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A Computer Code for General Analysis of Radon Risks (GARR)

U.S. Nuclear Regulatory Commission

Office of Nuclear Regulatory Research

M. Ginevan

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ABSTRACT

Evaluating the level of lung cancer risk associated with a given level of radon-daughter exposure is a complex matter. There is the basic question as to whether one's risk assessment should apply absolute risk models (which principally consider the amount of radon-daughter exposure) or relative risk models (which consider both the amount of radon-daughter exposure and baseline lung cancer risk). Even when a general model form has been selected, there are decisions as to the exact form of risk projection and the appropriate method of accounting exposure over time. Apart from these uncertainties, there is a question as to how much a personal habit such as smoking can modify risk.

This document presents a computer model for general analysis of radon risks that allows the user to specify a large number of possible models with a small number of simple commands. The model is written in a version of BASIC which conforms closely to the American National Standards Institute (ANSI) definition for minimal BASIC and thus is readily modified for use on a wide variety of computers and, in particular, microcomputers.

Model capabilities include generation of single-year life tables from 5-year abridged data, calculation of multiple-decrement life tables for lung cancer for the general population, smokers, and nonsmokers, and a cohort lung cancer risk calculation that allows specification of level and duration of radon exposure, the form of the risk model, and the specific population assumed at risk. Figure A, which shows the process of specifying and executing the cohort lung cancer risk calculation, illustrates some of these capabilities.

FIGURE A

REPRESENTATIVE GARR MODELING SESSION

```
INPUT: KEYBD.(K) OR FILE
(F)?> K
AGE AT FIRST RISK?> 30
AGE AT FIRST EXPOSURE?>
20
AGE AT LAST EXPOSURE?> 6
0
RISK/WLM-R.R.?> .01
R.R. OPTION(M,E,OR B)?>
B
RISK/WLM/PY-A.R.?> 1E-5
LATENCY IN YEARS?> 9
ANNUAL EXPOSURE IN WLM?>
 1
EXPONENTIAL CORRECTION?>
 Y
EXPONENT=?> -.014
AGE SPECIFIC SENSITIVITI
ES?> N
*********************
*********************


RADON RISK MODEL

R.R. COEF=1.00E-002/WLM
OPTION=B
A.R.=1.00E-005/PY/WLM
AGE AT F.E.= 20
AGE AT L.E.= 60
AGE AT FIRST RISK= 30
WLM PER YR.=10.00E-001
LATENCY= 9
EXPONENT COR=-1.40E-002
SENSITIVITY=1
*********************
*********************
```

```
FILE NAME FOR INPUT?> WM
LCMD
PURGE INPUT FILE?> N
WORKING
POP. 1 =WMLCMD

BASELINE
L.E.=50.167
DEATHS/10^5 -LC= 4835.7


RELRISK MODEL-M
L.E.=50.027
LOSS LE(MONS)=  1.67
D/10^5= 5906.0
EXCESS D/10^5= 1109.2

RELRISK MODEL-E
L.E.=50.011
LOSS LE(MONS)=  1.87
D/10^5= 60[illegible].4
EXCESS D/10^5= 1244.9


ABSRISK MODEL
L.E.=50.053
LOSS LE(MONS)=  1.37
D/10^5= 5455.4
EXCESS D/10^5=  645.1


RUN ANOTHER POPULATION?
N
*********************
NEW INITIAL CONDITIONS?>
 N
EXECUTION ENDS
```

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1. INTRODUCTION

Radon gas presents a threat to public health because its short-lived "daughters" are potent lung carcinogens (Lundin, 1971). Activities in which concern for radon-related lung cancer risk arises include uranium mining, uranium mill tailings disposal, and the "tightening" of homes as a part of energy conservation efforts (USRPC; ICRP; Collé).

There is obvious diversity in both the conditions of exposure and the populations at risk in different activities and, as noted below, an even broader diversity in expert opinion as to the type of risk model and modifying factors that are appropriate in a given radon risk assessment.

Because of this spectrum of exposure conditions and expert opinion, the computer code presented here was developed to provide the user with the means to construct General Analyses of Radon Risk (thus its name: GARR), rather than to solve a particular risk model. Its basic structure derives from the cohort life table that has been useful in more general considerations of radiation health effects (Cook; Bunger). However, it differs from earlier approaches in several ways. First, it provides great flexibility in specifying the population at risk and, in particular, the smoking status of that population. Second, it allows one to specify such features of the model as age at first risk (most authors suggest that the risk of radon-induced lung cancer is effectively zero before a certain age), latency between exposure and response, the age-specific sensitivity to radon exposure, and the "discount rate" for past radon exposure (Harley, 1981). Third, it allows one to select either an absolute risk model (wherein lung cancer risk depends only on dose and is independent of the baseline lung cancer rate) or a relative risk model (wherein cancer risk is proportional to the baseline rate) and to specify the risk coefficient for the model selected. Finally, it allows specification of the relevant exposure parameters, age at first exposure, age at last exposure, and exposure level. This level of flexibility requires only a moderate amount of user input, but it is my belief that most models currently proposed for estimation of radon-related lung cancer risk can be implemented.

The GARR code differs from previous radiation risk assessment codes in another important way. It was developed on and is designed for execution by a relatively small microcomputer. Its present implementation is restricted to the Hewlett Packard model 75C portable computer. However, the language is a fairly standard version of BASIC, and the program listings given in Appendix A should be readily translated for use on other small computers or, for that matter, any computer that has a BASIC interpreter.

2. ISSUES IN RADON RISK ASSESSMENT

There is one point of unanimity in expert opinion regarding radon daughters: Radon daughters under some conditions pose a significant hazard to human health and the principal risk associated with this hazard is the development of radiogenic lung cancer. Beyond this, there is considerable divergence in opinion on almost every point of the particulars of calculating radon risk.

[Note: The following discussion assumes a familiarity with basic units of radon-daughter measurement. For amplification and clarification, see Evans.]

One of the most basic dichotomies is the question of the form of the risk model. The first comprehensive study of lung cancer in American uranium miners (Lundin, 1971) suggests that there is greater than additive interaction between smoking and radon in inducing lung cancer. However, the same authors (Lundin, 1979) later concluded that the principal differences between smokers and nonsmokers was in the time between exposure to radon and development of a lung tumor (latency) and that smoking and radon exposure were nearly additive in their effect on lung cancer risk. This view is supported by Radford who based his conclusion on a study of Swedish miners. More recent evaluations using proportional hazards models (Hornung; Whittemore) return to the original view that smoking and radon act multiplicatively, while Harley and Pasternack (1981) introduce a repair term in their model on the assumption that the effectiveness of a given exposure declines exponentially with time (i.e., there is repair of radiation damage).

Aside from these considerations, Cohen suggests that, since not all histologic types of lung cancer may be induced by exposure to radon daughters, one must be careful in specifying "baseline" lung cancer rates for relative risk models. (There is some evidence that this is true for adenocarcinomas (Kunz), but most histologic types seem to be elevated in radon-exposed populations (Archer; Kunz).)

Given that one can pick a risk model, the question arises as to which population to use to determine the risk coefficient. Two populations, the United States uranium miners (Lundin, 1971; 1979) and the Czech uranium miners (Kunz), form the principal basis for such exercises, but others such as the Swedish iron miners (Radford; Axelson) or the Canadian fluorospar miners (Wright; Morrison) have also been used to generate risk estimates. The National Academy of Sciences has reviewed these and other studies and concluded that absolute risk coefficients in the range of 6 to 47 lung cancers per 1,000,000 person-years per working level month (WLM) express the range of risk estimates that can be developed from miner studies. A similar range for relative risk coefficients is not given explicitly but values in the range of 0.3 to 4 percent per WLM increase in baseline lung cancer rate approximate the spread of estimates derivable from miner populations.

The question of deriving estimates of risk for nonminer populations is complicated by the fact that miners represent an atypical group and exposure situation. As noted earlier, most miner populations have a rather high percentage of smokers, and it is quite possible that smoking and radon daughters interact multiplicatively in the induction of lung cancer. Another problem concerns the high prevalence of other forms of respiratory disease in miner populations (the American Miners nonmalignant respiratory disease is the second largest excess cause of death after lung cancer (Waxweiler)). This is a problem because we do not know the extent to which exposure to the agents, other than radon, responsible for these diseases (primarily rock dust) modifies lung cancer risk. Miners are also performing heavy manual labor, which modifies their breathing rate, and this may modify the actual dose to the lung for some given number of WLMs of exposure (Harley, 1982).

The last issue has a parallel in considering extrapolation to the general public because children have higher breathing rates than adults as well as anatomical differences, and there may also be some differences between men and women. These factors may modify delivered dose for a given WLM exposure (Harley, 1982; Hofmann). (Children may also be more sensitive to a given delivered dose, but there is no empirical evidence for or against this idea.)

Finally, there is an issue of conditions of exposure in that mine environments are rather dusty. This means that a high percentage of radon daughters are "attached" to particles (Evans). It may be that this attached fraction is much lower in some nonmine environments, and at least one author (Wise) has suggested that a large unattached fraction can dramatically increase the delivered dose per WLM.

This completes a synopsis of some of the major issues in radon risk assessment. Its purpose is to inform the reader of potential pitfalls rather than to suggest a particular risk modeling approach. Those looking for a more comprehensive review of issues, facts, and opinions should consult the following references: NAS; UNSCEAR; Peterson; and Thomas.

3. GARR ALGORITHMS

3.1 Brief Review of Cohort Risk Analysis

A cohort analysis asks the question: What would be the mortality experience of a group of people of the same age who have the same baseline mortality experience if they are uniformly exposed to some toxic agent that adds a certain amount of excess mortality to their baseline mortality? In this sort of analysis, two basic measures of effect can be calculated. The first, premature deaths, is the number of persons (usually per 100,000) who die earlier than they would have because of the toxic agent. The second, loss of life expectancy, is a measure of how premature the premature deaths really are. It is frequently expressed in one of two ways: (1) loss of life expectancy per exposed individual and (2) loss of life expectancy per premature death.

The basic quantity of interest in any cohort analysis is ${}_nq_x$, the baseline probability of dying in an interval of n years beginning at some exact age x. For our calculations, n is always one. Thus we will refer simply to q_x which is the probability that a person exactly x years old will die in the next year. Its converse, $p_x = 1 - q_x$, is the probability of surviving from age x to age x + 1. A final quantity, S_x, given by

$$S_x = \prod_{i=0}^{x-1} p_i; \quad [x = 1, 2, 3, \ldots, 100], \tag{1}$$

(Π is the notation for the product $p_o \times p_1 \cdot \cdot \cdot p_{x-1}$.)

is the probability that a newborn is alive at age x. S_o is taken as 1.

Note also that the conditional probability of survival to age x + m, given that one is alive at age x, can be expressed as the ratio S_{x+m}/S_x.

Our models of radon risk are simplified because only one source of excess mortality, lung cancer, is of interest. Here, in an absolute risk model, the excess probability of death in age interval x to x + 1, q_{ex}, is given by

$$q_{ex} = Cd_x , \tag{2}$$

where C is a constant with units of lung cancer cases per person per year per unit dose and d_x is the effective exposure acting at age x (the concept of effective exposure is discussed in detail below).

In a relative risk model, the risk coefficient, A, has units of proportional increase per unit exposure, and q_{ex} is a function of q_{cx}, the baseline risk. This model can take one of two forms. In the first

$$q_{ex} = Ad_xq_{cx}. \tag{3}$$

This is here termed our multiplicative relative risk model because excess risk is a simple product of risk coefficient, exposure, and baseline risk. A second possible formulation is

$$q_{ex} = [(1 + A)^{d_x} - 1]q_{cx} . \tag{4}$$

This is termed our exponential relative risk model because here risk increases exponentially with dose. It is equivalent to the form of relative risk assumed in the class of statistical models termed proportional hazard models (Cox). If A is small (less than 0.02) and exposure is fairly low (d is less than 20), Equations 3 and 4 will give nearly equivalent results. However, one should always be cautious in specifying exactly which model form one is talking about because the same inputs can give quite divergent results.

When an additional source of mortality q_e is acting, we first calculate modified survival probabilities S' for ages beyond r, the age at first risk.

$$S'_i = S_r \prod_{x=r+1}^{i} (p_x - q_{ex}) . \tag{5}$$

In the calculation of the probability of premature lung cancer death, R_e, one has

$$R_e = \frac{1}{S_f} [S_r q_{er} + \sum_{t=r+1}^{100} S'_t q_{et}] . \tag{6}$$

In this expression, f is the age at first exposure and r is the age at first risk. (Note that, because we are working in discrete time, we adopt the convention that dose received at age f cannot be expressed until age f + 1. Thus it is always true that r > f.)

The reciprocal of S_f converts the other survival probabilities into survival probabilities conditional on being alive at age f. Thus Equation 6 is simply the sum of the probabilities of surviving to all ages beyond exposure and dying of a premature lung cancer at those ages, which is the total probability of premature lung cancer death. This is easily converted to expected deaths per, say, 100,000 exposed by multiplication (i.e., R_e x 100,000).

Life expectancy, E_{bf}, for a person at age f (here equivalent to age at first exposure) is calculated as follows:

$$E_{bf} = \frac{q_f}{2} + [\frac{1}{S_f} \sum_{x=f+1}^{99} S_x(1 + \frac{q_x}{2})] . \quad (7)$$

Equation 7 assumes that survival to a particular age contributes 1 year to life expectancy, S_x/S_f, while death during a particular year of life contributes 1 half-year to life expectancy ($[S_x/S_f][q_x/2]$). (The observant reader may have noticed that our calculations to this point are truncated at age 100. Corrections for this are introduced below.)

The new life expectancy, E_{ef}, is then

$$E_{ef} = \frac{q_f}{2} + \frac{1}{S_f} [\sum_{x=f+1}^{r} S_x(1 + \frac{q_x}{2}) + S_r \frac{q_{er}}{2} + \sum_{t=r+1}^{99} S'_t(1 + \frac{q_t + q_{et}}{2})] . \quad (8)$$

Equation 8, which takes into account the new source of mortality, is a simple modification of Equation 7. (Note Equation 5.)

Loss in life expectancy, E_L, is simply: $E_L = E_{bf} - E_{ef}$.

One peculiarity of human mortality is that, during the first year of life (starting at age 0), most of the deaths take place early on. Therefore, the contribution of deaths in this interval to total life expectancy is less than the 0.5 year assumed elsewhere. We use 0.1 year (i.e., $q_0/10$) for calculations starting at age 0. It is also true that persons dying in an age interval may live, on average, more or less than 0.5 year in the interval depending on the age interval and population considered, but for our purposes 0.5 is a more than adequate approximation.

Finally, a correction is made to both life expectancy and risk of death calculations because it is assumed that no one lives beyond age 100. The expected number of years, G, to be lived by a person reaching age 100 is taken as

$$G = 0.8/q_{99} ,$$

where q_{99} is the probability of dying during the 99th year. This is used to modify life expectancy as follows:

$$E_m = E + (S_{100}G) \tag{9}$$

where E is the life expectancy before modification, E_m is modified life expectancy, and S_{100} is the probability of surviving to age 100 in our model population (i.e., conditional on being alive at age of first exposure and with excess lung cancer mortality in effect). The quantity G is also used to find q_{e100} for use in the excess risk calculation. In the absolute risk model

$$q_{e100} = Cd_{99+G}G \tag{10}$$

where d_{99+G} is the effective exposure acting at age 99 + G years and q_{e100} is the excess lung cancer death probability experienced by those over 100 years old.

The relative risk form of this correction is given by either

$$q_{e100} = Ad_{99+G}q_{c100}, \tag{11}$$

or

$$q_{e100} = [(1 + A)d_{99+G} - 1]q_{c100},$$

where q_{c100} is the baseline probability of dying of lung cancer beyond one's 100th birthday.

The probability of premature lung cancer death is modified as follows:

$$R_{em} = R_e + S_{100}q_{e100} \; . \tag{12}$$

The net effect of each of these corrections is quite small, so much so that good results can be obtained by truncating at age 99. The reason for their inclusion here is that they, at least in theory, improve our approximation to a cohort followed to extinction and do not greatly increase computational complexity.

This completes the calculations for the basic cohort risk calculation as used in GARR. Those wishing additional reading on cohort life tables can consult Elandt-Johnson; Keyfitz; or Bunger.

3.2 Specifying Population at Risk

In our model, the actuarial characteristics of the population at risk are specified by the age-specific probabilities of dying of lung cancer and the age-specific probabilities of dying of all other causes for the ages 0 to 100+. These quantities can be obtained directly from sources such as the United States Decennial Life Tables (NCHS, 1975). If this option is selected, one simply looks up the q_x values for x = 0 - 99 and sets q_{100} equal to one. Age-specific probabilities of lung cancer death can be obtained by the formula

$$q_{cx} = q_x(m_{cx}/m_{tx}) \quad , \tag{13}$$

where m_{cx} and m_{tx} are the number of deaths from lung cancer and all causes occurring in persons of age x. The background mortality probability q_{bx} is obtained by subtraction. That is

$$q_{bx} = q_x - q_{cx} \tag{14}$$

This calculation is very simple but, for 1-year intervals, requires rather detailed input data that are of somewhat limited availability (e.g., the last U.S. decennial life table available is for the years 1969-1971) and that are rather laborious to input. The GARR code simplifies matters by providing two programs, GRADUATE and MULDEC, which generate q_c and q_b for single years using input data from NCHS 5-year abridged mortality data (e.g., NCHS, 1974).

3.3 Generating Single-Year Life Table: The GRADUATE Program

An excerpt from an NCHS abridged life table is shown in Table 1. It provides ${}_nq_x$ values for intervals 0-1, 1-5, and 5-year intervals 5-10, ..., 80-85. The problem is to use these data to find q_x values for x = 0 - 99. For age 0 this is given. For ages 1 to 4 one can simply take

$$q_x = 1 - {}_4p_1^{0.25} \tag{15}$$

where ${}_4p_1 = 1 - {}_4q_1$.

Similarly for ages 5 to 9 and 10 to 14

$$q_{x+m} = 1 - {}_5p_x^{0.2} \tag{16}$$

where m = 0 - 4, x = 5 or 10.

Beyond age 15 the annual probability of death changes with age. Thus to estimate q_x for higher ages, one must make some assumptions about how mortality behaves in the population under consideration. A variety of approaches are discussed by Keyfitz in Chapter 10; the one used in our program contains elements of several of these together with some unique aspects dictated by the necessity of being able to solve the problem fairly quickly on a small microcomputer.

The assumption made in our approach is that the annual q_x values tend to increase by a constant percentage from year to year, which is a good approximation to reality for many populations. That is

$$q_{x+1} = q_x I \tag{17}$$

TABLE 1
MORTALITY DATA FROM UNITED STATES 1969
POPULATION (NCHS, 1974)

AGE INTERVAL	PROBABILITY OF DEATH ($_nq_x$)	TOTAL DEATHS	LUNG CANCER DEATHS
	WHITE MALES		
0-1	0.0213	32158	0
1-5	0.0033	5033	0
5-10	0.0024	4273	3
10-15	0.0024	4299	5
15-20	0.0077	12352	5
20-25	0.0101	13497	13
25-30	0.0086	9914	19
30-35	0.0092	8993	92
35-40	0.0132	12782	359
40-45	0.0210	22373	1133
45-50	0.0337	36257	2224
50-55	0.0540	53156	3938
55-60	0.0851	76206	6185
60-65	0.1294	97922	8045
65-70	0.1828	112983	8301
70-75	0.2655	124755	7147
75-80	0.3524	125861	4818
80-85	0.4630	102653	2156
85-90	*1	60602	696
90-95		23182	147
95-100		5197	18
100+		633	2
	WHITE FEMALES		
0-1	0.0161	22950	0
1-5	0.0028	4078	4
5-10	0.0016	2829	1
10-15	0.0015	2519	2
15-20	0.0029	4615	4
20-25	0.0033	4690	13
25-30	0.0035	4177	16
30-35	0.0049	4932	49
35-40	0.0076	7591	162
40-45	0.0120	12189	426
45-50	0.0181	20543	819
50-55	0.0272	28210	1165
55-60	0.0402	38264	1511
60-65	0.0598	49602	1447
65-70	0.0940	66888	1393
70-75	0.1522	90550	1263
75-80	0.2352	113486	969
80-85	0.3671	116612	644
85-90	*1	87714	303
90-95		41652	94
95-100		11393	14
100+		1569	2

*85+

where I is a constant greater than 1 and generally in the range of 1.04 to 1.09. This is approximately equivalent to assuming a Gompertz survival function (Elandt-Johnson). From this point, numerical arguments are used to derive estimates for q_x and I, assuming this process fits the data.

A preliminary estimator for q_{x+2} (the annual death probability at the midpoint of the interval defined by ${}_5q_x$) is taken as

$$\hat{q}_{x+2} = 1 - {}_5p_x^{0.2} \ , \tag{18}$$

where ${}_5p_x = 1 - {}_5q_x$.

A computer program was devised to examine the behavior of $\hat{q}_{x+2}$ for various parametric values of q_{x+2} and I. The results of this computation are presented in Table 2.

Clearly, $\hat{q}_{x+2}$ is consistently biased (that is, it overestimates q_{x+2}), and the the magnitude of the bias depends almost entirely on I. This observation suggests that the estimate of $\hat{q}_{x+2}$ might be substantially improved by adding a correction based on I. The term chosen, B, which is derived from fitting a quadratic in I to the data in the second row of Table 2, is given by

$$B = -0.778 + 1.571I - 0.793I^2 \ . \tag{19}$$

This B is then used to construct a new estimator of q, $\hat{\hat{q}}$ which is given by

$$\hat{\hat{q}}_{x+2} = \hat{q}_{x+2}(1 + B). \tag{20}$$

The result of applying this correction to Table 2 is shown in Table 3. The correction is very successful in that $\hat{\hat{q}}_{x+2}$ and our parametric q_{x+2} agree almost exactly.

The foregoing assumes that I is known, but in practice it does not matter that it is not. An excellent estimate is given by

$$\hat{I} = [\hat{q}_x/\hat{q}_{x-5}]^{0.2} \tag{21}$$

TABLE 2

PROPORTIONAL BIAS, $(q - \hat{q})/q$, in $\hat{q} = 1 - [{}_5p_x^{0.2}]$

FOR VARIOUS PARAMETRIC VALUES OF q AND I

	PARAMETRIC I			
	1.03	1.06	1.09	1.12
PARAMETRIC q				
0.10	-0.00097	-0.00376	-0.00821	-0.01415
0.01	-0.00088	-0.00342	-0.00746	-0.01286
0.001	-0.00087	-0.00339	-0.00739	-0.01274

TABLE 3

PROPORTIONAL BIAS, $(q - \hat{\hat{q}})/q$, in $\hat{\hat{q}}$ FOR VARIOUS PARAMETRIC VALUES OF q AND I

	PARAMETRIC I			
	1.03	1.06	1.09	1.12
PARAMETRIC q				
0.10	-0.00010	-0.00032	-0.00078	-0.0013
0.01	-0.00001	-0.00002	-0.00003	-0.0000
0.001	-0.00000	-0.00005	-0.00004	-0.00012

Note: $\hat{q} = {}_5p_x^{0.2}$ and $\hat{\hat{q}} = \hat{q}(1 + c)$ where c is a quadratic correction of the form $c = -0.778 + 1.571I - 0.793I^2$.

Table 4 gives absolute bias in $\hat{I}$, $(\hat{I} - I)$ for various parametric values of q and I. This bias is negligible.

Application of these formulae to generating a single-year life table for ages above 15 is as follows:

For each ${}_5q_x$

$$\hat{q}_{x+2} = 1 - {}_5p_x^{0.2} . \quad (22)$$

$\hat{I}_x$ is then calculated (for the interval x - 3 to x + 2) as in Equation 20.

Then $\hat{q}_{x+2}$ is calculated using

$$I = (\hat{I}_x + \hat{I}_{x+5})/2 \quad (23)$$

and Equations 18 and 19.

Intermediate values of $\hat{q}_x$ are calculated using

$$\hat{q}_{x+2+i} = \hat{q}_{x+2} I_{x+5}^{i} \quad (24)$$

for i = 1 - 4.

The final problem is extrapolating from $\hat{q}_{82}$ to $\hat{q}_{99}$ (q(100) = 1).

Here I is taken as

$$I = (\hat{I}_{80} + \hat{I}_{75} + \hat{I}_{70})/3 \quad (25)$$

and

$$\hat{q}_{82+i} = \hat{q}_{82} * I^{i} \quad (26)$$

TABLE 4

ABSOLUTE BIAS ($\hat{I} - I$) IN $\hat{I}$ FOR VARIOUS VALUES OF q AND I

(All Entries Should Be Multiplied by 10^{-4}.)

PARAMETRIC q	PARAMETRIC I: 1.03	1.06	1.09	1.12
0.10	0.0403	0.3932	1.6371	4.8684
0.06	0.0218	0.2078	0.8404	2.4040
0.03	0.0101	0.0950	0.3768	1.0524
0.01	0.0032	0.0299	0.1172	0.3228

Table 5 presents life expectancies calculated from Equation 7 with the modifications given in the text, and the survival function calculated as in Equation 1, both using q_x values derived from our procedure. Comparing these (labeled GARR) with the values taken directly from the relevant NCHS life tables suggests that the GRADUATE program does a good job of producing single-year life tables that accurately represent the mortality experience of the population at risk.

3.4 Considering Multiple Causes of Death: The MULDEC Program

Table 1 also contains sex- and age-specific values for total mortality and for mortality from cancers of the trachea, bronchus, and lung. These, together with the q_x values from GRADUATE, allow calculation of q_{cx}, the annual probability of lung cancer death, for ages 0 through 100.

Because there are so few lung cancer deaths prior to age 20, we will begin our consideration at age 20 and assume earlier q_{cx} values are zero. However, it should be noted that the MULDEC program is capable of generating q_{bx} and q_{cx} values starting at age 0 and for an arbitrary number of excess causes of death (see page 70, Appendix A). One can obtain the probability of dying of lung cancer in the 5-year period beginning at age x, given that one has died, ${}_5C_x$, as

$$ {}_5C_x = {}_5m_{cx}/{}_5m_{tx} \tag{27} $$

where m_c and m_t are defined as in Equation 13. One could simply apply this to all q_x values in the interval (as in Equation 13) to obtain q_{cx} values. However, this has the rather unrealistic feature of applying a step function with 5-year intervals to our laboriously calculated single-year q_x schedule. Therefore we consider ${}_5C_x$ to represent the value of C at the middle year of the interval (i.e., C_{x+2}) and obtain intermediate values by linear interpolation. That is,

TABLE 5

COMPARISON OF AGE-SPECIFIC SURVIVAL PROBABILITIES GIVEN IN NCHS LIFE TABLE TO THOSE CALCULATED FROM GRADUATE LIFE TABLE PRODUCED BY GARR

POPULATIONS

AGE	WF (75.12/75.23) NCHS	GARR	WM (67.75/67.82) NCHS	GARR	NM (60.47/60.52) NCHS	GARR
15	0.9781	0.9781	0.9708	0.9708	0.9527	0.9527
20	0.9753	0.9754	0.9634	0.9641	0.9415	0.9423
25	0.9721	0.9723	0.9537	0.9549	0.9231	0.9250
30	0.9686	0.9687	0.9455	0.9465	0.9023	0.9039
35	0.9638	0.9639	0.9368	0.9375	0.8761	0.8775
40	0.9565	0.9566	0.9245	0.9249	0.8421	0.8434
45	0.9451	0.9452	0.9050	0.9054	0.7977	0.7992
50	0.9279	0.9281	0.8745	0.8749	0.7429	0.7438
55	0.9027	0.9029	0.8273	0.8277	0.6718	0.6728
60	0.8664	0.8665	0.7569	0.7575	0.5840	0.5850
65	0.8146	0.8143	0.6589	0.6604	0.4813	0.4816
70	0.7381	0.7373	0.5385	0.5391	0.3631	0.3627
75	0.6257	0.6255	0.3956	0.3972	0.2362	0.2420
80	0.4786	0.4777	0.2562	0.2572	0.1575	0.1600
85	0.3029	0.3024	0.1375	0.1378	0.0997	0.1010

Note: White Females (WF), White Males (WM), and Nonwhite Males (NM) are shown. Numbers in parentheses are life expectancy at age 0.

$$C_{x+2+i} = [(5 - i)C_{x+2} + iC_{x+7}]/5 \quad (28)$$

The values for q_{cx} and q_{bx} are thus

$$q_{cx} = q_x C_x \quad (29)$$

and

$$q_{bx} = q_x(1 - C_x) \; . \quad (30)$$

This process of separating the q_x values into their cause-specific components is called constructing a multiple-decrement life table (Chiang).

The reader should note that all these calculations make the assumption that causes of death are mutually exclusive (i.e., one can die of one and only one cause) and independent (i.e., deaths from one cause at one age do not modify the expected number of deaths from another cause at a later age).

3.5 Addressing Influence of Smoking: The SMOKER Program

The procedures described to this point will create values for background probabilities of death (q_{bx}) and probability of lung cancer death (q_{cx}) for ages 0 through 100+, given abridged mortality data of the form shown in Table 1. Should one have such data for a pure population of smokers or nonsmokers one could generate a population at risk in a straightforward manner using GRADUATE and MULDEC. In practice, such data are unavailable and one must resort to a modeling approach.

Certain information about the mortality experience of smokers versus nonsmokers is readily obtainable. From the 1979 Surgeon General's Report on smoking (U.S. Public Health Service), we can obtain information as to the proportion of the population who are smokers and the general mortality experience of smokers versus nonsmokers. Likewise, information about the lung cancer rates experienced by nonsmokers is available. Table 6 presents nonsmoker lung cancer rates for males and females derived from the American Cancer Society study of cancer in

TABLE 6

NONSMOKER LUNG CANCER DEATH RATES
IN DEATHS/100,000 PERSON-YEAR (Garfinkel)

AGE	MALE	FEMALE
45-49	4.55	3.60
50-54	7.63	5.30
55-59	10.13	7.07
60-64	17.26	13.60
65-69	27.43	16.17
70-74	25.97	20.83
75-79	44.27	34.70
80-84	68.87	45.80
85-89	94.80	52.47

nonsmokers (Garfinkel). This kind of information is used by a GARR program called SMOKER to create hypothetical populations of smokers and nonsmokers.

The first problem is to separate the general population q_x values into age-specific total mortality probabilities for smokers, q_{sx}, and nonsmokers, q_{nx}. To do this, SMOKER requires a general population life table like that generated by MULDEC, an estimate of the proportion of smokers in the population at age 35, θ_{35}, and a value for the all-cause standardized mortality ratio, M, (Fleiss) in smokers as compared to nonsmokers. We assume that the age-specific mortality ratio, M_x, which equals q_{sx}/q_{nx}, starts at 1 at age 34 and increases linearly to M at ages 45 and beyond.

By our definition,

$$q_{sx} = q_{nx}M_x \tag{31}$$

Then at age x

$$q_x = (1 - \theta_x)q_{nx} + \theta_x M_x q_{nx} \tag{32}$$

and rearranging

$$q_{nx} = q_x/[(1 - \theta_x) + (\theta_x M_x)] \tag{33}$$

and

$$q_{sx} = M_x q_{nx} \tag{34}$$

This approach can be applied iteratively for subsequent ages because we have assumed M_x known for all x (for x less than 35 $M_x = 1$ and $q_{sx} = q_{nx} = q_x$) and, assuming differential mortality is the only thing affecting the age-specific proportion of smokers in the population,

$$\theta_{x+1} = \theta_x p_{sx}/[\theta_x p_{sx} + (1 - \theta)p_{nx}] \quad . \tag{35}$$

(Here the p's are defined as in Equation 1.)

Age-specific lung cancer death probabilities for nonsmokers, q_{ncx}, are derived from the nonsmoker lung cancer death rates, ${}_5r_x$, shown in Table 6. We take

$$q_{ncx+2} = {}_5r_x/100000 \ . \tag{36}$$

These midpoint values are then used to generate I_x values as in Equation 21. And interpolation is performed as in Equations 24 through 26. Ages 45 and 46 are handled as follows:

$$\hat{q}_{nc47-i} = \hat{q}_{nc47}/I_{50}^{i} \tag{37}$$

where i = 1; 2. The reader may note that rates are not precisely equivalent to probabilities, but in this case the difference is very small (less than 2 percent).

For ages less than 45, $q_{ncx} = q_{cx}$ unless q_{cx} is greater than q_{nc45}. If this holds, q_{ncx} is set equal to q_{nc45}. At older ages (90+), a check is also made to determine whether q_{ncx} is greater than q_{cx}. If this is true, q_{ncx} is set equal to q_{cx}. (This makes the assumption that nonsmokers cannot have higher lung cancer probabilities than the general population.)

The nonsmoker lung cancer death probabilities can also be modified by a user-supplied multiplier U that reflects the extent to which the calculated lung cancer death probabilities overestimate or underestimate risk in the nonsmoker population of interest. The new values are given by

$$q'_{ncx} = q_{ncx}U \ . \tag{38}$$

Age-specific nonsmoker probabilities, q_{nbx}, for background mortality are then determined by subtraction. That is

$$q_{nbx} = q_{nx} - q_{ncx} \tag{39}$$

for all x.

At this point the only remaining quantities of interest are the age-specific probabilities of lung cancer death for smokers, q_{scx}. These are developed as follows.

From values already calculated we can determine a_{sx}, the age-specific proportion of deaths who were smokers,

$$a_{sx} = \theta_x(q_{sx}/q_x) \quad . \tag{40}$$

We can also find a_{ncx}, the proportion of deaths who were nonsmoking lung cancer:

$$a_{ncx} = (1 - a_{sx})(q_{ncx}/q_{nx}) \quad . \tag{41}$$

Now we find a_{scx}, the proportion of deaths who were smoking lung cancer:

$$a_{scx} = (q_{cx}/q_x) - a_{ncx} \quad . \tag{42}$$

Finally q_{scx} is calculated as:

$$q_{scx} = q_{sx}(a_{scx}/a_{sx}) \quad .$$

At the option of the user, an arbitrary minimum risk of lung cancer, R, in smokers relative to nonsmokers for ages 45 and above may be declared. In this case if

$$q_{scx} < Rq_{ncx} \quad \text{then} \quad q_{scx} = Rq_{ncx} \quad .$$

The last, trivial calculation is determining q_{sbx} by subtraction in the same way as Equation 39, which completes both life tables.

At this point the reader may be concerned by some of the assumptions made in our development of smoker and nonsmoker populations. For example, the relative proportion of smokers versus nonsmokers at various ages is determined by much more than differential mortality (i.e., historical smoking "cohort" effects), and the all-cause standard mortality ratio for smokers is not constant across ages. Nonetheless, any model is, to some extent, arbitrary (else it would be unwieldy), and the procedures outlined here generate reasonable actuarial populations for smokers and nonsmokers in that differences in life expectancy and lung cancer risk between smokers and nonsmokers agree with those reported in the Surgeon General's Report (U.S. Public Health Service) (see Table 7).

Further, if one is dissatisfied with these assumptions, they are easily modified by using the same approach but providing parametric θ_x and M_x values explicitly for each x, or by performing a sensitivity analysis using the options for specifying θ (Equation 32), M (Equation 34), and U (Equation 38). An example of such an exercise is shown in Table 7. This illustrates the relative insensitivity of the actuarial characteristics of the smoker population generated to the choice of U and θ_{35}.

Likewise, it is true that our procedure could yield q_{sx} values greater than 1. However, in practice this does not happen, and the program provides adequate diagnostic information to assure the user that it has generated reasonable results.

3.6 Calculating Lung Cancer Risk from Radon-Daughter Exposure: The RADRISK Program

The calculation of radon-daughter-induced lung cancer risk is performed by the RADRISK program. The basic functioning of this program is as described in the review of cohort risk analysis presented earlier. Required inputs include sets of q_{bx} and q_{cx} values defining the population at risk; C and A coefficients for the absolute and relative risk models, respectively; f, the age at first exposure; g, the age at last exposure; L, the latency or time between exposure and onset of risk; h, the age at first risk (a number of models assume risk is zero before some age regardless of age at exposure or latency); and w, the continuous exposure to radon daughters in working levels. One may also elect to assume that sensitivity, Z, varies across ages and that the effect of dose delivered decays exponentially with time by specifying a decay rate constant, r.

At first glance, this large number of possible inputs would seem to make for a very complicated model; but, in fact, all these complications can be incorporated

TABLE 7

SENSITIVITY ANALYSIS: MALES

M = 1.75

	NONSMOKER LUNG CANCER DEATH PROBABILITIES			
	OBSERVED		2X OBSERVED	
	NS	S	NS	S
Proportion Smokers at Age 35				
0.40				
LE	70.0	64.6	70.0	64.6
LC	668	10656	1280	9764
0.50				
LE	70.5	65.1	70.6	65.1
LC	698	8633	1334	8032
0.60				
LE	71.1	65.6	71.1	65.6
LC	731	7306	1392	6904

Note: LE = Life Expectancy; LC = Expected Lifetime Lung Cancer Deaths Per 100,000; S = Smokers; NS = Nonsmokers.

into one term, d_x, the effective exposure acting at age x. Otherwise, our calculation is a straightforward application of Equations 1 through 12.

RADRISK assumes a constant annual exposure, d_y, given in working level months, for the period of exposure.

The exposure acting at age t, d_t, is for the simplest case (continuous exposure)

$$d_t = (t - f)d_y \ , \tag{43}$$

i.e., the difference between the age at present and the age at first exposure times the annual exposure.

More generally,

$$d_t = \sum_{i=m}^{k} d_y Z_{i-L-1} e^{-r(t-i+L)}; \ t \geq m \tag{44}$$

$$d_t = 0; \ t < m$$

Here m = f + L + 1 and k = t if t < g; otherwise k = g. Verbally, this says that the exposure active at time t is a function of the age-specific sensitivity at the age it was received and that risk from exposure received in the past decays exponentially from the time it was received. Further, only exposure received at least L + 1 years in the past is effective in determining risk (if exposure begins at age f, risk cannot commence until age f + 1). Finally, a restriction not reflected by Equation 45 is that if t < h, the age at first risk, then $d_t = 0$.

This completes the description of the new algorithms used in RADRISK (remember, the rest of RADRISK follows Equations 1 through 8) and thus the algorithmic description of GARR as a whole.

4. RUNNING GARR ON THE HP-75

4.1 HP-75 System

The following discussion assumes a minimal configuration of an HP-75C portable computer with an 8k memory expansion module (24k RAM total), an HP 82161A digital cassette drive, and an HP 821622A thermal printer. When the HP-IL interface loop is configured (refer to Section 9 of your HP-75 Cwner's Manual (Hewlett Packard)), the cassette drive should be named ":CA" and the printer should be named ":PR." Note also that the printer must be declared as the system print device. The command

PRINTER IS ":PR"

must be executed.

The following discussion assumes that the reader is somewhat familiar with the HP-75 and its Owner's Manual. For example, we always assume that adequate memory is available for program execution. However, if one copies a large number of files to memory, at some point an error #16, "not enough memory," will be generated. These errors can be avoided by judicious use of the PURGE and COPY commands, but we do not treat such problems explicitly here. For questions of this sort, the reader is referred to the HP-75 Owner's Manual.

4.2 Preparing Input File for GRADUATE and MULDEC

Figure 1 reproduces a representative input file for use in both GRADUATE and MULDEC. Line 10 is an optional comment line. Line 15 is a mandatory title (this is included to force the user to add a title), which can be up to 32 characters in length. Lines 20 and 30 are the DATA statements containing the 19 ${}_5q_x$ values from the abridged life table arranged from x = 0 to x = 85. Line 32 is an optional comment line. Line 35 is a DATA statement giving the number of disease-specific causes of death (for our purposes it is always 1). Line 40 is an optional comment line. Lines 50 and 60 contain the 22 ${}_5m_{tx}$ values from the mortality compilation (x = 0, 1, 5, 10,...90, 95, 100) arranged

FIGURE 1

SAMPLE INPUT DATA FILE FOR GRADUATE AND MULDEC

```
10 ! MORTALITY SCHEDULE
FOR WF,1969
15 DATA "MORTALITY WF 19
69"
20 DATA .0161,.0028,.001
6,.0015,.0029,.0033,.003
5,.0049,.0076,.012
30 DATA .0181,.0272,.040
2,.0598,.094,.1522,.2352
,.3671,1
32 ! NUMBER OF SPECIFIC
CAUSES OF DEATH
35 DATA 1
40 ! TOTAL DEATHS WF 69
50 DATA 22950,4078,2829,
2519,4615,4690,4177,4932
,7519,13189,20543
60 DATA 28210,38264,4960
2,66888,90550,113486,116
612,87714,41662,11393,15
69
70 ! LUNG CANCER DEATHS
WF 69
80 DATA 0,0,0,0,0,13,16,
49,162,426,819,1165
90 DATA 1511,1477,1393,1
263,969,644,303,94,14,2
```

from x = 0 to x = 85. Line 70 is an optional comment line. Lines 80 and 90 contain the 22 ${}_5m_{cx}$ values arranged in the same fashion as the ${}_5m_{tx}$ values.

The reader who is fluent in BASIC can refer to the program listings for GRADUATE and MULDEC (Appendix A, pp. 67-70) to determine the necessary features of the input file. Others are urged to follow exactly the format of the sample file shown in Figure 1 since this will always work. Details of creating data files can be found in the HP-75 Owner's Manual.

4.3 Running GRADUATE Program

To run the GRADUATE program, first determine that the program is in memory. Also make sure a file of input data like that discussed in the previous section is in memory. (Execute the CAT ALL command to scan the file directory.) If GRADUATE is not in memory, it must be loaded from cassette. The relevant command is

```
COPY "GRADUATE:CA" TO "GRADUATE"
```

Similar comments apply to the data file. To run the GRADUATE program, enter

```
EDIT "GRADUATE"
```

and then

```
RUN
```

or simply enter

```
RUN "GRADUATE"
```

(These comments apply to the other programs in GARR as well.) The computer will display the prompt

```
FILE FOR ABRIDGED?>
```

Enter the name of a file configured as in Figure 1. If the file is not configured properly or does not exist, the error message

BAD OR NONEXISTENT FILE

will be generated on the printer, and you will receive the prompt for a file. At this point two possibilities are raised. First, you may have mistyped the file name. In this case simply reenter the correct name. Second, there may be something wrong with the file. In this case enter

EDIT "FILE"

where "FILE" is the desired file name.

The computer should reply

FILE	B	564	tt:tt	00/00/00
Desired file	Basic	Length in bytes	time created	date created

where the fields have the meanings indicated by the labels. The two most important fields are the length in bytes, which should be about 564, and the file type, which should always be B for BASIC. If the length is zero, this means the file is not in memory. Consult the HP-75 Owner's Manual (Hewlett Packard), pp. 135-136, for the procedures involved in copying it to memory. A file type other than B probably means you have referenced the wrong file. Consult the HP-75 Owner's Manual, Appendix B, for information on file types.

If an appropriate file has been specified, an output like that in Figure 2 is generated. The first line is the name of the file referenced, in this case "WFLC." The second line gives the title read from the input file. This serves as a check that the appropriate file has been referenced. Following this are q_x values for x = (17; 22; 27 ··· 77; 82), the B values used to correct the q_x values (Equation 19), and the I values used to perform geometric interpolation (Equation 23). The last four items output are the I value used to

FIGURE 2

SAMPLE OUTPUT FOR GRADUATE

```
********************
GRADUATE LIFE TABLE
********************

INPUT FILE=WMLC
TITLE= MORTALITY WM 1969

qx(17)= .0015
B=-.02219
I= 1.160

qx(22)= .0020
B=0.00000
I= 1.012

qx(27)= .0017
B=0.00000
I=  .991

qx(32)= .0018
B=-.00193
I= 1.044

qx(37)= .0026
B=-.00691
I= 1.087

qx(42)= .0042
B=-.00895
I= 1.099

qx(47)= .0068
B=-.00918
I= 1.101

qx(52)= .0109
B=-.00899
I= 1.099

qx(57)= .0175
B=-.00822
I= 1.095

qx(62)= .0272
B=-.00656
I= 1.084

qx(67)= .0393
B=-.00616
I= 1.082

qx(72)= .0595
B=-.00556
I= 1.077

qx(77)= .0829
B=-.00452
I= 1.069

qx(82)= .1164
B=-.00495
I= 1.073

I(85+)=  1.075

P OF DEATH 100=  .398

PROB OF SURVIVAL
TO 100= .00164

LE=67.8241
```

extrapolate q_x from x = 82 to x = 99, the probability of death during the 100th year of life (age 99), the probability of surviving to one's 100th birthday, and the calculated life expectancy at birth (Equation 5). These quantities are provided to allow the user to check the validity of the generated single-year life table. In general, I values should be in the range of 1.06 to 1.12 for ages 32 and above, and the q_x values should agree closely with those obtained by manual application of Equation 17. Finally, the life expectancy should be within 0.5 year of the life expectancy given for the abridged life table. A single-year life table produced by a GRADUATE run that satisfies these criteria can be assumed to be reasonably accurate.

At the end of a GRADUATE run, consult the file directory (enter CAT ALL) and you will find a new file with the name

FILEGR

i.e., the name of the input file plus the letters GR. For the case of our example (Figure 2), this will be named WFLCGR. This file contains the single-year life table that will be used by MULDEC.

Attempting to list this file will generate the message

WARNING: line too long

This does not mean there is any problem with the file. Rather, the file has been generated to occupy the minimum amount of memory and is not fully listable on the display. For a discussion of this point, see the HP-75 Owner's Manual, p. 228. These files can be listed using the GARR LIST utility described below.

This completes our discussion of the GRADUATE program. A program listing for GRADUATE is given in Appendix A.

4.4 Running MULDEC Program

To run the MULDEC program, follow the same initial steps outlined for GRADUATE. A minimum of two additional files, one like that used for input to GRADUATE and

MULDEC (Figure 1) and a "GR" file containing q_x values for ages 0 to 100+, must be in memory. After you enter

RUN "MULDEC"

you will get the prompt

SINGLE YR LIFE TABLE FILE?>

This asks for the name of a "GR" file of the form generated by GRADUATE. For our example we would reply

WFLCGR.

If there were a problem with this name, a

BAD OR NONEXISTENT FILE

message would be generated and should be handled as in the GRADUATE program. (MULDEC will continue prompting for a file until execution is halted or a valid file name is entered.)

Following entry of a valid "GR" file, you will get the prompt

FILE FOR DEATH DATA?>

This asks for an input file of the format described under Section 4.2, "Preparing Input File for GRADUATE and MULDEC." Invalid file names will be handled in the manner described above.

For our example, the input file name would usually be

WFLC

That is the same file used to generate the GR file. (However, here we are interested in the death data that are used as in Equation 26.) The option of entering a different file name is provided because it might be of interest to generate multiple-decrement life tables with the basic mortality experience of one population but with the proportional mortality experience of another. An example might be "what would a population with the life expectancy of women and the proportional lung cancer experience of men look like in our risk model?".

If a valid file name is entered (or else "BAD OR NONEXISTENT FILE" will be generated), the prompt

HEADING FOR OUTPUT?>

will appear.

This asks for a string of up to 32 characters, which will be written on the first line of the output file. This is used to label the file and may contain whatever information the user chooses.

Following this, you will get the prompt

OUTPUT FILE NAME?

which asks for the name under which you wish to store the multiple-decrement life table that will be generated. For our example (Figure 3), the name chosen is

WFLCMD

After this information has been generated, the computer will display the word

WORKING

for about 30 seconds. During this period, the q_{bx} and q_{cx} values are calculated and the output file is created.

FIGURE 3

SAMPLE OUTPUT FROM MULDEC, INCLUDING
PARTIAL LISTING OF LIFE TABLE (AGES 0 - 43)

```
****************
CONSTRUCT MULDEC
****************

MORTALITY FILE=WFLCGR

DEATH DATA=WFLC

OUTFILE= WFLCMD
```

AGE	qby	qcx
0	1.61E-002	0.00E+000
1	7.01E-004	0.00E+000
2	7.01F-004	0.00E+000
3	7.01E-004	0.00E+000
4	7.01E-004	0.00E+000
5	3.20E-004	0.00E+000
6	3.20E-004	0.00E+000
7	3.20E-004	0.00E+000
8	3.20E-004	0.00E+000
9	3.20E-004	0.00E+000
10	3.00E-004	0.00E+000
11	3.00E-004	0.00E+000
12	3.00E-004	0.00E+000
13	3.00E-004	0.00E+000
14	3.00E-004	0.00E+000
15	4.43E-004	0.00E+000
16	5.06E-004	0.00E+000
17	5.77E-004	0.00E+000
18	5.92E-004	3.28E-007
19	6.07E-004	6.74E-007
20	6.22E-004	1.04E-006
21	6.38E-004	1.42E-006
22	6.55E-004	1.82E-006
23	6.67E-004	2.00E-006
24	6.74E-004	2.16E-006
25	6.82E-004	2.33E-006
26	6.90E-004	2.51E-006
27	6.98E-004	2.69E-006
28	7.45E-004	3.78E-006
29	7.96E-004	5.02E-006
30	8.50E-004	6.42E-006
31	9.08E-004	7.99E-006
32	9.70E-004	9.74E-006
33	1.05E-003	1.31E-005
34	1.15E-003	1.70E-005
35	1.25E-003	2.15E-005
36	1.36E-003	2.67E-005
37	1.48E-003	3.26E-005
38	1.62E-003	3.93E-005
39	1.77E-003	4.70E-005
40	1.94E-003	5.57E-005
41	2.12E-003	6.58E-005
42	2.31E-003	7.73E-005
43	2.51E-003	8.79E-005

The prompt

LIST MULDEC?>

will now appear. If you answer N, no listing will be produced and the message

EXECUTION ENDS

will appear. If your answer is Y, the message

HIT ANY KEY TO STOP

will appear, and a listing of q_{bx} and q_{cx} values will commence (see Figure 3).

As the message implies, hitting any key will cause listing to stop and the message

EXECUTION ENDS

will appear. Note that if you do not list the file at this point and wish to list it later, you must use the GARR LIST utility. Otherwise, the message

WARNING: line too long

will be generated as it was for the "GR" file produced by GRADUATE.

One additional comment regarding MULDEC should be made. If lung cancer mortality is input before total mortality, the message

FAILED CONSISTENCY CHECK
ORDER OF CAUSES WRONG?

will be generated on the printer and execution will terminate. If this happens, make sure that total deaths precede lung cancer deaths in the input file (Figure 1) and try again.

This completes our discussion of the MULDEC program. A program listing is given in Appendix A.

4.5 Running SMOKER Program

To run the SMOKER program, follow the same initial steps outlined for GRADUATE. A minimum of two additional files must be in memory. The first of these is a file containing q_{bx} and q_{cx} values for ages 0 to 100+ in the format generated by MULDEC. The second file must be named "NONSLC" and contains the nonsmoker death rates for the ages shown in Table 6 arranged in the format shown in Figure 4 (if one wishes to use Table 6, Figure 4 may simply be copied). The first prompt is

FILE FOR MULDEC?

which asks for the name of the file containing the q_{bx} and q_{cx} values. An invalid file name will generate the now familiar

BAD OR NONEXISTENT FILE

Following this, the program looks for the NONSLC file. If this is not found, the message

NONSLC INVALID OR MISSING

is generated on the printer and the prompt

LOAD FROM CA?>

will appear in the display. To continue execution, place a cassette containing a copy of NONSLC in the tape drive and answer Y. The file will then be loaded into memory.

FIGURE 4

COPY OF NONSLC FILE LISTING AND
REPRESENTATIVE OUTPUT FROM SMOKER PROGRAM

```
10 ! NONSMOKER DEATH RAT
ES IN DEATHS
20 ! PER 100000 PEOPLE.
SOURCE:GARFINKEL(1981)
30 ! MALES FIRST
40 DATA 4.55,7.63,10.13,
17.26,27.43,25.97,44.27,
68.87,94.8
50 ! THEN FEMALES
60 DATA 3.6,5.3,7.07,13.
6,16.17,20.83,34.7,45.8,
52.47
70 ! END
```

```
***********************
SMOK/NONS:LUNGC-MULDEC
***********************


INFILE=WMLC


BAD OR NONEXISTANT FILE


INFILE=WMLCMD
SEX=MALE

***ERROR***
U=  8.000
OUT OF RANGE .5<U<3

U=  1

***ERROR***
 P=  45.000
OUT OF RANGE .1<P<.9

% SMOKERS= .45

***ERROR***
SMR=  10.000
OUT OF RANGE 1<SMR<5

SMR=  1.75

***ERROR***
RELRISK=  40.000
OUT OF RANGE 1<RR<20

MIN RELRISK-L.C.=  5

% SMOKERS VS. AGE
AGE=40  P=4.49E-001
AGE=50  P=4.41E-001
AGE=60  P=4.19E-001
AGE=70  P=3.67E-001
AGE=80  P=2.58E-001
AGE=90  P=8.89E-002

AGE= 39
P. OF D.-N.S.=2.72E-003
P. OF D.-S.=3.74E-003
R.R.-L.C.=5.86E+000
SMR(TOTAL)=1.38E+000
```

```
AGE= 49
P. OF D.-N.S.=6.16E-003
P. OF D.-S.=1.08E-002
R.R.-L C.=2.07E+001
SMR(TOTAL)=1.75E+000


AGE= 59
P. OF D.-N.S.=1.58E-002
P. OF D.-S.=2.77E-002
R.R.-L.C.=3.06E+001
SMR(TOTAL)=1.75E+000


AGE= 69
P. OF D.-N.S.=3.61E-002
P. OF D.-S.=6.32E-002
R.R.-L.C.=2.88E+001
SMR(TOTAL)=1.75E+000


AGE= 79
P. OF D.-N.S.=7.82E-002
P. OF D.-S.=1.37E-001
R.R.-L.C.=1.72E+001
SMR(TOTAL)=1.75E+000


AGE= 89
P. OF D.-N.S.=1.77E-001
P. OF D.-S.=3.09E-001
R.R.-L.C.=6.56E+000
SMR(TOTAL)=1.75E+000


AGE= 99
P. OF D.-N.S.=3.96E-001
P. OF D.-S.=6.93E-001
R.R.-L.C.=5.00E+000
SMR(TOTAL)=1.75E+000

NONS. FILE=NONS
SMOK. FILE=SMOK

LIFE EXPECTANCIES
NONSMOKERS FIRST

LE= 70.29
PROB. OF SURVIVAL
TO 100=2.97E-003

LE= 64.81
PROB. OF SURVIVAL
TO 100=9.68E-006
```

The prompt

MULTIPLIER FOR NONS. L.C.?>

is now given. This asks for a multiplier in the range of .5 to 3 that is used, as in Equation 37, to modify nonsmoker lung cancer death probabilities. An answer of 1 leaves these quantities unmodified. An answer outside the range of 0.5 to 3 generates an error message (Figure 4) and causes the prompt to repeat.

The next prompt is

MALE OR FEMALE?>

One may answer M or F to select male or female lung cancer rates from NONSLC. An answer other than M or F causes females to be selected by default.

The next prompt

STARTING P OF SMOKERS?>

asks for the proportion of 35-year-old smokers in the population. Your reply must be a number in the range of 0.2 to 0.9. If this range is exceeded, an error message of the form shown in Figure 4 is generated and the prompt is repeated.

The next prompt is

SMOKER VS NS. TOTAL SMR?>

This asks for the all-cause smoking mortality ratio for smokers versus nonsmokers at ages 45 and above. A number in the range of 1 to 5 is expected. Exceeding this range will generate an error message (Figure 4) and cause the prompt to repeat.

The next prompt is

MIN RELRISK L.C.?>

This asks for a minimum value of the relative risk of lung cancer in smokers versus nonsmokers at ages 45 and above. Your answer must be in the range of 1 to 20 (see Figure 4).

Two final sets of prompts are

HEADING FOR NONS.?>

and

FILE NAME FOR NONS.?>

These ask for the heading (up to 32 characters) that will be written at the top of the nonsmoker file and the name of the file into which the nonsmoker file should be written. Similar prompts appear for the smoker file.

After this information is provided, the life expectancies for smokers and nonsmokers as well as their probabilities of surviving to 100 (S_{100}) are printed and the message

EXECUTION ENDS

appears on the display. Program execution is now complete.

Returning to the output of SMOKER reproduced in Figure 4, we start with the title

SMOK/NONS: LUNGC-MULDEC

This is followed by the phrase

INPUT FILE = WMLC

and the error message

BAD OR NONEXISTENT FILE

Taken together, these tell us that we attempted to access an inappropriate file named WMLC.

Then we see

INPUT FILE = WMLCMD

followed by

SEX = MALE

The first phrase says that our input file is named WMLCMD; the second says that we selected the male portion of NONSLC.

Following these is an error message that says

ERROR
P = 45.00
OUT OF RANGE .1 < P < .9

and the phrase

% SMOKERS = .45

These tell us that we attempted to declare 45 as the proportion of smokers at age 35 and that we corrected this to 0.45. Similar error messages appear for the all-cause standard mortality ratio (SMR) and for the minimum relative risk of lung cancer.

The next section of output is labeled

% SMOKERS VS. AGE

This gives the calculated age-specific proportion of smokers in the population (Equation 34) at 10-year intervals starting with age 40. Here the proportion of smokers falls from 0.449 at age 40 to 0.089 at age 90.

Most of the remaining output is devoted to displaying the age-specific probability of death, q_x, in nonsmokers (P. OF D. - N.S.), age-specific probability of death in smokers (P. OF D. - S), age-specific relative risk of lung cancer in smokers versus nonsmokers (R.R. - L.C.), and the age-specific all-cause SMR of smokers versus nonsmokers (SMR(TOTAL)) for 10-year intervals starting at age 39. This information is provided to give the user some insight as to the characteristics of the populations generated. Note that, for ages 49 and above, the all-cause SMR equals the SMR specified in setting up the program (1.75 in this case).

The final pieces of information provided are the names of the nonsmoker and smoker files generated (for our example, NONS and SMOK, respectively) and life expectancies and probabilities of survival to 100 for nonsmokers and smokers.

Note that both output files from SMOKER are the same format as that produced by MULDEC. Therefore, they too must be listed using the GARR LIST utility.

This completes our discussion of the SMOKER program. A program listing is given in Appendix A.

4.6 Running RADRISK Program

To run the RADRISK program, verify that it is in memory and enter

```
RUN "RADRISK"
```

After a few seconds (which are required for initialization), you will receive the prompt

```
INPUT: KEYBD.(K) or FILE (F)?>
```

This prompt asks whether you wish to parameterize the model by inputting values from the keyboard or by providing a data file containing the necessary inputs. We will consider input from the keyboard first, i.e., we assume that the option K is selected.

4.6.1 Input from Keyboard

The first prompt is

AGE AT FIRST RISK?>

which asks for the first age at which excess lung cancer risk can be greater than zero. The reply expected is a number in the range of 5 to 50. Ages outside this range cause the message

AGE AT FIRST RISK (nnn)
OUT OF BOUNDS; 4 < AO < 51,

where nnn is the faulty input, to appear on the printer and the prompt for age at first risk to be repeated.

The next prompt

AGE AT FIRST EXPOSURE?>

is self-explanatory. If a number less than 0 is entered, the age at first exposure is set equal to 0; if a number greater than 99 is entered, age at first exposure is set equal to 99.

The prompt

AGE AT LAST EXPOSURE?>

follows logically. If the reply is less than 1, age at last exposure is set equal to 0. If the reply is greater than 100, it is set equal to 100.

Following entry of age at first exposure and age at last exposure, RADRISK checks to make sure that the former is less than or equal to the latter. If this is not the case, an error message of the form

AGE F.E. (nnn) > AGE L.E. (mmm),

where nnn and mmm are the ages at first and last exposure that cause the problem, appears on the printer and the prompts for ages at first and last exposure are repeated. Following this, the prompt

RISK/WLM - R.R.?>

asks for the value for the relative risk coefficient. Your response must be in the range of 0 to 0.2. A reply outside this range causes an error message similar to that generated for an "out of bounds" age at first risk (see Figure 5A) to appear on the printer. When a relative risk coefficient greater than zero is entered, the prompt

R.R. OPTION (M, E, OR B)?>

appears. Entering M in reply causes the multiplicative form of the relative risk model (Equation 3) to be executed. Similarly, if E is entered, the exponential form of the model (Equation 4) is executed. A reply of B calls up both models as will replies other than M, P, or B. (That is, B is the default option.)

The next prompt

RISK/WLM - A.R.?>

asks for a value for the absolute risk coefficient. This must be in the range of 0 to 0.0002 or an "out of bounds" error message (Figure 5A) will appear on the printer.

FIGURE 5

REPRESENTATIVE OUTPUT FROM RADRISK PROGRAM:

A. ERROR MESSAGES, B. SENSITIVITY FILE,
C. PROGRAM OUTPUT, INCLUDING MODEL PARAMETERIZATION,
D. INPUT FILE FOR FILE OPTION

A.

```
AGE AT FIRST RISK(  2)
OUT OF BOUNDS; 4<A0<51

AGE F.E.( 99)) AGE L.E.(
  1)

RELATIVE RISK(1.00E+000)
OUT OF BOUNDS; 0<R1<.2

ABSOLUTE RISK(2.00E-004)
OUT OF BNDS; 0<R2<2E-4

LATENCY( 50.000)
OUT OF BOUNDS; 0<=T7<46

EXPOSURE  LEVEL(50.00E+0
01)
OUT OF BOUNDS; 0<W1<100
```

B.

```
5 ! AGE SPECIFIC SENSITI
VITIES FOR RADRISK
10 DATA 3,3,3,3,3,3,3,3,
3,3,2.5,2,1.5,1,1,1,1,1,
1,1,1,1,1,1,1,1
20 DATA 1,1,1,1,1,1,1,1,
1,1,1,1,1,1,1,1,1,1,1,1,
1,1,1,1,1,1,1,1
30 DATA 1,1,1,1,1,1,1,1,
1,1,1,1,1,1,1,1,1,1,1,1,
1,1,1,1,1,1,1,1
40 DATA 1,1,1,1,1,1,1,1,
1,1,1,1,1,1,1,1,1,1,1,1,
1,1,1,1,1,1,1,1
50 DATA 1,1,1,1,1,1,1,1,
1,1,1,1,1,1,1,1,1,1,1,1,
1,1,1,1,1,1,1,1
```

C.

```
RADON RISK MODEL

R.R. COEF=1.00E-002/WLM
OPTION=B
A.R.=1.00E-005/PY/WLM
AGE AT F.E.=  0
AGE AT L.E.=100
AGE AT FIRST RISK= 30
WLM PER YR.=10.00E-001
LATENCY=10
EXPONENT COR=-1.00E-002
AGE SP.SEN=SENS
*********************
*********************
POP. 1 =WMSMMD

BASELINE
L.E.=65.081
DEATHS/10^5 -LC= 8632.8

RELRISK MODEL-M
L.E.=64.607
LOSS LE(MONS)=  5.69
D/10^5=12591.2
EXCESS D/10^5= 4255.4

RELRISK MODEL-E
L.E.=64.475
LOSS LE(MONS)=  7.27
D/10^5=13721.5
EXCESS D/10^5= 5469.3

ABSRISK MODEL
L.E.=64.760
LOSS LE(MONS)=  3.86
D/10^5=10118.4
EXCESS D/10^5= 1621.0

*********************
POP. 2 =WMNSMD

BASELINE
L.E.=70.567
DEATHS/10^5 -LC=  698.5

RELRISK MODEL-M
L.E.=70.523
LOSS LE(MONS)=   .53
D/10^5= 1064.1
EXCESS D/10^5=  367.8

RELRISK MODEL-E
L.E.=70.510
LOSS LE(MONS)=   .68
D/10^5= 1179.0
EXCESS D/10^5=  483.5

ABSRISK MODEL
L.E.=70.136
LOSS LE(MONS)=  5.17
D/10^5= 2598.4
EXCESS D/10^5= 1913.0

*********************
```

D.

```
10 ! STANDARD INPUT PARA
METERS FOR RADRISK
20 DATA 30,0,100,.01,B,.
00001,10,1,Y,-.01,Y,SENS
```

It should be noted that if either the relative or absolute risk coefficient is specified as zero, RADRISK skips execution of that model because no effect is assumed a priori.

The program next asks for

LATENCY IN YEARS?>

The reply must be in the range of 0 to 45 or an "out of bounds" error will appear on the printer (see Figure 5A).

The next quantity requested is

ANNUAL EXPOSURE IN WLM?>

This asks for the constant working level month per year exposure that is assumed. Replies in the range of 0 to 100 are accepted. Otherwise, an "out of bounds" error is generated (Figure 5A).

The next query is

EXPONENTIAL CORRECTION?>

If your reply is Y, the prompt

EXPONENT=?>

appears. This asks for a constant in the range of -0.2 to 0, which is used to decrease effective exposure (the r of Equation 45) over time.

Replying N to the query "EXPONENTIAL CORRECTION" results in no correction (i.e., r = 0).

The next prompt in the sequence is

AGE SPECIFIC SENSITIVITIES?>

This asks whether a data file containing 101 numbers specifying age-specific sensitivities for the ages 0 to 100+ is to be read in. If the answer is Y, the query

FILE FOR AGE SENS?>

asks for the name of the file. At this point, one can either provide a valid file name or reply

NONE

which aborts the request for a sensitivity file and assumes all age-specific sensitivities are unity. A sample input file for this option is shown in Figure 5B. This file assumes that children under 10 are 3 times as sensitive to radon damage as those who are older and that sensitivity declines to 1 at ages 13 and beyond.

4.6.2 Designation of Population at Risk and Interpretation of Output

At this point the model parameterization (Figure 5C) is listed, and the prompt

FILE NAME FOR INPUT?>

asks for the file containing the multiple-decrement life table that describes the mortality experience of the population assumed at risk (e.g., an output file of MULDEC or SMOKER). If the name NONE is entered, the "NEW INITIAL CONDITIONS?>" prompt described below is displayed because RADRISK assumes that you do not want to run any populations at the exposure regime specified. Obviously, you cannot name a valid input file NONE.

Following the entry of a valid file, the prompt

PURGE INPUT FILE?>

appears. If your answer is Y, the input file will be erased from memory; otherwise, it will be retained in memory. This feature is included to prevent memory overflow when a number of input files are loaded from tape (described below under Section 4.6.4). After this, the output shown in Figure 5C is generated.

In the model parameterization shown in Figure 5C, the relative risk coefficient is 0.01; both forms of the relative risk model have been selected; the absolute risk coefficient is 0.00001; age at first exposure is 0; age at last exposure is 100 (lifetime exposure is assumed); age at first risk is 30; the exposure is 1 WLM per year; latency is 10 years; an exponential correction (r) of -0.01 is assumed; and age-specific sensitivities of the form shown in Figure 5B are input from a file called SENS.

The first population entered is WMSMMD, a population of male smokers. The part of the output labeled BASELINE shows that with no radon exposure the life expectancy of this population is about 64.8 years, and 9,529 lung cancer deaths per 100,000 are expected. The section labeled RELRISK MODEL-M shows that, under our multiplicative relative risk model, life expectancy is reduced 6.41 months, and 4,855.7 premature lung cancer deaths (EXCESS DEATHS/10^5) per 100,000 persons at risk are expected. The next section, labeled RELRISK MODEL-P, shows that the proportional form of the relative risk model predicts somewhat greater effects. Here the loss in life expectancy is 8.26 months, and the premature deaths are 6,294.8. The section labeled ABS RISK MODEL shows that for the absolute risk model loss in life expectancy is 3.95 months, and the premature deaths are 1,670.7.

Close inspection of the output shown in Figure 5 also makes the point that premature lung cancer deaths are not precisely the same thing as excess lung cancer deaths. As noted above, the premature deaths under the multiplicative relative risk model equal 4,855.7. If we instead tried subtracting total lung cancer deaths expected in the absence of exposure from total lung cancer deaths expected in the presence of exposure (D/10^4), we get

14005.6 - 9529.9 = 4475.7

or a difference of 380 deaths from our "premature" figure. Similar differences are apparent in our other models. This illustrates the fact that, because an excess source of cancer mortality "competes" with the baseline level of the cancer, the total cancer observed in the exposed population is always less than would be expected from summing baseline and premature cancer deaths.

After the output for population 1 (WMSMMD) is generated, we receive the prompt

RUN ANOTHER POPULATION?>

In our example we answered Y, which generated

FILE NAME FOR INPUT?>

Our reply was WMNSMD, which specified a file for male nonsmokers and generated the final section of the output using the new population and the previously entered model specification.

RADRISK will process populations for a given set of input parameters until one answers N to "RUN ANOTHER POPULATION?>." At this point, the prompt

NEW INITIAL CONDITIONS?>

appears. An answer of N stops execution and causes the message

EXECUTION ENDS

to appear on the display. An answer of Y returns us to the prompt "INPUT: KEYBD.(K) OR FILE (F)?>."

4.6.3 Input Via File

If we answer F to the prompt just mentioned, we are asked

    FILE NAME?>

which requests the name of a file configured as in Figure 5D. If the answer to this prompt is "NONE," you will be returned to keyboard input. The only necessary part of such a file is the data statement which contains, in this order, age at first risk, age at first exposure, age at last exposure, the relative risk coefficient, the choice of relative risk models (a reply must be included; if the relative risk coefficient is zero, use B), the absolute risk coefficient, latency, exposure level in WL, the answer to whether or not an exponential reduction factor is desired, a value for the exponential factor (this must be included; if a reduction is not specified, use zero), the answer to whether or not a file of age-specific sensitivities is to be used, and the name of such a file (here, too, a name must be given; if the preceding answer is N, use the name "NONE"). For the example file, the reader can verify that we have specified the same model parameterization used in our example output for RADRISK. If this format is not followed, error messages will be generated as described in the following section.

A useful feature of output from a file is that all the error checks provided for keyboard input are in effect for file input. Thus one will be asked for substitute values for any bad arguments (but only for bad arguments). A specific example might be reversing age at first and last exposure. This generates the message

    AGE F.E. (nnn) > AGE L.E. (mmm)

on the printer and prompts for revised ages of first and last exposure. Such an "error" could be of practical use. Say that we want to consider the same risk models for individuals exposed at different age ranges (as in an occupational setting). We can construct an input file with the age of first exposure greater than the age of last exposure. Each time we run the model we specify this file and are prompted only for ages of first and last exposure. In practice this saves a bit of time and typing.

4.6.4 Error Handling and Loading Input Files from Cassette

Thus far in our discussion of input files, we have assumed that valid files were resident in memory. If this is not the case, the message

FILE XXXX???

will appear on the printer, where XXXX is the problem file name, and the prompt

ON CASSETTE?>

appears. This sequence means either that there is something wrong with the file format of XXXX or that it is not in memory. If your response is Y, RADRISK attempts to load the file named XXXX from cassette. The user should be cautious in answering Y to the last prompt. That is, make sure a cassette containing the file of interest is in the drive. If this is not the case, a further error occurs and RADRISK, having determined that the necessary file is not in memory or on cassette, halts execution and displays the message

EXECUTION ENDS

To prevent such a termination, reply N and you will be returned to the prompt asking for the relevant information (e.g., either "INPUT: KEYBD (K) OR FILE (F)?>," "FILE FOR AGE SENS?>," OR "FILE NAME FOR INPUT?>"). The first two of these may be aborted by answering "NONE." The last must be answered with a valid file name. If no valid input file for the population exists, one must be created using GRADUATE, MULDEC, and SMOKER.

4.6.5 Additional Output Features

Figure 6 displays 3 additional outputs from RADRISK. These are intended to illustrate how changes in model specification affect the output. In the first, the model specification is the same as shown in Figure 5 except that age at first exposure is changed to 10, the exponential form of the relative risk model is specified, and the absolute risk coefficient is given as zero. Note that, as stated earlier, specifying the coefficient as zero prevents execution

FIGURE 6

THREE ALTERNATIVE PARAMETERIZATIONS OF RADRISK MODEL

********************	********************	********************
********************	********************	********************
RADON RISK MODEL	RADON RISK MODEL	RADON RISK MODEL
R.R. COEF=1.00E-002/WLM	R.R. COEF=0.00E+000/WLM	R.R. COEF=0.00E+000/WLM
OPTION=E	OPTION=	OPTION=
A.R.=0.00E+000/PY/WLM	A.R.=1.00E-005/PY/WLM	A.R.=0.00E+000/PY/WLM
AGE AT F.E.= 10	AGE AT F.E.= 30	AGE AT F.E.= 0
AGE AT L.E.=100	AGE AT L.E.=100	AGE AT L.E.=100
AGE AT FIRST RISK= 30	AGE AT FIRST RISK= 30	AGE AT FIRST RISK= 30
WLM PER YR.=10.00E-001	WLM PER YR.=10.00E-001	WLM PER YR.=00.00E-001
LATENCY=10	LATENCY=10	LATENCY=10
EXPONENT COR=-1.00E-002	EXPONENT COR=00.00E-001	EXPONENT COR=00.00E-001
SENSITIVITY=1	SENSITIVITY=1	SENSITIVITY=1
********************	********************	********************
********************	********************	********************
POP. 1 =WMSMMD	POP. 1 =WMSMMD	POP. 1 =WMSMMD
BASELINE	BASELINE	BASELINE
L.E.=56.848	L.E.=38.109	L.E.=65.081
DEATHS/10^5 -LC= 8871.1	DEATHS/10^5 -LC= 9117.1	DEATHS/10^5 -LC= 8632.8
RELRISK MODEL-E	ABSRISK MODEL	********************
L.E.=56.500	L.E.=38.052	
LOSS LE(MONS)= 4.18	LOSS LE(MONS)= .68	
D/10^5=11990.1	D/10^5= 9553.4	
EXCESS D/10^5= 3344.0	EXCESS D/10^5= 470.3	
********************	********************	

of the absolute risk model and that specifying the age at first exposure as 10 changes life expectancy to 56.57 years. The latter change is because we are now calculating life expectancy at age 10 rather than at age 0.

The next two outputs drop the exponential correction and age-specific sensitivities, change age at first exposure to 30 and 50, respectively, and suppress execution of first the relative risk and then both models.

4.6.6 Conclusion

This completes what is designed to be a tutorial on running the RADRISK model. Review of this material should enable even persons with little prior knowledge of computers or computer programming to run RADRISK and thus produce a wide variety of radon risk models. A program listing is given in Appendix A.

4.7 LIST Utility

We noted earlier that GRADUATE, MULDEC, and SMOKER all generate output files that cannot be listed using the system LIST command. This section describes the LIST utility that allows review of both file types (remember, MULDEC and SMOKER generate the same file format). To use LIST, simply enter

```
RUN "LIST"
```

You will (assuming the file is in memory) receive the prompt

```
PRINTER (P) OR DISPLAY (D)?>
```

if you answer D, the file will be listed on the display; if you answer P, the file will be listed on the printer (other replies cause the printer to be selected by default).

Following this, you will receive the prompt

```
FILE NAME?>
```

If the answer is the name of a GRADUATE output file, you will get the output shown in Figure 7A; if the answer is the name of a MULDEC or SMOKER output file, you will get the output shown in Figure 7B.

In either case, as soon as output begins, you will receive the message

    HIT ANY KEY TO STOP

As the message implies, hitting any alphanumeric key will stop the file from listing and will generate the prompt

    LIST ANOTHER FILE?>

If this is answered Y, you return to the PRINTER (P) OR DISPLAY (D)?> prompt; otherwise

    EXECUTION ENDS

appears on the display.

In the event that you enter a name that is invalid, you will receive the message

    BAD OR NONEXISTENT FILE

on the printer and will be prompted for a revised file name. LIST cannot load files from tape, so any files you wish to list must be in memory.

A final problem that may arise is that, if the ATTN key is hit during the listing of a file on the display, subsequent print operations will be directed to the display. To remedy this, enter

    PRINTER IS ":PR"

or

    RUN "LIST"

FIGURE 7A

REPRESENTATIVE OUTPUT FROM LIST UTILITY FOR A GR FILE (AGES 0 - 45)

NAME=WMLCGR
TYPE=GR

AGE	qx
0	2.13E-002
1	8.26E-004
2	8.26E-004
3	8.26E-004
4	8.26E-004
5	4.80E-004
6	4.80E-004
7	4.80E-004
8	4.80E-004
9	4.80E-004
10	4.80E-004
11	4.80E-004
12	4.80E-004
13	4.80E-004
14	4.80E-004
15	9.47E-004
16	1.20E-003
17	1.51E-003
18	1.60E-003
19	1.69E-003
20	1.78E-003
21	1.88E-003
22	1.98E-003
23	1.96E-003
24	1.90E-003
25	1.84E-003
26	1.78E-003
27	1.73E-003
28	1.75E-003
29	1.77E-003
30	1.80E-003
31	1.82E-003
32	1.85E-003
33	1.98E-003
34	2.13E-003
35	2.29E-003
36	2.46E-003
37	2.65E-003
38	2.89E-003
39	3.18E-003
40	3.49E-003
41	3.83E-003
42	4.21E-003
43	4.62E-003
44	5.08E-003
45	5.59E-003

FIGURE 7B

REPRESENTATIVE OUTPUT FROM LIST UTILITY FOR A MULDEC FILE (AGES 0 - 45)

NAME=WMLCMD
TYPE=MULDEC

HEADING=
WM 69 LC

AGE	qbx	qcx
0	2.13E-002	0.00E+000
1	8.26E-004	0.00E+000
2	8.26E-004	0.00E+000
3	8.26E-004	0.00E+000
4	8.26E-004	0.00E+000
5	4.80E-004	0.00E+000
6	4.80E-004	0.00E+000
7	4.80E-004	0.00E+000
8	4.80E-004	0.00E+000
9	4.80E-004	0.00E+000
10	4.80E-004	0.00E+000
11	4.80E-004	0.00E+000
12	4.80E-004	0.00E+000
13	4.80E-004	0.00E+000
14	4.80E-004	0.00E+000
15	9.47E-004	0.00E+000
16	1.20E-003	0.00E+000
17	1.51E-003	0.00E+000
18	1.60E-003	3.07E-007
19	1.68E-003	6.49E-007
21	1.88E-003	1.45E-006
22	1.98E-003	1.91E-006
23	1.96E-003	2.27E-006
24	1.90E-003	2.56E-006
25	1.84E-003	2.83E-006
26	1.78E-003	3.08E-006
27	1.72E-003	3.31E-006
28	1.74E-003	6.26E-006
29	1.76E-003	9.30E-006
30	1.79E-003	1.24E-005
31	1.81E-003	1.56E-005
32	1.83E-003	1.89E-005
33	1.95E-003	2.73E-005
34	2.09E-003	3.70E-005
35	2.24E-003	4.80E-005
36	2.40E-003	6.04E-005
37	2.57E-003	7.44E-005
38	2.80E-003	9.43E-005
39	3.06E-003	1.18E-004
40	3.34E-003	1.45E-004
41	3.65E-003	1.77E-004
42	3.99E-003	2.13E-004
43	4.37E-003	2.44E-004
44	4.80E-003	2.79E-004
45	5.27E-003	3.19E-004

followed by the ATTN key in answer to the first prompt. Either sequence will reactivate the printer.

This completes the discussion of the LIST utility. A program listing is given in Appendix A.

4.8 DUPER Utility

The last program to be included in the GARR package provides the means for making a backup copy of all the files included in the GARR standard tape (see listing in Figure 8). To run this program, enter

```
copy "DUPER:CA" TO "DUPER"
```

(make sure the GARR tape is in the drive; also make sure at least 16,000 bytes of memory are free before DUPER is copied). Then enter

```
RUN "DUPER"
```

Several minutes will elapse while the tape drive loads files from tape to memory. The HP-75 will beep when this operation is completed and the message

```
CHANGE CASSETTE (GARR>BACK) AND ENTER Y WHEN READY
```

will appear on the printer along with the prompt

```
READY?
```

on the display. When this occurs, remove the GARR tape from the drive, replace it with the tape that will contain the backup copy, and enter

```
Y
```

to the prompt.

Several more minutes will elapse while files are written to the backup tape. When writing is completed, the HP-75 will beep again and print the message

CHANGE CASSETTE (BACK>GARR) ENTER Y WHEN READY

and the display will prompt

READY?

When this occurs, change cassettes and enter

Y

Several more minutes will elapse while the remaining programs are copied to memory. The message to change from the GARR tape to the backup tape is then printed, and the READY prompt appears. Remove the GARR tape, insert the backup, and enter a final Y. The tape drive will be busy for a few more minutes. When it stops, the backup tape contains a copy of the GARR tape. This can be verified by entering

CAT ":CA"

which allows you to scan the file directory of the cassette.

This completes our discussion of DUPER. A program listing is given in Appendix A.

4.9 GARR Tape

The final section describes the files resident on the GARR tape as created by DUPER. The listing of files shown in Figure 8 gives the contents of the GARR tape.

The first two files, GRADUATE and MULDEC, contain the GARR programs of the same name. The next, NONSLC, contains a copy of the nonsmoker lung cancer rate file shown in Figure 4. Following this is SMOKER, which contains the

FIGURE 8

OUTPUT LISTING FILES ON STANDARD GARR TAPE

```
>CAT ":CA"
  Name   Type Len  Time
  Date
GRADUATE   B 2560 09:18
10/18/83
MULDEC     B 2560 16:33
11/01/83
NONSLC     B  512 16:44
06/21/83
SMOKER     B 5376 16:29
11/01/83
STANDARD   B  256 10:22
09/14/83
RADRISK    B 6144 11:25
11/07/83
SENS       B  768 16:45
11/02/83
WMLC       B  768 11:26
11/04/83
WFLC       B  768 13:14
04/19/83
LIST       B 1280 11:46
11/04/83
DUPER      B  768 15:34
11/04/83
```

GARR program of the same name. The STANDARD file contains a copy of the input file for RADRISK parameters shown in Figure 5A. The RADRISK file contains our risk assessment model. The SENS file contains the age-specific sensitivity file whose listing appears in Figure 5B. The files WMLC and WFLC contain the type of mortality input files required by GRADUATE and MULDEC (WFLC is listed in Figure 1). Finally, LIST and DUPER contain the GARR utilities of the same names.

Taken together, these files contain all the information needed to work through the examples given in the preceding sections and should enable new users to rapidly verify that they understand how to run the various GARR programs.

4.10 Conclusion

This concludes our discussion of GARR on the HP-75. At this point, the reader has a firm grasp of how to go about constructing radon risk models. I would greatly appreciate user feedback as to the truth of the last statement. Can you construct input files that work? Is the syntax confusing? Does the SMOKER program provide sufficient flexibility in specifying smoker versus non-smoker populations? Has your favorite radon health risk model been omitted from RADRISK? Answers to these questions and any other comments the user may have would be greatly appreciated. In the meantime, I hope that the present form of GARR is a useful tool for radon risk assessment.

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APPENDIX A

PROGRAM LISTINGS AND VARIABLE LISTS

GRADUATE VARIABLE LIST

VARIABLE	DESCRIPTION
C1	Step increment
C7	Quadratic correction term
F1$	Abridged input file name
F2$	Output file name
I	Loop counter
I9	Flag variable
J	Loop counter; delimiter
K, K1, K2	Working variables, age-specific probability of death
L	Loop counter
L1, L2	Loop delimiters
L9	Life expectancy
Q1(18)	Abridged life table
Q2(100)	Graduated life table
S	Step incrementer (line 510); years lived beyond 100th birthday (line 830)
S1(18)	Age-specific step increments
S9	Survival
T7$	Abridged file title
V1	Age variable

GRADUATE PROGRAM LISTING

```
10 ! GRADUATE STANDARD ABRIGED LIFE TABLE TO 0 TO 100+
15 ! FINAL REVISION 10/18/83
20 PRINT USING 30
30 IMAGE //"*******************"/"GRADUATE LIFE TABLE"/"*******************"///
40 DIM Q1(18),Q2(100),S1(18)
50 INPUT "FILE FOR ABRIGED?> ";F1$
60 PRINT "INPUT FILE=";F1$
70 F2$=F1$&"GR"
80 ON ERROR GOSUB 1000 @ GOTO 50
90 ASSIGN # 1 TO F1$
100 READ # 1 ; T7$
110 READ # 1 ; Q1() @ ASSIGN # 1 TO *
120 OFF ERROR
125 DISP "WORKING"
130 PRINT "TITLE= ";T7$ @ PRINT ""
140 ! DO INTERVAL 0 AGE 0-1
150 Q2(0)=Q1(0)
160 ! DO INTERVAL 1 AGE 1-4
170 K=(1-Q1(1))^.25 @ K=1-K
180 FOR I=1 TO 4
190 Q2(I)=K
200 NEXT I
210 ! RESCALE INTERVALS 2-18
220 ! TO ANNUAL AVERAGE (GEOMETRIC) RISK OF
230 ! DEATH  AND GET GEOMETRIC INCREMENTS (S1) FOR INTERPOLATION
240 Q1(2)=1-(1-Q1(2))^.2
250 Q1(3)=1-(1-Q1(3))^.2
260 FOR I=4 TO 17
270 Q1(I)=1-(1-Q1(I))^.2
280 S1(I)=(Q1(I)/Q1(I-1))^.2
290 NEXT I
300 S1(18)=(S1(17)+S1(16)+S1(15))/3
310 !  CORRECT Q1 FOR S
320 FOR I=4 TO 17
330 C1=(S1(I)+S1(I+1))/2
340 IF C1<1.04 THEN C7=0 @ GOTO 370
350 C7=-.77816+1.57115*C1-.79272*C1^2
360 Q1(I)=C7*Q1(I)+Q1(I)
370 V1=(I-1)*5+2
380 PRINT USING 390 ; V1,Q1(I),C7,C1
390 IMAGE "qx(",dd,")=",d.dddd/"B=",d.ddddd/"I=",dd.ddd/
400 NEXT I
410 ! DO INTERVALS 2-3 AGES 5-14
420 FOR I=1 TO 2
430 L1=5*I
440 L2=L1+4
450 FOR J=L1 TO L2
460 Q2(J)=Q1(I+1)
470 NEXT J
480 NEXT I
490 ! DO INTERVALS 4-17 AGES 15-82
500 K1=Q1(3) @ K2=Q1(4)
510 S=S1(4)
520 Q2(15)=K2/S^2
530 Q2(16)=K2/S
540 Q2(17)=K2
550 J=13
560 FOR I=5 TO 17
570 K1=K2 @ K2=Q1(I)
580 S=S1(I)
590 J=J+5 @ K=J+4
600 FOR L=J TO K
610 K1=K1*S @ Q2(L)=K1
620 NEXT L
630 NEXT I
640 ! PREPARE EXTRAP. 83-100+
650 S=S1(18)
660 PRINT USING 670 ; S
670 IMAGE /"I(85+)= ",dd.ddd/
680 K1=Q2(82)
690 I9=0
700 FOR I=83 TO 99
710 K1=K1*S
720 Q2(I)=K1
730 IF Q2(I)<1 THEN 780
740 IF I9=0 THEN PRINT USING 750 ; I
750 IMAGE /"FIRST 1 AT AGE ",ddd,/
760 I9=1
770 Q2(I)=1
780 NEXT I
790 PRINT USING 800 ; Q2(99)
800 IMAGE /"P OF DEATH 100= ",d.ddd/
810 Q2(100)=1
820 ! **FINISHED**..NOW CHECK LE
830 S=.8/Q2(99)
840 S9=1-Q2(0) @ L9=S9+Q2(0)*.1
850 FOR I=1 TO 99
860 L9=.5*S9*Q2(I)+L9
870 S9=S9*(1-Q2(I))
880 L9=L9+S9
890 NEXT I
900 IMAGE "LE=",dd.dddd
910 L9=L9+S9*S
920 PRINT USING 930 ; S9
930 IMAGE /"PROB OF SURVIVAL"/"TO 100=",d.ddddd/
940 PRINT USING 900 ; L9
950 ASSIGN # 1 TO F2$
960 PRINT # 1 ; Q2()
970 ASSIGN # 1 TO *
980 DISP "EXECUTION ENDS"
990 END
1000 PRINT USING 1010
1010 IMAGE //"BAD OR NONEXISTENT"/"FILE"//
1020 ASSIGN # 1 TO *
1030 RETURN
```

MULDEC VARIABLE LIST

VARIABLE	DESCRIPTION
A$	Answer to prompt line 930
D1(2,21)	Deaths array - converted to probabilities (line 330)
F1$	General input file name
F2$	Output file name
H1$	Heading for output
I	Loop counter
J	Loop counter
K	Number of specific causes of death (always 1)
K$	Keyboard variable
L1, L2	Loop delimiters
M	Loop counter
N	Index variable (line 530), loop counter (line 640)
Q2	Single-year life table; working array (line 870)
Q3(2,100)	Multiple-decrement life table
S	Additive step increment
S$	Format variable
T1(21)	Working array--reads in death data
Z	Working variable

MULDEC PROGRAM LISTING

```
10 S$="/"
20 ! MULDEC CALCULATES M
ULTIPLE
30 ! DECREMENT LIFETABLE
 FROM INPUTS FROM
40 ! DEATH FILE AND OUTF
ILE OF GRADUATE
45 ! FINAL REVISION 11/1
/83
50 PRINT USING 60
60 IMAGE //,"************
*****"/"CONSTRUCT MULDEC
"/"****************"/
70 DIM D1(2,21),Q2(100),
T1(21),Q3(2,100)
80 INPUT "SINGLE YR LIFE
 TABLE FILE?>";F1$
90 PRINT "MORTALITY FILE
=";F1$
100 ON ERROR GOSUB 1090
@ GOTO 80
110 IMAGE ddd,2X,d.ddde
120 ASSIGN # 1 TO F1$
130 READ # 1 ; Q2()
140 ASSIGN # 1 TO *
150 INPUT "FILE FOR DEAT
H DATA? >";F1$
160 ON ERROR GOSUB 1110
@ GOTO 150
170 PRINT ""
180 PRINT "DEATH DATA=";
F1$
190 ASSIGN # 1 TO F1$
200 READ # 1,35 ; K
210 OFF ERROR
220 FOR I=0 TO K
230 READ # 1 ; T1()
240 FOR J=0 TO 21
250 D1(I,J)=T1(J)
260 NEXT J
270 NEXT I
280 ! SCALE DEATHS TO PR
OPORTIONS
290 ASSIGN # 1 TO *
300 FOR J=0 TO 21
310 Z=1
315 ON ERROR GOTO 1140
320 FOR I=1 TO K
330 D1(I,J)=D1(I,J)/D1(0
,J)
340 Z=Z-D1(I,J)
350 NEXT I
360 IF Z<0 THEN GOTO 114
0
370 D1(0,J)=Z
380 NEXT J
390 INPUT "HEADING FOR O
UTPUT?>";H1$
400 INPUT "OUTPUT FILE N
AME?";F2$
410 PRINT ""
420 PRINT "OUTFILE= ";F2
$
430 PRINT ""
440 DISP "WORKING"
450 ! SCALE DEATH P'S 0
TO 100
460 FOR I=0 TO K
470 Q3(I,0)=D1(I,0)
480 FOR J=1 TO 4
490 Q3(I,J)=D1(I,1)
500 NEXT J
510 ! DO INTERVALS 2-3 A
GES 5-14
520 FOR M=1 TO 2
530 L1=5*M @ L2=L1+4 @ N
=M+1
540 FOR J=L1 TO L2
550 Q3(I,J)=D1(I,N)
560 NEXT J
570 NEXT M
580 ! DO INTERVALS 4-20;
 AGES 15-97
590 S=(D1(I,4)-D1(I,3))/
5
600 Q3(I,15)=D1(I,4)-2*S
610 Q3(I,16)=D1(I,4)-S
620 Q3(I,17)=D1(I,4)
630 L1=13
640 FOR N=5 TO 20
650 Z=N-1
660 S=(D1(I,N)-D1(I,Z))/
5
670 L1=L1+5 @ L2=L1+4 @
T3=D1(I,Z)
680 FOR J=L1 TO L2
690 T3=T3+S @ Q3(I,J)=T3
700 NEXT J
710 NEXT N
720 Q3(I,98)=Q3(I,97)+S
730 Q3(I,99)=Q3(I,98)+S
740 Q3(I,100)=D1(I,21)
750 NEXT I
760 ! CREATE DEATH PROB'
S BY CAUSE
770 FOR I=0 TO K
780 FOR J=0 TO 100
790 Q3(I,J)=Q3(I,J)*Q2(J
)
800 NEXT J
810 NEXT I
820 ! COPY TO OUTFILE AS
 INSTRUCTED
830 ASSIGN # 1 TO F2$
840 PRINT # 1 ; H1$,K
850 FOR I=0 TO K
860 FOR J=0 TO 100
870 Q2(J)=Q3(I,J)
880 NEXT J
890 PRINT # 1 ; Q2()
900 NEXT I
910 DISP "DONE"
920 INPUT "LIST MULDEC?>
";A$
930 IF A$="Y" THEN 950
940 GOTO 1060
950 DISP "HIT ANY KEY TO
 STOP"
960 PRINT "AGE   qbx
   qcx" @ PRINT ""
970 FOR J=0 TO 100
980 K$=KEY$ @ IF K$<>""
THEN 1060
990 PRINT J;
1000 FOR I=0 TO K
1010 PRINT USING 1020 ;
Q3(I,J);
1020 IMAGE 1X,d.dde
1030 NEXT I
1040 PRINT USING S$
1050 NEXT J
```

```
1060 DISP "EXECUTION END
S"
1070 CLEAR VARS
1080 END
1090 PRINT USING 1120
1100 RETURN
1110 PRINT USING 1120
1120 IMAGE /"BAD OR NONE
XISTANT FILE"/
1130 RETURN
1140 PRINT USING 1150
1150 IMAGE //"FAILED CON
SISTANCY CHECK"/"ORDER O
F CAUSES WRONG?"//
1160 END
```

SMOKER VARIABLE LIST

VARIABLE	DESCRIPTION
A2, A3	Working variables
A$	Answer to prompt line 160
A7$	Answer to prompt line 2080
D(1,8)	Nonsmoker lung cancer death rates
F1$	General input/output file name
H1$	Headings for output files
I	Loop counter
J	Loop counter
K1, K2	Working constants
K	Loop delimiter
L	Loop counter
L1, L2	Loop delimiters
L9	Life expectancy
M9	Minimum relative risk of lung cancer, smoker versus nonsmoker
N	Flag variable (male, female)
O1	Relative risk of lung cancer, smoker versus nonsmoker
O2	Age-specific SMR
P	Proportion of smokers in the population
P2	Proportion of deaths which are due to lung cancer
P3	Proportion of deaths who were smokers
P4	Proportion of deaths who were nonsmokers who died of lung cancer
P5	Proportion of deaths who are smokers who died of lung cancer
Q(100)	Working array
Q0, Q1	Working mortality variables
Q2(1,100)	Nonsmoker multiple decrement lifetable, working array (line 1860)
Q3	Input and smoker (line 1660) multiple decrement lifetable
S	Multiplicative increment-graduation of nonsmoking lung cancer (line 240), smoker versus nonsmoker SMR (line 660), expected number of years lived beyond 100th birthday (line 1930)
S9	Smoker versus nonsmoker SMR, survival (line 1920)
T	Additive increment, all-cause SMR
U	Multiplier for nonsmoker lung cancer
Z	Constant equal to 1
Z9	Counter for age-specific output

SMOKER PROGRAM LISTING

```
10 ! MAKE LUNG CAN. MULT
. DECREMENT LIFE TABLES
20 ! NONS.AND SMOK.
30 PRINT USING 40
40 IMAGE //"************
**********"/"SMOK/NONS:L
UNGC-MULDEC"/"*********
************"///
50 DIM D1(1,8),Q2(1,100)
,Q3(1,100),Q(100)
60 INPUT "FILE FOR MULDE
C?> ";F1$
70 PRINT "INFILE=";F1$
80 ON ERROR GOSUB 1810 @
 GOTO 60
90 ASSIGN # 1 TO F1$
100 READ # 1 ; T7$,I,Q3(
,)
110 ASSIGN # 1 TO *
120 ON ERROR GOTO 2060
130 ASSIGN # 1 TO "NONSL
C"
140 READ # 1 ; D1(,)
150 ASSIGN # 1 TO *
155 OFF ERROR @ N=1
160 INPUT "MALE OR FEMAL
E?(M/F)>";A$
170 IF A$="M" THEN N=0
180 IF A$="M" THEN PRINT
 "SEX=MALE" ELSE PRINT "
SEX=FEMALE"
182 INPUT "MULTIPLIER FO
R NONS. L.C.?>";U
184 IF U<.5 OR U>3 THEN
186 ELSE 190
186 PRINT USING 188 ; U
@ GOTO 182
188 IMAGE /"***ERROR***"
/"U= ",dd.ddd/"OUT OF RA
NGE .5<U<3"/
190 PRINT "U= ";U
195 ! SCALE RATE TO PROB
200 FOR I=0 TO 8
210 D1(N,I)=D1(N,I)/1000
00 @ D1(N,I)=D1(N,I)*U
220 NEXT I
230 ! DO  AGES 45-100
240 K1=D1(N,0) @ K2=D1(N
,1) @ S=(K2/K1)^.2
260 Q2(1,45)=K1/S^2
270 Q2(1,46)=K1/S
280 Q2(1,47)=K1
290 K2=D1(N,0)
300 J=43
310 FOR I=1 TO 8
320 K1=K2 @ K2=D1(N,I)
330 S=(K2/K1)^.2
340 J=J+5 @ K=J+4
350 FOR L=J TO K
360 K1=K1*S @ Q2(1,L)=K1
370 NEXT L
380 NEXT I
390 ! PREPARE EXTRAP. 88
-100+
400 K1=D1(N,8)
410 FOR I=88 TO 99
420 K1=K1*S
430 Q2(1,I)=K1
440 NEXT I
450 FOR I=0 TO 44
460 FOR J=0 TO 1
470 Q2(J,I)=Q3(J,I)
480 NEXT J
490 NEXT I
500 FOR I=35 TO 44
510 IF Q3(1,I)>Q2(1,45)
THEN Q2(1,I)=Q2(1,45)
520 NEXT I
530 FOR I=86 TO 99
540 IF Q3(1,I)<Q2(1,I) T
HEN Q2(1,I)=Q3(1,I)
550 NEXT I
560 Q2(1,100)=Q3(1,100)
570 ! GRADUATION OF NONS
. L.C. COMPLETE
580 !
590 ! BEGIN SMOKE-N.S. C
ALC.
600 INPUT "STARTING P OF
 SMOKERS?>";P
610 IF P>.1 AND P<.9 THE
N 650
620 PRINT USING 630 ; P
630 IMAGE /"***ERROR***"
/" P= ",ddd.ddd/"OUT OF
RANGE .1<P<.9"/
640 GOTO 600
650 PRINT "% SMOKERS=";P
660 INPUT "SMOKER VS. NS
. TOTAL SMR?>";S
670 IF S>1 AND S<5 THEN
710
680 PRINT USING 690 ; S
690 IMAGE /"***ERROR***"
/"SMR= ",ddd.ddd/"OUT OF
 RANGE 1<SMR<5"/
700 GOTO 660
710 PRINT "SMR= ";S
720 INPUT "MIN RELRISK L
.C.?>";M9
730 IF M9>1 AND M9<20 TH
EN 770
740 PRINT USING 750 ; M9
750 IMAGE /"***ERROR***"
/"RELRISK= ",ddd.ddd/"OU
T OF RANGE 1<RR<20"/
760 GOTO 720
770 PRINT "MIN RELRISK-L
.C.= ";M9
780 DISP "WORKING"
790 ! ADJUST INTERVALS 3
5-43
800 OFF ERROR
810 T=(S-1)/10 @ S9=1+T
820 L1=35 @ L2=43
830 Z9=40
840 ! CALL NESSM
850 GOSUB 1450
860 ! NOW DO 44-99
870 T=0 @ S9=S
880 L1=44 @ L2=99
890 ! CALL NESSM
900 GOSUB 1450
910 ! DO INTERVAL 100 NO
NSMOKERS 1ST
920 Q0=Q2(0,99)+Q2(0,98)
930 Q1=Q2(1,99)+Q2(1,98)
940 Q2(0,100)=Q0/(Q0+Q1)
950 Q2(1,100)=1-Q2(0,100
)
960 Q0=Q3(0,99)+Q3(0,98)
970 Q1=Q3(1,99)+Q3(1,98)
980 Q3(0,100)=Q0/(Q0+Q1)
990 Q3(1,100)=1-Q3(0,100
)
```

```
1000 FOR I=39 TO 99 STEP
 10
1010 A2=Q2(0,I)+Q2(1,I)
1020 IF A2>1 THEN PRINT
"N.S. P>1 AT AGE ";I
1030 A3=Q3(0,I)+Q3(1,I)
1040 IF A3>1 THEN PRINT
"SMOKER P>1 AT AGE ";I
1050 O1=Q3(1,I)/Q2(1,I)
1060 O2=A3/A2
1070 PRINT USING 1080 ;
I,A2,A3,O1
1080 IMAGE /"AGE=",ddd/"
P. OF D.-N.S.=",d.dde/"P
. OF D.-S.=",d.dde/"R.R.
-L.C.=",d.dde
1090 PRINT USING 1100 ;
O2
1100 IMAGE "SMR(TOTAL)="
,d.dde/
1110 NEXT I
1120 Z=1
1130 ! PREPARE TO OUTPUT
1140 INPUT "HEADING FOR
NONS.?)";H1$
1150 INPUT "FILE NAME FO
R NONS.?)";F1$
1160 ASSIGN # 1 TO F1$
1170 DISP "WORKING"
1180 PRINT "NONS. FILE="
;F1$
1190 PRINT # 1 ; H1$,Z
1200 FOR I=0 TO 1
1210 FOR J=0 TO 100
1220 Q(J)=Q2(I,J)
1230 NEXT J
1240 PRINT # 1 ; Q()
1250 NEXT I
1260 ASSIGN # 1 TO *
1270 INPUT "HEADING FOR
SMOK.?)";H1$
1280 INPUT "FILE NAME FO
R SMOK.?)";F1$
1290 ! SUBROUTINE NESSM
1300 ASSIGN # 1 TO F1$
1310 DISP "WORKING"
1320 PRINT "SMOK. FILE="
;F1$
1330 PRINT # 1 ; H1$,Z
1340 FOR I=0 TO 1
1350 FOR J=0 TO 100
1360 Q(J)=Q3(I,J)
1370 NEXT J
1380 PRINT # 1 ; Q()
1390 NEXT I
1400 ASSIGN # 1 TO *
1410 GOSUB 1840
1420 DISP "EXECUTION END
S"
1430 CLEAR VARS
1440 END
1450 IF L1>35 THEN 1480
1460 PRINT ""
1470 PRINT "% SMOKERS VS
. AGE"
1480 FOR I=L1 TO L2
1490 ! FIND TOTAL DEATH
P-GEN POP
1500 Q0=Q3(0,I)+Q3(1,I)
1510 ! FIND TOTAL DEATH
P-NONS.
1520 Q1=Q0/(1-P+S9*P)
1530 ! GET BACKGROUND NO
NS.
1540 Q2(0,I)=Q1-Q2(1,I)
1550 ! FIND % DEATHS DUE
 TO L.C.
1560 P2=Q3(1,I)/Q0
1570 ! FIND % DEATHS WHO
 SMOKE
1580 P3=P*Q1*S9/Q0
1590 ! FIND % DEATHS N.S
.-L.C.
1600 P4=(1-P3)*Q2(1,I)/(
Q2(0,I)+Q2(1,I))
1610 ! FIND % DEATH SM.-
L.C.
1620 P5=P2-P4
1630 ! FIND P. OF DEATH-
TOTAL FOR SMOK.
1640 Q0=S9*Q1
1650 ! FIND P. OF D. SMO
KER-L.C.
1660 Q3(1,I)=Q0*P5/P3
1670 O1=Q3(1,I)/Q2(1,I)
1680 IF O1<M9 AND I>45 T
HEN Q3(1,I)=M9*Q2(1,I)
1690 ! GET SMOKER BACKGR
OUND
1700 Q3(0,I)=Q0-Q3(1,I)
1710 S9=S9+T
1720 Q0=1-Q0 @ Q1=1-Q1
1730 P=P*Q0/(P*Q0+(1-P)*
Q1)
1740 Q(I)=P
1750 IF Z9>I THEN GOTO 1
790
1760 PRINT USING 1770 ;
I,P
1770 IMAGE "AGE=",dd,2X,
"P="d.dde
1780 Z9=Z9+10
1790 NEXT I
1800 RETURN
1810 PRINT USING 1820
1820 IMAGE //"BAD OR NON
EXISTENT FILE"//
1830 RETURN
1840 ! FIND LIFE EXPECTA
NCY NONS.;SMOK.
1850 FOR J=0 TO 100
1860 Q2(0,J)=Q2(1,J)+Q2(
0,J)
1870 Q2(1,J)=Q3(0,J)+Q3(
1,J)
1880 NEXT J
1890 PRINT USING 1900
1900 IMAGE /"LIFE EXPECT
ANCIES"/"NONSMOKERS FIRS
T"/
1910 FOR I=0 TO 1
1920 L9=0 @ S9=1
1930 S=1/Q2(I,99)
1940 FOR J=0 TO 99
1950 L9=L9+.5*S9*Q2(I,J)
1960 S9=S9*(1-Q2(I,J))
1970 L9=L9+S9
1980 NEXT J
1990 L9=L9+S9*S-.4*Q2(I,
0)
2000 IMAGE "LE= ",dd.dd
```

```
2010 PRINT USING 2000 ;
L9
2020 IMAGE "PROB. OF SUR
VIVAL "/,"TO 100=",d.dde
/
2030 PRINT USING 2020 ;
S9
2040 NEXT I
2050 RETURN
2060 PRINT ""
2070 PRINT "NONSLC INVAL
ID OR MISSING"
2075 PRINT ""
2080 INPUT "LOAD FROM CA
 ?>";A7$
2090 IF A7$="Y" THEN 210
0 ELSE 2130
2100 PURGE "NONSLC"
2110 COPY "NONSLC:CA" TO
 "NONSLC"
2120 GOTO 130
2130 DISP "EXECUTION END
S"
2140 END
```

RADRISK VARIABLE LIST

VARIABLE	DESCRIPTION
A	Loop counter
A0	Age at first risk
A3	A0-1
A5	Age at last exposure
A9	Age at first exposure
A3$	Answer to prompt line 110
C0	Lung cancer death probability
C2	Baseline lung cancer deaths
C8	Excess lung cancer probability
C9	Lung cancer death probability
D0	Dose variable
D1	Baseline lung cancer deaths RR and AR Models
D2	Excess lung cancer deaths RR and AR Models
D9(100)	Dose array
E8	Excess lung cancer mortality
E9	Total lung cancer mortality
F$	General input file name
F4$	File name - error handling subroutine
F7$	File name - sensitivities file
G9	Coefficient for exponential correction
H5	Dose range delimiter
H6	Dose range delimiter
I	Loop counter
J	Loop range delimiter-dose subroutine
K0	Age at first exposure plus latency
K1	Loop range delimiter
K2	Loop range delimiter
K6	Working variable
M5	Model specifier flag
M$	Model indicator for output
L0	Life expectancy
L1	Life expectancy
L2	Loss in life expectancy
L9	Life expectancy
Q(1,100)	Multiple-decrement life table
Q5	Probability of death at age 100
Q9	Total age-specific probability of death

VARIABLE	DESCRIPTION
R1	Relative risk coefficient
R2	Absolute risk coefficient
R9	Local risk coefficient
R5$	Answer to prompt line 710
S0	Survival
S7(100)	Sensitivity array
S9	Survival
S$	Answer to prompt line 2170
S7$	Answer to prompt line 790
T7	Latency
W1	Exposure in WLM/year
Y1	Approximate number of years lived beyond the 100th birthday
Z	Number of excess causes of death (Always 1)
Z7	Flag variable
Z$	Answer to prompt line 1110

```
10 ! FINAL VERSION 11/1/
83
20 ! RADON RISK CALCULAT
ION FOR ABSOLUTE AND REL
ATIVE RISK
30 ! SMOKERS,NONSMOKERS,
 AND GENERAL POP.-MALES
AND FEMALES
40 IMAGE //"RADON RISK M
ODEL"//"R.R. COEF=",d.dd
e,"/WLM"/"OPTION=",aa/"A
.R.=",d.dde,"/PY/WLM"
50 IMAGE "AGE AT F.E.=",
ddd/"AGE AT L.E.=",ddd/"
AGE AT FIRST RISK=",ddd
60 IMAGE "WLM PER YR.=",
dd.dde/"LATENCY=",dd/"EX
PONENT COR=",dd.dde
70 SHORT D9(100),S7(100)
80 DIM Q(1,100)
90 G9=0
100 Z7=0
110 INPUT "INPUT: KEYBD.
(K) OR FILE(F)?> ";A3$
120 IF A3$="K" THEN 210
130 ON ERROR GOSUB 2130
@ GOTO 110
140 INPUT "FILE NAME?> "
;F$
150 IF F$="NONE" THEN A3
$="K"
160 IF A3$="K" THEN 210
170 ASSIGN # 1 TO F$
180 READ # 1 ; A0,A9,A5,
R1,M$,R2,T7,W1,R5$,G9,S7
$,F7$
190 ASSIGN # 1 TO * @ OF
F ERROR
200 IF A3$<>"K" THEN 220
210 INPUT "AGE AT FIRST
RISK?> ";A0
220 IF A0<5 OR A0>50 THE
N 230 ELSE 250
230 PRINT USING 240 ; A0
 @ GOTO 210
240 IMAGE /"AGE AT FIRST
 RISK(",ddd,")"/"OUT OF
BOUNDS; 4<A0<51"
250 IF A3$<>"K" THEN 270
260 INPUT "AGE AT FIRST
EXPOSURE?> ";A9
270 IF A9<0 THEN A9=0
280 IF A9>99 THEN A9=99
290 IF Z7=1 THEN 310
300 IF A3$<>"K" THEN 330
310 INPUT "AGE AT LAST E
XPOSURE?> ";A5
320 Z7=0
330 IF A5<1 THEN A5=0
340 IF A5>100 THEN A5=10
0
350 IF A9<=A5 THEN 410
360 PRINT USING 370 ; A9
,A5
370 IMAGE /"AGE F.E.(",d
dd,")> AGE L.E.(",ddd,")
"
380 Z7=1
390 GOTO 260
400 ! GET RISK COEFFICIE
NTS
410 IF A3$<>"K" THEN 430
420 INPUT "RISK/WLM-R.R.
?> ";R1
430 IF R1>=0 AND R1<.2 T
HEN 470
440 PRINT USING 450 ; R1
450 IMAGE /"RELATIVE RIS
K(",d.dde,")"/"OUT OF BO
UNDS; 0<R1<.2"
460 GOTO 420
470 IF R1=0 THEN M$=" "
@ GOTO 510
475 IF A3$<>"K" THEN 490
480 INPUT "R.R. OPTION(M
,E,OR B)?> ";M$
490 IF M$="M" OR M$="E"
THEN 510
500 M$="B"
510 IF A3$<>"K" THEN 530
520 INPUT "RISK/WLM/PY-A
.R.?> ";R2
530 IF R2>=0 AND R2<.000
2 THEN 570
540 PRINT USING 550 ; R2
550 IMAGE /"ABSOLUTE RIS
K(",d.dde,")"/"OUT OF BN
DS; 0<R2<2E-4"
560 GOTO 520
570 ! GET LATENCY
580 IF A3$<>"K" THEN 600
590 INPUT "LATENCY IN YE
ARS?> ";T7
600 IF T7>=0 AND T7<46 T
HEN 640
610 PRINT USING 620 ; T7
 @ GOTO 570
620 IMAGE /"LATENCY(",dd
d.ddd,")"/"OUT OF BOUNDS
; 0<=T7<46"
630 ! GET CONTINUOUS EXP
OSURE AND CONVERT TO WLM
640 IF A3$<>"K" THEN 660
650 INPUT "ANNUAL EXPOSU
RE IN WLM?> ";W1
660 IF W1<0 OR W1>99 THE
N 670 ELSE 700
670 PRINT USING 680 ; W1
680 IMAGE /"EXPOSURE  LE
VEL(",dd.dde,")"/"OUT OF
 BOUNDS; 0<W1<100"
690 GOTO 650
700 IF A3$<>"K" THEN 720
710 INPUT "EXPONENTIAL C
ORRECTION?> ";R5$
720 IF R5$<>"Y" THEN 780
730 IF A3$<>"K" THEN 750
740 INPUT "EXPONENT=?> "
;G9
750 IF G9<0 AND G9>-.2 T
HEN 780
760 PRINT USING 770 ; G9
 @ GOTO 740
770 IMAGE /"EXPONENTIAL(
",dd.ddE,")"/"OUT OF BOU
NDS; -.2<G9<0"
780 IF A3$<>"K" THEN 800
790 INPUT "AGE SPECIFIC
SENSITIVITIES?> ";S7$
800 IF S7$<>"Y" THEN 890
810 ON ERROR GOSUB 2130
@ GOTO 830
820 IF A3$<>"K" THEN 840
830 INPUT "FILE FOR AGE
SENS.?> ";F7$
840 IF F7$="NONE" THEN 8
90 ELSE F$=F7$
```

```
850 ASSIGN # 1 TO F$
860 READ # 1 ; S7()
870 ASSIGN # 1 TO * @ OFF ERROR
880 GOTO 920
890 FOR I=0 TO 100
900 S7(I)=1
910 NEXT I
920 PRINT "********************"
930 PRINT "********************"
940 PRINT USING 40 ; R1,M$,R2
950 PRINT USING 50 ; A9,A5,A0
960 PRINT USING 60 ; W1,T7,G9
970 IF S7$="Y" THEN 990
980 PRINT "SENSITIVITY=1" @ GOTO 1000
990 PRINT "AGE SP.SEN=";F7$
1000 PRINT "********************"
1020 FOR A=1 TO 66
1030 ! GET POPULATION
1040 ON ERROR GOSUB 2130 @ GOTO 1060
1050 PRINT "********************"
1060 INPUT "FILE NAME FOR INPUT?> ";F$
1065 IF F$="NONE" THEN 1690
1070 ASSIGN # 1 TO F$
1080 READ # 1 ; H$,Z,Q(,)
1090 ASSIGN # 1 TO *
1100 OFF ERROR
1110 INPUT "PURGE INPUT FILE?> ";Z$
1120 IF Z$="Y" THEN PURGE F$
1130 DISP "WORKING"
1140 PRINT "POP.";A;"=";F$
1150 PRINT ""
1160 ! DO SURVIVAL TO AGE AT FIRST RISK
1170 K0=A9+T7
1180 IF K0<100 THEN 1210
1190 PRINT USING 1200 @ GOTO 1690
1200 IMAGE //"NO RISK-"/"AGE AT FIRST"/"RISK G.E. 100"/
1210 K1=A9
1220 A3=A0-1
1230 IF K0>A3 THEN K2=K0 ELSE K2=A3
1240 S9=1 @ L9=0 @ C9=0
1250 GOSUB 1740
1260 ! DO BASELINE K2+1 TO 99
1270 K1=K2+1
1280 S0=S9 @ L0=L9 @ C0=C9 @ K2=99
1290 GOSUB 1740
1300 ! FINISH BASELINE
1310 Y1=.8/Q9
1320 L9=L9+S9*Y1
1330 C9=C9+S9*Q(1,100)
1340 L1=L9 @ C2=C9*100000
1350 PRINT USING 1360 ; L1,C2
1360 IMAGE "BASELINE"/"L.E.=",dd.ddd/"DEATHS/10^5 -LC=",ddddd.d//
1370 ! GET DOSE DISTRIBUTION BY AGE
1380 IF A>1 THEN 1400
1390 GOSUB 2250
1400 ! NOW DO R.R. MODEL
1410 ! MULTIPLICATIVE VERSION FIRST
1420 IF R1=0 THEN 1560
1430 IF M$="E" THEN 1510 ELSE 1440
1440 L9=L0 @ S9=S0 @ C9=C0 @ C8=0 @ R9=R1 @ M5=2 @ H$="M"
1450 GOSUB 1900
1460 PRINT USING 1470 ; H$,L9,L2,D2
1470 IMAGE "RELRISK MODEL-",aa/"L.E.=",dd.ddd/"LOSS LE(MONS)=",ddd.dd/"D/10^5=",ddddd.d
1480 PRINT USING 1490 ; D1
1490 IMAGE "EXCESS D/10^5=",ddddd.d//
1500 ! THEN DO EXPONENTIAL VERSION-R.R.
1510 IF M$="M" THEN 1560 ELSE 1520
1520 L9=L0 @ S9=S0 @ C9=C0 @ C8=0 @ R9=R1+1 @ M5=3 @ H$="E"
1530 GOSUB 1900
1540 PRINT USING 1470 ; H$,L9,L2,D2
1550 PRINT USING 1490 ; D1
1560 ! DO A.R. MODEL
1570 IF R2=0 THEN 1640
1580 L9=L0 @ S9=S0 @ C9=C0 @ C8=0 @ R9=R2 @ M5=1
1590 GOSUB 1900
1600 PRINT USING 1610 ; L9,L2,D2
1610 IMAGE "ABSRISK MODEL"/"L.E.=",dd.ddd/"LOSS LE(MONS)=",ddd.dd/"D/10^5=",ddddd.d
1620 PRINT USING 1630 ; D1
1630 IMAGE "EXCESS D/10^5=",ddddd.d//
1640 INPUT "RUN ANOTHER POPULATION? ";A$
1650 IF A$="Y" THEN 1660 ELSE 1670
1660 NEXT A
1670 PRINT "*********************"
1680 F=3
```

```
1690 INPUT "NEW INITIAL
CONDITIONS?> ";A$
1700 IF A$="Y" THEN 90 E
LSE 1710
1710 DISP "EXECUTION END
S"
1720 END
1730 ! ^^^^^^^^^^^^^^^^
1740 ! SUBROUTINE LC BAS
E
1750 IF K1>0 THEN 1800
1760 Q9=Q(0,0)+Q(1,0)
1770 S9=S9*(1-Q9)
1780 L9=L9+Q9*.1+S9
1790 K1=K1+1
1800 FOR I=K1 TO K2
1810 Q9=Q(0,I)+Q(1,I)
1820 L9=L9+Q9*S9*.5
1830 C9=C9+S9*Q(1,I)
1840 S9=S9*(1-Q9)
1850 L9=L9+S9
1860 NEXT I
1870 RETURN
1880 ! ^^^^^^^^^^^^^^^^
1890 ! RISK SUBROUTINE
1900 FOR I=K1 TO K2
1910 IF M5<2 THEN K9=1 E
LSE K9=Q(1,I)
1920 IF M5<3 THEN E8=D9(
I)*R9*K9 ELSE E8=(R9^D9(
I)-1)*K9
1930 E9=E8+Q(1,I)
1940 Q9=Q(0,I)+E9
1950 L9=L9+Q9*S9*.5
1960 C8=C8+S9*E8
1970 C9=C9+S9*E9
1980 S9=S9*(1-Q9)
1990 L9=L9+S9
2000 NEXT I
2010 Y1=.8/Q9
2020 IF M5<2 THEN K9=1 E
LSE K9=Q(1,100)
2030 IF M5<3 THEN E8=D9(
100)*R9*K9 ELSE E8=(R9^D
9(100)-1)*K9
2040 E9=E8+Q(1,100)
2050 C8=C8+S9*E8
2060 C9=C9+S9*E9
2070 L9=L9+S9*Y1
2080 L2=(L1-L9)*12
2090 D1=C8*100000
2100 D2=C9*100000
2110 RETURN
2120 ! ^^^^^^^^^^^^^
2130 ! ERROR HANDLING FO
R DATA INPUT
2140 PRINT ""
2150 PRINT "FILE ";F$;"
???"
2160 PRINT ""
2170 INPUT "ON CASSETTE?
> ";S$
2180 IF S$<>"Y" THEN 223
0
2190 F4$=F$&":CA"
2200 PURGE F$
2210 ON ERROR GOTO 1710
2220 COPY F4$ TO F$
2230 RETURN
2240 ! ^^^^^^^^^^^^^^^^
2250 ! DOSE SUBROUTINE
2260 Q5=Q(0,99)+Q(1,99)
2270 Q5=.8/Q5
2280 D0=W1*S7(A9) @ H5=A
9+T7+1 @ H6=A5+T7
2290 IF R5$="Y" THEN 240
0
2300 FOR I=H5 TO K2
2310 D9(I)=D0
2320 IF I>H6 THEN 2340
2330 D0=D0+W1*S7(I-T7)
2340 NEXT I
2350 IF A5=100 AND H5<10
0 THEN 2370 ELSE 2360
2360 D9(100)=D9(99) @ GO
TO 2590
2370 D9(100)=D0+Q5*W1*S7
(100)
2380 GOTO 2590
2390 ! EXPONENTIAL CORRE
CTION
2400 G9=EXP(G9)
```

2400 G9=EXP(G9)

```
2410 D0=W1*S7(A9)*G9^T7
2420 FOR I=H5 TO K2
2430 D9(I)=D0
2440 D0=D0*G9
2450 IF I>H6 THEN 2470
2460 D0=D0+W1*S7(I-T7)*G
9^T7
2470 NEXT I
2480 IF A5=100 AND H5<10
0 THEN 2500 ELSE 2490
2490 D0=D0*G9^(Q5-1) @ G
OTO 2580
2500 J=IP(Q5+.5)-1
2510 IF J<1 THEN 2580
2520 FOR I=1 TO J
2530 K6=I-T7+99
2540 IF K6>100 THEN K6=1
00
2550 D0=D0*G9
2560 D0=D0+W1*S7(K6)*G9^
T7
2570 NEXT I
2580 D9(100)=D0
2590 RETURN
```

LIST VARIABLE LIST

VARIABLE	DESCRIPTION
A1$	Reply to prompt line 120
D$	Reply to prompt line 30
F$	Input file name
H$	MULDEC heading
I	Loop counter
J	Loop counter
K	Loop delimiter--read from MULDEC file
K$	Keyboard variable
Q(100)	Array for GR file
Q3(1,100)	Array for MULDEC file
S$	Format string

LIST PROGRAM LISTING

```
10 ! LIST UTILITY FOR GA
RR
20 DIM Q(100),Q3(1,100)
25 PRINTER IS ":PR"
30 INPUT "PRINTER(P) OR
DISPLAY(D)?> ";D$
40 IF D$="D" THEN PRINTE
R IS *
60 INPUT "FILE NAME?>";F
$
70 GOSUB 200
120 INPUT "LIST ANOTHER
FILE?";A1$
130 IF A1$<>"Y" THEN 170
140 PRINT USING 150
150 IMAGE ///
160 GOTO 25
170 DISP "EXECUTION ENDS
"
175 PRINTER IS ":PR"
180 END
190 ! ^^^^^^^^^^^^^^^^^^
200 ON ERROR GOSUB 370 @
 GOTO 340
210 PRINT "" @ PRINT "NA
ME=";F$
220 ASSIGN # 1 TO F$
230 READ # 1 ; Q()
240 ASSIGN # 1 TO *
245 PRINT "TYPE=GR" @ PR
INT ""
250 OFF ERROR
260 DISP "HIT ANY KEY TO
 STOP"
270 PRINT "AGE    «x" @ P
RINT ""
280 FOR J=0 TO 100
285 WAIT .2
290 K$=KEY$ @ IF K$<>""
THEN 340
300 PRINT J;
310 PRINT USING 320 ; Q(
J)
320 IMAGE 1X,d.dde/
330 NEXT J
340 RETURN
350 ! ^^^^^^^^^^^^^^^^^^
360 !
370 ON ERROR GOSUB 580 @
 GOTO 60
375 RESTORE # 1
400 READ # 1 ; H$,K,Q3(,
)
410 ASSIGN # 1 TO *
420 OFF ERROR
425 PRINT "TYPE=MULDEC"
430 PRINT "" @ PRINT "HE
ADING=" @ PRINT H$ @ PRI
NT ""
440 S$="/"
450 DISP "HIT ANY KEY TO
 STOP"
460 PRINT "AGE    «bx
   «cx" @ PRINT ""
470 FOR J=0 TO 100
475 WAIT .2
480 K$=KEY$ @ IF K$<>""
THEN 560
490 PRINT J;
500 FOR I=0 TO K
510 PRINT USING 520 ; Q3
(I,J);
520 IMAGE 1X,d.dde
530 NEXT I
540 PRINT USING S$
550 NEXT J
560 RETURN
570 ! ^^^^^^^^^^^^^^^^^^
580 ! ERROR HANDLING SUB
590 PRINT USING 600
600 IMAGE /"BAD OR NONEX
ISTENT FILE"/
610 RETURN
```

DUPER VARIABLE LIST

VARIABLE	DESCRIPTION
D$	Reply to prompts lines 130, 230
F$	Internal file name
G$	Cassette file name
I	Loop counter
K	Loop counter

DUPER PROGRAM LISTING

```
10 ! DUPER COPIES GARR T
O BACKUP TAPE
20 FOR K=1 TO 2
30 IF K=1 THEN RESTORE 2
90 ELSE RESTORE 300
40 FOR I=0 TO 4
50 READ F$
60 G$=F$&":CA"
70 ON ERROR GOSUB 270 @
GOTO 80
80 COPY G$ TO F$
90 NEXT I
100 IF K=1 THEN RESTORE
290 ELSE RESTORE 300
110 BEEP @ BEEP @ BEEP
120 PRINT "CHANGE CASSET
TE (GARR>BACK) AND ENTER
 Y WHEN READY"
130 INPUT "READY?";D$
140 FOR I=0 TO 4
150 READ F$
160 COPY F$ TO ":CA"
170 PURGE F$
180 NEXT I
190 IF K=2 THEN 240
200 BEEP @ BEEP @ BEEP
210 PRINT USING 220
220 IMAGE "CHANGE CASSET
TE (BACK>GARR)"/"ENTER Y
 WHEN READY"
230 INPUT "READY?";D$
240 NEXT K
250 COPY "DUPER" TO ":CA
"
260 END
270 PURGE F$
280 RETURN
290 DATA "GRADUATE","MUL
DEC","NONSLC","SMOKER","
STANDARD"
300 DATA "RADRISK","SENS
","WMLC","WFLC","LIST"
```

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Evaluating the level of lung cancer risk associated with a given level of radon-daughter exposure is a complex matter. There is the question of whether one's risk assessment should apply absolute risk models or relative risk models and, even when a general model form has been selected, there are decisions as to the exact form of risk projection, the appropriate method of accounting exposure over time, and how much a personal habit such as smoking can modify risk. This document presents a computer model for general analysis of radon risks that allows the user to specify a large number of possible models with a small number of simple commands. The model is written in a version of BASIC which conforms closely to the American National Standards Institute (ANSI) definition for minimal BASIC and thus is readily modified for use on a wide variety of computers and, in particular, microcomputers.

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