THE UNIFIED RADON RELATIVE RISK MODEL A COMPUTER PROGRAM FOR CALCULATING CANCER RISKS FROM RADON

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ABSTRACT

The Unified Radon Relative Risk Model (UR3M) computer program was developed to fill the need for a comprehensive approach to radon health risks and to allow users to make informed decisions with respect to radon reduction. The model combines three radon sources, three exposure pathways, and two risk reduction methods to give a composite assessment of health risks, attainable risk reductions, and initial cost factors associated with risk reduction.

UR3M communicates radon risk through bar graphs as well as numbers to simplify the presentation of risk information to the public. UR3M treats risk as a composite for the individual by combining the risk pathways and sources of risk within the context of an individuals smoking history.

INTRODUCTION

Radon as a Health Risk

Radon is a pollutant of indoor air believed to have the potential to cause cancer through inhalation. Radon can dissolve in water and is believed to cause cancer directly through ingestion. In addition, radon in water can contribute to the indoor air inhalation risk when it comes out of solution. This occurs particularly as a result of heating, spraying, or agitation of water (for example, taking a shower).

The exposure pathways are (1) Inhalation of radon progeny, (2) Inhalation of radon gas, and (3) Ingestion of radon gas. The sources of radon are (1) soil gas derived, (2) ambient air derived, and (3) water derived. Sources 1 and 2 involve risks via both inhalation pathways while the water source includes all three pathways.

Risks are calculated for the general population (useful for public health planning or multiple-occupants buildings) and presented both numerically and graphically. For single dwellings, individuals may customize their risk estimates based on their smoking histories (never smoked, former smoker, current smoker). All risk estimates come from published EPA documents.

Including in UR3M an individual's smoking history when calculating risk personalizes the assessment. Alternatively, the user of the program may choose to have the calculations performed using the *General Population* estimate, which includes all smoking categories. Risks are presented both numerically and graphically.

The effects of radon on health have customarily been expressed in terms of air or water sources separately, but an individual is concerned with the degree of total cancer risk regardless of the source of radon in his or her environment. Since smoking has been found to amplify the danger from radon inhalation, and plays a significant role in the development of lung cancer, it has been included in UR3M.

Purpose of the Program

The Unified Radon Relative Risk Model (UR3M) was developed to fill the need for a consolidated approach to radon health risks that allows people to make informed decisions with respect to removing radon from their environments.

The intended users of this program are personnel of state radon programs; state, county, and town departments of health; home radon mitigators; water suppliers; domestic water treatment specialists; various real estate interests; and to a limited extent those individual homeowners who have acquired the software through looking for information about radon health risks.

Risk Estimates and Changes Occurring in Health Effect Information

While no one believes that health physicists, radiation biologists or government agencies have developed the final answer on the extent of the cancer risks posed by radon exposure, we do have risk estimates that represent the best efforts of these groups based on available information up to about 1993. The Environmental Protection Agency in reports (EPA 1992a, EPA 1992b, and EPA 1994) states these cancer risks and other factors necessary to estimate the health effects of radon exposure. The National Academy of Sciences and the Environmental Protection Agency are currently reassessing these risks and we anticipate new and perhaps significantly different risk estimates by mid 1998.

We know UR3M will probably require revision to reflect radon health effect information contained in two currently pending National Academy of Sciences (NAS) studies. We understand that release of the NAS BEIR VI report is imminent and we will incorporate the appropriate information into the model when it becomes available. We realize that an additional revision to UR3M reflecting information from the NAS study of risks from radon in drinking water should be made when that study is completed around July 1998.

Use of existing risk estimates is justified and consistent with general scientific practice until such time as they are shown to either be based on flawed assumptions sufficient to dismiss them or they are supplanted by additional or better supported data. The UR3M program takes the information from the above references, and integrates the various and somewhat cumbersome number of factors, in order to present a single unified risk estimate that is customized for an individual based on their radon exposure and smoking history.

Typically, EPA's radon guidance is aimed at broad segments of the population and sometimes is expressed as the statistical risk to the general population. As such, it is in essence a generality. The statement from the *Citizens Guide to Radon* that EPA recommends you should "Consider fixing your home if the average of your first and second test is 4 pCi/l or higher" is good advice. However, if water radon and smoking history are included with the indoor air radon data in the information used to reach an informed decision, a better residence specific estimate of individual risk may be obtained.

NATURE OF THE MODEL AND SIGNIFICANCE OF PREDICTIONS

There are three significant sources of radon in indoor air and these are considered by UR3M: (1) soil gas derived radon that enters through openings, cracks, and pore spaces in basement walls or the floor slab, (2) water derived radon, which is dissolved in water and then released into the air as result of indoor water use, (3) ambient air (outside air) radon that enters the building principally through doors, windows and other openings, some of which intentionally facilitate air exchange. A generally insignificant source of radon, which is not considered by UR3M, is the construction material of the building.

The concept behind the UR3M model is that these three sources of radon risk combine, and when the radon concentration of indoor air is measured, the result reflects the combined radon sources at that point in time. If a residence is normally occupied but has no source of soil gas radon or water derived radon, the long term average of the radon content of the indoor environment should be the same as ambient air. If additional sources of radon are

then introduced, they effect the indoor air/ambient air equilibrium, and as a consequence indoor air radon content rises. This effect is cumulative and expressible as (Ambient Air Radon + Soil Gas Radon + Water Radon).

Risk Pathways

Pathway risk factors for the general population are expressed as a lifetime cancer risk per picocurie per liter (pCi/l) in water.

Inhalation of ^{222}Radon progeny (IHP)	3.00×10^{-07}	45%
Inhalation of ^{222}Radon gas (IHG)	2.00×10^{-08}	3%
Ingestion of ^{222}Radon gas (IGG)	3.50×10^{-07}	52%
Total all pathways	6.70×10^{-07}	100%

Cross-media transfer of radon from water to air (WTR) 10,000:1 or 0.0001

(From EPA 1994)

The significance of these figures to an individual is that if they ingest and use water containing 300 pCi/l of radon over a period of 70 years, their chance of developing radon related cancer is about 1 in 5,000.

Smoking History

Smoking History Risk Factors (multipliers of inhalation risks) are listed below.

General Population (GP) statistically combines the following:	1.00	No change to risk
Never Smoked (NS)	0.121	Much lower risk than GP
Former Smoker (FS)	1.03	Slightly higher risk than GP
Current Smoker (CS)	2.33	Much higher risk than GP

(From EPA 1992b)

Soil Gas

The model stipulates that if values for (1) the radon content of indoor air, (2) the radon content of ambient air, and (3) the radon content of water have been measured or appropriate values have been otherwise provided, then the radon content of the soil gas can be calculated through the following relationships.

Calculate:

Radon Content Soil Gas = RCS

Given:

Radon Content Indoor Air = RCH

Radon Content Ambient Air = RCA

Radon Content Water = RCW

Water to Air Transfer Ratio (10,000:1) = 0.0001

UR3M Equation:

RCS = RCH - (RCA + (RCW * WTR))

The model calculates ambient air and soil gas radon cancer risks for the general population as follows:

Ambient Air Risk (AARGP)

AARGP = ((RCA * IHP) + (RCA * IHG)) * KP * GP / WTR

Soil Gas Risk (SGRGP)

SGRGP = ((RCS * IHP) + (RCS * IHG)) * KP * GP / WTR

— where KP is 1000 and facilitates comparison by transposing the risk to the same number of people referenced in the *Citizens Guide to Radon* (EPA 1992a). The water transfer ratio is needed because the exposure pathway risks chosen are for water. If air exposure pathway risks had been chosen, the water risk would have an inverse correction. GP is the factor 1.00 and acts as a place holder for substitution of NS, FS, and CS when the same formula is used in conjunction with an individual's smoking history.

The model calculates water derived radon cancer risks for the general population as follows:

Partial risks by pathway

Inhalation of radon Progeny Risk (IHPR)

IRPR = RCW * IHP

Inhalation of radon Gas Risk (IHGR)

IHGR = RCW * IHG

Ingestion of Gas Risk (IGGR)

IGGR = RCW * IGG

Total risk

Total General Population Risk (TGPR)

TGPR = (IHPR * GP) + (IHGR * GP) + IGGR

The final equation used by UR3M is the one that caused the word "unified" to become part of the model name. The equation brings together the various risks and views radon cancer risks comprehensively.

The Total Ambient air, Soil gas, and Water Risk to the General population (TASWRG)

TASWRG = AARGP + SGRGP + (TGPR * KP)

Potential Imbalances

The UR3M program attempts to do mass balance calculations in terms of radioactivity. When a potential imbalance is detected, a caution message is given. For example, under certain conditions of user input a message

box may appear. The message box headed *Soil gas component set equal to 0* includes the accompanying explanation: *Ambient air plus water contribution equals or exceeds post mitigation house air radon level you entered!* This has certain significance. It is a caution to the user that, for the inputs as given, either (1) the house post-mitigation radon level is unrealistically low, (2) water treatment in addition to soil gas mitigation must be done to achieve this post mitigation radon level, or (3) the ambient air radon content as entered may be too high.

Health Risks and Accuracy

Risks in radiation and radon are probably better understood than many other categories of substances with health risks. They are founded on a large body of human data compared to data based on laboratory animals. However, health risks are often poorly defined in terms of accuracy, in many cases accurate only to within an order of magnitude. In the case of radon, many available laboratory analyses for radon concentrations are only accurate to +/- 25%. Nevertheless, there is legitimate concern that some people looking at risk data could be misled by the apparent precision or accuracy of numbers used to express health risks or reported by computer models including UR3M.

The UR3M program handles values internally in what is called scientific format, which in this case was inherited from the spreadsheet formulas of its mathematical prototype. This format is essentially a three significant figure exponential number. When UR3M or other similarly-based cancer risk models make a statistical prediction, such as 3.27 cancers per 1000 people, it is really saying you can expect a few cancers among 1000 people compared to a few per 100 or 10,000 people.

If estimates of risk are as imprecise as the previous example might indicate, some people, out of concern about implied accuracy, have suggested alternatives for expressing risk. For instance, (1) rounding to one decimal or even the nearest integer, (2) truncating all decimals, or (3) that it would be preferable to express risk verbally (such as high, medium, low). In writing UR3M, it was decided to bear in mind the cautionary statements above but to treat values internally in a consistent manner using scientific format. The Unified Radon Relative Risk Model contains the word "relative" for a reason. UR3M is about calculating and comparing risks.

To deal with cancer risks in a relative manner, you must be able to perform simple arithmetic functions on the risk value and compare risk from one source with that from another, the larger value having greater risk relative to the smaller. You can not do this with a verbal risk scale. Rounding or truncating does not improve understanding of risk, and in some instances can obscure or obliterate differences in risk that are real and worthy of consideration in making an informed decision.

Being aware that determined values have +/- error associated with them, and that two values may have ranges of error that overlap, does not mean they are without use in relative risk assessment. The determined value represents the central tendency of the range represented by the error. As such, it and values close to it in size are statistically more likely than the outlying values of the range and can be used in comparing one value relative to another.

THE USER INTERFACE: INPUT DATA WINDOW

The principle user inputs that form the basis of the models risk calculations are shown in Fig.1 and include the following:

Radon Content of Ambient Air (Outdoor)

This parameter could be measured directly but it is more likely that the value would be taken from the radon research literature or from a state's radon program. While ambient air radon concentrations vary with time and place, the average outdoor air radon concentration cited in EPA 1992b is 0.39 pCi/l. The U.S. Congress, in its 1996 deliberations on radon in drinking water, suggests setting a maximum contaminant level linked to 0.3 pCi/l for ambient air.

Radon Content of Water

There is a large variation in the radon concentration of groundwater. For that reason, only values from laboratory-analyzed samples should be used. The user is cautioned against using any type of average value for water sources within a geographic area. The state radon program office or the testing laboratory can provide information on how to collect an appropriate sample for analysis.

Radon Content of House Air (Indoor)

Only values from laboratory-analyzed samples should be used. The user is cautioned against using any type of average value from data gathered within a geographic area. The state radon program office or the testing laboratory can provide information on how and where to collect an appropriate sample for analysis.

Water Radon Removal Efficiency

This user-input value depends on the type of removal equipment used and how well it is maintained. In general, aeration devices in good condition will remove 98-99% of the radon present in raw water. Granular Activated Carbon, under optimal conditions, can remove 96-98%. However, using a value of 90-95% would be more prudent, as the removal efficiency of these devices has often been shown to deteriorate with time. Since the size and design of the equipment as well as the general condition of the treatment device are factors, additional information concerning removal efficiency might be obtained from the manufacturer's specifications.

House Post-mitigation Radon Measurement

The radon found after mitigation will vary with the house and the skill of the mitigator. Post-mitigation radon concentrations in the range of 1.5 - 2.0 pCi/l are often attainable. Mitigators, however, may only be willing to stipulate less than 4 pCi/l in the terms of their contracts. This value is meant to reflect only reductions associated with mitigation of soil gas radon contribution.

House Radon Contributed by Soil Gas

This is not a user input. This field reports radon concentration calculated by formula rather than user entry. It is RCS that is described above.

THE USER INTERFACE: OUTPUT WINDOWS

Risks by Source, Risks by Action, and Cost Data

The *Sources of Risk, Risk Lowering Actions* and *Cost Data* are windows where both calculated numerical and graphical information is displayed. There are similarly named command buttons in all the windows allowing the user to move freely back and forth between windows. Returning to the Input Data window causes information in all other windows to be reset and input boxes cleared. The same functionality is available from the View menu.

Percent Risk and Percent Risk Reduction

The check boxes toggle between the risk and the percent risk or the reduced risk and the percent risk reduction. Risk percents are reported relative to the combined risk.

Percent Risk defined as:	Source of Risk / Combined Risk * 100
Percent Risk Reduction defined as:	(Combined Risk - Reduced Risk) / Combined Risk * 100

How Smoking History Affects Risk

The UR3M program furnishes user option buttons located on the *Source of Risk, Risk Lowering Action, and Cost Data* windows to allow the selection of general population or one of the individual smoking history categories. Selection of an individual smoking history risk factor (multipliers of inhalation risks) causes the program to recalculate the risk based on a factor expressing the degree of risk deviation from the statistically combined smoking risk of the general population

THE SOURCES OF RADON RISK WINDOW

This window shows a 4 bar graph. The 3 shorter bars are the risks by source. The tallest bar is the combined risk, the sum of the three sources of risk. You may choose a smoking category, which will affect the size of the bars. Thus an individual deciding whether to reduce radon in his home environment may be aided in his decision by considering the influence of his smoking history on his cancer risk.

The next two illustrations, Fig. 2 and Fig. 3 show bar graphs and numerical data that are the sources of radon risk for the values entered in Fig. 1. Note the change in relative heights between the center two bars of both figures. Fig. 2 displays information for the *General population* while Fig. 3 shows the same information for a person who has *Never smoked.* In this instance the person who never smoked has a somewhat greater risk from water borne radon than from soil gas radon. From left to right the bars are: *Ambient Air, Soil Gas, Water*, and the *Combined Risk.* The numeric data in this instance is displayed as cancers since the percent risk option is not selected.

THE RISK LOWERING ACTIONS WINDOW

This window shows a 4 bar graph. The tallest bar is the sum of the risks for the values you entered and is labeled the *UnreducedRrisk.* This is the same as the combined risk bar from the *Sources of Radon Risk* window if the same smoking category is selected. Two of the shorter bars show the risk remaining after either water is treated or soil gas is mitigated. The third bar indicates the risk that would remain if both water treatment and soil gas mitigation are done.

The results of risk lowering actions are shown in Figs. 4, 5, and 6. Fig.4 shows the result of *Risk Lowering Actions* for the general population on the sources of risk shown in Fig 2. Note the far left bar *Unreduced Risk* in Fig. 4) and its numeric value are the same as the far right bar and value *Combined Risk* in Figs. 2. For the other bars in Fig. 4, the change in heights compared to the left bar represent the change in risk achieved by water treatment, air mitigation, or both. Risk lowering actions of Fig. 5 are identical with those of Fig. 4 but are expressed as percent risk reduction. For the conditions shown in Fig. 1 the person who has never smoked will derive a greater risk reduction by treating their water than mitigating their air as illustrated by Fig. 6 This is really not a new finding, it is just presented in a new way that does not obscure the composite health effects of radon exposure. The never-smoked category is an increasingly large segment of the population and people with private water supplies exceeding 4000 pCi/l are rather common, particularly in areas like New England.

THE COST DATA WINDOW

This window is more useful for public risk reduction policy planning and municipal purposes than for home owners. It presents a 3 bar graph. The bars represent the dollar cost divided by estimated cancer cases avoided in a population of 1000 that result from treating the water source, mitigating the soil gas source, or fixing both.

Treatment Cost (Water Treatment)

This represents the dollar amount that would be spent on a water treatment system for removing radon. If an actual costs estimate is not available, $3500 is used as a default for an aeration system and $1000 for a granular activated carbon (GAC) system.

Mitigation Cost (Indoor Air Mitigation Cost)

This represents the dollar amount that would be spent on installing a sub-slab depressurization system, filling cracks, and closing openings in order to inhibit the movement of soil gas radon into the indoor environment. If an actual cost estimate is not available, $1250 is used as a default for this type of mitigation.

Typically, costs associated with incremental health benefits are a public health issue rather than a concern for an individual homeowner. The homeowner is less interested in per capita costs than in the total cost of the risk reduction. However, as shown by Fig. 7, cost benefits of various treatment/mitigation combinations can be quickly explored in this way. In a latter version of UR3M it is planned to expand the functionality of the cost section of the program as an aid to municipal planners and water suppliers trying to evaluate multimedia approaches to radon health risk control.

CONCLUSIONS

The goal of UR3M is to communicate radon risks to the public in a comprehensible as well as comprehensive way. It accomplishes this in two ways:

1. Through narrowing the focus of the risk estimates to the individual and including all significant risk parameters

2. By presenting risks in easy-to-understand bar graphs

Much of the communication barrier between the scientific-technical community and the public is overcome by use of these graphical displays. The health risks presented by UR3M is really not new information, it is just presented in a new way that does not obscure the composite health effects of radon exposure. Using the UR3M approach can give the public specific information on which to base their decisions. Introducing cost factors while trying various ranges of values for radon in residential air and water can give insights into the cost effectiveness of multimedia approaches to risk reduction.

HOW TO GET THE PROGRAM AND ITS UPGRADES

UR3M is available by download from the Region 1 Internet web page (www.epa.gov). It runs under the following Windows operating systems: 3.1, 95, NT 3.51, and 4.0. It is intended to be used on a standalone PC with the Windows operating system files on the local hard disk. However, the program may also be used on a networked PC with the Windows files residing on a server.

Versions

It is anticipated that by the end of 1998 the UR3M program will have been released in several updated versions to accommodate changes in health risk information. This version (Version 1.1) is primarily based on EPA risk estimates as published in EPA 400-R-92-011, 1992 and EPA 811-R-94-001, 1994.

Acknowledgments

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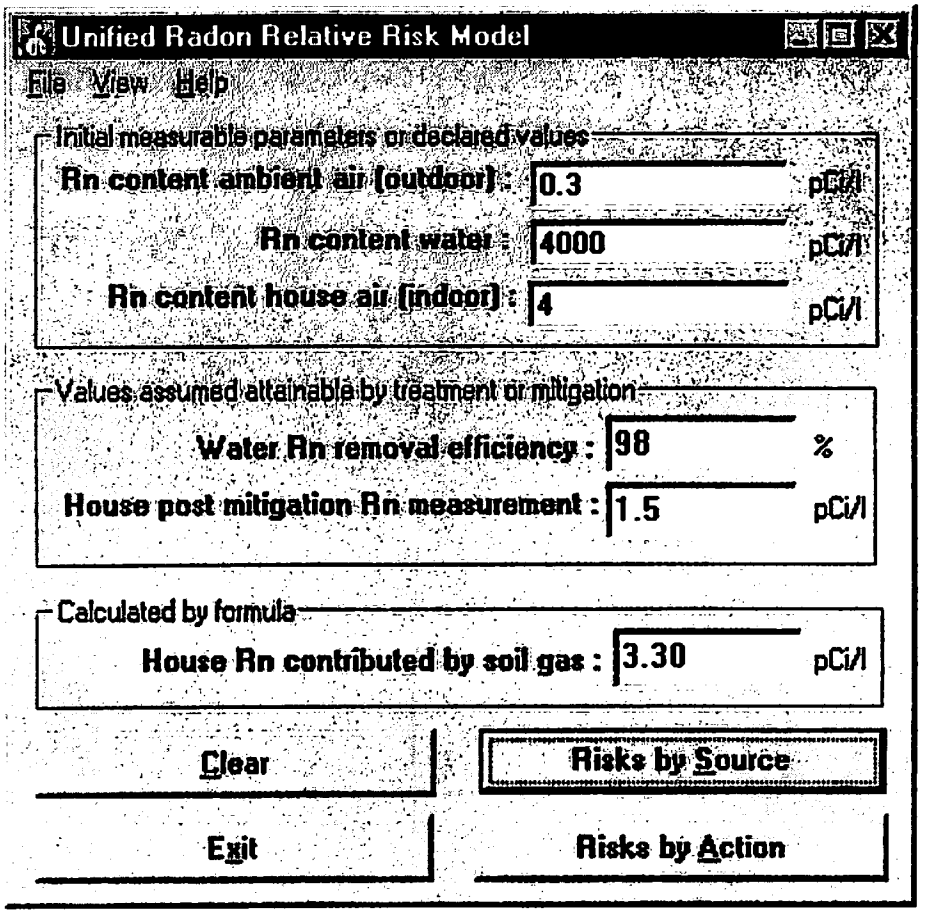
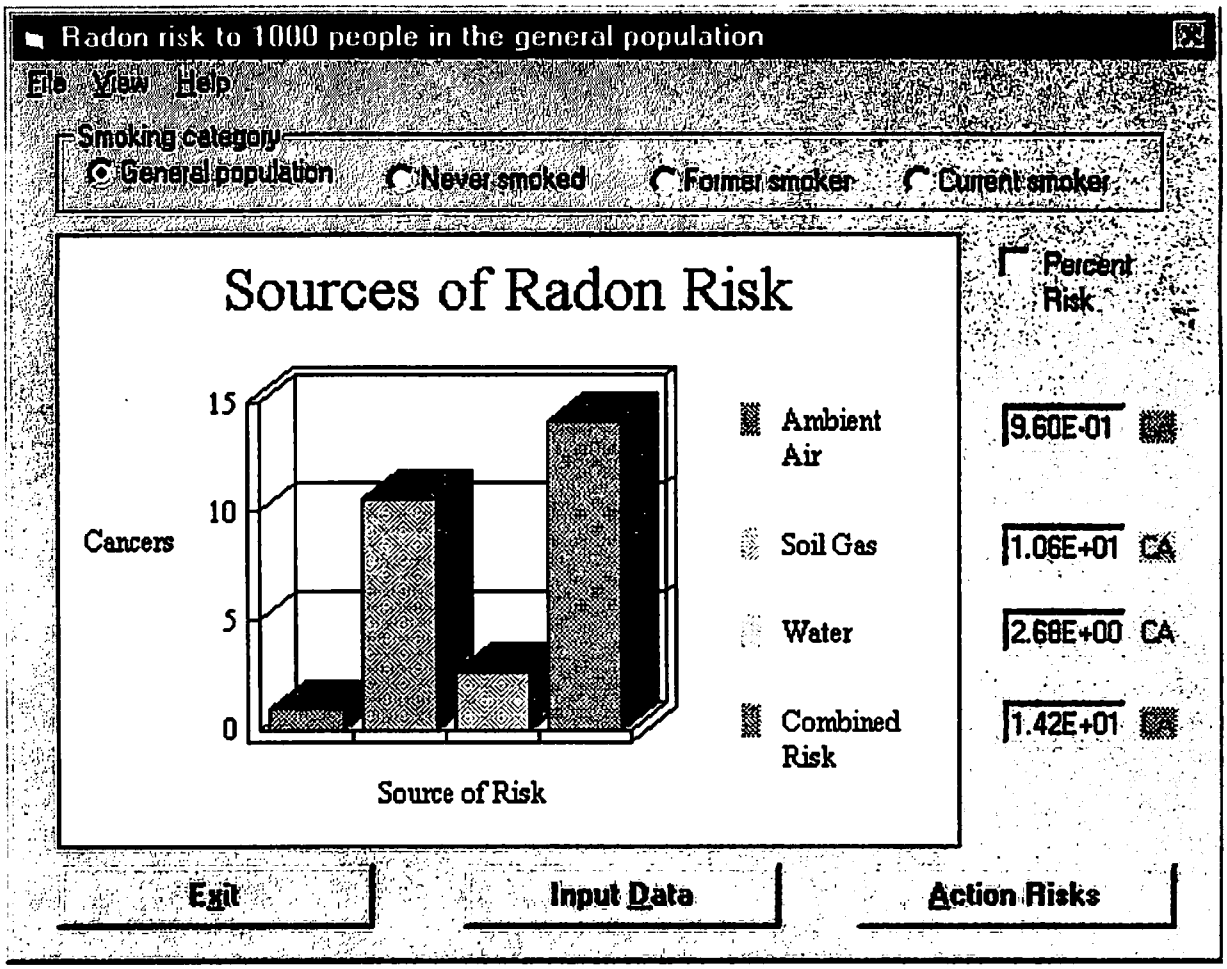
REFERENCES

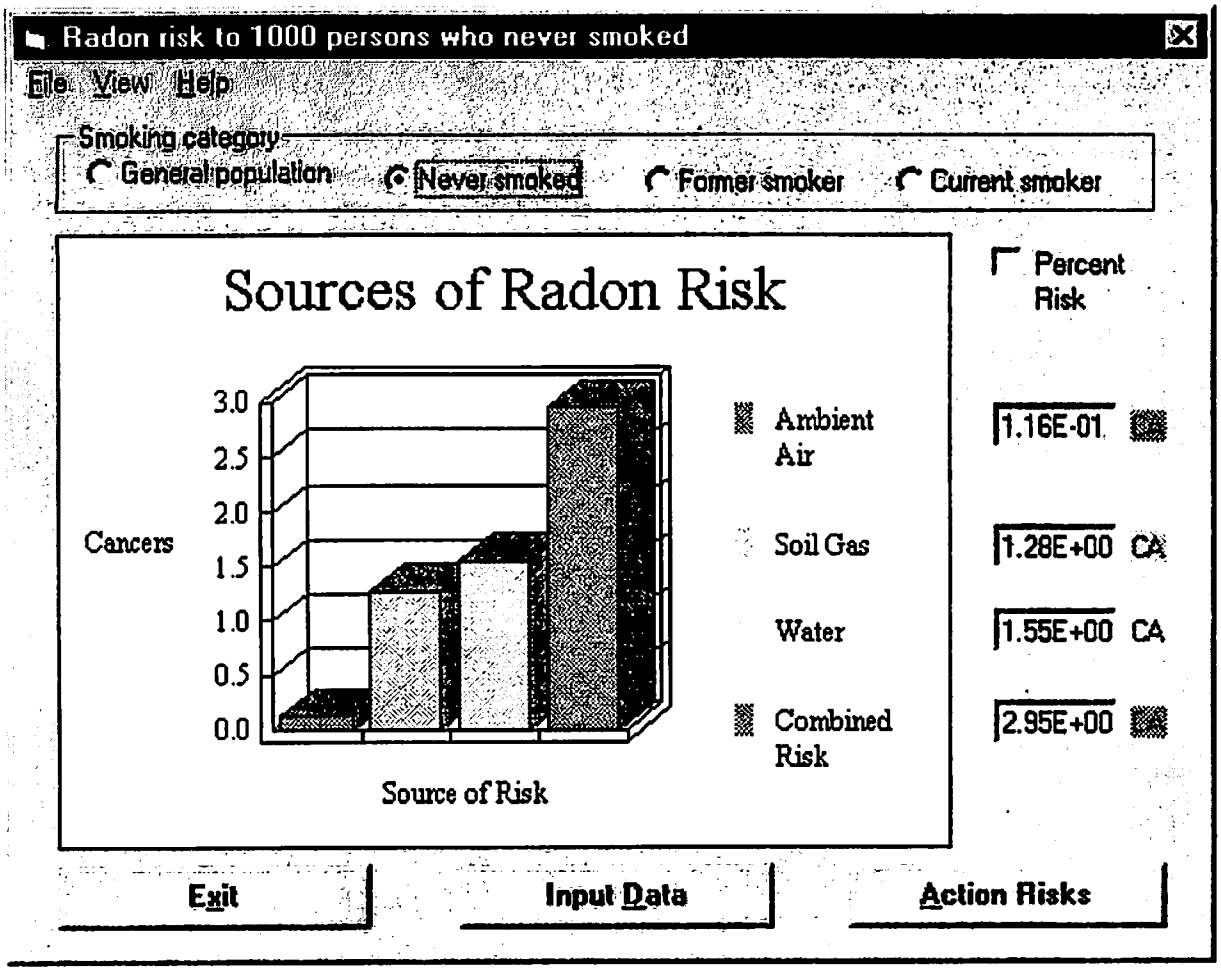
EPA 1992a, A Citizens Guide to Radon (Second Edition): "The Guide to Protecting Yourself and Your Family from Radon", EPA ANR-464

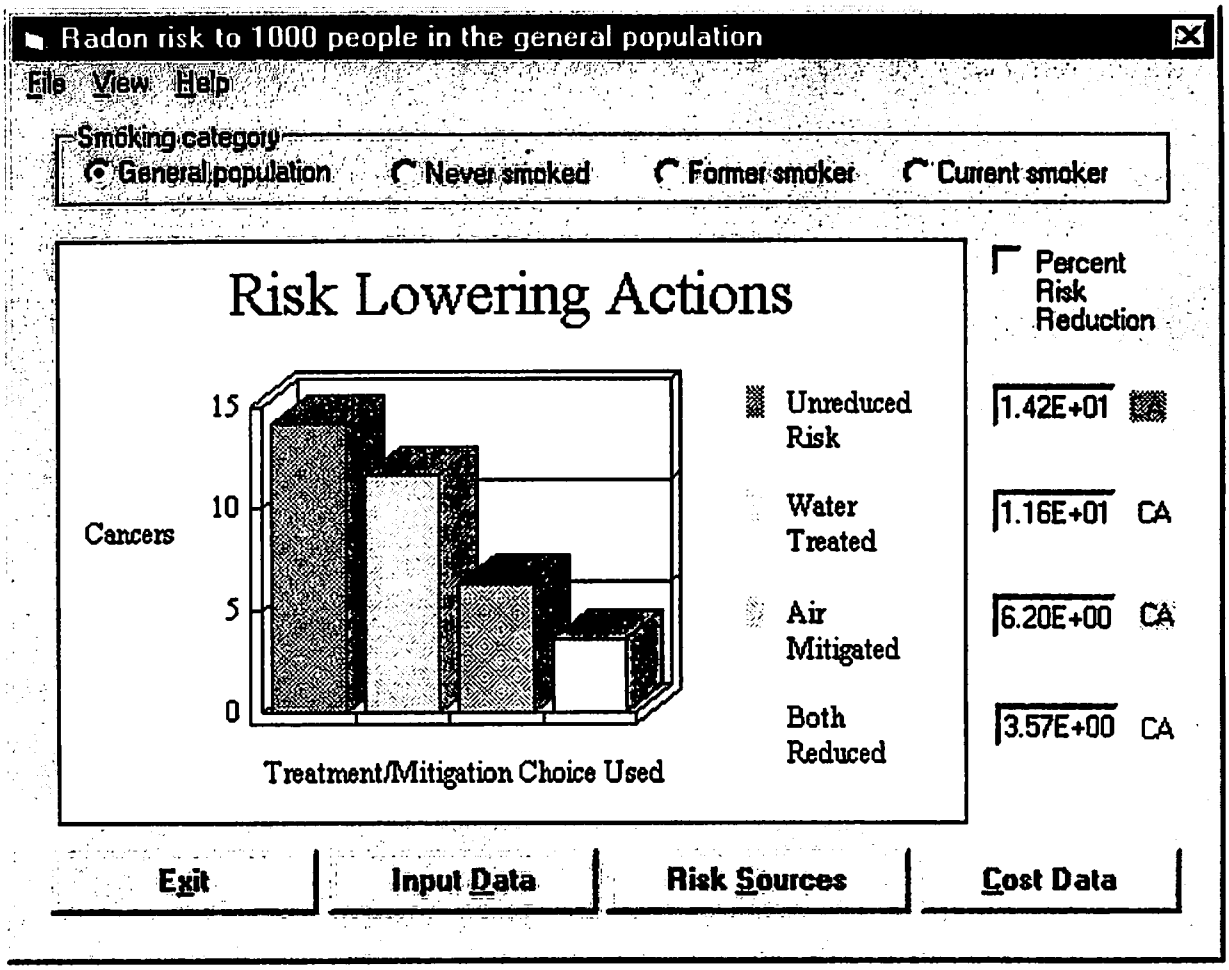
EPA 1992b, Technical Support Document for the 1992 Citizens Guide to Radon, EPA 400-R-92-011

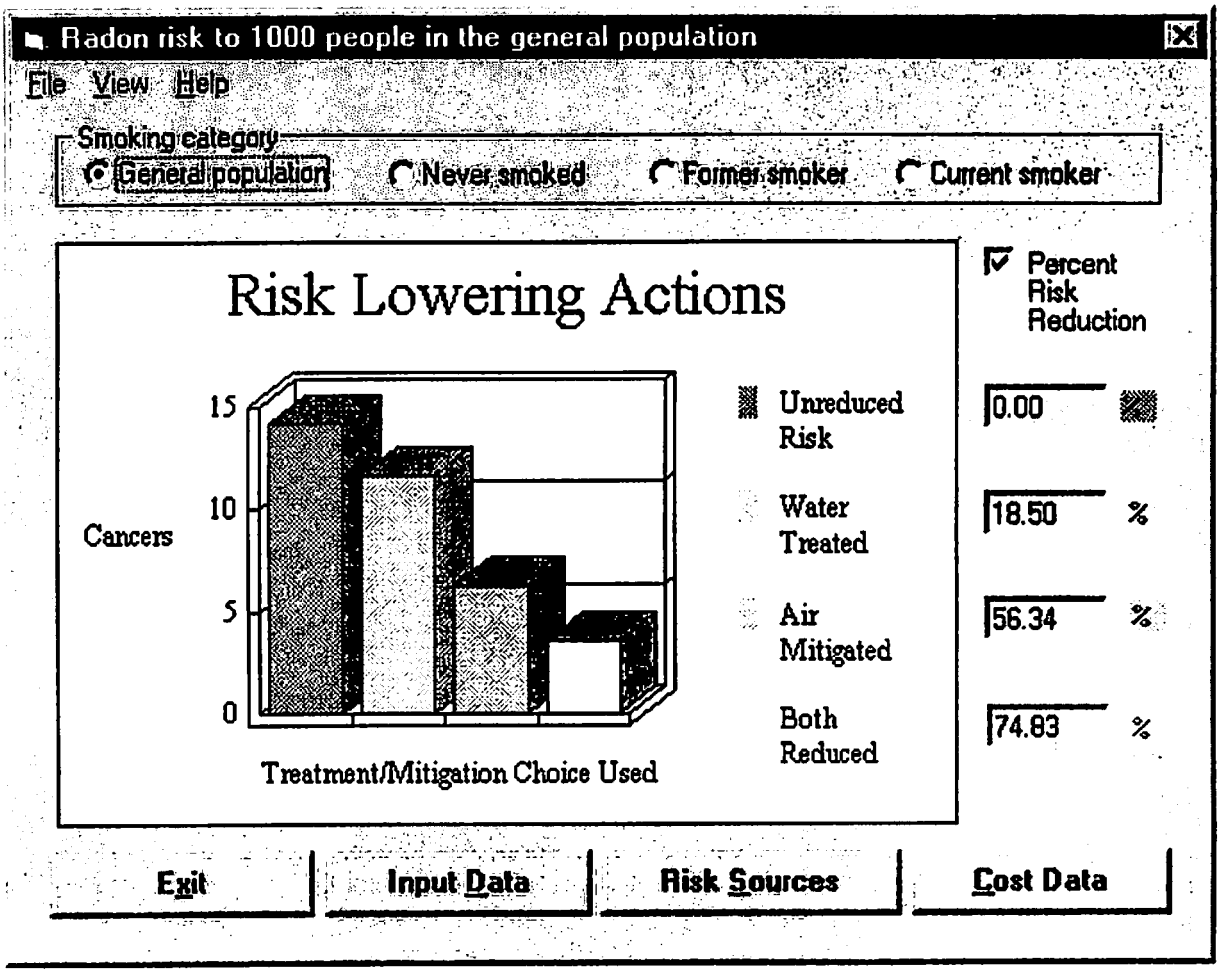
EPA 1994, Report to the United States Congress on Radon in Drinking Water: "Multimedia Risk and Cost Assessment of Radon", EPA 811-R-94-001

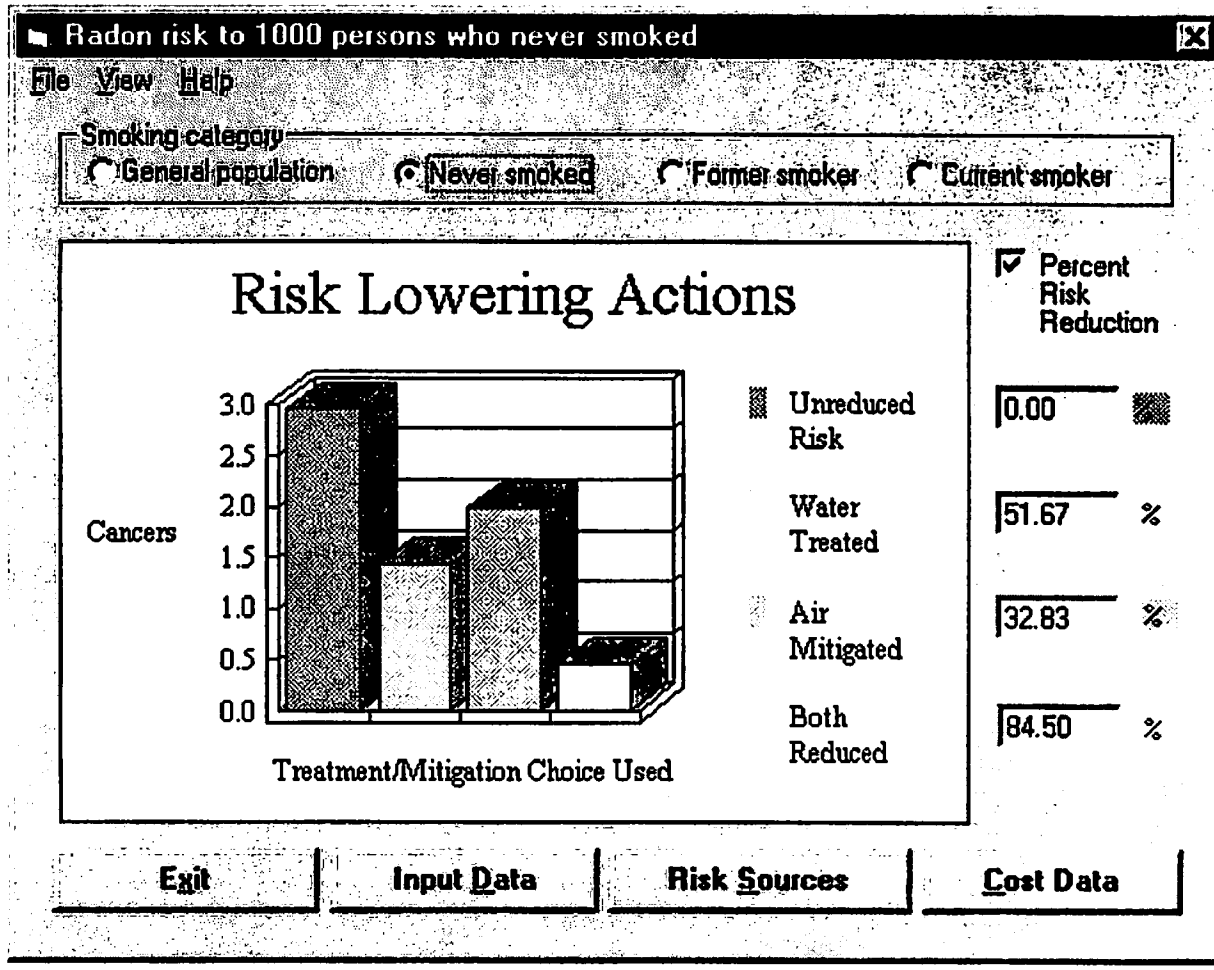

Unified Radon Relative Risk Model
File View Help
Initial measurable parameters or declared values
Rn content ambient air (outdoor) : 0.3 pCi/l
Rn content water : 4000 pCi/l
Rn content house air (indoor) : 4 pCi/l
Values assumed attainable by treatment or mitigation
Water Rn removal efficiency : 98 %
House post mitigation Rn measurement : 1.5 pCi/l
Calculated by formula
House Rn contributed by soil gas : 3.30 pCi/l
Clear
Risks by Source
Exit
Risks by Action

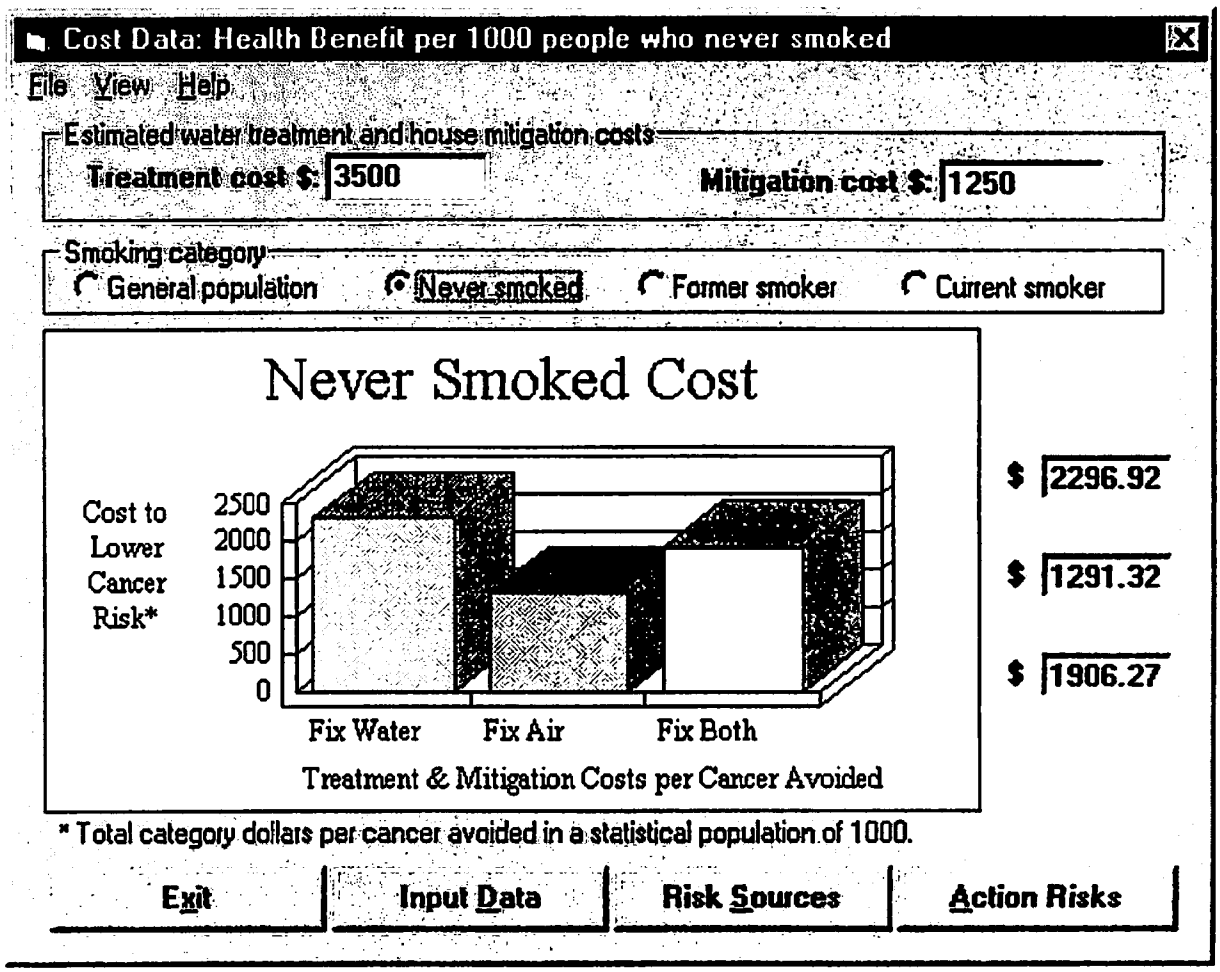

Radon risk to 1000 people in the general population
File View Help
Smoking category
General population
Never smoked
Former smoker
Current smoker
Sources of Radon Risk
Percent Risk
15
10
5
0
Cancers
Source of Risk
Ambient Air
Soil Gas
Water
Combined Risk
9.60E-01
1.06E+01
2.68E+00
1.42E+01
Exit
Input Data
Action Risks


Radon risk to 1000 persons who never smoked
File View Help
Smoking category
General population
Never smoked
Former smoker
Current smoker
Sources of Radon Risk
Percent Risk
Cancers
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Source of Risk
Ambient Air
1.16E-01
Soil Gas
1.28E+00
CA
Water
1.55E+00
CA
Combined Risk
2.95E+00
Exit
Input Data
Action Risks


Radon risk to 1000 people in the general population
File View Help
Smoking category
General population
Never smoked
Former smoker
Current smoker
Risk Lowering Actions
Percent Risk Reduction
15
10
5
0
Cancers
Treatment/Mitigation Choice Used
Unreduced Risk
Water Treated
Air Mitigated
Both Reduced
1.42E+01
1.16E+01 CA
6.20E+00 CA
3.57E+00 CA
Exit
Input Data
Risk Sources
Cost Data


Radon risk to 1000 people in the general population
File View Help
Smoking category
General population
Never smoked
Former smoker
Current smoker
Risk Lowering Actions
15
10
5
0
Cancers
Treatment/Mitigation Choice Used
Unreduced Risk
Water Treated
Air Mitigated
Both Reduced
Percent Risk Reduction
0.00
18.50 %
56.34 %
74.83 %
Exit
Input Data
Risk Sources
Cost Data


Radon risk to 1000 persons who never smoked
File View Help
Smoking category
General population
Never smoked
Former smoker
Current smoker
Risk Lowering Actions
Percent Risk Reduction
Cancers
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Treatment/Mitigation Choice Used
Unreduced Risk
0.00
Water Treated
51.67 %
Air Mitigated
32.83 %
Both Reduced
84.50 %
Exit
Input Data
Risk Sources
Cost Data


Cost Data: Health Benefit per 1000 people who never smoked
File View Help
Estimated water treatment and house mitigation costs
Treatment cost $: 3500
Mitigation cost $: 1250
Smoking category
General population
Never smoked
Former smoker
Current smoker
Never Smoked Cost
Cost to Lower Cancer Risk*
2500
2000
1500
1000
500
0
Fix Water
Fix Air
Fix Both
Treatment & Mitigation Costs per Cancer Avoided
$ 2296.92
$ 1291.32
$ 1906.27
* Total category dollars per cancer avoided in a statistical population of 1000.
Exit
Input Data
Risk Sources
Action Risks