

The Polonium Brief

A Hidden History of Cancer, Radiation, and the Tobacco Industry

By *Brianna Rego**

ABSTRACT

The first scientific paper on polonium-210 in tobacco was published in 1964, and in the following decades there would be more research linking radioisotopes in cigarettes with lung cancer in smokers. While external scientists worked to determine whether polonium could be a cause of lung cancer, industry scientists silently pursued similar work with the goal of protecting business interests should the polonium problem ever become public. Despite forty years of research suggesting that polonium is a leading carcinogen in tobacco, the manufacturers have not made a definitive move to reduce the concentration of radioactive isotopes in cigarettes. The polonium story therefore presents yet another chapter in the long tradition of industry use of science and scientific authority in an effort to thwart disease prevention. The impressive extent to which tobacco manufacturers understood the hazards of polonium and the high executive level at which the problem and potential solutions were discussed within the industry are exposed here by means of internal documents made available through litigation.

The American public is exposed to far more radiation from the smoking of tobacco than they are from any other source.
—Reimert Thorolf Ravenholt (1982)

[Publishing our research] has the potential of waking a sleeping giant.
This subject is rumbling . . . and I doubt we should provide facts.
—Paul A. Eichorn of Philip Morris, cautioning against publishing internal industry research on polonium (1978)

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ON 1 NOVEMBER 2006, former KGB operative Alexander V. Litvinenko fell ill after a meeting at a London sushi restaurant. Over the next three weeks his illness took several unexpected turns for the worse, ultimately prompting doctors to announce that he had been poisoned by an unknown radioactive substance. Litvinenko died on 23 November, and the next day the cause of death was determined to be radiation poisoning from polonium-210. In subsequent days, as concern grew in London that others had been exposed, the British Health Protection Agency reassured the population that there was “no radiation risk” to the general public, stressing that polonium-210 “can only contaminate if it is ingested, inhaled, or taken in through a wound.” Shortly thereafter, a *New York Times* op-ed by Robert N. Proctor pointed out that this statement was misleading, given that more than a billion people worldwide expose themselves daily—most often unknowingly—to polonium-210. The vector of this mass irradiation is not a vengeful government, nor an adversary in the style of Cold War espionage, but, rather, something far more common and available, something that is in fact quite ordinary: cigarettes.¹

That tobacco contains polonium comes as a surprise to many. A 2001 survey by K. Michael Cummings of the Roswell Park Cancer Institute found that 86 percent of 1,046 adult smokers polled were unaware that there are radioactive isotopes in tobacco.² The scientific evidence, however, dates back more than four decades. The radiochemists Edward Radford and Vilma Hunt first published on this topic in the 17 January 1964 issue of *Science*, only a few days after the appearance of the surgeon general’s report on smoking and health on 11 January.³ Their paper launched an extensive and often impassioned debate, as public and industry researchers alike pursued the problem with great interest.

The presence of polonium-210 in tobacco is of particular concern because it is one of the most radioactive isotopes, and even a very small dose can have devastating consequences. An extremely rare metalloid that occurs naturally in uranium ores, polonium was discovered in 1898 by Marie and Pierre Curie and named for her homeland of Poland. It has several radioactive isotopes, the most common of which is polonium-210 (²¹⁰Po), an alpha emitter, which means that it releases a high-energy helium ion (⁴He) in its radioactive decay. Alpha radiation is innocuous so long as it remains outside the body, but internally alpha particles are, generally speaking, the most hazardous form of radiation. Polonium-210 is a product of the natural uranium-238 decay series; the parent isotopes include radium-226, radon-222, and lead-210. Polonium-210 itself decays to the stable isotope lead-206 (plus an alpha particle). The isotope has a half-life of 138 days, which is short when compared to the 4.5 billion-year and 1,600-year half-lives of uranium-238 and radium-226, respectively. Its short half-life means that the isotope is very “hot,” emitting alpha particles at a rapid rate. And since smokers are exposing themselves to new doses with each cigarette, a constant cycle of exposure and decay is played out in the lung.

¹ “‘No Radiation Risk,’ Public Told,” *BBC News*, 24 Nov. 2006, <http://news.bbc.co.uk/go/pt/ft/-/2/hi/health/6181190.stm> (accessed 1 Dec. 2006); Jill Lawless, “Putin Faces Barrage in Death of Ex-Spy,” *Washington Post*, 26 Nov. 2006; and Robert N. Proctor, “Puffing on Polonium,” *New York Times*, 1 Dec. 2006.

² K. Michael Cummings, Andrew Hyland, Gary A. Giovino, Janice L. Hastrup, Joseph E. Bauer, and Maansi A. Bansal, “Are Smokers Adequately Informed about the Health Risks of Smoking and Medicinal Nicotine?” *Nicotine and Tobacco Research*, 2004, 6(S3):S333–S340, on p. S336. My own experience discussing polonium in tobacco suggests that this statistic is too high and that far fewer than 14 percent of smokers are in fact aware that there is polonium in their cigarettes. Polonium is often confused with plutonium, and only one smoker and a handful of nonsmokers I’ve spoken with have been aware that there are radioactive particles in tobacco.

³ Edward P. Radford and Vilma R. Hunt, “Polonium-210: A Volatile Radioelement in Cigarettes,” *Science*, 1964, 143(3603):247–249.

Although polonium-210 is quite rare in the earth's crust, it is extremely toxic. Estimates judge it to be about 250 million times more toxic than cyanide (by weight), and the isotope emits five thousand more radioactive particles per unit time than an equal amount of radium-226. Before its recent use as a spy-killing poison, polonium's most common industrial use was as an antistatic agent for large machinery and in brushes to remove dust from photographic film. The isotope was also used by the military as an initiator for nuclear weapons. In addition, it has been employed as a lightweight heat source for artificial space satellites. Considering its industrial and military uses, polonium-210 does not seem the sort of isotope wanted in one's lungs, yet the number of those exposed every day is staggering. About 5.7 trillion cigarettes are smoked annually worldwide—lined up end to end, they would reach to the sun and back, with enough left over for several trips to Mars.⁴ Each of those cigarettes contains about 0.04 picocuries (pCi) of polonium-210.⁵ Although that might seem like a very small dosage, puff by puff the radioactive particles concentrate in a smoker's lungs to the equivalent, by one estimate, of three hundred chest x-rays per year. That is a nontrivial exposure to radiation over the course of a lifetime—and a massive aggregate exposure that in terms of public health effects is the most important source of radiation to which humans are exposed.⁶

Exposure to polonium has been as wide ranging and long standing as the cigarette itself, which has permeated every aspect of society, adapting to the smoker's every imaginable mood, need, and image. The love affair with smoking, however, has been filled with contradictions—"smoking is patriotic yet rebellious, risky yet safe, calming yet exciting." But the history of tobacco is about much more than the history of smoking. Recent scholarship has documented the increasing popularity of tobacco in developing countries, the unquestioned brilliance and success of tobacco advertising, and smoking's leading role in Hollywood. We know a lot about the marvel that is the ephemeral yet persistent cigarette: the triumph of popular protests against secondhand smoke, the indignant responses of smokers to their increasing marginalization, and the trials of the tobacco industry. As Allan Brandt summarizes in *The Cigarette Century*, "there are few, if any, central aspects of American society that are truly smoke-free."⁷ Despite a shift in the

⁴ "Polonium," *Human Health Fact Sheet*, August 2005, Argonne National Laboratory, EVS, <http://www.ead.anl.gov/pub/doc/polonium.pdf> (accessed 5 Mar. 2007); and Robert N. Proctor, "Tobacco and the Global Lung Cancer Epidemic," *Nature Reviews Cancer*, 2001, 1:82–86, on pp. 85–86.

⁵ Several units for radiation are used in the United States. The curie (Ci) measures the actual amount of radiation: 1 Ci = 3.7×10^{10} decays/second (or the activity of 1 gram of radium-226). A picocurie (pCi) is one trillionth (10^{-12}) of a curie. The international equivalent of the curie is the becquerel (1 Bq = 1 decay/sec and 1 Bq = 2.7×10^{-11} Ci). A rad (radiation absorbed dose) is a unit of radiation dose equivalent to 0.01 joule of energy absorbed per kilogram of tissue. It measures the amount of radioactive energy actually in the tissue. In order to measure the physiological effect of a dose, the amount in rad is multiplied by the relative biological effectiveness (RBE, a "quality factor" often represented by the letter *Q*) of the radioactive element in question to get the dose in rem (röntgen equivalent in man), which measures the biological effectiveness (the degree to which the actual tissue is affected and destroyed) of an absorbed dose of radiation. The RBE differs from radioisotope to radioisotope, depending on many factors, including the type of radiation and the location and type of tissue affected. Alpha particles can have a *Q* as high as 20 (beta particles, x-rays, and gamma particles usually have *Q* = 1). Given its chemical properties as an alpha emitter, the amount of polonium-210 that is in cigarettes is, according to Ann Kennedy, who did research on polonium in the 1970s, "quite capable of promoting damage that could lead to cancer": telephone conversation with Ann Kennedy, 24 May 2007.

⁶ Thomas H. Winters and Joseph R. Difranza, "Letter to the Editor," *New England Journal of Medicine*, 1982, 306:364–365 (chest x-ray equivalence); and Reimert Thorolf Ravenholt, cited by the Associated Press, "Smokers Said to Risk Cancers beyond Lungs," *New York Times*, 29 July 1982.

⁷ Robert N. Proctor, "Agnotology: A Missing Term to Describe the Cultural Production of Ignorance (and Its Study)," in *Agnotology: The Making and Unmaking of Ignorance*, ed. Proctor and Londa Schiebinger (Stanford, Calif.: Stanford Univ. Press, 2008), pp. 1–33, on p. 11 ("patriotic yet rebellious"); and Allan M. Brandt, *The*

United States in recent years toward limiting and marginalizing smoking, Brandt was right to stress the extent to which tobacco permeated the twentieth century. The cigarette became an essential prop in hand and a cornerstone of the American economy.

The World Health Organization has stressed that smoking is the most avoidable cause of death.⁸ The destructive nature of smoking (as described by historians and scientists alike) has driven much of the scholarship on cigarettes, which until internal industry documents became available in the mid-1990s was largely focused either on quantifying disease consequences or on tracing the cultural responses to the rise of the industry. Following the release of millions of industry documents, scholars have been able to gain insights into the industry side of tobacco's history as well—and thus to offer a more nuanced and multifaceted story.

One aspect that has especially interested scholars is how the tobacco companies have understood and taken advantage of scientific authority, consensus, and controversy. The primary goal of cigarette manufacturers has been to influence and even minimize the extent to which the smoking public has understood the dangers of smoking. Emphasizing any wisp of uncertainty in science or any whisper of disagreement among scientists—if only with regard to what methods or tools to use in their research—has been a long-standing tactic of the tobacco industry.⁹ In response to mounting evidence that smoking is harmful, the industry launched a campaign in the mid-twentieth century to stress that, despite what had been published in the scientific literature, the dangers of smoking had not been “proven” and the results were little more than “statistics.” Any lack of consensus among researchers has therefore been spun by the tobacco industry in its continued insistence that even the experts “don't really know” what makes smoking harmful.¹⁰ Emphasizing the argument that science cannot offer “proof” but only a “suggestion” that smoking is dangerous, the tobacco industry has attempted to undermine any kind of evidence demonstrating the harms of smoking.

The tobacco companies have been successful in their use of science, influencing and even manipulating their customers by enlisting experts to defend their product in the face of increasing evidence that smoking is harmful: witness the advertisements proclaiming that “More Doctors Smoke Camels” and that L&M filters are “Just What the Doctor Ordered.” The industry used its own scientific authorities to counter and even undermine the scientific and medical legitimacy of countless researchers and doctors who stressed the dangers of tobacco. Smokers could choose which doctor they wanted to believe, and—as was the aim of the industry's advertising campaign—that doctor was often the one who

Cigarette Century: The Rise, Fall, and Deadly Persistence of the Product That Defined America (New York: Basic, 2007), p. 3.

⁸ World Health Organization, *WHO Report on the Global Tobacco Epidemic, 2008: MPOWER Package* (Geneva: World Health Organization, 2008), p. 8.

⁹ On the goals of the cigarette manufacturers see Robert N. Proctor, “Tobacco and Health” [expert witness report submitted in *United States of America v. Philip Morris*], *Journal of Philosophy, Science, and the Law*, 2004, 4:2–32, esp. pp. 9–18. On the tactic of emphasizing uncertainties and disagreements see Brandt, *Cigarette Century* (cit. n. 7); Richard Kluger, *Ashes to Ashes: America's Hundred-Year Cigarette War, the Public Health, and the Unabashed Triumph of Philip Morris* (New York: Knopf, 1997); Stanton Glantz, *The Cigarette Papers* (Berkeley: Univ. California Press, 1998); and Proctor, *Cancer Wars: How Politics Shapes What We Know and Don't Know about Cancer* (New York: Basic, 1995).

¹⁰ Proctor, “Agnotology” (cit. n. 7), p. 11. In her work on climate science Naomi Oreskes has discussed a similar stress on a lack of consensus among scientists. Some corporations have emphasized uncertainty in science in an effort to undermine scientific knowledge about global climate change, essentially echoing the tobacco industry's strategy. See Naomi Oreskes, “The Scientific Consensus on Climate Change,” *Science*, 2004, 306:1686; and Oreskes and Erik M. Conway, “Challenging Knowledge: How Climate Science Became a Victim of the Cold War,” in *Agnotology*, ed. Proctor and Schiebinger (cit. n. 7), pp. 55–89, on p. 78.

smoked Camels. Thus, as Brandt discusses, the industry's "strategic campaign to obscure and confuse the ongoing scientific enterprise" resulted in disordered responses by the public and delayed acceptance of the dangers of smoking.¹¹

In the case of polonium, the tobacco industry went so far as to initiate a research program of its own, staffed by industry scientists whose knowledge, training, awareness, and expertise were similar to those of scientists outside the industry. Cigarette manufacturers could therefore be selective about what science they promoted and used in their own defense, what science they hushed, and what science they questioned, either publicly or privately. So while the external scientific community stressed that the concentration of polonium in tobacco was significant and perfectly capable of causing cancer, tobacco industry scientists worked in silence to stress just as firmly that this had not been proven with absolute certainty. Despite extensive research, industry results were never published. Nor—underlining the unpublicized nature of this research—have I been able to find a single instance in which the industry issued a public denial on polonium. This silence is in stark contrast to the thousands of denials released by the industry on other hazards, such as nicotine. With polonium, the industry did not even engage in a public discussion—neither admitting nor denying the hazards—remaining silent rather than risk inspiring a debate that could only be harmful to the tobacco companies.

Despite the extensive scope of Richard Kluger's *Ashes to Ashes* and Brandt's *Cigarette Century*, neither mentions either polonium or the history of radiation research on tobacco. Aside from the 2006 *New York Times* op-ed by Proctor and a brief discussion in his 1995 book *Cancer Wars*, the presence of radioisotopes in cigarette smoke and the research conducted on alpha radiation as a cause of lung cancer in smokers have been ignored by historians. However, the topic of polonium in tobacco has had an extensive and somewhat tumultuous career within the tobacco industry, the external scientific community, and the wider public sphere. A recent article published in the *American Journal of Public Health* by a group from the Mayo Clinic and the Stanford University School of Engineering discussed the tobacco industry's response to the polonium issue. Quoting at length from internal documents, the authors stress that the industry has known about the presence of polonium in cigarettes for forty years and has done nothing to reduce the danger. This paper concluded that cigarette packs should be labeled with radiation warnings.¹² It is remarkable, however, how often such concerns have been raised, only to be quickly forgotten.

The story of polonium in cigarettes lies at the junction of tobacco, cancer, risk, policy, and radiation, and, as evidenced by the wide-ranging scholarship on these subjects, there are many angles from which to study their intricate and multifaceted stories. In contrast to previous histories treating tobacco, the purpose of this essay is to chronicle the largely untold story of a single hazardous element and to use this to expose the depravity of the tobacco industry in its use of science.¹³ The story of polonium-210 offers an opportunity

¹¹ Brandt, *Cigarette Century* (cit. n. 7), p. 4.

¹² Proctor, *Cancer Wars* (cit. n. 9), pp. 174, 306 n 1; and Monique E. Muggli, Jon O. Ebbert, Channing Robertson, and Richard D. Hurt, "Waking a Sleeping Giant: The Tobacco Industry's Response to the Polonium-210 Issue," *American Journal of Public Health*, 2008, 98(9):1–8.

¹³ This study is part of a larger "elemental historiography" I am exploring in my doctoral thesis. My sources for the project include papers from scientific journals, press releases, and articles from newspapers and magazines, as well as the Legacy Tobacco Documents Library, maintained by the University of California at San Francisco. This database has made available internal tobacco industry memoranda, meeting notes, research reports, and correspondence pertaining to the polonium issue, as well as many other aspects of the internal workings of the tobacco industry. The documents are online at <http://legacy.library.ucsf.edu>, and users can

to look into the relationship between science and the tobacco industry and to explore the sophisticated and well-funded scientific investigations conducted by the industry. Despite their extensive and long-term research on polonium, the tobacco companies never published their results nor even admitted the existence of their research program. Nor did the manufacturers ever make any serious effort to remove polonium from tobacco, despite the availability of several different techniques for doing so. Instead, the policy recommended by company scientists and supported by executives and attorneys was to stay abreast of external knowledge on the topic and to be prepared, if the need ever arose, to face the issue and deal with the problem.¹⁴ The impressive extent to which the industry understood the hazards of polonium and the high executive level on which the problem and potential solutions were discussed are exposed here by means of internal documents that have become available through litigation.¹⁵

HOT SPOTS

The discovery of polonium in tobacco was the result of chance and curiosity stemming from increased radiation research and nuclear fear during the 1950s. Like other labs across the country at the time, the radiochemical group at Harvard was involved in Atomic Energy Commission–sponsored research on the effects of radioactive fallout. Key figures in the discovery were Edward Radford and Vilma Hunt. Radford (1922–2001) was educated in biology and medicine at MIT and Harvard before he joined the Air Force and became involved in nuclear arms testing following World War II; Hunt (b. 1926), a native Australian, was originally trained in dentistry (after serving in the Royal Australian Air Force) before moving to the United States and refocusing her research on radiochemistry and occupational health. Collaborating at the Harvard School of Public Health, Radford and Hunt (and others in the radiochemical group) measured tooth and bone samples from across New England to determine the concentration in human tissue of naturally occurring alpha-emitting isotopes—specifically radium and polonium. The unexpected detection in 1962 of a particular radium isotope in one skeletal sample would divert Radford and Hunt from the fallout studies and lead to the publication a few months later of their discovery of polonium in cigarette smoke.¹⁶

The Harvard group’s analyses of teeth and bones had shown the consistent presence of radium-224 and radium-226, but in one skeleton from a three-year-old child the group observed a new phenomenon: a pattern of decay that indicated the possible presence of radium-223. Hunt recalls this being “of interest, to say the least!” as it indicated that a different chain of uranium was responsible for the radium in this child’s skeleton. As she was contemplating these results—and wondering what might have caused this pattern—Hunt’s eye glided over cigarette ash left behind by a smoking colleague, and she thought to test it for radium and polonium. Exactly why, she doesn’t know; as she now recalls, it was the way her “brain worked that day.” She knew it was “a long shot that radium-223 might be a constituent with a different pattern of radioactive decay,” but she recognized

search by keyword or browse through different collections. Documents are identified by a Bates number stamped on each page. I have followed the citation format used and recommended by Robert N. Proctor.

¹⁴ Gonzalo Segura to Abraham Bavley, “Polonium in Tobacco and Smoke” (memo), 27 Oct. 1964 (Philip Morris), Bates 100188168.

¹⁵ To give a sense of the often-overwhelming magnitude of the Legacy Tobacco Documents Library: in early July 2009 a search for “polonium” yielded more than thirteen thousand results in the entire archive and a search for “radiation” more than eighty thousand results.

¹⁶ Telephone conversation with Vilma Hunt, 2 Feb. 2009.

that such a finding could improve the analytical method the Harvard group was using at the time for very low concentrations of radium isotopes in biological materials.¹⁷

The results of her spontaneous study would stun her: no polonium was detected in the ash. No other biological material the group had tested in their laboratory (including plants) had lacked polonium when radium was found. As Hunt recalled in a recent conversation, she must have had the volatile temperature of polonium-210 in the back of her mind while looking over her lab notes, because it suddenly made sense to her that if there were no polonium in the ash it must have gone into the smoke.¹⁸ And so Hunt diverted her studies to focus more intensively on polonium and worked with Radford to measure the radioactivity in smoke.

Studies in the 1950s had looked into the possibility that radioactive isotopes might be responsible for lung cancer in smokers. But the particles measured—potassium-40 and radium isotopes—were quickly dismissed as insufficiently volatile at the temperature of a burning cigarette (600° to 800° C), which means they could not be responsible for irradiating the lungs of smokers. Radford and Hunt undertook their studies with the intent of reevaluating the presence of alpha emitters in tobacco, determined not only to measure the concentration of radioisotopes but also to explore whether the levels were significant enough to cause lung cancer in smokers.¹⁹

Before Radford and Hunt could hypothesize how much polonium was actually deposited on the bronchial epithelium (the membrane lining the respiratory tract), they had to measure the minimal dose that would result from the smoke simply passing through the lung, without accumulating in any one place. Radford and Hunt artificially “smoked” cigarettes, drawing air through a filter designed to collect all tobacco smoke-sized particles. Cigarettes were “puffed” in this manner at a rate of a two- to three-second puff every fifty seconds—the average rate Radford and Hunt observed while spying on their smoking colleagues. The smoke was passed through a trap to capture both mainstream and sidestream smoke and treated with hydrogen chloride. The polonium was then plated on silver and counted for alpha activity in windowless gas-flow proportional counters, following radiochemical procedures developed by the Harvard group during their research into radium and polonium in teeth and bones. They found that for a person who smoked two packs of cigarettes a day for twenty-five years, the total-lung minimum dose was about 36 rem, or seven times the normal background radiation exposure.²⁰

Radford and Hunt also realized, however, that this minimum dose was not a meaningful representation of the way polonium-210 behaves when inhaled through a cigarette. Because of the way the lung branches, the radioisotopes settle and concentrate at the points of bifurcation, forming so-called hot spots of intense radioactivity. Radford and Hunt focused their original study on these areas of greatest concentration. Accurately

¹⁷ *Ibid.*; and email correspondence with Hunt, 27 Feb. 2009. Radium-223 decays from uranium-235, radium-226 decays from thorium-232, and radium-224 (a parent isotope of polonium-210) decays from uranium-238.

¹⁸ Email correspondence with Hunt, 27 Feb. 2009; and telephone conversation with Hunt, 2 Feb. 2009.

¹⁹ Radford and Hunt, “Polonium-210” (cit. n. 3), p. 247. For the 1950s studies see F. W. Spiers and R. D. Passey, “Radioactivity of Tobacco and Lung Cancer,” *Lancet*, 1953, 265:1259–1260; R. C. Turner and J. M. Radley, “Naturally Occurring Alpha Activity of Cigarette Tobaccos,” *ibid.*, 1960, 1:1197–1198; and E. S. Harlow and Charles R. Greene, “Some Comments on ‘Temperature Profiles throughout Cigarettes, Cigars, and Pipes,’” *Science*, 1956, 123(3189):226–227.

²⁰ Radford and Hunt, “Polonium-210,” pp. 247–248. For the radiochemical procedures see Edward P. Radford, Jr., Vilma R. Hunt, and Dwyn Sherry, “Analysis of Teeth and Bones for Alpha-Emitting Elements,” *Radiation Research*, 1963, 19(2):298–315, on pp. 300–301; they were also discussed in my telephone conversation with Hunt, 2 Feb. 2009.

measuring the precise dosage of radiation at these hot spots was not easy, as it was difficult to reproduce a proper smoking technique in the lab. Rising to this challenge, they estimated a range of several hundred to more than 1,000 rem for somebody smoking two packs a day for twenty-five years.²¹ It was already known that, in addition to the high doses of radiation at such hot spots, certain pathological consequences of heavy smoking (such as ciliastasis) made the epithelium even more vulnerable to the effects of polonium. Because of the delicacy of the bronchial system and the well-known physiological damage caused by cigarette smoke, Radford and Hunt proposed that even minimal radiation from polonium-210 could cause lung cancer by initiating mutations in cellular development.²²

Radford and Hunt's research was focused on measuring radioactivity in smoke, and they hypothesized about its deposition in the lungs. It was their colleague at Harvard, John ("Jack") Little, who conducted a study of human lung tissue and showed that polonium was "indeed deposited and retained in specific regions of the bronchi." Little, a radiobiologist and physician, was able to collect samples of human lung tissue within a few hours of death from pathologists in the Boston area (a project that, he recalls, involved many late-night dashes to the hospital). Little dissected specimens of the epithelium from multiple areas in the bronchial tree and showed that the highest concentration of polonium was found in segmental bifurcations, just as Radford and Hunt had proposed.²³

These papers on polonium in tobacco provoked an impressive response from radiochemists, cancer biologists, and tobacco researchers both inside and outside the industry. Radford and Hunt's first paper inspired numerous letters to the editor of *Science*, and more papers on the subject were published within the year. Much of the research that followed Radford and Hunt's original publication and Little's 1965 study focused on the biology and chemistry of the tobacco plant itself. During the late 1960s, researchers measured concentrations of polonium in various tobacco crops and cigarette brands in an attempt to determine the origin of polonium-210 in the tobacco plant and the stage of the cigarette manufacturing process during which it could be most effectively and efficiently removed.

In November 1964, T. C. Tso of the U.S. Department of Agriculture, Naomi Hallden of the U.S. Atomic Energy Commission (who would stay involved in polonium research, later publishing under her married name Harley), and L. T. Alexander, also of the Department of Agriculture, published a paper suggesting that there were significant differences in the concentrations of polonium in tobacco grown in different regions of the country. Sampling tobacco crops from various localities, Tso, Hallden, and Alexander found that North Carolina tobacco contained about three times more polonium than Maryland tobacco. These results were viewed as particularly significant, since more than a third of American tobacco was grown in North Carolina, accounting for a billion dollars per year in state income. The authors suggested that these variations in polonium levels could be caused by the natural radiation content of the soil and phosphate fertilizer used, as some phosphate rocks naturally contain more uranium than others.²⁴

Research by the New Zealand-born scientist L. P. Gregory in 1965 expanded Tso,

²¹ Radford and Hunt, "Polonium-210," p. 248.

²² *Ibid.*, pp. 248–249. Ciliastasis is the stiffening of the cilia, the hair-like organelles, similar to flagella, that line the surface of the lung. In a healthy lung the cilia wave back and forth, cleansing the lung.

²³ Email correspondence with John Little, 4 Mar. 2009; telephone conversation with Little, 5 Mar. 2009; and J. B. Little, E. P. Radford, Jr., H. L. McCombs, and V. R. Hunt, "Distribution of Polonium-210 in Pulmonary Tissues of Cigarette Smokers," *N. Engl. J. Med.*, 1965, 273(25):1343–1351.

²⁴ T. C. Tso, N. A. Hallden, and L. T. Alexander, "Radium-226 and Polonium-210 in Leaf Tobacco and Tobacco Soil," *Science*, 1964, 146(3647):1043–1045, esp. pp. 1043–1044.

Hallden, and Alexander's work, showing that there were significant variations in the polonium-210 concentration of tobacco grown in different countries. Gregory found that the radioactivity of New Zealand tobacco was less than half that of American tobacco. South African tobacco had concentrations similar to the American, while Rhodesian was slightly more radioactive.²⁵ Despite such dramatic differences in tobacco crops, Gregory, along with other researchers, found no significant difference between various brands of cigarettes or between filter and nonfilter varieties.²⁶ The lack of variation among brands suggested that the isotope was naturally present in the tobacco leaf, not something added during the curing process.

In their original report, Radford and Hunt had speculated briefly on the origins of polonium in tobacco. They had suggested two possibilities: either daughter isotopes of natural atmospheric radon-222 (a polonium precursor) settled on the leaves, decaying to polonium once attached to the tobacco plant, or lead-210 (polonium-210's parent isotope) decayed to polonium-210 after being absorbed through the plant's roots.²⁷ In order to test the first hypothesis—that polonium was absorbed by the tobacco plant from nuclear fallout—Tso, Harley, and Alexander conducted an experiment growing tobacco plants inside a greenhouse pumped full of radon to about five hundred times the normal background atmospheric concentration, as determined by German tests.²⁸ Although there was an increase in the polonium measured in the tobacco plants grown in this radioactive atmosphere, the concentration was not significant enough for fallout to be the primary source of radioactive particles in tobacco. To test the second hypothesis—that lead-210 in phosphate fertilizer entered the tobacco plant through the roots—Tso, Harley, and Alexander conducted a soil experiment, testing two different kinds of fertilizers: a commercial superphosphate and a specially mixed fertilizer made from chemically pure secondary calcium phosphate. The differences between the two were remarkable. The commercial fertilizer had about thirteen times more radon-226 than the specially mixed fertilizer, resulting in polonium levels in the leaf that were nearly seven times higher.²⁹

Tso, Harley, and Alexander felt they had established that most of the polonium in tobacco originated in the phosphates used to fertilize the plant, but subsequent research by Chester Francis, Gordon Chesters, and Wilfred Erhardt, of the University of Wisconsin, suggested that phosphate fertilizers were not a significant enough source of polonium to eliminate fallout as the "principal mechanism" of polonium-210 entry into the tobacco plant. In order to determine the amount of polonium resulting from fallout, Francis, Chesters, and Erhardt measured the concentration of lead-210 in rainwater they collected in Wisconsin during the summer of 1966.³⁰ Although their results were intriguing, they did

²⁵ Gregory hypothesized that the lower levels of polonium-210 in New Zealand tobacco could be due to an "insular effect" that could cause most natural nuclear fallout to be dispersed over the ocean, rather than over crops; see L. P. Gregory, "Polonium-210 in Leaf Tobacco from Four Countries," *Science*, 1965, 150(3692): 74–76, esp. pp. 74–75.

²⁶ Thomas F. Kelley, "Polonium-210 Content of Mainstream Cigarette Smoke," *Science*, 1965, 149(3683): 537–538, on p. 537.

²⁷ Radford and Hunt, "Polonium-210" (cit. n. 3), p. 248.

²⁸ The "normal" atmospheric radon concentration cited by Tso, Harley, and Alexander came from work by the German radiation physicist Wolfgang Jacobi. See W. Jacobi, "Die natürliche Radioaktivität der Atmosphäre," *Biophysik*, 1963, 1:175–188.

²⁹ T. C. Tso, Naomi Harley, and L. T. Alexander, "Source of Lead-210 and Polonium-210 in Tobacco," *Science*, 1966, 153(3783):880–882, esp. p. 881. Superphosphate fertilizer is made by treating phosphate rock with sulfuric acid.

³⁰ Chester Francis, Gordon Chesters, and Wilfred Erhardt, "²¹⁰Polonium Entry into Plants," *Environmental Science and Technology*, 1968, 2:690–695, on p. 690. Although tobacco was apparently the first plant to be

not sample rainwater in other tobacco-producing areas—notably North Carolina—and their data were limited to a single summer. It is therefore not known if the results were an accurate representation of average annual fallout over tobacco crops.

As research on the origins of polonium-210 in the tobacco plant continued through the 1960s, and as the physiological effects began to be understood, cigarette manufacturers became increasingly concerned. Internal tobacco industry documents reveal a flurry of activity and correspondence in reaction to the 1964 paper by Radford and Hunt. The same day that this paper was published in *Science*, for example, Philip Morris researcher Ted Katz scrawled a note to Abraham Bavley, manager of the company's research division, commenting on the discovery. Katz wrote that polonium is "reportedly an alpha emitter" that, it seemed to him, "would be a most dangerous material once inside the body." Bavley was sufficiently concerned to commission Philip Morris radiochemist Gonzalo Segura to do a literature review on the topic, the results of which he received ten months later. Segura confirmed that "it is true" that polonium could cause cancer and stressed that both dose and rate of intake should be considered. He immediately recognized that the study of polonium in tobacco had the potential to become a "major project" but did not think that Philip Morris should worry about pursuing the issue. He did, however, strongly recommend that management keep a "particularly sharp look-out" for any research developments that might unfavorably affect the industry. The company should strive to keep "ahead of adverse publicity and be in a position to counter it quickly" if the problem of polonium in tobacco ever became critical.³¹

Management took Segura's advice and continued to keep a close eye on relevant scientific literature. In 1965, Philip Morris senior research chemist Robert Carpenter wrote to his supervisors Helmut Wakeham (vice president of research and development) and Robert Seligman (assistant director of tobacco research and development), pointing out that polonium was receiving increased attention from the biomedical field. He suggested, therefore, that it might be time for Philip Morris to look into the "polonium situation" or "problem," as it was often called.³²

"THE INDUSTRY MIGHT BE INTERESTED . . ."

In February 1965 the Department of Research and Development at the American Tobacco Company released its budget for the following year, earmarking \$95,725 for its radiochemical section. Twenty percent of this was to go to development, leaving 80 percent for applied research. Philip Morris also decided to pursue its own research on polonium and by the end of 1965 had talked with Edward Radford (who was described, in something of an understatement, as being "actively interested in the polonium in smokers").³³ Despite

studied as a source of polonium, by the late 1960s researchers were beginning to realize that everything from fruit trees to lettuce contained traces of polonium. As Radford and Hunt noted, what makes polonium dangerous in tobacco and not in, say, broccoli, is that polonium-210 is volatile above 500° C, well below the temperature of a burning cigarette (about 600° to 800° C), which allows it to adhere strongly to the smoke particles and to gain direct access to the lung. According to a 2005 fact sheet from Argonne National Laboratory, the cancer risk from inhaling polonium-210 is about six times greater than the risk from ingesting it, a determination that highlights the danger of the presence of polonium-210 in tobacco. See Radford and Hunt, "Polonium-210" (cit. n. 3), p. 248; Francis *et al.*, "²¹⁰Polonium Entry into Plants," p. 690; and "Polonium," *Human Health Fact Sheet, August 2005* (cit. n. 4).

³¹ Ted Katz, "Polonium in Smoke," 17 Jan. 1964 (Philip Morris), Bates 1001896995; and Segura to Bavley, "Polonium in Tobacco and Smoke" (memo), 27 Oct. 1964 (Philip Morris), Bates 1001896688–6689.

³² R. D. Carpenter, "Polonium in Tobacco," 16 Dec. 1965 (Philip Morris), Bates 1001881339.

³³ For the American Tobacco Company budget figures see "Department of Research and Development New

the companies' interest in the matter and increasingly sophisticated radiochemical programs, the industry did not publicize its internal research or interest in this area. The closeted nature of their research, however, did not stop industry scientists from discussing methods and materials with outside experts.

Following the publication of his 1965 paper in the *New England Journal of Medicine*, Jack Little was visited by several scientists from the large tobacco companies who were interested in learning in detail the techniques used by Little's group, as well as their results. As he recalls, they "seemed very pleasant and interested, were clearly actively investigating the question themselves, and seemed open in discussing their findings." However, he was unable to establish any further contact with the scientists; and despite the visits he was not aware of the extent of the research being conducted by the industry. In 1967, American Tobacco sent Ronald Davis to the University of Massachusetts at Lowell to confer with Professor of Radiological Sciences Kenneth Skrable on various techniques involved in measuring polonium in tobacco. Applying information gleaned through such interactions with outside scientists, American Tobacco confirmed in its own laboratories earlier reports that existing filters had no effect on the concentration of polonium in cigarette smoke. By November, Philip Morris had also measured and reconfirmed polonium concentrations in cigarettes. The results, like those of the other tobacco companies, were never published.³⁴

Over the next few years, industry scientists would become increasingly involved in pursuing polonium. The industry's scientific effort, however, had goals that differed from those of researchers like Radford and Hunt, who were hoping to prevent cancer. Industry researchers pursued the same problem—polonium in tobacco—but they tweaked parameters and methods so as to suggest that Radford and Hunt's measurements might be exaggerated. Philip Morris (and perhaps other tobacco companies) measured the concentration of polonium over the *entire* bronchial area and did not take the varying concentrations in different parts of the lung into account. The Harvard researchers, in contrast, had focused their measurements on the branching points of the bronchial epithelium (the so-called hot spots), which account for only 2 to 3 percent of the weight of the lung. As Little and Radford stressed in a 1967 letter to the editor of *Science*, much higher concentrations of polonium are found there than in the rest of the bronchial area.³⁵ Industry results were therefore diluted, showing lower concentrations of polonium-210 than were found by Radford, Hunt, and Little.

As research on polonium in tobacco continued, and as work by external scientists strengthened the argument that radioactive particles in cigarette smoke could pose a health hazard, one might have anticipated that the public media would pick up the story. The issue would seem to offer the makings of a full-blown press frenzy, along the lines of the thalidomide and asbestos stories of the 1960s and 1970s. However, the press never seized

Products Division Budget—1966," 24 Nov. 1965 (American Tobacco Company), Bates 966013836–3838. On the talks with Radford see R. D. Carpenter, "Polonium in Tobacco," 16 Dec. 1965 (Philip Morris), Bates 1001881339.

³⁴ Email correspondence with Little, 4 Mar. 2009; Ronald W. Davis, "Visit to Industrial Reactor Laboratory," 14 Aug. 1967 (American Tobacco Company), Bates 950113464–3465 (conferring with Skrable); E. C. Cogbill and R. W. Davis, "Progress Report—Month of February," 6 Mar. 1969 (American Tobacco Company), Bates 950282988–2989; Cogbill and Davis, "Progress Report—Radiochemical Section March 1969," 11 Apr. 1969 (American Tobacco Company), Bates 950282986–2987; and J. L. Charles to R. B. Seligman, "Meeting with Mr. Alex Holtzman" (interoffice correspondence), 14 Nov. 1980 (Philip Morris), Bates 2060534987 (on confirmations of polonium concentrations).

³⁵ John B. Little and Edward P. Radford, "Polonium-210 in Bronchial Epithelium of Cigarette Smokers," *Science*, 1967, 155(3762):606–607, esp. p. 606.

on and pursued the story of radioactive material in tobacco to the extent one might have expected. Though a small number of pieces were published in a few newspapers and journals following Radford and Hunt's original report, sustained coverage of the issue was minimal.

Indicative of the lack of public concern about the subject is the surprising absence of consumer letters written to the tobacco industry on this topic. One might expect anxious smokers to have written the tobacco companies, wondering about the radioactivity levels of their favorite brand of cigarettes. However, among the many thousands of letters on countless topics (the surgeon general's report, for example, inspired more than five thousand queries), I could find only a couple from the 1960s that mentioned polonium at all. On 27 January 1964, only ten days after Radford and Hunt's first publication on polonium, Charles J. Smyth of Staten Island, New York, wrote to the director of research at R. J. Reynolds Tobacco Company:

The Surgeon General's recent report linking cigaret smoking to lung cancer and the subsequent report by the Harvard scientists, which indicated the presence of the radioactive heavy metal polonium in tobacco leaves has done little to enhance the future of the cigaret industry.

. . . It is with the finding of polonium in the tobacco leaves that I concern myself and it is after some thought and urging of others that I forward the following suggestion in an effort to provide a "safe" cigaret.

Smyth's suggestion—developing a "porous filter" that he believed would remove the risk of inhaling polonium—was acknowledged in a response from Reynolds to the effect that his letter was "appreciated" and that the company felt "complimented" that he had turned to them with his suggestion.³⁶ And then the matter was dropped. The tobacco companies clearly did not have much to worry about from their customers on this issue. Once the press coverage immediately following the 1964 paper died down, the tobacco industry simply refrained from comment and waited for the research and reporting to abate.

Even though there were not many papers on polonium published in the late 1960s, and therefore not much public awareness, there was a significant amount of scientific research during this time. Following Radford and Hunt's 1964 paper, the industry received several calls and even visits from scientists interested in pursuing polonium studies. During the first few months after the discovery, the tobacco manufacturers were not particularly interested in funding or supporting any research on the issue.³⁷ By 1967, however, as the industry was strengthening its own internal research programs, the Council for Tobacco Research (the industry's external research arm) began to receive more serious proposals from reputable scientists. One of these in particular caught their attention.

In July 1967 John E. Noakes of Oak Ridge Associated Universities (now professor of geology and director of the Center for Applied Isotope Studies at the University of Georgia) submitted an application for a research grant to the Council for Tobacco Research (CTR). The application proposed a three- to four-year project in two phases. The first phase, estimated to last about a year, was to be a geochemical study of the origins of polonium in the tobacco plant, including research to identify the parent isotopes (radium-226, radon-222, or lead-210) responsible for its presence. The second phase, to be

³⁶ Charles J. Smyth, "Letter to R. J. Reynolds," 27 Jan. 1964 (R. J. Reynolds), Bates 11294070; and Robert D. Rickert, "Response to Charles J. Smyth," 31 Jan. 1964 (R. J. Reynolds), Bates 11294071.

³⁷ Robert C. Hockett, "Proposals for Study of Radiation in Tobacco," 20 July 1964 (Council for Tobacco Research), Bates 01127511.

completed during the second and third (and, if necessary, fourth) years of research, would be a medical study of the levels of polonium needed to cause cancer in humans. The funding requested by Noakes was \$30,900 for the first phase and \$61,200 per year for the second. Citing Gregory's 1965 study of varying levels of polonium in different regions, Noakes stressed that the polonium content of U.S. tobacco was among the highest in the world. He then referenced Tso's soil studies and proposed to focus his own research on phosphate fertilizer as a source of polonium in the tobacco plant. Noakes hypothesized that the high polonium content of American-grown tobacco could be due to the extensive use of Florida phosphate fertilizer, which has a naturally high level of uranium and therefore high levels of its daughter isotopes, including lead-210 and polonium-210. During the 1960s the majority of American phosphate used in fertilizer was from the central Florida region, and Noakes suggested that using phosphate from a different source might lower the levels of polonium in tobacco.³⁸

Noakes's proposal was submitted to the Council for Tobacco Research after he had made "two or three visits" to the office of Robert Hockett (associate scientific director of the CTR), during which he discussed his past work and future research goals. Noakes impressed Hockett, who remarked in a CTR memo that his research had the potential to demonstrate "relatively simple and inexpensive means of reducing the [polonium] content materially." Hockett went on to say that, regardless of the actual hazard posed by polonium, "the industry might be interested in . . . minimizing this contamination, as a matter of public policy." In August 1967 Hockett wrote to Helmut Wakeham, vice-president and director of research and development at Philip Morris, asking him to attend a meeting of the CTR's science advisory board and offer his input on Noakes's grant application. According to Hockett, the general opinion of the board was that polonium in tobacco did not "constitute any appreciable hazard." However, if Noakes's proposed research were to deliver the results it promised, then the board "would probably agree that 'the less the better' if it can be reduced easily."³⁹

In Hockett's view, if Noakes's hypothesis that polonium levels in tobacco could be reduced simply by switching fertilizer sources proved correct, it would give the tobacco companies a chance to "benefit chiefly in terms of public relations." While all this sounded perfectly fine to the board, the main question was the "economic feasibility" of such a large-scale change. As Hockett said, "If the 'solution' to the problem is not really practical or practicable, the value of pointing a finger at the source of the polonium (or unknown hazard) would vanish." Convinced that this might be the case, the CTR ultimately rejected Noakes's proposal. The board had not found any fault in the proposed research plan itself. However, in their response to Noakes the CTR focused on the basis of his proposed project, questioning the "evidence implicating polonium in tobacco as a health hazard," despite well-documented internal concern at the time. The CTR was clearly worried that highlighting the dangers of radioisotopes in tobacco might harm the industry. What's more, by funding such research the industry would be admitting that polonium was a

³⁸ Noakes, "Application for Research Grant," submitted to the Council for Tobacco Research, 11 July 1967, Bates 1003546978-6995.

³⁹ Robert C. Hockett to Leon O. Jacobson, Clayton G. Loosli, and Stanley P. Reimann, "New Grant Application from John E. Noakes, Ph.D.—No. 624" (memo), 29 Aug. 1967 (Council for Tobacco Research), Bates 01188040-8041; and Hockett to Helmut Wakeham, 31 Aug. 1967 (Philip Morris), Bates 001609361-9362.

problem. With all this in mind, the board rejected Noakes's proposal, telling him they felt funds should be "committed in other directions."⁴⁰

Despite the CTR's rejection of Noakes's proposal, his idea of investigating fertilizers clearly appealed to the tobacco companies. Apparently willing to give Noakes's solution a try, despite not funding his research, the industry experimented with North Carolina phosphate in the early 1970s. T. C. Tso believed that the North Carolina phosphate was "free" of radium (and therefore of radium's daughter isotopes), and he suggested conducting several studies to determine if phosphate were, in fact, the origin of polonium in tobacco. Tso also stressed to the Council for Tobacco Research that even if the cost of removing polonium from tobacco were high, it would ultimately prove to be a "self-supporting" investment.⁴¹

During the late 1960s, the tobacco men were focusing a significant amount of attention and resources on the polonium problem behind closed doors, yet there were not many publications during this time. Some isolated papers appeared in the late 1960s and early 1970s, but for the most part work on the topic remained quiet. In May 1974, a paper published in *Nature* by Edward Martell of the National Center for Atmospheric Research in Boulder, Colorado, revived interest in the subject. Martell, a graduate of West Point, earned his doctorate in radiochemistry from the University of Chicago. Following World War II he was involved in researching radiation effects at the Nevada Test Site and at Bikini Atoll. After witnessing the destructive power of nuclear energy he made a switch in his professional life, dedicating himself to researching radiation-induced cancers.⁴² In the 1970s he became interested in radioactive particles as a cause of lung cancer and focused his research on the physiological effects of polonium and the biology of the tobacco plant.

Much of Martell's 1974 paper discussed the presence of lead-210 in cigarette smoke. Stating that previous research on the origins of polonium in tobacco had been "contradictory" (with Tso, Harley, and Alexander finding that most of the polonium was from root uptake of soil enriched with phosphate fertilizers, while Francis, Chesters, and Erhardt believed that the source of polonium was radioactive fallout), Martell began his study by looking closely at the tobacco leaf in order to determine how polonium behaves in the plant itself.⁴³

He noted that the surface of the tobacco leaf is covered by tiny hairs called trichomes, about 85 percent of which have a glandular head coated with a sticky organic substance. A mature tobacco leaf can have up to nine hundred trichomes per cm² on each side of the leaf. Martell suggested that the stickiness of these trichomes attracts settling particles and provides a surface on which radioactive fallout can collect while the tobacco leaf is growing. Because the sticky coating on the glandular head is hydrophobic, he postulated

⁴⁰ Hockett to Wakeham, 31 Aug. 1967; and W. T. Hoyt to John Noakes, 19 Dec. 1967 (Council for Tobacco Research), Bates 50083248.

⁴¹ Noakes's proposed research appealed to the tobacco companies: see E. S. Harlow to Wakeham, 14 Sept. 1967 (American Tobacco Company), Bates 1001609331. Regarding industry work on this topic see R. C. Hockett, "Visit by Dr. T.C. Tso of the U.S. Department of Agriculture, to Discuss Martell's Concepts of Lead-210 and Polonium-210 as Contaminants of Tobacco, August 21, 1975," 25 Aug. 1975 (Council for Tobacco Research), Bates 1000279828-9830.

⁴² Bob Henson, "NCAR Mourns the Death of Ed Martell, Its Only Radiochemist," *Staff Notes Monthly* [University Corporation for Atmospheric Research], July 1995, 30(7).

⁴³ Edward Martell, "Radioactivity of Tobacco Trichomes and Insoluble Cigarette Smoke Particles," *Nature*, 1974, 249:215-217. He was referring to Tso *et al.*, "Source of Lead-210 and Polonium-210 in Tobacco" (cit. n. 29); and Francis *et al.*, "²¹⁰Polonium Entry into Plants" (cit. n. 30).

that even soluble particles would not be washed away by rain. Measuring the polonium-210 content of two thousand trichomes from North Carolina-grown tobacco leaves, he found that the average concentration of lead-210 was $3.2 \pm 0.6 \times 10^{-6}$ pCi per trichome. In keeping with earlier research indicating that North Carolina tobacco has a higher concentration of radioactive particles than tobacco grown in most other places, tobacco grown in Turkey and Kentucky showed lead-210 concentrations that were a half and a quarter, respectively, of that in the North Carolina tobacco.⁴⁴

Martell agreed with Noakes and Tso, Harley, and Alexander that the geographic variations in tobacco concentration were due to variations in the uranium concentration in the rock used to make phosphate fertilizers. Rather than believing that polonium was taken up by the roots, Martell suggested that soils with a concentration of uranium-rich phosphate fertilizer would release increased amounts of radon-222 into the surrounding atmosphere; it would then be deposited in the form of lead-210 on the leaves of the growing tobacco crop.⁴⁵

Like Radford and Hunt, Martell was concerned with the buildup of polonium-210 in certain areas of the lung. It had been generally accepted for some time that exposure to radiation from radon daughters was the cause of elevated cancer risk among uranium miners, so Martell reasoned that radiation should also be accepted as the agent of cancer in smokers. He concluded that, given the chronic exposure to low doses of insoluble radioactive particles that were concentrated in specific areas of the lungs, polonium-210 was likely the primary cause of smokers' lung cancer and perhaps, as he suggested in a later paper, other types of cancer as well.⁴⁶ Martell shifted his studies from polonium-210 to lead-210, which is present in tobacco in a volatile state and as soluble and insoluble particles. He suggested that it was the *insoluble* lead-210 particles that were most likely the primary agents of lung cancer in smokers. The volatile lead-210 could disperse easily and be exhaled, and the soluble particles would dissolve into the bloodstream and ultimately would be excreted, resulting in the higher levels of polonium measured in the urine of smokers.⁴⁷

On the basis of comparisons with radiation exposures of uranium miners, Martell

⁴⁴ Martell, "Radioactivity of Tobacco Trichomes and Insoluble Cigarette Smoke Particles," p. 215. The earlier work on polonium concentrations included Gregory, "Polonium-210 in Leaf Tobacco from Four Countries" (cit. n. 25); and Little *et al.*, "Polonium-210 in Bronchial Epithelium of Cigarette Smokers" (cit. n. 35).

⁴⁵ For an industry report on Martell's findings see "Polonium-210 Entry into Plants from Superphosphate Fertilizers," 5 Dec. 1975 (American Tobacco Company), Bates 962004691-4693.

⁴⁶ In the 1960s, researchers found elevated levels of polonium in the lungs and also in the blood, urine, bronchial lymph nodes, and even the skeletons of smokers. In addition to their original measurements of the levels of polonium-210 in the bronchial epithelium, Radford and Hunt also measured the concentration in urine. Heavy smokers (two packs a day) had a urine concentration of 0.065 pCi of polonium per twenty-four hours, nearly six times as much as the 0.011 pCi of nonsmokers. The presence of elevated levels of polonium in urine suggested an increased level in the bladder as well, indicating that the radioactive polonium-210 isotope, originally inhaled into the lung, can be traced throughout the body. Because of this, Martell suggested that polonium-210 in cigarette smoke could be tied to other radiation-induced cancers, such as osteosarcoma and leukemia, in addition to lung cancer. Hannes Eisler of the University of Stockholm suggested in a letter to the editors of *Science* that the presence of polonium in the urine of smokers could be an indication that the increased risk of bladder cancer among smokers might be attributed to radiation from tobacco. See Radford and Hunt, "Polonium-210" (cit. n. 3); Richard B. Holtzman and Frank H. Ilcewicz, "Lead-210 and Polonium-210 in Tissues of Cigarette Smokers," *Science*, 1966, 153(3741):1259-1260, esp. p. 1260; Hannes Eisler, "Polonium-210 and Bladder Cancer," *ibid.*, 1964, 144(3621):952-953; Martell, "Radioactivity of Tobacco Trichomes and Insoluble Cigarette Smoke Particles" (cit. n. 43), p. 217; and Edward Martell, "Tobacco Radioactivity and Cancer in Smokers," *American Scientist*, 1975, 63(4):404-412.

⁴⁷ Martell, "Radioactivity of Tobacco Trichomes and Insoluble Cigarette Smoke Particles," p. 217. Lead-210 (²¹⁰Pb) is a precursor of polonium-210 in the natural uranium-238 decay series. A beta emitter, it decays to

suggested that the danger came not with the volume dose at any given time but, rather, with exposure over time. He argued that lead-210 (which has a half-life of twenty-two years) entered the lungs along with the polonium, settling in the lower bronchial lobes. The high exposure associated with a lifetime of smoking would presumably give the lead enough time to decay to polonium-210. Basing his findings on the average North Carolina flue-cured tobacco concentration (3×10^{-6} pCi of lead-210 per smoke particle), Martell found that the alpha radiation dose to cells in the immediate vicinity of a radioactive particle (about six cell diameters) would be about 0.5 rad, or 5 rem per year. Over a twenty-five-year period, the total radiation dose would exceed 200 rem, with much higher doses possible in hot spots of concentrated activity.⁴⁸ A lifelong smoker, therefore, could be at a high risk for cancer despite the relatively low dose of polonium-210 per cigarette.

“NO COMMERCIAL ADVANTAGE”

Like Radford and Hunt’s paper a decade earlier, Martell’s inspired a flood of research and new publications that expanded polonium research from botany to animal studies. In the years since the publication of Radford and Hunt’s paper, the polonium scene at Harvard had shifted away from radiochemistry and toward radiobiology. Radford had left Harvard for the University of Cincinnati and Hunt had moved to Yale; polonium research at Harvard was taken up by the radiobiologist John Little, who had worked with Radford and Hunt in the 1960s. Under Little, the focus was on biological studies and animal experiments that would help researchers show just how damaging even low doses of polonium could be.

In a 1974 paper, Little and fellow Harvard scientist William O’Toole showed astonishing results after forcing polonium into the tracheas of hamsters in an effort to determine whether extremely low doses could cause cancer: 94 percent of hamsters in the highest exposure group developed lung tumors with doses so small that there was no inflammation. A similar study conducted a year later by Little, Ann Kennedy, and Robert McGandy exposed hamsters to a very low dose of polonium-210 aerosols over a period of several weeks.⁴⁹ The results showed that 10–36 percent of the animals developed malignant tumors in their lungs, compared to the 15 percent of lifelong smokers who develop lung cancer. Little, Kennedy, and McGandy continued their research for several years, and their experiments demonstrated that lung cancer *could* be caused by relatively small amounts of radioactive polonium (and alpha particles more generally); this concerned the tobacco companies a great deal.⁵⁰

Much as in the 1960s, however, the tobacco industry did not respond publicly to this

bismuth-210, which itself decays to polonium-210 via beta decay. Lead-210 has a half-life of twenty-two years; see Holtzman and Ilcewicz, “Lead-210 and Polonium-210 in Tissues of Cigarette Smokers,” p. 1260.

⁴⁸ Martell, “Radioactivity of Tobacco Trichomes and Insoluble Cigarette Smoke Particles,” p. 216.

⁴⁹ John B. Little and William F. O’Toole, “Respiratory Tract Tumors in Hamsters Induced by Benzo(α)pyrene and ^{210}Po α -Radiation,” *Cancer Research*, 1974, 34:3026–3039; Little, Ann R. Kennedy, and Robert B. McGandy, “Lung Cancer Induced in Hamsters by Low Doses of Alpha Radiation from Polonium-210,” *Science*, 1975, 188(4189):737–738; and Little, Kennedy, and McGandy, “Effect of Dose Rate on the Induction of Experimental Lung Cancer in Hamsters by α Radiation,” *Radiation Res.*, 1985, 103(2):293–299. The Syrian golden hamster was chosen for Little’s studies because it tends to be resistant to pulmonary infections and rarely develops spontaneous lung tumors.

⁵⁰ Although Little, Kennedy, and McGandy’s work on low doses was the most prominent, their studies were not the first on the subject. In 1967, C. L. Yuile, H. L. Berke, and T. Hull of the University of Rochester had found lung cancer growths in rats exposed to a single dose of polonium aerosol; see C. L. Yuile, H. L. Berke, and T. Hull, “Lung Cancer Following Polonium-210 Inhalation in Rats,” *Radiation Res.*, 1967, 31(4):760–774.

latest wave of research. Internally, on the other hand, there was a significant amount of activity. There are over two thousand documents from the 1970s in the UCSF Legacy Tobacco Documents online library that mention polonium, and more than a third of these date from 1974 and 1975. They show a flurry of interdepartmental correspondence, research reports, and meetings between top-level representatives from several tobacco manufacturers. In many of these memos one can sense a certain level of apprehension and urgency as the industry realized that it might eventually have to face this potentially embarrassing problem.

Only a couple of months after Martell's paper was published in *Nature*, Walter Gannon, director of new product development at Philip Morris, wrote a memo recapping a phone conversation he had had with Martell on 2 July 1974. Martell had mentioned that he was studying lung samples sent to him by Edward Radford and that he (Martell) expected the polonium-210/lead-210 ratio of these samples to support his previous research and hypotheses. Martell also said that he would be in touch with Gannon before he presented a paper to the Tobacco Working Group of the National Cancer Institute in September of that year.⁵¹

This was not the first time Philip Morris representatives had spoken with Martell. The company's contact with him reached back at least to March 1973, when Tibor Laszlo met with Martell at the National Center for Atmospheric Research. During his visit to the "new and unusually beautiful" research building at the center, Laszlo was able to spend quite some time speaking with Martell about his research on polonium and lead in tobacco. Martell displayed an interest in staying in touch with the R&D department at Philip Morris; he noted that he traveled back and forth to Washington quite regularly and would be pleased to stop in and discuss his research, as he was "very anxious" to gauge the general attitude of the department concerning the validity of his work. In response to Martell's entreaties for his opinion, Laszlo "gave a noncommittal answer."⁵² Cigarette manufacturers were not yet ready, it would seem, to come out in the open on the matter of polonium.

Despite the amount of work on the subject and the accumulating evidence that polonium was indeed present in cigarette smoke and likely one of its carcinogens, there was still a sense among some in the industry that the science was wrong—or at the very least exaggerated. In a memo to Tim Cahill of the R. J. Reynolds corporate public relations department, Alan Rodgman, head of the analytical section of the Reynolds research department, wrote:

While the biological results presented by the Harvard group [i.e., Little, Kennedy, and McGandy's 1975 paper] are suggestive of a relationship between polonium and cancers observed in hamsters so treated, it should be realized that the experiment conducted was unrealistic in terms of dose of polonium in an artificial way not related to the cigarette smoke inhalation process. The smoker probably receives his exposure in small incremental doses during the puffs with ample opportunity for his lung clearance mechanism to function either between exposures to individual puffs or between the smokings of successive cigarettes.⁵³

⁵¹ W. F. Gannon to Wakeham, F. E. Resnik, Thomas Osdene, D. A. Lowitz, T. S. Laszlo, and Robert Jenkins, "Call to Dr. E. A. Martell on July 2, 1974" (interoffice memo), 10 July 1974 (Philip Morris), Bates 2012601880.

⁵² Laszlo to Wakeham, "IRI Meeting, March 26–27, 1973" (interoffice memo), 29 Mar. 1973 (Philip Morris), Bates 000016756–6758.

⁵³ Alan Rodgman to Tim Cahill (interoffice memo), 15 July 1975 (R. J. Reynolds), Bates 501016384. Rodgman is referring to Little, Kennedy, and McGandy's 1975 paper, "Lung Cancer Induced in Hamsters by Low Doses of Alpha Radiation from Polonium-210" (cit. n. 49), published four months before this memo was

Rodgman was being somewhat economical with the truth, however, as the challenges of replicating a “proper” smoking technique in the lab were well known and discussed by researchers. Moreover, his statement that radiation posed no long-term health hazards because the lung will cleanse itself of any inhaled polonium reveals a lot of unfounded faith in the weakened bronchial “clearance mechanism” of smokers, which could have been damaged by such physiological effects of long-term smoking as ciliastasis.

In several of the industry minutes and memos written on the subject in the late 1970s, one can sense that tobacco manufacturers were aware that they might eventually be called on to address this problem and had begun exploring various techniques to remove at least some of the polonium from tobacco. The industry knew that polonium could cause problems as a carcinogenic “additive,” and Philip Morris was concerned that tobacco might fall under “something akin” to the Delaney proviso of the 1958 Food and Drug Administration Food Additives Amendment, which prohibited any known carcinogens from being added to food.⁵⁴ If such a proviso were ever extended to tobacco, the companies could be forced to remove polonium from their product (or at least reduce levels “below existing methods of detection”). In a memo to the president of the American Tobacco Company in 1975, R&D manager R. M. Irby wrote, “If the future should dictate that steps would have to be taken to ensure that zero amounts of polonium were present, work would certainly have to include treatment of tobacco as well as filtration.”⁵⁵ Both of these potential solutions would be brought up repeatedly throughout the following decade by external and internal scientists and by high-level industry executives. But it seems that in most cases research on the removal of polonium went no further than brainstorming or preliminary experimentation, and no industry results were ever published.

Regarding a proposed solution that would presumably also remove many of the other criticized constituents of tobacco, Rodgman wrote to Cahill,

It should be noted that the members of the Harvard group [i.e., Little, Kennedy, and McGandy] have little, if any, knowledge about the ease of removal of specific components from tobacco smoke. While polonium probably does not contribute to the “flavor” of tobacco smoke, it is a component of the so-called particulate phase of smoke. The particulate phase consists of the aerosol particles—small liquid spheres—each containing many thousands of components. To remove polonium selectively from these spherical balls by filtration is virtually impossible. Since the polonium is present in the particulate phase, one way to decrease its level in smoke is to reduce the level of “tar” delivered by the cigarette during smoking.⁵⁶

written. In “The Golden Holocaust: A History of the Global Tobacco Plague” (ms draft, forthcoming) Robert N. Proctor calls Tim Cahill “Cold Facts Cahill” for his consistent use of the phrase “the cold facts are . . .” in response to consumer inquiries.

⁵⁴ On 11 June 2009 the U.S. Senate passed the Family Smoking Prevention and Tobacco Control Act, which was signed by President Obama on 22 June. The bill gives the Food and Drug Administration regulation over tobacco and the power to set standards, such as requiring graphic images on cigarette packs, banning certain cigarette flavors, limiting or lowering chemicals in tobacco, and banning the use of marketing terms such as “light” or “low-tar” by cigarette manufacturers. Although the legislation does not allow the federal government to outlaw cigarettes, it does for the first time bring tobacco under the jurisdiction of the FDA. As has concerned Philip Morris and other tobacco companies, polonium is likely to be one of the constituents of cigarettes that the FDA will choose to regulate.

⁵⁵ “Radiochemistry—Polonium,” 15 Apr. 1977 (Philip Morris), Bates 1003372188; and R. M. Irby, Jr., to Robert Heimann, “Polonium-210” (memo), 19 May 1975 (American Tobacco Company), Bates 950113500. Polonium is not, strictly speaking, an “additive,” but in this memo the industry called it such, interestingly placing it in the same category as other substances that are added to tobacco during the curing process.

⁵⁶ Rodgman to Cahill (interoffice memo), 15 July 1975 (R. J. Reynolds), Bates 501016384.

Despite differing opinions as to the most efficient and straightforward way of removing polonium, industry scientists had determined that if the isotope *were* in tobacco, it would show up in the particulate phase of smoke. This determination allowed research on the removal of polonium to focus on a filter. On 22 July 1975 the Council for Tobacco Research held an Industry Technical Committee meeting with representatives from all the tobacco companies, including the CTR's Hockett, Philip Morris's Wakeham, Osdene, Seligman, and Jenkins, and R. J. Reynolds's Nystrom and Rodgman. Much of the meeting was spent discussing polonium, and the attendees were given a thorough literature review as well as photocopies of selected references. To the high-powered industry personnel involved in this discussion, a filter was an attractive solution, as it might remove particulate matter (and a proportional amount of polonium) without altering the chemistry of the cigarette or the process of growing and curing the tobacco leaf.⁵⁷

The idea of a filter would resurface the following month in a meeting on polonium held by the Tobacco Working Group of the National Cancer Institute in Bethesda, Maryland. The August 1975 meeting, unlike the CTR meeting in July, was attended not only by representatives of the tobacco industry but also by figures from the National Cancer Institute and the U.S. Department of Agriculture and external polonium researchers, including T. C. Tso, Naomi Harley, and Ann Kennedy (of the Little *et al.* group from Harvard that caused such a stir with its paper on the consequences of low doses of polonium in hamsters).⁵⁸ Kennedy, then a graduate student in radiation biology working with Jack Little at Harvard (and today a professor of research oncology at the University of Pennsylvania School of Medicine), represented the position of the Harvard group. She stood by their research indicating that polonium posed a health hazard and stated that "something should be done about its removal." But there was outspoken disagreement among the other attendees, many of whom felt that the risks were being exaggerated. After Kennedy raised the possibility of removing polonium from cigarette smoke by means of an ion-exchange resin filter, industry representatives questioned its likely effectiveness. The position of the tobacco manufacturers at this meeting is remarkable, given that in their own meeting only a month earlier they seem to have favored exploring the possibility of using a filter to remove polonium from cigarette smoke.⁵⁹

Had the tobacco industry changed its stance on removing radioactive isotopes in the time between the two meetings? More likely, the opinions expressed during the meeting with Kennedy fit with the tobacco industry's lawyered public stance on polonium, while

⁵⁷ "Minutes from Industry Technical Committee Meeting, Council for Tobacco Research," 25 July 1975 (CTR), Bates 950149527-9529. As suggested by these meeting minutes, the industry continued to shy away from admitting the presence of radioactive materials in cigarettes (at least publicly), saying that "polonium-210 in cigarette smoke, if any," would exist in the particulate phase of smoke. The attendees at this meeting included Helmut Wakeham (vice president for research and development), Thomas Osdene (director of research), Robert Seligman, and Robert Jenkins from Philip Morris, as well as Charles Nystrom and Alan Rodgman from R. J. Reynolds. Following the discussion on polonium, Wakeham gave a brief demonstration on the presence of carbon monoxide in cigarette smoke. He claimed that its dangers are not as grave as some have suggested because "the smoke is diluted first by the air already in the smoker's lungs as well as by that taken in with the puff."

⁵⁸ "National Cancer Institute Smoking and Health Program: Workshop on the Significance of Po210 in Tobacco and Tobacco Smoke," 25 Aug. 1975 (Lorillard), Bates 01421854-1857. In a telephone interview on 24 May 2007, Ann Kennedy recalled that her attendance at this meeting was funded by the National Institutes of Health. She stressed that she would not have attended a meeting funded by the tobacco industry, as her research focuses on cancer prevention—something that is clearly not the top priority of the tobacco industry!

⁵⁹ On Kennedy's position see Wakeham to Resnik, "Meeting on Polonium" (cc'd to Seligman, Osdene, and Jenkins), 26 Aug. 1975 (Philip Morris), Bates 1003728418-8419.

the memoranda, notes, and minutes from the July 1975 CTR meeting that were exclusive to industry personnel reveal private and internal views of the matter. In the years since Radford and Hunt's first paper on polonium, the industry had been careful not to draw attention to the issue by keeping results unpublished and avoiding public debate with researchers or health officials. At the same time, however, top-level industry managers and executives had kept abreast of ongoing external research. Industry scientists had worked on their own parallel experiments and had recorded their results and measurements, always keeping their work secret and private. Thus, there had been a wide discrepancy and inconsistency between what the industry was admitting publicly about polonium and what it was saying and doing privately.

Despite their outspoken disagreement during much of the joint industry-NIH meeting of the Tobacco Working Group, and despite the fact that it was decided that an ion-exchange filter would not be pursued, Kennedy and the industry representatives were able to come up with a research plan recommending three areas of further study. First, the amount of polonium in cigarettes would be determined for both filter and nonfilter commercial brands. The polonium concentration remaining in the filter after a cigarette had been smoked would also be measured to determine the effectiveness of the filter and how much polonium had actually been inhaled. Second, laboratory dogs would be exposed to polonium-210 particulates in smoke, and their lungs would be examined for any radioactivity and ensuing damage. (Dogs were often used in radiation research because "people believe dogs," as they are much more similar to humans than rodents.)⁶⁰ Special attention would be focused on how polonium was distributed through the lung and on whether there were indeed areas of concentration, or hot spots, as first suggested by Radford and Hunt in 1964. Third, the amount of polonium in tobacco would be "monitored," as it varied with the use of different fertilizers. Work led by T. C. Tso of the Department of Agriculture would consider various sources of fertilizer.⁶¹

Concern about polonium remained strong within the tobacco industry into the late 1970s, and there was considerable worry that more scientists and researchers would become interested in the problem. In 1977, Robert Jenkins of Philip Morris traveled to Arizona to meet with John McKlveen, a professor of nuclear engineering at Arizona State University, to dissuade him from studying polonium. McKlveen had shown an interest in beginning research similar to that of Martell, but Jenkins cautioned against it, convincing him that "there are areas of unknown science that are more important and are necessary before" he should commence research on polonium.⁶²

The industry's own researchers, on the other hand, had been addressing the issue since 1964, and following Martell's publication in 1974 industry scientists conducted several projects and experiments on removing polonium from tobacco. By 1975, 80 percent of the personnel in Philip Morris's radiochemical section were involved in the polonium project.

⁶⁰ Telephone conversation with Kennedy, 24 May 2007.

⁶¹ It was suggested that the industry should look into a new uranium-free fertilizer developed in the 1970s by the Uranium Recovery Corporation, which was by then being prepared commercially. In the mid-1970s, several companies researched the possibility of producing uranium-free fertilizers, among them Uranium Recovery Corporation, Gulf Oil, Westinghouse Electric Company, and Freeport Minerals. According to Gulf Oil, 96 percent of the uranium could be removed from phosphate fertilizers, with a loss of only 0.01 percent of the phosphate. See Wakeham to Resnik, "Meeting on Polonium" (cc'd to Seligman, Osdene, and Jenkins), 26 Aug. 1975 (Philip Morris), Bates 1003728418-8419; and "Uranium from Phosrock," *Chemical Week*, 9 July 1975, p. 24.

⁶² Jenkins to Osdene, "Visit with Dr. J. McKlveen" (interoffice correspondence), 23 Nov. 1977 (Philip Morris), Bates 000016590-6591.

Their work included measuring the concentration of polonium in tobacco, but the majority of industry scientists focused on ways to remove or reduce it. In June 1977 Robert Jenkins of Philip Morris completed a three-month study titled “Nuclear and Radiochemistry of Smoke.” In keeping with Martell’s findings, Jenkins reported that about 50 percent of the soluble polonium-210 could be removed from the bottom leaves of the tobacco plant by simple washing. The amount of polonium removable by washing decreased toward the top of the stalk, leading Jenkins to conclude that the technique was not effective enough to be worth implementing, despite the intimation that any reduction of polonium would reduce radioactive exposures.⁶³

By 1980 there seems to have been a certain acceptance within the tobacco industry that the issue was not going to fade away as it had in the 1960s. In a meeting at Philip Morris on 11 November of that year it was noted that the “key point here is that interest is continuing” on the issue, with the principal concern being that future publications and research might draw a new wave of attention to the isotope. In a memo written the next day, Roger Comes of Philip Morris followed up with Alex Holtzman, the company’s vice president and associate general counsel, stressing that the polonium problem “will not be leaving us.”⁶⁴ Although Philip Morris acknowledged the advantage of not engaging publicly on polonium, the company also recognized the necessity of monitoring the issue very closely so it could respond to any new developments. In his memo to Holtzman, Comes was careful to urge that “the entire subject of low level radiation effects on public health from whatever source (Mt. St. Helens, Three Mile Island, Chinese Nuclear Testing, Tobacco, etc, etc) is one we must be aware of and must be addressing.”⁶⁵

The tobacco industry was in fact mulling over new methods for reducing the polonium in cigarettes. Several years earlier, Ramsey Campbell of the Stauffer Chemical Company had submitted a patent application for a treatment of tobacco leaves that would reduce the levels of radioactive lead and polonium in tobacco. The patent was granted on 25 March 1980, and it launched several years of correspondence and deliberations between the Stauffer Chemical Company and several of the major tobacco manufacturers, including Philip Morris and R. J. Reynolds.⁶⁶ The patent proposed to remove radioactive lead and polonium from tobacco by washing the leaves with a dilute acid solution of hydrogen peroxide. The process would involve either spraying the leaves with the solution while they were still growing or dipping them in the acid solution after they were harvested. The leaves would then be rinsed with water before being allowed to dry.

Philip Morris had been in contact with Campbell since the mid-1970s, and Robert Jenkins in particular had spoken with him on several occasions. In January 1976 Jenkins

⁶³ R. W. Jenkins, “Nuclear and Radiochemistry of Smoke” (report), 7 June 1977 (Philip Morris), Bates 1001925327–5328. On work in the Philip Morris radiochemical section see Jenkins to W. R. Johnson, “Projected Six-Month Research Plans for-210Pb-210Po” (interoffice correspondence), 24 Sept. 1975 (Philip Morris), Bates 2012614839–4843.

⁶⁴ Charles to Seligman, “Meeting with Mr. Alex Holtzman—210 Polonium Briefing—November 11, 1980” (interoffice correspondence) (cc’d to Osdene, Alexander Holtzman, Jenkins, Roger A. Comes, and Edward B. [“Ted”] Sanders), 14 Nov. 1980 (Philip Morris), Bates 000016574–6575; and Comes to A. Holtzman, “Follow-up to Discussion of November 11, 1980” (interoffice correspondence) (cc’d to Seligman, Osdene, Sanders, Charles, and Jenkins), 12 Nov. 1980 (Philip Morris), Bates 1000083336.

⁶⁵ Comes to A. Holtzman, “Follow-up to Discussion of November 11, 1980.” Regarding the importance of following all developments closely see Marian DeBardleben to Comes (memo), 28 Feb. 1980 (Philip Morris), Bates 2012600443; Osdene to A. Holtzman (memo), 11 Apr. 1980, Bates 000016577; and Charles to Seligman (interoffice correspondence), 14 Nov. 1980 (Philip Morris), Bates 2060534987.

⁶⁶ Ramsey G. Campbell, “United States Patent: Removal of Radioactive Lead and Polonium from Tobacco,” 25 Mar. 1980 (R. J. Reynolds), Bates 501522607–2611.

traveled to California to visit with Campbell to discuss his interest in polonium. Jenkins offered a brief review of the “open literature,” including an explanation of “just what Martell was saying.” Campbell then asked (with what seemed to Jenkins to be “previous knowledge”) about any polonium research being conducted by the tobacco industry. All Jenkins revealed was that, “in general terms, Martell’s findings were essentially accurate in their radiochemical determinations.” Jenkins and Campbell followed up this visit with a phone conversation on 16 February, during which (in response to questioning) Jenkins recommended certain laboratory equipment that Campbell might find useful for his own polonium research. He also referred Campbell to T. G. Williamson of the University of Virginia as someone who might be able to help him with polonium analyses. In recommending Williamson, Jenkins felt he was ensuring that Philip Morris would have full access to any of the resulting data and could control their release; as Jenkins put it, “Dr. Williamson ‘knows where his bread is buttered.’”⁶⁷

Between 1980 and 1985, several tobacco companies reviewed the Stauffer patent, considering whether they should adopt the acid washing procedure to reduce the polonium in tobacco leaves. Philip Morris had been experimenting with washing leaves since the 1970s, and Jenkins had obtained results similar to Campbell’s (perhaps Jenkins pursued his own research following his discussion of this technique with Campbell in January 1976?). On 14 April 1980, Philip Morris patent agent Susan Hutcheson wrote to Seligman that she thought Jenkins was quite unhappy about the Stauffer patent; but, as she reasoned, not much could be done about it, as “Stauffer is *not* in the tobacco business—which makes a difference!” Several years later, Philip Morris was still discussing whether it should adopt the process described in the Stauffer patent. In March 1985 Jenkins described the research Philip Morris had conducted in the 1970s on washing. He stated that it is “well known that, under the right chemical conditions,” soluble lead-210 and polonium-210 can be dissolved. These results were supported not only by the work leading to Campbell’s technique but also by research conducted by Jenkins himself. Jenkins’s data showed that about 60 percent of all soluble polonium-210 could be removed by washing tobacco leaves.⁶⁸

Jenkins himself said in this same 1985 memo that “Mr. Campbell utilizes accepted technology and at this time no fault can be found with his radiochemistry.” Despite the “scientific validity” and promising results of Campbell’s washing process, however, both Philip Morris and R. J. Reynolds conclusively decided not to adopt it. According to Reynolds’s “resident expert on polonium,” Charlie Nystrom, the greatest challenge of the Stauffer patent was the impracticality of implementing the procedure on a “commercial scale basis.” Numbered first among the company’s reasons for rejecting the patent was that “complete removal . . . would have no commercial advantage.”⁶⁹

Philip Morris, like R. J. Reynolds, also seemed most concerned with the “practicality of this patent,” rather than with the potential health benefits of washing. Because the tobacco leaf would have to be washed before curing, it was likely the farmer who would

⁶⁷ Jenkins to Osdene (interoffice correspondence), 25 Feb. 1976 (Philip Morris), Bates 2012614498.

⁶⁸ For the Philip Morris patent expert’s comment see S. Hutcheson to Seligman, “Re: Washing Tobacco” (memo), 14 Apr. 1980 (Philip Morris), Bates 1003725586. Regarding Jenkins’s data see Jenkins to Tom Goodale, “Removal of Radioactive Lead and Polonium from Tobacco, U.S. Patent 41 94 541” (interoffice correspondence), 15 Mar. 1985 (Philip Morris), Bates 2012615307.

⁶⁹ Jenkins to Goodale, “Removal of Radioactive Lead and Polonium from Tobacco, U.S. Patent 41 94 541”; and C. W. Nystrom to Rodgman, “Comments on the Stauffer Patent No. 4,194,514 for Removal of Radioactive Lead and Polonium from Tobacco” (interoffice memo), 5 Mar. 1982 (R. J. Reynolds), Bates 504970288.

apply Campbell's technique.⁷⁰ Both Philip Morris and R. J. Reynolds were rightly worried about the added expense for the tobacco farmer, but they listed other concerns about the impracticality of the Stauffer patent process, including the problem of disposing of the acid solution once the leaves had been washed and the fact that a large portion of cured tobacco leaves are water soluble. If, however, the washing took place *before* the tobacco leaf were cured, the second concern would be a nonissue, leaving only the matter of disposing of the used acid solution, a problem that could probably have been resolved. Ultimately, Reynolds opted to not pursue the patent because it was felt that, given the lack of consumer concern, there would be "no commercial advantage in providing a tobacco product with reduced quantities of these constituents."⁷¹

Despite the companies' decision not to wash tobacco leaves, Robert Jenkins noted that if it were ever "deemed desirable" to remove or reduce the amount of radioactive material in tobacco, there were procedures and methods in addition to those patented by the Stauffer Chemical Company that promised to do just that. He concluded, however, that the "real question" was whether it would be of any commercial value to the industry to remove polonium from tobacco. In concert with Jenkins, Alan Rodgman of R. J. Reynolds noted that the polonium issue had "appeared and disappeared periodically" since 1964, suggesting that there was really no need to invest in resolving the problem as it would certainly disappear once again.⁷²

"THE WORST PART . . . THERE MAY BE SOME DEGREE OF VALIDITY"

By 1980 the wave of polonium-related research that followed Martell's papers had subsided somewhat, but the tobacco industry correctly anticipated that this lull would be short lived. Interest in the issue was revived in early 1982 by a letter written to the editor of the *New England Journal of Medicine* by Thomas Winters and Joseph Difranza, both of the University of Massachusetts Medical Center. Winters and Difranza felt that there had not been nearly enough research on polonium as a carcinogen in tobacco, and they stressed that in the seventeen years since the surgeon general's original report work on radiation had been "conspicuous because of its absence."⁷³ In their brief review of the relevant research, however, Winters and Difranza overlooked most of the papers that had been published on the topic, citing only Radford and Hunt's "Polonium-210: A Volatile Radioelement in Cigarettes" (1964), Little, Radford, McCombs, and Hunt's "Distribution of Polonium-210 in Pulmonary Tissues of Cigarette Smokers" (1965), and Martell's "Radioactivity of Tobacco Trichomes and Insoluble Cigarette Smoke Particles" (1974).

Their limited references embittered many of the other scientists who had published on the topic, and the 29 July 1982 issue of the *New England Journal of Medicine* published seven responses to Winters and Difranza, including letters from Martell, Cohen, and

⁷⁰ Jenkins to Goodale, "Removal of Radioactive Lead and Polonium from Tobacco, U.S. Patent 41 94 541"; and Hutcheson to Seligman, "U.S. Patent 4,194,514 Assigned to Stauffer" (law department memo), 14 Apr. 1980 (Philip Morris), Bates 1003725585.

⁷¹ Nystrom to G. R. Di Marco, "Evaluation of Idea from Ramsey G. Campbell for Removal of Radioactive Lead and Polonium from Tobacco" (interoffice memo), 22 July 1985 (R. J. Reynolds), Bates 504205144-5146. For other company concerns with regard to impracticality see Jenkins to Goodale, "Removal of Radioactive Lead and Polonium from Tobacco, U.S. Patent 41 94 541"; and Hutcheson to Seligman, "U.S. Patent 4,194,514 Assigned to Stauffer."

⁷² Jenkins to Goodale, "Removal of Radioactive Lead and Polonium from Tobacco, U.S. Patent 41 94 541"; and Rodgman to Roy Morse, "Stauffer Patent" (memo), 8 Mar. 1982 (R. J. Reynolds), Bates 501522602.

⁷³ Winters and Difranza, "Letter to the Editor" (cit. n. 6).

Harley. Although a couple of these letters criticized Winters and Difranza's suggestion that there had been little research on polonium as a tobacco carcinogen and offered extensive lists of references as proof of earlier work, most applauded the renewed attention they had drawn to the subject. In the same issue, Winters and Difranza wrote a letter responding to the enormous reaction they had provoked. It had become clear to them that although there had certainly been an extensive amount of work on polonium in tobacco, only a few people were aware of this research.⁷⁴

Unlike the tobacco industry memoranda written following the publication of Martell's paper, several of the industry's internal documents from the months after Winters and Difranza's letter display a surprising lack of knowledge on the subject of polonium in tobacco, not to mention polonium itself. Some industry employees in 1982 were surprised and shocked to learn that there is polonium in tobacco and flatly denied that radioactive particles could be a cause of cancer in smokers. In a Brown & Williamson report written just after Winters and Difranza's original letter, Senior Field Manager Arthur Flynn wrote,

The N.E. Journal of Medicine reports this week that two scientists working for the University of Massachusetts report that after extensive testing, found that cigarette smoke produces an extremely high amount of a Radioactive ingredient called "Polonium."

Websters Definition: Polonium—So named by its co-discoverer, Marie Curie, after her native land, Poland. A Radioactive chemical element formed by the disintegration [*sic*] of Radium.

It was further stated that Polonium in cigarette smoke is absorbed in the tissue of the lungs and that a cigarette smoker that smokes a pack and a half a day receives the Radioactive equivalent [*sic*] of 300 chest X-Rays during a given year!

Our R&D Dept. will just love to hear this!

But of course the company's R&D department *already* knew all about it—or at least had known about it only a few years before. The initial shock of learning about radioisotopes in tobacco aside, in 1982 manufacturers were clearly concerned with the potential consequences of this newest wave of interest in polonium research, especially after Winters and Difranza noted in the 29 July issue of the *New England Journal of Medicine* that they were "gratified to receive hundreds of phone calls from smokers who quit on learning about the alpha radiation in cigarette smoke." This evidence that "more smokers are encouraged to quit as they learn of the presence of radiation" was striking, and the industry realized that it could lose many customers because of the recent attention drawn to the issue.⁷⁵

From several documents produced following Winters and Difranza's letter, it is evident that the industry was now focusing on the fact that there was no way of knowing for certain whether radioactivity in tobacco could cause cancer in smokers. That is, instead of acknowledging that polonium *could* be a carcinogen and taking precautions, the industry was drawing attention to any doubt and disagreement there might be among researchers.⁷⁶

⁷⁴ Letters were sent by Edward A. Martell, Jeffrey I. Cohen, Beverly S. Cohen and Naomi H. Harley, C. R. Hill, Walter L. Wagner, R. T. Ravenholt, and Dietrich Hoffman and Ernst L. Wynder: "Letters to the Editor," *N. Engl. J. Med.*, 1982, 307(5):309–313. For the rejoinder see Winters and Difranza, "Letter to the Editor," *ibid.*, p. 313.

⁷⁵ Arthur J. Flynn, "Senior Field Manager's Report," Feb. 1982 (Brown & Williamson), Bates 670915637; Winters and Difranza, "Letter to the Editor" (cit. n. 74), p. 313; and Andrew A. Napier to PM Munich, Brussels, Paris, Amstelveen, Benelux BOX, Athens, and UK Feltham, "Polonium-210" (interoffice correspondence), 11 Oct. 1982 (Philip Morris), Bates 2501025243.

⁷⁶ See, e.g., Napier to PM Munich, Brussels, Paris, Amstelveen, Benelux BOX, Athens, and UK Feltham,

In an R. J. Reynolds memorandum with the subject line “With Friends Like This, We NEED Enemies,” Frank G. Colby of the legal department reacted to a German paper written in response to Winters and Difranza’s letter by Franz Adlkofer, director of the scientific division of the German Cigarette Industry Trade Association. Adlkofer had suggested that polonium, and its role as a carcinogen in tobacco, “has not received sufficient attention to date by researchers.” He went on to say that, in his opinion, “everything should be done to avoid introducing polonium into tobacco through fertilizers” and, presumably, through other sources as well. In his memorandum, Colby—clearly concerned by Adlkofer’s statement—said, “It is glaringly obvious that instead of making this appalling and scientifically erroneous statement,” Adlkofer should instead have drawn attention to the fact that there is not complete agreement among physicians and scientists on this issue.⁷⁷

In a June 1982 memo to Thomas Osdene, director of research at Philip Morris, Robert Jenkins expressed his concern that future papers on polonium would only feed the current frenzy. He was particularly worried about Martell, whom he called “sensationalism at its best” and who, he felt, would “receive wide acclaim from the anti-smoking foes and the press media.” Jenkins strongly urged Osdene to consider making Philip Morris’s radiochemical research public, as the company could not properly counter such “hypothetical papers” by “anti-smoking foes” if it did not become actively involved in the scientific debate on the subject:

At present, the major funding support for any research along these lines is from the anti-smoking forces. The tobacco industry has chosen not to answer these types of studies with well conducted scientific research, but has chosen to remain quiet in hopes “it too shall pass.” As we have constantly seen since 1964, it continues to make news. The worst part being that there may be some degree of validity amongst [*sic*] the many assumptions that are grossly incorrect.⁷⁸

Jenkins wrote to Osdene again in July 1982, stressing that it was time for Philip Morris to publish some of its research on polonium (research that had been largely conducted by Jenkins himself in the 1970s), as the results “would serve to offer an alternative interpretation to the world’s scientific community.” Jenkins felt that by publishing its own work Philip Morris “would cause the public to realize that this issue is indeed just an unproven controversy, not a fact.”⁷⁹ The best way to approach the matter was for the tobacco manufacturers to be open about the research they had done on polonium and to fund private scientists working on the question. Publishing would draw attention to the fact that the industry had been working on the problem since the 1960s, perhaps lending some legitimacy to its point of view. However, it could also backfire, as it would leave the

“Polonium-210”; and Frank G. Colby to Samuel B. Witt III, “RE: With Friends Like This, We NEED Enemies—Part VI. Polonium—Lung Cancer—Prof. Adlkofer” (memo), 20 Apr. 1982 (R. J. Reynolds), Bates 511221904.

⁷⁷ Colby to Witt, “RE: With Friends Like This, We NEED Enemies—Part VI. Polonium—Lung Cancer—Prof. Adlkofer” (this includes the quotation from Adlkofer). At a 1988 joint meeting of the worldwide tobacco industry held in London, Adlkofer “deviated from the agenda” to discuss the direction of future secondhand smoke research. He stated that nothing was likely to come from continuing present research and suggested that, rather than using marketable science in public relations campaigns against the secondhand smoke issue, the industry should use its resources to develop a safe threshold for secondhand smoke exposure. This notion met with great disagreement from the other meeting attendees, who felt that it was dangerous to set a threshold as that “provides *a priori* proof of causation for anti-smoking advocates”: “Joint Meeting on ETS—London, England” (memo), 15 July 1988 (Philip Morris), Bates 2021548222–8235.

⁷⁸ Jenkins to Osdene, “Review of Manuscript by E. A. Martell” (interoffice correspondence), 11 June 1982 (Philip Morris), Bates 1000083314–3319.

⁷⁹ Jenkins to Osdene, “Significant Scientific Accomplishments of Our Past-210Po Research Studies” (interoffice correspondence), 2 July 1982 (Philip Morris), Bates 1000083334–3335.

manufacturers vulnerable to criticism that in spite of more than twenty years of unpublished research, there were as yet no concrete advances in reducing the polonium in cigarettes.

Despite such fears—and fortunately for the industry—the matter would once again receive little public attention. Polonium was mentioned briefly in an April 1985 article in *Reader's Digest*, titled “Deadly Mixers”; following this, a concerned smoker named Chris Heimerl wrote to R. J. Reynolds to ask whether there was any polonium in his Salem Lights 100's. He also wanted to know how a radioactive material could come to be in cigarettes. Unaccustomed to answering such questions, Miriam Adams of the company's public relations office forwarded the letter to Alan Rodgman, saying that she had “no information in file to offer” in answer to Heimerl's questions. Rodgman, in turn, forwarded Adams's memo to Charlie Nystrom. In the R. J. Reynolds “Quarterly Status Report on Smoking and Health,” dated 16 July 1985, it was mentioned in the “miscellaneous” section that a memo had been sent to Adams outlining appropriate responses by public relations representatives to consumer concerns about polonium.⁸⁰ This correspondence shows how rarely the industry was forced to confront such worries, despite the significant research that had been conducted since the 1960s.

The issue was reignited in February 1986 by a paper published in the *Southern Medical Journal* by Jerome Marmorstein, a physician and medical writer from Santa Barbara, California. In this paper, titled “Lung Cancer: Is the Increasing Incidence Due to Radioactive Polonium in Cigarettes?” Marmorstein, citing most of the research published since the 1960s, suggested that the increased incidence of lung cancer among smokers in recent decades could be due to an increase in the amount of polonium in tobacco. Despite the fact that by the mid-1980s 90 percent of American cigarettes were filtered and 15 percent of the population (nearly thirty million Americans) had quit smoking, the incidence of lung cancer among smokers had actually risen since the 1960s, and twice as many American men and three times as many women had died of the disease in 1980 as in 1960. As 85 percent of lung cancers were in smokers, it was clear to Marmorstein that whatever was responsible for this increase would be found in changes to tobacco and cigarette design since the mid-twentieth century.⁸¹

Marmorstein laid out four features of tobacco carcinogens that would be necessary for the higher incidence of cancer he was trying to explain: the carcinogen must be “inadequately filtered” by existing cigarette filters; it must cause cancer even at a very low dose; smokers' lungs must have a greater concentration of the carcinogen than the lungs of nonsmokers; and there must be a reason for an increase in the levels of this carcinogen since the 1960s.⁸² After considering more than a hundred known carcinogens in tobacco, Marmorstein found only three that caused cancer by inhalation: benzopyrene, nitrosamines, and polonium-210.⁸³

⁸⁰ Lowell Ponte, “Deadly Mixers: Alcohol and Tobacco,” *Reader's Digest*, Apr. 1986, 126:53–56; Chris Heimerl, “Consumer Inquiry,” 27 Mar. 1985 (R. J. Reynolds), Bates 504974166–4167; Miriam G. Adams, “Consumer Inquiry: Chris Heimerl” (interoffice memo), 4 Apr. 1985 (R. J. Reynolds), Bates 504974165; and Anthony V. Colucci, “Quarterly Status Report on Smoking and Health, 2nd Quarter, 1985,” 16 July 1985 (R. J. Reynolds), Bates 504974078–4088.

⁸¹ Jerome Marmorstein, “Lung Cancer: Is the Increasing Incidence Due to Radioactive Polonium in Cigarettes?” *Southern Medical Journal*, 1986, 79(2):145–150.

⁸² *Ibid.*, p. 145. Polonium had been shown by both industry and external scientists to be unaffected by existing cigarette filters, and so it seemed likely to Marmorstein that it was a leading cause of cancer among smokers.

⁸³ For a while benzopyrene had been considered the leading candidate for the dubious honor of being the cancer-causing constituent of tobacco, but its concentration in tobacco had been shown to decline dramatically

Testing his hypothesis that the rising incidence of lung cancer was due to a change in the tobacco itself, Marmorstein looked at shifts in fertilizer use since the 1960s. Tobacco samples from 1938 were measured for radioactivity and the measurements compared to those made by Tso, Hallden, and Alexander in the 1950s and 1960s. The tobacco from 1938 had one-third to one-sixth the concentration of polonium, indicating that there had been a significant rise in radioactive particles in tobacco crops throughout the middle part of the century. Marmorstein then asked *why* there was more radioactive polonium-210 in tobacco grown in the 1960s, which would presumably account for the higher incidence of lung cancers developing twenty years later. He pointed to the increasingly widespread usage of artificial high-phosphate fertilizers in developing countries. In the United States, fertilizer manufacturing had begun in earnest with the establishment of the Tennessee Valley Authority in the 1930s, and phosphate fertilizers gained further popularity through the “Big Agriculture” movement of the postwar era. Marmorstein also noted that the quality of a tobacco crop and the resulting flavor of the cigarette were adversely affected by high nitrogen concentrations. In order to reduce the amount of nitrogen in their tobacco plants, therefore, farmers had been saturating their land with exceptionally large amounts of phosphate fertilizer. This, of course, resulted in even higher levels of polonium in tobacco grown in areas of high fertilizer use. Citing a 1965 paper by C. R. Hill, Marmorstein also noted the lower concentration of polonium found in tobacco grown in developing countries such as Turkey, India, and Indonesia, where organic fertilizers (such as manure and guano) were used instead of phosphates.⁸⁴

Marmorstein’s paper depicted the hazards of polonium rather dramatically, but other researchers—industry and otherwise—had shown essentially the same results since 1964. And yet, despite early evidence that the tobacco industry had at various times been interested in investigating ways to reduce the levels of radioisotopes in cigarettes, nothing had been done along these lines. This lack of action is all the more incredible given the fact that—as revealed by internal industry documents—several methods for reducing radioactivity in cigarette smoke had been evaluated and considered by the manufacturers.

Since the 1960s the industry had flirted with several potential solutions, among them developing a strain of tobacco that did not have trichomes and adding materials to tobacco that would react with lead and polonium to prevent their transfer to smoke.⁸⁵ One option that significantly intrigued the manufacturers involved developing an ion-exchange resin filter, as suggested in the late 1960s by Erick Bretthauer and Stuart Black of the U.S. Public Health Service (and recommended once again in the mid-1970s). Such a filter had been shown by Bretthauer and Black to “markedly reduce” exposure to polonium. Ann Kennedy had pushed this option in 1975, stressing that an ion-exchange filter could

with the advent of filter cigarettes. Furthermore, the type of cancer caused by benzopyrene, squamous cell carcinoma, had become less prevalent among smokers, replaced in the preceding twenty years by adenocarcinoma as the most common type of lung cancer among smokers. Similarly, approximately 80 percent of nitrosamines were removed by filters, so they, too, were unlikely causes of the increased prevalence of lung cancer. See Ronald G. Vincent, John W. Pickren, Warren W. Lane, Irwin Bross, Hiroshi Takita, Loren Houton, Alberto C. Gutierrez, and Thomas Rzepka, “The Changing Histopathology of Lung Cancer: Review of 1682 Cases,” *Cancer*, 1977, 39:1647–1655.

⁸⁴ Marmorstein, “Lung Cancer” (cit. n. 81), p. 148; and C. R. Hill, “Polonium-210 in Man,” *Nature*, 1965, 208(5009):423–428.

⁸⁵ Regarding potential solutions see P. D. Schickedantz to H. J. Minneveyer, “Comments on Recent Articles Concerning Polonium-210 as a Tobacco Smoke Carcinogen” (memo), 5 Sept. 1975 (Lorillard), Bates 01092297–2299; and J. D. Mold to R. W. Tidmore, “Radioactive Particles in Cigarette Smoke” (memo), 3 Dec. 1975 (Liggett & Myers), Bates 81151936–1938.

remove up to 92 percent of the polonium in cigarette smoke.⁸⁶ Bretthauer and Black gave a rough estimate that it would cost the tobacco industry 0.5 cents per pack of cigarettes to incorporate the 0.12 grams of resin needed for each cigarette, making the ion-exchange resin filter a relatively cheap fix that could be used until a more effective solution could be found.

Another straightforward option, following Martell's research in the 1970s, had been to wash the tobacco leaves to remove polonium that had collected on the trichomes that covered the leaf's surface, per the discarded Stauffer patent and Robert Jenkins's research at Philip Morris. Yet a third solution would have been to remove trichomes from the cured tobacco leaf mechanically. T. C. Tso had estimated in 1975 that 30–50 percent of polonium could easily be removed from fertilizer and that washing could eliminate another 25 percent.⁸⁷ Adding to that the effects of an ion-exchange filter, the polonium content of tobacco could have been significantly reduced using techniques that were well known and repeatedly discussed by both external and industry scientists and by high-level industry executives and attorneys. But the tobacco companies were clearly focused on other priorities.

A "SLEEPING GIANT"

Although research on polonium has slowed in recent years, the tobacco industry has continued to monitor relevant literature, keeping abreast of advances by compiling bibliographies and extensive reviews of scientific papers and news articles.⁸⁸ In 1999, polonium, along with other potentially hazardous smoke constituents, was reviewed for Philip Morris by scientists at INBIFO (Institut für Biologische Forschung [Institute for Biological Research]), a bioresearch laboratory in Germany acquired by Philip Morris in 1971. The first of the two reviews was written by INBIFO Manager of Bioresearch Support Helmut Schaffernicht. Work at INBIFO focused on "quantitative biological product evaluation," but Schaffernicht's review of radioisotopes in tobacco was brief and uninformed: he had not read any of the literature on the topic, nor did he scan internal industry research and reports. Schaffernicht gave polonium the lowest priority level (1 on a scale of 1 to 5) for contributing to potential Philip Morris programs in relation to health and safety, potential need to alter the product, and company credibility. The second review, however, saw polonium as a more serious threat. This reviewer, INBIFO Manager of Cell Biology Jan Oey, had taken quite an extensive look at the scientific literature since 1964 but did not examine the internal industry literature. Oey gave polonium a rank of 3 for "Potential Contribution to a PM Smoking/Health Program," describing it as an issue

⁸⁶ Erick W. Bretthauer and Stuart C. Black, "Polonium-210: Removal from Smoke by Resin Filters," *Science*, 1967, 156(3780):1375–1376; and Resnik to Wakeham, "Meeting on Polonium—August 26, 1975" (memo), 26 Aug. 1975 (Philip Morris), Bates 1003728418–8419 (Kennedy's view).

⁸⁷ Schickedantz to Minneveyer, "Comments on Recent Articles Concerning Polonium-210 as a Tobacco Smoke Carcinogen" (memo), 5 Sept. 1975 (Lorillard), Bates 01092297–2299 (mechanical removal); and "National Cancer Institute Smoking and Health Program: Minutes of the Workshop on the Significance of Po²¹⁰ in Tobacco and Tobacco Smoke," 25 Aug. 1975 (Philip Morris), Bates 1000268053–8056 (Tso's estimates).

⁸⁸ Ronald Davis, Radiochemical Section, "Radionuclide Concentration: A Literature Survey of the Principal Radionuclides Found in Tobacco, Tobacco Smoke, Soil, Other Agricultural Products, Air, Water, Human, and Other Animals," June 1967 (American Tobacco Company), Bates 962004628–4682; Robert Jenkins, "Polonium-210," 9 Nov. 1976 (Philip Morris), Bates 1002977456–7473; Roger Comes, "Investigations of Polonium-210 in Cigarette Tobacco and Whole Smoke Condensate," 12 May 1977 (Philip Morris), Bates 1000365379–5414; and "Polonium," 1986 (American Tobacco Company), Bates 950008179–8208.

of “moderate” priority to Philip Morris. Both reviewers felt that the only future step necessary on the part of the company was to monitor any relevant literature.⁸⁹

External researchers, in contrast, have given far more dire assessments. Reimert Thorolf Ravenholt, a career epidemiologist with the U.S. Centers for Disease Control, the U.S. Agency for International Development, and the U.S. Food and Drug Administration, said in a 1982 interview that “the American public is exposed to far more radiation from the smoking of tobacco than they are from any other source.”⁹⁰ Nonetheless, and despite forty years of research, there is little awareness of the problem outside of a small group of scientists and tobacco industry personnel. The serial irradiation of smokers’ lungs by polonium-210 remains a repeatedly exposed and then forgotten story.

In a sweeping call for awareness, Monique Muggli, Jon Ebbert, Channing Robertson, and Richard Hurt of the Mayo Clinic and Stanford’s School of Engineering suggested in a recent issue of the *American Journal of Public Health* that all cigarette packs should come with a radiation warning.⁹¹ Yet another admonition, however, is unlikely to make a dent in the smoking population significant enough to concern the tobacco industry. After all, warnings pertaining to the smoker’s own health, the health of the smoker’s unborn child, and the health of those around the smoker are already displayed on packs of cigarettes. The grotesque images of foul teeth and gums, cancerous lungs, and open-heart surgeries on European packs go so far as to enshroud cigarettes in the very images of their consumers’ potential futures. And yet people still smoke. Would one more warning—even one highlighting the specific dangers posed by radiation to the smoker’s lungs—really make a difference?

Although it is certainly striking that the tobacco manufacturers have not made a definitive move to reduce the concentration of radioisotopes in cigarettes, it is equally striking that, despite forty years of research suggesting that polonium is a leading carcinogen in tobacco, they have felt no pressure from the public, the government, or the medical and public health communities to do so. So long as there continues to be only episodic awareness of the issue, and no pressure from powerful entities (such as the Food and Drug Administration, the surgeon general, or public opinion) to remove polonium from cigarettes, the tobacco industry does not need to worry about designing new filters or washing leaves.

No matter how simple and straightforward some of the proposed solutions to reducing polonium may seem, implementing them would cost the industry money and manpower. As tobacco manufacturers have never shown much concern about the health hazards of cigarettes (which they didn’t even publicly admit until the late 1990s), it is no wonder that they have remained passive on the issue of polonium as well. It is unlikely, too, that the latest wave of interest, provoked by the death of Alexander Litvinenko in November 2006, will have much of an impact on their thinking or behavior.⁹² The tobacco industry no doubt kept a close eye on press releases and commentaries written in the months following Litvinenko’s death. Statements such as the one by the British Health Protection Agency that polonium poses no risk to the general public only continue to limit awareness of the presence and health hazards

⁸⁹ H. Schaffernicht, “WSA Categorization Form: Smoke Constituents,” 27 Oct. 1999 (Philip Morris), Bates 2074168043; and J. Oey, “WSA Categorization Form: Smoke Constituents,” 27 Oct. 1999 (Philip Morris), Bates 2074168044. On the INBIFO mission see Institut für Biologische Forschung, “History and Capabilities of INBIFO,” 1988 (Philip Morris), Bates 2505235055–5088.

⁹⁰ Ravenholt, quoted in “Smokers Said to Risk Cancers beyond Lungs” (cit. n. 6).

⁹¹ Muggli *et al.*, “Waking a Sleeping Giant” (cit. n. 12).

⁹² *Ibid.*; and Proctor, “Puffing on Polonium” (cit. n. 1).

of polonium in tobacco. What's more, smokers do not see themselves as victims of radiation poisoning, and there is no group of polonium sufferers in solidarity with each other. Most do not even know that their lungs have been infiltrated by a highly radioactive isotope, and they certainly do not identify with the sickly images of Alexander Litvinenko.

As historians of tobacco have illustrated, a smoker's death is not the dramatic and sensational one generally associated with radiation poisoning but, rather, a quiet and lonely one consuming its victims slowly, decades after their smoking habit began. This is a marked contrast with the perceived injustice and sin against youth and vitality attributed to other cancers. The physician and historian of science Robert Aronowitz has argued that over the past two hundred years breast cancer has evolved from a matter of private suffering and endurance on the part of the individual victim to a collective focus for societal fear and concerns about risk.⁹³ This shift has resulted in public pleas for more studies on risk and treatments and has motivated walks and other events to raise money for research. Exhibiting breast cancer awareness and activism has become a part of modern society; a simple pink ribbon graces the clothing, jewelry, and bumper stickers of victims, loved ones, survivors, and supporters. Strikingly, Aronowitz notes that the mortality rate from breast cancer has remained more or less steady through the second half of the twentieth century. The number of deaths from lung cancer, in contrast, has shot up dramatically. It is the *awareness* of breast cancer, not the actual number of cases, that has grown over the past hundred years; this sort of public awareness and solidarity has not become a part of the story of lung cancer.

More than a general lack of awareness, however, the story of polonium is marked by cycles of forgetting and remembering—or, better said, of the dying down and reigniting of awareness. Such a waxing and waning of interest and of gaining, then losing and forgetting, knowledge is discussed in a volume on “the making and unmaking of ignorance” edited by Robert N. Proctor and Londa Schiebinger. To describe this phenomenon, a new term was introduced as the title of the book: agnotology. Defined broadly as the study of ignorance, agnotology pays homage to the lost and forgotten, the never known and the carefully concealed.⁹⁴ Addressing the importance of ignorance throughout history and the impressive extent to which it has been disregarded by scholars, Proctor discusses three categories: “ignorance as *native state* (or resource), ignorance as *lost realm* (or selective choice), and ignorance as a deliberately engineered and *strategic ploy* (or active construct).” I would add a fourth: ignorance (or forgetting) as default. It takes *something* to keep a memory going: momentum, reignition, power, emotion. And certainly the press is all too ready to leap ahead to the next big story, leaving yesterday's headlines as kindling. For a story to continue beyond a single news cycle is extraordinary, a phenomenon the tobacco industry understands well and has taken full advantage of in its quest to minimize the polonium-210 problem. In discussing agnotology in relation to the tobacco industry, Proctor compares the ways in which cigarette companies have censored knowledge to the classifications of military secrecy: in both cases “we don't know what we don't know” because “steps have been taken to keep [us] in the dark!”⁹⁵

In this spirit, Big Tobacco has been careful to avoid drawing attention to what Paul Eichorn of Philip Morris, in a handwritten 1978 memo to his boss, Robert Seligman (then vice president of research and development), called the “sleeping giant” of polonium. (See

⁹³ Robert A. Aronowitz, *Unnatural History: Breast Cancer and American Society* (Cambridge: Cambridge Univ. Press, 2007).

⁹⁴ Proctor and Schiebinger, eds., *Agnotology* (cit. n. 7), p. vii.

⁹⁵ Proctor, “Agnotology” (cit. n. 7), pp. 3, 11.

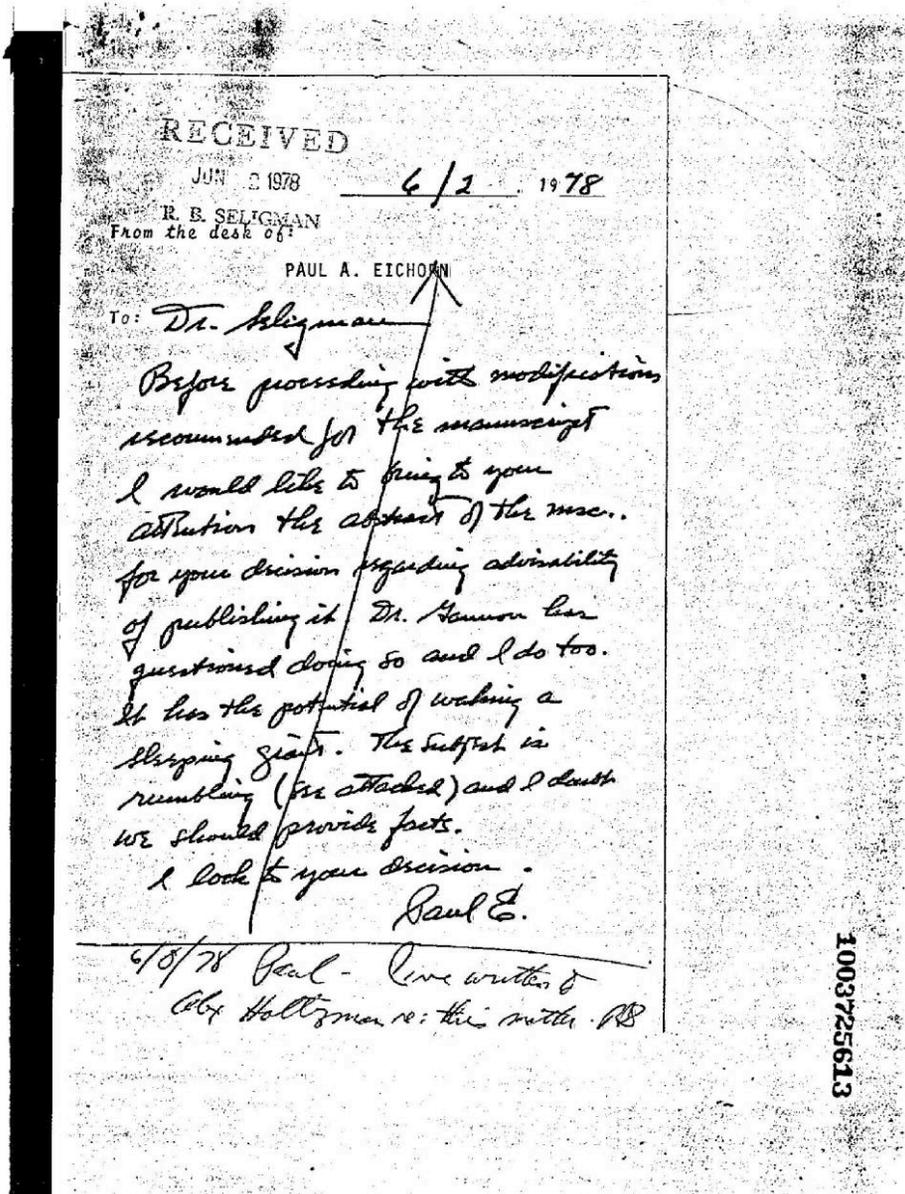


Figure 1. Philip Morris memorandum from Paul A. Eichorn of the R&D department to Robert Seligman, vice president for R&D, cautioning against publishing the company's research on polonium. Eichorn was concerned that providing any facts at all had the potential to wake the "sleeping giant" of polonium. Seligman responded that articles related to this matter should be given to the company's vice president and general counsel, Alexander Holtzman. See Paul A. Eichorn to Robert Seligman (memo), 2 June 1978 (Philip Morris), Bates 1003725613.

Figure 1.) The giant was to be kept quiet by keeping results unpublished and by avoiding public debate with researchers or health officials. At the same time, tobacco manufacturers have continuously stayed abreast of the research, conducting their own parallel experiments and recording their own results and measurements, always careful to keep their

work secret and private. The industry got so far as to single out and debate the drawbacks and benefits of several potential solutions to the polonium problem; however, as Charlie Nystrom of R. J. Reynolds wrote to Alan Rodgman, “removal of these materials would have no commercial advantage.”⁹⁶

When I told Ann Kennedy of the extensive radiochemical research programs at Philip Morris and R. J. Reynolds, she was “astonished” to hear that the tobacco industry had been conducting its own polonium research throughout the 1960s, 1970s, and 1980s.⁹⁷ That someone as deeply involved in researching radioactivity in tobacco as Kennedy had no idea that the manufacturers themselves were spending hundreds of thousands of dollars investigating the same topic—always in secret—highlights the discrepancy between what the industry was admitting publicly and what it was saying and doing privately.

The polonium story reveals a dark chapter in the history of science and scientific authority. Tobacco manufacturers have long used the persuasive powers of science to their advantage, hindering disease prevention. Here in the annals of a single isotope is this microcosm of deceit and silence, with disease and death as its result. And although the story of polonium has been repeatedly forgotten, the stakes have remained consistently high: in 2008, the National Cancer Institute estimated that there were 162,000 deaths from lung cancer in the United States, 90 percent of them due to smoking. It is impossible to know how many of these cancers were caused by alpha-emitting isotopes in tobacco, but if the polonium had been reduced through methods known to the industry a certain fraction could have been avoided. The industry made the conscious choice not to act on the results of its own scientific investigations; but it is the customers who have had to live with—and die from—that decision.

⁹⁶ Paul Eichorn to Seligman (memo), 2 June 1978 (Philip Morris), Bates 1003725613; and Nystrom to Rodgman, “Comments on the Stauffer Patent No. 4,194,514 for Removal of Radioactive Lead and Polonium from Tobacco” (interoffice memo), 5 Mar. 1982 (R. J. Reynolds), Bates 504970288.

⁹⁷ Telephone conversation with Kennedy, 24 May 2007.