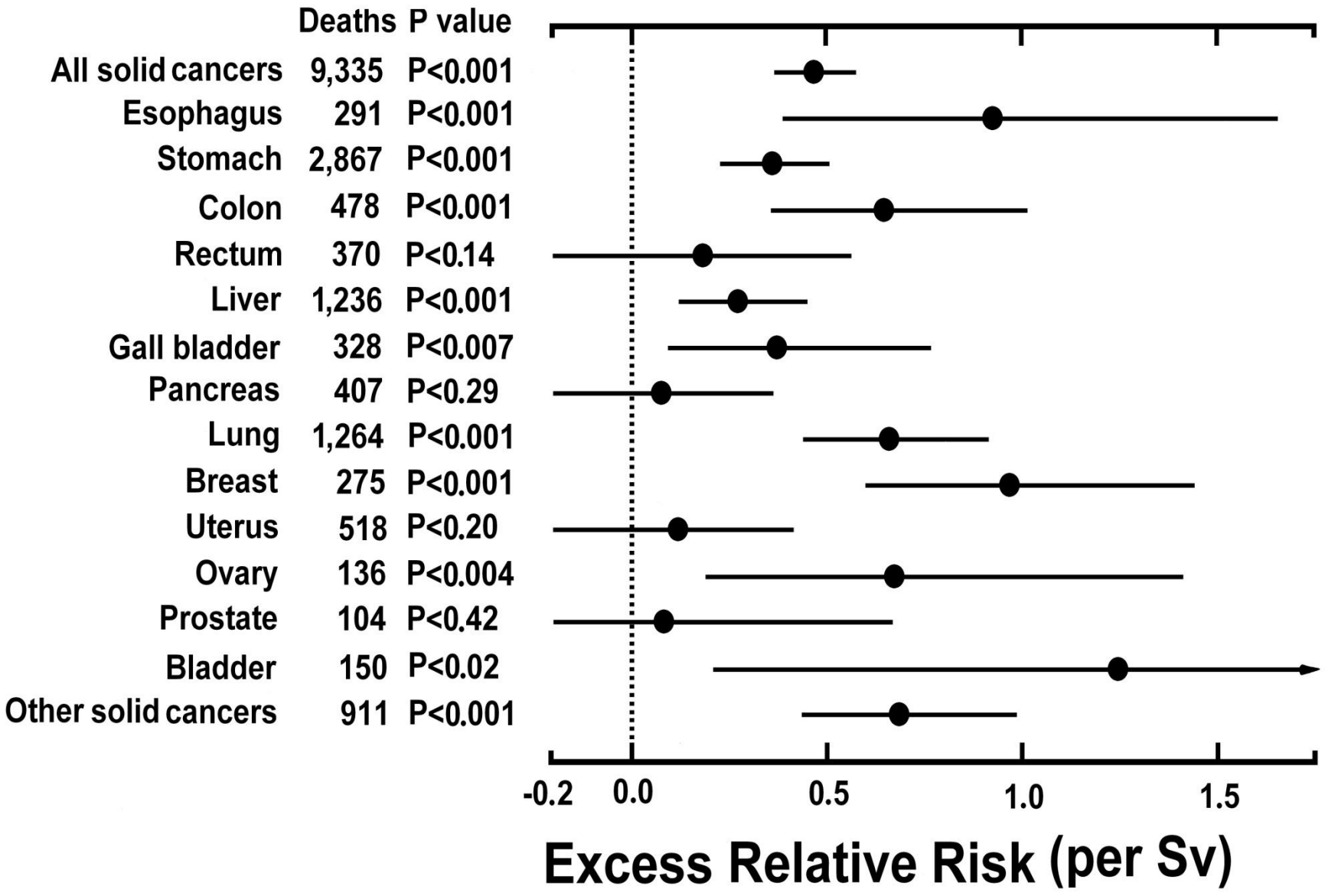
- Radiation Effects Research Foundation,**RERF**
- 79,972 survivors with calculated rad doses
- 44,636 survivors with doses > 0.005 Sv

Solid Cancer Incidence in Atomic Bomb Survivors: 1958-1998, Preston, Ron, Tokuoka, Funamoto, Nishi, Soda, Mabuchi, Kodama,

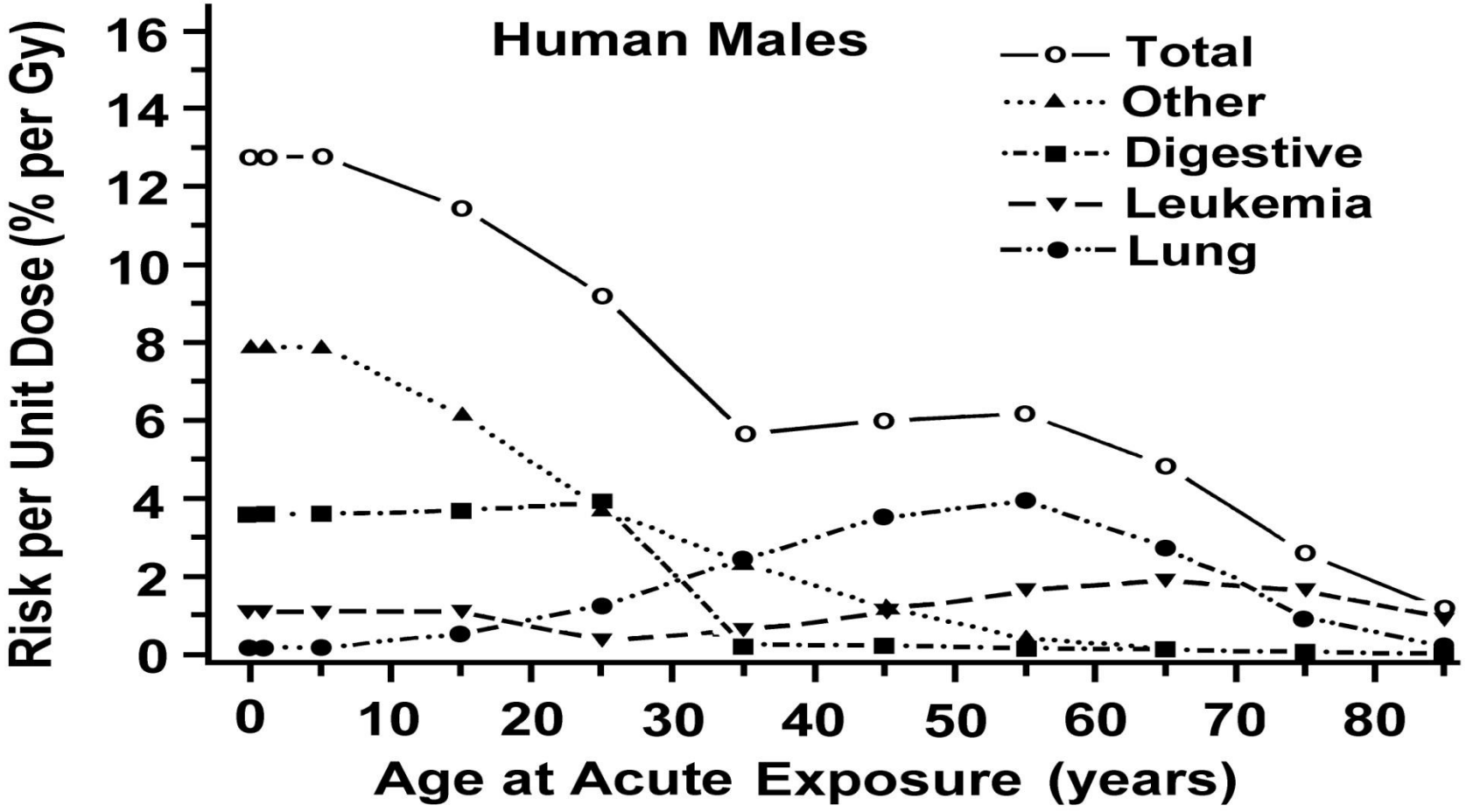
Radiat. Res. 168, 1-64 (2007).


RERF Solid Cancer Dose Response
Excess Relative Risk
1.5
1
0.5
0
0
1
2
3
Weighted Colon Dose (Gy)


EXCESS CANCER INCIDENCE FOR 1 Sv
EXPOSURES AT AGES 10, 30 & 50 YEARS
EXCESS RATE PER 10,000 PERSON-YEARS
0
20
40
60
80
40
50
60
70
80
AGE (years)
10
30
50


Deaths P value
All solid cancers 9,335 P<0.001
Esophagus 291 P<0.001
Stomach 2,867 P<0.001
Colon 478 P<0.001
Rectum 370 P<0.14
Liver 1,236 P<0.001
Gall bladder 328 P<0.007
Pancreas 407 P<0.29
Lung 1,264 P<0.001
Breast 275 P<0.001
Uterus 518 P<0.20
Ovary 136 P<0.004
Prostate 104 P<0.42
Bladder 150 P<0.02
Other solid cancers 911 P<0.001
-0.2
0.0
0.5
1.0
1.5
Excess Relative Risk (per Sv)

- A-Bomb Survivor Risk for 1 Gy Exposure
- Age 5: 13%/80 y; Age 25: 9.5%/60 y;
- Age 45: 6.5%/40 y. ALL = 0.16% per year



CANCER INDUCTION IS NOT PROPORTIONAL TO DOSE

- A-Bomb cancer promotion data for a very high dose-rate instantaneous exposure cannot be used to estimate cancer induction risk from protracted exposures to ionizing radiation.

- Liner models to currently used by the International Commission on Radiological Protection and the U.S. Environmental Protection Agency are not valid.

References

- **Raabe, OG: Concerning the Health Effects of Internally Deposited Radionuclides, Health Phys. 98: 515-536; 2010.**

- **Raabe, OG: Toward Improved Ionizing Radiation Safety Standards, Health Phys. 101: 84 -93; 2011.**


THE END
CHRYSLER
300
M
SILVER OAK
DEC
California
2009
NUCLIDE
LIFE IS A CABERNET