LNT, LWT, SNT and the Radium Dial Painters

Jack Devanney

Many SARI members advocate a Linear With Threshold (LWT) model of radiation harm. Such a model requires:

1. A threshold dose below which there is zero harm.
2. A "repair period". The exposure period to which the threshold refers.
3. A slope for the straight line portion of the response.

Under intense interrogation, SARI members came up with a threshold of 100 mSv over 3 days. Rather than further harass SARI, I assumed a slope of 1.1 times the LNT slope without DDREF. In other words, the LWT slope was based on getting to the LNT harm at 1 Sv.

Figure 1 compares LNT, this LWT, and SNT on the dial painters data. Since both LWT and SNT need a a dose rate profile rather than just the cumulative dose, I assumed the dial painters dose was received evenly over 10 years. This is almost certainly conservative. The real dose profile was almost certainly spikier. But it is about the best we can do.

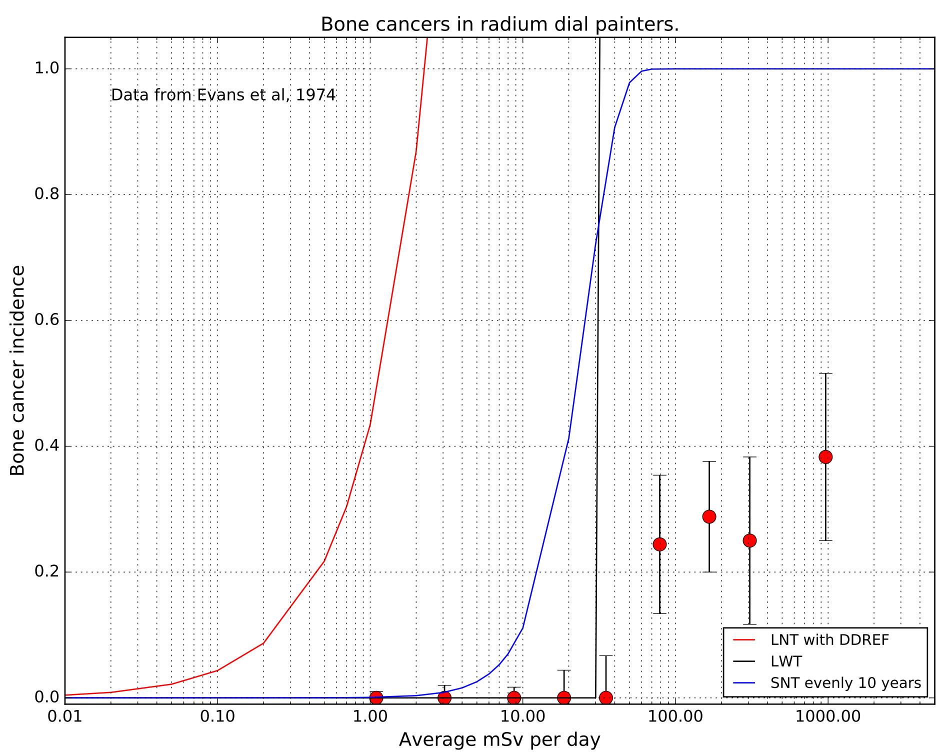

Figure 1: Radium Dial Painter Bone Cancer versus Dose Rate

LNT is hopelessly pessimistic. SNT is within the errors bars up to about 3 mSv/d, but then jumps up to over 80% incidence around 40 mSv/d. The actual jump takes place between about 40 mSv/d and 80 mSv/d and the incidence never get above 40%. LWT is zero to 33 mSv/d and then jumps into the stratosphere. On a log scale, the line looks vertical. You will just have to take my word that it is not.

Up to about 2 mSv per day, the differences between LWT and SNT are statistically negligible LWT does a better job of matching the data between 2 mSv/d and the threshold. Above about 1.5 MICROsieverts per day above the threshold, LWT comes up with cancer incidences above 100% which is nonsensical.

A practical problem with this strange behavior is it pretty much disqualifies LWT as a base for an exposure compensation program. Either you compensation is zero or its through the roof. If I were a thresholder, I would abandon the L in LWT and opt for a more reasonable curve above the threshold.

One lesson I draw from this is SNT could use a sharper lower hook. This may be possible by using a Richards variation of the logistic. I intend to try fitting a Richards curve to the RERF data.

The Low End It is important that we focus on the low end of the mSv/d range. That's where nearly all real world, non-medical exposures are. Figure 2 is the log-log version of Figure 1. It makes the point that at the low end, the relative differences in the three models are very large: infinite in the case of LWT below the threshold. Once again LWT looks like a vertical line.

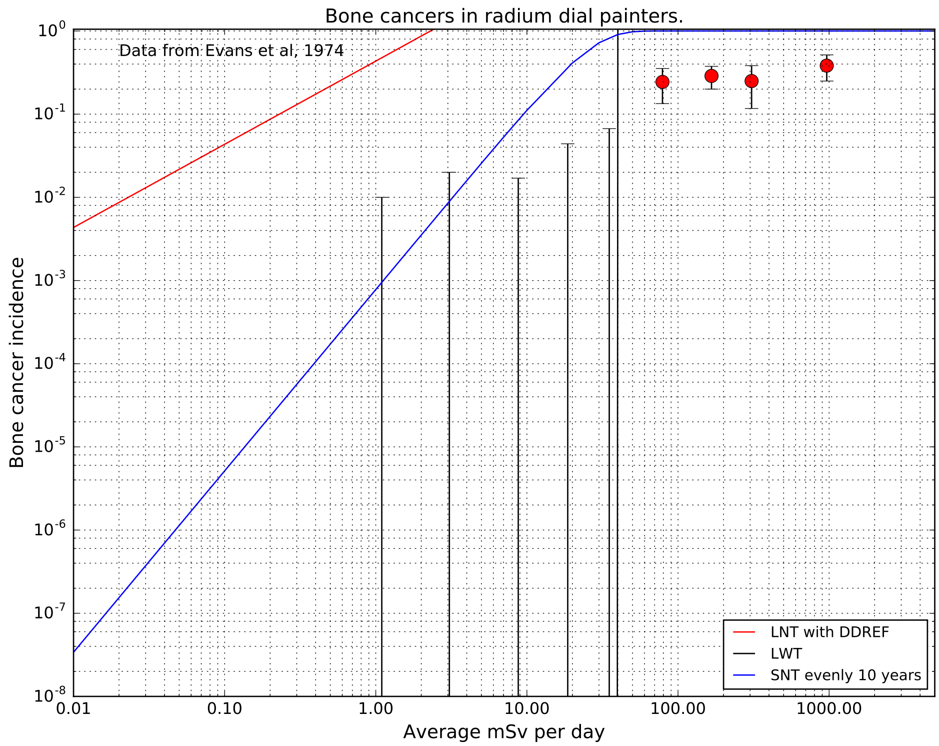

Figure 2: Log-log Radium Dial Painter Bone Cancer versus Dose Rate

But there is a very important difference between the relative difference between LNT and SNT and the relative difference between SNT and LWT. In a release, the dose rate will be above 1 mSv/d for at most a few weeks, and only close to the plant. Figure 3 shows an estimate of the high end profile in Namie, a town very close to Fukushima Daiichi and in the path of the worst plume. The SNT cancer mortality is 0.016% with an LLE of less than a day. The LNT cancer mortality is 12% with an LLE of 519 days. The LWT cancer mortality for this profile is zero. The SNT/LNT difference is 518 days. The SNT/LWT difference is 0.7 days. The SNT/LNT difference is manifestly significant. The SNT/LWT difference is in the noise.

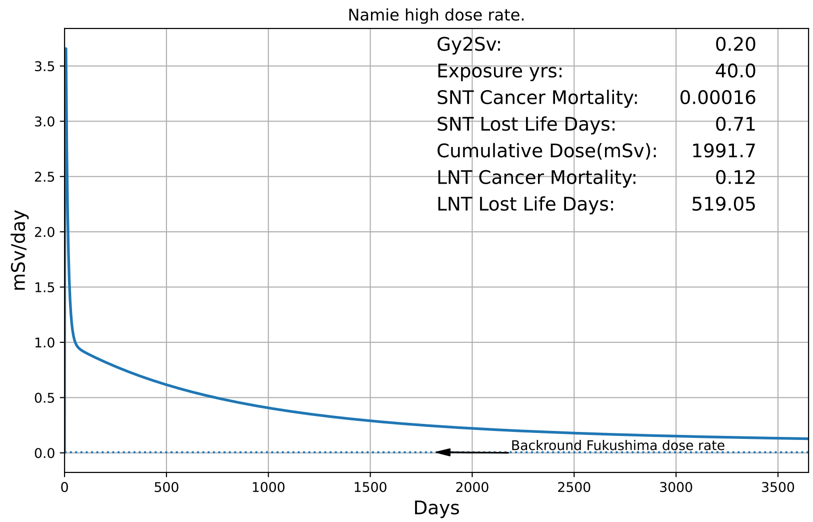

Figure 3: Namie High End Dose Rate Profile

The Top End The top end in of Figure 1 needs our attention. Instead of going to 1.0, the cancer incidence/mortality levels off below 0.5. This is not a fluke. We see the same phenomemon in the RERF data, and in childhood thyroid cancer at Chernobyl. I don't know why; but I think it's real. It's possible that really high dose rate radiation kills people before they have a chance to develop cancer. In which case, the radiation harm models should go to 1.00. But this clearly is not the case for thyroid cancer at Chernobyl. All I know is, this can'be ignored, as it currently is in all three models.

Other High Dose Populations Another way to compare SNT and LWT is via Table 1. When a daily dose is repeated for scores of consecutive days or more, we start seeing signs of increased cancer in the 20 to 30 mSv/day range. I call your attention to childhood cancer at Chernobyl and Evans study of the Radiothor and other radium imbibers. The current version of SNT is clearly too conservative. But the version of LWT under study is pretty aggressive. It we were to use it to set regulatory limits, we'd probably want something like a factor of ten margin, which would put us in the 10 mSv per 3 day (3 mSv/day) range. This is quite close to the 2009 Allison recommendation. This also happens to be rather close to the pre-1950 tolerance dose of 2 mSv/d, which is the GKG's proposal.

Single acute dose above top horizontal line; repeated doses below. Belarus/Ukraine kids: thyroid dose

Group	Size	Period	Cumulative dose mSv	Dose rate mSv/day	Result
Atom bomb survivors					
Leuk 5-150[16]	33,459	seconds	5 to 150	5 to 150	Insignificant decrease in leukemia
Leuk 150-300[16]	5,463	seconds	150 to 300	150 - 300	Insignificant increase in leukemia.
Leuk 300+[16]	6,793	seconds	300-5000+	300-5000+	Significant increase in leukemia.
Solid 5-20[2]	14,555	seconds	5 to 20	5 to 20	Insignificant decrease in solid cancers.
Solid 20-40[2]	6,411	seconds	20 to 40	20 to 40	Solid cancers same as control
Solid 40-125[2]	10,970	seconds	40 to 125	40 to 125	Insignificant increase in solid cancers.
Solid 125+[2]	16,166	seconds	125+	125+	Significant increase in solid cancers.
Louis Slotin[11]	1	seconds	21000	21000	Died in 9 days
H. Daghlian[11]	1	seconds	5900	5900	Died in 25 days
Norway tech[5]	1	< hour	38500	38500	Died in 13 days
Tokaimura[11]	3	seconds	3000-17000	3000-17000	>10,000 mSv died
Goiania[7]	≈46	hrs or less	1000-6000	1000-6000	50% mortality abv 4000 mSv
Thai scrap[8]	≈10	hrs or less	1000-6000	1000-6000	100% mortality abv 6000 mSv
Chern firemen+[17]	134	<2 hrs	1000-16000	1000-16000	Sigmoid mortality, 50% mortality at 6000 mSv.
Chernobyl liquidators[9]	220,000	2 min to 90 days	1-1500	nil to 1500 most < 2	Low/high dose rate mushed together. 6% increase in cancer. Decrease in mortality.
Litvinenko[4]	1	3 weeks	96,000	4,000	Died in 23 days
Belarus kids[20]	13,127	2-3 weeks	ave 780 max 48k	39-2400	45 thyroid cancer, eventual 50? deaths
Ukraine kids[15]	11,611	2-3 weeks	ave 560 max 33k	28-1600	87 thyroid cancer, eventual 50? deaths
Eben Byers[10]	1	2 years	366,000	300	Horrible bone cancer. Died in 3 years.
Evans radium hi[3]	127	10 years	>80000	80+	Cancers. Hi mortality >200 mSv/d
Dial painters hi[14]	273	up to 15 yrs	190000-440000	35 to 80+	96 bone cancers
Evans radium mid[3]	17	10 years	20000-80000	20 to 80	Abnormalities. Nil clinical symptoms.
Dial painters lo[14]	2,110	up to 15 yrs	200 - 160000	up to 30	Zero bone cancers.
Evans radium lo[3]	59	10 years	up to 20000	max 20	Nil abnormalities.
Albert Stevens[13]	1	20 years	61,000	8	Died at age 79 of heart failure.
UPPU Club[18]	26	≈10y	up to 7200	0.03-2	Lower mortality than coworkers.
Taipei Apt hi[1, 6]	1,100	18 years	up to 4000	up to 3	Decrease in cancer, maybe non-rad.
Taipei Apt mid[1, 6]	900	18 years	ave 420	up to .160	Decrease in cancer, maybe non-rad.
Taipei Apt low[1, 6]	8,000	18 years	ave 120	up to .050	Decrease in cancer, maybe non-rad.
Keralans[12]	69,956	10-15 yrs	50-650	.016 to .160	Insignificant decrease in cancer
NRX Clean Up[19]	≈1000	90s jumps	up to 200	up to 150	Insignificant decrease in cancer

Table 1: Populations who have received very large doses

References

[1] W. Chen, Y. Luan, and M. Shen. Effects of cobalt-60 exposure on health of taiwan residents suggest new approach needed in radiation protection. *Dose Response*, 5(1), 2007.

[2] J. Devanney. *Why Nuclear Power has been a Flop, 3nd Edition*. CTX Press, 2023. Available at `https://gordianknotbook.com`.

[3] R. Evans. The effect of skeletally deposited alpha-ray emitters in man. *British Journal of Radiology*, 39(468):881–895, December 1966.

[4] J. Harrison and et al. The polonium-210 poisoning of mr. alexander litvinenko. *Journal Radiological Protection*, 37(1):266–278, March 2017.

[5] T. Henriksen. *Radiation and Health*. University of Oslo, 2013.

[6] S. Hwang, H. Guo, W. Hsieh, J. Hwang, and S. Lee. Cancer risks in a population with prolonged low dose-rate gamma radiation exposure in radiocontaminated buildings, 1983-2002. *International Journal of Radiation Biology*, 82:849–858, 2006.

[7] iaea. The radiological accident in goiania. Technical report, International Atomic Energy Agency, September 1988. IAEA-PUB-815.

[8] iaea. The radiological accident in samut prakarn. Technical report, International Atomic Energy Agency, February 2002. IAEA-PUB-1124.

[9] V. Kashcheev, S. Yu, and M. et al Chekin. Incidence and mortality of solid cancer among emergency workers of the chernobyl accident: assessment of radiation risks for the follow up period of 1992-2009. *Radiation Environmental Biophysics*, 54:13–23, 2015.

[10] R. Macklis, M. Bellerive, and J. Humm. The radiotoxicology of radithor. *Journal of American Medical Association*, 264(5):619–621, August 1990.

[11] J. Mahaffey. *Atomic Accidents*. Pegasus Books, 2014.

[12] M. Nair, S. Nambi, S. Amma, and P. Gangadharam. Population study in the high natural background radiation area in kerala, india. *Radiation Research*, 152:S145–S148, 1999.

[13] Advisory Committee on HUumans Radiation Experiments. Final report. Technical report, Department of Energy, 1994. ehss/energy.gov/ohre/roadmap/achre/index.html.

[14] R. Rowland. Radium in humans, a review of u.s. studies. Technical report, Argonne National Laboratory, September 1994. ANL/ER-3, UC-408.

[15] M. Tronko, G. Howe, and T. Bogdanova. A cohort study of thyroid cancer and other thyroid diseases after the chornobyl accident: Thyroid cancer in ukraine. *Journal of the National Cancer Institute*, 98(13), July 2006.

[16] UNSCEAR. Sources and effects of ionizing radiation. Technical report, United Nations Scientific Committee of the Effects of Atomic Radiation, 1994. Annex B.

[17] UNSCEAR. Sources and effects of ionizing radiation, volume ii. Technical report, United Nations Scientific Committee of the Effects of Atomic Radiation, 2011.

[18] G. Voelz, J. Lawrence, and E. Johnson. Fifty years of plutonium exposure to the manhattan project plutonium workers: an update. *Health Physics*, 73:611–619, October 1997.

[19] M. Werner and et al. Follow-up of crnl employees involved in the nrx reactor clean-up. Technical report, AECL, 1982. AECL-7760.

[20] L. Zablotska, E. Ron, A. Rozhko, and M. Hatch. Thyroid cancer risk in belarus among children and adolescents exposed to radioiodine after the chornobyl accident. *British Journal of Cancer*, 104:181–187, 2011.