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# CANCER MORTALITY IN SIX LOWEST VERSUS SIX HIGHEST ELEVATION JURISDICTIONS IN THE U.S.

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□ Low levels of background radiation exist around us continuously. These levels increase with increasing land elevation, allowing a comparison of low elevations to high elevations in regard to an outcome such as cancer death rates. The present study compares archived cancer mortality rates in six low versus six high elevation jurisdictions. The study also compares mortality rates for all causes, heart disease, and diabetes in low versus high elevation jurisdictions in an effort to see if other mortality outcomes are different in low versus high elevations. Statistically significant decreases in mortality, with very large effect sizes, were observed in high land elevation for three of the four outcomes, including cancer. One possible explanation for the decreased mortality in high elevation jurisdictions is radiation hormesis. Another possible explanation, at least in the case of heart disease mortality, is the physiologic responses that accompany higher elevations regarding decreased oxygen levels. Since this is an ecological study, no causal inferences can be made, particularly when viewpoints on possible effects of low level radiation are diametrically opposed. Further research is indicated.

*Keywords: Radiation effects, background radiation, cancer, mortality*

## INTRODUCTION

There is controversy as to whether low level radiation poses a significant health risk. One side of the argument holds to the linear no-threshold (LNT) model, which essentially states that even the smallest amounts of radiation are harmful (Preston, 2008). The other side of the argument states that low level radiation appears to be not only harmless (Nair et al, 1999), but may actually provide a health benefit through hormesis (Allright et al, 1983; Jagger, 1998; Luckey, 2006; Scott and Di Palma, 2006). What is not controversial is that the levels of natural background radiation (NBR) are lower at lower elevations than at higher elevations (NRC, 2009). Jagger (1998), for example, in an apparently non-numeric method of selection of low states, compared low and high elevation states for cancer rates and found lower cancer rates in high elevation states.

The purpose of the present study is to compare cancer mortality rates in low versus high elevations, using a numeric method of jurisdiction selection, and to compare the difference, if any, to other mortality outcomes, one of which (heart disease) is also thought to be related to elevation (altitude) while the other mortality outcomes (all causes and dia-

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betes) seemingly would be less-related to elevation. The null hypothesis is that there will be no difference in mortality rates between low and high elevation jurisdictions while the alternate hypothesis is that at least one of the outcomes will show a statistically significant difference. If there are differences between low and high elevations, then further research would be needed to determine causality of such an association given that the present inquiry is an ecological study.

## METHODS

Age-adjusted mortality rates were obtained by jurisdiction for the following four mortality outcomes: 1) all causes, 2) malignant neoplasms ("cancer"), 3) diseases of the heart ("heart disease"), and 4) diabetes mellitus ("diabetes") for the following five years: 2001 (Arias et al, 2003), 2002 (Kochanek et al, 2004), 2003 (Hoyert et al, 2006), 2004 (Minino et al, 2007), and 2005 (Kung et al, 2008). The outcomes of cancer mortality and heart disease were selected because of they have been linked with elevation (for heart disease, the term "altitude" is typically used in the literature). The other two mortality outcomes (all causes and diabetes) were selected because of their apparent *lack* of being linked to elevation, in an effort to further compare the cancer mortality rates to.

Jurisdictions were identified using the U.S. Geological Survey data by viewing their table of lowest and highest elevations by jurisdiction (U.S. Geological Survey, 2005). In this table's lowest elevation column, six jurisdictions having the lowest elevation were selected ("low elevations"). As an example of the selection process, Delaware's highest elevation is 448 feet above sea level while its lowest elevation is at sea level. Consequently, all people in Delaware were considered to live in areas not exceeding 448 feet above sea level. Six jurisdictions having the highest elevation were selected using similar methodology ("high elevations"). As an example of the selection process of jurisdictions in the high elevation category, Colorado's lowest elevation is 3315 feet above sea level although its highest point is 14433 feet above sea level. Colorado was therefore considered to have its entire population living at an elevation of at least 3315 feet above sea level. The highest elevation jurisdiction in the low elevation category is Rhode Island, having a maximum elevation of 812 feet above sea level. The lowest elevation jurisdiction in the high elevation category is South Dakota, having a lowest elevation of 966 feet above sea level. The next highest elevation jurisdiction after 966 was Illinois, having a highest elevation of 1235 feet above sea level and a lowest elevation of 279 feet above sea level. Consequently, this state (Illinois) would not have been an appropriate addition to either the low or high elevation category because its highest elevation crosses over into the high elevation category when its lowest elevation (of 279 feet above sea level) would disqualify it from being in the high elevation category.

**TABLE 1.** Elevations, means and standard deviations in low versus high jurisdictions.

| LOW | HIGHEST ELEVATION | |
|---|---|---|
| Elevation/jurisdiction | Feet above sea level | Estimated mrem |
| Delaware | 448 | 74 |
| District of Columbia | 410 | 74 |
| Florida | 345 | 51 |
| Louisiana | 535 | 51 |
| Mississippi | 806 | 51 |
| Rhode Island | 812 | 74 |
| Mean | 559.3 | 62.5 |
| Standard deviation | 209.9 | 12.6 |
| HIGH | LOWEST ELEVATION | |
| Elevation/jurisdiction | Feet above sea level | Estimated mrem |
| Colorado | 3315 | 81 |
| Montana | 1800 | 77 |
| New Mexico | 2842 | 81 |
| South Dakota | 966 | 74 |
| Utah | 2000 | 77 |
| Wyoming | 3099 | 81 |
| Mean | 2337.0 | 78.5 |
| Standard deviation | 902.6 | 2.9 |
| p-value* | 0.004 | 0.025 |
| Effect size* | 2.7 | 1.8 |

* p-value and effect size pertain to comparison of low versus high elevation and NBR.

The annual NBR for all jurisdictions consisted a minimum value of 26 mrem for cosmic radiation at sea level + the additional radiation according to feet above sea level, as follows: up to 1000 feet above sea level= 2 additional mrem; 1000-2000 feet above sea level = 5 additional mrem; 2000-4000 feet above sea level = additional 9 mrem (NRC, 2009). The radiation levels from terrestrial sources (i.e., radon) were added as follows: 23 mrem for states bordering the Gulf coast (Louisiana, Mississippi, and Florida); 46 mrem for all other states (NRC, 2009). Ninety mrem can be assigned to the Colorado Plateau areas but since entire states were assessed, and some areas would not be part of the Colorado Plateau, the addition of the 90 mrem value was omitted. Thus, six jurisdictions in each of the low and high categories were obtained (Table 1). Five years of mortality data were analyzed for each of the 12 jurisdictions for the four mortality outcomes (Table 2). This meant that each mortality outcome in each of the two categories (low versus high elevation) had a sub-total of 30 observations each or a total of 60 observations for each mortality outcome (Table 2). The population for each jurisdiction, for each year, was

**TABLE 2.** Age-adjusted mortality for four outcomes, five years, 12 jurisdictions (six in each of low and high elevation categories.

| | | all causes age-adjusted rate | cancer age-adjusted rate | heart age-adjusted rate | diabetes age-adjusted rate | population |
|---|---|---|---|---|---|---|
| | **Low elevation** | | | | | |
| 1 | Delaware 2001 | 891.9 | 219.3 | 257.2 | 27.2 | 796595.0 |
| 2 | Delaware 2002 | 838.2 | 193.8 | 236.0 | 25.9 | 807366.4 |
| 3 | Delaware 2003 | 844.4 | 201.4 | 243.1 | 28.2 | 817530.1 |
| 4 | Delaware 2004 | 823.3 | 207.4 | 232.3 | 24.1 | 830388.3 |
| 5 | Delaware 2005 | 830.5 | 197.8 | 224.3 | 25.9 | 843531.3 |
| 6 | District of Columbia 2001 | 1038.2 | 235.3 | 308.5 | 37.0 | 573811.6 |
| 7 | District of Columbia 2002 | 1021.4 | 230.0 | 291.7 | 33.7 | 570885.0 |
| 8 | District of Columbia 2003 | 982.3 | 199.7 | 287.3 | 32.2 | 564354.4 |
| 9 | District of Columbia 2004 | 974.0 | 207.0 | 274.9 | 40.2 | 553537.0 |
| 10 | District of Columbia 2005 | 971.4 | 206.0 | 268.2 | 34.6 | 550502.0 |
| 11 | Florida 2001 | 799.7 | 187.2 | 233.2 | 22.0 | 16373238.1 |
| 12 | Florida 2002 | 786.4 | 183.4 | 222.0 | 21.4 | 16712877.2 |
| 13 | Florida 2003 | 776.0 | 181.4 | 212.7 | 21.8 | 17018869.8 |
| 14 | Florida 2004 | 763.6 | 179.9 | 204.9 | 21.6 | 17396603.2 |
| 15 | Florida 2005 | 749.4 | 178.1 | 194.6 | 22.6 | 17790729.2 |
| 16 | Louisiana 2001 | 1005.9 | 227.4 | 280.1 | 41.7 | 4470292.3 |
| 17 | Louisiana 2002 | 1000.5 | 222.9 | 269.6 | 42.1 | 4482596.6 |
| 18 | Louisiana 2003 | 1004.6 | 221.9 | 274.2 | 40.8 | 4496263.6 |
| 19 | Louisiana 2004 | 986.1 | 216.7 | 256.6 | 39.9 | 4515939.2 |
| 20 | Louisiana 2005 | 1020.8 | 209.3 | 255.7 | 38.7 | 4523712.4 |
| 21 | Mississippi 2001 | 1023.2 | 216.3 | 329.0 | 24.1 | 2859643.8 |
| 22 | Mississippi 2002 | 1036.3 | 218.3 | 326.6 | 24.2 | 2871802.5 |
| 23 | Mississippi 2003 | 1014.0 | 211.1 | 310.3 | 24.1 | 2881169.1 |
| 24 | Mississippi 2004 | 998.2 | 209.8 | 300.1 | 23.6 | 2902926.8 |
| 25 | Mississippi 2005 | 1026.9 | 208.4 | 306.8 | 23.5 | 2921060.5 |
| 26 | Rhode Island 2001 | 806.4 | 200.6 | 240.5 | 21.7 | 1059638.4 |
| 27 | Rhode Island 2002 | 809.5 | 196.9 | 239.1 | 21.2 | 1069743.2 |
| 28 | Rhode Island 2003 | 786.9 | 190.2 | 227.7 | 20.2 | 1076222.1 |
| 29 | Rhode Island 2004 | 741.1 | 194.1 | 216.0 | 21.9 | 1080641.6 |
| 30 | Rhode Island 2005 | 747.3 | 184.1 | 213.8 | 21.6 | 1076137.2 |
| | mean | 903.3 | 204.5 | 257.9 | 28.3 | 4482953.6 |

*continued on next page*

estimated by the following calculation where total number of case, crude rate per 100,000 persons was known:

$$\frac{\text{Total number of cases}}{\text{Population}} = \frac{\text{Crude rate}}{100{,}000}$$

Analysis consisted of assessing the data as follows: a) skew, performed in a spreadsheet, with values between - 2 and + 2 considered to be not sig-

**TABLE 2.** *Continued*

| | | all causes age-adjusted rate | cancer age-adjusted rate | heart age-adjusted rate | diabetes age-adjusted rate | population |
|---|---|---|---|---|---|---|
| | **High elevation** | | | | | |
| 1 | Colorado 2001 | 787.8 | 169.6 | 181.0 | 18.7 | 4431323.4 |
| 2 | Colorado 2002 | 790.2 | 171.8 | 178.9 | 17.7 | 4506325.2 |
| 3 | Colorado 2003 | 784.3 | 169.2 | 178.0 | 19.0 | 4550586.1 |
| 4 | Colorado 2004 | 736.4 | 160.1 | 162.7 | 18.2 | 4601593.0 |
| 5 | Colorado 2005 | 742.8 | 159.6 | 162.0 | 19.2 | 4664934.7 |
| 6 | Montana 2001 | 840.3 | 198.8 | 197.9 | 23.1 | 905356.6 |
| 7 | Montana 2002 | 849.7 | 190.7 | 191.6 | 21.0 | 909440.8 |
| 8 | Montana 2003 | 828.1 | 180.9 | 190.7 | 25.5 | 917633.0 |
| 9 | Montana 2004 | 778.6 | 180.2 | 173.6 | 22.6 | 926829.3 |
| 10 | Montana 2005 | 798.4 | 184.4 | 169.4 | 26.5 | 935703.3 |
| 11 | New Mexico 2001 | 825.4 | 167.0 | 203.4 | 31.4 | 1830892.8 |
| 12 | New Mexico 2002 | 815.0 | 172.5 | 193.3 | 32.9 | 1855147.4 |
| 13 | New Mexico 2003 | 823.8 | 169.6 | 191.5 | 33.0 | 1874525.2 |
| 14 | New Mexico 2004 | 778.9 | 161.9 | 180.4 | 31.7 | 1903354.6 |
| 15 | New Mexico 2005 | 795.0 | 162.6 | 184.5 | 31.2 | 1928314.0 |
| 16 | South Dakota 2001 | 784.8 | 187.9 | 218.1 | 24.2 | 758352.5 |
| 17 | South Dakota 2002 | 771.2 | 182.4 | 209.7 | 22.6 | 761032.7 |
| 18 | South Dakota 2003 | 790.5 | 189.6 | 208.0 | 22.9 | 764333.9 |
| 19 | South Dakota 2004 | 746.4 | 176.8 | 187.1 | 25.2 | 770870.9 |
| 20 | South Dakota 2005 | 757.0 | 180.9 | 182.1 | 25.8 | 775952.7 |
| 21 | Utah 2001 | 776.8 | 143.4 | 185.2 | 31.9 | 2278567.6 |
| 22 | Utah 2002 | 782.0 | 143.3 | 185.1 | 31.4 | 2316086.9 |
| 23 | Utah 2003 | 782.3 | 144.1 | 183.5 | 31.2 | 2351332.4 |
| 24 | Utah 2004 | 760.4 | 141.2 | 175.0 | 28.6 | 2389068.1 |
| 25 | Utah 2005 | 731.2 | 139.4 | 162.6 | 30.4 | 2469571.6 |
| 26 | Wyoming 2001 | 851.7 | 192.9 | 209.5 | 25.5 | 493750.0 |
| 27 | Wyoming 2002 | 864.3 | 175.1 | 210.0 | 30.0 | 498685.8 |
| 28 | Wyoming 2003 | 849.9 | 188.4 | 199.5 | 27.7 | 501261.6 |
| 29 | Wyoming 2004 | 789.7 | 170.8 | 191.0 | 22.1 | 506531.8 |
| 30 | Wyoming 2005 | 801.4 | 167.7 | 186.9 | 25.7 | 509319.1 |
| | mean | 793.8 | 170.8 | 187.7 | 25.9 | 1829555.9 |

nificantly different from normal (Garson, 2009); b) statistical differences between low and high elevation regions for the mortality outcomes, performed in SAS 9.2 (Cary, NC), elevation and NBR (performed in a spreadsheet), and c) effect size, performed in a spreadsheet for low versus high elevation groups for each variable, using a pooled standard deviation (Morgan et al, 2007). Interpretation of effect size ranges were as follows: Very large = greater than or equal to 1.00; Large = 0.80; Medium = 0.50; Small = 0.20 (Morgan et al, 2007). Since multiple tests for statistical significance were performed (n = 4, for the four mortality outcomes and n = 2 for elevations and NBR), a stringent Bonferroni-adjusted alpha was applied where the number of tests was divided by the traditional alpha of 0.05 (0.05/4 for outcomes) resulting in an adjusted alpha of 0.0125 (for

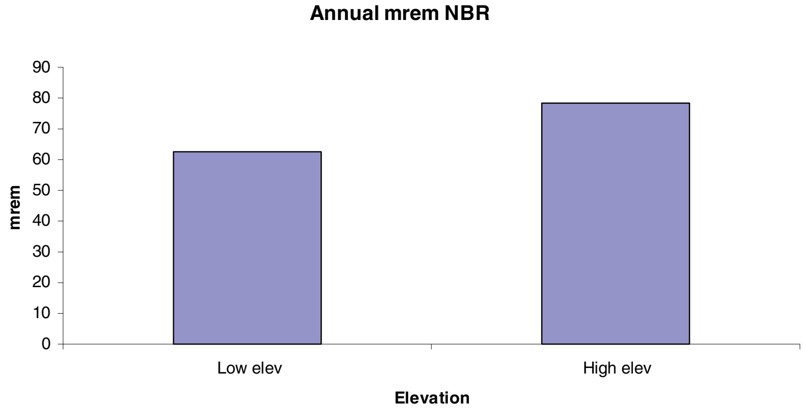


**FIGURE 1.** NBR comparison between low and high elevation jurisdictions. The difference between low and high elevation jurisdictions (p = 0.025) was statistically significant along with a very large effect size between the two NBR means (effect size = 1.8).

outcomes) and 0.025 (0.05/2) for land and NBR, below or equal to which, statistical significance was considered to be present.

## RESULTS

The data fell between skew values and -2 and + 2. Consequently, a t-test was used (two tails) to assess statistical differences. The mean elevation above sea level for low elevation jurisdictions was 559.3 compared to 2337 feet for high elevation jurisdictions, a statistically significant difference (p = 0.004) with a very large effect size (2.7). The mean annual NBR level for low elevation states was 62.5 mrem compare to 78.5 mrem for high elevation states, a statistically significant difference (p = 0.025; Figure 1), and therefore considered to be not statistical significant, while exhibiting a very large effect size (1.8) (Table 1).

Mortality rates for the outcomes were as follows. All causes: low elevation = 903.3; high elevation = 793.8, a statistically significant difference (p < 0.0001) with a very large effect size (1.3); heart disease: low elevation = 257.9; high elevation = 187.7, a statistically significant difference (p < 0.0001) with a very large effect size (2.5); Cancer: low elevation = 204.5; high elevation = 170.8, a statistically significant difference (p < 0.0001) with a very large effect size (2.1); Diabetes: low elevation = 28.3; high elevation = 25.9, a statistically insignificant difference (p < 0.1) with a small-medium effect size (0.4) (Figure 2).

## DISCUSSION

Cancer mortality rates were significantly lower in high elevation jurisdictions, which of course consist of higher NBR levels. This suggests the

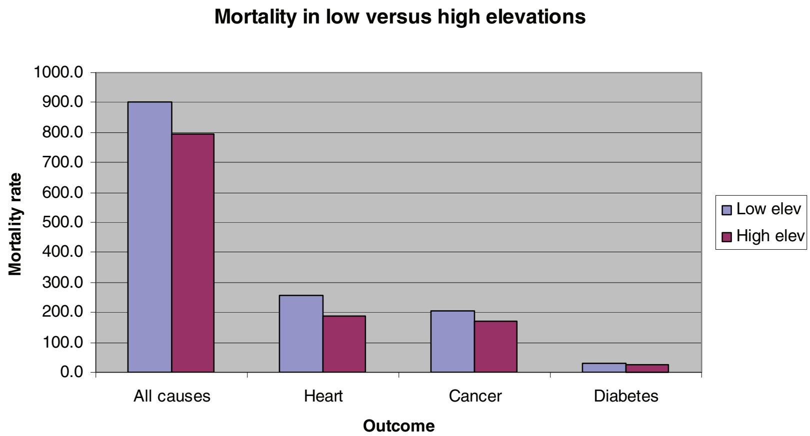


**FIGURE 2.** Mortality rate means, differences, and effect sizes in low versus high elevation jurisdictions. Statistically significant differences, along with very large effect sizes were found between low and high elevation jurisdictions for all-causes mortality rates ($p < 0.0001$, effect size = 1.3), heart disease ($p < 0.0001$, effect size = 2.5), cancer ($p < 0.0001$, effect size = 2.1). Diabetes mortality was lower in higher elevation jurisdictions but this difference was not statistically significant ($p = 0.1$) with a small-medium effect size (0.4).

presence of radiation hormesis. However, heart disease mortality (as well as mortality from all causes) was also significantly lower in the high elevation jurisdictions. The finding of lower cancer mortality in the present study is consistent with similar previous studies. Jagger (1998) for example found that cancer death rates were 1.26 times that of Rocky Mountain states. Tao et al (2000) also found that in high NBR areas in China cancer mortality was also lower in high background radiation regions. Conversely, Cardis et al (2005) found a small increased risk of cancer for low dose exposure to nuclear workers.

In high elevations, decreased heart disease mortality may be related to decreased oxygen levels. In high altitudes effects of decreased oxygen can range from being factors in conditions such as pulmonary edema and right cardiac failure with peripheral edema (Ausiello et al, 2004), to being innocuous (Erdmann, 1998) to providing a protective effect against cardiovascular disease and cancer (Weinberg et al, 1987). In addition, this beneficial effect is thought to be related not to NBR but rather, due to thinner oxygen levels at higher altitudes (Weinberg et al, 1987). Mortimer et al (1977) theorize that the benefit of higher altitudes on arteriosclerotic heart disease may relate to the increased levels of exertion needed at higher altitudes for the same work done at lower altitudes, hence more exercise at the higher altitudes compared to lower altitudes. Whether the decreased heart disease mortality is due to increase NBR (i.e., radiation hormesis) or to physiologic responses that accompany decreased oxygen at high altitudes, or some other factor(s), or due to interaction of all of the above, is a question beyond the scope of this paper.

Mortality from all causes is an outcome that perhaps is too general to attempt to suggest possible explanations as to why it would be less in higher elevations. The outcome of diabetes, which was theorized by the author to not be related to elevation, showed the weakest relationship with elevation.

The question may arise as to the possibility of cancer clusters being a factor in the mortality rates. This was considered but no clusters were found for the jurisdictions and years in this study (CDC, 2009).

Ecological studies such as the present one do not allow causal inferences to be made but can be a first step for inquiry into new areas of research (Grimes and Schulz, 2002). Furthermore,there remains a lack of clear understanding in regard to the possible effects of exposure to low level radiation (Hendry et al, 2009). There is certainly a divergence of opinion as to what effects, if any, result from exposure to low level radiation. On the one hand there is the viewpoint that low level radiation provides a protective (hormetic) effect (Allright et al, 1983; Jagger, 1998; Luckey, 2006; Scott and Di Palma, 2006) while on the other hand there is the view that supports the LNT model (Brenner et al, 2003) as reported in BEIR VII (Health Physics, 2005). Clearly there is a need for further research, particularly they type that follows a given population over time such as done by Nair et al (2009), as well as research that assesses confounding variables.

## CONCLUSION

Statistically significant decreases, with very large effect sizes were observed in high elevation jurisdictions compared to low elevation jurisdictions for the mortality outcomes of all causes, heart disease, and cancer. Diabetes mortality was also lower in high elevation jurisdictions compared to low elevation jurisdictions but the difference was not statistically significant and exhibited a small-medium effect size. These findings suggest the presence of radiation hormesis, at least in regard to the cancer mortality from a plausibility standpoint (i.e., hormesis theory). However, causal inferences cannot be made since this is an ecological study. Future study should include other variables that are thought to be related to cancer death rates, such as educational attainment, smoking, and diet.

## REFERENCES

Allright SP, Colgan PA, McAulay IR, Mullins E. 1983. Natual background radiation and cancer mortality in the Republic of Ireland. *International Journal of Epidemiology.* 12(4): 414-418.

Arias E, Anderson R, Kung H, Murphy SL, Kochanel KD. 2003. Deaths: Final data for 2001. Centers for Disease Control. *National Vital Statistics Reports.* 52(3). Available from: www.cdc.gov

Ausiello DA, Benos DJ, Abboud F, Koopman W. 2004. The physiologic basis of high-altitude diseases. *Annals of Internal Medicine*. 141:789-800.

Brenner DJ, Doll R, Goodhead DT, Hall EJ, Land CE, Little JB, Lubin JH,

Preston DL, Preston RJ, Puskin JS, Ron E, Sachs RK, Samet JM, Setlow RB, Zaider M. 2003. *Proceedings of the National Academy of Scientists (USA)*. Available from: http://www.pnas.org/content/100/24/13761.full.pdf+html

Cardis E, et al. 2005. Risk of cancer after low doses of ionizing radiation: retrospective cohort study in 15 countries. *British Medical Journal* (online). Doi:10.1136/bmj.38499.599861.EO.

Centers for Disease Control and Prevention. 2009. CDC's Role in Investigating Cancer Clusters. [Cited 2009 Dec 18]. Available from: http://www.cdc.gov/nceh/clusters/investigations.htm

Erdmann J. 1998. Effects of Exposure to Altitude on Men With Coronary Artery Disease and Impaired Left Ventricular Function. *The American Journal of Cardiology*. 81 (3): 266-270.

Grimes DA, Schulz KF. 2002. Descriptive studies: what they can and cannot do. *The Lancet* 359: 145-149.

Garson G. Testing of assumptions. February 26, 2009. Statnotes. [Internet]. North Carolina State University. [Cited 2009 Feb 27]. Available from: http://faculty.chass.ncsu.edu/garson/PA765/assumpt.htm

Health Physics Society. 2005. BEIR VII report supports LNT model. Available from: http://www.hps.org/newsandevents/newsarchive/oldnews497.html

Hendry JH, Simon SL, Wojcik A, Sohrabi M, Burkart W, Cardis E, Laurier D, Tirmarche M, Hayata I. 2009. Human exposure to high natural background radiation: what can it teach us about radiation risks. *Journal of Radiological Protection* 29: A29-A42.

Hoyert DL, Heron MP, Murphy SL, Kung H. 2006. Deaths: Final data for 2003. Centers for Disease Control. *National Vital Statistics Reports*. 54(13). Available from: www.cdc.gov

Jagger J. 1998. Natural background radiation and cancer death in Rocky Mountain States and Gulf Coast states. Health Physics.75(4):428-430.

Kochanek KD, Murphy SL, Anderson R, Scott C. 2004. Deaths: Final data for 2002. Centers for Disease Control. *National Vital Statistics Reports*. 53(5). Available from: www.cdc.gov

Kung H, Hoyert DL, Xu J, Murphy SL. 2008. Deaths: Final data for 2005. Centers for Disease Control. National Vital Statistics Reports. 56(10). Available from: www.cdc.gov

Luckey TD. 2006. Radiation hormesis: the good, the bad, and the ugly. *Dose Response*. 4(3): 169-190.

Minino AM, Heron MP, Murphy SL, Kochanek KD. 2007. Deaths: Final data for 2004. Centers for Disease Control. *National Vital Statistics Reports*. 55(19). Available from: www.cdc.gov

Morgan GA, Leech NL, Gloeckner GW, Barrett KC. 2007. SPSS for introductory statistics. Mahwah, NJ; Lawrence Erlbaum Associates, Publishers..

Mortimer EA, Monson RR, MacMahon B. 1977. Reduction in mortality from coronary heart disease in men residing at high altitude. *New England Journal of Medicine*. 296:581-585.

Nair MK, Nambi KSV, Amma NS, Gangadharan P, Jayalekshmi P, Jayadevan S, Cherian V, Reghuram KN. 1999. Population study in the high natural background radiation area in Kerala, India. *Radiation Research*. 152:S145-S148.

Nair RRK, Rajan B, Akiba S, Jayalekshmi P, Nair MK, Gangadharan P, Koga T, Morishima H, Nakamura S, Sugahara T. 2009. Background Radiation and Cancer Incidence in Kerala, India-Karanagappally Cohort Study. *Health Physics*. 96(1): 55-66.

U.S. Nuclear Regulatory Commission (NRC). 2009. [Cited 2009 Apr 30]. Available from: www.nrc.gov/

Preston RJ. 2008. Update on linear non-threshold dose-response model and implications for diagnostic radiology procedures. *Health Physics*. 95(5):541-546.

Scott BR, Di Palma J. 2006. Sparsely ionizing diagnostic and natural background radiations are likely preveting cancer and other genomic-instability-associated diseases.. *Dose Response*. 5:230-255.

Tao Z, Zha Y, Akiba S, Sun Q, Zou J, Li J, Liu Y, Kato H, Sugahara T, Wei L. 2000. Cancer mortality in high background radiation areas of Yangjiang, China during period between 1979 and 1995. *Radiation Research*. 41: Suppl 31-41.

Weinberg CR, Brown KG, Hoel DG. 1987. Altitude, radiation, and mortality from cancer and heart disease. *Radiation Research*. 112: 381-390.

U.S. Geological Survey. Online Edition. 2005. Elevations and distances in the United States.. [Cited 10-19-09]. Available from http://egsc.usgs.gov