IS THE INCREASING LUNG CANCER EPIDEMIC DUE TO RADIOACTIVE POLONIUM IN CIGARETTES?

NBC 212-966-4
Mariani Dilco

By

Jerome Marmorstein, M.D.
Assistant Clinical Professor of Internal Medicine
U.S.C. College of Medicine

Santa Barbara Cottage Hospital
Santa Barbara, California
teaching hospital associated with
University of Southern California (U.S.C.) College of Medicine

Reprint Requests

Jerome Marmorstein, M.D.
2320 Bath Street
Santa Barbara, California 93105

Phone: (805) 682-7604

ABSTRACT

Is The Increasing Lung Cancer Epidemic
Due to Radioactic Polonium in Cigarettes?

Clinical, experimental, and epidemiologic evidence is presented to help explain why primary lung cancer incidence should still be rapidly increasing, with recently observed reversal in leading cell type from squamous cell to adenocarcinoma. It is postulated that this may be due to the decreasing amounts of benzopyrene and other polyaromatic hydrocarbons in modern filtered cigarette smoke, along with evidence of increasing amounts of radioactive lead and polonium inhaled readily through the filter.

Evidence for this claim is based on measurements of increased concentrations of radioactive polonium: in lungs of cigarette smokers; in modern tobaccos grown since 1950; and, in high phosphate fertilizers used for tobacco farming in industrialized countries. Critical support for this thesis is based on experimental animal inductions of lung cancers that resemble adenocarcinomas with as little as 15 rads of radioactive polonium, equal to one-fifth the dosage inhaled by the average two pack a day cigarette smoker during a 25 year period.

The Lung Cancer Paradox

Lung cancer incidence is still rapidly increasing during the past two decades. Yet, 15% or 30,000,000 Americans have since quit smoking. Also, 90% of American cigarettes have filters and contain an average of ½ its former amounts of nicotine and tars.[1,2] In spite of this, twice as many men died from lung cancer in 1980 than in 1960, and three times as many women.[3]

Since at least 85% of lung cancers are reported to occur in cigarette smokers, the major carcinogens must be within the cigarettes, themselves.[4] Furthermore, increased incidences of lung cancer are directly proportional to increased amounts of daily cigarette consumption.[5]

Criteria For The Increasing Tobacco Carcinogen(s)

Whatever the increasing tobacco carcinogen(s) should turn out to be, it should be: 1) inadequately filtered by cigarette filters, 2) be able to cause lung cancers with small doses in experimental animals, especially of the increasing adenocarcinoma type, 3) be found in greater concentrations in the lungs of cigarette smokers, and 4) have some reason to be increasing in recent decades.

Animal Induction of Lung Cancers

There have been only three types of tobacco chemicals demonstrated to cause lung cancers by inhalation or tracheal installation into experimental animals.[6] As early as 1957 polyaromatic hydrocarbons formed by the combustion of carbon and hydrogen in tobacco and its main prototype, benzopyrene, has been acknowledged as the most widely recognized carcinogen in tobacco smoke.[7] This carcinogen resulted almost exclusively in squamous cell cancers of the lung when it was instilled into the respiratory tracts of hamsters and mice. However, benzopyrene's

concentration in tobacco smoke has been greatly reduced in the last 30 years by changes in tobacco processing and use of filters.[8] Therefore, benzopyrene seems unlikely to be responsible for the continued increasing incidence of lung cancer, especially of the increasing adenocarcinoma type. Several nitrosamines are found in trace amounts of tobacco smoke which can also induce respiratory cancers in experimental animals, but with greater difficulty. Furthermore, since 80% of nitrosamines are eliminated by cigarette filters and since 90% of cigarettes are now filtered, these chemicals do not appear to be responsible for the recently increasing lung cancer rates.[9]

Radioactive Polonium

The only other chemical carcinogen found in tobacco known to be capable of readily producing lung cancers in experimental animals is radioactive polonium. This emits the most powerfully carcinogenic form of radiation known, alpha radiation.[10,11] Of all of the three proven pulmonary tobacco carcinogens in animals, radioactive polonium is the least reduced by cigarette filters and is the only one able to cause lung cancers in animals by actual inhalation.[12,13]

Radioactive polonium is completely volatized into the smoke at the combustion temperature of cigarettes and half is transferred directly into the main stream smoke. Of great interest, radioactive polonium produced combined squamous and adenocarcinomas after being instilled into the trachea and lungs of Syrian hamsters, but were noted to more closely resemble adenocarcinoma. Furthermore, when transplanted into a host animal, these tumors became pure adenocarcinomas. Ninety-seven percent of Syrian hamsters could be induced to develop these lung cancers with sufficiently small doses of radioactive polonium that no inflammatory radiation damage occurred to the lungs.[14] Doses as low as only 15 rads could induce lung cancer in 13% of the hamsters. This is equivalent to less than 1/5 the amount of radioactive polonium inhaled by a two pack a day cigarette smoker over a 25 year period.[15]

Thirteen percent of rats could also be induced to develop lung cancer by inhaling 583 rads of this chemical. Unlike alpha radiation, it required from thousands to tens of thousands of rads from beta or gamma emitting radioactive chemicals to induce lung cancers in experimental animals. Of great importance is that giving both radioactive polonium and benzopyrene at the same time produced twice the number of lung cancers than would have been expected from the added effects of either carcinogen alone.[16]

Concentration of Radioactive Polonium in Lungs of Smokers

What evidence is there that radioactive polonium from cigarette smoke actually concentrates in lungs of human smokes? Measurements of concentrations of radioactive polonium were made on lung specimens obtained at autopsy and at surgery from 25 active cigarette smokers and 8 non-smokers. The average concentration of radioactive polonium in peripheral lung tissue was over four times greater in cigarette smokers than in non-smokers or pipe smokers. The source of the lesser amounts of radioactive polonium in non-smokers' lungs was thought to be due to dietary intake but could also have occurred by passive inhalation from nearby smokers. Radioactive concentrations were highest in those with greatest daily cigarette consumptions. Furthermore, the average concentration of radioactive polonium was more than 100 times greater in the basalar bronchial epithelium that in the rest of the lung, especially at the level of segmental bronchial bifurcations where most lung cancers were occurring. These scientists, therefore, concluded that tobacco radioactive polonium was an important factor in the causation of human lung cancer.[17] Other studies have also shown four times greater concentration of radioactive polonium in peripheral lung tissue as well as twice the concentration in the blood, urine, bones and some soft tissues of cigarette smokers.[18]

Other Sources of Radioactive Polonium

What evidence is there that radioactive polonium actually causes human lung cancers? Alpha radiation from polonium and related sources such as radon gas has been implicated in very high lung cancer incidences in certain underground mine workers. Forty to eighty percent of all the deaths among the central European miners in Joachimsthal and Schneeberg were said to be due to alpha radiation induced lung cancer. More recently, alpha radiation caused lung cancers have been found among Newfoundland fluospar miners, West Cumberland hematite miners, and Colorado plateau uranium miners. The lung cancer rate for non-smoking uranium miners was seven times higher than for non-miners who also did not smoke. For those uranium miners who did smoke cigarettes their incidence was six times higher than in those miners who did not smoke.[19]

Biologic Nature of Alpha Radiation

Why should the relatively low levels of radiation found in tobacco smoke measured only in picocuries be able to cause lung cancer? This is because radioactive polonium emits an alpha type of radiation. Picocurie for picocurie, alpha radiation has at least 10 to 20 times the cancer causing disruption for living cells as other forms of radiation. Some scientists estimate that it may be as high as 100 times. The reason is that it causes a higher density of radiation damage to produce an increased relative biologic effect. This is because it is concentrated inside the cells where it can produce its greatest damage to the genetic DNA materials in the nucleus, producing fractures and translocations of the chromosomes. Alpha radiation is also known to preferentially cause cancer with low dosages frequently given, rather than several large doses. Other forms of radiation travel much wider and further and spread out their energy, thinning it over broader amounts of tissue. In addition, alpha radiation is unique in that decreasing the dose in hamsters two hundred fold only caused a reduction of its cancer incidence by about one third.[20]

While radioactive polonium has only a half life of about a third of a year, its precursor, radioactive lead, which accompanies it, has a half life of 22 years. Furthermore, the average cigarette smoker continues to bathe his lungs in radioactive polonium repeatedly day after day, year after year.

Insoluble Radioactive Particles

One reason for early skepticism about radioactive polonium's role in causing lung cancer was that it was soluble in water and, therefore, rapidly cleared. Therefore, its mechanism for prolonged rentention in the lung was seriously questioned. However, in 1974 Martell demonstrated the presence of insoluble microscopic particles of radioactive lead in cigarette smoke, which is the immediate precursor, and therefore, responsible for the continued presence of radioactive polonium in the lungs. These insoluble crystals are formed by combustion of tobacco containing increased amounts of calcium phosphate and radioactive lead and polonium, especially from high phosphate fertilized tobacco. Furthermore, these insoluble radioactive particles are not uniformly distributed throughout the lungs, but are focalized to relatively small amounts of lung tissue. As a result, the small volumes of lung tissue around each cluster of radioactive insoluble smoke particle receives from 100 to 10,000 times the natural level of alpha radiation exposure.[21,22]

Radioactive Polonium and Lead in Tobacco Plants

How does radioactive polonium and its immediate precursor, radioactive lead, get into tobacco leaves and why is it increasing? Studies have shown that most of these radioactive chemicals enter the tobacco plant from natural and unnatural deposits in the soil during growth. Lesser amounts of radioactive polonium and lead enter the tobacco leaves directly from the atmosphere. The major reason for the increased amounts of radioactive polonium and lead in tobacco in recent decades has been found to be due to the increased use of artificial high phosphate fertilizers in moderate industrialized countries. These fertilizers are made from apa-

tite rock which contains significant amounts of natural radioactive chemicals, including radium, polonium, and lead. These rocks are ground up and dissolved in sulfuric acid to make the fertilizer. Their widespread use did not appear in this country until after the completion of the Tennessee Valley Authority in 1940 which was responsible for the development of these fertilizer plants.[23,24]

Tobacco is a unique farm product in that the quality of the tobacco requires reduction of tobacco nitrogen. Therefore, large amounts of high phosphate fertilizers are repeatedly applied to restricted amounts of land to use up to the soil nitrogen while stimulating greater tobacco growth. Studies have demonstrated that the amounts of these radioactive chemicals found in the soil and in the tobacco leaves increases with the amounts of high prosphate fertilizer used. Furthermore, American tobacco farmers are subsidized on the basis of not planting all of their available land, encouraging them to use more fertilizer on more densely grown tobacco.[25]

Geographic Variations in Tobacco Radiation

Since the highest lung cancer rates occur among smokers in more highly industrialized countries, like the British Commonwealth and the United States, it is suspected that their use of high phosphate fertilizers may be the major factor. Lesser developed countries use more natural fertilizers and apply it to lands less densely cultivated, often using crop rotation. Tobacco samples from lesser developed countries such as India, Indonesia, and Turkey have been measured to have about one-third the radioactivity of more modern countries.[26]

Recently Increased Tobacco Radioactivity

Radioactivity in tobacco has actually been measured to be increased in this country. Studies measured radioactivity in tobacco samples from 1938 to be only one-third to one-sixth the amounts in samples obtained in the 1950s and 1960s.[27]

A number of scientific articles have suggested that radioactive nuclear explosive fall-outs have also contributed to soil and tobacco leaf absorption of radioactivity. Since uranium is a source of radioactive polonium and lead, this is not unreasonable. If peak contaminations occurred between 1945 and 1960 when atmospheric detonations were occurring more frequently, the resulting increase in lung cancer incidence might not be seen until a number of years later. It is also known that the Northern Temperate hemisphere, which includes the United States and Europe, receives disproportionately larger amounts of fall-out than from any other part of the world. Atomic bomb survivors in Hiroshima and Nagasaki suffered increased lung cancer incidence but not until years later. Half the lung cancers were of the adenocarcinoma lung type.[28]

Occupational Exposures

In addition to uranium and related mining already discussed, another occupational hazard that promotes lung cancer is asbestos. The most frequent source of exposure has been in shipyard workers, especially during World War II, and other forms of asbestos exposing occupations. Even several months exposure would increase the tendency for lung or pleural lining cancer many years later. This tendency was greaterly increased if the person also smoked cigarettes.[29] Martell suggests that radioactive chemicals and tars are absorbed on the inert asbestos fibers and trapped deep within the lungs where it cannot be disposed of.

Air Pollution

What about air pollution just from living in cities? Although usually only relatively slight differences in lung cancer incidences have been shown between city and rural non-smokers, significant increases in lung cancer do occur in cigarette smokers who live in cities. However, these differences are still relatively small when compared to the overwhelming influence of cigarette smoking, itself.[30] Cit

cigarette smokers are more likely to spend more time indoors in smoke-filled, crowded rooms. Martell has demonstrated that radioactive polonium and lead particles adhere to other smoke particles and remain suspended in room air to be breathed over and over by smoker and non-smoker alike. He found the greater the smoke concentration, the longer and the denser the suspension in the room air.[31]

Changing Type of Predominant Lung Cancer

Contrary to what most textbooks have reported in the past, the most common type of primary lung cancer reported in a number of recent surveys is turning out to be primary adenocarcinoma rather than squamous cell carcinoma.[32]

A 1977 article from the Roswell Park Memorial Institute based on 1600 cases indicated that their primary lung adenocarcinoma rate surpassed squamous cell cancer for the first time in 1974. To determine if changes in the interpretation of pathology slides could be a factor, they re-evaluated their older slides by the newer criterion. As a result, there would have been a 17% more frequent diagnosis of adenocarcinoma in this old group, still leaving a substantial number of increased lung adenocarcinomas unaccounted for. Since their male adenocarcinoma rate was increasing at an even greater rate than the female, the increase in adenocarcinoma was not just due to the increase in female lung cancer rates. The Roswell Park Group also found that 95% of all their lung cancer patients had smoked tobacco as did 89% of those with adenocarcinoma, thereby refuting previous impressions that primary lung adenocarcinomas were frequently found in non-smokers. Since lung cancers diagnosed after 1968 were most often found in two pack a day cigarette smokers, while the group before 1968 were most often one pack a day smokers, they suspected that the reduction in nicotine in modern filtered cigarettes promoted greater amounts of individual cigarette consumption. In turn, this might allow alterations in chemical carcinogen intake that would lead to the increased prevalence of primary lung adenocarcinomas.[33]

Passive Smoking

Of concern to many non-smokers is the risk of lung cancer from frequent exposure to other people's smoking, so-called passive or secondhand smoke. Already several studies, including a large one from Japan involving hundreds of thousands of people [34] and a smaller one from Greece, [35] have shown significantly increased incidence of lung cancer among non-smoking wives of smoking husbands. This could be related, at least in part, to the demonstration that 75% of radioactive polonium of a cigarette escapes back into the room air to be repeatedly re-inhaled by the smoker and nonsmoker alike. This might explain a significant portion of lung cancers that have occurred in those who have never smoked or who had smoked many years earlier but were still being exposed to smoke from others. To support the potency of secondary smoking, studies have measured significant bronchial constriction in those exposed to the cigarette smoke of others.[36]

Conclusions

Since benzopyrene induced in hamsters almost exclusively squamous cell carcinomas in proximal bronchi, and radioactive polonium produced more peripheral lung cancers that more closely resembeled adenocarcinomas, this suggested a possible cause and effect relationship of benzopyrene to squamous cell carcinoma, and of radioactive polonium to adenocarcinoma. Accordingly, the relative decrease in human squamous cell lung cancer incidence has occurred during a period of decreasing concentration of benzopyrene in moderate filtered cigarette smoke. At the same time, the increased incidence of human peripheral lung adenocarcinomas has been occurring during a period of increased average daily consumption of cigarettes by individual smokers, which would provide greater total intake of inadequately filtered radioactive polonium. In addition, radioactive polonium and lead had actually been measured to be increasing in tobacco concentration in recent decades.

Therefore, the increasing lung cancer epidemic primarily in cigarette smokers

during recent decades, especially of primary adenocarcinoma, may be related to the increased amounts of radioactive polonium and lead inhaled from modern cigarettes. These are likely to interact and potentiate any amounts of other tobacco carcinogens, such as benzopyrene or nitrosomines. At the same time the decreased prominence of pulmonary squamous carcinomas may be due to decreased amounts of benzopyrene and other polyaromatic hydrocarbons in modern filtered cigarettes. Support of this possibility was the study by Auerbach et al that showed dramatic reductions in bronchial squamous hyperplasia in cigarette smokers who died between 1970 and 1977 as compared to those who died between 1955 and 1960.[37] Other types of lung cancers would also be due to the various combinations of carcinogens in cigarettes also.

Summary

Clinical, experimental and epidemiologic evidence is presented to help explain why lung primary cancer incidence is still rapidly increasing, with a recently observed reversal in leading cell type from squamous cell to adenocarcinoma. It is postulated that this may be due to the decreasing amounts of benzopyrene and other polyaromatic hydrocarbons in modern filtered cigarette smoke, along with evidence of increasing amounts of radioactive lead and polonium inhaled readily through the filter.

Evidence for this claim is based on measurements of increased concentrations of radioactive polonium: In lungs of cigarette smokers; in modern tobaccos grown since 1950; and in high phosphate fertilizers used for tobacco farming in industrialized countries. Critical support for this thesis is based on experimental animal inductions of lung cancers that resemble adenocarcinomas with as little as 15 rads of radioative polonium, equal to one-fifth the dosage inhaled by the average two pack a day cigarette smoker during a 25 year period.

REFERENCES

1) U.S. Department of Health, Education and Welfare. Smoking and Health- A report of the Surgeon General. Preface PVII, 1979

2) Medical World News. Page 12, October 11, 1982.

3) C.A. A Cancer Journal for Clinicians. Vol 32, No.1, Jan-Feb. 1982

4) U.S. Department of Health, Education and Welfare. The Health Consequences of Smoking-Cancer. Pg.6. 1982.

5) Wynder, Ernst, The latest datea on tobacco as a carcinogen. Our patient and Cancer. Page 42, August 1981.

6) U.S. Department of Health, Education and Welfare. Smoking and Health- A report of the Surgeon General, No. I, pp 5-30; 14-60-61, 1979

7) Wynder, E.W., Wright, G. A study of tobacco carcinogenesis. Cancer 10 (2):257-71, March-April, 1957.

8) U.S. Department of Health, Education and Welfare. Smoking and Health- A report of the Surgeon General, No. I, pp 14-112, 1979

9) U.S. Department of Health, Education and Welfare. Smoking and Health- A report of the Surgeon General, No. I, pp 14-107, 1979.

10) Winters, T.H., Difranza, J.R. New England Journal of Medicine 306 (6): 365, February 11, 1982.

11) Wynder, E., Hoffman, D. Tobacco and tobacco smoking. Academic Press New York and London, pp 464-70, 1967.

12) Radford, E., Hunt, V. Polonium-210: A volatile radioelement in cigarettes Science (143) pp 247-249, January 17, 1964.

13) Muille, C.C., Berk, H.L., Hull, T. Lung cancer following polonium-210 inhalation in rats. Radiation Reserch (31) pp 760-74, 1967.

14) Little, J.F., O'Toole, W. Respiratory tract tumors in hamsters induced by benzo-pyrene and polonium-210 alpha radiation. Cancer Research Vol 34: 3026-39,Nov. 197

REFERENCES CONT.

15) Little, J.B., Kennedy, A.R., and McGrandy, R.B. Lung cancer induced in hamsters by low doses of alpha radiation from polonium-210.Science (188) pp 737-38, 1978

16) McGrady, R.B., Kennedy, A.R., Terzaghi, M., Little, J.B. Experimental lung carcinogenesis. Springer-Verlag, pp 485-91, 1974.

17) Little, J., Radford, E., McCombs, H., and Hunt, V. Distribution of Polonium 210 in pulmonary tissues of cigarette smokers. NEJM Vol. 273 (25), pp 1343-51, December 16, 1965.

18) Ratewsky, B., and Stahlhoffen, V. Polonium-210 activity in the lungs of cigarette smokers. Nature (209) pp 1312-13, 1966.

19) Wagoner, J.K., Archer, V.E., Lundin, F.E., Holaday, D.A., Lloyd, J.W. Radiation as a cause of lung cancer in uranium miners. NEJM 273 (4) pp 181-88, July 22, 1965.

20) Martell, E.A. Tobacco radioactivity and cancer in smokers. American Scientist Vol. 63: 404-410, July-August 1975.

21) Martell, E.A. Radioactivity of tobacco trichomes and insoluble cigarette smoke particles. Nature Vol. 249 pp 215-217, May 17, 1974.

22) Martell, E. A., Sweder, K.S. The roles of polonium isotopes in the etiology of lung cancer in cigarette smokers and uranium miners. Radiation Hazards in Mining. M. Gomez, Editor: AIME, New York, 1981.

23) Tso, T.S., Harley, N., Alexander, L.T. Source of lead-210 and polonium-210 in tobacco. Science Vol. 153: 880-83, May 5, 1966.

24) Wynder, E., Hoffman, D. Tobacco and tobacco smoking. Academic Press New York and London, pp 464-70, 1967.

25) Tso, T.S. Hallden, N.A., Alexander, L.T. Radium-226 and polonium-210 in leaf tobacco and tobacco soil. Science pp 1043-44, November 30, 1964. Also source of chart comparing tobacco radioactivity from 1938 and 1950 and 1960.

26) Hill, C.R. Polonium-210 in man. Nature Vo. 208:423-528, October 30, 1965.

REFERENCES CONT.

27) Tso, T.C. Hallden, N.A., Alexander, L.T. Radium-226 and polonium-210 in leaf tobacco and tobacco soil. Science pp 1043-44, November 30, 1964. Also source of charge comparing tobacco radiactivity from 1938 and 1950 and 1960.

28) Ishimaru, T., Cihak, R., Land, E.E. Stter A., and Yamada, A. Lung cancer at autopsy in A-Bomb survivors and controls. Cancer Vol 36 (5) pp 1723-28, November 1975.

29) Wagoner, J.K., Archer, V.E., Lundin, F.E., Holaday, D.A., Loyd, J.W. Radiation as a cause of lung cancer in uranium miners. NEJM 273 (4) pp 181-88, July 22, 1965.

30) Schottenfeld, D., and Fraumeni, J., Jr. Cancer epidemiology and prevention. W.B. Saunders, Philadelphia, pp 338-338, 1982.

31) Martell, E.A. Radioactivity of tobacco trichomes and insoluble cigarette smoke particles. Nature. Vol. 249 pp 215-217, May 17, 1974.

32) Valaitis, J., Warren, S., Gamble, D. Increasing incidence of adenocarcinoma of lung. Cancer 1042-46, March 1 47 (5), 1981.

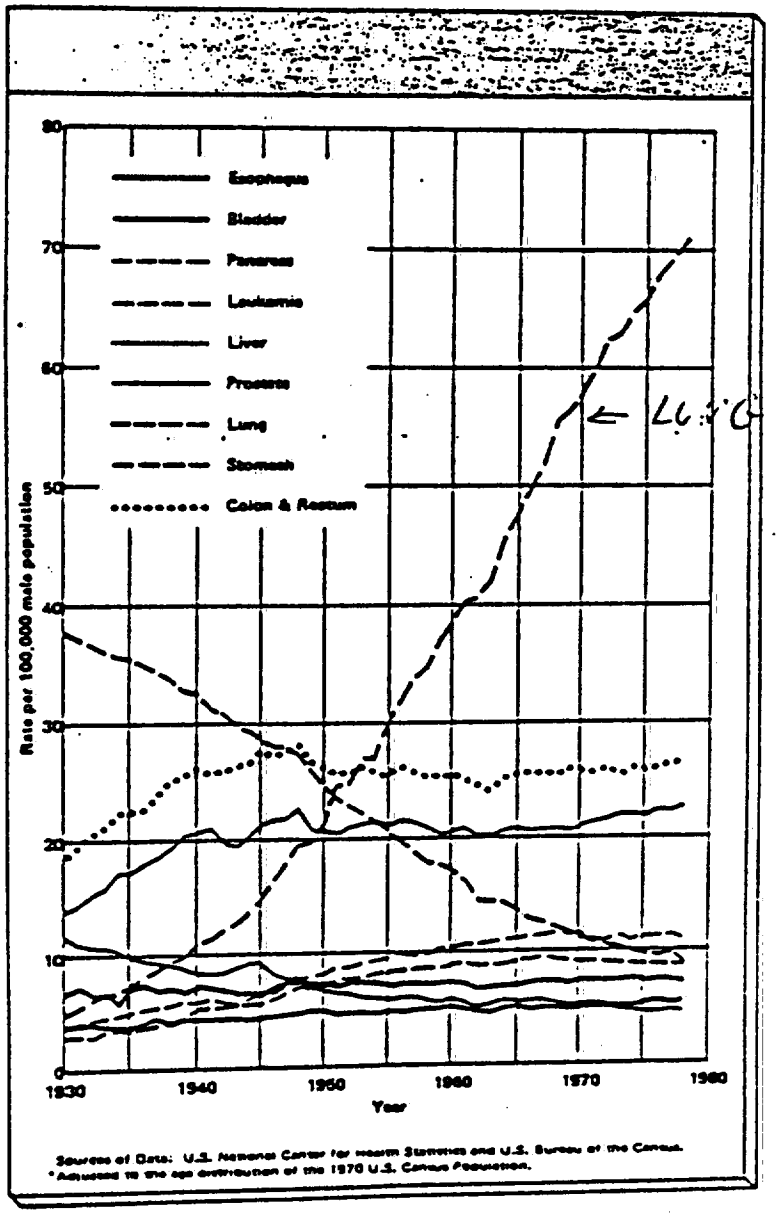
33) Vincent, R.G., Pickren, J.W., Lane, W.W., Bross, I., Takita, H., Houten, L., Gutierrez, A.C., Psepk, T. The changing histopathology of lung cancer. Cancer Vol. 39: 1647-54, April 1977.

34) Hirayama, T. Non-smoking wives of heavy smokers have a higher risk of lung cancer. British Medical Journal (282) pp 183-185, Jan. 17, 1981.

35) Trichopoulos, D., Kalandidi, I., Sparros, L., MacMahon, B. Lung cancer and passive smoking. International Journal of Cancer 27 (1) pp 1-4, January 15, 1981.

36) White, J. and Froeb, H. Small airways dysfunction in non-smokers chronically exposed to tobacco smoke. New England Journal of Medicine Vol. 302 (13) pp720-23, March 27, 1980.

37) Auerbach, O., Hammond, E.C., and Garfinkel, L. Changes in bronchial epithelium in relation to cigarette smoking, 1955-1960 vs. 1970-1977. New England Journal of Medicine Vol. 300, No. 8, February 22, 1979.



CANCER DEATH RATES
FOR U.S. MALES 1930-1976
AGE ADJUSTED.

Polonium Content in American Cigarettes and Smoke

Po^{210} content (pc)

Whole cigarette	Ash	Butt	Total smoke	Total in ash, butt, and smoke	Recovery*	Po^{210} in mainstream smoke (pc)	Ratio of mainstream to total smoke (%)
			Brand A, nonfilter				
0.43(4)	0.031(2)	0.13(2)	0.19 (2)	0.35	81	0.10(3)	52
			Brand B, nonfilter				
0.48(5)	0.053(2)	0.12(2)	0.26 (2)	0.43	90	0.12(2)	46
			Brand C, filter				
0.39(4)	0.035(2)	0.094(2)	0.19 (2)	0.32	82	0.088(2)	47
			Brand D, filter				
0.40(4)	0.033(2)	0.13(2)	0.17 (2)	0.35	88	0.070(3)	41

*Ratio of total in ash, butt, and smoke to total in whole cigarette

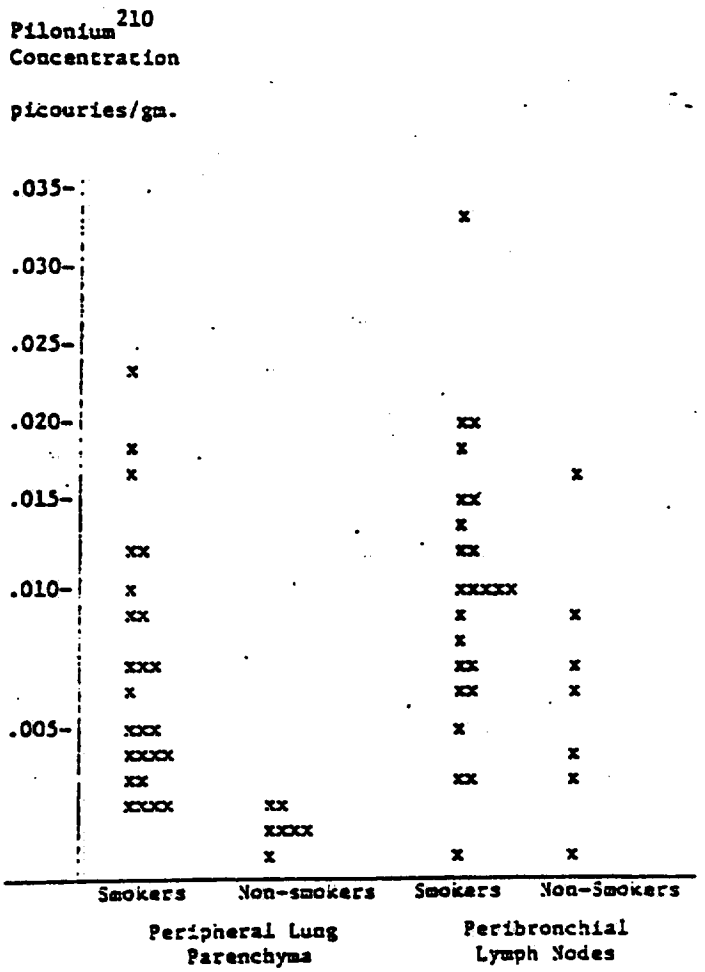
From Radford, E.P., and Hunt, V.R.

Tumor incidence in hamsters given multiple intratracheal instillations of ^{210}Po or BP

Treatment group	Carcinogen	Dose/ instillation	No. of animals autopsied	No. respiratory tumors	Tumor incidence
1	Control; no instillations		60	0	0
2	Control; hematite only		34	0	0
3	^{210}Po	0.2 mCi	35	35	97%
4	^{210}Po	0.2mCi[c]	37	25	68%
5	^{210}Po	0.01mCi	32	17	53%
6	Benzo(a)pyrene	3 mg	39	24	62%
7	Benzo(a)pyrene	0.3 mg	37	3	8%

From Little, J.B., and O'Toole, W.F.

Polonium-210 Concentrations in Peripheral Lung Parenchyma and Peribronchial Lymp Nodes in 25 Current Cigarette Smokers and 8 Non-smokers



From Little, J.B., Radford, E.P., McCombs, H.L., and Hunc, V.R.

Polonium-210 Content of Various Cigarette Tobaccos

Origin of Sample	No. of samples	^{210}Po activity (pc./kg) Max.	Min.	Mean
United States	8	650	390	510
Cent. and S. America	6	1,350	290	370
Rhodesia	3	700	600	650
Australia	2	669	610	640
India and Pakistan	2	570	250	410
Indonesia	1	---	---	230
Turkey and Greece	3	280	210	240

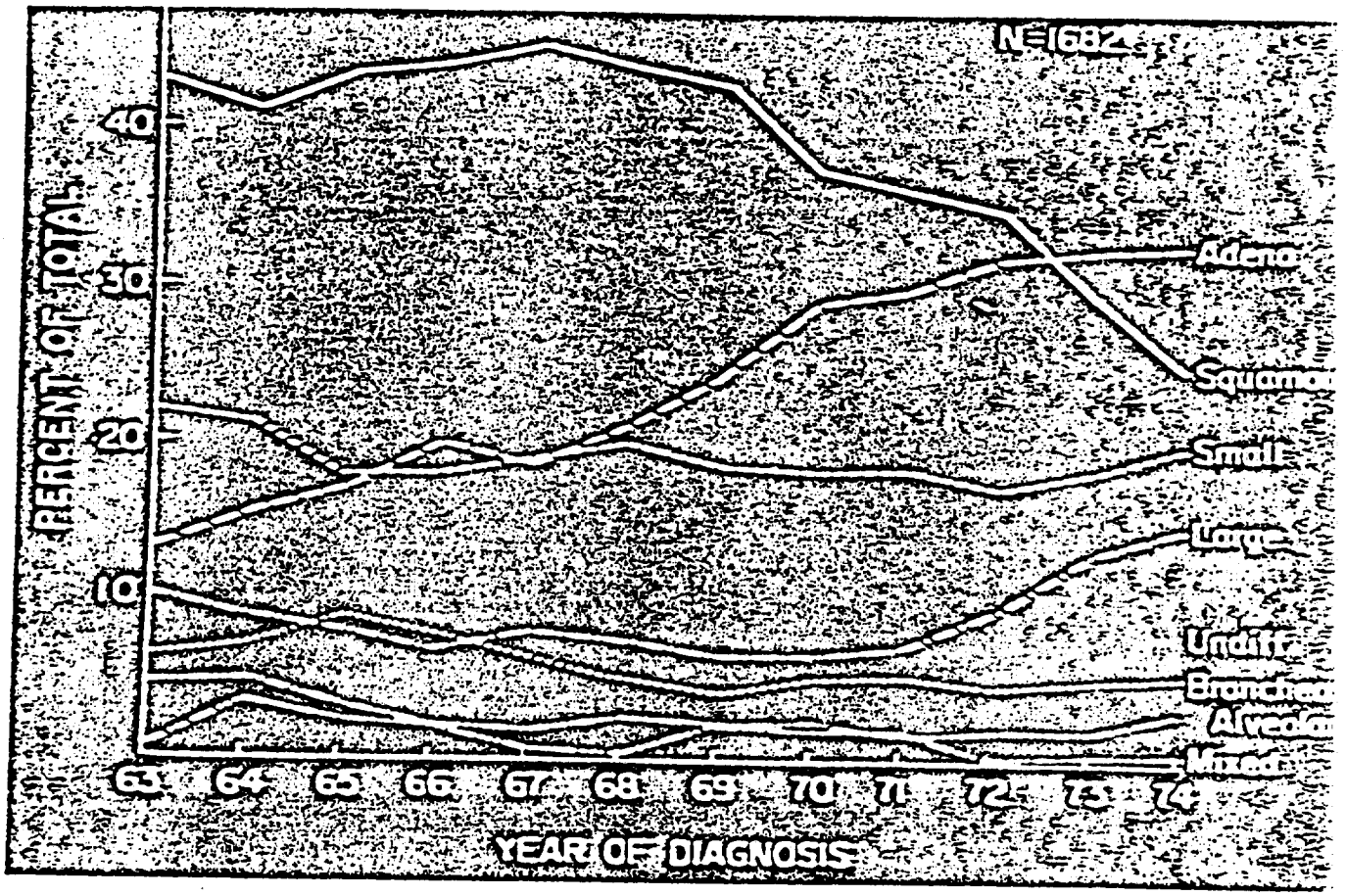
From Hill, C.R.

Natural Radioactivity in Tobaccos

Tobacco type	Year produced	Activity (pc g) (A) Measured Ra^{226} (May 1964)	(B) Calc. Pb^{226} from Ra^{226} (May 1964)	(C) Calc. Pb^{210} from Po^{210} (At harvest)	(C/A) Pb/Ra	(D) Measured Po^{210} (May 1964)
			Air-Cured			
Maryland	1958	0.059± 0.038*	0.03	0.27	4.6	0.13±0.01*
Pennsylvania cigar	1958	0.059±0.006	0.03	0.32	5.4	0.17±0.01
			Flue-cured			
Georgia (Tifton only)	1950	0.31±0.002	0.11	0.46	1.5	0.41±0.01
	1950	0.17±0.26	0.13	0.34	1.5	0.48±0.01
	1963	0.15±0.011	0.004	0.41	2.7	0.40±0.02
Georgia (mixed)	1959	0.19±0.002	0.06	0.27	0.7	0.10±0.01
	1960	0.30±0.016	0.03	0.25	0.8	0.25±0.01
	1961	0.30±0.008	0.02	0.42	1.4	0.40±0.01
	1962	0.21±0.013	0.01	0.36	1.7	0.33±0.03
	1963	0.30±0.018	0.008	0.42	1.4	0.42±0.06
East North Carolina	1955	0.15±0.002	0.04	0.28	1.9	0.25±0.03
	1956	0.14±0.000	0.03	0.38	2.7	0.33±0.02
	1959	0.19±0.001	0.03	0.37	1.9	0.35±0.14
	1960	0.25±0.007	0.03	0.41	1.6	0.39±0.03
	1961	0.16±0.007	0.01	0.31	1.2	0.43±0.01
	1962	0.14±0.013	0.008	0.45	1.2	0.43±0.03
	1963	0.16±0.011	0.004	0.31	1.9	0.30±0.01

*Error terms are one standard deviation calculated from two measurements of each radium sample and at least three measurements of each Po^{210} sample.

From Tso, T.C., Hallden, N.A., and Alexander, L.T.



INCREASING INCIDENCE OF ADENOCARCINOMA OF LUNG
Valaitis, J., Warren, S., Gamble, D. Cancer 1042-46, March 1 47 (5), 1981