A REPORT ON THE PROGRESS OF A STUDY TO ASSESS THE POTENTIAL FOR A LUNG CANCER RISK ASSOCIATED WITH DOMESTIC RADON EXPOSURE IN THE STATE OF MAINE

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ABSTRACT

The potential for a radon-related health risk in Maine was evaluated because geologic and environmental survey data suggest that high radon exposure may be wide-spread in the State. In order to evaluate the presence of radon exposure, data were collected by reviewing existing information and conducting a case/control study of cancer patients and a control group.

The purpose of this study was to determine if the radon levels found in homes in Maine are associated with an increased incidence of cancer, especially cancer of the lung. To accomplish this, data were collected on three groups of patients: lung cancer patients, other cancer patients, and a control group of patients free of cancer. To be selected for the study, a patient had to have lived in a house supplied by a privately-owned drilled well for at least 10 years. Demographic information, including occupation, history of smoking, and medical history, was gathered through questionnaires. Data on the water supply was also requested in the questionnaire, and geological information was taken from bedrock and surficial maps in order to better predict where high radon levels might occur.

The data collected suggested that up to 10 percent of homes in Maine may have 5 pCi/L or more of radon in their air environment during the heating season. Also, several towns were identified in which homes were served by groundwater supplies which have radon concentrations in excess of 20,000 pCi/L.

The metamorphic grade of the bedrock showed the only strong association with water radon levels, with the mean radon level tripling from low-grade to highly altered rock, and doubling from high-grade metamorphic rock to granite.

However, 20% of the homes with high air radon values had low levels of radon in their water supplies, suggesting that soil as well as water is an important source of radon in the home environment. Average air radon levels were highest in homes built on permeable sand and gravel and lowest on dense clays.

To date, too few lung cancer cases have entered the study for a reliable comparison of radon exposure among the three patient groups; however, the study is continuing and this analysis will be done when 100 lung cancer patients have been entered into the study.

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INTRODUCTION

The potential health consequences of exposure to radon gas in the home is a pressing environmental health concern. To evaluate this problem in Maine, a review of existing information was undertaken, followed by a preliminary epidemiological study employing a case/control research design which evaluated the presence of elevated air and water radon levels in homes of lung cancer patients, non-lung cancer patients, and controls. This project was funded in part by $40,000 allocated by the 1982 Maine Legislature, and was conducted as a cooperative effort by the following groups: the Maine Department of Human Services, Environmental Health Unit; the Maine Geological Survey; the Research Department of the Maine Medical Center; and the Physics Department of the University of Maine at Orono.

This report will not attempt to communicate a detailed review and analysis of all information accumulated for this project; rather, it will try to summarize important public health findings as they apply to the situation present in Maine.

BACKGROUND

A large volume of published research is available which describes the source, occurrence, and carcinogenic potential of radon gas, and examines the health effects associated with elevated radon exposures in specific populations (epidemiologic studies).

Source and Occurrence of Radon Gas

Radon (Rn-222) is a decay product of radium, and is a naturally-occurring radioactive gas that is released into the home environment either directly from underlying bedrock or soils, or indirectly by escaping from water drawn from wells drilled into bedrock. With the emission of alpha particles, radon decays to form a series of short-lived heavy metal daughters, three of which also undergo alpha decay. Half of a given volume of radon decays to its daughter products in 3.82 days.

Although radon levels in private water supplies from drilled wells are generally less than 2,000 pCi/L, in several areas of the United States levels 50 to 100 times this amount are not uncommon. Individual wells in Finland (Kahlos, 1980) and in Maine have been measured at over 1 million pCi/L. A well with 750,000 to 1,000,000 pCi/L was discovered in Georgetown, Maine in 1981, and recently another well, with levels as high as 1.7 million pCi/L, was identified in Leeds, Maine. However, closely adjacent wells may differ widely in their radon content due to variations in local geology. The Maine Department of Human Services currently suggests remedial action be taken when water radon levels exceed 20,000 pCi/L.

In the late 1970's researchers at the University of Maine at Orono observed the following (Hess,1979):

1. Radon is present in Maine's well water in varying amounts. Radioactivity of water from 2,000 wells tested averaged approximately 10,000 pCi/L. (These wells were not from a random sample.)

2. In general, radon concentrations are highest in granite bedrock.

3. Public water supplies have relatively low radon levels.

Public water supplies usually have low levels of radon because the source is frequently a lake or other surface water which allows radon to escape readily into the atmosphere. Also, there may be significant retention time in distribution pipes and water tanks, which allows radon and its progeny to decay to low levels. Shallow water supplies (dug wells, springs, and well points) finished in sand and gravel deposits are usually low in radon because of dilution from rainwater and emanation of radon to the atmosphere via air spaces in these permeable materials.

Table I. Mean Radon Levels in Shallow Wells, Springs, and Public Supplies

SOURCE	MEAN RADON (pCi/L)	NO. OF SAMPLES
Dug Wells	1,432	46
Well Points	1,448	5
Springs	3,705	22
Water Companies	1,936	63

(original data from Hess, 1979)

A description of the pattern of reliance on water from individual drilled wells is depicted in Figure 1. The map shows that for a majority of the towns in Maine, more than 20 percent of the households are served by individual drilled wells, and that in several towns in central and northern Maine more than 60 percent of homes are on drilled wells.

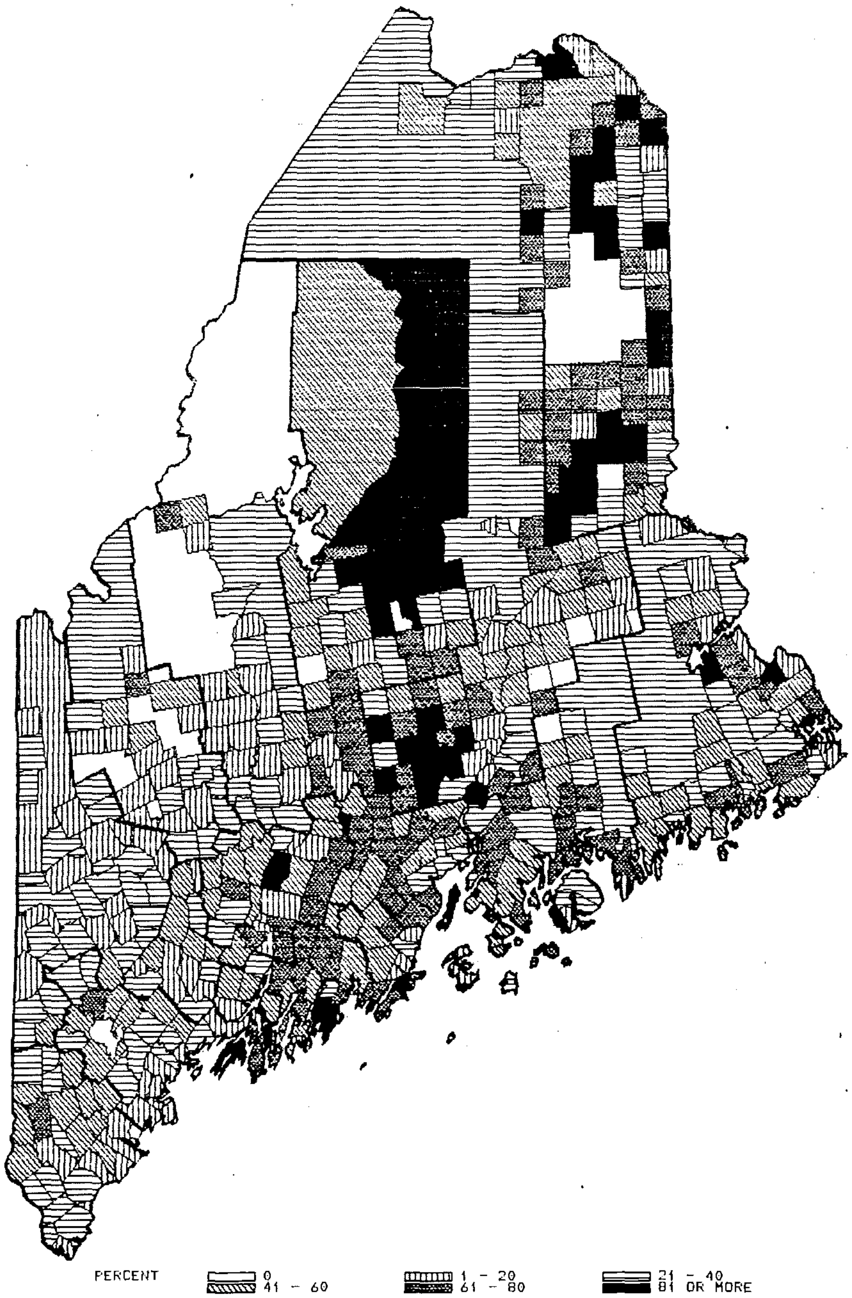
Figures 2, 3, and 4 display water radon data obtained from two sources: analysis of samples submitted to the Maine Public Health

Laboratory from 1980 to 1984, and data collected by C.T. Hess et al., (1979). Together, more than 2,500 water radon analyses are depicted in these maps. Figure 2 displays the geographic distribution of the number of water radon samples by town. The data shows that in most towns, at least one sample was collected, and in 14 towns located in south-central and coastal Maine 25 or more samples were collected. Figures 3 and 4 show the maximum and median water radon analysis results by town. These data show that high values (exceeding 20,000 pCi/L) are found in towns located in south-central and coastal Maine, the most populated areas of the State.

Often, radon emanating from the soils on which houses are built represents a more important domestic source of radon than does well water. It is important to realize that the concentration of home air radon - which is the principal health concern - can be highly variable, since it is affected by the physical and chemical characteristics of the soil (particle size, permeability, water content, and radium concentration), ambient weather conditions, house construction, and seasonal changes in heating and insulation, as well as by household water use when groundwater radon is high. It has been estimated that in homes undergoing one air exchange per hour, 10,000 pCi/L of radon in household water will result in 1 pCi/L in air (Hess, 1979). The U.S. Environmental Protection Agency has set a guideline of 4 pCi/L for remedial action for homes built in the phosphate mining regions of Florida (U.S.E.P.A., 1979). In Maine, levels twice as high are not uncommon.

Figure 1

PERCENT OF HOUSEHOLDS ON DRILLED WELLS BY TOWN
MAINE, 1980



Source: U.S. Bureau of Census, Maine Census of Population and Housing Computor Tape Files, Washington, D.C., 1983

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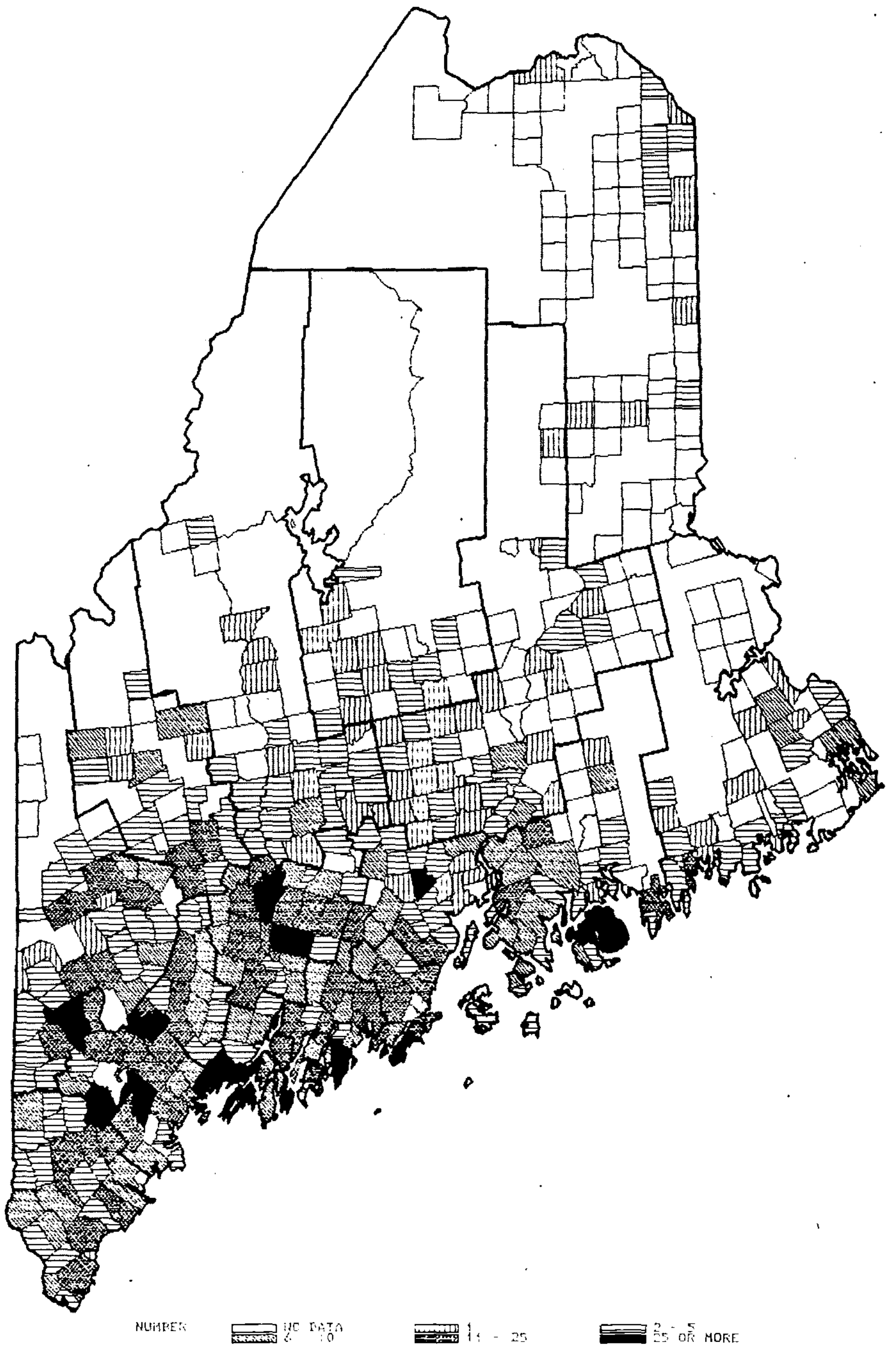
Figure 2

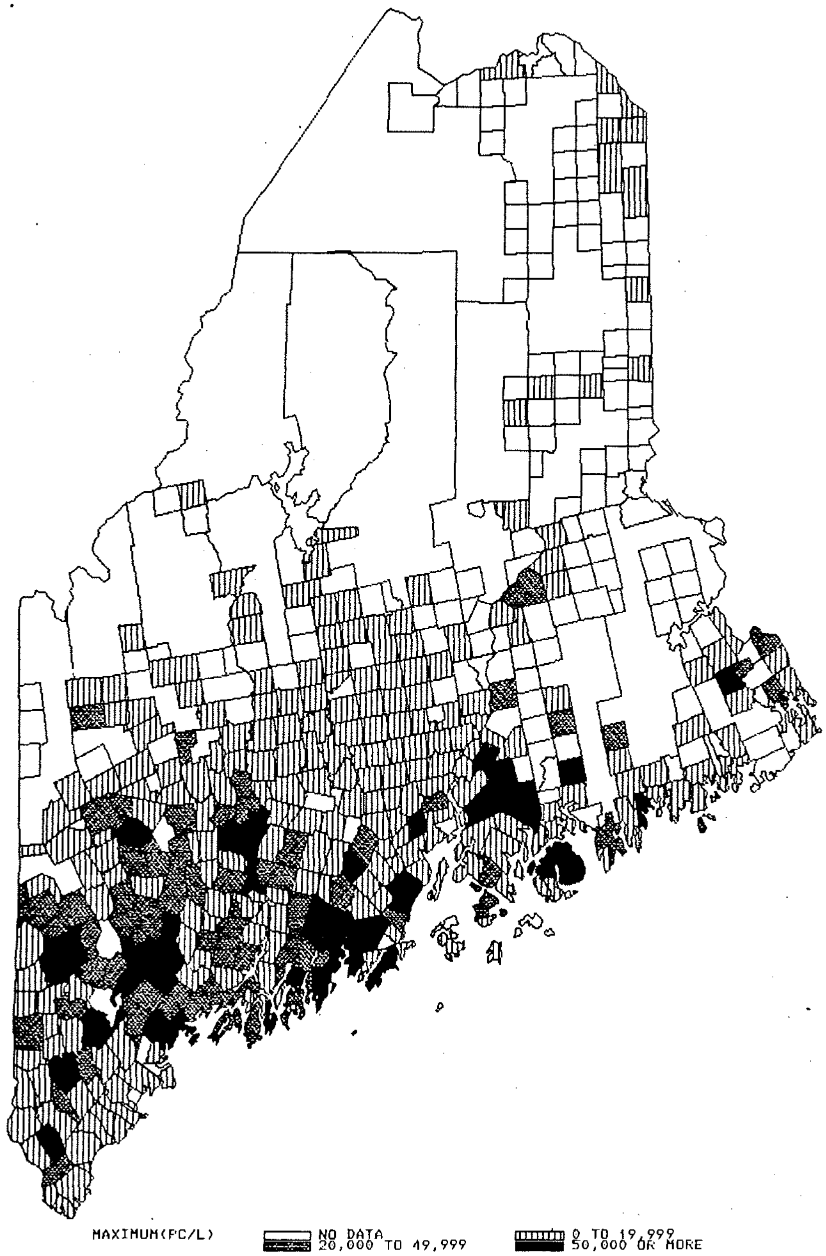
NUMBER OF WATER RADON SAMPLE ANALYSIS REPORTS BY TOWNS
MAINE, 1979 TO 1984



Source: Laboratory Analysis Results from Samples Submitted to the Maine Public Health Laboratory, 1980 to 1984 and Data Contained in Report, "Radon-222 in Potable Water Supplies in Maine," C.T. Hess et al., Land and Water Resources Center, University of Maine at Orono, Orono, Maine 1979

Figure 3

MAXIMUM WATER RADON LEVELS IN PCI/L FOR TOWNS
MAINE, 1979 TO 1984



SOURCE: LABORATORY ANALYSIS RESULTS FROM SAMPLES SUBMITTED TO THE MAINE PUBLIC HEALTH LABORATORY, 1980 TO 1984 AND DATA CONTAINED IN REPORT, "RADON-222 IN POTABLE WATER SUPPLIES IN MAINE," C. T. HESS ET AL, LAND AND WATER RESOURCES CENTER, UNIVERSITY OF MAINE AT ORONO, ORONO, MAINE 1979
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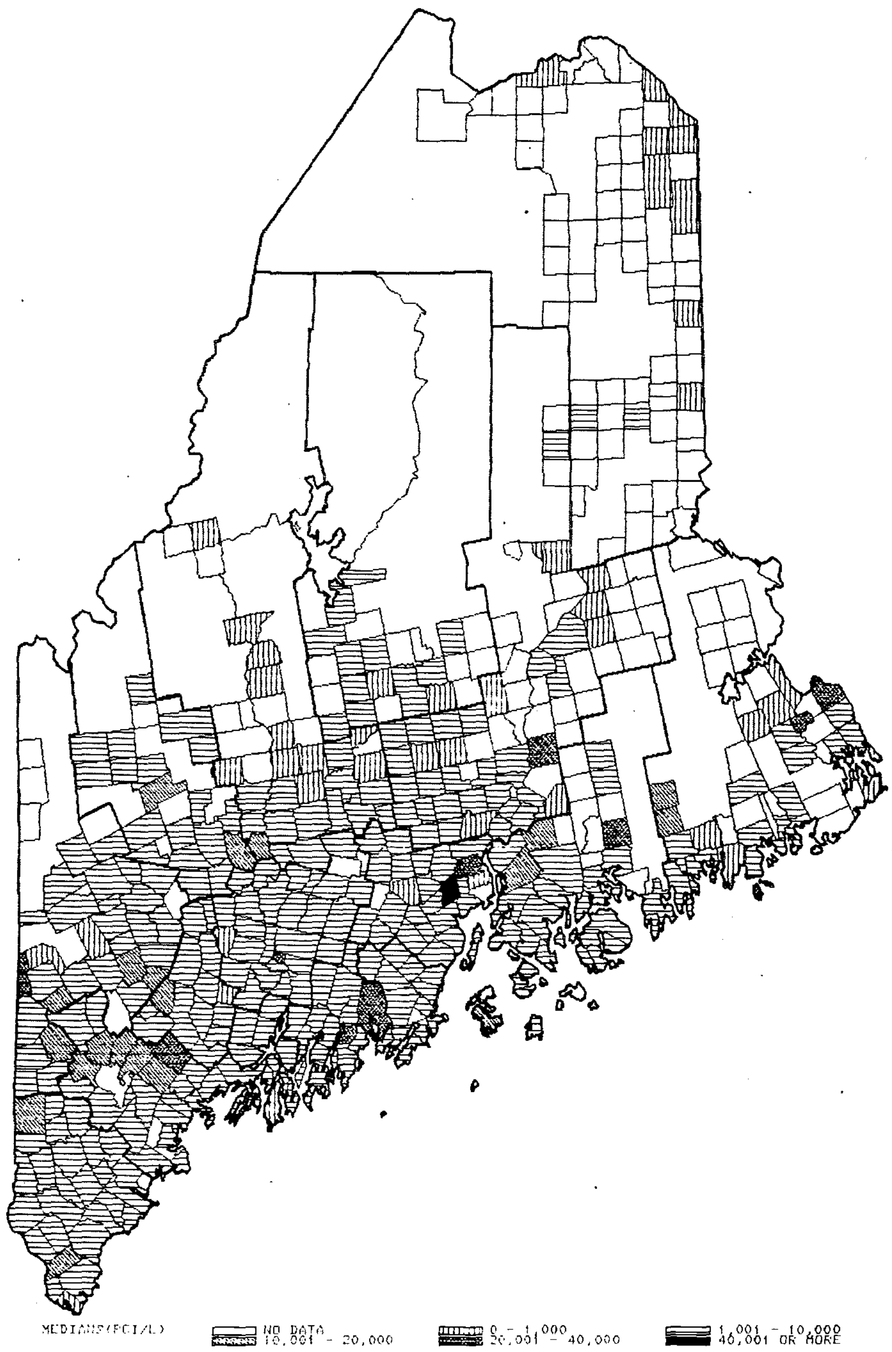
Figure 4

MEDIAN WATER RADON LEVELS IN PCI/L FOR TOWNS
MAINE, 1979 TO 1984



Source: Laboratory Analysis Results from Samples Submitted to the Maine Public Health Laboratory, 1980 to 1984 and Data Contained in Report, "Radon-222 in Potable Water Supplies in Maine," C.T. Hess et al., Land and Water Resources Center, University of Maine at Orono, Orono, Maine 1979

Carcinogenic Potential of Radon Gas

Radon in well water may be ingested into the body directly when a person drinks the water or consumes food that contains the water. Or it may enter the body after diffusing from the household water into the air that residents of the household breathe. Health risks from direct consumption of well water are thought to be insignificant. It is the airborne radon that provides the greatest exposure to radioactivity.

Because of their mass, alpha particles emitted by radon penetrate epithelial tissue to a depth of approximately 75 microns. This distance is sufficient to expose the layer of basal cells underlying the bronchial epithelium, which is the origin of most forms of bronchogenic cancer. Despite their short penetration, alpha particles cause intense ionization long their tracks and therefore do greater damage to living cells than do other forms of radiation. Recent cytogenetic studies have demonstrated chromosome aberrations in cultured white blood cells from the occupants of high-radon houses (Stenstrand, et al., 1979) and from the employees of a high-radon Austrian health spa (Pohl-Ruling, et al., 1980).

The possibility that a radon-induced lung cancer risk is present in Maine is illustrated by the fact that in 1983, 18 percent more female lung cancer cases occurred than were expected based on national rates. This excess in lung cancer incidence is consistence with radon as a possible etiologic exposure variable since females generally spend more time at home than males, and females are not routinely employed in occupations associated with a high lung cancer risks, i.e., welders, pipe fitters, etc. Also, this finding increases in importance when one considers that the proportion of female smokers in Maine differs little from that in the rest of the nation (about 33 percent for Maine females versus 30 percent for the U.S. females (Maine Department of Human Services, 1983)).

Epidemiological Studies

Most of the human risk estimates relative to radon's health effects come from studies of miners. In the 1500's, up to 50 percent of European bedrock miners died of a lung disease subsequently shown to be bronchogenic carcinoma (Hueper, 1942). More recently, several studies involving uranium, iron, fluorspar, and other bedrock miners in the United States, Czechoslovakia, Canada, and Scandinavia (National Research Council (Beir III Report), 1980) have shown significant associations between radon levels and an excess incidence of lung cancer. These studies demonstrate a linear dose response, a latency period of from 7 to 50 years, and both increased risk and decreased latency with increasing age at first exposure.

Evidence of a cancer risk from radon in the domestic environment is less definitive. A geographic comparison of Maine by Hess et al., (1983) found a positive association between average county well water radon levels and male and female average annual age-adjusted mortality rates for lung cancer, and for all cancer sites combined. A similar ecologic study in Sweden related background radiation in homes to cancers of the lung and pancreas in both sexes and to leukemia in males (Edling, 1982). A four-fold increase in mortality from lung cancer has been found in residents living in radon-prone homes on an island in the Baltic Sea (Edling, 1984) and, in Iowa, Bean, et al. (1982), observed an increased incidence of lung and bladder cancer in males and lung and breast cancer in females for areas served by drinking water supplies with high levels of radon's precursor, radium-226. Very recently, Lyman, et al. (1985) reported an association between groundwater radium and adult leukemia in Florida where elevated radon levels are also a problem.

While statistically significant differences in the incidence of lung and other types cancers between areas of high and low radon are consistent with the hypothesis that high domestic radon exposure causes cancer, ecologic study designs cannot be used to test this hypothesis. The marked local variability of both water and soil gas radon prohibits making generalizations about radon levels for geographic areas.

Using data from the mining studies, various workers and review groups have derived a range of risk estimates. A sampling of these, expressed as deaths from lung cancer per WLM* per lifetime, appears below:

Air Radon/Lung Cancer Risk Estimates

Reference	Lifetime Risk/WLM
Evans (1982)	1×10^{-4}
NCRP (1984)	$1\text{-}2 \times 10^{-4}$
ICRP (1980)	$1.5\text{-}4.5 \times 10^{-4}$
UNSCEAR (1977)	$2\text{-}4.5 \times 10^{-4}$
Radford (1984)	10×10^{-4}
NRC (BEIR III) (1980)	$2\text{-}14 \times 10^{-4}$

However, because miners differ from "average" household residents with respect to their environment, physical activity, length and degree of daily and long-term exposure, male-female ratio, smoking, and lifestyle, these risk estimates are highly speculative. Thus, the true impact of domestic radon on human health is not yet known.

*One "working level" (WL), at a radon - radon daughter equilibrium of 0.5, equals 200 pCi/L. One "working level month" (WLM) equals exposure to one WL for 170 hours in the mining environment. This figure is multiplied by 50 (720 hrs/170 hrs x 12 months) to convert to WLM/yr in the domestic environment.

METHODOLOGY

The radon and lung cancer case/control study employed a scientific method appropriate for this study design. The details of the case/control methodology will be highlighted in this report.

Because the concern at the time this study was initiated was radon in ground water, admission was limited to subjects (cases and controls) who lived in Maine (excluding Aroostook County where water radon levels are known to be low) and were served by a privately-owned drilled well for at least ten years. Cases (lung cancer patients and other cancer patients) were limited either to living or recently deceased persons. Arrangements were made with hospitals within the study area to provide tumor registry lists. However, it became apparent that this information might be as much as six months old by the time it was received, so a system was established to also receive pathology reports. More recently, two further resources for finding lung cancer patients - cytology and radiation therapy reports - have been employed. Special affidavits were developed to assure patient confidentiality. When a case or control was identified, permission for contacting this individual was obtained from this person's physician. Then the project was described to the patient and written consent obtained. Controls were selected by an informational insert placed in pre-admission packets sent to all persons scheduled for inpatient admission at two of the larger medical centers in the study area. Similar material was distributed to interested physicians throughout the area.

All subjects were provided with a questionnaire to be self-administered, and unanswered questions and ambiguous responses were checked by phone. For deceased subjects, the next of kin was contacted. The questionnaire included sections on house construction, water use, occupancy habits, tobacco and occupational exposures, and medical history. Each subject's present house, and their previous house if occupied within the last ten years, were visited by a technician who obtained duplicate water samples at the faucet and, if possible, on the inflow side of any installed filter. The technician also left a Terradex Type F track-etch air radon detector, usually on top of the refrigerator in the kitchen. Water samples were analyzed within two days by a modification of the scintillation method of Prichard and Marien (1983) in Dr. Hess' laboratory at the University of Maine at Orono, and air cups were generally returned after two months and forwarded to Terradex for counting. During the first year, household samples were collected shortly after subjects entered the study, but air radon results showed a seasonal influence, thus necessitating that samples only be collected between October 1 and April 1, except in the homes of severely ill cancer patients.

At the Maine Geological Survey, patients' residences were located on bedrock and surficial maps in order to correlate air and water radon levels with geological parameters, and thereby improve our capability to predict where high radon levels might occur.

RESULTS

Presently, the control and other cancer groups have been filled and the lung cancer group is about half full. Figure 5 depicts the age and sex distribution of the three groups. It is apparent that among this primarily rural population of long-term drilled-well users, radon levels are frequently high, and the source of radon is not limited to outgassing from well water. Figure 6 shows that about 18.5 percent of the wells sampled have water radon above 10,000 pCi/L and nearly 9.5 percent exceed 20,000 pCi/L. Of the air samples taken, 42 percent exceed 2 pCi/L, 24 percent exceed 3 pCi/L, and 9 percent exceed 5 pCi/L (Figure 7). These air samples were obtained throughout the year; if one considers only samples obtained during winter months, 12.5 percent of these exceed 5 pCi/L. Thus, about ten percent of Maine's rural population is exposed to over 5 pCi/L Rn-222 in the air of their homes. The average level within this group is approximately 8 pCi/L.

The only bedrock parameter that correlated with radon levels in well water, was the metamorphic grade (the degree to which heat and pressure reformed the rock). High grade metamorphic rock and granite had been to some degree in a molten state, which concentrates uranium. This could explain the observed increase in average water radon levels with increasing metamorphic grade (see Figure 8). The granites that we studied had the highest average radon levels, especially the "two-mica" granites labelled 1,2 and 3 in Figure 8.

However, little correlation appears to be present between water and air radon levels; in fact, up to 20 percent of homes with water radon below 10,000 pCi/L have air radon levels above 3 pCi/L based on winter measurements. This suggests that there is another important source of radon, which appears to be the soil. When average airborne radon levels were calculated for each general soil type (sand and gravel, till, and clay), radon levels increased with the permeability of the soil on which the house was built - lowest over dense clay and highest over permeable sand and gravel.

Table II. Mean Values of Airborne Radon by Soil Type (pCi/L)

TYPE	NO. OF SAMPLES	MEAN
Sand, gravel	46	3.03
Till	230	2.31
clay	82	1.82

At this point in time, only 50 lung cancer cases have joined the study, which precludes a statistically reliable comparison of radon exposure among the three patient groups; however, data is still being collected and this analysis will be made when there is data on 100 lung cancer patients.

Figure 5

Distribution of Radon Study Subjects

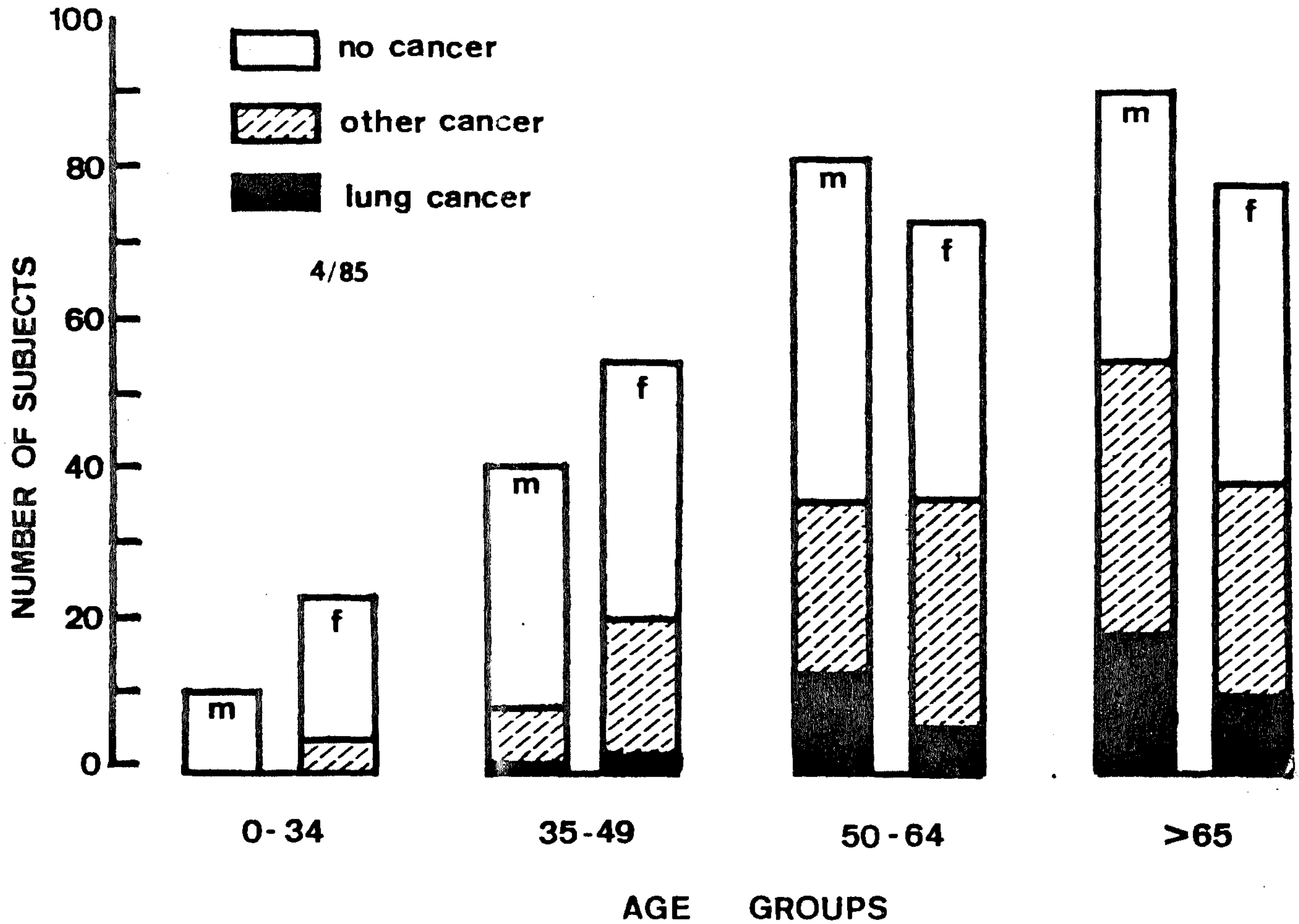


Figure 6

Water Radon Distribution of All Subjects

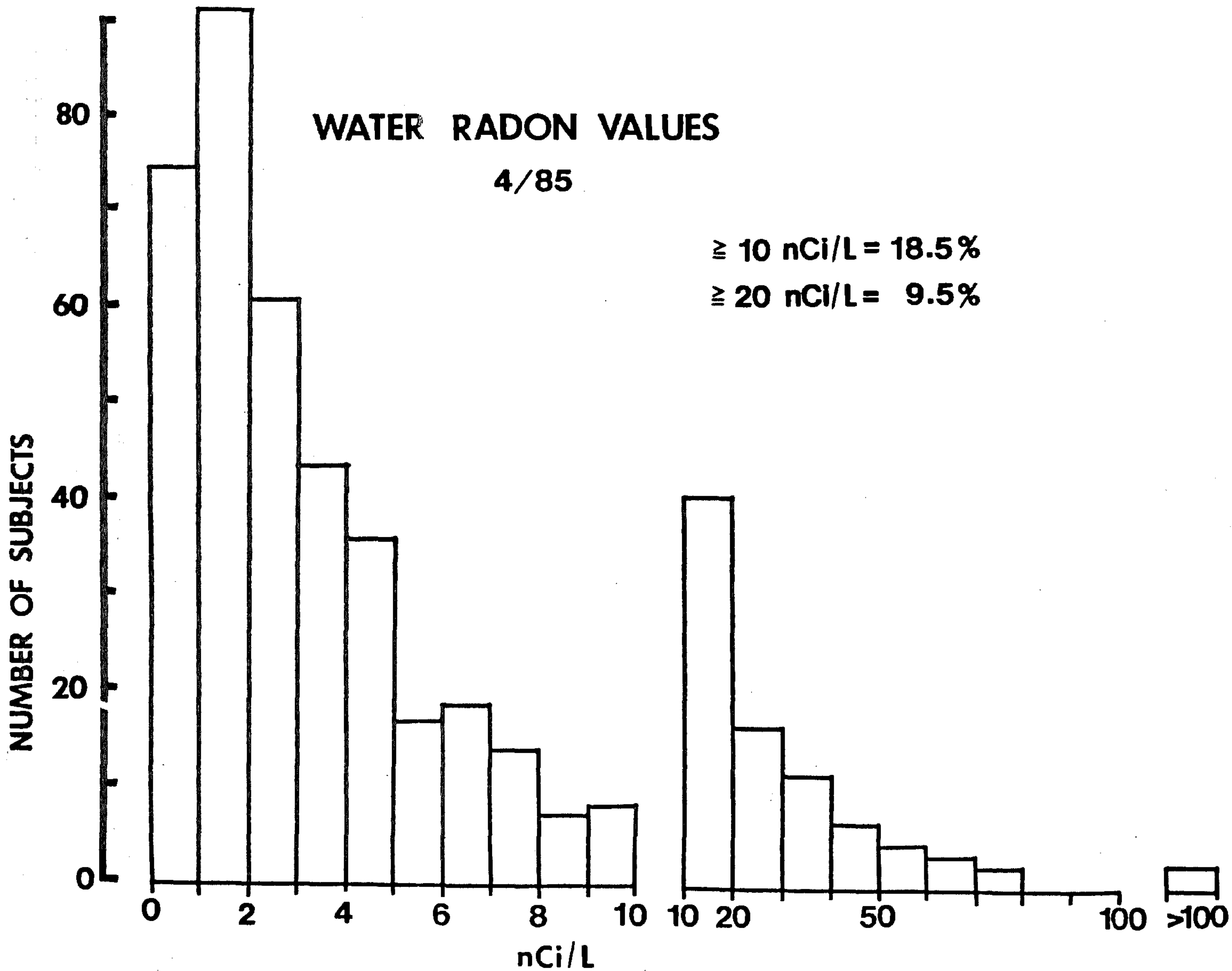


Figure 7

Air Radon Disbribution of All Subjects

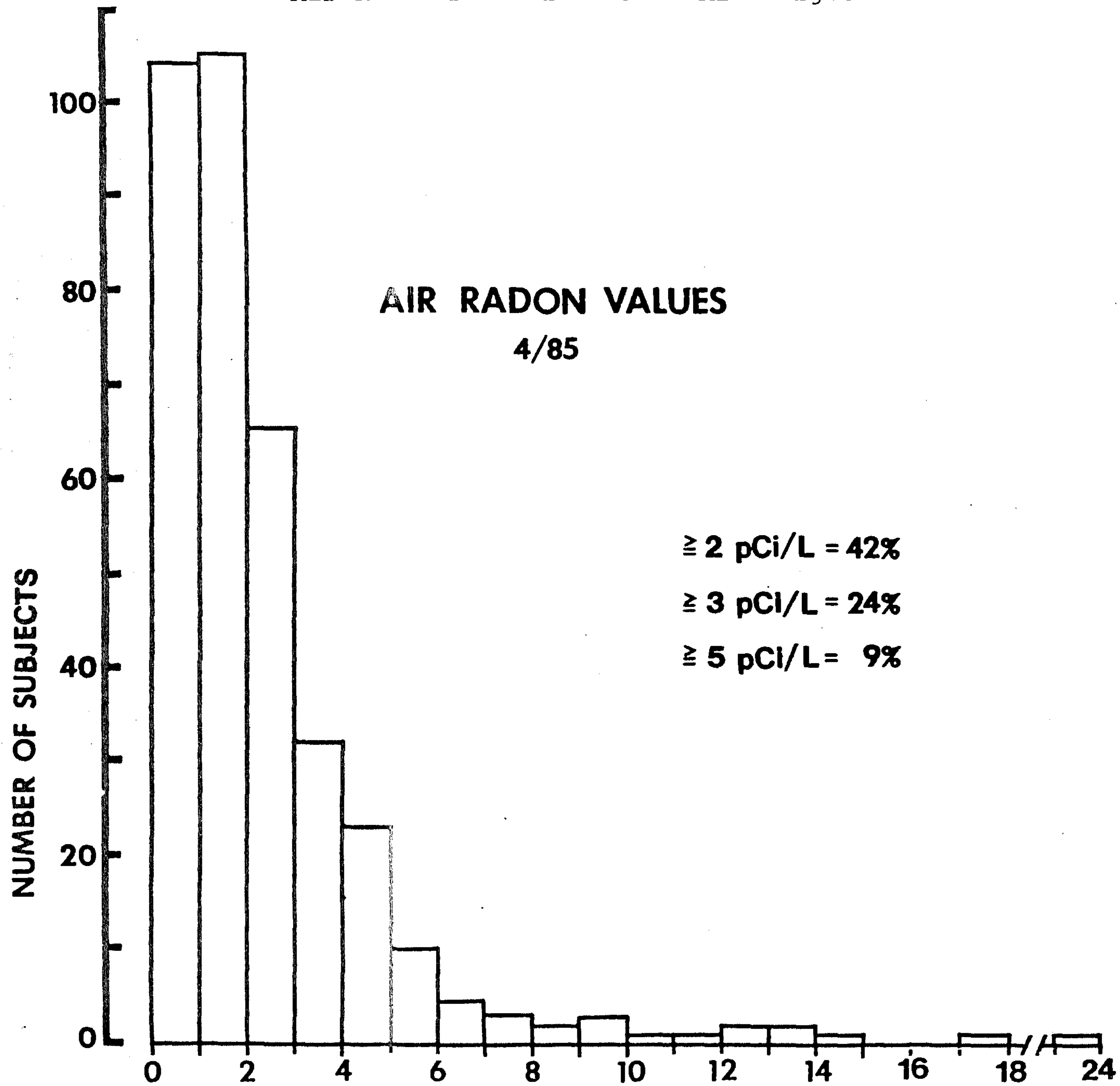
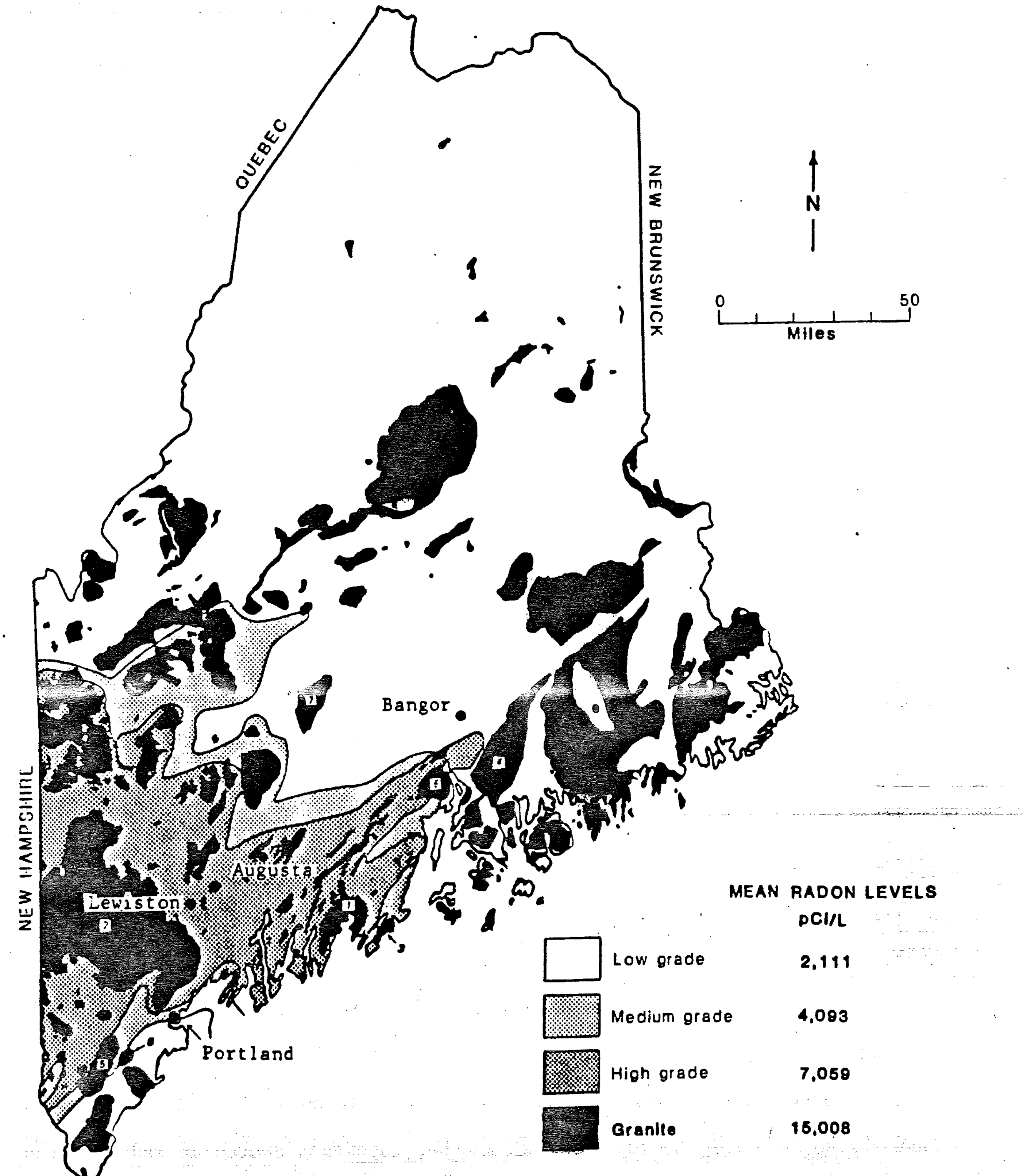


Figure 8

Mean Radon Levels by Metamorphic Grade of Bedrock in Maine



DISCUSSION

On the basis of financial, temporal, and staffing constraints, the sizes of the groups were arbitrarily set at 100 lung cancer patients, 100 other cancer patients, and 200 controls. Currently, the predesignated number of lung cancer patients has not been reached; consequently, the presence or absence of a radon related lung cancer risk can not be considered at this time.

The possibility of bias in this study needs to be considered because in recruiting controls, the information provided explained that the project dealt with radon. This raises the possibility of pre-selection bias if controls from high radon areas were more likely to enroll in the study. We believe this probably did not occur, since during the period over which data was collected, high radon areas had not been recognized locally. The problem is becoming increasingly important and will affect future studies as more is learned about radon, and as the public becomes better informed.

Certainly, the number of hours per day that a subject occupied their house, and perhaps the number of showers taken per week, how and where laundry is done, the total number of occupants, and the amount of draftiness in the home, all affect an occupant's radon exposure. We are presently exploring the possibility that this information can be utilized in formulas to estimate total radon exposure. In general, the questionnaire approach has worked well, although it requires considerable staff time.

Data collected by this evaluation suggests that approximately 10 percent of households in the State on drilled wells have air radon levels exceeding 5 pCi/L. The average air radon concentration in the upper 10th percentile for this group is 8.2 pCi/L. The data further suggest that the metamorphic grade of the bedrock can be used to predict where high radon wells might occur, and that the soils should be evaluated as another important source of radon in the home.

The experience gained and data acquired in this project have been used to design an expanded study. The unnecessarily restrictive entrance criteria of ten years on a drilled well, which ignores soil radon as a source of exposure, has been dropped and, in order to access all lung cancer patients, both living an deceased cases (provided through death certificates) will be studied. Furthermore, measurements of individual exposure will be expanded by measuring air and water radon levels in previous homes occupied by subjects back to 35 years ago. However, procedures will need to be developed to adjust for changes in water supplies, house construction, or home usage, to assure temporal comparability of present air radon measurements with past exposures.

Despite these and other study design limitations, we believe it is essential that radon-related health risk research be continued so that appropriate standards and recommendations can be developed, and sound public health policy can be established to assure the maximum protection of potentially exposed citizens.

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