Probabilities of Eventually Developing and of Dying of Cancer
(Risk among persons previously undiagnosed with the cancer)

Herbert Seidman, M.B.A., Edwin Silverberg, B.S. and Ashley Bodden

The risk of developing or dying of cancer is usually presented as observations of annual incidence or deaths, giving a picture for the immediate future. However, exposures to carcinogenic agents have long-term effects and what is more important is the accumulation of risks over greater periods of time—10, 20 or more years. Using life table procedures, the annual figures can be extended to calculate such accumulations. Whether a person will develop or die of cancer during the intervals is then dependent on the interplay of two forces at various ages: (1) the cancer frequency and (2) the rate of removal from further risk of cancer by competitive causes of death. Some previous analyses of the probabilities of eventually developing cancer include that by Cutler and Haenszel, based on the National Cancer Institute 1947 Cancer Morbidity Survey, and those based on the New York State Cancer Registry.14

The life table procedures assume that the rates of cancer and of total deaths for the various age groups in a given chronologic period will prevail throughout the future lifetime of a person as he advances in age. Since these may not be the rates which will prevail at the time he does attain a given age, the probabilities should be regarded only as approximations of the actual ones.

In this paper, “developing” cancer means being diagnosed as having cancer. The probabilities presented are influenced by the capability of detecting the disease at particular times. The deaths from cancer are those in which cancer was coded as the underlying cause based on information on the death certificate; the deaths in which cancer was present but not specified as the underlying cause are not included. There are sometimes discrepancies in the recording of site of cancer between the morbidity surveys and the death certification. In addition, the deaths are referable not only to the cancer cases diagnosed in the given year, but also to cases diagnosed in previous years. Thus the difference between those eventually developing and those eventually dying of cancer cannot be construed to be those “cured” or those free of cancer at time of death, though one would anticipate that for highly lethal cancers, the two measures would be close to one another.

Material
The probabilities of developing cancer presented in this paper are based on age-, race-, and sex-specific incidence rates

Mr. Seidman is Chief, Statistical Analyses, Department of Epidemiology and Statistics, Department of Research, American Cancer Society, New York, New York. Mr. Silverberg is Project Statistician, Department of Epidemiology and Statistics, Department of Research, American Cancer Society, New York, New York. Mr. Bodden is Programmer Analyst, Department of Epidemiology and Statistics, Department of Research, American Cancer Society, New York, New York.
| Site               | White Male         | Nonwhite Male       | White Female       | Nonwhite Female     |
|--------------------|--------------------|---------------------|--------------------|--------------------|
|                    | 1950    | 1970    | 1970    | 1950    | 1970    | 1970    | 1950    | 1970    | 1970    | 1950    | 1970    | 1970    |
|                    | Exc. in | Inc. in | ca in situ | Exc. in | Inc. in | ca in situ | Exc. in | Inc. in | ca in situ | Exc. in | Inc. in | ca in situ |
| All Cancer*        | 23.3%   | 26.2%   | 26.3%   | 15.4%   | 23.3%   | 23.4%   | 28.2%   | 27.4%   | 29.8%   | 19.5%   | 21.5%   | 25.5%   |
| Buccal & Pharynx   | 1.9     | 1.3     | 1.5     | 0.7     | 0.9     | 0.9     | 0.7     | 0.6     | 0.6     | 0.4     | 0.5     | 0.5     |
| Esophagus          | 0.8     | 0.4     | 0.4     | 0.6     | 1.1     | 1.1     | 0.2     | 0.2     | 0.2     | 0.2     | 0.3     | 0.3     |
| Stomach            | 3.1     | 1.2     | 1.2     | 2.7     | 1.5     | 1.5     | 2.4     | 0.9     | 0.9     | 1.9     | 1.0     | 1.0     |
| Colon & Rectum     | 4.4     | 4.4     | 4.5     | 1.8     | 2.8     | 2.9     | 5.0     | 5.1     | 5.2     | 2.3     | 3.5     | 3.6     |
| Pancreas           | 0.9     | 1.1     | 1.1     | 0.8     | 1.1     | 1.1     | 0.7     | 1.0     | 1.0     | 0.5     | 0.9     | 0.9     |
| Larynx             | 0.7     | 0.7     | 0.7     | 0.4     | 0.5     | 0.6     | 0.7     | 0.1     | 0.1     | 0.0     | 0.1     | 0.1     |
| Lung               | 2.5     | 5.9     | 5.9     | 1.7     | 5.7     | 5.8     | 0.7     | 1.6     | 1.6     | 0.4     | 1.3     | 1.3     |
| Female Breast      | —       | —       | —       | —       | —       | —       | 7.2     | 7.7     | 8.0     | 3.8     | 5.0     | 5.2     |
| Uterus             | —       | —       | —       | —       | —       | —       | 5.3     | 3.8     | 6.5     | 6.6     | 4.2     | 8.8     |
| Ovary              | —       | —       | —       | —       | —       | —       | 1.4     | 1.5     | 1.5     | 0.7     | 0.9     | 0.9     |
| Prostate           | 3.5     | 4.8     | 4.9     | 3.4     | 5.8     | 5.8     | —       | —       | —       | —       | —       | —       |
| Kidney             | 0.5     | 0.7     | 0.7     | 0.3     | 0.5     | 0.5     | 0.3     | 0.5     | 0.5     | 0.2     | 0.3     | 0.3     |
| Bladder            | 1.7     | 2.0     | 2.0     | 0.5     | 0.8     | 0.8     | 1.0     | 0.8     | 0.8     | 0.7     | 0.4     | 0.4     |
| Leukemia           | 0.7     | 1.1     | 1.1     | 0.6     | 0.7     | 0.7     | 0.6     | 0.9     | 0.9     | 0.2     | 0.5     | 0.5     |
| Lymphoma           | 1.1     | 1.5     | 1.5     | 0.6     | 1.1     | 1.1     | 0.9     | 1.2     | 1.2     | 0.5     | 1.1     | 1.1     |

*Exclusive of non-melanoma skin cancer.
per 100,000 population from morbidity studies conducted by the National Cancer Institute in 1947 and in 1969-1971. These rates are not necessarily completely representative of the rates for the whole U.S. population, but they are the best available. The 1947 incidence rates were used in conjunction with U.S. life tables and mortality for 1949-1951 to calculate the "1950" probabilities. The 1969-1971 incidence rates were used in conjunction with U.S. life tables and mortality for 1969-1971 to calculate the "1970" probabilities. For 1969-1971, incidence rates were available only for the black population component of the total non-white population. Since the blacks comprised such a predominant part of the total non-whites, the rates for blacks can be regarded as essentially equivalent to those for the total non-whites.

In accordance with the 1969-1971 morbidity survey, non-melanoma skin cancer is not included in these calculations. We adjusted the 1947 over-all cancer incidence rates to this concept by subtracting an estimate of the non-melanoma skin cancer incidence rates for 1947 from the over-all rates originally given. With the aid of unpublished data very kindly supplied by Mr. Frank W. McKay of the National Cancer Institute and Mrs. Mabel Smith of the National Center for Health Statistics, a similar adjustment was made to exclude deaths from non-melanoma skin cancer from the 1949-1951 and 1969-1971 cancer death figures.

In this report, "cancer" generally means "invasive cancer," which covers virtually all of the cancers detected in 1947, though hardly so in 1969-1971. For the 1970 data we have presented some findings on the probabilities of developing cancer in which "cancer" encompasses both invasive tumors and carcinoma in situ. We are indebted to Mr. Roger Connelly of the National Cancer Institute for providing us with the unpublished data which permitted us to perform the latter calculations. The two categories are usually regarded separately, though it may be very difficult to distinguish between carcinoma in situ and microinvasive lesions. However, it is presumed that invasive tumors are irreversible in their natural history while there is uncertainty as to how often carcinoma in situ will progress to invasion.

It may be that there were separate reports for the two categories for the same individual in the course of the 1969-1971 morbidity study period. The duplications should be inconsequential since the carcinoma in situ cases were followed for about four months to see if they should be reclassified as invasive cancers.

Method
The probabilities we present in this paper for a given form of cancer at a given age are for persons of that age not previously diagnosed with that form of cancer. For total cancer, only the first diagnosis of any form is considered. For particular forms of cancer, only the first diagnosis of that particular form is considered but the person remains eligible for developing another form. For example, after a woman develops cancer of the breast, a diagnosis of cancer in the other breast is disregarded, but she remains eligible to develop colorectal or another form of cancer.

In the procedures originated by Goldberg et al., the fact that their basic data was limited to a single cancer per individual permitted them to compute the number of newly developed cancer cases without separating the population at risk of cancer into those with and without prior diagnoses of cancer. However, the morbidity survey data do include multiple primary cancers. For example, 181,027 primary invasive non-melanoma cancers were diagnosed during 1969-1971 among 177,504 survey area residents. We, therefore, devised our own method to calculate the required results.

Each form of cancer for each of the race-sex groups (white males, white females, non-white males, and non-white females) for each of the time periods was treated as a separate entity in the following procedures. Calculations were carried out for age groups 0 to 1 year, 1 to 5 years and quinquennial age groups thereafter to the ter-
mination of the life table at age 110 years.

The subscripts and superscripts to the symbols we have employed have the following meanings:

- The left subscript denotes the number of years of the interval, if relevant.
- The right subscript denotes the age at start of an interval.
- The left superscript denotes the following:
  - o — Persons never with this cancer at start of interval.
  - c — Persons ever with this cancer at start of interval.
  - oc — Persons never with this cancer at start of interval who developed this cancer during interval.

Blank — Total persons at start of interval, if relevant.

- The right superscript denotes the following:
  - o — Died of causes other than this cancer.
  - c — Died of this cancer.

Blank — Total who died, if relevant.

The life tables provided the following values: \( l_x \) (the number of persons surviving to exact age \( x \) out of a cohort of 100,000 live births), and \( d_x \) (the number of deaths from exact age \( x \) to exact age \( x + n \)).

The morbidity studies provided the cancer incidence rates for age \( x \) to \( x + 5 \) which we term \( s_x \). The incidence rates specified as age 85 and over were used as quinquennial age group rates from age 85 on. Such limited data as are available suggest that the cancer rates are higher for age group 85-89 and decline thereafter. However, this can have but very small effect on our calculations.

The mortality data provided the proportions of cancer deaths out of total deaths from age \( x \) to \( x + n \), which we designate as \( r_x \). The proportions specified for 100 years and over were used as quinquennial age group proportions for ages 100-105 and 105-110.

The probability of developing a particular cancer from age \( x \) to age \( x + n \), \( g_x \), was calculated from the incidence rate, \( s_x \), through the hyperbolic relationship:

\[
\frac{(2n) (s_x)}{2 + (n) (s_x)}
\]

The life table deaths from this cancer from age \( x \) to \( x + n \), \( d_x \), were computed as:

\[
d_x = (s_x) (s_x) c
\]

The life table deaths not from this cancer from age \( x \) to \( x + n \), \( d_x \), were then:

\[
d_x = d_x - d_x
\]

Goldberg et al. noted that \( d_x \) included not only deaths among persons who had not developed this cancer, but also deaths from other causes among those who had. We have followed their assumption that, allowing for deaths from this cancer from age \( x \) to \( x + n \), those ever with this cancer at age \( x \) had the same risk of dying of other causes during the interval as those never with this cancer. We have done this as a practical matter though it is possible that in a specific situation the ever cancer group’s risk would be higher and in another situation the ever cancer group’s risk would be lower. We have also followed their assumption that deaths from this cancer occurred uniformly throughout the interval and that, on the average, those who died of this cancer from age \( x \) to \( x + n \) were exposed to the risk of dying of other causes for half of the interval and not exposed for half of the interval.

Henceforth, we proceed with the methods we have devised. The number of persons effectively exposed to the risk of dying of other causes at age \( x \) was the total number of persons at age \( x \) minus half of the cancer deaths from age \( x \) to \( x + n \). Consequently, for an effective person alive at age \( x \), \( q_x \), the probability of dying from other causes from age \( x \) to \( x + n \), was:

\[
q_x = d_x + (l_x - \frac{1}{2} s_x d_x)
\]

The corresponding probability of not dying from other causes from age \( x \) to \( x + n \), \( p_x \), was:

\[
p_x = 1 - q_x
\]
### Table 2

**Probability at Birth of Eventually Dying of Cancer of Major Sites by Race and Sex, United States, 1950 and 1970**

| Site               | White Male 1950 | White Male 1970 | White Female 1950 | White Female 1970 | Non-white Male 1950 | Non-white Male 1970 | Non-white Female 1950 | Non-white Female 1970 |
|--------------------|-----------------|-----------------|-------------------|-------------------|---------------------|---------------------|-----------------------|-----------------------|
| All Cancer*        | 13.4% 16.9%     | 9.5% 15.3%      | 15.3% 15.9%       | 10.9% 13.4%       |
| Buccal & Pharynx   | 0.5 0.5         | 0.3 0.5         | 0.2 0.2           | 0.1 0.2           |
| Esophagus          | 0.4 0.4         | 0.5 0.7         | 0.1 0.2           | 0.1 0.2           |
| Stomach            | 2.0 0.9         | 1.9 1.3         | 1.5 0.7           | 1.2 0.8           |
| Colon & Rectum     | 2.2 2.3         | 1.0 1.5         | 2.9 2.8           | 1.4 2.0           |
| Pancreas           | 0.7 1.0         | 0.4 0.8         | 0.6 0.9           | 0.3 0.8           |
| Larynx             | 0.2 0.2         | 0.1 0.2         | 0.0 0.0           | 0.0 0.0           |
| Lung               | 1.8 4.9         | 1.0 4.1         | 0.5 1.2           | 0.3 1.0           |
| Female Breast      | — —             | 2.7 3.0         | 1.5 2.2           |
| Uterus             | — —             | 2.0 1.1         | 3.0 2.0           |
| Ovary              | — —             | 0.8 1.0         | 0.4 0.7           |
| Prostate           | 1.6 1.7         | 1.5 2.3         | — —               |
| Kidney             | 0.3 0.4         | 0.1 0.2         | 0.2 0.3           | 0.1 0.2           |
| Bladder            | 0.6 0.6         | 0.3 0.4         | 0.4 0.3           | 0.2 0.3           |
| Leukemia           | 0.6 0.8         | 0.3 0.4         | 0.5 0.7           | 0.2 0.4           |
| Lymphoma           | 1.0 1.1         | 0.5 0.7         | 0.8 0.9           | 0.4 0.6           |

*Exclusive of non-melanoma skin cancer.*
To determine the probability that a person ever with this cancer during the interval would die of other causes, it was necessary to take into account the fact that death from this cancer terminated the risk of death from other causes. This was done by subtracting half of the probability of dying of this cancer multiplied by \( nq^2 \) from \( q^2 \).

However, a person who was never with this cancer at the start of the interval and who remained never with this cancer during the interval had zero probability of dying of this cancer and therefore, \( nq^2 \) was his probability of dying during the interval.

The number of life table survivors never with this cancer at age \( x+n \), \( q_{ix+n} \), was then computed from \( q_{ix} \), starting with \( q_0 = l_0 \), from the fact that the survivors at age \( x+n \) never with this cancer were those never with this cancer at age \( x \) who survived \( n \) years without developing this cancer, or:

\[
q_{ix+n} = (q_0)(q_{ix})(1-nq_x) \\
\text{(subject to the adjustment discussed in Appendix II).}
\]

Then, the number of life table survivors ever with this cancer at age \( x+n \), \( c_{ix+n} \) was:

\[
c_{ix+n} = l_{ix+n} - q_{ix+n} \\
\text{(subject to the adjustment discussed in Appendix II).}
\]

We have followed the assumption of Goldberg et al. that cases of this cancer and deaths from other causes occurred uniformly from \( x \) to \( x+n \). In our procedures, the number of cases of this cancer developing during the interval among those never with this cancer at age \( x \), \( \alpha_{ax} \), was the number of persons at age \( x \) multiplied by the probability of not dying of other causes prior to developing this cancer, multiplied by the probability of developing this cancer in \( n \) years. This was approximated by:

\[
c_{ax} = (q_x)(1-\frac{1}{2}nq^2)(\alpha q_x) \\
\text{(subject to the adjustment discussed in Appendix II).}
\]

The probability of developing this cancer in specified intervals of time by persons never with this cancer at age \( x \) was then computed by summing the number of cases of this cancer developing during the interval and dividing by \( q_{ix} \).

The probability of birth of dying of this cancer in specified intervals of time could be computed similarly by summing the number of deaths of this cancer during the interval and dividing by \( q_{ix} \).

However, for persons never with this cancer at ages other than birth, a more complicated procedure had to be constructed to determine the probabilities of dying of this cancer in various intervals of time. This computation, which gave identical results for the probabilities at birth, is outlined in Appendix I.

**PROBABILITY AT BIRTH OF EVENTUALLY DEVELOPING CANCER**

Table 1 shows the probability of eventually developing cancer of major sites from birth on for the 1950 to 1970 periods. In whites, in the 1970 figures, the chances of eventually developing any form of cancer were greater than one in four, and were close to one in four in non-whites. Except for the uterus and the totals of sites to which the uterus contributed, carcinoma in situ is seen as adding very little to the probabilities. Whether or not carcinoma in situ is included, white females showed the highest 1970 probabilities for all forms of cancer. However, the inclusion or exclusion of in situ cancer for white females in 1970 did determine whether there was a small increase to 30 percent or small decrease to 27 percent compared with the 28 percent for 1950. In non-white females, there was an increase in 1970 compared with the 20 percent for 1950, the magnitude of the increase depending on the inclusion or exclusion. The non-white males showed the largest increase of any of the race-sex groups, rising from 15 percent for the 1950 figures to 23 percent in 1970. For white males, the corresponding increase was 23 percent to 26 percent.

The changes in eventual probabilities are due not only to changes in the cancer
incidence rates but also to changes in the life table values which reflect the increases in life expectancy through declines in overall death rates. To show the effect introduced by changes in death rates from causes of death other than cancer, we computed probabilities of eventually developing cancer using the 1947 cancer incidence rates together with a life table constructed from 1949-1951 death rates for cancer except non-melanoma skin cancer and 1969-1971 death rates for causes of death other than such cancers. For white males this probability turned out to be 25.0 percent compared with the 1950 figure in Table 1 of 23.3 percent. The corresponding probabilities for the other race-sex groups were:

- non-white males: 17.2 percent and 15.4 percent;
- white females: 31.3 percent and 28.2 percent;
- non-white females: 23.3 percent and 19.5 percent.

Among both males and females, the sharpest increases in the eventual probabilities shown in Table 1 are those for lung cancer. With the continuing upward progression of the lung cancer rates in years subsequent to 1970, especially in females, the actual eventual probabilities of cancer of the lung are likely to be substantially higher than those indicated in Table 1.

In Table 1, in males, large increases in eventual probabilities are seen for cancer of the prostate, due both to increases in incidence rates and to gains in life expectancy, since this is mostly a disease of older men. In females, breast cancer shows the highest eventual probabilities in whites, and for invasive cancer in non-whites in the 1970 figures. Considering the probabilities added by carcinoma in situ, cancer of the uterus showed the highest probabilities among the non-white females.

There are difficulties in distinguishing between cancer of the cervix and cancer of the corpus in death certifications of cancer of the uterus in the United States. Since the death reports are essential to our procedures for computing eventual probabilities of developing cancer, we present findings only for total cancer of the uterus. It is evident in Table 1 that there were decreases in the eventual probabilities of cancer of the uterus being diagnosed in an invasive stage. The eventual probabilities of carcinoma in situ more than offset these decreases.

**PROBABILITY AT BIRTH OF EVENTUALLY DYING OF CANCER**

The chances at birth of eventually dying of cancer were over one in seven in the 1970 figures (Table 2). The eventual probabilities for white and non-white males exceeded those of their female counterparts, reversing the situation observable in the data for 1950. The lung cancer increase accounted for a large part of the total increase in eventual probabilities for males. For white females, the increase in the probability of eventually dying of cancer is due not to any increase in cancer death rates but to decreases in other causes of death. Thus using 1949-1951 death rates for cancer except non-melanoma skin in conjunction with 1969-1971 death rates from other causes, the eventual probability of dying of cancer for white females was calculated to be 17.6 percent; the analogous probability for white males was 14.5 percent; for non-white males it was 10.8 percent; and for non-white females it was 13.5 percent.

**PROBABILITY AT SELECTED AGES OF DEVELOPING CANCER WITHIN 10 YEARS, 20 YEARS, AND EVENTUALLY AMONG PERSONS WITHOUT PRIOR DIAGNOSIS OF THAT CANCER**

Table 3 shows, for the 1970 period, the probabilities at age 20, age 35, age 50 and age 65 of developing cancer of major sites within 10 years, 20 years, and eventually. Since most forms of cancer reach a really appreciable frequency only at middle ages or older, at age 20 the probability of developing invasive cancer within 20 years is only one or two percent. However,
| Site               | Sex, Race Group | Age 20 Years | Age 35 Years | Age 50 Years | Age 65 Years |
|-------------------|-----------------|--------------|--------------|--------------|--------------|
|                   |                 | 10%          | 20%          | 10%          | 20%          | 10%          | 20%          | 10%          | 20%          |
| All Invasive      | White Male      | 0.33%        | 0.90%        | 26.87%       | 3.86%        | 27.15%       | 4.93%        | 13.91%       | 27.12%       | 13.51%       | 22.85%       | 25.04%       |
| Cancer            | Nonwhite Male   | 0.24         | 0.82         | 24.49        | 1.25         | 5.00         | 25.93        | 6.48         | 15.85        | 27.48        | 14.85        | 24.00        | 26.28        |
|                   | White Female    | 0.41         | 1.53         | 27.84        | 1.91         | 6.08         | 27.51        | 5.50         | 12.64        | 25.32        | 9.04         | 16.76        | 19.70        |
|                   | Nonwhite Female | 0.48         | 1.79         | 22.21        | 2.11         | 5.88         | 22.02        | 4.94         | 11.00        | 20.37        | 8.27         | 14.25        | 16.68        |
| All Cancer        | White Male      | 0.33         | 0.91         | 27.03        | 0.96         | 3.89         | 27.31        | 4.97         | 14.04        | 27.29        | 13.62        | 22.96        | 25.17        |
| Including Ca In Situ | Nonwhite Male | 0.24         | 0.82         | 24.57        | 1.27         | 5.05         | 26.02        | 6.50         | 15.61        | 27.56        | 14.84        | 24.07        | 26.33        |
|                   | White Female    | 1.20         | 3.37         | 30.28        | 2.71         | 7.32         | 28.98        | 5.87         | 13.24        | 26.02        | 9.31         | 17.13        | 20.06        |
|                   | Nonwhite Female | 2.27         | 5.36         | 26.35        | 3.30         | 7.52         | 24.01        | 5.44         | 11.78        | 21.32        | 8.61         | 14.76        | 17.23        |
| Stomach           | White Male      | 0.00         | 0.01         | 1.27         | 0.02         | 0.13         | 1.30         | 0.18         | 0.53         | 1.33         | 0.60         | 1.16         | 1.33         |
|                   | Nonwhite Male   | 0.01         | 0.04         | 1.55         | 0.06         | 0.27         | 1.68         | 0.37         | 0.85         | 1.80         | 0.87         | 1.50         | 1.82         |
|                   | White Female    | 0.00         | 0.01         | 0.94         | 0.02         | 0.07         | 0.95         | 0.08         | 0.27         | 0.94         | 0.31         | 0.70         | 0.90         |
|                   | Nonwhite Female | 0.01         | 0.02         | 0.99         | 0.03         | 0.10         | 1.01         | 0.13         | 0.38         | 1.04         | 0.46         | 0.83         | 1.03         |
| Colon-Rectum      | White Male      | 0.02         | 0.07         | 4.54         | 0.11         | 0.53         | 4.63         | 0.72         | 2.15         | 4.68         | 2.22         | 4.01         | 4.45         |
|                   | Nonwhite Male   | 0.03         | 0.10         | 3.00         | 0.15         | 0.52         | 3.18         | 0.71         | 1.71         | 3.37         | 1.76         | 3.08         | 3.35         |
|                   | White Female    | 0.01         | 0.07         | 5.22         | 0.11         | 0.50         | 5.25         | 0.65         | 1.90         | 5.18         | 1.81         | 3.80         | 4.60         |
|                   | Nonwhite Female | 0.02         | 0.08         | 3.67         | 0.13         | 0.48         | 3.73         | 0.61         | 1.78         | 3.79         | 1.70         | 2.96         | 3.49         |
| Lung              | White Male      | 0.01         | 0.07         | 6.14         | 0.19         | 0.96         | 6.29         | 1.38         | 3.79         | 6.25         | 3.19         | 4.75         | 4.97         |
|                   | Nonwhite Male   | 0.01         | 0.15         | 6.09         | 0.40         | 1.63         | 6.52         | 2.10         | 4.52         | 6.62         | 3.15         | 4.70         | 4.95         |
|                   | White Female    | 0.00         | 0.04         | 1.60         | 0.08         | 0.35         | 1.60         | 0.38         | 0.86         | 1.47         | 0.50         | 0.84         | 0.96         |
|                   | Nonwhite Female | 0.00         | 0.06         | 1.33         | 0.10         | 0.39         | 1.35         | 0.35         | 0.72         | 1.28         | 0.49         | 0.80         | 0.90         |
|                     | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female | White Female | Nonwhite Female |
| Site                  | Sex, Race Group | Age 20 Years | Age 35 Years | Age 50 Years | Age 65 Years |
|-----------------------|-----------------|--------------|--------------|--------------|--------------|
|                       |                 | 10 Years     | Eventually   | 10 Years     | Eventually   | 10 Years     | Eventually   |
| All Cancer            | White Male      | 0.00%        | 17.21%       | 0.29%        | 17.23%       | 2.09%        | 7.36%        | 16.69%       |
|                       | Nonwhite Male   | 0.07         | 16.05        | 0.53         | 16.87        | 3.24         | 8.87         | 17.11        |
|                       | White Female    | 0.06         | 16.03        | 0.39         | 15.60        | 1.42         | 4.64         | 13.46        |
|                       | Nonwhite Female | 0.08         | 13.82        | 0.66         | 13.45        | 1.70         | 4.97         | 11.57        |
| Stomach               | White Male      | 0.00         | 0.92         | 0.01         | 0.94         | 0.11         | 0.36         | 0.94         |
|                       | Nonwhite Male   | 0.00         | 1.36         | 0.04         | 1.44         | 0.25         | 0.74         | 1.53         |
|                       | White Female    | 0.00         | 0.73         | 0.01         | 0.73         | 0.05         | 0.18         | 0.72         |
|                       | Nonwhite Female | 0.00         | 0.85         | 0.02         | 0.87         | 0.12         | 0.32         | 0.88         |
| Colon-Rectum          | White Male      | 0.00         | 2.34         | 0.03         | 2.38         | 0.23         | 0.88         | 2.32         |
|                       | Nonwhite Male   | 0.01         | 2.13         | 0.05         | 2.15         | 0.24         | 0.79         | 2.10         |
|                       | White Female    | 0.00         | 2.85         | 0.04         | 2.86         | 0.21         | 0.77         | 2.74         |
|                       | Nonwhite Female | 0.00         | 1.07         | 0.07         | 1.08         | 0.23         | 0.51         | 0.94         |
| Lung                  | White Male      | 0.00         | 5.07         | 0.13         | 5.20         | 0.26         | 1.80         | 3.90         |
|                       | Nonwhite Male   | 0.01         | 4.38         | 0.24         | 4.69         | 1.34         | 3.04         | 4.83         |
|                       | White Female    | 0.00         | 2.12         | 0.05         | 2.28         | 0.25         | 0.60         | 1.14         |
|                       | Nonwhite Female | 0.00         | 1.07         | 0.07         | 1.08         | 0.23         | 0.51         | 0.94         |
| Female Breast         | White Female    | 0.01         | 3.08         | 0.16         | 3.00         | 0.34         | 0.93         | 2.15         |
|                       | Nonwhite Female | 0.02         | 2.25         | 0.17         | 2.15         | 0.29         | 0.71         | 1.47         |
| Uterus                | White Female    | 0.01         | 1.16         | 0.04         | 1.07         | 0.10         | 0.32         | 0.81         |
|                       | Nonwhite Female | 0.02         | 1.17         | 0.04         | 1.13         | 0.21         | 0.65         | 1.38         |
| Prostate              | White Male      | 0.00         | 1.78         | 0.00         | 1.83         | 0.29         | 0.80         | 1.97         |
|                       | Nonwhite Male   | 0.00         | 2.39         | 0.00         | 2.57         | 0.18         | 0.80         | 2.97         |
| Bladder               | White Male      | 0.00         | 0.65         | 0.00         | 0.66         | 0.04         | 0.20         | 0.66         |
|                       | Nonwhite Male   | 0.00         | 0.40         | 0.00         | 0.42         | 0.04         | 0.18         | 0.43         |
|                       | White Female    | 0.00         | 0.33         | 0.00         | 0.34         | 0.01         | 0.06         | 0.33         |
|                       | Nonwhite Female | 0.00         | 0.29         | 0.00         | 0.30         | 0.01         | 0.03         | 0.30         |
| Leukemia              | White Male      | 0.01         | 0.69         | 0.02         | 0.68         | 0.06         | 0.23         | 0.65         |
|                       | Nonwhite Male   | 0.02         | 0.42         | 0.02         | 0.39         | 0.05         | 0.15         | 0.37         |
|                       | White Female    | 0.01         | 0.61         | 0.02         | 0.60         | 0.05         | 0.16         | 0.57         |
|                       | Nonwhite Female | 0.01         | 0.36         | 0.02         | 0.35         | 0.04         | 0.12         | 0.31         |

*Exclusive of non-melanoma skin cancer
carcinoma in situ of the cervix uteri has high rates in younger women and the probability at age 20 for cancer within 20 years, including carcinoma in situ, became as much as five percent in non-white females.

It is interesting to examine the data in Table 3 from the viewpoint of how much of the eventual probability occurs within 10 years and 20 years. Thus, at age 35, less than 10 percent of the total eventual probability of invasive cancer occurs within 10 years, whereas at age 65 about 50 percent occurs within 10 years.

The eventual probabilities of breast cancer in women over age 35 are of considerable current interest with respect to a presumed risk of inducing breast cancer through the radiation involved in screening for breast cancer with mammography. In 1972, the Biological Effect of Ionizing Radiation (BEIR) Committee arrived at a tentative estimate of six breast cancers induced per rad to each breast per million women per year after a 10-year latent period. In 1977, under its assumptions, the Upton Committee affirmed a range for women 35 years and over of 3.5-7.5 cases per million women per year subsequent to 10 years after irradiation. Table 3 shows how much additional breast cancer is implied by a mammographic examination involving a dose of one rad to each breast according to the BEIR Committee estimate. At age 35, the eventual probability of developing breast cancer, including carcinoma in situ, for white women is then 8.17 percent, as compared with the baseline 8.15 percent; for non-white women it is 5.35 percent compared with 5.33 percent, relative increases of 0.2 percent and 0.4 percent respectively. At age 50 the corresponding probabilities are 6.86 percent compared with 6.85 percent for white women and 4.43 percent compared with 4.42 percent for non-white women. Miller et al. estimate that, with today's low dose techniques, an examination with xeromammography is accomplished with a mid-breast dose of 0.5 rad and an examination with film-screen mammograms using a molybdenum target x-ray beam involves a mid-breast dose of but 0.1 rad.

### PROBABILITY AT SELECTED AGES OF DYING OF CANCER WITHIN 10 YEARS, 20 YEARS, AND EVENTUALLY AMONG PERSONS WITHOUT PRIOR DIAGNOSIS OF THAT CANCER

Table 4 shows for the 1970 data the probabilities of dying of cancer that are analogous to the probabilities of developing cancer presented in Table 3. As in Table 3, there is no one age at which the eventual risk of cancer is uniformly highest for the different sites. Cancer of the uterus, which includes the high cervical cancer rates in younger women, shows the greatest eventual probability at age 20, while cancer of the prostate with its predominant frequency in older men, shows the greatest eventual probability at age 65.

### Summary

A new method has been devised to compute the probabilities of developing and dying of cancer among persons not previously diagnosed with that cancer. Non-melanoma skin cancer is not included in these calculations. In general, "cancer" means invasive cancer though some findings are presented for data which include carcinoma in situ.

The probability of eventually developing cancer including carcinoma in situ is increasing in all race-sex groups. This has also occurred for invasive cancer except in white females. In white females, the decline in invasive cancer incidence rates has been great enough to balance the added number of cancer cases resulting from increases in life expectancy and a consequent larger population subject to cancer risk. In males, there have been substantial increases in the probabilities of eventually developing cancer of the lung and of the prostate. In the 1970 figures, the white females still show the highest probability at birth of eventually developing cancer of any of the race-sex groups, 27 percent for invasive cancer and 30 percent including carcinoma in situ. The sharpest increases were evident for the non-white males, up from 15 percent in the 1950 figures to 23 percent in 1970.

The probability of eventually dying of
cancer is increasing, even among white females; the cancer death rates are decreasing for white females, but the death rates for other causes are decreasing more rapidly. The probability at birth of eventually dying of cancer is now greater for males of a given race than for females, reversing the situation of a number of years ago. In the 1970 figures, the probabilities were 17 percent for white males compared with 16 percent for white females; they were 15 percent for non-white males compared with 13 percent for non-white females.

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APPENDIX I

To determine the probabilities of dying of this cancer in various intervals of time for persons never with this cancer at ages subsequent to birth, we devised the following procedures:

The deaths from this cancer from age \( x \) to \( x + n \) were composed of deaths of persons ever with this cancer at age \( x \), plus deaths among those who developed this cancer during the \( n \) years. To allocate the cancer deaths between the two groups in any exacting fashion would require very elaborate assumptions, specific for site, age, sex, race, and period. We used much simpler procedures. Cancer end result studies have demonstrated that cancer patients have an especially high probability of dying in the years immediately following diagnosis and that the probability abates as time goes on.\(^\text{18}\) The newly developed cancer cases in this report were considered to be, on the average, subject to death from cancer for half of an interval. For less lethal forms of cancer, it is in general accord with the facts that the probability of dying of this cancer in half the interval for cases newly developed during the interval, \( \tilde{s}q^i \), was roughly equivalent to that for the whole interval for cases already present at the start of the interval, \( s_q^i \).

For lethal forms of cancer such as lung or pancreas, this is not realistic. However, for such forms of cancer, the probabilities of dying in the first two or three years after diagnosis are so high that there are very few survivors who would be subject to very much lower probabilities in ensuing years. Therefore, these exceptions count for little in the overall picture. Thus, we have defined:

\[
\tilde{s}q^i = \tilde{s}q^i = (\tilde{s}d^i + \tilde{s}a^i)
\]

(See Appendix II for possible modifications).

Under our assumptions, for a person ever with this cancer at age \( x \) the probability of dying of any cause, in \( n \) years \( s_q \), was the probability of dying of this cancer, plus the probability of dying of other causes, allowing for the probability of dying of this cancer, or:

\[
\tilde{s}q = \tilde{s}q + s_q = \frac{1}{2} (\tilde{s}q + s_q)
\]

Then for a person ever with this cancer at age \( x \), the probability of surviving \( n \) years, \( \tilde{s}p \), was:

\[
\tilde{s}p = 1 - \tilde{s}q
\]

For a person at the midpoint of an interval, who remained never with this cancer during the interval, the probability of dying of causes other than this cancer in the remaining interval was:

\[
\frac{1}{2} (s_q) + [1 - \frac{1}{2} (s_q)] \times (2 - s_q)
\]

The probability of dying of other causes for persons who developed this cancer during the interval, allowing for deaths from this cancer, \( \tilde{o}p \), was then:

\[
\tilde{o}p = s_q + (2 - s_q)
\]

and the corresponding probability of surviving, \( \tilde{o}p \), was

\[
\tilde{o}p = 1 - \tilde{o}p
\]

For a person developing this cancer from age \( x \) to \( x + n \), the probability of dying of any cause during the interval, \( \tilde{o}q \), was given by:

\[
\tilde{o}q = \tilde{o}q + \tilde{o}q
\]

and the probability of surviving the interval, \( \tilde{o}p \), was:

\[
\tilde{o}p = 1 - \tilde{o}q
\]

The probability that a person ever with cancer at age \( x \) survived \( i \) quinquennial age groups, \( \tilde{o}p \), was computed as the chain product of \( i \) survival probabilities:

For \( i = 1 \), \( \tilde{o}p = \tilde{o}p \)

For \( i = 2 \), \( \tilde{o}p = (\tilde{o}p) \times \tilde{o}p \)

For \( i > 2 \), \( \tilde{o}p = (\tilde{o}p) \times (\tilde{o}p) \times \ldots \)
The probability that a person who developed this cancer from age \( x \) to \( x + 5 \) would die of this cancer in \( i \) quinquennial age groups, \( q_5^i \), was the probability of dying of this cancer in age group \( x + 5 \) plus the probability of surviving to age \( x + 5 \) times the probability of dying of this cancer from age \( x + 5 \) to \( x + 10 \), . . . plus the probability of surviving to age \( x + 5(i - 1) \) times the probability of dying of this cancer from age \( x + 5(i - 1) \) to age \( x + 5i \). Then:

For \( i = 1 \),

\[
\frac{q_5^1}{q_x} = \frac{q_5^1}{q_x} 
\]

For \( i = 2 \),

\[
\frac{q_5^2}{q_x} = \left( \frac{q_x}{q_5} \right) + \left( \frac{q_x}{q_5} \right) \left( \frac{q_x}{q_5} \right)
\]

For \( i > 2 \),

\[
\frac{q_5^i}{q_x} = \left( \frac{q_x}{q_5} \right) + \left( \frac{q_x}{q_5} \right) \left[ \frac{q_x}{q_5} \right] + \sum_{j=1}^{i-2} \left( \frac{q_x}{q_5} \right) \left( \frac{q_x}{q_5} \right)
\]

Finally, the probability that a person never with this cancer at age \( x \) would die of this cancer in \( i \) quinquennial age groups, \( q_5^i \), was the probability of developing this cancer in age group \( x + 5i \) times the probability of dying of this cancer by age \( x + 5i \) plus the probability of surviving to age \( x + 5i \) without developing this cancer times the probability of developing this cancer in age group \( x + 5i \) to \( x + 10 \) times the probability of dying of this cancer by age \( x + 5i \), etc.

Since

\[
\frac{q_x}{q_x} = \frac{q_x}{q_x} 
\]

was the probability that a person never with this cancer at age \( x \) would survive \( i \) quinquennial age groups without this cancer and then develop this cancer in that quinquennial age group, \( q_5^i \) was computed as:

\[
q_5^i = \sum_{j=0}^{i-1} \left( \frac{q_x}{q_5} \right) \left( \frac{q_x}{q_5} \right) + q_x
\]

APPENDIX II

Cancer incidence rates at young ages may be recorded by morbidity surveys as zero, or so close to zero that they do not encompass the occasional cancer deaths recorded at such ages in vital statistics reports. At advanced ages there are few persons still surviving and most life tables have been artificially ended at these ages by a mathematical formula because of doubt as to the quality of the death rates for all causes (though for the U.S. 1969-1971 tables actual data from the experience of the Medicare program were used). At these advanced ages, there is further doubt as to the quality of assignment of cause of death in the face of the many competing causes. Under such conditions, it is not surprising that anomalies occurred which were quite unimportant in magnitude, but unsatisfying conceptually. More specifically, inconsistencies among the death rates, the cancer incidence rates, and the assumptions employed occasionally led to results whereby the contradiction developed that:

\[
q_5^i + q_x > 1
\]

or stated otherwise:

\[
q_5^i > \frac{1}{2} q_x
\]

To avoid this, \( \frac{q_x}{q_5} \) was required to be at least:

\[
\frac{q_x}{q_5} \geq \frac{q_x}{q_5}
\]

minimum

\[
\frac{q_x}{q_5} = \frac{q_x}{q_5}
\]

In this eventuality: Revised \( \frac{q_x}{q_5} = \)

Revised \( \frac{q_x}{q_5} = \frac{q_x}{q_5}
\]

Revised \( \frac{q_x}{q_5} = \frac{q_x}{q_5}
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Revised \( \frac{q_x}{q_5} = \frac{q_x}{q_5}
\]

Revised \( \frac{q_x}{q_5} = \frac{q_x}{q_5}
\]

Revised \( \frac{q_x}{q_5} = \frac{q_x}{q_5}
\]

and finally:

Revised \( \frac{q_x}{q_5} = \frac{q_x}{q_5}
\]

Revised \( \frac{q_x}{q_5} = \frac{q_x}{q_5}
\]

Revised \( \frac{q_x}{q_5} = \frac{q_x}{q_5}
\]