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Preliminary Comparison Between Radon in Water and the Incidence of Cancer

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Abstract

A preliminary comparison has been made between radon in drinking water and the incidence of cancer using 1278 home occupants in Virginia and Maryland who lived in their present home for at least 5 years. In this study group, the incidence of cancer (all types taken together) is 5.1% among people who consume high-radon well water (2,500-25,000 pCi/l), 3.7% among people who consume municipal water (less than 100 pCi/l), and 2.0% among people who consume low-radon well water (100-2,500 pCi/l). In the study area, where the average indoor radon is about 3 pCi/l and only about 10% of the population use high-radon water wells, the incidence of cancer related to drinking water is five times the total cancer risk from indoor radon.

Key Words. radon, cancer, well water

Introduction

The biological significance of radon is related to the fact that radon and its radioactive daughter products comprise the major portion of the natural internal radiation dose to man. For the general population, excess amounts of these radionuclides can be inhaled when in buildings built over soils with high radon emanation properties, or ingested by consuming well or spring water.

Early work suggested that the radioactive decay products of radon are accumulated in the lungs by filtration, as they are not exhaled along with radon. For this reason, the radiation dose of the respiratory tract is closely studied. However, it has been shown that these radioactive decay products of radon do not remain in the lungs (Pohl and Pohl-Ruling 1967, Lykken and Ong 1989, Henshaw et al 1990). They are transported throughout the body, along with radon, by direct absorption from pulmonary alveoli into the blood, and they are swallowed in the mucus which is removed from the respiratory tract by pulmonary cilia. Measurements by Pohl and Pohl-Ruling show that inhaled radon and its radioactive daughters accumulate in the lungs, blood, kidneys, liver, bone marrow, and adrenal glands, and elsewhere to lesser amounts.

Although the ingestion of radon-enriched water also supplies radionuclides to the blood, the possibility that cancer can occur due to drinking naturally radioactive water has not been studied nearly as extensively as might be expected. Private water supplies are not regulated for radionuclides, but public water supplies must be monitored for radium according to regulations promulgated by the U.S. Environmental Protection Agency (US-EPA 1976). The alpha emitters are of particular concern, because the energy is absorbed in small tissue volumes when they are present internally.

The alpha dose from drinking naturally radioactive water is primarily due to the presence of uranium decay chain nuclides, including Ra-226, Rn-222, Po-218 and Po-214. Of these radionuclides, radon most easily escapes from the surfaces of cracks in rocks and from the surfaces of sediment grains to enter ground water, because radon is a noble gas. For this reason, its concentration is usually many times greater then the other alpha emitters in drinking water. Radon gas and its associated radionuclides are always found in ground water, and the ingestion of excessive amounts of these elements is of concern to health officials.

Radon is chemically inert and highly soluble in groundwater. Alpha decay recoil and diffusion are thought to be the mechanism by which radon moves from grain and fracture surfaces into groundwater. Municipal water supplies are usually very low in radon, because the half-life of radon (3.8 days) is less than the time between removal of groundwater and delivery to homes. Even in small municipal systems that use well water (rather than radon-poor reservoir water), the duration between well water removal and home delivery is usually more than the radon half-life. However, for private wells the pumping-to-consumption interval is usually less than the radon half-life. Private wells tend to be relatively low-yield wells, in which the water has a long residence time of moving though the source rock. Consequently, in private wells the radon tends to be more concentrated (Brutsaert et al 1981, Smith et al 1961).

Although ingestion of radioactive water has long been a cause for concern, most studies are concerned with short exposures to relatively high concentrations of radionuclides, as might occur due to an accident at a nuclear power station. Only a few studies have examined instances of prolonged exposure to radionuclide concentrations found in natural settings, and natural concentrations of uranium and radium are among the most frequently studied (Aieta et al 1987, Hess et al 1985, Lappenbusch and Cothern 1985, Wrenn et al 1987). For example, Lyman et al (1985) correlated high levels of radium in domestic water in Florida counties with an higher than normal incidence of leukemia. A similar study in Iowa towns reported on a correlation between radium and increases in lung, bladder and breast cancer (Bean et al 1982).

Few of the radionuclides occurring in natural water are sufficiently studied to facilitate the adoption of regulatory guides. The interim Maximum Contaminant Level for the sum of Ra-226 and Ra-228 has been set by the U.S. Environmental Protection Agency at 5 pCi/l (Cothern 1987a). US-EPA drinking water standards have not yet been set for uranium or radon.

The geochemical behavior of radium and radon are rather different (Graves 1988), but radium is the parent radionuclide of radon, so radium enriched water can be enriched in radon (Smith et al 1961). This close association of radium and radon in terms of both their origin and their carcinogenic behavior serves to complicate studies of natural radionuclides. One example, which is probably not atypical, is that internally deposited radium and/or radon induces brain carcinomas (Wrenn et al 1987). Cech et al (1987, 1988a, 1988b) noted a correlation between radium and radon in domestic water and the development of lung cancer in a study of several Texas counties. Hess et al (1982, 1983) noted a correlation between radon in home water supplies in Maine and the incidence of lung cancer. In both the Texas and Maine studies, the cancer producing mechanism is thought to be an outgassing of radon from water, which thereby increases the airborne radon concentration and presumably the rate of lung cancer.

A few studies have been directed toward the possibility of developing cancer by the ingestion of radon enriched water (Cross et al 1985, Cothern 1987b). Early work indicated that radon in water at a level of about 20,000 pCi/l, assuming an average consumption of about 300 ml/day, would lead to the maximum stomach dose of 0.5 rem/year which was specified by the International Commission on Radiological Protection (Hems 1966). Since levels at or above 20,000 pCi/l apparently are very rare (Cothern 1987b, Michel and Jordana 1988, Dixon and Lee, 1988), and because airborne radon can be measurably enriched by the outgassing of the home water supply (e.g., Cothern 1987b, Prichard 1987), it has been thought that the cancer risk from the inhalation of radon released from water would almost always exceed the cancer risk that results from the ingestion of radon enriched drinking water.

Three booklets published by the U.S. Environmental Protection Agency (US-EPA 1987a, 1987b, 1987c) inform readers that radon enriched domestic water can contribute to indoor radon, but indicate that dissolved radon is not a health risk through its ingestion by drinking water. The following report will show that at rather modest concentrations of radon in drinking water (2,500 to 25,000 pCi/l), there is a measurable increase in the incidence of cancer compared to the population that consumes low-radon water (less than 2,500 pCi/l). It will show that in the study area, the regional incidence of cancer estimated for breathing the typical indoor radon concentration is less than the regional cancer rate estimated for drinking well water.

Approach

The Center of Basic and Applied Science conducted a study of regional indoor radon in 1987 and 1988 (Mose and Mushrush 1988). Most of the approximately 1500 study homes are in Fairfax County in northern Virginia, and the immediately adjacent Montgomery County in southern Maryland. Both are located along the western margin of Washington, D.C.. About half of the participants of our indoor radon project joined the radon-in-water study, and additional homeowners subsequently joined only the radon-in-water study.

Arrangements were made with Dr. Ed Vitz of the Waterborne Radon Survey at Kutztown University in Pennsylvania for the radon analyses using liquid scintillation. To gather the measurements of radon in drinking water, the homeowners were provided with an inexpensive syringe, a capped vial with 5 mL of toluene based liquid scintillation fluid, along with directions about how to collect 10 mL of drinking water from a commonly used water tap. The homeowners filled out a pre-test survey about their family health which asked, in part, the age of each home occupant, the time spent in the home (i.e., when did the person come to the home), and a few questions about cancer (e.g., did any type develop, and if so, when was it discovered and what type).

Although only a single water sample was analyzed for its radon content from each home, radon concentration in groundwater is thought to usually show variation below a factor of two (Prichard and Gesell 1981). Precipitation and recharge rates affect the radon concentration in ground water, so radon tends to decrease during high precipitation periods and increase during drought periods. However, precipitation in the study area tends to occur thoughout the year. Studies now in progress will serve to determine if the level of groundwater radon variation in the study area is small, but preliminary data suggest that the variation is indeed below a factor of two.

The homeowners who obtained the test kit also filled out a post-test questionnaire about the water supply to the home (e.g., from where is the water obtained, if from a well how deep and how far away is the well, is the water treated, and if so how, etc.). Several studies have noted that well water radioactivity increases with the depth of the well (Smith et al 1961, Bean et al 1982, Cech et al 1988a and 1988b), and we anticipate commenting upon this observation using data from our study. However, the present report is confined to a comparison between radon and cancer, without reference to the well depth and to other physical and chemical properties.

Since there had been no testing of water for its radon concentration in the study area, and there had been almost no news media coverage about radon in water, the data shown later is not biased toward homes for which the homeowner had some prior data from their drinking water. In the introductory letter to all the participants, it was noted that drinking water can contain radon and radium, that some municipal systems contain these radionuclides, and that private well water often contains at least some radon and radium. This resulted in a data base in which about 70 percent of the homes have municipal water and 30 percent of the homes have private wells; in the study area, the actual portion of homes using private water wells is about 20 percent.

Results

In order to examine the possible relationship between radon in water and cancer, we made the assumption that the body reaches an equilibrium with its normal level of radon (and other radionuclides) consumed by drinking water. We assumed, as discussed in Prichard and Gesell (1981), that radon and other radionuclides act in concert with other carcinogens to produce the cancers. We assumed that radon and other dissolved radionuclides move throughout the body, and while it is perhaps not possible to know what fraction of these radionuclides decay before being removed from the body, this natural radiation could contribute in a measurable way to the development of cancer.

The number of deaths from cancer in the U.S. has doubled since 1950, from about 200,000/year to 400,000/year, and has increased an estimated 10-fold since 1900 (Moolenaar, 1988). This observation is largely responsible for the upsurge in public fear and environmental regulation. However, most of the increase in cancer mortality is due to the growth in the U.S. population. Also, cancer is largely a disease of old age, and the only major cause of cancer mortality that has increased in cases per 10,000 population since 1950 is lung cancer, which is believed to be largely due to smoking. Cancer mortality, adjusted for increasing population and age, and exclusive of respiratory cancer, has decreased by about 10% since 1950, and now stands at about 10/year per 10,000 population. The mortality is about equally divided between breast, digestive and gland cancer (Moolenaar 1988).

The identification of natural and industrial-age carcinogens has proven successful when high carcinogen levels are present. The currently used no-threshold model of chemical carcinogenesis, in which mortality at high exposure levels is extrapolated to estimate mortality at lower levels, has resulted in public health policies implimented in the absense of certainty on the scientific judgements. Current U.S. Environmental Protection Agency policy on indoor radon is currently the most widely known example of high-to-low extrapolated risk estimates.

In most respects, the use of mortality estimates based on low exposure estimates found in the general population are more widely accepted. The radon-in-water data reported in this paper are measurements that were accumulated in 1988 and 1989, using water taps in area homes. In these more than 1000 homes, there about 2,500 occupants. However, data from about 35 homes were not used due to problems in the sampling procedure or in the questionnaire accuracy. Also, all individuals who had lived in their present home for less than 5 years were not counted. Consequently, the following figures are based on the results for 794 home occupants who used municipal water, and 484 people who used well water. The correlations between cancer and radon level in drinking water are based on tabulations of all types of cancers taken together.

Of the many variables involved in a study of this type, the two most significant are the effect of increasing age, which is associated with higher rates of cancer, and increasing radon in drinking water, which may be also related to higher rates of cancer. In this particular study, the effect of increasing age is obvious (Fig. 1). In this and subsequent figures, the "age" of test participants who have not developed cancer is their age when they filled out their questionnaire, and the "age" of the people with cancer is the age at which the cancer was discovered).

To examine in more detail the relationship between increasing age and cancer, the participants were divided into three groups according to the radioactivity of their drinking water. The first group was composed of study participants using municipal water, which was found to contain less than 100 pCi/l. A compilation of all water radon measurements from homes that use a private water well showed that the average well water radon concentration was about 2,500 pCi/l (Fig. 2). In the following figures, the cancer verses radon compilations will be made using municipal water (0 to 100 pCi/l), low-radon well water (100 to 2,500 pCi/l) and high-radon well water (2,500 to 25,000 pCi/l).

The population that consumed municipal water clearly showed the effect of increasing age (Fig. 3). The age effect was less pronounced in the population that consumed low-radon well water (Fig. 4), but the age effect increased again in the population that consumed high-radon well water (Fig. 5).

The cancers that were counted in this study include many types: bladder, bone, breast, colon, esophagus, gastric, kidney, liver, lung (in non-smokers), lymph nodes, pancreas, prostate, thyroid, skin, and uterus. This approach is similar to that of Hess and others (1982, 1983), who found a significant correlation for all cancers together verses county averages for radon in water. In order to determine if the three types of water (municipal, low-radon well water, high-radon well water) carried cancer incidences that might be related to increasing radon in drinking water, the cancer rate for each type of water was compiled (Fig. 6). The data indicate that high radon well has the highest incidence of cancer, when all types of cancer are compiled together. A similar pattern emerged when only the more common types of cancer were compiled (Fig. 7).

The significance of the observation that high-radon well water carries a higher incidence of cancer would be diminished if this subset of the study group was composed of a significantly older population. The average ages of the three populations in which cancer was not detected were very similar, but the three populations in which cancer was detected showed differences (Fig. 8). Based on the expectation that the incidence of cancer increases as people age, Fig. 8 would be expected to show that the municipal water population should have a higher rate of cancer than the high-radon well water population. This is not what occurs. Although the high-radon well water group has a lower average age than the municipal water population, the high-radon well water group has a considerably higher incidence of cancer (compare Fig.s 7 and 8).

To determine if the study population shows a similar cancer verses water radon relationship for people of different ages, the population was divided into groups who were 5 to 25 years of age, 26 to 50 years of age, and over 50 years of age. In the group of people who are 5 to 25 years of age, there is no significant correlation between the type of water consumed and the incidence of cancer (Fig. 9). In the group of people who are 26 to 50 years of age, the incidence of cancer is again low, except in the subset that consumes high-radon well water (Fig. 10). In the group of people who are over 50 years of age, the cancer rates are all increased, as would be expected due to aging. However, as was found for the 26 to 50 years old group, the cancer rate for the high-radon well water people greatly exceeded the rate for the low-radon well water people (Fig. 11).

Discussion

It is possible to make comparisons between the incidence of cancer related to radon ingested while drinking well water and the incidence of lung cancer related to inhaling airborne radon. In the study area, the average first floor indoor radon concentration is about 3 pCi/l (Mose and Mushrush 1988). If we assume that an average person spends their time in locations whose radon concentrations are such that their average radon exposure is about 3 pCi/l, we could conclude from US-EPA estimates that only about 1-2 deaths out of 100 deaths will be due to indoor radon. This corresponds to about 1-2 indoor radon related deaths per 10,000 people.

According to the data gathered in this study (Fig. 6), consumption of high-radon well water can be correlated with an excess (above municipal water) cancer rate of about 100 to 200 cases per 10,000 people who consume high-radon well water. Since only about 10% of the population uses private water wells in this rapidly growing area in northern Virginia and southern Maryland, and only half these water wells supply drinking water above 2,500 pCi/l, the high-radon water supplies would cause an additional (i.e., above municipal water level) cancer incidence in the entire population of about 5 to 10 cases per 10,000 people.

In short, although only about 10% of the population consumes high-radon well water, the incidence of cancer in the study area appears to be about 5 times greater from ingesting water than from inhaling indoor radon. In a similar area where a greater part of the population uses private wells, the radon in the drinking water would be associated with an even greater incidence of cancer.

Conclusions

The airborne radon inside a home originates from the geological material beneath the home, as does the radon in the water of homes with private water wells. The only difference is that the radon in well water originates from somewhat deeper geological material beneath the home. Differences in weather, home use and home design strongly influence indoor radon derived from the soil, but these factors probably do not significantly influence the quantity of radon in the home water supply, nor the rate at which dissolved radon escapes the home water supply. Our study of indoor radon in Virginia and Maryland shows that the indoor radon concentrations are almost all between 1 and 25 pCi/l (Mose and Mushrush 1988). Municipal water supplies provide potable water at less than 100 pCi/l. Radon in drinking water for private wells ranges from about 100 pCi/l to about 25,000 pCi/l.

Several studies have shown that the concentration of radium in drinking water can be correlated with the incidence of cancer, and it is generally true that water enriched in radium is also enriched in radon. A few studies have shown that the concentration of radon in drinking water can be correlated with the incidence of lung cancer, but the process of lung cancer development described in these reports is one of inhalation. It was proposed in these papers that the outgassing of domestic water enriched in radon adds to the indoor radon concentration, which in turn is thought to increase the rate of lung cancer.

The compilations of cancer incidence and radon concentration in drinking water which we present in this paper indicate that a homeowner with a typical indoor radon level of about 3 pCi/l and a typical waterborne radon of more than 2,500 pCi/l is more at risk from the water than from the airborne radon. Pending more definative data, we suspect that radon enriched water could be related to the incidence of other cancers. This would include lung cancers that are being attributed to airborne radon, since radon consumed by drinking well water is lost mainly by exhalation.

It now appears that the ingestion of radon enriched water is a health concern, but much remains unclear. Both radon and radium carried by ingested water can move throughout the body, to produce an effect at many cancer prone sites. Studies cited earlier indicate that radium can be a cause of many types of cancer, and that radium and radon are often both found in groundwater. It is possible that radon is merely a "flag" for radium or some other groundwater component, but a useful flag because the measurement of dissolved radon is quick and inexpensive. On the other hand, it may be that the carcinogen is simply radon. Presumably the radon, as well as the other carcinogens, are all at some equilibrium concentration in the body, but the radon can more easily enter into well water, and is often 10 to 1000 times more concentrated than radium.

As in most investigations, thoughtful precautions and additional data are often useful. In our study, we provide indoor radon monitors and we encourage homeowners with private water supplies to obtain a measurement of the radon concentration in their water. In homes with an indoor radon concentration that the homeowner views as representing an unreasonable risk, we suggest that they reduce the airborne radon with the use of sub-slab ventilation. Similarly, in homes with unreasonably high radon concentrations in the drinking water, we suggest the installation of a charcoal water purification system. Unfortunately for the general population, the perception of what represents an unreasonable risk depends on many factors, only one of which is advice. At this stage of public awareness policy, airborne radon is clearly more discussed than waterborne radon. We suggest, pending the gathering of additional data of the type compiled in this report, that radon in both air and water be equally cited by public health officials.

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Figure Captions

1. Percentage of the study population that developed cancer, using study subgroups based on participant age. In this and the subsequent Figures, all cancers were counted, and all the study participants had lived in their home for at least 5 years.

2. Compilation of well water radon measurements, derived from outlets commonly used for drinking water.

3. Percentages of the study population consuming municipal water (less than 100 pCi/l) that developed cancer, using study subgroups based on the age of each subgroup.

4. Percentages of the population consuming 100-2,500 pCi/l well water that developed cancer, using subgroups based on age.

5. Percentages of the population consuming 2,500-25,000 pCi/l well water that developed cancer, using subgroups based on age.

6. Percentages of the study population that developed cancer, using study subgroups based on the type of home water supply.

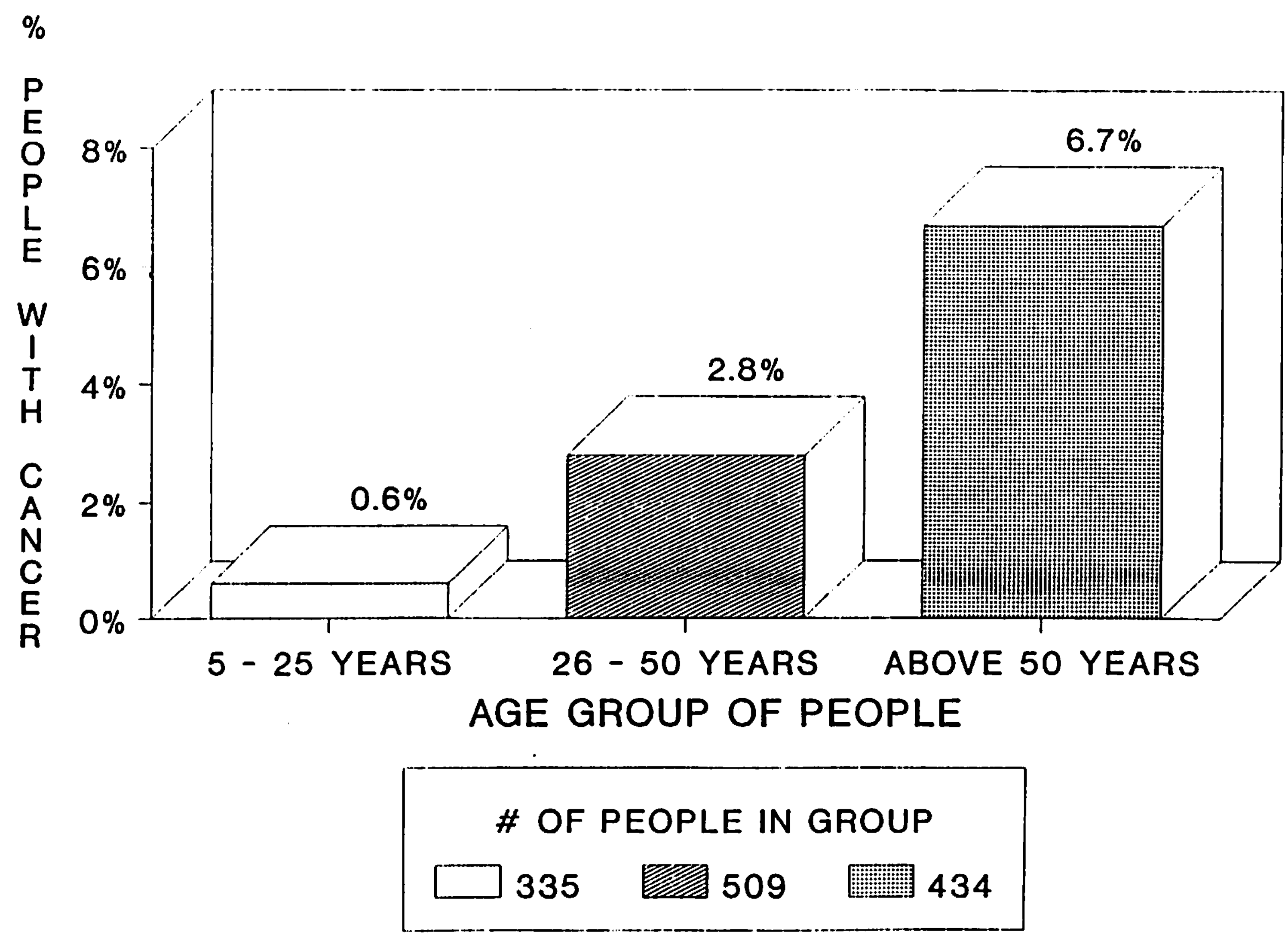
7. Percentages of the study population that developed the more common types of cancer, using subgroups based on the type of home water supply.

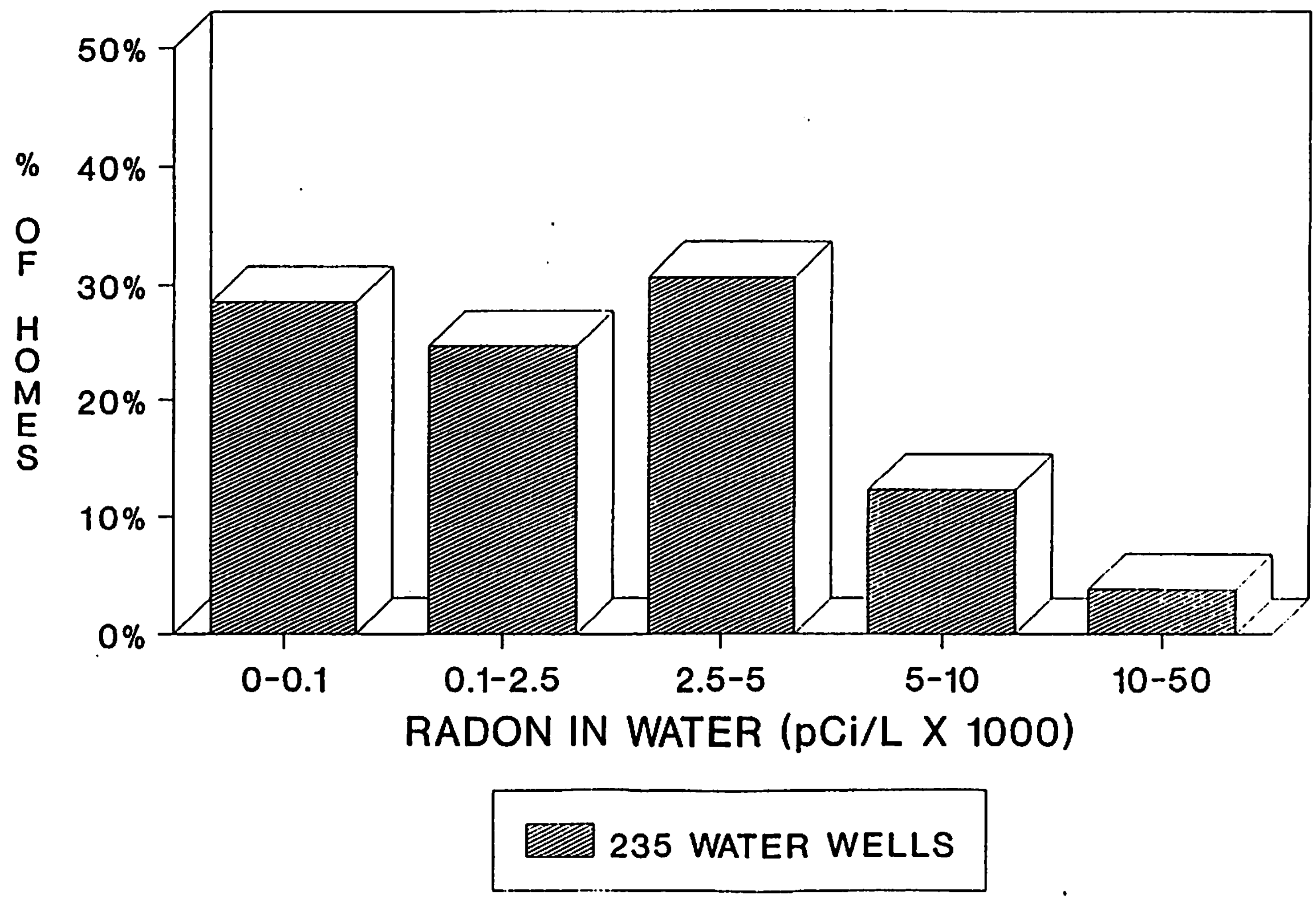
8. Average ages of the study population, using subgroups based on the type of home water supply.

9. Percentages of people in the 5 to 25 years old subgroup that developed cancer, using subgroups based on the type of home water supply.

10. Percentages of people in the 26 to 50 years old subgroup that developed cancer.

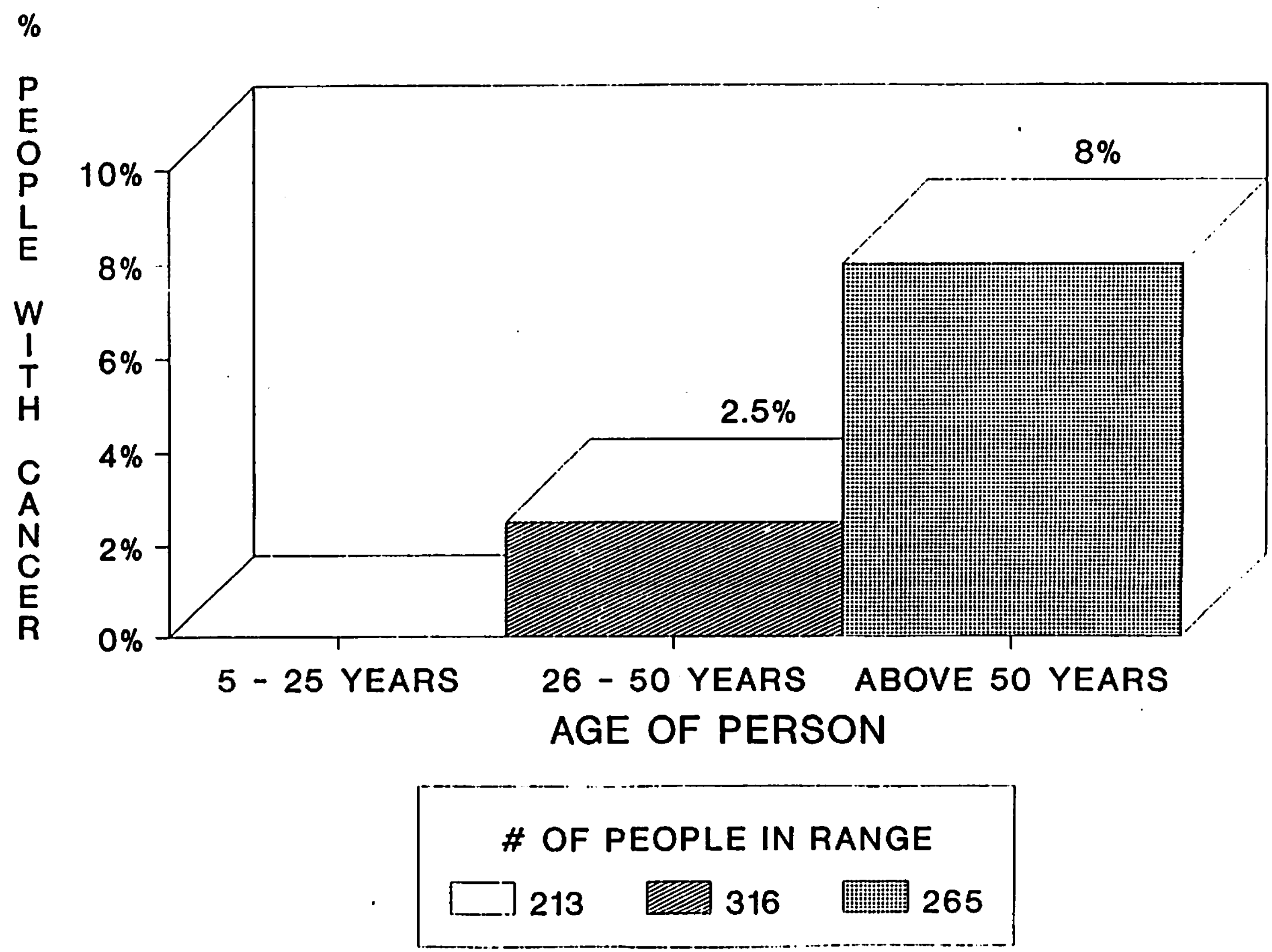
11. Percentages of people over 50 years of age that developed cancer.


% PEOPLE WITH CANCER
8%
6%
4%
2%
0%
0.6%
2.8%
6.7%
5 - 25 YEARS
26 - 50 YEARS
ABOVE 50 YEARS
AGE GROUP OF PEOPLE
OF PEOPLE IN GROUP
335
509
434



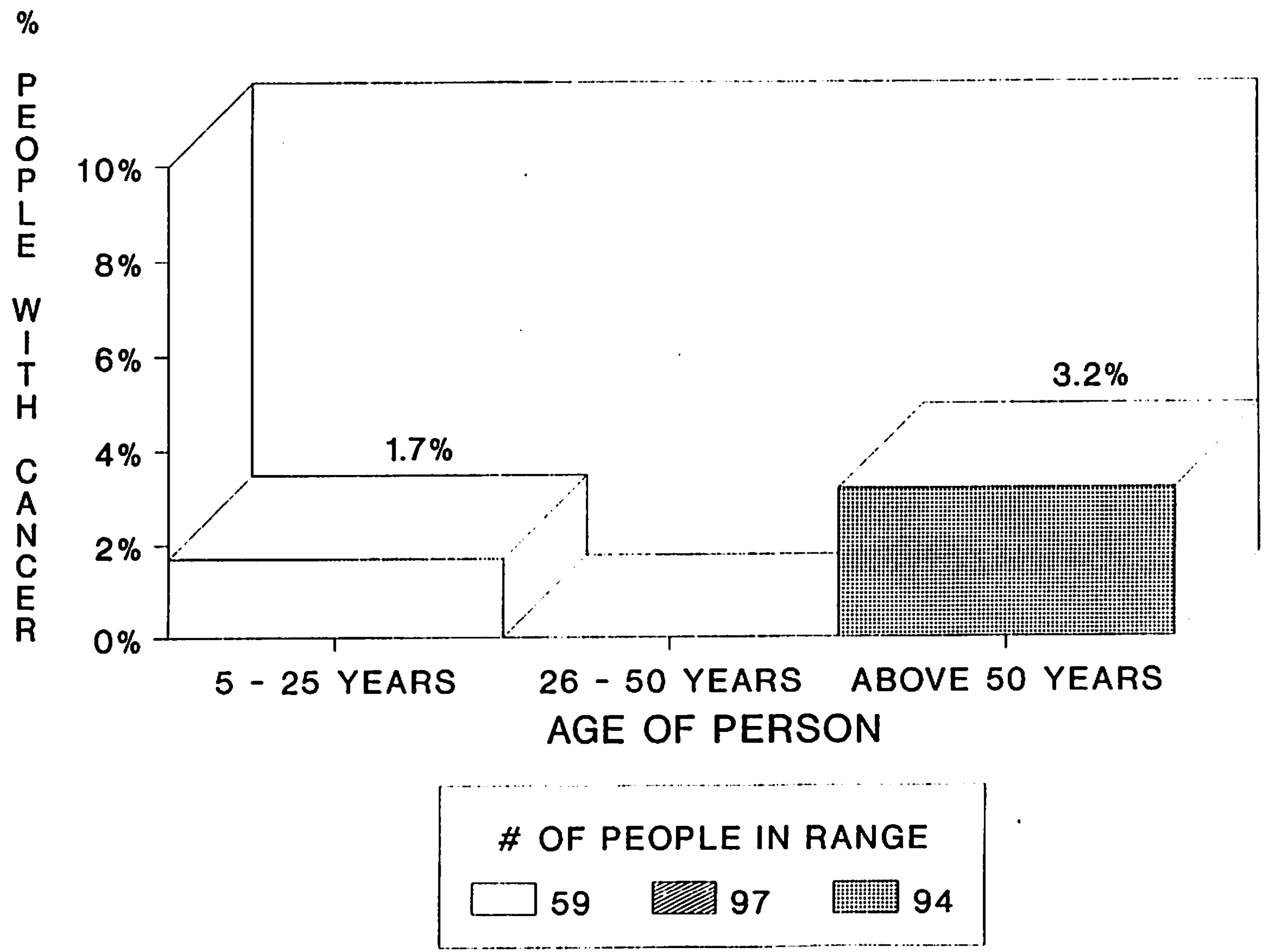
% OF HOMES
50%
40%
30%
20%
10%
0%
0-0.1
0.1-2.5
2.5-5
5-10
10-50
RADON IN WATER (pCi/L X 1000)
235 WATER WELLS

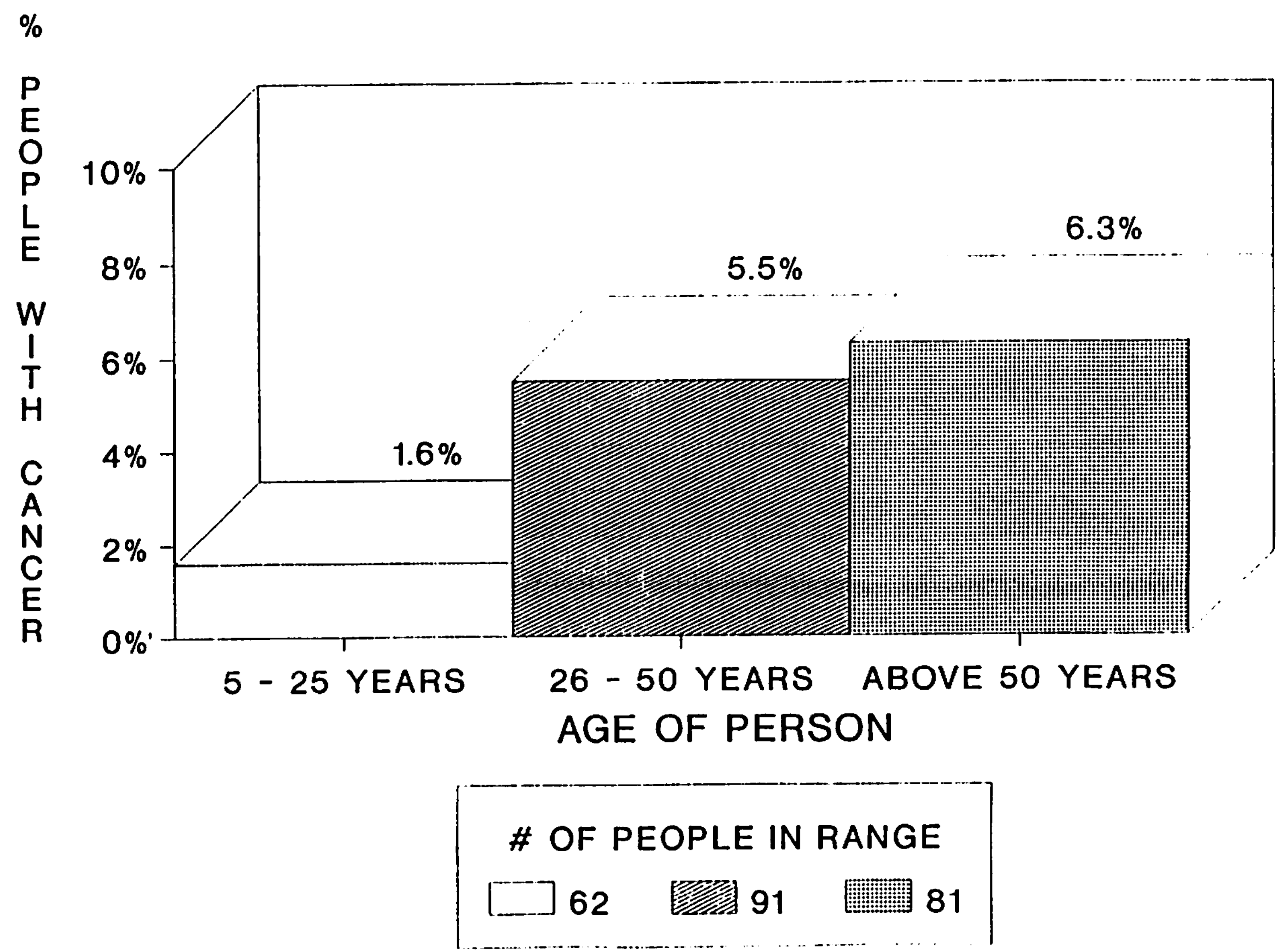
(2)



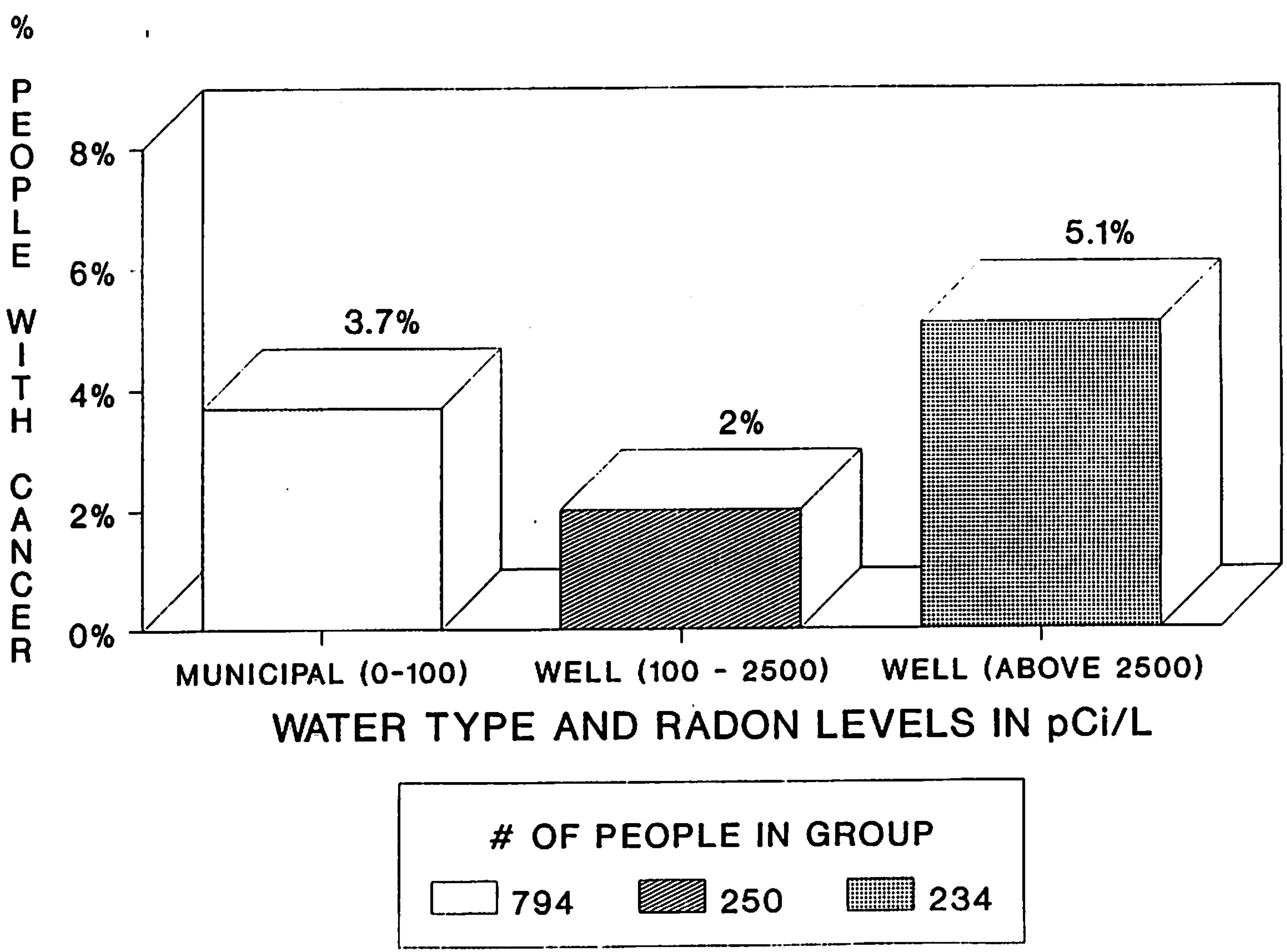
% PEOPLE WITH CANCER
10%
8%
6%
4%
2%
0%
2.5%
8%
5 - 25 YEARS
26 - 50 YEARS
ABOVE 50 YEARS
AGE OF PERSON
OF PEOPLE IN RANGE
213
316
265

(3)

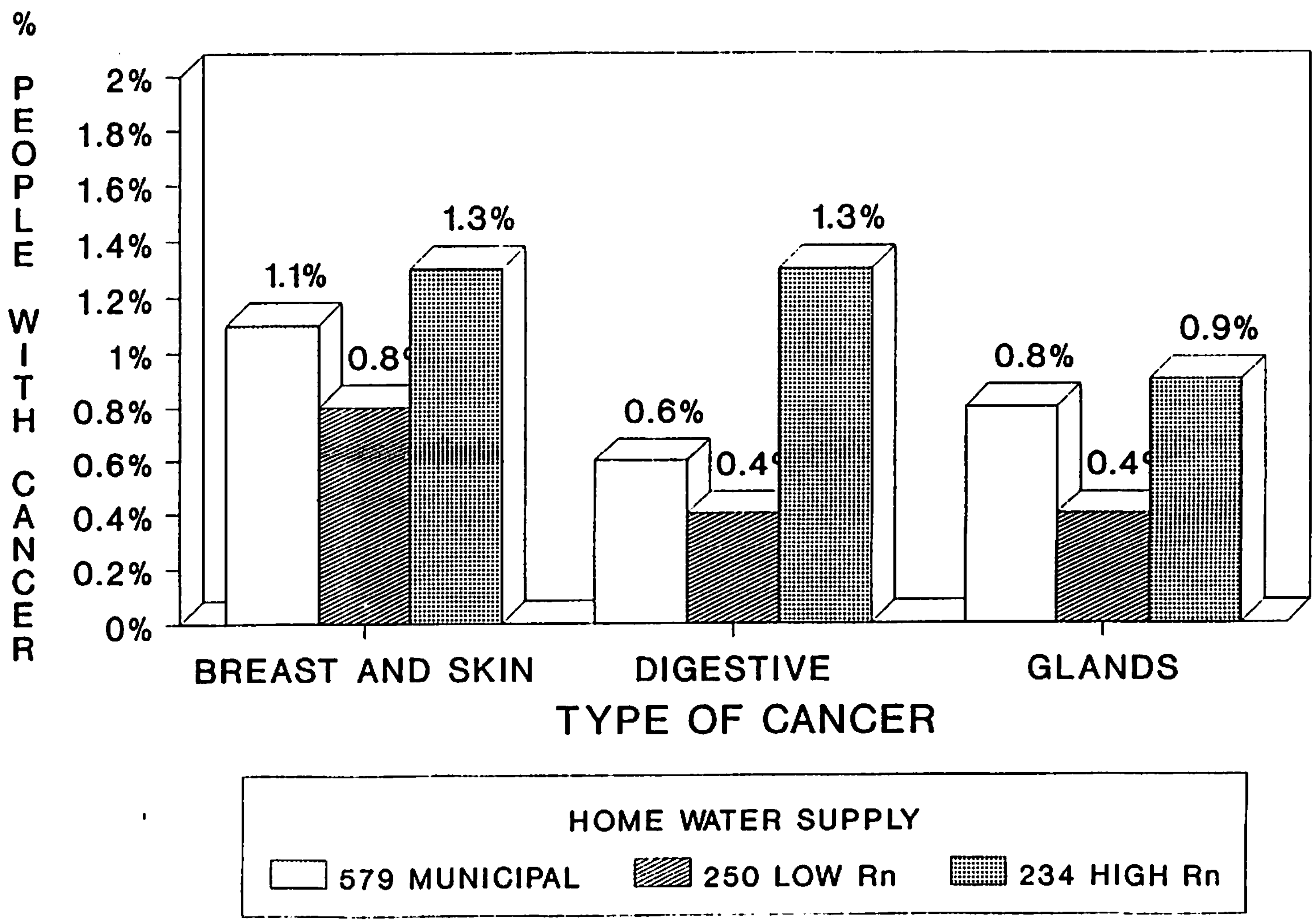

% PEOPLE WITH CANCER
10%
8%
6%
4%
2%
0%
1.7%
3.2%
5 - 25 YEARS
26 - 50 YEARS
ABOVE 50 YEARS
AGE OF PERSON
OF PEOPLE IN RANGE
59
97
94



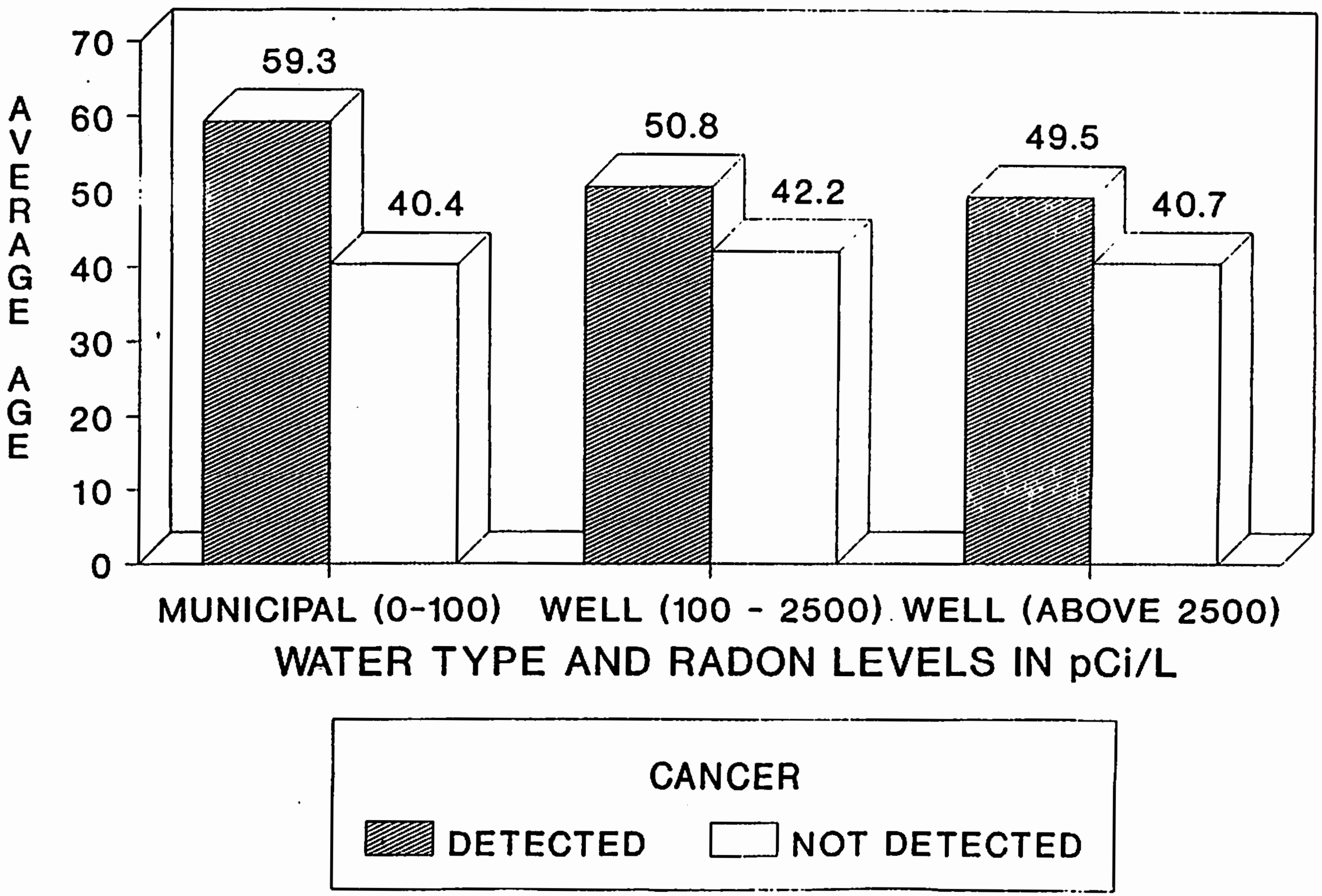
% PEOPLE WITH CANCER
10%
8%
6%
4%
2%
0%
1.6%
5.5%
6.3%
5 - 25 YEARS
26 - 50 YEARS
ABOVE 50 YEARS
AGE OF PERSON
OF PEOPLE IN RANGE
62
91
81



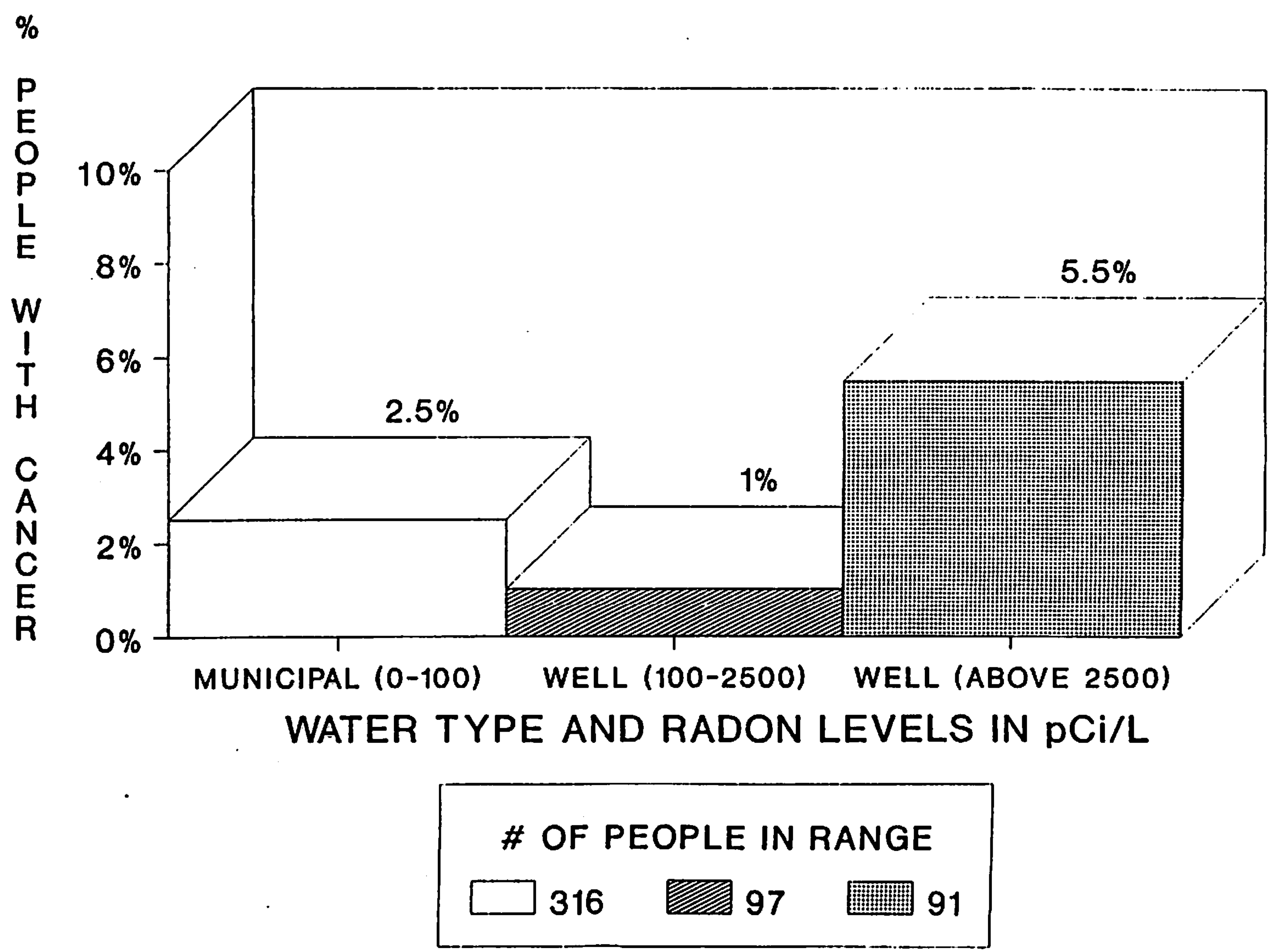
% PEOPLE WITH CANCER
8%
6%
4%
2%
0%
3.7%
2%
5.1%
MUNICIPAL (0-100)
WELL (100 - 2500)
WELL (ABOVE 2500)
WATER TYPE AND RADON LEVELS IN pCi/L
OF PEOPLE IN GROUP
794
250
234



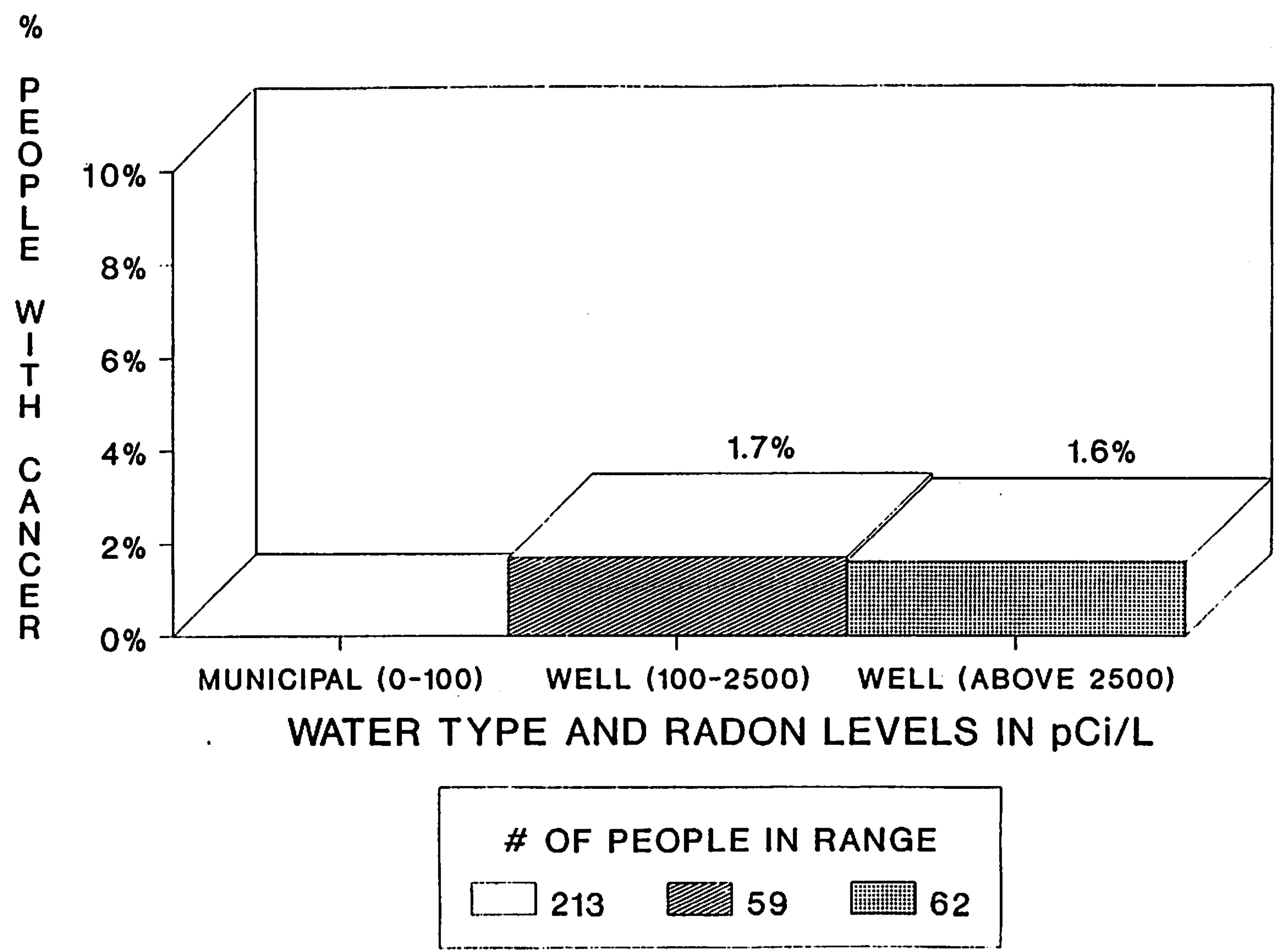
% PEOPLE WITH CANCER
2%
1.8%
1.6%
1.4%
1.2%
1%
0.8%
0.6%
0.4%
0.2%
0%
1.1%
0.8%
1.3%
0.6%
0.4%
1.3%
0.8%
0.4%
0.9%
BREAST AND SKIN
DIGESTIVE
GLANDS
TYPE OF CANCER
HOME WATER SUPPLY
579 MUNICIPAL
250 LOW Rn
234 HIGH Rn

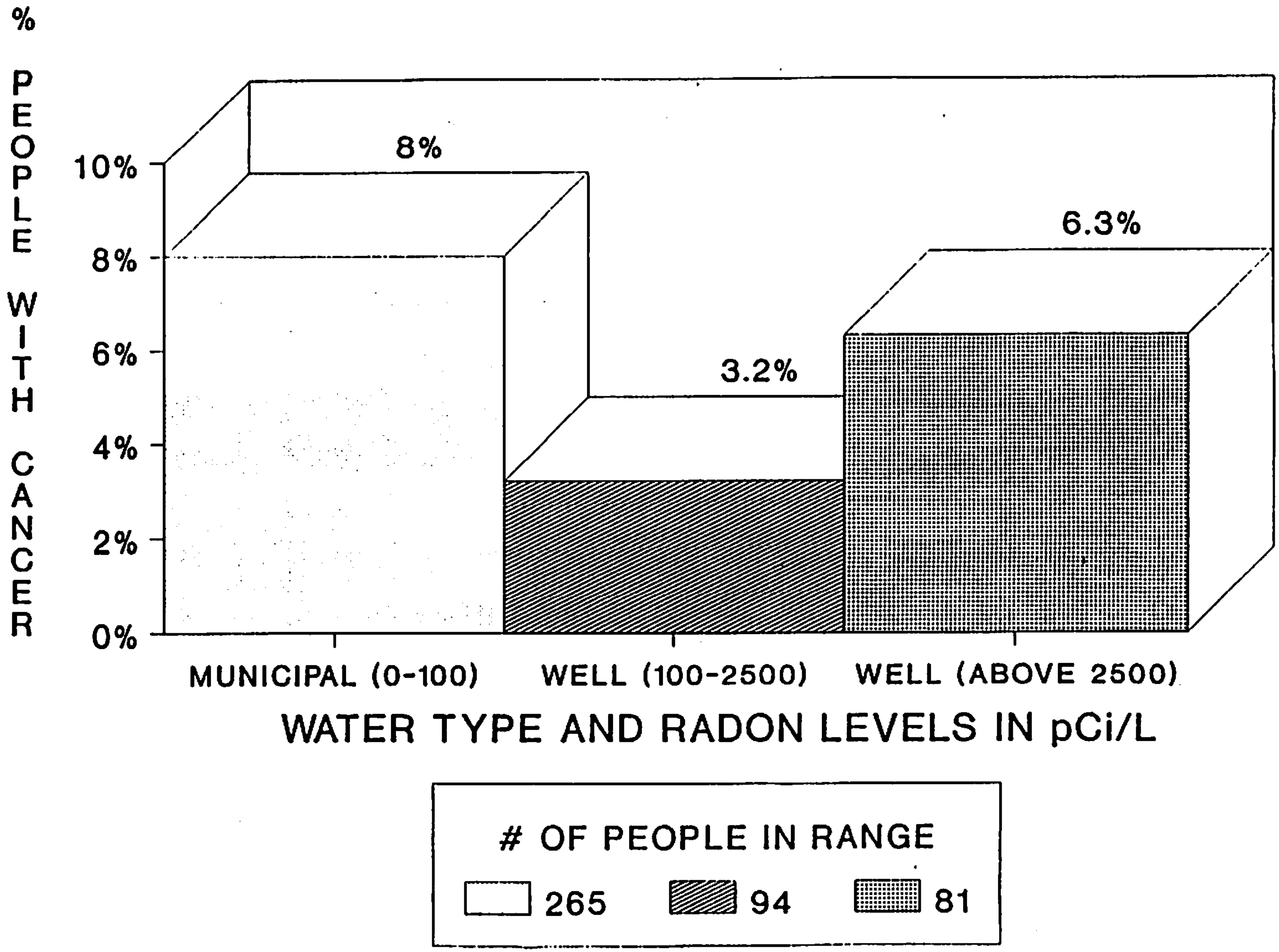


AVERAGE AGE
70
60
50
40
30
20
10
0
59.3
40.4
50.8
42.2
49.5
40.7
MUNICIPAL (0-100)
WELL (100 - 2500)
WELL (ABOVE 2500)
WATER TYPE AND RADON LEVELS IN pCi/L
CANCER
DETECTED
NOT DETECTED



% PEOPLE WITH CANCER
10%
8%
6%
4%
2%
0%
2.5%
1%
5.5%
MUNICIPAL (0-100)
WELL (100-2500)
WELL (ABOVE 2500)
WATER TYPE AND RADON LEVELS IN pCi/L
OF PEOPLE IN RANGE
316
97
91


% PEOPLE WITH CANCER
10%
8%
6%
4%
2%
0%
1.7%
1.6%
MUNICIPAL (0-100)
WELL (100-2500)
WELL (ABOVE 2500)
WATER TYPE AND RADON LEVELS IN pCi/L
OF PEOPLE IN RANGE
213
59
62


% PEOPLE WITH CANCER
10%
8%
6%
4%
2%
0%
8%
3.2%
6.3%
MUNICIPAL (0-100)
WELL (100-2500)
WELL (ABOVE 2500)
WATER TYPE AND RADON LEVELS IN pCi/L
OF PEOPLE IN RANGE
265
94
81