



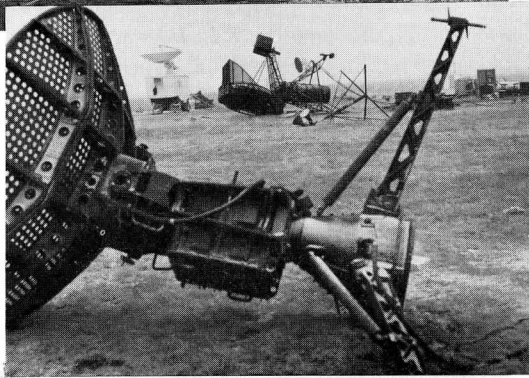
Predicting Downslope Winds

Early in the day on 11 January 1972 the surface air pressure across eastern Colorado began to fall. In Boulder, at the foot of the eastern slope of the Rocky Mountains, the pressure drop was even faster. In late morning the wind began to blow. For several hours high winds gusted across Boulder, Denver, and other heavily populated eastern slope communities, unleashing immense destructive force. Anemometers ran off scale at 45 m/sec (100 mph) or more; some were torn apart. Roof shingles, gravel, branches, dust, and debris were stirred up into a turbid, gray cloud.

While the violent *chinook* blew down from the mountains, an NCAR Queen Air research plane flew a data-gathering mission through the lowest 3,000 m of the atmosphere between Denver and the continental divide. In late afternoon, the wind abated; and NCAR's Sabreliner jet—unable to take off earlier because of wind-blown gravel over the runway—left the Jefferson County Airport



Boulder Camera



Boulder Camera



Boulder's winds blow roofs off houses, shatter windows, overturn mobile homes, and cause approximately \$1 million worth of property damage annually. A storm on 7 January 1969 damaged half the residences in Boulder. The 11 January 1972 storm caved in the wall of NCAR's hanger at Jefferson County Airport, shown in the lower photographs here.

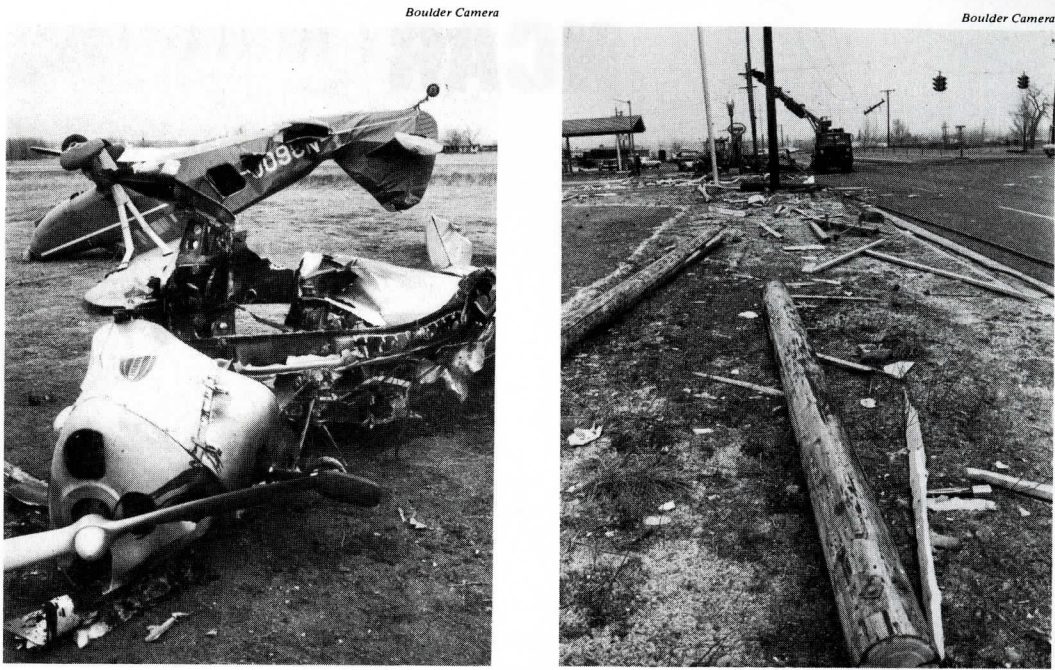
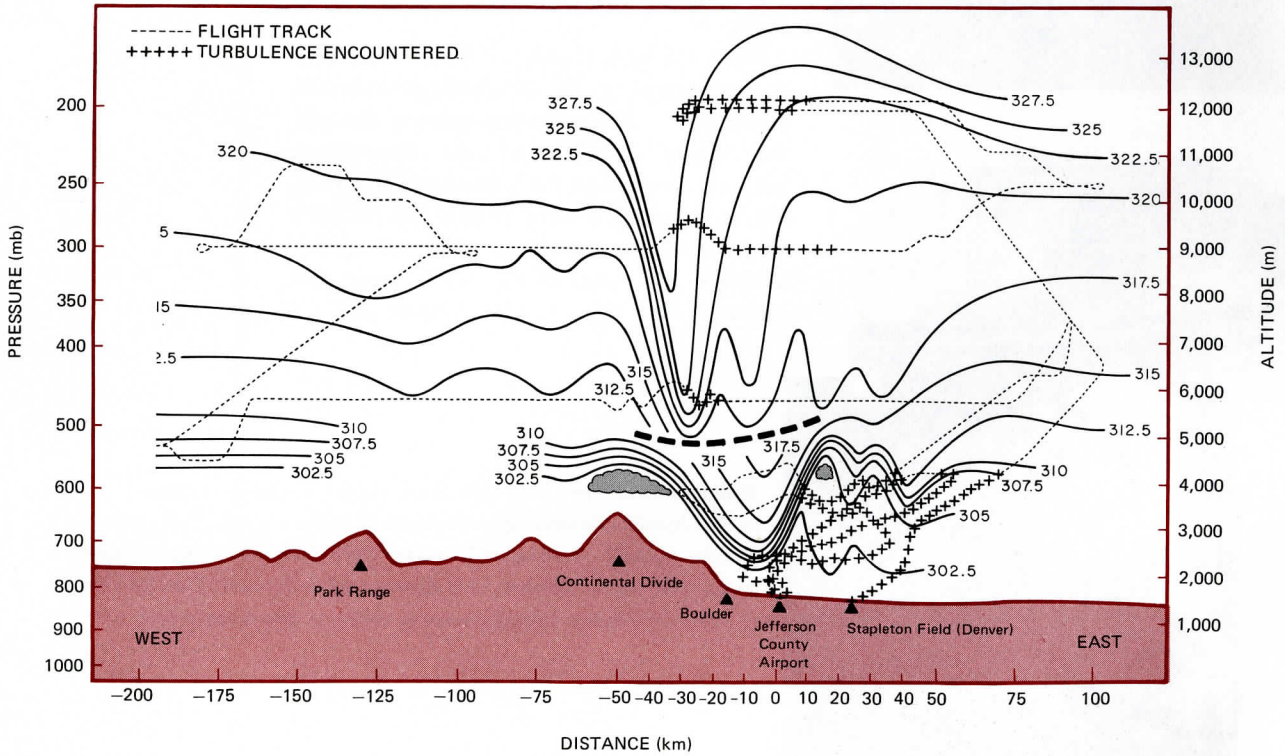


Fig. 1 Streamlines of airflow across the Colorado Rocky Mountains west of Boulder obtained from NCAR aircraft records are shown here for the severely damaging downslope windstorm of 11 January 1972. The streamlines are potential temperature isolines ($^{\circ}\text{K}$) and depict the actual paths of air motion. The closely spaced lines west of the Park Range station represent the upwind region of increased stability, characteristic of a windstorm situation. High winds at Boulder (not indicated) are the surface manifestations of the wave activity.



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Managing Editor: Joann Dennett
 Contributing Editors: Joann Dennett
 Merry Malsel
 Lynnie Mesrirow

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for a high-altitude exploratory flight. It landed in midevening at Denver's Stapleton Airport, about the time the windstorm renewed its force. At the Sabreliner's home airport, gusts over 38 m/sec had blown in the west side of NCAR's hangar.

The damage along the eastern slope was considerable. The storm had struck without warning, and by morning it had inflicted \$2.5 million worth of property damage in Boulder alone. The data gathered by the aircraft would, however, prove crucial to a group of scientists seeking ways to predict the hurricane-force Rocky Mountain windstorms in time for people to protect their property.

NCAR's Small-Scale Analysis and Prediction Project, led by Douglas K. Lilly, began studying severe windstorms in the mid-1960s; and in 1967, 1968, 1970, and 1973 Lilly's group coordinated several interagency observation programs to gather aircraft, balloon, radar, and surface data during the windy winter months. The flights on 11 January 1972 provided the best data (shown in Fig. 1), which were used in two years of theoretical analysis and numerical modeling that resulted in a successful technique for predicting violent downslope windstorms along the Rocky Mountains and in similar geographic regions.

The Wind Felt around the World

Strong downslope winds are a climatic feature of many mountainous regions. Yugoslavia's cold *bora* blows riders off their horses. The warm Alpine *foehn*, while not so violent, is reputed in folklore (and in legal statistics) to cause temporary mental stress and even lunacy. The *mistral*, *Santa Ana*, *germich*, and *zonda* are local names for similar winds in other areas of the world.

Boulder's downslope windstorms occur most often in January, but have been recorded in every month except July. They tend to blow hardest from dusk to dawn. Despite their violence, they are usually local and intermittent. In Boulder gusts may jump from 5 to 45 m/sec in a few seconds, while over the plains, a few kilometers to the east, wind speeds may be only half as high.

These winds are the surface manifestations of wave motions in the atmosphere that develop when a strong, stably stratified air-

flow passes over a mountain barrier. Meteorologists have studied "lee waves" for years and know that when the oncoming flow is stable, the air layers, elevated by their passage over the mountains, will seek to regain their original levels, under the influence of gravity. Lee waves are thus part of a larger class of air motions called gravity waves. Large accelerations of the wind near the wave troughs often cause strong, gusty winds on the lee slopes of the mountains.

In addition to causing damaging winds at the surface, mountain waves exert an influence on large-scale motions of the atmosphere. The waves propagate upward to the lower stratosphere; there they break down and exert a drag force that diminishes the atmosphere's overall westerly momentum. Such a disturbance over the Rocky Mountains can have global effects in the higher atmosphere at midlatitudes. The drag that accompanies a single local windstorm can equal or exceed the drag normally produced around the entire globe by all mountains at the same latitude.

Studies in Boulder

Working cooperatively with Lilly's group, Waltraud Brinkmann, a doctoral student at the University of Colorado, investigated Boulder winds through a detailed analysis of 20 windstorm cases. As part of the study, she characterized environmental conditions before and during windstorms. On the basis of her observations and their own, Lilly and his group were able to identify the meteorological mechanisms responsible for strong downslope winds in the Boulder area and to simulate them with a computer model.

Lilly and his colleague Joseph Klemp developed a theory that explains the strong surface winds through analysis of wave motion in simple, multilayer representations of the atmosphere. Their theory indicates that the waves can attain a very large amplitude if a temperature inversion overlies the mountain crest in the upstream environment (to the west in the case of Boulder) and if the stability and wind profiles lead to one reversal in the phase of the waves between the surface and the tropopause.

The mechanism which produces the large-

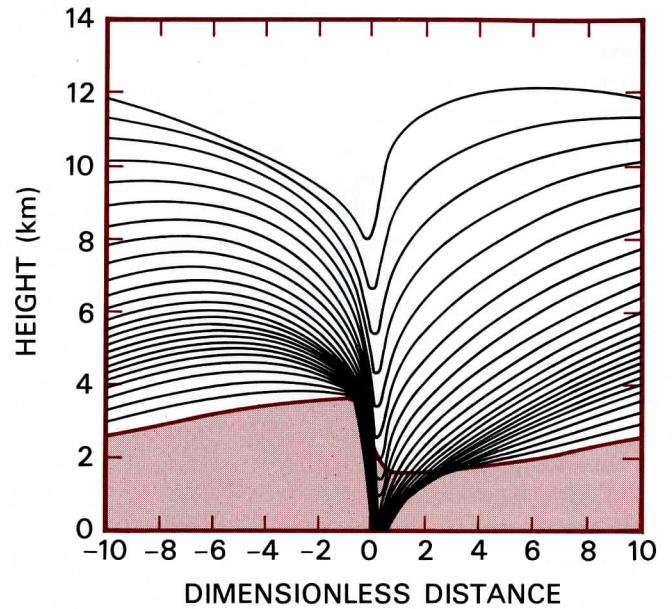
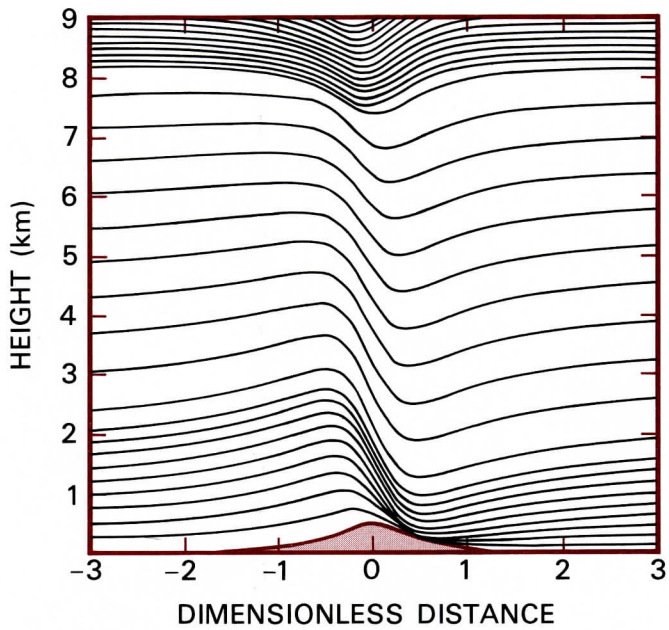


Fig. 2 Flow streamlines in the Klemp-Lilly model reproduce conditions of surface wind amplification (left). The three layers evident in the pattern correspond to a stable lower level, a less stable troposphere, and a stable stratosphere. The streamlines are separated by equal increments of potential temperature; close packing of the lines occurs near the lee slope of the mountains and corresponds to high surface wind velocities. The right-hand picture shows the stream flow pattern predicted by the model from real data for 11 January 1972; wind speed predictions correlate well with observations.

amplitude mountain waves can be explained in terms of partial reflections of the upward-propagating wave due to vertical changes in the atmospheric stability. These reflections are similar to those which occur when light passes through a medium in which the index of refraction is changing. When the low-level stable layer and the less stable region above have optimum thicknesses, partial reflections of the wave motion constructively reinforce the wave in the lower part of the atmosphere and can produce a wave amplitude several times that of the mountain height.

Lilly and Klemp incorporated their theory into a numerical model. Figure 2 shows the model's predictions, starting with the upstream conditions from the 11 January 1972 flight data. The flow patterns and wave amplitudes are consistent with the conditions observed by the aircraft.

Practical Forecasting Ability

William Bergen, then an NCAR student intern from Miami University (Ohio), used standard sounding data and wind records from NCAR's local anemometer network to test the model's forecasting ability. Figure 3 is a forecast contingency table that shows a high correlation between the predicted and observed winds in Boulder, although it overpredicts

Fig. 3 A contingency table compares predictions of the model with observed wind speeds for 51 test cases. The figure in each box indicates the number of cases for which the model predicted winds in the range given at the left and for which the maximum observed winds 2 to 5 hr later were in the ranges shown at the top of the table.

		MAXIMUM GUSTS OBSERVED IN BOULDER (m/sec)			
		≥ 37.5	25–37.5	12.5–25	≤ 12.5
MAXIMUM PREDICTED SURFACE WIND (m/sec)	≥ 75	5	1	0	0
	50–75	1	3	2	0
	25–50	0	2	37	
	≤ 25	0	0		

observed wind speeds by a factor of about two. Of six potentially damaging storms (gusts over 37.5 m/sec), five were predicted to be over 75 m/sec and one between 50 and 75 m/sec. Of six predictions of winds over 75 m/sec, all but one were actually observed to have gusts over 37.5 m/sec. Although the model overpredicts wind intensities, it does so consistently and is consequently quite valuable as a forecasting tool.

Further testing of the model is currently being conducted, using atmospheric soundings taken during the past winter from existing weather stations and from a special sounding site west of Boulder. The National Weather Service, the U.S. Air Force's Air Weather Service, and the National Oceanic and Atmospheric Administration cooperated in obtaining these data.

Cooperation with the Community

Since the model's predictions agree well with observations, the technique is now sufficiently reliable, according to Lilly, to warrant its experimental use by forecasting agencies for short-range hazardous weather warnings.

In Boulder, Lilly's group has been helping the community to develop its windstorm defenses. Lilly, Klemp, and Paul Julian served on an advisory committee that recently recommended new criteria for the Boulder County uniform building code to achieve better wind protection. Other committee members were from the University of Colorado, the National Bureau of Standards, and private consulting firms. Abdel Amr, University of Colorado doctoral student in engineering, authored the final report for submission to county officials; the report notes that revised wind loading criteria are needed because structures in the county have suffered a considerable increase in damage during the past six years.

Strong public interest in wind warnings was revealed through a local survey conducted by Bergen in cooperation with NCAR's Environmental and Societal Impacts Group, led by Allan Murphy (see inset).

Commenting on the research, Lilly says, "We like to think that the program is an example, on a rather small scale, of the kinds of interactions between basic and applied

physical science and social science that are necessary for dealing with the various problems of short-range forecasting and hazardous weather warnings that are increasingly engaging the attention of the weather services."

Public Opinion Favors Wind Warnings

How does the public in Boulder view local windstorms? William Bergen, while an NCAR student intern from Miami University (Ohio), surveyed a representative sample of the general population and commercial interests. His results, analyzed in cooperation with NCAR's Environmental and Societal Impacts Group, covered a number of topics.

Ninety-five percent of those surveyed felt that windstorms should be predicted; 70% said they became alarmed or frightened during windstorms. While currently few would wish to be awakened at night to take preventive actions against wind damage, almost two-thirds said they would favor being awakened if windstorm warnings were highly reliable. While about 80% of those surveyed would not favor cancellation of public school classes if windstorm predictions were only 30% reliable, more than 80% of the respondents would favor school closings if windstorms could be predicted with 80% accuracy. In answer to another question, respondents estimated that they could prevent 17% of the damage that is normally experienced from severe windstorms if 80% - reliable, short-term warnings (2 to 4 hr in advance) were available. Savings could thus total about \$200,000 a year for the city of 90,000. Those surveyed would be willing to support the cost of forecasts to the extent of \$3.77 per household per year; the total of \$79,000 for Boulder alone is comparable to the cost of facilities required for the reliable forecasts.

The study showed in many ways how significant social and economic benefit would result from dramatic improvements in short-range windstorm forecasts. Bergen is continuing this analysis in depth with additional segments of the community that could be affected by improved windstorm forecasting.

Radioactive Smoke Particles:

New Link to Lung Cancer?

Since the late 1950s, when health statistics revealed a relationship between smoking and cancer, scientists have sought for links in the chain of causation. Recent research by Edward A. Martell of NCAR's Atmospheric Aerosol Project brings to light a possible primary agent of bronchial cancer in the lungs of smokers.

The agent is radioactive polonium - 210 (^{210}Po), and Martell has contributed a study of how it might get into smokers' lungs and stay there, emitting alpha particles that produce a high cumulative radiation dose.* The research is a byproduct of work in radioactive aerosol research carried out by Martell and his colleagues Stewart E. Poet and Howard E. Moore.

For years it has been known that uranium miners inhale air containing the isotopes ^{218}Po and ^{214}Po , both alpha emitters like ^{210}Po . Continuous exposure to these isotopes is thought to account for the documented excess incidence of bronchial cancer in uranium miners. In the mid-1960s, medical researchers found that smokers' lung tissues had higher concentrations of ^{210}Po than tissues from the lungs of nonsmokers.

Radon Daughters

The isotope ^{210}Po is a radon daughter, a product of the radioactive decay of radon gas, which emanates from radium naturally oc-

curing in soils and which is present in low concentrations in the atmosphere. Radon is transformed into a number of short-lived elements by radioactive decay. Ultimately it becomes radioactive lead-210 (^{210}Pb), which emits one beta particle (or electron) to become bismuth-210 (^{210}Bi) and one further beta particle to become ^{210}Po . The half-life of the radioactive lead is quite long—about 22 years. By contrast, ^{210}Bi has a half-life of only five days, and ^{210}Po has a half-life of 138 days.

Both ^{210}Po and its long-lived parent ^{210}Pb have been observed in tobacco, in cigarette smoke, and in smokers' lungs. The exact mechanisms by which the isotopes get into the tobacco, the smoke, and the lungs, however, have been in question—and as a result there has been some doubt about how much radiation the smoker might receive. Moreover, recent trends in cancer research have stressed chemical or viral carcinogenesis rather than radioactive carcinogenesis.

In 1964, Drs. Edward P. Radford and Vilma Hunt of the Harvard University School of Public Health suggested that smokers get a radiation dose from volatile compounds of ^{210}Po inhaled in hot cigarette smoke. But others showed that these gaseous compounds are rapidly expelled from the lungs, and that any volatile ^{210}Po compounds that are deposited on lung surfaces are quickly cleared away by normal fluid circulation. Thus when Dr. Radford and Dr. John B. Little (also of the Harvard University School of Public Health) nevertheless observed high local ^{210}Po concentrations in tissue from the lungs of deceased smokers, their results were puzzling.

*The research is described by Martell in a recent issue of *Nature* (249, 17 May 1974, p. 215).

Martell's Hypothesis

The high local concentrations of ^{210}Po occurred at the bifurcations of the bronchi in the lower lobes of the lungs, sites where inhaled particles would be expected to accumulate.

When Martell considered the Harvard lung-tissue data, he reasoned that locally high concentrations of ^{210}Po in the bronchi of cigarette smokers might be explained by the accumulation of insoluble ^{210}Pb particles in the bronchial bifurcations. The insoluble ^{210}Pb particles would persist and continuously decay through ^{210}Bi into alpha-emitting ^{210}Po .

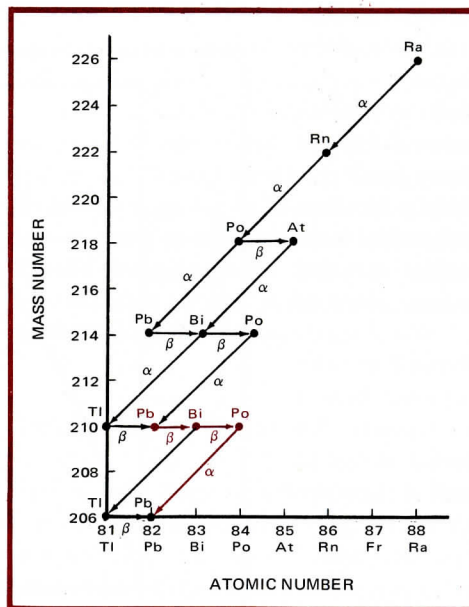
But lead isotopes in the environment generally occur in soluble compounds. Where would insoluble particles of radioactive lead come from? Martell's work with aerosols—very small airborne particles—enabled him to follow the life cycle of ^{210}Pb and led him to a novel theory about the way ^{210}Pb can accumulate on tobacco surfaces and become incorporated into insoluble particles.

Trichomes

Although other researchers had concluded that radioisotopes were taken up into tobacco from soils and fertilizers or were deposited on tobacco surfaces by rainfall, Martell concluded that ^{210}Pb on aerosol particles could be captured directly from the air by the tiny hairs on the surfaces of tobacco leaves. The tiny hairs are called *trichomes*, and they thickly cover both sides of tobacco leaves—200 to 900 per cm^2 on mature leaves. The tips or heads of about 85% of trichomes exude a sticky mixture of organic compounds. This exudate, Martell found, collects minuscule airborne particles called Aitken particles. Aitken particles are the smallest class of aerosols, those having diameters less than $0.2\ \mu\text{m}$.

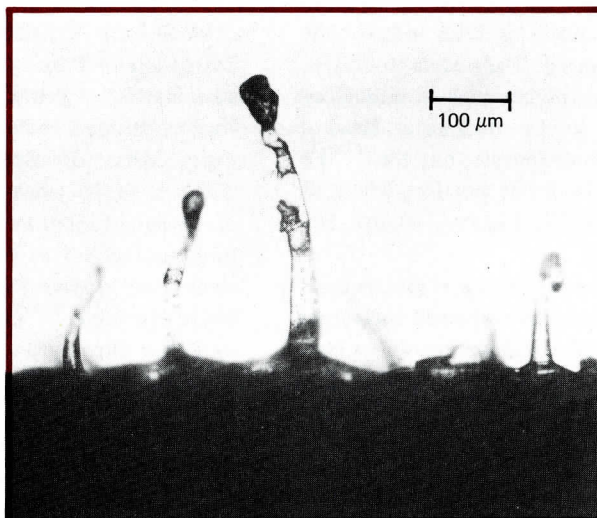
Radon daughters in the air attach to small Aitken particles, and their concentrations increase with decreasing particle size. Thus particles less than $0.1\ \mu\text{m}$ in diameter may have ^{210}Pb activities greater than 10^6 picocuries per gram. That is more radioactive than pure uranium or thorium.

How does tobacco collect these particles? The forest of trichomes on each leaf maintains



Radioactive decay series. Radium in soils and rocks, ^{226}Ra (top right), decays by emitting an alpha (α) particle to become radon, ^{222}Rn , which emanates from surface soils into the atmosphere. It then decays through a number of short-lived daughter elements to become ^{210}Pb (half-life 22 years). The last three members of the series (shown in color) were of special interest in this study.

Microphotograph of tobacco leaf trichomes. Dark blobs at tips of trichomes in the foreground are the sticky glandular heads that capture Aitken particles from surface air. (Photo courtesy of M. B. Gardner.)



a stagnant air layer over the leaf surface. Because of the low air flow rate around the trichome heads, the only effective means of particle capture is diffusive deposition (Brownian capture). The process of diffusive capture is effective only for very small particles, and the deposition efficiency increases with decreasing particle size; thus trichomes collect many more of the smallest particles, those on which radon daughter concentrations are the highest.

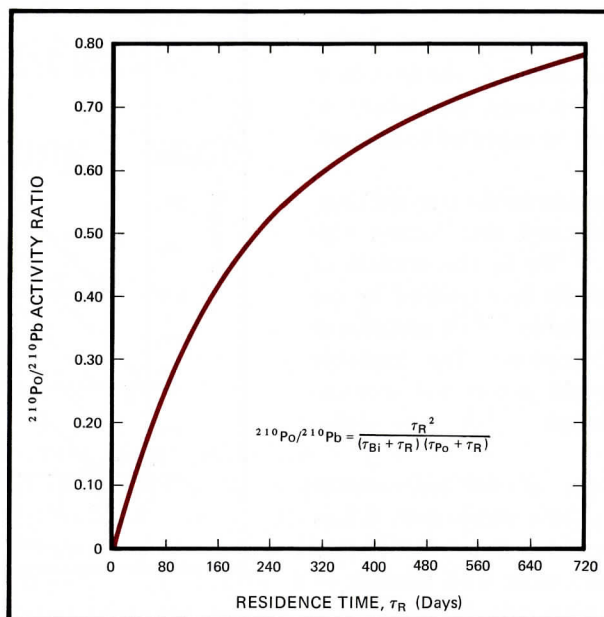
This was verified by Martell and Poet, who measured ^{210}Po activity in large numbers of trichomes removed from tobacco leaves. The high activity indicated the presence of tens to hundreds of thousands of small Aitken particles on each trichome head.

Insoluble Smoke Particle Formation

Because the sticky exudate on trichome heads is hydrophobic, the particles are not washed off by rain as the tobacco plants grow. Moreover, when the leaves are cured, polymerization of the exudate renders the trichome heads insoluble in most solvents and acids; the sticky compounds become a hard plastic. When a smoker draws on a cigarette, the tobacco at the tip is heated to 750 - 900C. Fusion of the trichome heads at these temperatures yields insoluble smoke particles with extremely high ^{210}Pb activity.

In laboratory tests, smoke condensate was prepared from unfiltered commercial brands of cigarettes using standard "smoking" techniques. The samples of smoke condensate were heated to expel the volatile portion, and ^{210}Pb concentrations in the nonvolatile residue were measured. They were found to be about 100 times higher than in either dry tobacco or inhaled smoke condensate. Most of the residue was water-soluble, but the ^{210}Pb was lodged in the insoluble portion, where its concentration was still higher—about 10^4 picocuries per gram.

In sum, the natural clearance mechanisms of the lung remove both dispersed molecular constituents of smoke and water-soluble constituents of deposited smoke particles. But Martell suggests that smokers do retain some of the highly insoluble particles enriched in ^{210}Pb . These particles accumulate in the bronchi and decay into ^{210}Po , and they tend



The $^{210}\text{Po}/^{210}\text{Pb}$ activity ratio vs time for insoluble smoke particles in the lung. (τ_R represents the average time the particles reside in lung tissue; τ_{Bi} and τ_{Po} are the mean lifetimes of the radioisotopes ^{210}Bi and ^{210}Po .)

to remain at their deposition sites in the lungs. For the most persistent particles, the ^{210}Po alpha disintegration rate becomes equal to that of ^{210}Pb beta activity.

Dosage Measurement

How large a radiation dose is produced? Studying ^{210}Po concentrations in small samples of bronchial tissue, Little and Radford concluded that smokers receive a maximum dose of alpha radiation of about 200 rem in 25 years. (One rem is the dosage of ionizing radiation that will cause the same biological effect as one roentgen of x-ray or gamma-ray dosage.) Martell calculated that a single insoluble ^{210}Pb particle resident in the lungs for three years or more could produce an average alpha dose from ^{210}Po of 5 rem per year in about 100 nearby cells.

Pulmonary accumulation of insoluble dust particles (radioactive or not) provokes a "sequestering" reaction in tissue that results

in the formation of plaques or nodules involving large numbers of particles. Clusters of insoluble smoke particles could therefore result in delivery of a cumulative alpha radiation dose from ^{210}Po to small volumes of tissue that would greatly exceed the estimated maximum of 200 rem in 25 years. Exact measurements of ^{210}Pb and ^{210}Po distribution in lung tissue remain to be made, but there is a large body of evidence to support this concept of particle clusters yielding high radiation doses to small volumes of tissue.

Supporting Evidence

Excess incidence of lung cancer is found in uranium miners receiving a total alpha-equivalent dose of 600 to 1,200 rem or more. Comparable doses in cigarette smokers would occur only in very small bronchial tissue volumes, according to Martell—implying a lower risk for smokers. But animal experiments have shown that the risk of cancer associated with a given alpha radiation dose increases when the rate of accumulation of that dose is reduced and the period of exposure is lengthened—implying a higher risk for smokers.

Asbestos workers who smoke cigarettes have ten times the bronchial cancer incidence of other smokers. Insoluble dust accumulations in the bronchi appear to cause lymphatic stagnation, resulting in decreased ability to clear the lungs of accumulated insoluble particles. If the smoke particle theory is correct, cigarette-smoking asbestos workers will have an increased burden of insoluble smoke particles, thus explaining their higher cancer risk.

Other lines of evidence also point to the primacy of radioactive smoke particles in carcinogenesis in the bronchi of smokers. The proposed chemical carcinogens have not been proved carcinogenic at the low concentrations found in cigarette smoke, for one thing. And there is greater risk among smokers who inhale deeply and smoke unfiltered cigarettes, consistent with the insoluble smoke particle theory. Smokers have a residual cancer risk for a considerable time after they stop smoking—also consistent with the slow clearance of particles. Finally, smokers also get more cancers than nonsmokers in organs other than the lungs, which may be explained

by transport of insoluble radioactive particles via the lymph circulation and the bloodstream to these other sites.

Further research to evaluate these possibilities is, of course, called for. But it is noteworthy that this information about a possible particle etiology for bronchial cancer derives from research in atmospheric chemistry. And Martell's work has some important implications for other areas of public health involving pollutant aerosols of Aitken particle size.

The Fast Breeder Issue

If low-level alpha radiation is in fact shown to be the primary agent of lung cancer, then there will be a basis for estimating the magnitude of the public health problem that may result—analogously—from chronic inhalation exposure of the entire population to other sources of insoluble particulate alpha emitters, such as plutonium oxide.

In testimony at the public hearings on the Atomic Energy Commission's liquid metal fast breeder reactor program, held at Germantown, Pennsylvania, on 26 April 1974, Martell pointed out that the fast breeder could be a public health menace. The possibility that only a few disintegrations per minute of alpha radioactivity may give rise to significant cancer risk raises serious questions regarding the safety of plutonium technology and the acceptability of the AEC's reactor program. Airborne plutonium contamination is usually present in the form of insoluble plutonium oxide particles of respirable size. The risks to plutonium workers and the general public exposed to inhalation of this highly toxic material should be fully and rapidly evaluated, Martell contended, before the U.S. and other nations are irretrievably committed to the fast breeder reactor program.

Climate and the Politics of Food

A heightened international awareness of food production and distribution problems is urgently needed and must begin with the recognition that serious crises are imminent and are related in part to climatic variability.

This is the message that Stephen H. Schneider, deputy head of NCAR's Climate Project, and Walter Orr Roberts, past president of UCAR, have been carrying to some of the nation's decision-makers. They conferred several times in the spring and summer with various federal agencies that are responsible for U.S. food policies.

As Program Committee chairperson of the International Federation of Institutes for Advanced Study (IFIAS), in which 24 countries are represented, Roberts has also played a major role in raising international awareness of climate problems. He is leader of the IFIAS Climate Project, which is sponsoring research programs involving climatologists, meteorologists, oceanographers, agricultural economists, and political scientists from nine countries. These scientists are addressing the societal consequences of changes in global climate.

At the request of the National Security Council, Schneider and Reid Bryson, director of the Institute for Environmental Studies at the University of Wisconsin, briefed several dozen White House aides this June on the probability of climate-induced worldwide food shortages. The scientists urged consideration of strategies to avert disasters that could result from natural fluctuations of the climate.

In recent years, U.S. agricultural planning—particularly food-reserve policies—has been based largely on the assumption that relatively stable weather patterns persist from one year to the next. Schneider and Bryson presented evidence to their White House audience that this is not always the case and that the climatic conditions of the past decade were more than usually favorable for crops. They recommended that officials who develop planting and food-reserve strategies should consult historical climatic records to assess the effect on crop yields of periods of adverse weather. And they urged support to more complex studies of the mechanisms of climatic variability and their effect on agriculture.

The White House briefing was preceded by a meeting in April 1974 between officials of the U.S. State Department's Agency for International Development (AID) and Schneider, Thomas Malone (chairperson of the UCAR Board of Trustees), and Edwin Wolff (NCAR assistant director). AID is an agency responsible for offering agricultural assistance to developing countries. AID officials confirmed that much of their thinking has been based on the assumption of a constant climate, and they expressed interest in guidance by climatologists.

Food Reserves Are Low

Schneider points out that world grain reserves are dwindling. Recent figures obtained

from Lester Brown of the Overseas Development Council show fewer than 30 days' supply of grain, compared to global stockpiles in 1966 of about 66 days. In countries where large percentages of the population are already at or below subsistence levels, shortfalls in anticipated yields could be especially disastrous.

Yet it is well known that adequate food production to sustain a rapidly growing world population depends on the presence of two conditions: sufficiently developed energy resources and a stable climate. On both counts, the specter of a world food crisis in the late 1970s looms ominously before us.

Energy

Energy is essential to plant, fertilize, harvest, process, transport, and store food. Chemical fertilizer—a highly energy-dependent product—is mandatory for the large-scale mechanized agriculture of modern industrial societies. But fertilizer is now scarce and expensive to produce because of energy shortages. In particular, the worldwide petroleum crisis of 1973, highlighted by the Arab oil embargo, created a fertilizer crisis in 1974.

Countries that need energy to avert starvation have been unable to afford petroleum or its byproducts at world market prices that have been at an all-time high. This problem is especially critical in the heavily populated tropical and subtropical regions of the world. Because population is growing rapidly and food production is hard pressed to keep up, there has been a shift in such areas to emphasis on a few high-yield "miracle" crops, such as those of the so-called Green Revolution. But without optimal fertilization, these miracle strains produce even less than the more conventional varieties.

There is also an inherent danger in the homogeneity of these special strains, because it means that uncomfortably large percentages of the world's crops are now vulnerable to a single pest. The 1970 southern corn-leaf blight in the midwestern United States was a startling example of this vulnerability. Pest infestation is strongly dependent on climatic conditions, and changes in those conditions might foster the spread of known pests or the

intrusion of new ones. There is concern, too, that the highly specialized strains that now supply much of the world's food may not adapt easily to climate variability, since many have been bred specifically for the narrow ranges of rainfall and temperature of the past few decades.

A Cooling Trend

It is now well established that the peak of the recent optimum climate, characterized by warmer temperatures, was reached in the late 1940s. A return to slightly cooler conditions, similar to pre-1900 times, has occurred in the northern hemisphere. While the changes seem small on a global scale, their effects can be significant.

Schneider notes, "There is some evidence that climate varies more during cooler periods; thus, a higher frequency and degree of climatic variability (increases in droughts, floods, and temperature extremes) is more likely in this decade. That probability, unfortunately, is still difficult to quantify—although the consequences are easily felt."

In the mid-twentieth century, a benign and stable climate and great technological strides were accompanied by rapid population growth and the attendant need for more food. In many countries, rising affluence also increased food demands. But the continuation of the extremely favorable weather of recent decades cannot be assured from year to year.

The Politics of Food

Schneider believes that the world should prepare to fight mass starvation by building and maintaining adequate reserves as part of a world food security plan. Along with such stockpiling, he sees the need for decisive political action—both domestic and international—to fight the coming hunger on many fronts.

Many political analysts have sketched the broad outlines of action that might be taken. A U.S. policy of full production for a balanced domestic market and for export is required. Internationally, efforts could include agreements about the types and locations of crops and food reserves, production

and consumption levels, and the logistics of distribution and storage. Other international agreements on prices and exchanges of resources to improve global productivity could end the wastefulness of blockades, tariffs, and boycotts. And international pressures toward stabilizing population growth and decreasing birthrates, while difficult to implement or even advocate, could help to assure that the growth in numbers of humans will not outpace the increase in food supplies.

A Scientific Task

Schneider thinks an important first step for the climatologists who have sounded the alarm is to work to provide answers to the scientific questions posed by climate variability.

At NCAR, Schneider, Roy Jenne, Henry van Loon, and other researchers are examining

climatic history to determine the probability of climatic variability. Through this historical approach to research, using NCAR's computer archive of climate data, the scientists also hope to discover cause-and-effect mechanisms in the earth's climate system. To test possible causal relationships, they are continuing to develop a hierarchy of climate models. Climate sensitivity studies—running the computer models to test hypotheses suggested by NCAR researchers and others—are used by the Climate Project to meet a number of research objectives. One objective is to provide a scientific basis for realistic international food planning.

“This kind of work is a part—and not a small one—of an intensely serious race against time,” Schneider says. “Time is short. It may run out for millions in the developing countries before world consciousness is adequately aware of the problem and before such planning could reduce the danger.”