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Report 80-1

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EPA

Cost-Risk Analysis of Protective Actions for a Low-Level Deposition of Radionuclides

Final Report

NOTICE

This report was prepared by Science Applications, Inc., for the United States Environmental Protection Agency's Office of Radiation Programs (ORP) under Contract No. 68-01-3549. ORP has reviewed it, and the contractor has responded to our comments. We are publishing this report because of its useful information. We have not verified all of the results ourselves, however; nor have we applied our own editorial standards to the text. ORP does not necessarily publish all of the contractor reports it receives.

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Cost-Risk Analysis of Protective Actions for a Low-Level Deposition of Radionuclides

Final Report
November 1979

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FOREWORD

The Office of Radiation Programs carries out a national program designed to evaluate the exposure of man to ionizing and nonionizing radiation and to promote the development of controls necessary to protect the public health and safety and assure environmental quality.

Office of Radiation Programs technical reports allow comprehensive and rapid publishing of the results of intramural and contract projects. The reports are distributed to groups who have known interests in this type of information such as the Nuclear Regulatory Commission, the Department of Energy, and State radiation control agencies. These reports are also provided to the National Technical Information Service in order that they may be readily available to the scientific community and to the public.

Comments on this report, as well as any new information, would be welcomed; they may be sent to the Director, Surveillance and Emergency Preparedness Division (ANR-461), Office of Radiation Programs, U. S. Environmental Protection Agency, Washington, D. C. 20460.

Floyd L. Galpin
Acting Director, Surveillance
and Emergency Preparedness Division

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1. SUMMARY OF PROJECT

This report summarizes the results of a cost-effectiveness analysis of protective actions following a low-level deposition of radionuclides. The media contaminated were land, property, water supplies, persons, and biota. This work has been funded by the Environmental Protection Agency (EPA), Office of Radiation Programs (ORP), under Contract EPA-68-01-3549. The material generated in the five major investigative portions, Phases III through VII[1,2,3,4,5] of the study, are summarized and subject to critical analysis in this report. Each phase was independent of the other phases.

The end products of each phase are dose and costs associated with dose reduction techniques. The mechanisms by which radionuclides may be taken up by humans were modelled, and control technologies (protective actions) which result in a reduction in the dose were defined. With the exception of Phase VI, the consequences were expressed as the 100-year collective dose commitment equivalent, in person-rem. In Phase VI, the dose calculated was the dose equivalent, also expressed in person-rem. The dose commitment is defined as the

(1) V. P. Dura, G. L. Simmons, S. K. Julin, S. P. Meyer, Costs and Effectiveness of Protective Actions for Six Generic Land Times Contaminated with a Radionucloide Deposition, SAI-77-539-LJ/F, August 1977.

(2) S. K. Julin, V. P. Dura, G. L. Simmons, Radiological Dose Assessment and the Application and Effectiveness of Protective Actions for Major Property Types Contaminated by a Low-Level Radionuclide Deposition, SAI-77-883-LJ/F, October 1977.

(3) S. P. Finn, V. P. Dura, G. L. Simmons, Protective Actions, Costs and Cost Effectiveness for Contaminated Water Supplies, SAI-78-523-LJ/F, August 1978.

(4) S. P. Finn, V. P. Dura, G. L. Simmons, Protective Actions, Costs and Cost Effectiveness for Personnel Contamination, SAI-78-712-LJ/F, October 1978.

(5) S. P. Finn, V. P. Dura, G. L. Simmons, Protective Actions, Costs and Cost Effectiveness for Contaminated Biota, SAI-78-721-LJ/F, October 1978.

sum of all doses to individuals over the entire time period that radioactive material persists in the environment in a state available for interaction with humans[6]. There are two time periods involved, (1) the intake period, during which radionuclides are taken up by humans, in this study taken to be 100 years, as recommended by EPA in Contract EPA-68-01-3549, and (2) the time interval over which the dose rate is integrated, which was seventy years. The collective dose commitment is obtained by integrating the individual dose commitments over the affected population.

For the sake of brevity, hereafter in this report the term dose will mean 100-year dose commitment equivalent. When population dose is calculated this will be denoted by collective dose.

Two types of source terms for the dose calculations were used. One consisted of 1 μCi (37 kBq) per unit area or unit volume, depending on the type of problem, of each of the 24 radionuclides listed in Table 1, provided by EPA. The second source term was based on a unit deposition, totalling 1 μCi, of a mixture of the 24 nuclides in the relative abundances listed in Table 1. This mixture is designed to simulate the relative amounts of various fission products likely to be released following a nuclear incident at a commercial power plant. It is assumed that these contaminants are in aerosol form, as opposed to particulate form. This assumption is considered conservative because it is felt that aerosols would be more readily dispersed than particulates, resulting in a wider affected area. It is also felt that aerosols would be more resistant to protective action than particulates.

For each pathway investigated, protective actions (PA's) were devised and analyzed as to their effectiveness in reducing the collective dose. Each PA also has associated with it a cost of implementation. The cost-effectiveness of a particular PA is determined by dividing the cost of application by the reduction in the collective dose brought about by the PA, relative to the case where no PA is applied; and is given as:

$$\text{Cost Effectiveness (\$/person-rem)} = \frac{\text{Cost of PA (\$)}}{\text{Dose w/o PA (person-rem)} - \text{Dose with PA (person-rem)}}$$

(6) "Environmental Radiation Dose Commitment: An Application to the Nuclear Power Industry," EPA-520/4-73-0021, U.S. Environmental Protection Agency, Office of Radiation Programs, Washington, D.C., 1974.

Table 1. Source Term Radionuclides and Their Relative Abundances at t = 0.

Radionuclide	Radioactive Half Life (days)	Relative Abundances at t = 0	Normalized Relative Abundances ($\mu Ci/m^2$)
Sr^{89}	50.6	2.6	5.01E-3
$Sr^{90}(Y^{90})$	10,500	0.012	2.31E-5
Y^{91}	59.0	0.082	1.58E-4
$Zr^{95}(Nb^{95})$	65.5	0.094	1.81E-4
Mo^{99}	2.8	0.094	1.81E-4
Ru^{103}	40.0	117	2.25E-1
Ru^{106}	368	223	4.29E-1
Rh^{105}	1.5	68	1.31E-1
Te^{129M}	34.1	5.9	1.14E-2
Te^{131M}	1.2	8.8	1.69E-2
Te^{132}	3.25	70	1.35E-1
I^{131}	8.05	17	3.27E-2
Cs^{134}	752	0.29	5.58E-4
Cs^{136}	12.9	1.05	2.20E-3
Cs^{137}	11,000	1.00	1.93E-3
$Ba^{140}(La^{140})$	12.8	4.1	7.89E-3
Ce^{141}	32.8	0.094	1.81E-4
Ce^{143}	1.37	0.088	1.69E-4
Ce^{144}	285	0.065	1.25E-4
Pr^{143}	13.6	0.088	1.69E-4
Nd^{147}	11.0	0.035	6.74E-5
Pm^{147}	960	0.010	1.93E-5
Pu^{238}	32,000	5.0E-5	9.63E-8
Pu^{239}	8,700,000	6.0E-6	1.16E-8

Each phase of the study utilized an abundance of reference material. Some of these references are denoted in this report where applicable. The entire body of source material used in this study is listed in the bibliography.

It should be noted that proposed guidance regarding contaminated foodstuffs were published in the Federal Register in December, 1978[7]. The present study was completed prior to the release of these protective action guides.

1.1 PHASE III - NON-OCCUPIED LAND

The work of Phase III identified five generic land types: field crop lands, orchard crop lands, vegetable crop lands, grazing lands, and recreational lands such as State and National parks. For this phase, the principal concern is the ingestion pathway, with the exception of recreational lands, where resuspension of radionuclides due to recreational activities causes inhalation to be the principal pathway. For grazing lands, transfer of radionuclides can result via both the grass-beef and grass-milk pathways.

Doses were calculated on a per 100 ha* (1 km^2) basis using a source term of 1 $\mu Ci/m^2$ (370 MBq/ha) of each of the 24 radionuclides listed in Table 1. Using the appropriate agricultural statistics from Reference 8 the average amount of each type of crop grown per 100 ha of farm land, and average per capita consumption rates were determined. Given these data, the resultant collective dose is readily calculated.

The pathway models developed for each generic land type are similar. Each model describes the movement of nuclides from the point of deposition to human consumption. A representative example, that of the orchard crop pathway

(7) "Accidental Radioactive Contamination of Human and Animal Feeds and Potassuim Iodide as a Thyroid - Blocking Agent in a Radiation Emergency," U.S. Department of Health, Education, and Welfare; Food and Drug Administration in Federal Register, Friday, December 15, 1978, Part VII.

(8) U.S. Department of Agriculture, Agricultural Statistics, 1975, Washington, D.C., 1976.

* ha is the abbreviation for hectare. 1 hectare = 2.47 acres.

model, is shown in Figures 1A and 1B, and described below. The principal partitioning is between fruit, soil and market usages. All fruit is considered to enter either the fresh fruit market or the process fruit market. Significant decontamination occurs during the normal commercial processing of the process market fraction of the harvested crops. Removal efficiencies for such processing were estimated by comparison with removal of pesticide residues from vegetables[9]. It is believed that the sorptive mechanisms associated with the adhesion of pesticides and the mechanisms associated with the adhesion of aerosols are similar[10].

The following is a summary of the assumptions used in the orchard crop model, based upon an extensive review of the available lierature. In some cases engineering judgement was used to consolidate this information into a representative approximation.

1. Deposition partitioning is 20% and 80% between the fruit tree and soil, respectively, at time of harvest. Half of exposed fruit tree foliage is orchard fruit.

2. All of the deposition remaining on the foliage at harvest is eventually "weathered," and becomes part of the soil source term.

3. Fresh market and process market usage fractions are determined for each fruit from U.S. Department of Agriculture statistics[8].

4. No decontamination factor (DF) is credited to commercial or home processing of internally contaminated (by uptake) crops.

5. Ninety percent of the fresh market fraction is washed and

(9) National Canners Association Research Foundation, <u>Investigation on the Effects of Preparation and Cooking on the Pesticide Content of Selected Vegetables, Final Report, March 13, 1965 to November 13, 1967</u>, Prepared for Agricultural Research Service, U.S. Department of Agriculture.

(10) Dennis, R. (Ed.), <u>Handbook of Aerosols</u> U.S. Energy, Research and Development Administration, TID-26608 (1976).

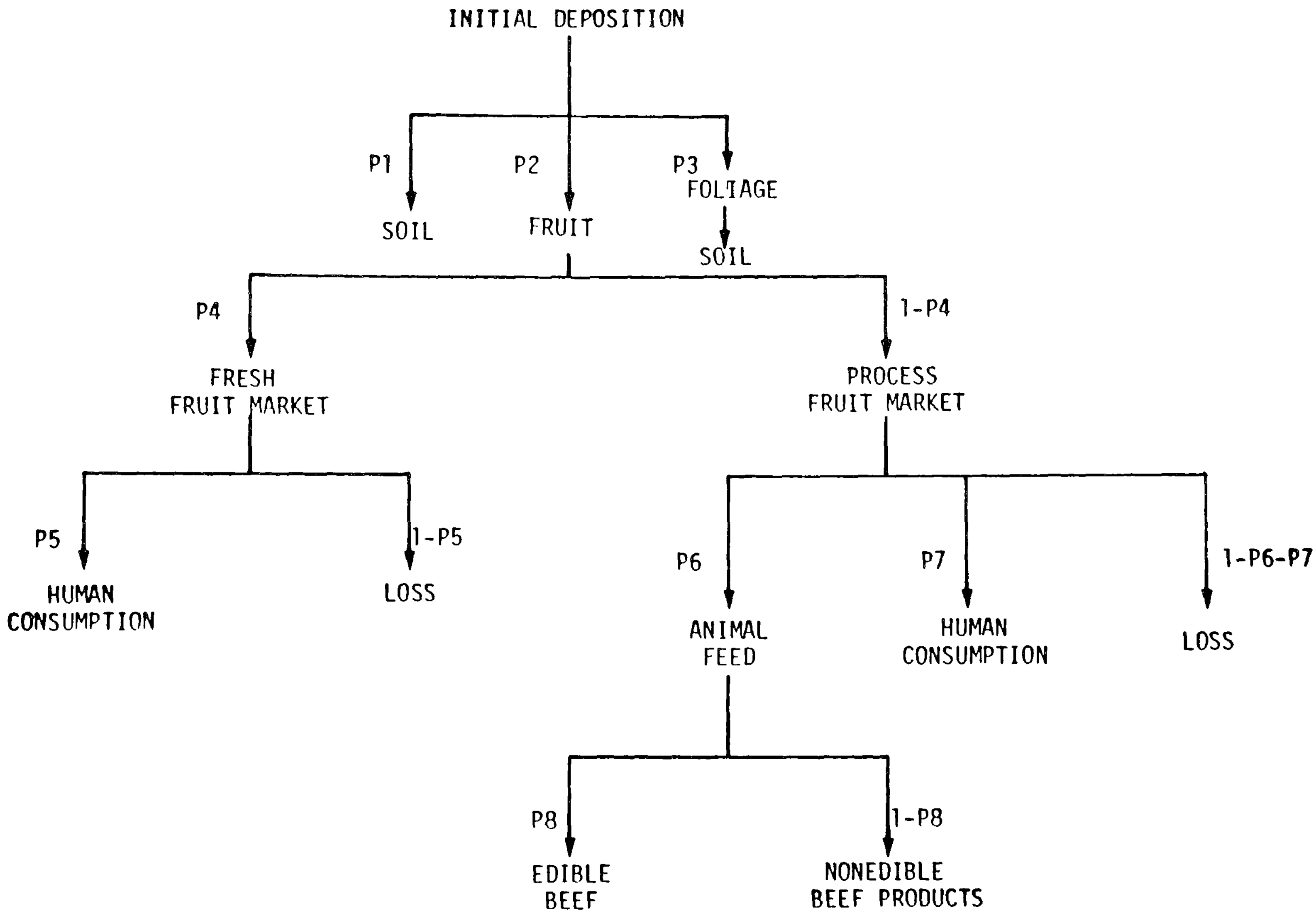


Figure 1A. Orchard Pathway Model for First Crop.

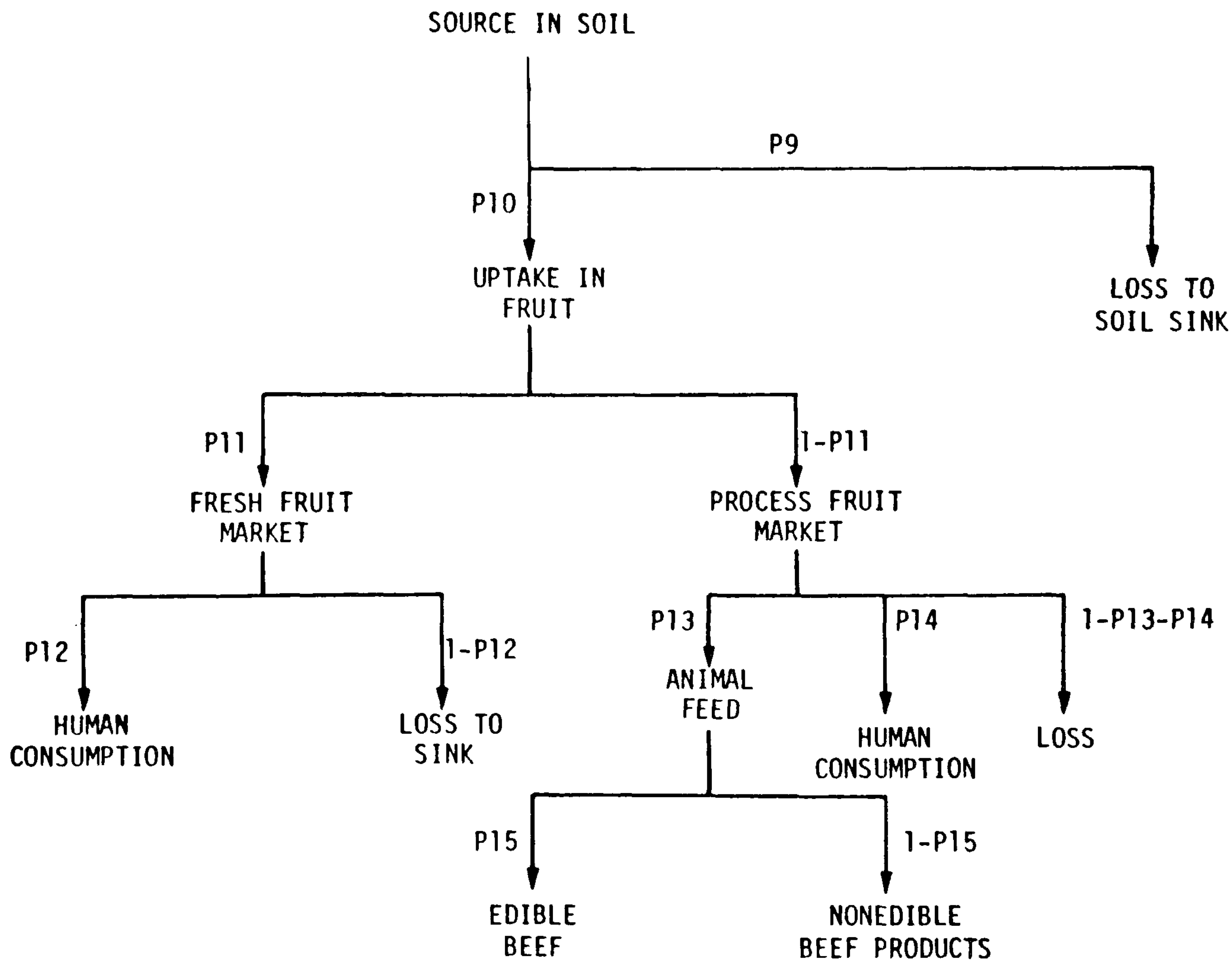


Figure 1B. Orchard Pathway Model for Subsequent Crops.

eaten, while the remaining 10% of process market fraction is diverted to agricultural feed as byproduct.

6. The concentration of nuclides in beef flesh, resulting from diversion of contaminated orchard crops to animal feed, is determined according to NRC guidance[11].

7. Nuclide uptake in fruit is assumed to be 2%/year of the quantity in the soil, while loss to soil sink is assumed to be 4%/year.

The orchard crop pathway model, as described above and in Figures 1A and 1B, may be compared with other food pathway models in the literature[12,13].

Protective actions (PA's) chosen for study with regard to crop lands are those which either reduce the level of contamination in food destined for human consumption or reduce the quantity of contaminated food to be consumed, or both. For grazing lands, PA's were chosen which result in a reduction in the contaminated feed intake of the cattle. The only PA investigated for recreational lands was that of temporary interdiction. Further study of recreational lands was made in Phase IV. Table 2 summarizes protective actions for Phase III. A more detailed description of some PA's appears below.

Onsite disposal of contaminated soil and crops consists of forming a pile on the 100 ha of affected land. In addition, a catchment pond is required for runoff from the disposal pile. The entire disposal area is assumed to cover 4.05 hectares (10 acres). Offsite disposal involves shipment of contaminated soil and crops to an authorized low level radwaste disposal area. Interdiction consists of designating the contaminated land as appropriate for production of

(11) U.S. Nuclear Regulatory Commission, Regulatory Guide 1.119 (March 1976).

(12) D. L. Brenchley, et al, "Environmental Assessment Methodology for the Nuclear Fuel Cycle", BNWL-2219, Battelle Northwest Laboratories, Richland, Washington, July 1977.

(13) J. F. Fletcher and W. L. Dotson, HERMES - A Digital Computer Code for Estimating Regional Radiological Effects from the Nuclear Power Industry, HEDL-TME-71-168, Hanford Engineering Development Laboratory, Richland, Washington, December 1971.

Table 2. Protective Actions for Contaminated Land Types.

PROTECTIVE ACTION	GRAIN CROPS	ORCHARD CROPS	VEGETABLE CROPS	GRAZING LAND	RECREATIONAL LAND
I	Restrict contaminated crop to use as animal feed.	Commercial processing of contaminated crop and all subsequent crops.	Commercial processing of contaminated crop and all subsequent crops.	Plow and reseed.	Interdict land.
II	Restrict contaminated crop and all subsequent crops to use as animal feed.	Commercial processing/ augmented wash.	Restrict contaminated crop to use as animal feed.	Deep plow and reseed.	
III	Plow contaminated crop.	Interdict land.	Plow contaminated crop into ground.	Interdict land.	
IV	Offsite disposal of contaminated crop.	Purchase land.	Offsite disposal of contaminated crop.	Use stored feed.	
V	Offsite disposal of contaminated crop, subsequent crops to be used as feed.	Remove topsoil, on-site disposal.	Contaminated crop and all subsequent crops used as feed.	Purchase land.	
VI	Plow contaminated crop, subsequent crops to be used as feed.	Remove topsoil, off-site disposal.	Offsite disposal of contaminated crop, subsequent crops to be used as feed.	Remove topsoil, on-site disposal.	
VII	Deep plow contaminated crop.		Deep plow contaminated crop.		
VIII	Plow contaminated crop, interdict land.		Plow contaminated crop, interdict land.		
IX	Purchase land.		Purchase land.		
X	Remove topsoil, on-site disposal.		Remove topsoil, on-site disposal.		
XI	Remove topsoil, off-site disposal.		Remove topsoil, off-site disposal.		

non-food crops only, such as cotton, flax, or timber. This restriction may be eased later if radiological surveys and transfer test results indicate a significant reduction in activity. Purchasing land refers to the purchase of the affected land by the cognizant government agency and removing it from productivity. This is also considered to be a temporary measure.

1.1.1 Results of Phase III

The critical pathway for contaminated crop and grazing lands is the ingestion pathway. For recreational lands it is the inhalation pathway. The major results of the Phase III study can be summarized as follows:

- A major fraction of the dose commitment is due to a small number of radionuclides.
- The relative hazard of a particular radionuclide depends, in part, upon the generic land class in which the deposition takes place. The greatest hazards for a unit deposition are due to Sr^{90} and Ru^{106} for grain, vegetables, and fruit crops; Sr^{90} and I^{131} for the grass-milk pathway; Ru^{103} and Ru^{106} for the grass-beef pathway; and Pu^{238} and Pu^{239} for recreational lands.
- The first crop causes the greatest single radionuclide input to the population.
- A greater hazard is associated with fruits and vegetables than with grains. This is due to less severe processing of fruits and vegetables, and shorter harvest-consumptions delay times.

1.2 PHASE IV - PROPERTY

The Phase IV[2] portion of the study involved the calculation of doses due to radioactive contaminants adhering to the surfaces of various types of property. Certain generic property types are grouped together in order to more realistically simulate existing neighborhoods, or composite land use areas. The four neighborhoods analyzed can be generally defined as: (1) single unit residential; (2) multiple unit residential (apartments); (3) commercial/community use; and (4) recreational lands. Property use features such as occupancy factors, representing the fraction of time the population occupies or utilizes a specific property, and effective shielding factors are employed to completely describe each neighborhood. The values for these factors were those recommmended by WASH-1400[14]. As an illustration, the single unit residential neighborhood is described below; the characteristics of the 100 hectares are those presented in WASH-1400* for medium dwelling density at approximately twelve units per hectare (five units per acre).

The single unit residential neighborhood consists of 1237 houses, each occupying 186 m^2 (2000 ft^2), which is assumed to be the equivalent roof surface area. Twenty-five percent of the houses are brick, the rest are made of wood. Structures comprise 23% of the surface area of the neighborhood, while 57% consists of lawns or open areas and 20% is paved. There are 3958 people in the neighborhood (3.2 per house), and cars totalling 1979 in number. The fractions of time that people spend inside their home, outside, and commuting are 69.2%, 6.2%, and 5%, respectively.

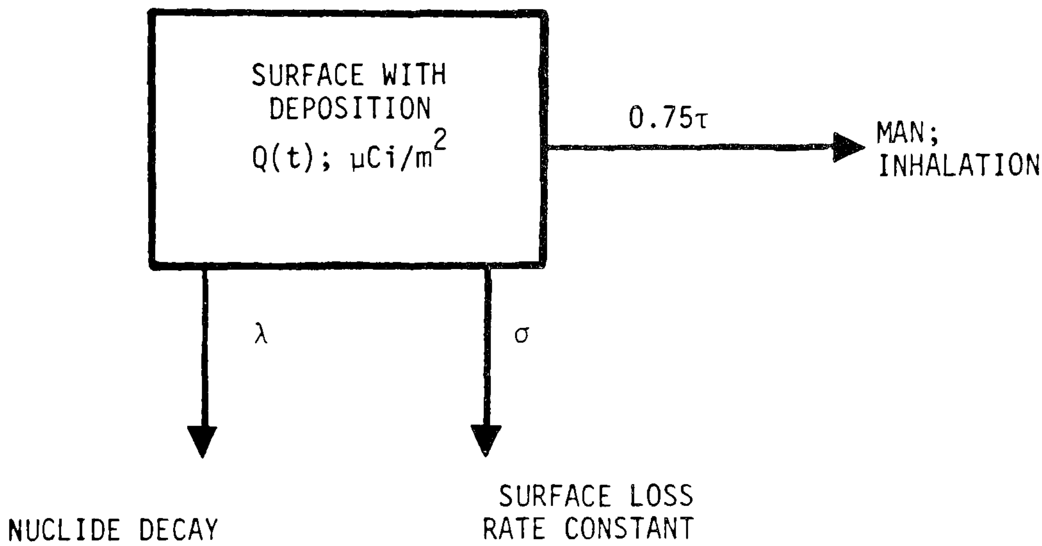
Three primary pathways were considered: direct exposure from gamma and beta radiation (so-called surface shine), inhalation of and immersion in resuspended contaminants resulting from activities associated with occupancy of contaminated neighborhoods. Each neighborhood is 100 ha in area, and is contaminated by 1 $\mu Ci/m^2$ (370 MBq/ha) of each of the nuclides listed in Table 1.

The behavior of the radiation source term as a function of time is characterized by the same depletion mechanisms for all three exposure path ways. A simple proportional transfer model describing the ground surface nuclide density with time, Q(t) in $\mu Ci/m^2$, as shown in Figure 2, is sufficient for describing the source term for all three pathways. Both the inhalation and immersion pathways depend on the air concentration of contaminants as a function of time x(t) as follows:

$$x(t) = k(t) \cdot Q(t),$$

(14) U.S. Nuclear Regulatory Commission, Reactor Safety Study, WASH-1400, Washington D.C., 1975.

* WASH-1400, Appendix VI, Section 11.



$$Q(t) = Q_o \exp[-(\lambda+\sigma+0.75\tau)t]$$

$$Q_o = 1\ \mu Ci/m^2$$

Figure 2. Model for Describing Ground Surface Nuclide Density.

where k(t) is the time dependent resuspension factor in m^{-1}.

The model used for characterizing the surface concentration source term depletion with time is shown in Figure 2. Three mechanisms are available for nuclide activity depletion, they are: (1) radionuclide decay, (λ), (2) resuspension-inhalation loss, (τ), and (3) surface loss rate, (σ) from soil fixation, runoff, erosion, and all other loss paths. Tau, (τ) represents both the depletion of the source term, Q(t), as well as the redeposition of suspended particles. Depletion occurs as a result of the inhalation of a certain fraction of the resuspended radionuclides. Redeposition is accounted for by the assumption that whatever fraction is not depleted by inhalation is instantaneously redeposited on the surface. The surface concentration level is then described by:

$$Q(t) = Q_o \exp[-(\lambda+\sigma+0.75\tau)t]$$

where

$$Q_o = 1 \ \mu Ci/m^2$$

The factor 0.75 in the above equations and in Figure 2 is derived from the assumption, taken from the ICRP standard person model[(15)], that 75 percent of the activity inhaled by an individual is retained in the body, and the other 25 percent is exhaled. Therefore, the air concentration level is described similarly by

$$\chi(t) = k(t)\ Q(t) = Q_o\ k(t)\ \exp[-(\lambda+\sigma+0.75\tau)t]. \qquad (1\text{-}1)$$

The inhalation pathway depends upon the amount of resuspended contaminants available for inhalation. At a given time, the activity accumulation rate due to inhalation by the people occupying a specific neighborhood, I(t) (μCi/day), is given by the product of the air concentration and the volumetric inhalation rate:

(15) Recommendations of the International Commission on Radiological Protection, ICRP Publication 2, Pergamon Press, Oxford, 1959.

$$I(t) = \chi(t) \cdot \rho \cdot A \cdot I_r \cdot O_f \tag{1-2}$$

where ρ = population density of neighborhood (persons/m^2)

A = area of neighborhood (m^2)

I_r = 20 m^3/day-person, standard ICRP person volumetric inhalation rate

O_f = average fraction of the time that the population occupies the area (occupancy factor)

The 100-year collective dose commitment equivalent due to inhalation is then the time integral, over 100 years, of the product of the volumetric inhalation rate, given by Equation 1-2, and the appropriate inhalation dose conversion factor (rem/μCi). Doses for air immersion and surface shine are based on similar analyses.

Protective actions for each neighborhood were developed as combinations of sixteen protective measures (PM's) designed to be applied to specific property classes within the neighborhood. Examples of protective measures are firehosing (hosing with large volumes of water under high pressure) surfaces, sodcutting lawns, sandblasting, and paving (covering with asphalt). Protective actions for Phase IV are listed in Table 3.

1.2.1 Results of Phase IV

Inhalation of resuspended radioactivity is the critical pathway when contaminated property is considered. Doses for the inhalation pathway are greater than those for air immersion and surface shine. Doses due to surface shine are approximately equal for all organs. The nuclide giving the highest dose for a unit deposition are Pu^{238} and Pu^{239} for inhalation, Cs^{134} for air immersion, and Cs^{134} and Cs^{137} for surface shine.

1.3 PHASE V - WATER SUPPLIES

Water supplies contaminated with radionuclides were subject to analysis in Phase V[(3)]. Water supplies considered were drinking water taken from reservoirs or rivers, water consumed by animals destined for human consumption (meat and milk pathways), and water supplies used in irrigation.

Table 3. Protective Actions for Contaminated Property Types.

PA	Residential: Single Family Units	Residential: Apartments	Commercial: Public Use	Recreational Land
I	Firehose Pavement (PM-1) Firehose Houses (PM-1) Gypsum-Water Leach (PM-7)	Firehose Pavement (PM-1) Firehose Buildings (PM-1)	Firehose Pavement (PM-1) Firehose Buildings (PM-1)	Firehose Pavement (PM-1) Pave Open Area (PM-2)
II	Firehose Pavement (PM-1) Paint Houses (PM-3) Mow Lawn (PM-8)	Firehose Pavement (PM-1) Paint Buildings (PM-3)	Firehose Pavement (PM-1) Paint Buildings (PM-3)	Firehose Pavement (PM-1) Cover Open Area with 6" of Dirt (PM-10)
III	Pave Pavement (PM-2) Paint Houses (PM-3) Pave Lawn (PM-2) Wash Cars (PM-16)	Pave Pavement (PM-2) Paint Buildings (PM-3) Wash Cars (PM-16)	Pave Pavement (PM-2) Paint Buildings (PM-3) Wash Cars (PM-16)	Firehose Pavement (PM-1) Cover Open Area with 12" of Dirt (PM-14)
IV	Pave Pavement (PM-2) Remove-Replace Roof (PM-4) Sodcut Lawn (PM-15) Wash Cars (PM-16)	Pave Pavement (PM-2) Pave Roofs (PM-2) Wash Cars (PM-16)	Pave Pavement (PM-2) Pave Roofs (PM-2) Wash Cars (PM-16)	Firehose Pavement (PM-1) Plow Open Area (PM-9)
V	Paint Pavement (PM-3) Paint Houses (PM-3) Cover Lawn with 6" of Dirt (PM-10) Wash Cars (PM-16)	Paint Pavement (PM-3) Paint Building (PM-3) Wash Cars (PM-16)	Paint Pavement (PM-3) Paint Building (PM-3) Wash Cars (PM-16)	Firehose Pavement (PM-1) Scrape Topsoil (PM-12)
VI	Pave Pavement (PM-2) Firehose Houses (PM-1) Cover Lawn with 6" of Dirt (PM-10) Wash Cars (PM-16)	Firehose Pavement (PM-1) Pave Roofs (PM-2)	Firehose Pavement (PM-1) Pave Roofs (PM-2)	Firehose Pavement (PM-1) Oil Open Area (PM-11)
VII	Firehose Pavement (PM-1) Remove-Replace Roofs (PM-4) Cover Lawn with 12" of Dirt (PM-14) Wash Cars (PM-16)	Mechanized Flush Pavement (PM-6) Pave Roofs (PM-2)	Mechanized Flush Pavement (PM-6) Pave Roofs (PM-2)	Firehose Pavement (PM-1) Oil and Scrape Open Area (PM-13)
VIII	Mechanized Flush Pavement (PM-6) Pave Roofs (PM-2) Mow Lawn (PM-8)	Sandblast Pavement (PM-5) Paint Buildings (PM-3) Wash Cars (PM-16)	Sandblast Pavement (PM-5) Paint Buildings (PM-3) Wash Cars (PM-16)	Pave Pavement (PM-2) Pave Open Area (PM-2)
IX	Sandblast Pavement (PM-5) Remove and Replace Roofs (PM-4) Sodcut Lawn (PM-15) Wash Cars (PM-16)	Sandblast Pavement (PM-5) Pave Roofs (PM-2) Wash Cars (PM-16)	Sandblast Pavement (PM-5) Pave Roofs (PM-2) Wash Cars (PM-16)	
X	Sandblast Pavement (PM-5) Paint Houses (PM-3) Cover Lawn with 12" of Dirt (PM-14) Wash Cars (PM-16)			

Drinking water supplies were assumed to pass through a distribution system which includes a water treatment plant, prior to consumption. A "base" plant was defined consisting of a pumping station and chlorinator, with no removal of radionuclides. In addition, five model water treatment plants were defined, based upon common practices[16], as follows:

Plant #1: Coagulation and settling, rapid-sand filtration.

Plant #2: Lime-soda softening, coagulation and settling, rapid sand filtration.

Plant #3: Rapid-sand filtration, ion exchange.

Plant #4: Evaporation.

Plant #5: Reverse osmosis.

The design of a particular water treatment facility depends upon the intake water quality. Radionuclides are not usually a concern, although some treatment facilities are geared to the removal of radium-226[17,18]. However, each of the processes mentioned above in the description of the five model treatment plants are capable, to some extent, of removing radionuclides from water. Decontamination factors for each nuclide of interest and each model plant were estimated.

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(16) The American Water Works Association, Water Quality and Treatment, Third Edition, McGraw-Hill Book Company, 1971.

(17) D. L. Bennett, C. R. Bell, and I. M. Markwood, Determination of Radium Removal Efficiencies in Illinois Water Supply Treatment Processes, Technical Note ORP/TAD-76-2, U.S. Environmental Protection Agency, Office of Radiation Programs, Washington, D.C, May 1976.

(18) R. J. Schliekelman, Determination of Radium Removal Efficiencies in Iowa Water Supply Treatment Process, Technical Note ORP/TAD-76-1, U.S. Environmental Protection Agency, Office of Radiation Programs, Washington D.C., June 1976.

In addition to decontamination by the water treatment plant, radionuclide levels in reservoir water will be reduced due to turnover of the contents of the reservoir. The turnover rate for a reservoir is defined as the fraction of the total volume that is replaced by incoming water, per unit time, if the rate of inflow is equal to the rate of outflow. This turnover concept is not to be confused with the concept of turn-over as applied to the transfer of water between two layers of a stratified reservoir, caused by seasonal differences in temperature. The Phase V study considered three reservoir turnover rates, which are representative of high, intermediate, and low turnover rates in the United States.

The basic model for the calculation of doses from the consumption of contaminated reservoir water is shown in Figure 3. The quantity of nuclide, Q(t) (pCi), in a reservoir of volume V (m^3) is described by

$$\frac{dQ(t)}{dt} = C_{in} \cdot (R+r) - C \cdot (R+r) - \lambda Q(t) - \sigma Q(t)$$

where C_{in} is the concentration of nuclide in the inflow (pCi/m^3)

- C is the concentration of nuclide in the reservoir (pCi/m^3)
- R is the outflow rate (m^3/day)
- r is the intake rate to the water treatment facility (m^3/day)
- λ is the radiological decay constant (day^{-1})
- σ is the scavenging or surface loss rate constant (day^{-1})

Assuming $C_{in} = 0$ and $C = Q(t)/V$, then

$$\frac{dQ(t)}{dt} = \frac{-Q(t)}{V} (R+r) - (\lambda+\sigma)\, Q(t)$$

The quantity (R+r)/V (day^{-1}) is the turnover rate for the reservoir, τ. Integrating the above equation, using the initial condition that at t = 0, $Q=Q_0$, yields

$$Q(t) = Q_0\, e^{-(\lambda+\sigma+\tau)t} \qquad (1\text{-}3)$$

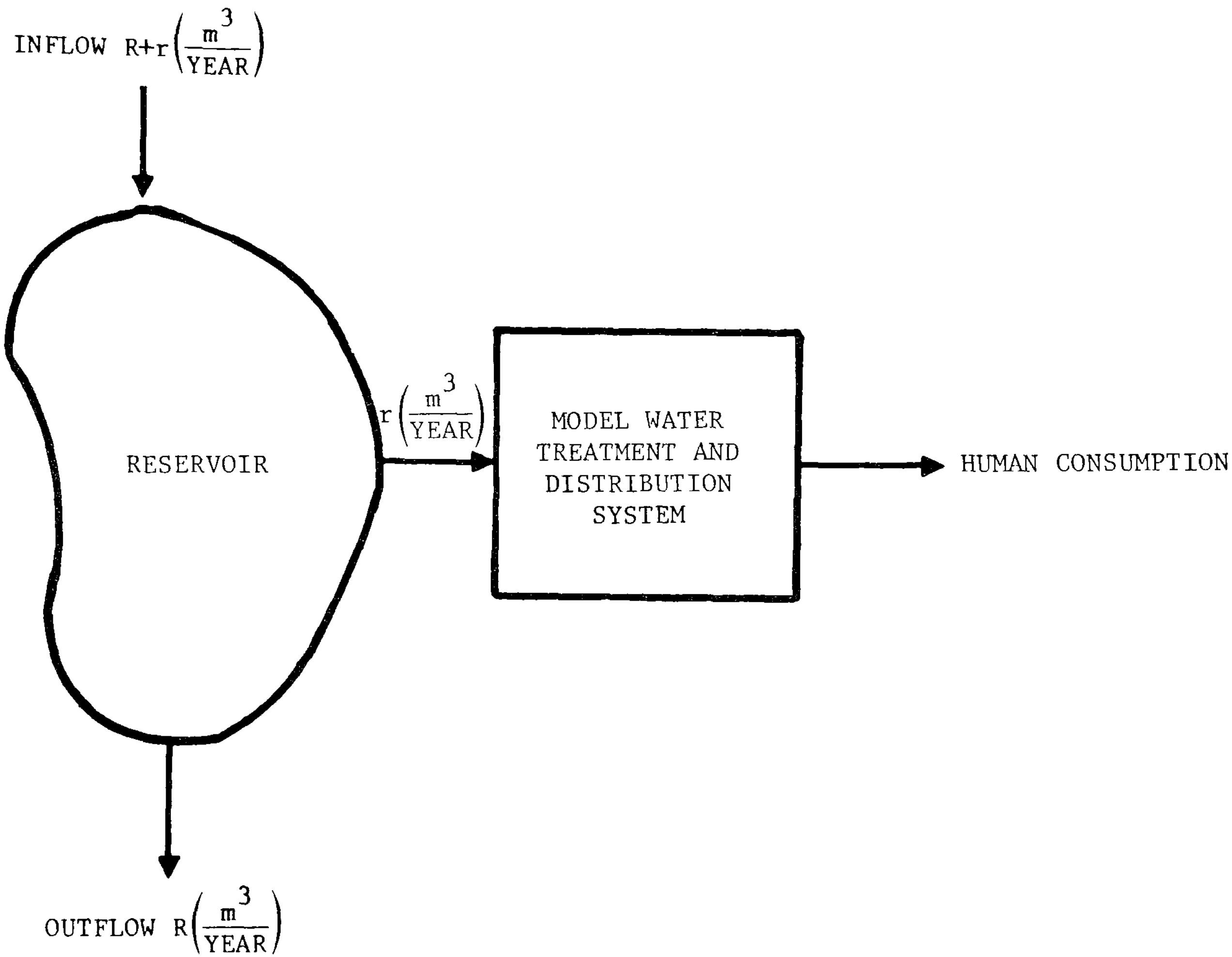


Figure 3. Basic Model for the Calculation of Dose Commitments from the Consumption of Contaminated Reservoir Water.

Annual population doses for an invariant concentration of radionuclides in water were calculated with the LADTAP* computer code, with a source term of 1 μCi/liter (1 mCi/m^3) of each of the nuclides listed in Table 1. Since the concentration is considered constant, conversion to a daily basis is simply a matter of division by 365 days/year. The 100-year collective dose commitment equivalent is determined from the following expression

$$PV_{ipj} = \frac{LTP_{ipj}}{365} \int_0^{36525} e^{-(\lambda_i+\tau+\sigma_i)t}\, dt \qquad (1\text{-}4)$$

where PV_{ipj} is the 100-year collective dose commitment equivalent due to nuclide i through pathway p to organ j (person-rem)

LTP_{ipj} is the annual collective dose commitment equivalent due to an invariant concentration of nuclide i through pathway p to organ j obtained from LADTAP (person-rem/year)

36525 is the number of days in 100 years

The analysis for river water was somewhat different from that for reservoir water. The radionuclide concentration in a river is not likely to remain elevated for very long due to the cleansing action of the river water flow. The river was considered to be non-tidal. This was accounted for by considering intake by the water treatment plant for only seven days, as recommended by EPA in Contract EPA-68-01-3549. By contrast, reservoir water was considered to contain some radionuclide contamination during the entire 100-year period over which the dose commitment was calculated. Also, when considering water supplies consumed by animals and water supplies used in irrigation, the radionuclide source term was integrated for only seven days.

*"Liquid Annual Doses To All Persons," NRC Radiological Assessment Branch Code, Revised 7/10/77. This code incorporates the calculations model and parameters that are presented in Regulatory Guide 1.109 (Reference 8).

Included in the Phase V study was a model describing the transport of radionuclides from a watershed to a reservoir. The model considered runoff only. Percolation into aquifers and feeding of the reservoir by the aquifers were neglected. The primary motive mechanism for the radionuclides is sorption to soil sediment particles and subsequent movement into hydrologic systems as a result of erosion during periods of runoff. In addition, a small percentnage, approximately 5%, moves in solution in the runoff waters. The model describes the fraction of a radionuclide concentration deposited on a watershed at time t=0, which is present in the reservoir at time t=T, and is based upon a nuclide's solubility, its ability to be absorbed by the soil, the soil's susceptibility to erosion, and the turnover rate of the reservoir.

Protective actions for contaminated drinking water supplies involved augmenting the model water treatment plants with various chemical processes designed to increase the effectiveness of contaminant removal. Plants 4 and 5 are not suited to the addition of chemicals, however, and because of the relatively high degree of decontamination associated with evaporation and reverse osmosis, the application of protective actions to Plants 4 and 5 was deemed unnecessary. The base plant is also not suited to the addition of chemicals. PA's for the base plant involved its replacement by constructing a new treatment facility which would be effective in removing radionuclides from water, with construction being completed within one year. Each of the five model plants were studied as possible replacements for the base plant. However, for drinking water taken from rivers, this approach is not recommended because radionuclide concentrations in river water are expected to be elevated only for a few days. Therefore, for river water, no PA's were studied for the base plant.

For water supplies consumed by animals, the protective actions chosen were those which would be applied to the animals themselves, such as delaying the time when the animals become available for human consumption to allow for additional radiological decay and biological removal, and condemnation (destruction). For water supplies used in irrigation, the sole PA investigated was condemnation, a more detailed study of contaminated vegetables having already been accomplished in Phase III. In the case of both animals and plants, sacrifice and impoundment includes compensation to the owners for the destroyed goods. In the analysis of both of these pathways, uptake of radionuclides for seven days was considered.

Doses were calculated for a concentration of 1 mCi/m^3 (1 µCi/liter) of each of the radionuclides listed in Table 1, on the assumption that the water supplies affected by the contamination serve a population of 100,000 persons. Protective actions for Phase V are summarized in Table 4.

1.3.1 Results of Phase V

Ingestion is the critical pathway for radionuclides in water supplies. The nuclides giving the highest dose, based on a unit concentration, are Sr^{90} for drinking water, Sr^{90}, Ru^{106}, and Te^{129m} for meat consumption, Sr^{90} and I^{131} for milk consumption, and Sr^{90} for irrigated vegetables.

1.4 PHASE VI - PERSONNEL

The pathway considered in Phase VI[4] was the deposition of radionuclides directly on persons resulting from physical contact with airborne radionuclides. A model describing the rate at which radionuclides are deposited on and eliminated from the surface of the skin was developed. Because the time during which contamination is accumulated is short, on the order of hours or days, and because most of this contamination is removed within a few months due to the normal biological process of skin regeneration, the 100-year dose commitment has no meaning for this pathway. Instead, the quantity calculated was the dose equivalent, the product of a dose rate and a time. The time involved is the time required for complete regeneration of surface skin cells.

Figure 4 depicts the basic model for the accumulation of radionuclides on the skin. Nuclides are added by deposition from the radioactive cloud and removed by radioactive decay and skin regeneration. The activity present on the skin, as a function of time, is described by

$$\frac{dN(t)}{dt} = Q(t)\ v_d A - \lambda N(t) - \lambda_s N(t) \qquad (1\text{-}5)$$

where N is the number of microcuries on the individual at time t

Q is the concentration of radionuclides in the cloud at time t, µCi/m^3

Table 4. Protective Actions for Contaminated Water Supplies.

PA's	DRINKING WATER SUPPLIES						WATER SUPPLIES FOR ANIMALS		WATER SUPPLIES FOR IRRIGATION
	BASE* PLANT	MODEL PLANT #1	PLANT #2	PLANT #3	PLANT #4	PLANT #5	MEAT PATHWAY	MILK PATHWAY	
I	Build model treatment plant #1	Add Clay	Add Clay	Add lime and soda ash	None	None	Quarantine for 1 week	Divert milk to other dairy uses	Impound Vegetables
II	Build model treatment plant #2	Add KH_2PO_4	Add KH_2PO_4	Add Alum			Quarantine for 2 weeks	Impound Milk	
III	Build model treatment plant #3	Add lime and soda ash					Quarantine for 3 weeks		
IV	Build model treatment plant #4						Quarantine for 4 weeks		
V	Build model treatment plant #5						Quarantine for 3 months		
VI							Quarantine for 6 months		
VII							Sacrifice Animals		

Plant #1: Coagulation and settling, rapid-sand filtration.
Plant #2: Lime-soda softening, coagulation and settling, rapid-sand filtration.
Plant #3: Rapid-sand filtration, ion exchange.
Plant #4: Evaporation.
Plant #5: Reverse osmosis.

*Applicable only to reservoir water; no PA's for Base Plant with river water. The model plants are built to replace the existing Base Plant.

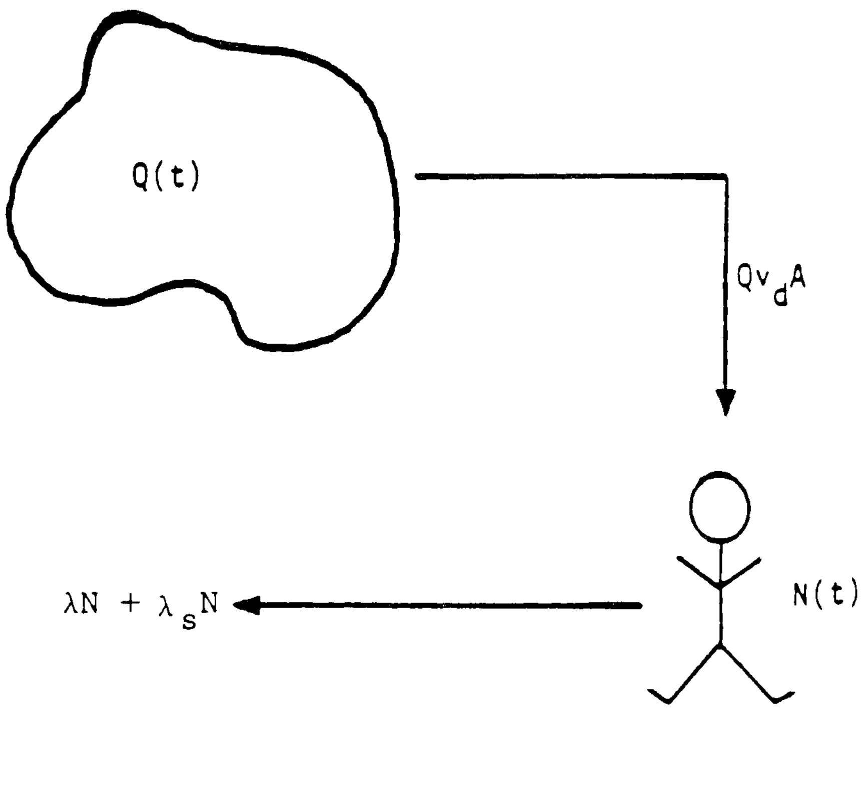


Figure 4. Model for the Accumulation of Radioactivity on Skin

v_d is the velocity of deposition of radionuclides from the cloud, m/day

A is the area of deposition on the individual, m^2

λ is the radioactive decay constant, day^{-1}

λ_s is a factor describing the rate at which skin surface cells are replaced by normal biological processes, day^{-1}.

The cloud concentration, $Q(t)$, decreases exponentially from an initial value of Q_o, due to radioactive decay.

$$Q(t) = Q_o e^{-\lambda t}$$

Therefore,

$$N(t) = Q_o v_d A e^{-(\lambda+\lambda_s)t} \qquad (1\text{-}6)$$

The dose equivalent is obtained by taking the product of the appropriate conversion factor (rem/μCi) and the time integral of Equation 1-6.

The dose equivalent in the scenario postulated is strongly dependent upon the times at which certain events occur. The three time intervals involved are: T_1, the time between the occurrence of the release of radionuclides and the beginning of deposition on persons; T_2, the time at which deposition ends; and T_3, the time at which protective action is taken.

For the purposes of this study, it was sufficient to divide the surface of the human body into three sections: clothed areas, exposed skin, and hair. Protective measures were devised for treatment of each of these three areas. Protective actions were then developed as combinations of protective measures.

Protective actions may be implemented by the individual at home or at a decontamination station. Such a facility will be established and operated by the Civil Defense or Emergency Service Staff as part of a sound public domain emergency plan, such as described in Reference 19. The site chosen would be an

(19) Nuclear Power Plant Emergency Response Plan, Unified San Diego County Emergency Services Organization, 1976.

existing facility containing showers. Schools and fire stations are examples of such facilities. Decontamination stations would not be special facilities maintained in stand-by status or imported from outside the affected area.

Stations will be staffed by trained personnel who can instruct individuals in effective decontamination techniques. It is assumed that radiation detectors will also be available for monitoring people on arrival and prior to release.

PA's for contaminated persons are summarized in Table 5. After application of protective action, individuals may resume normal functions, but should continue to listen to their radios for further instructions from Civil Defense.

1.4.1 Results of Phase VI

Dose equivalents from radionuclides adhering to people's skin were calculated given a radioactive cloud concentration of mixed radionuclides totaling 1 $\mu Ci/m^3$ in the relative abundances indicated in Table 1. The population at risk was assumed to be 100,000 persons. The nuclides that produce the highest dose equivalents, based on a unit deposition, are Y^{91} and Ru^{103}.

1.5 PHASE VII - BIOTA

Phase VII[5] analyzed protective actions for biota contaminated by a low-level radionuclide deposition. Here biota is defined as farm animals destined for human consumption, with the contamination occurring through the consumption by these animals of contaminated feed. Four generic classes of farm animals were studied: hogs, sheep, turkeys, and chickens.

The feed-animal-people pathway of Phase VII is similar to the grass-beef-people pathway investigated in Phase III. Therefore, cattle were omitted from the Phase VII study. Crops -- fruits, vegetables, and grains -- may also be defined as biota; however, these were also omitted here because they were studied in Phase III.

Table 5. Protective Actions for Contaminated Persons.

PA 1:	Actions to be taken at home: Remove clothing -- clothing to be disposed of by cognizant civil authorities. Wash skin with soap* and water. Shampoo hair.
PA 2:	Same as PA 2 except wash skin with detergent* instead of soap.
PA 3:	Actions to be taken at a public decontamination station: Wash skin with soap and water. Shampoo hair. No treatment of clothing. Clothing is to be worn home where removal and disposal, as in PA 1, is accomplished.
PA 4:	Same as PA 3, except clothes are laundered at the station. Ultimate removal and disposal of clothing occurs at home.

* In this table, the term "soap" means ordinary bath soap, which is a detergent of natural origin, or natdet. The term "detergent" means a detergent of synthetic origin, or syndet.

The quantity of nuclide carried by the edible portions of the biota was estimated using a single compartment proportional transfer model, shown in Figure 5, in which nuclides are added by consumption of contaminated feed and removed by biological elimination and radioactive decay. The effects of transportion delay and of non-contaminated feed consumption following cessation of contaminated feed intake were also considered. Transportation delay refers to the time between processing of the animal and consumption by people. Equation 1-7 describes the nuclide burden carried by the animal's edible flesh at the time of consumption by humans. The equation does not allow for nonattainment of saturation and decay during intake, and therefore yields conservative results. Therefore,

$$q(T_3) = \frac{f_w \cdot U \cdot CF_o}{\lambda_b} \left[\exp(-\lambda T_1) - \exp(-\lambda_e T_1)\right] \cdot \exp(-\lambda_e T_2) \cdot \exp(-\lambda T_3) \qquad (1\text{-}7)$$

where $q(T_3)$ is the nuclide burden carried by the animal at time T_3 (μCi/head)

f_w is the fraction of the nuclides taken into the body by ingestion that is retained in the organ (edible flesh) of concern (dimensionless)

U is the biota dry weight feed consumption rate (kg ash/day-head)

CF_o is the initial dry weight concentration of nuclide in the feed (μCi/kg ash)

λ_b is the biological elimination constant (day^{-1})

λ is the radiological decay constant (day^{-1})

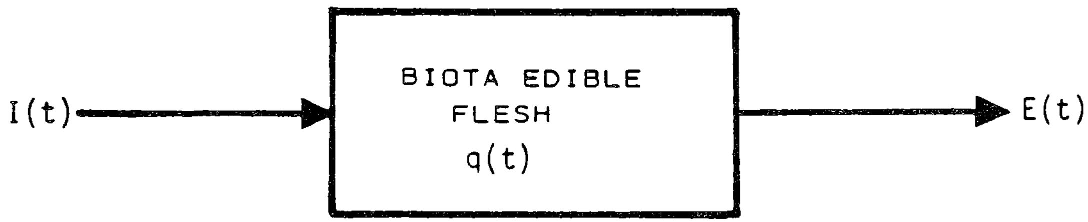
λ_e is the effective elimination constant (day^{-1})

T_1 is the period of contaminated feed intake (day)

T_2 is the period following T_1 of non-contaminated feed intake (day)

T_3 is the period of time between processing and consumption of the biota (day)

A population transfer function (P) of unity for the transfer of radionuclides from biota flesh to the population was assumed. That is, all of the edible flesh of each animal, and all of the nuclides in the flesh, is consumed by humans. The consumption of each contaminated animal was considered to take place entirely at time T_3. Therefore, the 100-year collective dose commitment equivalent (D) is given simply by



q(t) IS THE NUCLIDE QUANTITY IN FLESH (μCI)

I(t) IS THE NUCLIDE INTAKE RATE (μCI/DAY)

E(t) IS THE NUCLIDE ELIMINATION RATE (μCI/DAY)

Figure 5. Model Describing Nuclide Quantity in Edible Portions of Biota.

$$D\left(\frac{\text{person-rem}}{\text{head}}\right) = DCF\left(\frac{\text{rem}}{\mu Ci}\right) \cdot q(T_3)\left(\frac{\mu Ci}{\text{head}}\right) \cdot P\ (\text{persons}) \qquad (1\text{-}8)$$

where DCF is the appropriate dose conversion factor.
P equals one (1)

To convert to a per kg ash of feed basis, Equation 1-8 is divided by the total quantity of contaminated feed consumed. Assuming a uniform rate of feed consumption by the animals, this quantity is $T_1 \cdot U$.

Protective actions for this phase were designed to either reduce the amount of contaminated feed intake or delay the time at which consumption by humans takes place. The effect of these PA's is to change the parameters T_1, T_2, and T_3. A list of the PA's investigated is given in Table 6.

1.5.1 Results of Phase VII

Doses were calculated on a per animal basis for a contamination level of 1 μCi/kg ash of feed of each of the radionuclides listed in Table 1. The results are readily scaled upward for a larger number of affected animals. The nuclide giving the highest dose, on the basis of a unit deposition, is Sr^{90}, for each class of farm animals.

Table 6. Protective Actions for Contaminated Biota.

PA 1:	Reduce contaminated feed intake by one-half.
PA 2:	Freeze biota for six months.
PA 3:	Extend non-contaminated feed time by 10%.
PA 4:	Extend non-contaminated feed time by 15%.
PA 5:	Extend non-contaminated feed time by 20%.
PA 6:	Sacrifice animals. Animals are disposed of properly.

2. RISK ANALYSIS

Risk to the population may be expressed in terms of health effects. Health effect factors, supplied by the EPA,* convert dose or dose commitment to health effects. The units for health effect factors are effects per million person-rem (10 kSv).

In this report the health effects are fatal and non-fatal cancers. A fatal health effect is defined as a cancer which results in death within 10 years of the first confirmed diagnosis. Non-fatal health effects are cancers which result in death occurring in a time period greater than 10 years after first confirmed diagnosis.

In each phase, doses were calculated for as many as eight organs: bone, liver, total body, thyroid, kidney, lung, G.I. tract, and skin. Health effect conversion factors, fatal and non-fatal, as provided by the EPA for each of these organs, are listed in Table 7. A health effect factor for the G.I. tract was not available.

A weighted sum of the doses from each of the 24 radionuclides of interest was obtained by summing the products of the dose and the relative abundance of each nuclide. That is,

$$\text{Total Dose} = \sum_{i=1}^{24} (\text{Dose})_i \cdot (\text{Relative Abundance})_i \qquad (2\text{-}1)$$

Equation 2-1 gives the dose for a unit concentration consisting of each of the 24 nuclides in the relative abundances given in Table 1.

* Letter from Mr. C.G. Amato, U.S. Environmental Protection Agency, Office of Radiation Programs, Washington, D.C., June 8, 1978, transmittal of Table of Health Effects Factors supplied by Dr. N. Nelson, Criteria and Standards Division of ORP, dated June 5, 1978. Values in Table 7 are taken verbatim from Dr. Nelson's Table.

Table 7. Health Effect Conversion Factors.

Organ	Health Effects Per M Person-rem	
	Fatal	Non-Fatal
Bone	6	6
Liver	25	1
Total Body	240	200
Thyroid	10	100
Kidney	10	0
Lung	80	0
Skin	1	10

Once the total dose is obtained for each of the eight organs, the number of committed health effects can be calculated

$$HE = \sum_{j=1}^{8} (\text{Total Dose})_j \cdot HEF_j \qquad (2\text{-}2)$$

where HE is the number of health effects and HEF_j is the health effect conversion factor for the jth organ.

In this way the number of health effects for each exposure pathway and each pathway component (e.g., ingestion of specific fruits and vegetables), with the application of each protective action, was calculated. For Phases III and IV, contaminated land and property, the basis of the calculations was an affected area of 100 ha. For Phases V and VI, contaminated water supplies and persons, the basis of the calculations was a population potentially at risk of 100,000 persons. For Phase VII the bases were 1 kg ash of contaminated feed and one (1) affected farm animal, i.e., head.

Tables 8 through 12 summarize the results of the calculations. The term "cost of PA" refers to the present worth cost incurred as a result of applying each protective action. This concept is explained in greater detail in the next section. The number of health effects averted by each PA is also listed. This is defined as

$$\text{HE Averted} = (\text{HE})_{\text{no PA}} - (\text{HE})_{\text{with PA}}$$

This difference gives the number of health effects potentially saved by each PA, and is therefore an indication of PA effectiveness.

Table 8. Health Effects for Phase III.

PATHWAY COMPONENT	* P.A.	COST OF P.A. ($1000)	** HEALTH EFFECTS FATAL	NON-FATAL	HEALTH EFFECTS AVERTED FATAL	NON-FATAL
WHEAT CROP	NONE		3.32E-04	2.18E-04		
WHEAT CROP	1	67	8.43E-05	5.47E-05	2.47E-04	1.63E-04
WHEAT CROP	2	437	1.36E-05	7.75E-06	3.18E-04	2.10E-04
WHEAT CROP	3	81	8.91E-05	5.91E-05	2.43E-04	1.59E-04
WHEAT CROP	4	87	8.84E-05	5.86E-05	2.43E-04	1.59E-04
WHEAT CROP	5	457	3.67E-07	2.30E-07	3.31E-04	2.18E-04
WHEAT CROP	6	451	3.67E-07	2.30E-07	3.31E-04	2.18E-04
WHEAT CROP	7	119	6.65E-05	4.41E-05	2.65E-04	1.74E-04
WHEAT CROP	8	395	0.00E+00	0.00E+00	3.32E-04	2.18E-04
WHEAT CROP	9	385	0.00E+00	0.00E+00	3.32E-04	2.18E-04
WHEAT CROP	10	2410	0.00E+00	0.00E+00	3.32E-04	2.18E-04
WHEAT CROP	11	13561	0.00E+00	0.00E+00	3.32E-04	2.18E-04
RYE CROP	NONE		1.52E-04	9.75E-05		
RYE CROP	1	67	4.66E-05	2.97E-05	1.05E-04	6.78E-05
RYE CROP	2	437	1.36E-05	7.75E-06	1.38E-04	8.98E-05
RYE CROP	3	81	4.13E-05	2.74E-05	1.11E-04	7.01E-05
RYE CROP	4	87	4.10E-05	2.72E-05	1.11E-04	7.03E-05
RYE CROP	5	457	3.67E-07	2.30E-07	1.52E-04	9.73E-05
RYE CROP	6	451	3.67E-07	2.30E-07	1.52E-04	9.73E-05
RYE CROP	7	119	3.09E-05	2.05E-05	1.21E-04	7.70E-05
RYE CROP	8	395	0.00E+00	0.00E+00	1.52E-04	9.75E-05
RYE CROP	9	385	0.00E+00	0.00E+00	1.52E-04	9.75E-05
RYE CROP	10	2410	0.00E+00	0.00E+00	1.52E-04	9.75E-05
RYE CROP	11	13561	0.00E+00	0.00E+00	1.52E-04	9.75E-05
RICE CROP	NONE		3.16E-04	2.09E-04		
RICE CROP	1	67	7.14E-05	4.61E-05	2.44E-04	1.63E-04
RICE CROP	2	437	1.36E-05	7.75E-06	3.02E-04	2.01E-04
RICE CROP	3	81	7.26E-05	4.82E-05	2.43E-04	1.61E-04
RICE CROP	4	87	7.23E-05	4.79E-05	2.43E-04	1.61E-04
RICE CROP	5	457	3.67E-07	2.30E-07	3.15E-04	2.09E-04
RICE CROP	6	451	3.67E-07	2.30E-07	3.15E-04	2.09E-04
RICE CROP	7	119	5.45E-05	3.62E-05	2.61E-04	1.73E-04
RICE CROP	8	395	0.00E+00	0.00E+00	3.16E-04	2.09E-04
RICE CROP	9	385	0.00E+00	0.00E+00	3.16E-04	2.09E-04
RICE CROP	10	2410	0.00E+00	0.00E+00	3.16E-04	2.09E-04
RICE CROP	11	13561	0.00E+00	0.00E+00	3.16E-04	2.09E-04
CORN CROP	NONE		2.17E-05	1.33E-05		
CORN CROP	1	67	1.85E-05	1.10E-05	3.21E-06	2.30E-06
CORN CROP	2	437	1.36E-05	7.75E-06	8.10E-06	5.55E-06
CORN CROP	3	81	6.54E-06	4.33E-06	1.52E-05	8.97E-06
CORN CROP	4	87	6.51E-06	4.31E-06	1.52E-05	8.99E-06
CORN CROP	5	457	3.67E-07	2.30E-07	2.13E-05	1.31E-05
CORN CROP	6	451	3.67E-07	2.30E-07	2.13E-05	1.31E-05
CORN CROP	7	119	4.92E-06	3.26E-06	1.68E-05	1.00E-05
CORN CROP	8	395	0.00E+00	0.00E+00	2.17E-05	1.33E-05
CORN CROP	9	385	0.00E+00	0.00E+00	2.17E-05	1.33E-05
CORN CROP	10	2410	0.00E+00	0.00E+00	2.17E-05	1.33E-05
CORN CROP	11	13561	0.00E+00	0.00E+00	2.17E-05	1.33E-05
OATS CROP	NONE		4.59E-05	2.86E-05		
OATS CROP	1	67	2.89E-05	1.79E-05	1.70E-05	1.07E-05

* - FOR DESCRIPTION OF PROTECTIVE ACTIONS SEE TABLE 2
** - HEALTH EFFECTS DUE TO A 1 MICROCURIE/100 HECTARES DEPOSITION

Table 8. Health Effects for Phase III.
(Continued)

PATHWAY COMPONENT	* P.A.	COST OF P.A. ($1000)	** HEALTH EFFECTS FATAL	HEALTH EFFECTS NON-FATAL	HEALTH EFFECTS AVERTED FATAL	HEALTH EFFECTS AVERTED NON-FATAL
OATS CROP	2	437	1.36E-05	7.75E-06	3.23E-05	2.08E-05
OATS CROP	3	81	1.94E-05	1.29E-05	2.65E-05	1.57E-05
OATS CROP	4	87	1.93E-05	1.28E-05	2.66E-05	1.58E-05
OATS CROP	5	457	3.67E-07	2.30E-07	4.56E-05	2.83E-05
OATS CROP	6	451	3.67E-07	2.30E-07	4.56E-05	2.83E-05
OATS CROP	7	119	1.46E-05	9.68E-06	3.13E-05	1.89E-05
OATS CROP	8	395	0.00E+00	0.00E+00	4.59E-05	2.86E-05
OATS CROP	9	385	0.00E+00	0.00E+00	4.59E-05	2.86E-05
OATS CROP	10	2410	0.00E+00	0.00E+00	4.59E-05	2.86E-05
OATS CROP	11	13561	0.00E+00	0.00E+00	4.59E-05	2.86E-05
BARLEY CROP	NONE		2.27E-05	1.38E-05		
BARLEY CROP	1	67	1.86E-05	1.10E-05	4.14E-06	2.78E-06
BARLEY CROP	2	437	1.36E-05	7.75E-06	9.08E-06	6.05E-06
BARLEY CROP	3	81	6.57E-06	4.35E-06	1.61E-05	9.45E-06
BARLEY CROP	4	87	6.54E-06	4.33E-06	1.62E-05	9.47E-06
BARLEY CROP	5	457	3.67E-07	2.30E-07	2.23E-05	1.36E-05
BARLEY CROP	6	451	3.67E-07	2.30E-07	2.23E-05	1.36E-05
BARLEY CROP	7	119	4.93E-06	3.26E-06	1.78E-05	1.05E-05
BARLEY CROP	8	395	0.00E+00	0.00E+00	2.27E-05	1.38E-05
BARLEY CROP	9	385	0.00E+00	0.00E+00	2.27E-05	1.38E-05
BARLEY CROP	10	2410	0.00E+00	0.00E+00	2.27E-05	1.38E-05
BARLEY CROP	11	13561	0.00E+00	0.00E+00	2.27E-05	1.38E-05
AVG. GRAIN CROP	NONE		8.91E-05	5.76E-05		
AVG. GRAIN CROP	1	67	3.30E-05	2.07E-05	5.60E-05	3.69E-05
AVG. GRAIN CROP	2	437	1.36E-05	7.73E-06	7.55E-05	4.99E-05
AVG. GRAIN CROP	3	81	2.20E-05	1.64E-05	6.71E-05	4.12E-05
AVG. GRAIN CROP	4	87	2.48E-05	1.64E-05	6.43E-05	4.12E-05
AVG. GRAIN CROP	5	457	3.67E-07	2.30E-07	8.87E-05	5.74E-05
AVG. GRAIN CROP	6	451	3.67E-07	2.30E-07	8.87E-05	5.74E-05
AVG. GRAIN CROP	7	119	1.87E-05	1.24E-05	7.04E-05	4.53E-05
AVG. GRAIN CROP	8	395	0.00E+00	0.00E+00	8.91E-05	5.76E-05
AVG. GRAIN CROP	9	385	0.00E+00	0.00E+00	8.91E-05	5.76E-05
AVG. GRAIN CROP	10	2410	0.00E+00	0.00E+00	8.91E-05	5.76E-05
AVG. GRAIN CROP	11	13561	0.00E+00	0.00E+00	8.91E-05	5.76E-05
TOMATO CROP	NONE		2.39E-03	1.55E-03		
TOMATO CROP	1	524	1.15E-03	7.57E-04	1.24E-03	7.89E-04
TOMATO CROP	2	220	1.35E-03	8.65E-04	1.04E-03	6.81E-04
TOMATO CROP	3	313	1.40E-03	9.31E-04	9.85E-04	6.15E-04
TOMATO CROP	4	319	1.12E-03	7.45E-04	1.27E-03	8.01E-04
TOMATO CROP	5	1000	2.32E-04	1.22E-04	2.16E-03	1.42E-03
TOMATO CROP	6	1099	2.89E-06	1.81E-06	2.39E-03	1.54E-03
TOMATO CROP	7	351	1.06E-03	7.04E-04	1.33E-03	8.42E-04
TOMATO CROP	8	1497	0.00E+00	0.00E+00	2.39E-03	1.55E-03
TOMATO CROP	9	1626	0.00E+00	0.00E+00	2.39E-03	1.55E-03
TOMATO CROP	10	2377	0.00E+00	0.00E+00	2.39E-03	1.55E-03
TOMATO CROP	11	13793	0.00E+00	0.00E+00	2.39E-03	1.55E-03
BEAN CROP	NONE		1.81E-03	1.18E-03		
BEAN CROP	1	524	1.78E-03	1.16E-03	3.62E-05	2.40E-05
BEAN CROP	2	220	1.36E-03	8.67E-04	4.56E-04	3.14E-04
BEAN CROP	3	313	1.42E-03	9.39E-04	3.95E-04	2.42E-04

* - FOR DESCRIPTION OF PROTECTIVE ACTIONS SEE TABLE 2
** - HEALTH EFFECTS DUE TO A 1 MICROCURIE/100 HECTARES DEPOSITION

Table 8. Health Effects for Phase III. (Continued)

PATHWAY COMPONENT	* P.A.	COST OF P.A. ($1000)	** HEALTH EFFECTS FATAL	HEALTH EFFECTS NON-FATAL	HEALTH EFFECTS AVERTED FATAL	HEALTH EFFECTS AVERTED NON-FATAL
BEAN CROP	4	319	1.13E-03	7.47E-04	6.86E-04	4.34E-04
BEAN CROP	5	1000	2.32E-04	1.22E-04	1.58E-03	1.06E-03
BEAN CROP	6	1099	2.89E-06	1.81E-06	1.81E-03	1.18E-03
BEAN CROP	7	351	1.06E-03	7.06E-04	7.47E-04	4.75E-04
BEAN CROP	8	1497	0.00E+00	0.00E+00	1.81E-03	1.18E-03
BEAN CROP	9	1626	0.00E+00	0.00E+00	1.81E-03	1.18E-03
BEAN CROP	10	2377	0.00E+00	0.00E+00	1.81E-03	1.18E-03
BEAN CROP	11	13793	0.00E+00	0.00E+00	1.81E-03	1.18E-03
SPINACH CROP	NONE		2.37E-03	1.53E-03		
SPINACH CROP	1	524	1.87E-03	1.22E-03	4.93E-04	3.12E-04
SPINACH CROP	2	220	1.36E-03	8.67E-04	1.01E-03	6.66E-04
SPINACH CROP	3	313	1.40E-03	9.31E-04	9.64E-04	6.02E-04
SPINACH CROP	4	319	1.13E-03	7.47E-04	1.24E-03	7.86E-04
SPINACH CROP	5	1000	2.32E-04	1.22E-04	2.14E-03	1.41E-03
SPINACH CROP	6	1099	2.89E-06	1.81E-06	2.36E-03	1.53E-03
SPINACH CROP	7	351	1.06E-03	7.04E-04	1.31E-03	8.29E-04
SPINACH CROP	8	1497	0.00E+00	0.00E+00	2.37E-03	1.53E-03
SPINACH CROP	9	1626	0.00E+00	0.00E+00	2.37E-03	1.53E-03
SPINACH CROP	10	2377	0.00E+00	0.00E+00	2.37E-03	1.53E-03
SPINACH CROP	11	13793	0.00E+00	0.00E+00	2.37E-03	1.53E-03
BROCCOLI CROP	NONE		3.97E-03	2.55E-03		
BROCCOLI CROP	1	524	1.20E-03	7.91E-04	2.77E-03	1.76E-03
BROCCOLI CROP	2	220	1.38E-03	8.86E-04	2.59E-03	1.67E-03
BROCCOLI CROP	3	313	1.45E-03	9.61E-04	2.52E-03	1.59E-03
BROCCOLI CROP	4	319	1.16E-03	7.68E-04	2.81E-03	1.78E-03
BROCCOLI CROP	5	1000	2.32E-04	1.22E-04	3.74E-03	2.43E-03
BROCCOLI CROP	6	1099	2.89E-06	1.81E-06	3.97E-03	2.55E-03
BROCCOLI CROP	7	351	1.09E-03	7.26E-04	2.88E-03	1.83E-03
BROCCOLI CROP	8	1497	0.00E+00	0.00E+00	3.97E-03	2.55E-03
BROCCOLI CROP	9	1626	0.00E+00	0.00E+00	3.97E-03	2.55E-03
BROCCOLI CROP	10	2377	0.00E+00	0.00E+00	3.97E-03	2.55E-03
BROCCOLI CROP	11	13793	0.00E+00	0.00E+00	3.97E-03	2.55E-03
POTATO CROP	NONE		1.85E-03	1.21E-03		
POTATO CROP	1	524	1.18E-03	7.78E-04	6.73E-04	4.29E-04
POTATO CROP	2	220	1.38E-03	8.86E-04	4.67E-04	3.20E-04
POTATO CROP	3	313	1.44E-03	9.55E-04	4.10E-04	2.52E-04
POTATO CROP	4	319	1.15E-03	7.64E-04	6.98E-04	4.42E-04
POTATO CROP	5	1000	2.32E-04	1.22E-04	1.62E-03	1.08E-03
POTATO CROP	6	1099	2.89E-06	1.81E-06	1.85E-03	1.20E-03
POTATO CROP	7	351	1.09E-03	7.23E-04	7.60E-04	4.83E-04
POTATO CROP	8	1497	0.00E+00	0.00E+00	1.85E-03	1.21E-03
POTATO CROP	9	1626	0.00E+00	0.00E+00	1.85E-03	1.21E-03
POTATO CROP	10	2377	0.00E+00	0.00E+00	1.85E-03	1.21E-03
POTATO CROP	11	13793	0.00E+00	0.00E+00	1.85E-03	1.21E-03
AVG. VEGT. CROP	NONE		2.04E-03	1.33E-03		
AVG. VEGT. CROP	1	524	1.20E-03	7.91E-04	8.43E-04	5.36E-04
AVG. VEGT. CROP	2	220	1.37E-03	8.80E-04	6.68E-04	4.47E-04
AVG. VEGT. CROP	3	313	1.43E-03	9.46E-04	6.15E-04	3.81E-04
AVG. VEGT. CROP	4	319	2.34E-03	1.76E-03	-3.00E-04	-4.30E-04
AVG. VEGT. CROP	5	1000	2.32E-04	1.22E-04	1.81E-03	1.21E-03

* - FOR DESCRIPTION OF PROTECTIVE ACTIONS SEE TABLE 2
** - HEALTH EFFECTS DUE TO A 1 MICROCURIE/100 HECTARES DEPOSITION

Table 8. Health Effects for Phase III.
(Continued)

PATHWAY COMPONENT	P.A.*	COST OF P.A. ($1000)	HEALTH EFFECTS** FATAL	HEALTH EFFECTS** NON-FATAL	HEALTH EFFECTS AVERTED FATAL	HEALTH EFFECTS AVERTED NON-FATAL
AVG. VEGT. CROP	6	1099	2.89E-06	1.81E-06	2.04E-03	1.33E-03
AVG. VEGT. CROP	7	351	1.08E-03	7.17E-04	9.61E-04	6.10E-04
AVG. VEGT. CROP	8	1497	0.00E+00	0.00E+00	2.04E-03	1.33E-03
AVG. VEGT. CROP	9	1626	0.00E+00	0.00E+00	2.04E-03	1.33E-03
AVG. VEGT. CROP	10	2377	0.00E+00	0.00E+00	2.04E-03	1.33E-03
AVG. VEGT. CROP	11	13793	0.00E+00	0.00E+00	2.04E-03	1.33E-03
APPLE CROP	NONE		4.99E-03	3.31E-03		
APPLE CROP	1	369	1.46E-03	9.66E-04	3.54E-03	2.34E-03
APPLE CROP	2	468	1.39E-03	9.23E-04	3.60E-03	2.38E-03
APPLE CROP	3	1754	0.00E+00	0.00E+00	4.99E-03	3.31E-03
APPLE CROP	4	658	0.00E+00	0.00E+00	4.99E-03	3.31E-03
APPLE CROP	5	5185	0.00E+00	0.00E+00	4.99E-03	3.31E-03
APPLE CROP	6	15798	0.00E+00	0.00E+00	4.99E-03	3.31E-03
APRICOT CROP	NONE		1.89E-03	1.26E-03		
APRICOT CROP	1	369	1.39E-03	9.21E-04	5.06E-04	3.35E-04
APRICOT CROP	2	468	1.32E-03	8.78E-04	5.70E-04	3.78E-04
APRICOT CROP	3	1754	0.00E+00	0.00E+00	1.89E-03	1.26E-03
APRICOT CROP	4	658	0.00E+00	0.00E+00	1.89E-03	1.26E-03
APRICOT CROP	5	5185	0.00E+00	0.00E+00	1.89E-03	1.26E-03
APRICOT CROP	6	15798	0.00E+00	0.00E+00	1.89E-03	1.26E-03
ORANGE CROP	NONE		2.61E-03	1.73E-03		
ORANGE CROP	1	369	1.41E-03	9.36E-04	1.20E-03	7.91E-04
ORANGE CROP	2	468	1.35E-03	8.93E-04	1.26E-03	8.34E-04
ORANGE CROP	3	1754	0.00E+00	0.00E+00	2.61E-03	1.73E-03
ORANGE CROP	4	658	0.00E+00	0.00E+00	2.61E-03	1.73E-03
ORANGE CROP	5	5185	0.00E+00	0.00E+00	2.61E-03	1.73E-03
ORANGE CROP	6	15798	0.00E+00	0.00E+00	2.61E-03	1.73E-03
GRAPEFRUIT CROP	NONE		4.08E-03	2.70E-03		
GRAPEFRUIT CROP	1	369	1.43E-03	9.51E-04	2.64E-03	1.75E-03
GRAPEFRUIT CROP	2	468	1.37E-03	9.08E-04	2.71E-03	1.80E-03
GRAPEFRUIT CROP	3	1754	0.00E+00	0.00E+00	4.08E-03	2.70E-03
GRAPEFRUIT CROP	4	658	0.00E+00	0.00E+00	4.08E-03	2.70E-03
GRAPEFRUIT CROP	5	5185	0.00E+00	0.00E+00	4.08E-03	2.70E-03
GRAPEFRUIT CROP	6	15798	0.00E+00	0.00E+00	4.08E-03	2.70E-03
LEMON CROP	NONE		4.60E-03	3.05E-03		
LEMON CROP	1	369	1.45E-03	9.60E-04	3.15E-03	2.09E-03
LEMON CROP	2	468	1.38E-03	9.16E-04	3.22E-03	2.13E-03
LEMON CROP	3	1754	0.00E+00	0.00E+00	4.60E-03	3.05E-03
LEMON CROP	4	658	0.00E+00	0.00E+00	4.60E-03	3.05E-03
LEMON CROP	5	5185	0.00E+00	0.00E+00	4.60E-03	3.05E-03
LEMON CROP	6	15798	0.00E+00	0.00E+00	4.60E-03	3.05E-03
TANGERINE CROP	NONE		5.45E-03	3.61E-03		
TANGERINE CROP	1	369	1.47E-03	9.75E-04	3.97E-03	2.63E-03
TANGERINE CROP	2	468	1.40E-03	9.31E-04	4.04E-03	2.68E-03
TANGERINE CROP	3	1754	0.00E+00	0.00E+00	5.45E-03	3.61E-03
TANGERINE CROP	4	658	0.00E+00	0.00E+00	5.45E-03	3.61E-03
TANGERINE CROP	5	5185	0.00E+00	0.00E+00	5.45E-03	3.61E-03
TANGERINE CROP	6	15798	0.00E+00	0.00E+00	5.45E-03	3.61E-03
GRAPE CROP	NONE		2.02E-03	1.34E-03		
GRAPE CROP	1	369	1.40E-03	9.27E-04	6.25E-04	4.14E-04

* - FOR DESCRIPTION OF PROTECTIVE ACTIONS SEE TABLE 2
** - HEALTH EFFECTS DUE TO A 1 MICROCURIE/100 HECTARES DEPOSITION

Table 8. Health Effects for Phase III.
(Continued)

PATHWAY COMPONENT	P.A. *	COST OF P.A. ($1000)	HEALTH EFFECTS ** FATAL	HEALTH EFFECTS ** NON-FATAL	HEALTH EFFECTS AVERTED FATAL	HEALTH EFFECTS AVERTED NON-FATAL
GRAPE CROP	2	468	1.32E-03	8.78E-04	6.99E-04	4.64E-04
GRAPE CROP	3	1754	0.00E+00	0.00E+00	2.02E-03	1.34E-03
GRAPE CROP	4	658	0.00E+00	0.00E+00	2.02E-03	1.34E-03
GRAPE CROP	5	5185	0.00E+00	0.00E+00	2.02E-03	1.34E-03
GRAPE CROP	6	15798	0.00E+00	0.00E+00	2.02E-03	1.34E-03
PEACH CROP	NONE		3.76E-03	2.49E-03		
PEACH CROP	1	369	1.43E-03	9.51E-04	2.32E-03	1.54E-03
PEACH CROP	2	468	1.37E-03	9.08E-04	2.39E-03	1.58E-03
PEACH CROP	3	1754	0.00E+00	0.00E+00	3.76E-03	2.49E-03
PEACH CROP	4	658	0.00E+00	0.00E+00	3.76E-03	2.49E-03
PEACH CROP	5	5185	0.00E+00	0.00E+00	3.76E-03	2.49E-03
PEACH CROP	6	15798	0.00E+00	0.00E+00	3.76E-03	2.49E-03
PEAR CROP	NONE		2.15E-03	1.43E-03		
PEAR CROP	1	369	1.40E-03	9.27E-04	7.53E-04	4.99E-04
PEAR CROP	2	468	1.33E-03	8.84E-04	8.17E-04	5.42E-04
PEAR CROP	3	1754	0.00E+00	0.00E+00	2.15E-03	1.43E-03
PEAR CROP	4	658	0.00E+00	0.00E+00	2.15E-03	1.43E-03
PEAR CROP	5	5185	0.00E+00	0.00E+00	2.15E-03	1.43E-03
PEAR CROP	6	15798	0.00E+00	0.00E+00	2.15E-03	1.43E-03
AVG. ORCH. CROP	NONE		3.13E-03	2.07E-03		
AVG. ORCH. CROP	1	369	1.42E-03	9.40E-04	1.71E-03	1.13E-03
AVG. ORCH. CROP	2	468	1.35E-03	8.97E-04	1.78E-03	1.18E-03
AVG. ORCH. CROP	3	1754	0.00E+00	0.00E+00	3.13E-03	2.07E-03
AVG. ORCH. CROP	4	658	0.00E+00	0.00E+00	3.13E-03	2.07E-03
AVG. ORCH. CROP	5	5185	0.00E+00	0.00E+00	3.13E-03	2.07E-03
AVG. ORCH. CROP	6	15798	0.00E+00	0.00E+00	3.13E-03	2.07E-03
RECREATIONAL	NONE		2.78E-04	9.81E-07		
RECREATIONAL	1	156	0.00E+00	0.00E+00	2.78E-04	9.81E-07
MILK	NONE		1.48E-07	1.01E-07		
MILK	1	201	1.33E-07	9.06E-08	1.48E-08	1.00E-08
MILK	2	250	1.11E-07	7.55E-08	3.70E-08	2.52E-08
MILK	3	223	0.00E+00	0.00E+00	1.48E-07	1.01E-07
MILK	4	2092	0.00E+00	0.00E+00	1.48E-07	1.01E-07
MILK	5	259	0.00E+00	0.00E+00	1.48E-07	1.01E-07
MILK	6	2361	0.00E+00	0.00E+00	1.48E-07	1.01E-07
BEEF	NONE		9.31E-07	5.27E-07		
BEEF	1	201	8.38E-07	4.73E-07	9.38E-08	5.36E-08
BEEF	2	250	6.98E-07	3.94E-07	2.33E-07	1.33E-07
BEEF	3	223	0.00E+00	0.00E+00	9.31E-07	5.27E-07
BEEF	4	2092	0.00E+00	0.00E+00	9.31E-07	5.27E-07
BEEF	5	259	0.00E+00	0.00E+00	9.31E-07	5.27E-07
BEEF	6	2361	0.00E+00	0.00E+00	9.31E-07	5.27E-07

* - FOR DESCRIPTION OF PROTECTIVE ACTIONS SEE TABLE 2
** - HEALTH EFFECTS DUE TO A 1 MICROCURIE/100 HECTARES DEPOSITION

Table 9. Health Effects for Phase IV.

PATHWAY	PROPERTY TYPE	* P.A.	COST OF P.A. ($1000)	** HEALTH EFFECTS FATAL	HEALTH EFFECTS NON-FATAL	HEALTH EFFECTS AVERTED FATAL	HEALTH EFFECTS AVERTED NON-FATAL
INHALATION	SINGLE UNIT RESIDENTIAL	NONE		4.46E-03	4.49E-06		
INHALATION	SINGLE UNIT RESIDENTIAL	1	2427	9.44E-04	9.50E-07	3.52E-03	3.54E-06
INHALATION	SINGLE UNIT RESIDENTIAL	2	4423	9.13E-04	9.19E-07	3.55E-03	3.57E-06
INHALATION	SINGLE UNIT RESIDENTIAL	3	4120	5.12E-04	5.15E-07	3.95E-03	3.98E-06
INHALATION	SINGLE UNIT RESIDENTIAL	4	16221	1.90E-04	1.92E-07	4.27E-03	4.30E-06
INHALATION	SINGLE UNIT RESIDENTIAL	5	7167	4.02E-04	4.04E-07	4.06E-03	4.09E-06
INHALATION	SINGLE UNIT RESIDENTIAL	6	2727	5.15E-04	5.19E-07	3.95E-03	3.97E-06
INHALATION	SINGLE UNIT RESIDENTIAL	7	18061	1.16E-04	1.17E-07	4.35E-03	4.38E-06
INHALATION	SINGLE UNIT RESIDENTIAL	8	1018	1.17E-03	1.18E-06	3.29E-03	3.31E-06
INHALATION	SINGLE UNIT RESIDENTIAL	9	17587	8.08E-05	8.13E-08	4.38E-03	4.41E-06
INHALATION	SINGLE UNIT RESIDENTIAL	10	6743	8.93E-05	8.98E-08	4.37E-03	4.40E-06
INHALATION	MULTIPLE UNIT RESIDENTIAL	NONE		2.78E-02	2.79E-05		
INHALATION	MULTIPLE UNIT RESIDENTIAL	1	4012	1.39E-03	1.40E-06	2.64E-02	2.65E-05
INHALATION	MULTIPLE UNIT RESIDENTIAL	2	7251	1.14E-03	1.15E-06	2.66E-02	2.68E-05
INHALATION	MULTIPLE UNIT RESIDENTIAL	3	6446	2.94E-03	2.96E-06	2.48E-02	2.50E-05
INHALATION	MULTIPLE UNIT RESIDENTIAL	4	194	3.97E-03	3.99E-06	2.38E-02	2.40E-05
INHALATION	MULTIPLE UNIT RESIDENTIAL	5	16631	5.55E-04	5.59E-07	2.72E-02	2.74E-05
INHALATION	MULTIPLE UNIT RESIDENTIAL	6	2597	2.16E-03	2.18E-06	2.56E-02	2.58E-05
INHALATION	MULTIPLE UNIT RESIDENTIAL	7	2252	5.08E-03	5.11E-06	2.27E-02	2.28E-05
INHALATION	MULTIPLE UNIT RESIDENTIAL	8	10691	5.55E-04	5.59E-07	2.72E-02	2.74E-05
INHALATION	MULTIPLE UNIT RESIDENTIAL	9	6149	1.58E-03	1.59E-06	2.62E-02	2.64E-05
INHALATION	COMMERCIAL/COMMUNITY USE	NONE		7.30E-02	7.35E-05		
INHALATION	COMMERCIAL/COMMUNITY USE	1	5192	3.65E-03	3.67E-06	6.93E-02	6.98E-05
INHALATION	COMMERCIAL/COMMUNITY USE	2	12665	2.55E-03	2.57E-06	7.04E-02	7.09E-05
INHALATION	COMMERCIAL/COMMUNITY USE	3	14182	5.94E-03	5.98E-06	6.70E-02	6.75E-05
INHALATION	COMMERCIAL/COMMUNITY USE	4	4449	1.04E-02	1.05E-05	6.26E-02	6.30E-05
INHALATION	COMMERCIAL/COMMUNITY USE	5	21515	1.46E-03	1.47E-06	7.15E-02	7.20E-05
INHALATION	COMMERCIAL/COMMUNITY USE	6	2259	7.04E-03	7.08E-06	6.60E-02	6.64E-05
INHALATION	COMMERCIAL/COMMUNITY USE	7	2190	1.25E-02	1.26E-05	6.05E-02	6.09E-05
INHALATION	COMMERCIAL/COMMUNITY USE	8	17406	1.46E-03	1.47E-06	7.15E-02	7.20E-05
INHALATION	COMMERCIAL/COMMUNITY USE	9	7282	5.94E-03	5.98E-06	6.70E-02	6.75E-05
INHALATION	URBAN/SUBURBAN REC. USE	NONE		3.20E-03	3.22E-06		
INHALATION	URBAN/SUBURBAN REC. USE	1	1900	3.97E-04	4.00E-07	2.80E-03	2.82E-06
INHALATION	URBAN/SUBURBAN REC. USE	2	7846	3.97E-04	4.00E-07	2.80E-03	2.82E-06
INHALATION	URBAN/SUBURBAN REC. USE	3	9957	8.31E-05	8.36E-08	3.11E-03	3.13E-06
INHALATION	URBAN/SUBURBAN REC. USE	4	6259	8.84E-04	8.90E-07	2.31E-03	2.33E-06
INHALATION	URBAN/SUBURBAN REC. USE	5	14789	2.02E-04	2.04E-07	2.99E-03	3.01E-06
INHALATION	URBAN/SUBURBAN REC. USE	6	2034	2.88E-04	2.89E-07	2.91E-03	2.93E-06
INHALATION	URBAN/SUBURBAN REC. USE	7	15924	8.31E-05	8.36E-08	3.11E-03	3.13E-06
INHALATION	URBAN/SUBURBAN REC. USE	8	1533	4.57E-04	4.60E-07	2.74E-03	2.76E-06
AIR IMMERSION	SINGLE UNIT RESIDENTIAL	NONE		2.22E-07	1.88E-07		
AIR IMMERSION	SINGLE UNIT RESIDENTIAL	1	2427	4.69E-08	3.98E-08	1.75E-07	1.48E-07
AIR IMMERSION	SINGLE UNIT RESIDENTIAL	2	4423	4.54E-08	3.85E-08	1.76E-07	1.50E-07
AIR IMMERSION	SINGLE UNIT RESIDENTIAL	3	4120	2.54E-08	2.16E-08	1.96E-07	1.67E-07
AIR IMMERSION	SINGLE UNIT RESIDENTIAL	4	16221	9.46E-09	8.03E-09	2.12E-07	1.80E-07
AIR IMMERSION	SINGLE UNIT RESIDENTIAL	5	7167	2.00E-08	1.69E-08	2.02E-07	1.71E-07
AIR IMMERSION	SINGLE UNIT RESIDENTIAL	6	2727	2.56E-08	2.17E-08	1.96E-07	1.66E-07
AIR IMMERSION	SINGLE UNIT RESIDENTIAL	7	18061	5.76E-09	4.89E-09	2.16E-07	1.83E-07
AIR IMMERSION	SINGLE UNIT RESIDENTIAL	8	1018	5.83E-08	4.95E-08	1.63E-07	1.39E-07
AIR IMMERSION	SINGLE UNIT RESIDENTIAL	9	17587	4.01E-09	3.41E-09	2.18E-07	1.85E-07

* - FOR DESCRIPTION OF PROTECTIVE ACTIONS SEE TABLE 3
** - HEALTH EFFECTS DUE TO A 1 MICROCURIE/100 HECTARES DEPOSITION

Table 9. Health Effects for Phase IV. (Continued)

PATHWAY	PROPERTY TYPE	* P.A.	COST OF P.A. ($1000)	** HEALTH EFFECTS FATAL	HEALTH EFFECTS NON-FATAL	HEALTH EFFECTS AVERTED FATAL	HEALTH EFFECTS AVERTED NON-FATAL
AIR IMMERSION	SINGLE UNIT RESIDENTIAL	10	6743	4.43E-09	3.76E-09	2.17E-07	1.84E-07
AIR IMMERSION	MULTIPLE UNIT RESIDENTIAL	NONE		1.38E-06	1.17E-06		
AIR IMMERSION	MULTIPLE UNIT RESIDENTIAL	1	4012	6.89E-08	5.85E-08	1.31E-06	1.11E-06
AIR IMMERSION	MULTIPLE UNIT RESIDENTIAL	2	7251	5.65E-08	4.80E-08	1.32E-06	1.12E-06
AIR IMMERSION	MULTIPLE UNIT RESIDENTIAL	3	6446	1.46E-07	1.24E-07	1.23E-06	1.05E-06
AIR IMMERSION	MULTIPLE UNIT RESIDENTIAL	4	194	1.97E-07	1.67E-07	1.18E-06	1.00E-06
AIR IMMERSION	MULTIPLE UNIT RESIDENTIAL	5	16631	2.76E-08	2.34E-08	1.35E-06	1.15E-06
AIR IMMERSION	MULTIPLE UNIT RESIDENTIAL	6	2597	1.07E-07	9.11E-08	1.27E-06	1.08E-06
AIR IMMERSION	MULTIPLE UNIT RESIDENTIAL	7	2252	2.52E-07	2.14E-07	1.13E-06	9.56E-07
AIR IMMERSION	MULTIPLE UNIT RESIDENTIAL	8	10691	2.76E-08	2.34E-08	1.35E-06	1.15E-06
AIR IMMERSION	MULTIPLE UNIT RESIDENTIAL	9	6149	7.84E-08	6.65E-08	1.30E-06	1.10E-06
AIR IMMERSION	COMMERCIAL/COMMUNITY USE	NONE		3.62E-06	3.08E-06		
AIR IMMERSION	COMMERCIAL/COMMUNITY USE	1	5192	1.81E-07	1.54E-07	3.44E-06	2.92E-06
AIR IMMERSION	COMMERCIAL/COMMUNITY USE	2	12665	1.27E-07	1.08E-07	3.50E-06	2.97E-06
AIR IMMERSION	COMMERCIAL/COMMUNITY USE	3	14182	2.95E-07	2.50E-07	3.33E-06	2.83E-06
AIR IMMERSION	COMMERCIAL/COMMUNITY USE	4	4449	5.18E-07	4.39E-07	3.11E-06	2.64E-06
AIR IMMERSION	COMMERCIAL/COMMUNITY USE	5	21515	7.25E-08	6.15E-08	3.55E-06	3.01E-06
AIR IMMERSION	COMMERCIAL/COMMUNITY USE	6	2259	3.50E-07	2.97E-07	3.27E-06	2.78E-06
AIR IMMERSION	COMMERCIAL/COMMUNITY USE	7	2190	6.21E-07	5.28E-07	3.00E-06	2.55E-06
AIR IMMERSION	COMMERCIAL/COMMUNITY USE	8	17406	7.25E-08	6.15E-08	3.55E-06	3.01E-06
AIR IMMERSION	COMMERCIAL/COMMUNITY USE	9	7282	2.95E-07	2.50E-07	3.33E-06	2.83E-06
AIR IMMERSION	URBAN/SUBURBAN REC. USE	NONE		1.59E-07	1.35E-07		
AIR IMMERSION	URBAN/SUBURBAN REC. USE	1	1900	1.97E-08	1.67E-08	1.39E-07	1.18E-07
AIR IMMERSION	URBAN/SUBURBAN REC. USE	2	7846	1.97E-08	1.67E-08	1.39E-07	1.18E-07
AIR IMMERSION	URBAN/SUBURBAN REC. USE	3	9957	4.13E-09	3.50E-09	1.55E-07	1.31E-07
AIR IMMERSION	URBAN/SUBURBAN REC. USE	4	6259	4.39E-08	3.73E-08	1.15E-07	9.74E-08
AIR IMMERSION	URBAN/SUBURBAN REC. USE	5	14789	1.00E-08	8.53E-09	1.49E-07	1.26E-07
AIR IMMERSION	URBAN/SUBURBAN REC. USE	6	2034	1.43E-08	1.21E-08	1.44E-07	1.23E-07
AIR IMMERSION	URBAN/SUBURBAN REC. USE	7	15924	4.13E-09	3.50E-09	1.55E-07	1.31E-07
AIR IMMERSION	URBAN/SUBURBAN REC. USE	8	1533	2.27E-08	1.92E-08	1.36E-07	1.15E-07
SURFACE SHINE	SINGLE UNIT RESIDENTIAL	NONE		4.25E-04	3.44E-04		
SURFACE SHINE	SINGLE UNIT RESIDENTIAL	1	2427	7.10E-05	5.75E-05	3.54E-04	2.86E-04
SURFACE SHINE	SINGLE UNIT RESIDENTIAL	2	4423	2.86E-04	2.32E-04	1.38E-04	1.12E-04
SURFACE SHINE	SINGLE UNIT RESIDENTIAL	3	4120	2.55E-04	2.07E-04	1.70E-04	1.37E-04
SURFACE SHINE	SINGLE UNIT RESIDENTIAL	4	16221	1.04E-05	8.43E-06	4.14E-04	3.35E-04
SURFACE SHINE	SINGLE UNIT RESIDENTIAL	5	7167	2.54E-04	2.06E-04	1.71E-04	1.38E-04
SURFACE SHINE	SINGLE UNIT RESIDENTIAL	6	2727	3.94E-05	3.19E-05	3.85E-04	3.12E-04
SURFACE SHINE	SINGLE UNIT RESIDENTIAL	7	18061	9.09E-06	7.36E-06	4.15E-04	3.37E-04
SURFACE SHINE	SINGLE UNIT RESIDENTIAL	8	1018	9.53E-05	7.72E-05	3.29E-04	2.67E-04
SURFACE SHINE	SINGLE UNIT RESIDENTIAL	9	17587	7.89E-06	6.39E-06	4.17E-04	3.38E-04
SURFACE SHINE	SINGLE UNIT RESIDENTIAL	10	6743	2.31E-04	1.87E-04	1.94E-04	1.57E-04
SURFACE SHINE	MULTIPLE UNIT RESIDENTIAL	NONE		1.12E-03	9.08E-04		
SURFACE SHINE	MULTIPLE UNIT RESIDENTIAL	1	4012	5.61E-05	4.54E-05	1.07E-03	8.63E-04
SURFACE SHINE	MULTIPLE UNIT RESIDENTIAL	2	7251	2.66E-04	2.16E-04	8.56E-04	6.93E-04
SURFACE SHINE	MULTIPLE UNIT RESIDENTIAL	3	6446	3.49E-04	2.83E-04	7.73E-04	6.26E-04
SURFACE SHINE	MULTIPLE UNIT RESIDENTIAL	4	194	1.60E-04	1.29E-04	9.62E-04	7.79E-04
SURFACE SHINE	MULTIPLE UNIT RESIDENTIAL	5	16631	9.49E-04	7.69E-04	1.73E-04	1.39E-04
SURFACE SHINE	MULTIPLE UNIT RESIDENTIAL	6	2597	7.71E-05	6.24E-05	1.04E-03	8.46E-04
SURFACE SHINE	MULTIPLE UNIT RESIDENTIAL	7	2252	2.11E-04	1.71E-04	9.10E-04	7.37E-04
SURFACE SHINE	MULTIPLE UNIT RESIDENTIAL	8	10691	2.39E-04	1.94E-04	8.83E-04	7.14E-04

* - FOR DESCRIPTION OF PROTECTIVE ACTIONS SEE TABLE 3
** - HEALTH EFFECTS DUE TO A 1 MICROCURIE/100 HECTARES DEPOSITION

Table 9. Health Effects for Phase IV.
(Continued)

PATHWAY	PROPERTY TYPE	* P.A.	COST OF P.A. ($1000)	** HEALTH EFFECTS FATAL	HEALTH EFFECTS NON-FATAL	HEALTH EFFECTS AVERTED FATAL	HEALTH EFFECTS AVERTED NON-FATAL
SURFACE SHINE	MULTIPLE UNIT RESIDENTIAL	9	6149	5.01E-05	4.06E-05	1.07E-03	8.68E-04
SURFACE SHINE	COMMERCIAL/COMMUNITY USE	NONE		1.69E-03	1.37E-03		
SURFACE SHINE	COMMERCIAL/COMMUNITY USE	1	5192	8.44E-05	6.84E-05	1.60E-03	1.30E-03
SURFACE SHINE	COMMERCIAL/COMMUNITY USE	2	12665	3.01E-04	2.44E-04	1.39E-03	1.12E-03
SURFACE SHINE	COMMERCIAL/COMMUNITY USE	3	14182	4.28E-04	3.47E-04	1.26E-03	1.02E-03
SURFACE SHINE	COMMERCIAL/COMMUNITY USE	4	4449	2.33E-04	1.89E-04	1.45E-03	1.18E-03
SURFACE SHINE	COMMERCIAL/COMMUNITY USE	5	21515	3.71E-04	3.00E-04	1.32E-03	1.07E-03
SURFACE SHINE	COMMERCIAL/COMMUNITY USE	6	2259	1.07E-04	8.65E-05	1.58E-03	1.28E-03
SURFACE SHINE	COMMERCIAL/COMMUNITY USE	7	2190	3.24E-04	2.62E-04	1.36E-03	1.10E-03
SURFACE SHINE	COMMERCIAL/COMMUNITY USE	8	17406	2.57E-04	2.08E-04	1.43E-03	1.16E-03
SURFACE SHINE	COMMERCIAL/COMMUNITY USE	9	7282	6.23E-05	5.05E-05	1.62E-03	1.32E-03
SURFACE SHINE	URBAN/SUBURBAN REC. USE	NONE		7.26E-04	5.88E-04		
SURFACE SHINE	URBAN/SUBURBAN REC. USE	1	1900	9.98E-05	8.08E-05	6.27E-04	5.07E-04
SURFACE SHINE	URBAN/SUBURBAN REC. USE	2	7846	9.98E-05	8.08E-05	6.27E-04	5.07E-04
SURFACE SHINE	URBAN/SUBURBAN REC. USE	3	9957	1.58E-05	1.28E-05	7.11E-04	5.75E-04
SURFACE SHINE	URBAN/SUBURBAN REC. USE	4	6259	1.94E-04	1.57E-04	5.33E-04	4.31E-04
SURFACE SHINE	URBAN/SUBURBAN REC. USE	5	14789	4.77E-05	3.86E-05	6.79E-04	5.49E-04
SURFACE SHINE	URBAN/SUBURBAN REC. USE	6	2034	7.05E-05	5.71E-05	6.56E-04	5.31E-04
SURFACE SHINE	URBAN/SUBURBAN REC. USE	7	15924	1.58E-05	1.28E-05	7.11E-04	5.75E-04
SURFACE SHINE	URBAN/SUBURBAN REC. USE	8	1533	1.04E-04	8.40E-05	6.23E-04	5.04E-04

* - FOR DESCRIPTION OF PROTECTIVE ACTIONS SEE TABLE 3
** - HEALTH EFFECTS DUE TO A 1 MICROCURIE/100 HECTARES DEPOSITION

Table 10. Health Effects for Phase V.

PATHWAY - RESERVOIR WATER

TREATMENT PLANT *	TURNOVER RATE(YR-1)	CONTROL TECHNOLOGY	COST OF C.T. ($1000)	HEALTH EFFECTS ** FATAL	HEALTH EFFECTS ** NON-FATAL	HEALTH EFFECTS AVERTED FATAL	HEALTH EFFECTS AVERTED NON-FATAL
BASE PLANT	2.0	NO CNTR TECH		3.97E+00	9.58E+00		
BASE PLANT	2.0	PLANT NO. 1	18230	3.85E+00	9.50E+00	1.23E-01	7.93E-02
BASE PLANT	2.0	PLANT NO. 2	19610	3.82E+00	9.47E+00	1.52E-01	1.04E-01
BASE PLANT	2.0	PLANT NO. 3	50420	3.76E+00	9.44E+00	2.10E-01	1.42E-01
BASE PLANT	2.0	PLANT NO. 4	32750	3.76E+00	9.44E+00	2.11E-01	1.42E-01
BASE PLANT	2.0	PLANT NO. 5	17540	3.77E+00	9.44E+00	1.99E-01	1.34E-01
BASE PLANT	6.0	NO CNTR TECH		2.20E+00	7.62E+00		
BASE PLANT	6.0	PLANT NO. 1	18230	2.20E+00	7.62E+00	1.08E-03	6.63E-04
BASE PLANT	6.0	PLANT NO. 2	19610	2.20E+00	7.62E+00	1.08E-03	6.63E-04
BASE PLANT	6.0	PLANT NO. 3	50420	2.20E+00	7.62E+00	1.68E-03	1.13E-03
BASE PLANT	6.0	PLANT NO. 4	32750	2.20E+00	7.62E+00	1.68E-03	1.13E-03
BASE PLANT	6.0	PLANT NO. 5	17540	2.20E+00	7.62E+00	1.44E-03	9.25E-04
BASE PLANT	50.0	NO CNTR TECH		5.94E-01	3.20E+00		
BASE PLANT	50.0	PLANT NO. 1	18230	5.94E-01	3.20E+00	0.00E+00	0.00E+00
BASE PLANT	50.0	PLANT NO. 2	19610	5.94E-01	3.20E+00	0.00E+00	0.00E+00
BASE PLANT	50.0	PLANT NO. 3	50420	5.94E-01	3.20E+00	0.00E+00	0.00E+00
BASE PLANT	50.0	PLANT NO. 4	32750	5.94E-01	3.20E+00	0.00E+00	0.00E+00
BASE PLANT	50.0	PLANT NO. 5	17540	5.94E-01	3.20E+00	0.00E+00	0.00E+00
PLANT NO. 1	2.0	NO CNTR TECH		2.27E+00	7.12E+00		
PLANT NO. 1	2.0	PLUS CLAY	1524	1.92E+00	6.90E+00	3.46E-01	2.26E-01
PLANT NO. 1	2.0	PLUS KH2PO4	18550	1.41E+00	5.42E+00	8.59E-01	1.71E+00
PLANT NO. 1	2.0	PLUS LIME	1300	1.89E+00	6.79E+00	3.76E-01	3.28E-01
PLANT NO. 1	6.0	NO CNTR TECH		1.45E+00	5.92E+00		
PLANT NO. 1	6.0	PLUS CLAY	1524	1.32E+00	5.84E+00	1.26E-01	8.22E-02
PLANT NO. 1	6.0	PLUS KH2PO4	18550	1.04E+00	4.66E+00	4.06E-01	1.26E+00
PLANT NO. 1	6.0	PLUS LIME	1300	1.27E+00	5.77E+00	1.72E-01	1.52E-01
PLANT NO. 1	50.0	NO CNTR TECH		4.46E-01	2.55E+00		
PLANT NO. 1	50.0	PLUS CLAY	1524	4.29E-01	2.54E+00	1.69E-02	1.11E-02
PLANT NO. 1	50.0	PLUS KH2PO4	18550	3.51E-01	2.04E+00	9.44E-02	5.11E-01
PLANT NO. 1	50.0	PLUS LIME	1300	4.17E-01	2.52E+00	2.83E-02	2.52E-02
PLANT NO. 2	2.0	NO CNTR TECH		1.89E+00	6.79E+00		
PLANT NO. 2	2.0	PLUS CLAY	1524	1.55E+00	6.57E+00	3.46E-01	2.25E-01
PLANT NO. 2	2.0	PLUS KH2PO4	18550	1.33E+00	5.35E+00	5.59E-01	1.44E+00
PLANT NO. 2	6.0	NO CNTR TECH		1.27E+00	5.77E+00		
PLANT NO. 2	6.0	PLUS CLAY	1524	1.15E+00	5.69E+00	1.26E-01	8.20E-02
PLANT NO. 2	6.0	PLUS KH2PO4	18550	1.01E+00	4.63E+00	2.69E-01	1.14E+00
PLANT NO. 2	50.0	NO CNTR TECH		4.17E-01	2.52E+00		
PLANT NO. 2	50.0	PLUS CLAY	1524	4.01E-01	2.51E+00	1.68E-02	1.10E-02
PLANT NO. 2	50.0	PLUS KH2PO4	18550	3.46E-01	2.03E+00	7.17E-02	4.91E-01
PLANT NO. 3	2.0	NO CNTR TECH		6.93E-02	3.87E-01		
PLANT NO. 3	2.0	PLUS LIME	1300	6.91E-02	3.87E-01	1.95E-04	1.70E-04
PLANT NO. 3	2.0	PLUS ALUM	1825	5.32E-02	3.09E-01	1.61E-02	7.79E-02
PLANT NO. 3	6.0	NO CNTR TECH		5.26E-02	3.39E-01		
PLANT NO. 3	6.0	PLUS LIME	1300	5.25E-02	3.39E-01	9.18E-05	8.10E-05
PLANT NO. 3	6.0	PLUS ALUM	1825	4.23E-02	2.72E-01	1.03E-02	6.70E-02
PLANT NO. 3	50.0	NO CNTR TECH		1.99E-02	1.52E-01		
PLANT NO. 3	50.0	PLUS LIME	1300	1.99E-02	1.52E-01	1.49E-05	1.33E-05
PLANT NO. 3	50.0	PLUS ALUM	1825	1.63E-02	1.22E-01	3.63E-03	3.01E-02

* - FOR DESCRIPTION OF MODEL TREATMENT PLANTS SEE TABLE 4

** - HEALTH EFFECTS INDUCED IN A POPULATION AT RISK OF 100,000 ADULTS AND A CONCENTRATION OF 1 MILLICURIE/CUBIC METER

Table 10. Health Effects for Phase V.
(Continued)

PATHWAY - RIVER WATER

TREATMENT PLANT *	CONTROL TECHNOLOGY	COST OF C.T. ($)	HEALTH EFFECTS ** FATAL	HEALTH EFFECTS ** NON-FATAL	HEALTH EFFECTS AVERTED FATAL	HEALTH EFFECTS AVERTED NON-FATAL
PLANT NO. 1	NO CNTR TECH		4.98E-01	2.97E+00		
PLANT NO. 1	PLUS CLAY	2923	4.81E-01	2.96E+00	1.66E-02	1.09E-02
PLANT NO. 1	PLUS KH2PO4	3558	3.95E-01	2.37E+00	1.03E-01	5.96E-01
PLANT NO. 1	PLUS LIME	2493	4.70E-01	2.94E+00	2.82E-02	2.51E-02
PLANT NO. 2	NO CNTR TECH		4.70E-01	2.94E+00		
PLANT NO. 2	PLUS CLAY	2923	4.53E-01	2.93E+00	1.63E-02	1.06E-02
PLANT NO. 2	PLUS KH2PO4	3558	3.89E-01	2.37E+00	8.03E-02	5.76E-01
PLANT NO. 3	NO CNTR TECH		2.28E-02	1.78E-01		
PLANT NO. 3	PLUS LIME	2493	2.28E-02	1.78E-01	2.94E-05	2.54E-05
PLANT NO. 3	PLUS ALUM	3500	1.87E-02	1.44E-01	4.07E-03	3.44E-02

PATHWAY - RIVER WATER, 30 DAY DECAY

TREATMENT PLANT *	CONTROL TECHNOLOGY	COST OF C.T. ($)	HEALTH EFFECTS ** FATAL	HEALTH EFFECTS ** NON-FATAL	HEALTH EFFECTS AVERTED FATAL	HEALTH EFFECTS AVERTED NON-FATAL
PLANT NO. 1	NO CNTR TECH		2.10E-01	4.81E-01		
PLANT NO. 1	PLUS CLAY	2923	1.87E-01	4.66E-01	2.33E-02	1.52E-02
PLANT NO. 1	PLUS KH2PO4	3558	1.46E-01	3.70E-01	6.41E-02	1.11E-01
PLANT NO. 1	PLUS LIME	2493	1.76E-01	4.51E-01	3.44E-02	3.04E-02
PLANT NO. 2	NO CNTR TECH		1.76E-01	4.51E-01		
PLANT NO. 2	PLUS CLAY	2923	1.52E-01	4.36E-01	2.33E-02	1.52E-02
PLANT NO. 2	PLUS KH2PO4	3558	1.39E-01	3.64E-01	3.67E-02	8.66E-02
PLANT NO. 3	NO CNTR TECH		5.80E-03	2.39E-02		
PLANT NO. 3	PLUS LIME	2493	5.78E-03	2.39E-02	1.74E-05	1.54E-05
PLANT NO. 3	PLUS ALUM	3500	4.68E-03	1.93E-02	1.12E-03	4.65E-03

* - FOR DESCRIPTION OF MODEL TREATMENT PLANTS SEE TABLE 4
** - HEALTH EFFECTS INDUCED IN A POPULATION AT RISK OF 100,000 ADULTS AND A CONCENTRATION OF 1 MILLICURIE/CUBIC METER

Table 10. Health Effects for Phase V.
(Continued)

PATHWAY COMPONENT	CONTROL TECHNOLOGY	COST OF C.T. ($)	HEALTH EFFECTS** FATAL	HEALTH EFFECTS** NON-FATAL	HEALTH EFFECTS AVERTED FATAL	HEALTH EFFECTS AVERTED NON-FATAL
MEAT CONSUMPTION	NO CNTR TECH		7.88E+00	5.81E+00		
MEAT CONSUMPTION	QUAR. 1 WK.	1099	4.20E+00	3.12E+00	3.68E+00	2.69E+00
MEAT CONSUMPTION	QUAR. 2 WK.	2198	2.26E+00	1.69E+00	5.62E+00	4.12E+00
MEAT CONSUMPTION	QUAR. 3 WK.	3297	1.23E+00	9.32E-01	6.65E+00	4.86E+00
MEAT CONSUMPTION	QUAR. 4 WK.	4396	6.85E-01	5.21E-01	7.20E+00	5.29E+00
MEAT CONSUMPTION	QUAR. 3 MO.	14130	2.45E-02	1.73E-02	7.86E+00	5.80E+00
MEAT CONSUMPTION	QUAR. 6 MO.	28260	8.93E-03	6.25E-03	7.87E+00	5.81E+00
MEAT CONSUMPTION	CONDEMNATION	2573000	0.00E+00	0.00E+00	7.88E+00	5.81E+00
MILK CONSUMPTION	NO CNTR TECH		1.22E-01	8.34E-01		
MILK CONSUMPTION	DIV TO DAIRY	8331	5.02E-03	4.08E-03	1.17E-01	8.30E-01
MILK CONSUMPTION	CONDEMNATION	50670	0.00E+00	0.00E+00	1.22E-01	8.34E-01
IRRIGATED VEGETABLES	NO CNTR TECH		3.98E-01	3.33E-01		
IRRIGATED VEGETABLES	CONDEMNATION	1234000	0.00E+00	0.00E+00	3.98E-01	3.33E-01
IRRIGATED LEAFY VEGETABLES	NO CNTR TECH		5.11E-03	4.22E-03		
IRRIGATED LEAFY VEGETABLES	CONDEMNATION	1234000	0.00E+00	0.00E+00	5.11E-03	4.22E-03

** - HEALTH EFFECTS INDUCED IN A POPULATION AT RISK OF 100,000 ADULTS AND A CONCENTRATION OF 1 MILLICURIE/CUBIC METER

Table 11. Health Effects for Phase VI.

TIMES(HRS) T1	T2	T3	* P.A.	COST OF P.A. ($100,000)	** HEALTH EFFECTS FATAL	NON-FATAL	HEALTH EFFECTS AVERTED FATAL	NON-FATAL
1	2	3	NO		6.71E-01	6.86E-01		
1	2	3	1	244	3.52E-03	3.86E-03	6.68E-01	6.82E-01
1	2	3	2	244	3.36E-03	3.67E-03	6.68E-01	6.82E-01
1	2	3	3	322	4.55E-03	4.93E-03	6.67E-01	6.81E-01
1	2	3	4	324	3.58E-03	3.93E-03	6.68E-01	6.82E-01
1	2	6	NONE		6.71E-01	6.86E-01		
1	2	6	1	244	6.88E-03	7.36E-03	6.64E-01	6.78E-01
1	2	6	2	244	6.70E-03	7.18E-03	6.64E-01	6.78E-01
1	2	6	3	322	7.88E-03	8.41E-03	6.63E-01	6.77E-01
1	2	6	4	324	6.92E-03	7.41E-03	6.64E-01	6.78E-01
1	2	12	NONE		6.71E-01	6.86E-01		
1	2	12	1	244	1.34E-02	1.42E-02	6.58E-01	6.71E-01
1	2	12	2	244	1.32E-02	1.40E-02	6.58E-01	6.72E-01
1	2	12	3	322	1.44E-02	1.52E-02	6.57E-01	6.70E-01
1	2	12	4	324	1.34E-02	1.42E-02	6.58E-01	6.71E-01
1	5	6	NONE		2.67E+00	2.73E+00		
1	5	6	1	244	2.07E-02	2.23E-02	2.65E+00	2.71E+00
1	5	6	2	244	2.00E-02	2.16E-02	2.65E+00	2.71E+00
1	5	6	3	322	2.47E-02	2.65E-02	2.65E+00	2.71E+00
1	5	6	4	324	2.09E-02	2.25E-02	2.65E+00	2.71E+00
1	5	9	NONE		2.67E+00	2.73E+00		
1	5	9	1	244	3.38E-02	3.60E-02	2.64E+00	2.70E+00
1	5	9	2	244	3.31E-02	3.53E-02	2.64E+00	2.70E+00
1	5	9	3	322	3.78E-02	4.02E-02	2.64E+00	2.69E+00
1	5	9	4	324	3.40E-02	3.62E-02	2.64E+00	2.70E+00
1	5	15	NONE		2.67E+00	2.73E+00		
1	5	15	1	244	5.93E-02	6.27E-02	2.62E+00	2.67E+00
1	5	15	2	244	5.89E-02	6.21E-02	2.62E+00	2.67E+00
1	5	15	3	322	6.31E-02	6.67E-02	2.61E+00	2.67E+00
1	5	15	4	324	5.97E-02	6.30E-02	2.61E+00	2.67E+00
4	5	6	NONE		6.68E-01	6.83E-01		
4	5	6	1	244	3.47E-03	3.80E-03	6.64E-01	6.79E-01
4	5	6	2	244	3.30E-03	3.61E-03	6.64E-01	6.79E-01
4	5	6	3	322	4.48E-03	4.85E-03	6.63E-01	6.78E-01
4	5	6	4	324	3.52E-03	3.85E-03	6.64E-01	6.79E-01
4	5	9	NONE		6.68E-01	6.83E-01		
4	5	9	1	244	6.76E-03	7.24E-03	6.61E-01	6.75E-01
4	5	9	2	244	6.60E-03	7.06E-03	6.61E-01	6.76E-01
4	5	9	3	322	7.74E-03	8.27E-03	6.60E-01	6.74E-01
4	5	9	4	324	6.80E-03	7.29E-03	6.61E-01	6.75E-01
4	5	15	NONE		6.68E-01	6.83E-01		
4	5	15	1	244	1.32E-02	1.39E-02	6.54E-01	6.69E-01
4	5	15	2	244	1.30E-02	1.37E-02	6.55E-01	6.69E-01
4	5	15	3	322	1.41E-02	1.49E-02	6.53E-01	6.68E-01
4	5	15	4	324	1.32E-02	1.40E-02	6.54E-01	6.69E-01
4	8	9	NONE		2.66E+00	2.72E+00		
4	8	9	1	244	2.03E-02	2.19E-02	2.64E+00	2.70E+00
4	8	9	2	244	1.97E-02	2.12E-02	2.64E+00	2.70E+00
4	8	9	3	322	2.42E-02	2.60E-02	2.64E+00	2.70E+00
4	8	9	4	324	2.05E-02	2.21E-02	2.64E+00	2.70E+00

* - FOR DESCRIPTION OF PROTECTIVE ACTIONS SEE TABLE 5

** - HEALTH EFFECTS DUE TO DEPOSITION ON PERSONNEL FROM A CLOUD CONC. OF 1 MICROCURIE/CUBIC METER FOR A POPULATION AT RISK OF 100,000 ADULTS

Table 11. Health Effects for Phase VI.
(Continued)

TIMES(HRS) T1	T2	T3	* P.A.	COST OF P.A. ($100,000)	** HEALTH EFFECTS FATAL	NON-FATAL	HEALTH EFFECTS AVERTED FATAL	NON-FATAL
4	8	12	NONE		2.66E+00	2.72E+00		
4	8	12	1	244	3.33E-02	3.54E-02	2.63E+00	2.69E+00
4	8	12	2	244	3.26E-02	3.47E-02	2.63E+00	2.69E+00
4	8	12	3	322	3.71E-02	3.95E-02	2.63E+00	2.68E+00
4	8	12	4	324	3.34E-02	3.56E-02	2.63E+00	2.69E+00
4	8	18	NONE		2.66E+00	2.72E+00		
4	8	18	1	244	5.86E-02	6.18E-02	2.61E+00	2.66E+00
4	8	18	2	244	5.79E-02	6.10E-02	2.61E+00	2.66E+00
4	8	18	3	322	6.21E-02	6.55E-02	2.60E+00	2.66E+00
4	8	18	4	324	5.86E-02	6.18E-02	2.61E+00	2.66E+00

* - FOR DESCRIPTION OF PROTECTIVE ACTIONS SEE TABLE 5

** - HEALTH EFFECTS DUE TO DEPOSITION ON PERSONNEL FROM A CLOUD CONC. OF 1 MICROCURIE/CUBIC METER FOR A POPULATION AT RISK OF 100,000 ADULTS

Table 12. Health Effects for Phase VII.

TABLE 12. HEALTH EFFECTS FOR PHASE 7

PATHWAY COMPONENT	CONTROL * TECHNOLOGY	COST OF C.T. ($)	HEALTH EFFECTS ** FATAL	HEALTH EFFECTS ** NON-FATAL	HEALTH EFFECTS AVERTED FATAL	HEALTH EFFECTS AVERTED NON-FATAL
HOGS	BASE CASE		2.76E-09	2.00E-09		
HOGS	P.A. 1	65.30	1.35E-09	1.06E-09	1.41E-09	9.46E-10
HOGS	P.A. 2	18.48	2.66E-09	1.93E-09	9.91E-11	7.04E-11
HOGS	P.A. 3	6.54	1.93E-09	1.44E-09	8.31E-10	5.58E-10
HOGS	P.A. 4	9.80	1.64E-09	1.25E-09	1.12E-09	7.52E-10
HOGS	P.A. 5	13.06	1.41E-09	1.10E-09	1.35E-09	9.04E-10
HOGS	P.A. 6	160.60	0.00E+00	0.00E+00	2.76E-09	2.00E-09
SHEEP	BASE CASE		2.76E-09	2.00E-09		
SHEEP	P.A. 1	114.80	1.35E-09	1.06E-09	1.41E-09	9.46E-10
SHEEP	P.A. 2	7.56	2.66E-09	1.93E-09	9.91E-11	7.04E-11
SHEEP	P.A. 3	114.80	1.93E-09	1.44E-09	8.31E-10	5.58E-10
SHEEP	P.A. 4	17.22	1.64E-09	1.25E-09	1.12E-09	7.52E-10
SHEEP	P.A. 5	22.96	1.41E-09	1.10E-09	1.35E-09	9.04E-10
SHEEP	P.A. 6	60.80	0.00E+00	0.00E+00	2.76E-09	2.00E-09
TURKEYS	BASE CASE		1.84E-08	1.27E-08		
TURKEYS	P.A. 1	0.54	1.49E-08	1.04E-08	3.45E-09	2.32E-09
TURKEYS	P.A. 2	1.87	1.69E-08	1.15E-08	1.53E-09	1.22E-09
TURKEYS	P.A. 3	0.05	1.62E-08	1.12E-08	2.20E-09	1.52E-09
TURKEYS	P.A. 4	0.08	1.52E-08	1.05E-08	3.15E-09	2.17E-09
TURKEYS	P.A. 5	0.11	1.44E-08	9.93E-09	4.03E-09	2.76E-09
TURKEYS	P.A. 6	21.58	0.00E+00	0.00E+00	1.84E-08	1.27E-08
CHICKENS	BASE CASE		2.98E-08	2.06E-08		
CHICKENS	P.A. 1	0.40	2.74E-08	1.90E-08	2.46E-09	1.63E-09
CHICKENS	P.A. 2	0.37	2.75E-08	1.87E-08	2.33E-09	1.89E-09
CHICKENS	P.A. 3	0.04	2.80E-08	1.94E-08	1.85E-09	1.26E-09
CHICKENS	P.A. 4	0.06	2.74E-08	1.90E-08	2.42E-09	1.67E-09
CHICKENS	P.A. 5	0.08	2.65E-08	1.84E-08	3.28E-09	2.25E-09
CHICKENS	P.A. 6	3.48	0.00E+00	0.00E+00	2.98E-08	2.06E-08

* - FOR DESCRIPTION OF PROTECTIVE ACTIONS SEE TABLE 6
** - HEALTH EFFECTS PER KG ASH PER ANIMAL FOR 1 MICROCURIE/KG ASH FEED

3. ECONOMIC ANALYSIS

If an actual deposition of radionuclides were ever to take place, the accident manager or decision maker given the prevailing conditions would effect protective actions to control doses to the members of the general public. This would be done by selecting from available protective actions those which would be the most effective as well as those which would be most cost effective. A protective action in this sense may be described by a "cost effectiveness ratio", defined as the cost of the PA divided by the reduction in the number of health effects (HE) brought about by the application of the PA.

$$\text{Cost Effectiveness} \left(\frac{\$}{\text{health effect}}\right) = \frac{\text{Cost of PA } (\$)}{\text{HE w/o PA} - \text{HE with PA}} \qquad (3\text{-}1)$$

The cost of a protective action is the present worth cost, consisting of first (immediate) costs combined with any associated annual costs using an appropriate annuity present worth factor. First costs may include capital costs, if capital equipment is required. Annual costs usually refer to continued application of the PA, and general operation and maintenance.

In order to facilitate the decision-making process, the protective actions investigated in this study have been ranked in Table 13 according to decreasing cost-effectiveness. In each case, the first PA listed is the most economical.

The cost-effectiveness ratio, as defined above, may be a misleading indication of the economic value of a protective action if the cost and the dose reduction associated with a particular protective action do not vary in direct proportion to each other. This may be illustrated by an analysis of a contaminated property. A particular PA may have a total cost of $1000, and have a decontamination factor (DF) of 10. Let it be assumed that only $500 is spent, resulting in only one-half the area of the property being treated. To find the

Table 13. Cost-Effectiveness Rankings of Protective Actions.

Pathway Component	Order of PA's* By Number
Phase III	
Ingestion of Grain Crops	1,3,4,7,9,8,6,5,2,10,11
Ingestion of Vegetable Crops	2,7,3,6,5,1,8,9,10,11,4
Ingestion of Orchard Crops	4,1,2,3,5,6
Grass - Milk	3,5,2,1,4,6
Grass - Beef	3,5,2,1,4,6
Recreational Land	1
Phase IV**	
Single Unit Residential	8,1,6,3,2,10,5,4,9,7
Multiple Unit Residential	4,7,6,1,9,3,2,8,5
Commercial/Community Use	6,7,4,1,9,2,3,8,5
Recreational	8,1,6,4,2,3,5,7
Phase V - Reservoir Water	
Base Plant, Turnover Rate = 2.0 yr^{-1}	5,2,1,4,3
Plant #1, Turnover Rate = 2.0 yr^{-1}	3,1,2
Plant #2, Turnover Rate = 2.0 yr^{-1}	1,2
Plant #3, Turnover Rate = 2.0 yr^{-1}	2,1
Plant #4	None
Plant #5	None
Phase V - River Water	
Plant #1	2,3,1
Plant #2	2,1
Plant #3	2,1

Table 13 (Continued)

Pathway Component	Order of PA's* By Number
<u>Phase V - Others</u>	
Meat	1,2,3,4,5,6,7
Milk	1,2
Vegetables	1
<u>Phase VI</u>	
All Values of T_1, T_2, T_3 ***	2,1,3
<u>Phase VII</u>	
Hogs	3,4,5,6,2,1
Sheep	3,4,5,6,2,1
Turkeys	3,4,5,1,2,6
Chickens	3,4,5,6,2,1

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* See Tables 2-6 for description of PA's.

** For inhalation; air immersion, and surface shine.

*** T_1 is the time between occurrence of the release of radionuclides and the beginning of deposition on persons. T_2 is the time at which deposition ends. T_3 is the time at which protective action is taken.

DF for this PA, in relation to the entire property, the individual DFs for each area of the property are combined as follows

$$DF_{total} = \left(\sum_{i=1}^{n} \frac{A_i}{DF_i} \right)^{-1} \qquad (3\text{-}2)$$

where A_i is the fraction of the total area to which the decontamination factor

DF_i is applied

n is the number of divisions of the total area

Therefore, the DF for the above example is

$$DF = \left[\frac{0.5}{10} + \frac{0.5}{1} \right]^{-1} = 1.82$$

Therefore, reducing the cost by a factor of two reduced the benefits of the PA by more than a factor of five.

The costs developed in this study are pertinent to a specific level of treatment depending on the size of the contaminated area or volume. Varying the amount of money spent by a certain factor will not result in a change in benefits of the same factor.

In view of the above, it is felt that a more meaningful criterion for judging the effectiveness of a protective action is the number of health effects averted. These quantities appear in Tables 8-12, with values of health effects incurred if no PA were taken. The decision maker may wish to implement the PA which, within a given budgetary framework, yields the greatest reduction in health effects, although another PA might have a higher cost-effectiveness ratio. By examining the information in Tables 8-12, the most effective PA for a particular monetary commitment may be identified.

Cost is not the only criterion for judging the efficacy of a protective action. Convenience of application and incremental risk associated with the PA itself should also be considered. For instance, for contaminated personnel, washing with detergent and water as opposed to soap and water provides a greater reduction in dose for essentially the same cost. However, use of detergent may defat and abrade the skin. Breaking the skin may result in increased risk, due to infection or worsened contamination, thereby reducing the desirability of this particular PA.

4. CRITICAL PATHWAYS

In each phase of this study, several pathways by which radionuclides may be transported to and taken up by people were investigated. Of these pathways there is one that can be termed the "critical" pathway because it is the mechanism of principal exposure to individuals[20]. In this study the critical pathway for a given type of deposition of radionuclides is defined as the pathway which results in the greatest number of health effects when no protective action is taken. It is the purpose of this section to identify the critical pathway for each phase, and to provide detailed information regarding the costs and effectiveness of protective actions for that path.

In order to facilitate the analysis, three sets of graphs have been formulated for each phase. These graphs appear in Appendix A. The first graph, denoted by a suffix "a" on the figure identification number, is a plot of number of health effects for no protective action versus pathway component for each pathway and each generic unit within a given phase. From this graph, or from the tables of health effects (Tables 8-12), one can identify the critical pathway for that phase. The critical pathway is the subject of the second graph, denoted by suffix "b". This plot shows the numbers of health effects averted (WHE) by each protective action (PA) versus the present worth cost of each PA for the critical pathway. This plot should help decision makers choose the appropriate protective action within a given budgetary framework. The convention used for drawing the line between points was to keep the line moving upward and to the right (i.e., positive slope) at all times. This serves to isolate those protective actions which are uneconomical due to a combination of high cost and reduced effectiveness compared to other PA's. A smooth curve was not drawn between the points in order to avoid the implication that there is a functional relationship

(20) International Committee on Radiological Protection, Principles of Environmental Monitoring Related to the Handling of Radioactive Materials, ICRP Publication 7, Pergamon Press, Oxford, 1965.

between the points when in fact no such relationship exists. The third graph plots health effects averted versus cost of PA for all pathways. However, in some phases, there were a large number of pathways. In order to prevent the third graph from becoming too cluttered, some condensing was done. In Phase III, the six grain crops, five vegetable crops, and nine orchard crops were combined into a generic grain crop, a generic vegetable crop, and a generic orchard crop, respectively. This was accomplished using relative production factors obtained from U.S. Department of Agriculture statistics[8], as described in the Phase III report[1]. In Phase V, for reservoir water only the most common of the three representative turnover rates is presented, namely the low turnover rate, 2.0 yr^{-1}. In Phase VI, twelve combinations of the three times of interest were looked at; however, the graph shows only the two cases which produce the greatest and least number of health effects, thus producing an envelope into which the other cases fall. In each graph, the value of health effects plotted is the sum of the fatal and the non-fatal health effects.

The pathways that are detailed in the second group of graphs are defined as the critical pathways or pathway components for their respective phases because they produce the greatest number of health effects when no PA is applied. However, these pathways might not be relevant to specific sites. In this case, the accident manager can look at the first plot and identify the critical pathway of those relevant to his site. Then, a study of the third plot, or the health effects tables, will yield the necessary information regarding the PA's for that pathway.

4.1 CRITICAL PATHWAY FOR CONTAMINATED LAND TYPES

Ingestion is the critical pathway for contaminated land. Figure A-1a shows that the consumption of tangerines grown on contaminated orchard lands results in the highest risk of the potential pathway components, 9.06×10^{-3} health effects per 100 ha of contaminated land. There are four protective actions (PA's 3-6) which essentially result in a 100% reduction in health effects. Of these, PA 4, purchasing the land and removing it from productivity, has the lowest present worth cost. PA 4 also has the lowest cost-effectiveness ratio. PA 1, restricting the fruit to commercial processing, and PA 2, commercial processing with augmented wash cycle, are somewhat less effective but are also less expensive, and may be desirable alternatives if finances are limited.

In general, orchard crop lands and, to a lesser extent, vegetable crop lands, produce the highest risk of the five generic land types when contaminated by a radionuclide deposition.

4.2 CRITICAL PATHWAY FOR CONTAMINATED PROPERTY TYPES

Inhalation of resuspended radioactivity is the critical pathway for contaminated property. The property class in which the greatest number of health effects occurs is the commercial/community use type. The most effective protective actions for this case are PA's 5 and 8, which involve painting buildings, washing cars, and either painting or sandblasting pavement. However, these PA's have the highest present worth cost and the highest cost-effectiveness ratio. In general, for all property types, the most effective PA's are the most expensive, while the less expensive PA's have the smallest cost-effectiveness ratios.

4.3 CRITICAL PATHWAY FOR CONTAMINATED WATER SUPPLIES

The largest risk comes from eating animals which have consumed contaminated water. With no protective action, the expected number of health effects is 13.7. Sacrifice of the animals and impoundment of the remains results in the most health effects averted; however, the cost is very high. A quarantine period of approximately one month, prior to sending the animals to market, will produce virtually the same results at a fraction of the cost. The PA with the lowest cost-effectiveness ratio is PA 1, quarantine for one week. After meat consumption, the reservoir water pathway produces the most risk.

4.4 CRITICAL PATHWAY FOR CONTAMINATED PERSONNEL

In this case, there is only one pathway to consider, deposition of radionuclides directly on people. The sequence of events that results in the most health effects is one that places the individual in contact with the radioactive cloud soon after the release occurs, with contact maintained for several hours and protective action delayed for several hours. The most effective PA's are those taken by the individual at home, and involve removal and disposal of clothing, washing skin with water and either soap or detergent, and shampooing the hair.

4.5 CRITICAL PATHWAY FOR CONTAMINATED BIOTA

The sole pathway investigated here was the contaminated feed-farm animal-people pathway. Of the four classes of farm animals investigated, consumption of chickens produced the most risk. On a per-animal basis, the protective actions for chickens all have low present worth costs, and PA 6, sacrifice and impoundment of the remains, is the most effective at reducing the risk.

5. ERROR ANALYSIS

5.1 DESCRIPTION

This study calculated the risk to the public, in terms of health effects, resulting from a low-level deposition of radionuclides. The results have been summarized in Tables 8 through 12. These values, however, were calculated with some degree of uncertainty. Because the risk is a computed quantity, uncertainty in the risk is the composite effect of the uncertainties in the component variables. This effect is called the "propagation of error"[21]. The manner in which errors are propagated is discussed in this section, and the uncertainty in the risk is estimated.

If a quantity y is a function of several independent variables x_1, x_2, ..., x_n, the uncertainty Δy, in y, is

$$(\Delta y)^2 = \left(\frac{\partial y}{\partial x_1}\,\Delta x_1\right)^2 + \left(\frac{\partial y}{\partial x_2}\,\Delta x_2\right)^2 + \ldots + \left(\frac{\partial y}{\partial x_n}\,\Delta x_n\right)^2 \qquad (5\text{-}1)$$

For a given pathway, Equation 2-2 gives the number of health effects, HE, in terms of the total 100-year collective dose commitment equivalent, D, and the health effect conversion factors, HEF. Therefore, the error in HE is given by

$$(\Delta HE)^2 = \sum_{j=1}^{8} \left[(D_j\,\Delta HEF_j)^2 + (HEF_j\,\Delta D_j)^2\right] \qquad (5\text{-}2)$$

where subscript j refers to the jth organ.

(21) Y. Beers, Introduction to the Theory of Errors, Addison-Wesley Publishing Co., Reading, Mass, 1953

In order to reduce the complexity involved in applying this analysis to the numerous pathways investigated in this study, only the critical pathway component in each phase will be looked at. It is believed that the critical pathway component is sufficiently representative to allow generalization of the error analysis to other pathway components in the same phase. In addition, since the magnitude of ΔHE is proportional to the size of the doses, the critical pathway component, which has the highest doses, will have the largest uncertainty. Therefore, generalizing the uncertainty in the critical pathway component to the other pathway components will be conservative, given a similarity in pathway models.

This analysis will assume that the health effect conversion factors are known to within a factor of two*. For example, the fatal health effect factor for bone, which has a nominal value of 6 effects per million person-rem, ranges in value from a minimum of 3 to a maximum of 12 effects per million person-rem. Since the uncertainty ΔHEF, is 100% on the high side, this analysis will use a value of ΔHEF equal to HE, for all organs. It will also be assumed, unless otherwise noted, that dose conversion factors are known to within a factor of 2.

<u>Phase III - Tangerine Crop:</u> The 100-year collective dose commitment. equivalent can be expressed as

$$D = DCF \cdot IF \qquad (5\text{-}3)$$

where DCF is a dose conversion factor

IF is the 100-year integral of the function describing the rate of uptake of radionuclides by people.

Therefore,

$$\left(\frac{\Delta D}{D}\right)^2 = \left(\frac{\Delta DCF}{DCF}\right)^2 + \left(\frac{\Delta IF}{IF}\right)^2 \qquad (5\text{-}4)$$

* Telephone conversation with Mr. C.G. Amato, U.S. Environmental Protection Agency, Washington, D.C., September 21, 1978.

The quantity IF is dependent upon various environmental transfer parameters. In Reference 22, evaluations of certain transport parameters are made, including comparisons of values in the literature, and estimations of the range of values. For the most part, the average or recommended values have uncertainties of less than 100% on the high side. The intake function for the orchard crop pathway is dependent upon 15 transfer functions. The relationship between the transfer functions is complex, however, a conservative estimate of $\frac{\Delta IF}{IF}$ can be obtained by assuming that the intake function is equal to the product of the 15 transfer parameters. If each transfer parameter is assumed to have 100% uncertainty, then

$$\frac{\Delta IF}{IF} = \sqrt{\sum_{i=1}^{15} \left(\frac{\Delta TF}{TF}\right)_i} = \sqrt{15} = 3.87$$

where $\left(\frac{\Delta TF}{TF}\right)_i$ is the uncertainty in the i^{th} transfer function TF.

Now the uncertainty in the doses can be calculated with equation 5-4, and with $\frac{\Delta DCF}{DCF} = 1.0$. Thus,

$$\frac{\Delta D}{D} = 4.0$$

The following values are the total collective doses for the tangerine pathway with no protective action, calculated in Reference 1.

Bone:	34.8 person-rem
Liver:	38.7 person-rem
Total Body:	16.8 person-rem
Kidney:	23.7 person-rem
G.I.:	275.0 person-rem

(22) The Evaluation of Models Used for the Assessment of Radionuclide Releases to the Environment, ORNL-5382, Oak Ridge National Laboratory, Health and Safety Division, Oak Ridge, TN, 1978.

Using these values, the values of the health effect conversion factors in Table 7, and equation 5-2, the uncertainty in the number of health effects is obtained.

ΔHE = 9.5E-4 health effects

A useful quantity is the percent error, which gives an indication of the relative size of the uncertainty compared to the calculated risk value. Percent error is defined as

$$\text{Percent error} = \frac{\text{Uncertainty in Calculated Value}}{\text{Calculated Value}} \times 100\%$$

The number of health effects calculated for the tangerine pathway is 9.06E-3. Therefore, the percent error is approximately 11%. It is believed resonable to generalize this result to all pathways in Phase III, and say that the uncertainty in the number of health effects due to contaminated lands is $\pm$ 11%

When protective actions are taken, there will be an additional error due to uncertainties in the decontamination factors (DF's) of the PA's. The effect of errors in decontamination factors was not quantified, but is expected to be small.

Phase IV - Inhalation: For the inhalation pathway, the dose and its associated uncertainty can be expressed by Equations 5-3 and 5-4, respectively. The intake function is the product of five quantities - a resuspension factor, the population density of the neighborhood, the surface area of the neighborhood, the occupany factor for the population, and the standard ICRP person volumetric inhalation rate. It is assumed that possible values of these parameters form a normal distribution whose mean value, μ, is the value used in the calculations. It is also assumed that the possible values range from zero to μ, and that 2μ is four standard deviations (4σ) from the mean. This implies that the probability of the value of the parameter falling between zero and 2μ is greater than 99%. This situation is depicted in Figure 6. If the uncertainty is taken to be one standard deviation from the mean, then the error is 1/4 of μ, or $\pm$ 25% of the value used in the calculation. These assumptions result in $\frac{\Delta D}{D}$ = 1.27.

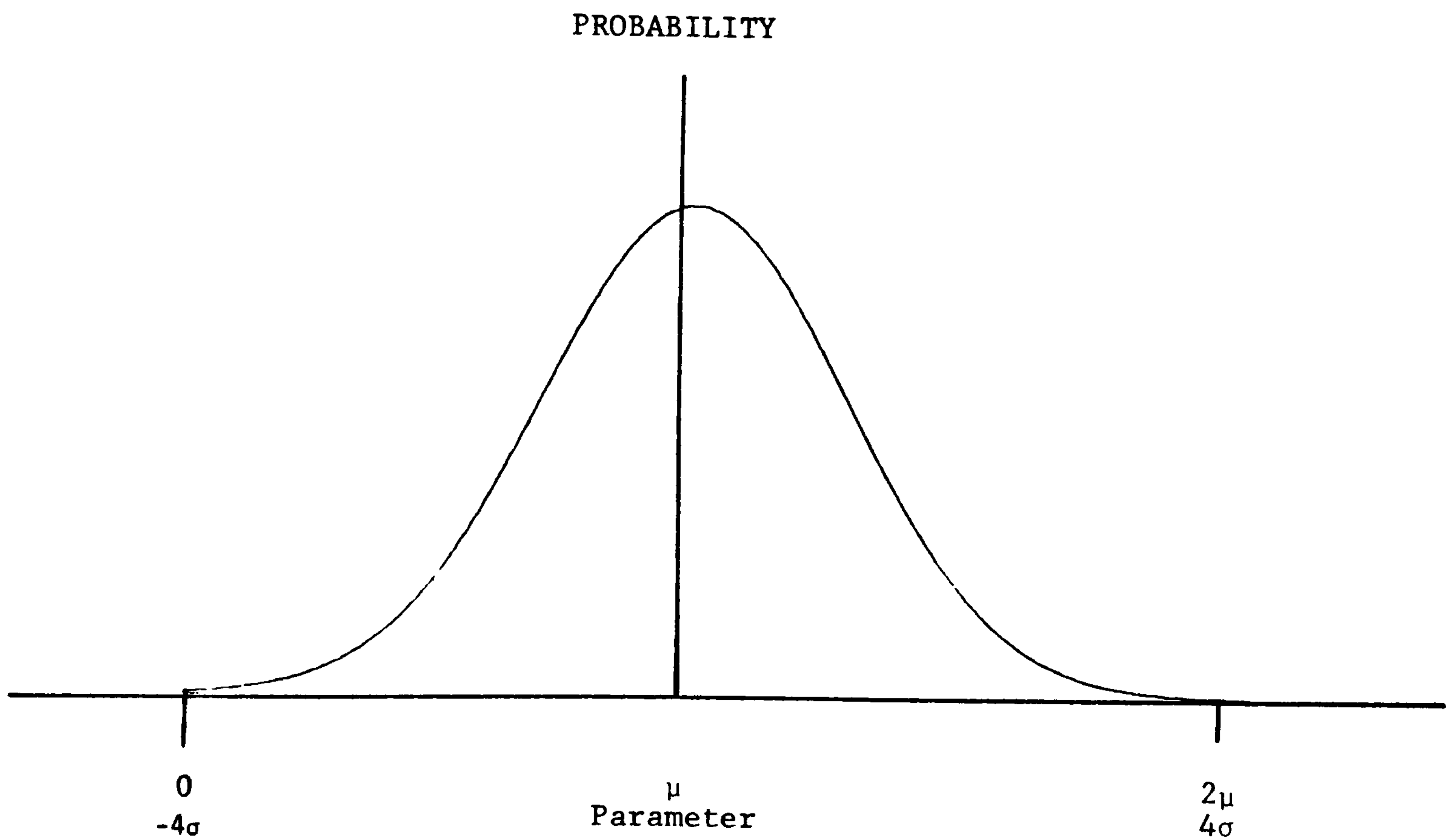

Figure 6. Normal Distribution.

The calculated collective doses for the inhalation pathway, commercial-community use neighborhood, with no protective action, are

Bone:	1.54 person-rem
Liver:	0.353 person-rem
Total Body:	0.319 person-rem
Lung:	911.0 person-rem
G.I.:	3.06 person-rem

The uncertainty in the calculated number of health effects for this pathway is

$\Delta HE = 0.118$ health effects

The number of health effect calculated for this pathway is 0.073. Therefore, the percent error is 162%. Generalizing this result to the other pathways and property types in Phase IV, it can be said that the uncertainty in the risk is equal to approximately 1-1/2 times the number of calculated health effects.

<u>Phase V - Meat Consumption:</u> Equations 5-3 and 5-4 are again valid. For the meat pathway, the intake function has an exponential dependence. The time constant is the effective decay constant, combining radiological decay with biological removal. These decay constants are known with a great degree of accuracy, so that it is believed reasonable to estimate that $\Delta IF = 0$. Therefore,

$$\frac{\Delta D}{D} = 1.$$

Collective doses for the water-meat pathway are

Bone:	1.36E+5 person-rem
Liver:	6.83E+3 person-rem

Total Body:	1.86E+4 person-rem
Thyroid:	1.27E+4 person-rem
Kidney:	2.30E+5 person-rem
Lung:	2.99E+1 person-rem
G.I.:	5.78E+6 person-rem

This gives ΔHE = 12.4 health effects. For this pathway, HE = 13.67 health effects, so the percent error for the risk from contaminated water supplies is estimated at 91%.

Phase VI - Surface Contamination of Personnel: In Phase VI the only pathway investigated was the deposition of radionuclides on people. The critical time sequence was T_1 = 1 hour, T_2 = 5 hours, T_3 = 15 hours.

In Reference 4, the percent error in the dose equivalent due to contaminated personnel was stated to be approximately 92%. The dose equivalents calculated were

Bone:	6.76E+3 person-rem
Liver:	5.69E+3 person-rem
Total Body:	7.73E+3 person-rem
Thyroid:	7.04E+3 person-rem
Kidney:	6.32E+3 person-rem
Lung:	5.74E+3 person-rem
G.I.:	5.06E+3 person-rem
Skin:	4.38E+4 person-rem

This gives ΔHE = 4.84 health effects. For this time sequence, HE = 5.4 health effects, therefore the percent error is 90%.

Phase VII - Chickens: In Reference 5, the percent error in the dose due to the consumption of chickens which have eaten contaminated feed was stated to be approximately 50%. The collective doses calculated were

Bone:	3.52E-4 person-rem
Liver:	1.98E-4 person-rem
Total Body:	9.16E-5 person-rem

Kidney: 7.67E-5 person-rem
G.I.: 2.90E-4 person-rem

This results in an uncertainty of 91%; HE = 5.04E-8 ± 4.57E-9 health effects.

The percent error for each phase are summarized in Table 14.

Table 14. Percent Errors.

Phase III	11%
Phase IV	162%
Phase V	91%
Phase VI	90%
Phase VII	91%

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APPENDIX A

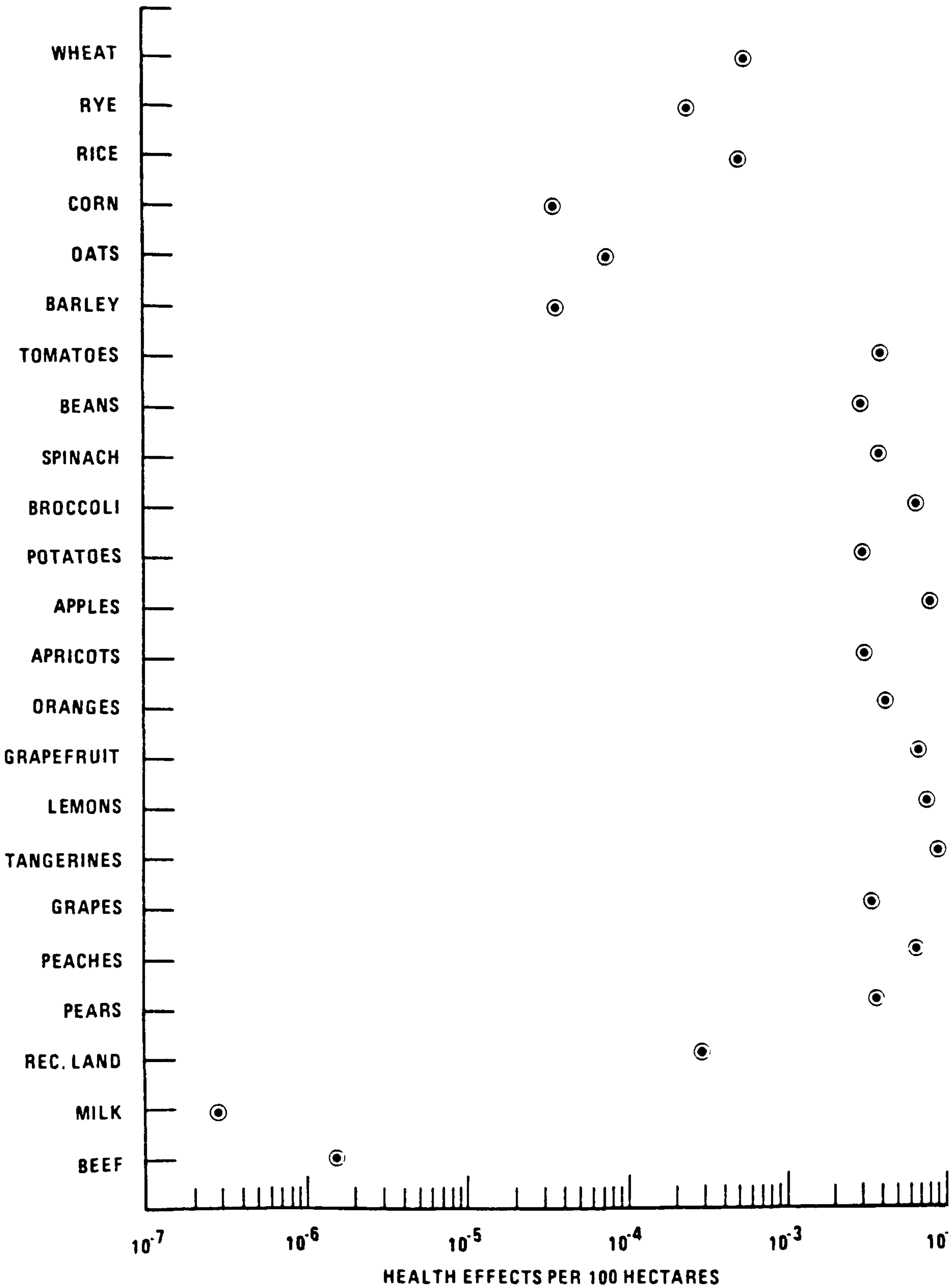

Figure A-1a. Health Effects with No PA for Pathway Components of Contaminated Land Types.

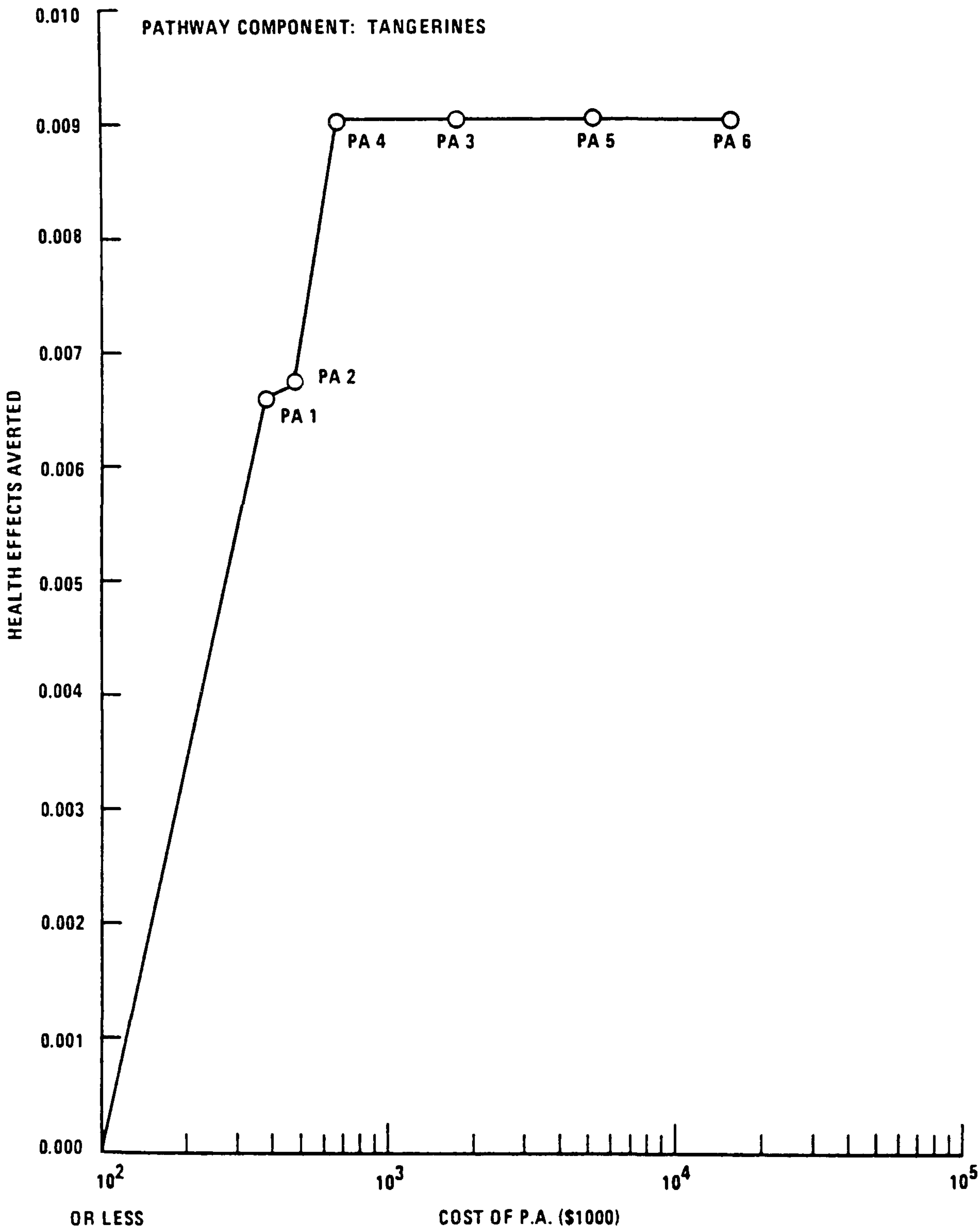

Figure A-1b. Critical Pathway Component for Contaminated Land Types.

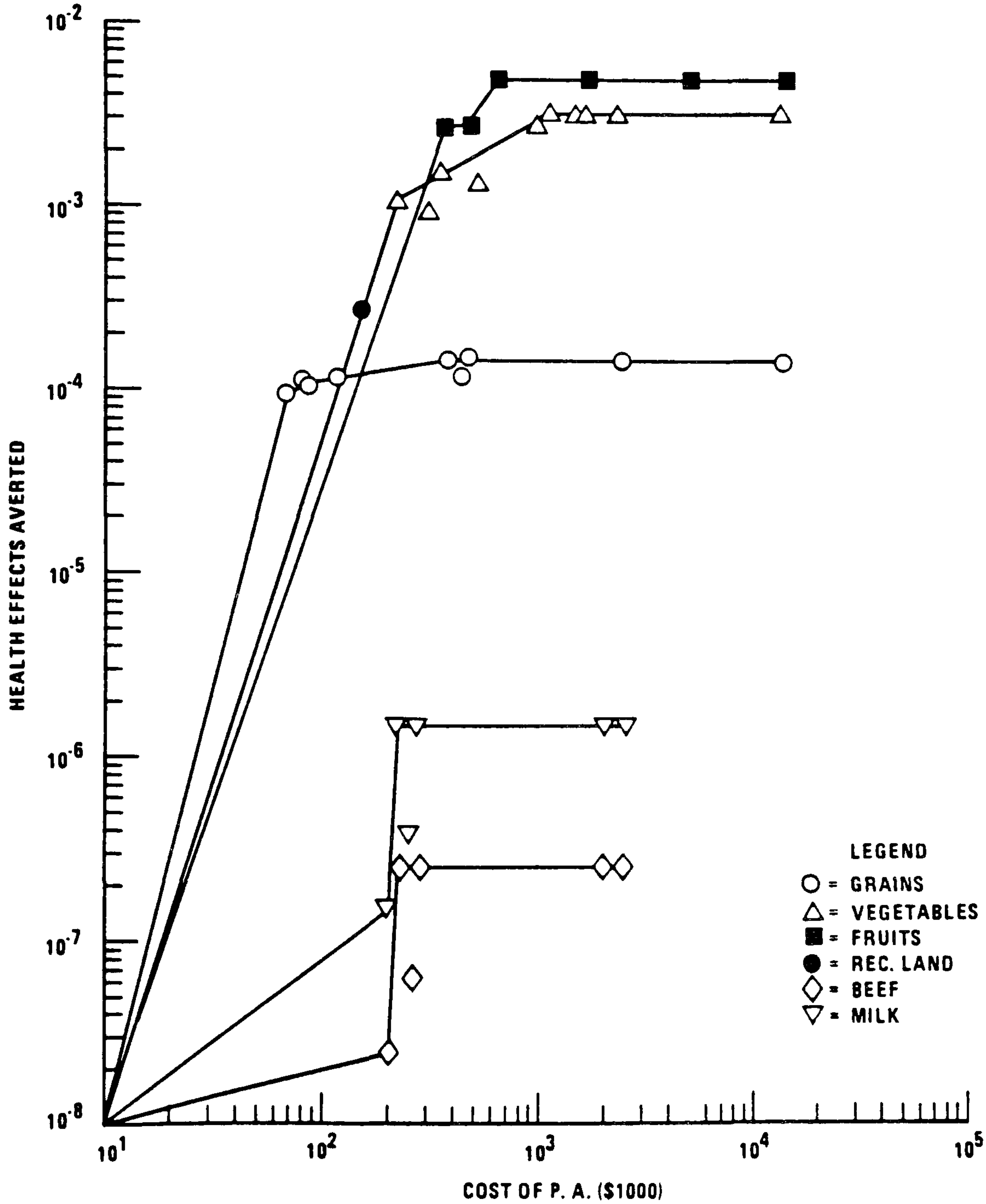

Figure A-1c. Protective Actions for Pathway Components of Contaminated Land Types.

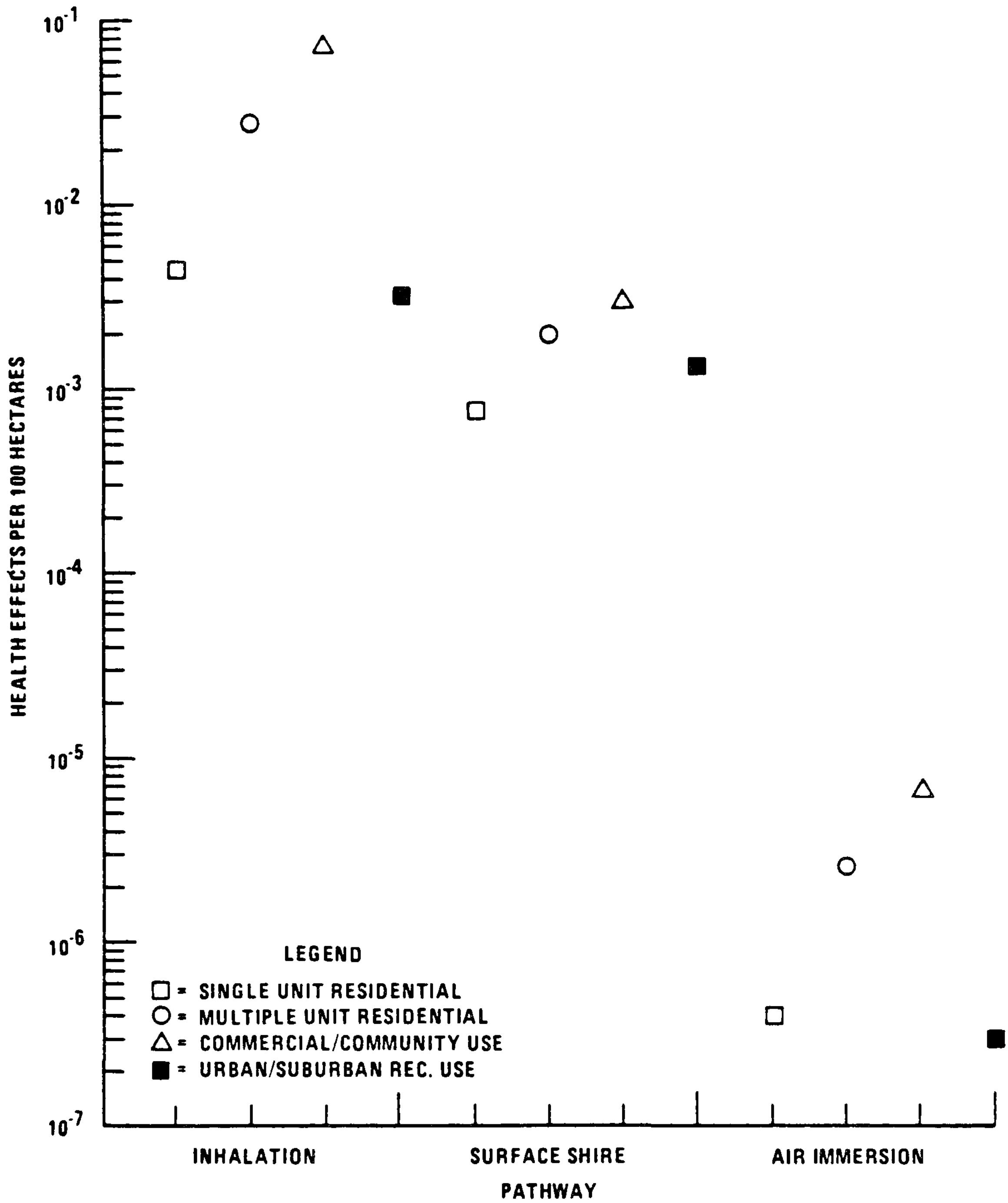

Figure A-2a. Health Effects with No PA for Contaminated Property Types.

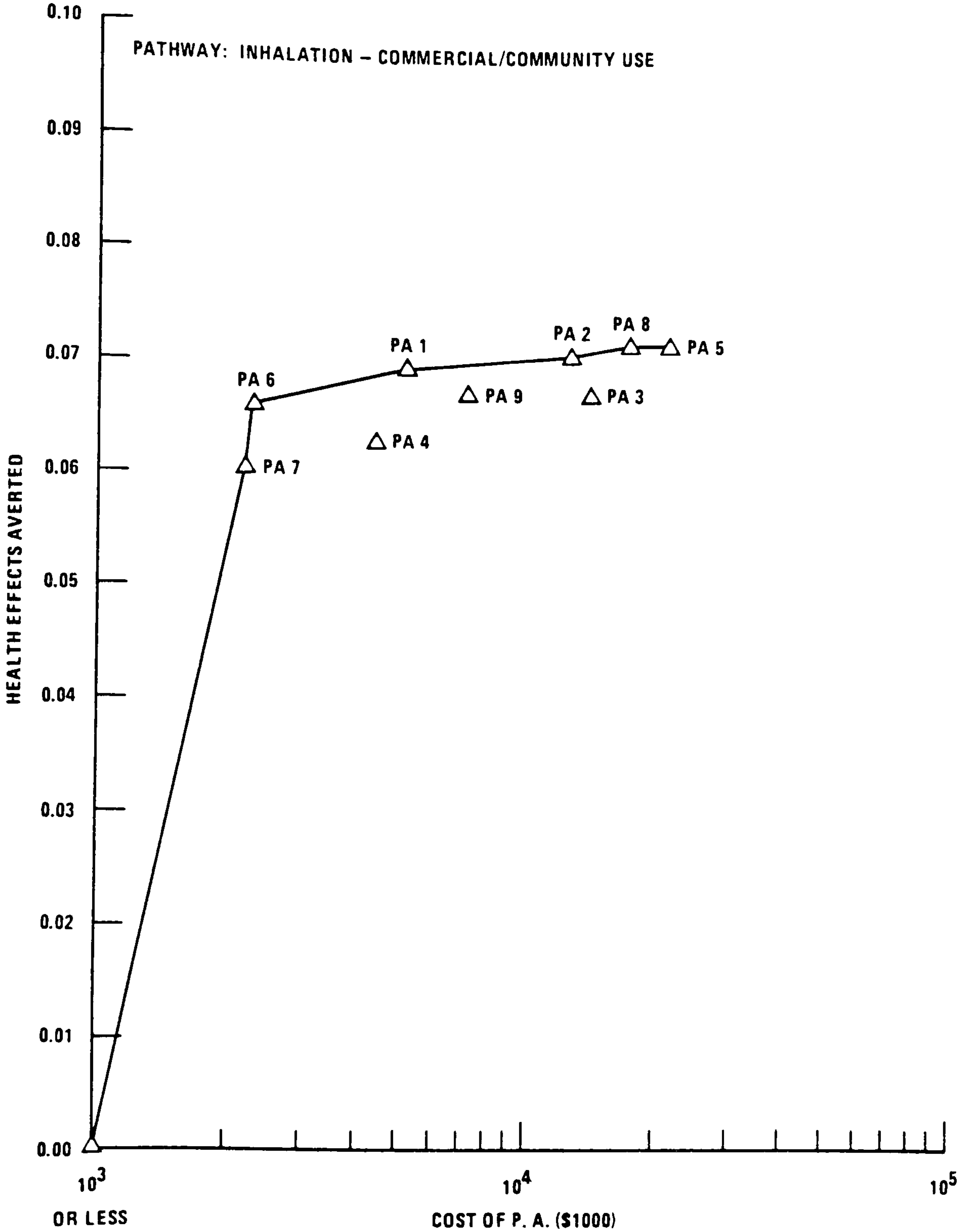

Figure A-2b. Critical Pathway for Contaminated Property Types.

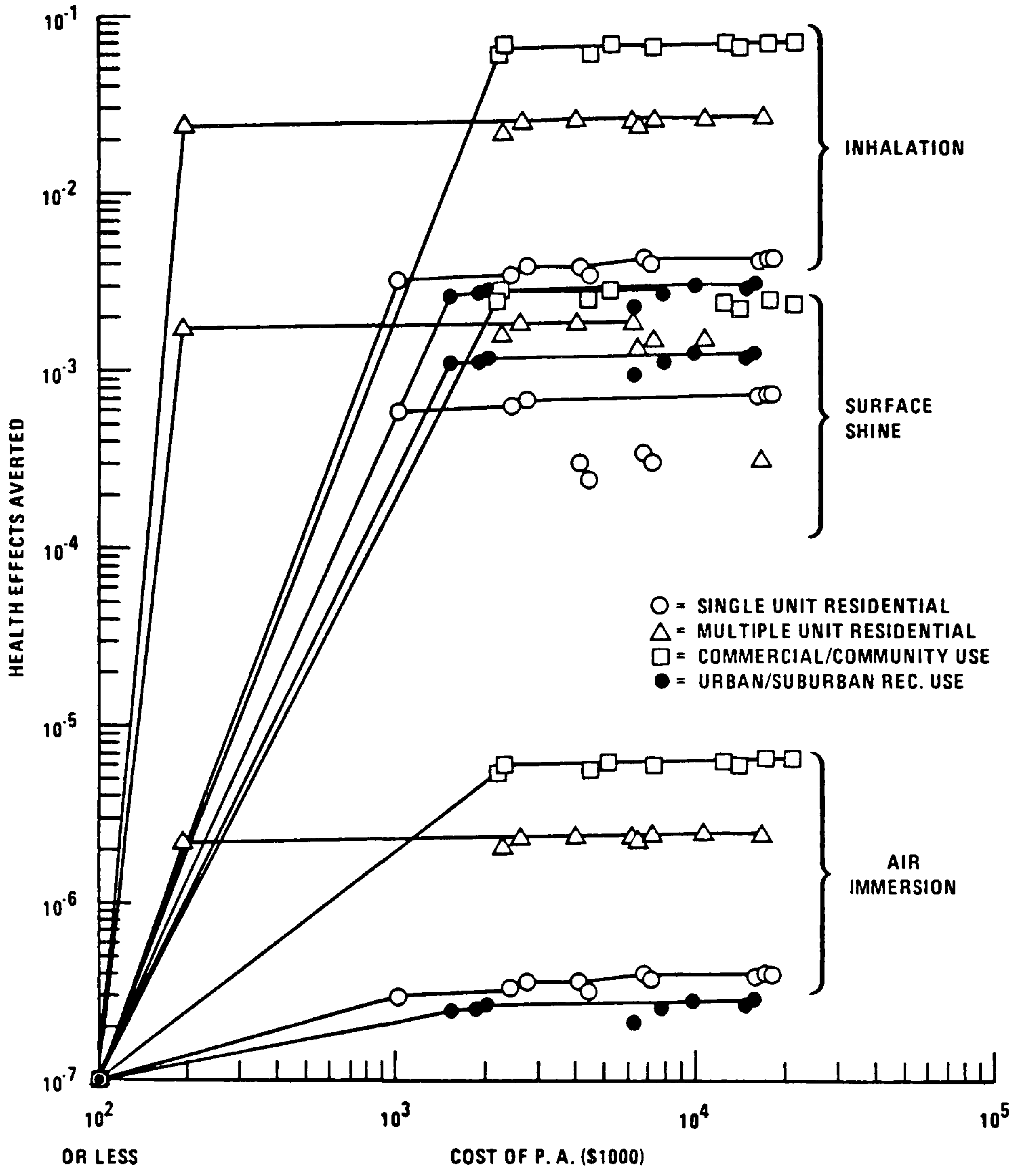

Figure A-2c. Protective Actions for Contaminated Property Types.

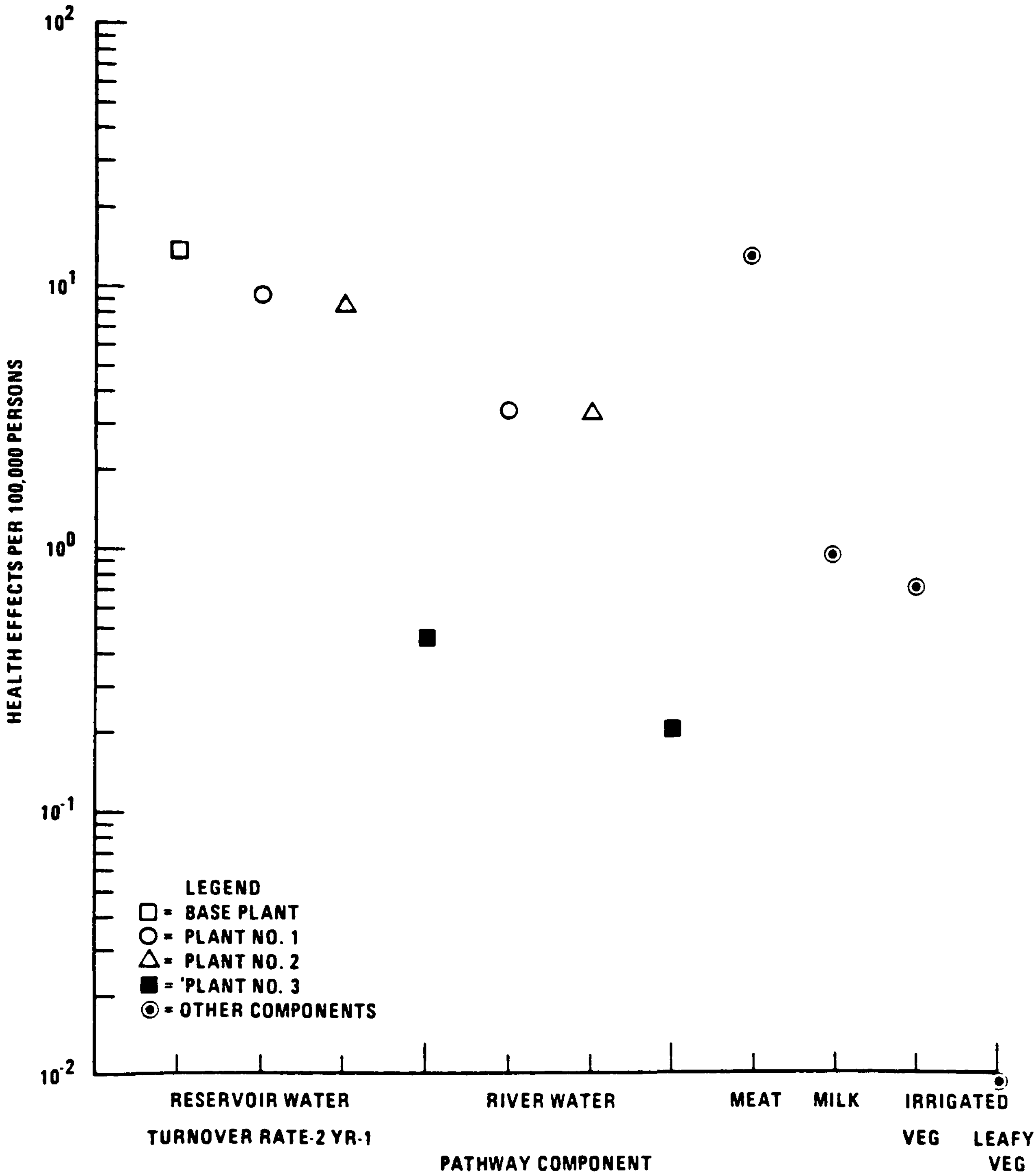

Figure A-3a. Health Effects with No PA for Pathway Components of Contaminated Water Supplies.

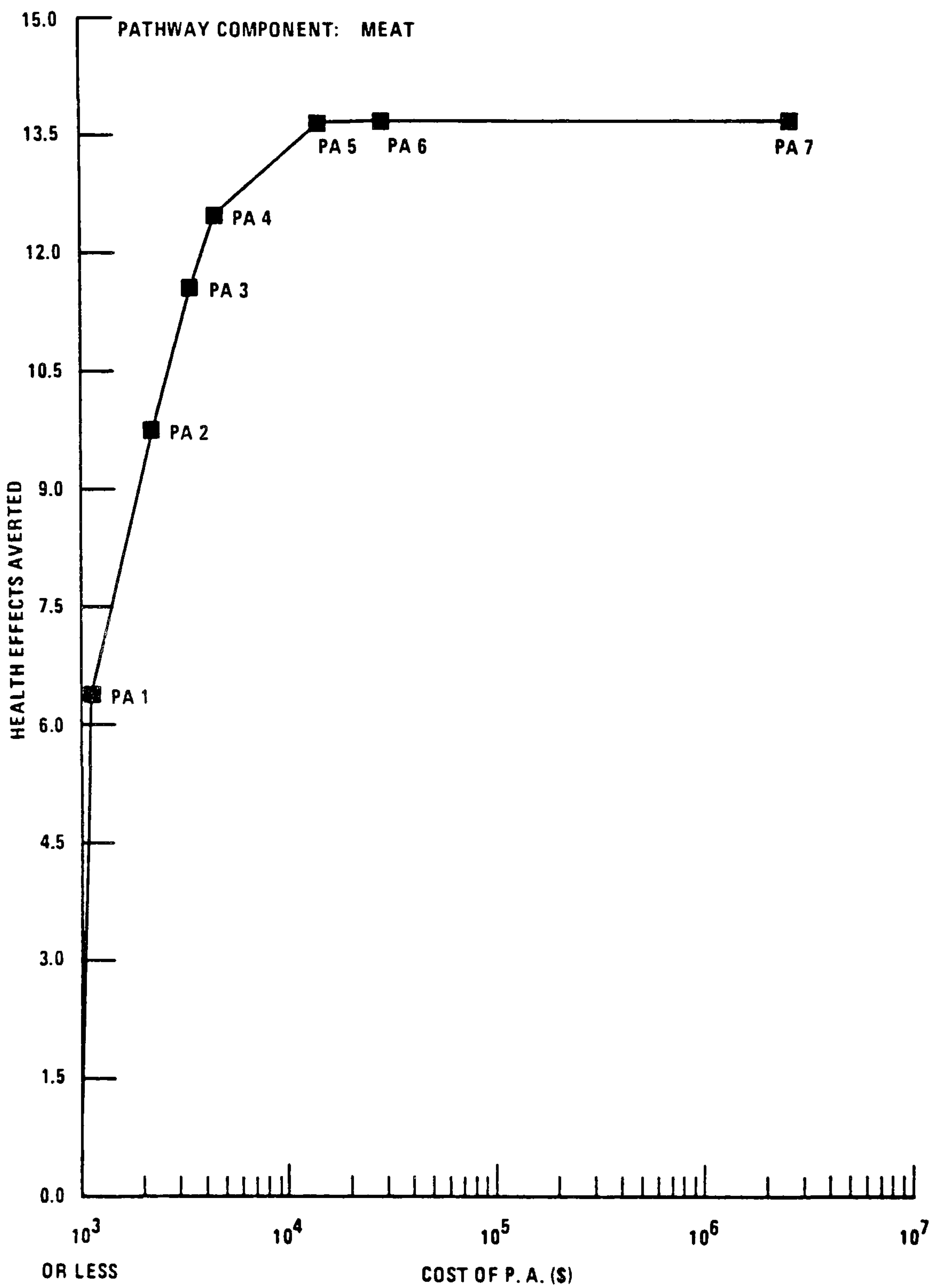

Figure A-3b. Critical Pathway Component for Contaminated Water Supplies.

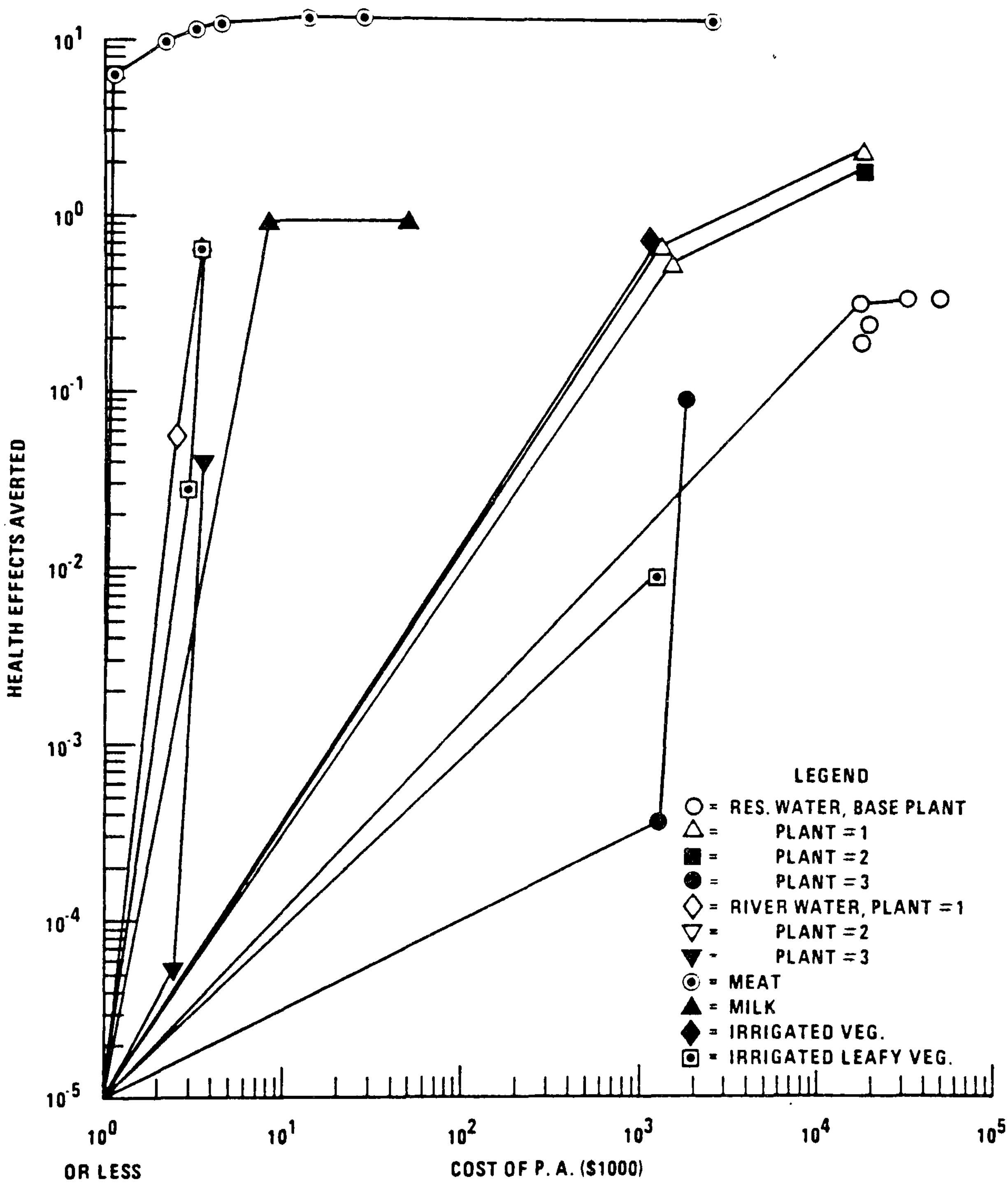

Figure A-3c. Protective Actions for Pathway Components of Contaminated Water Supplies.

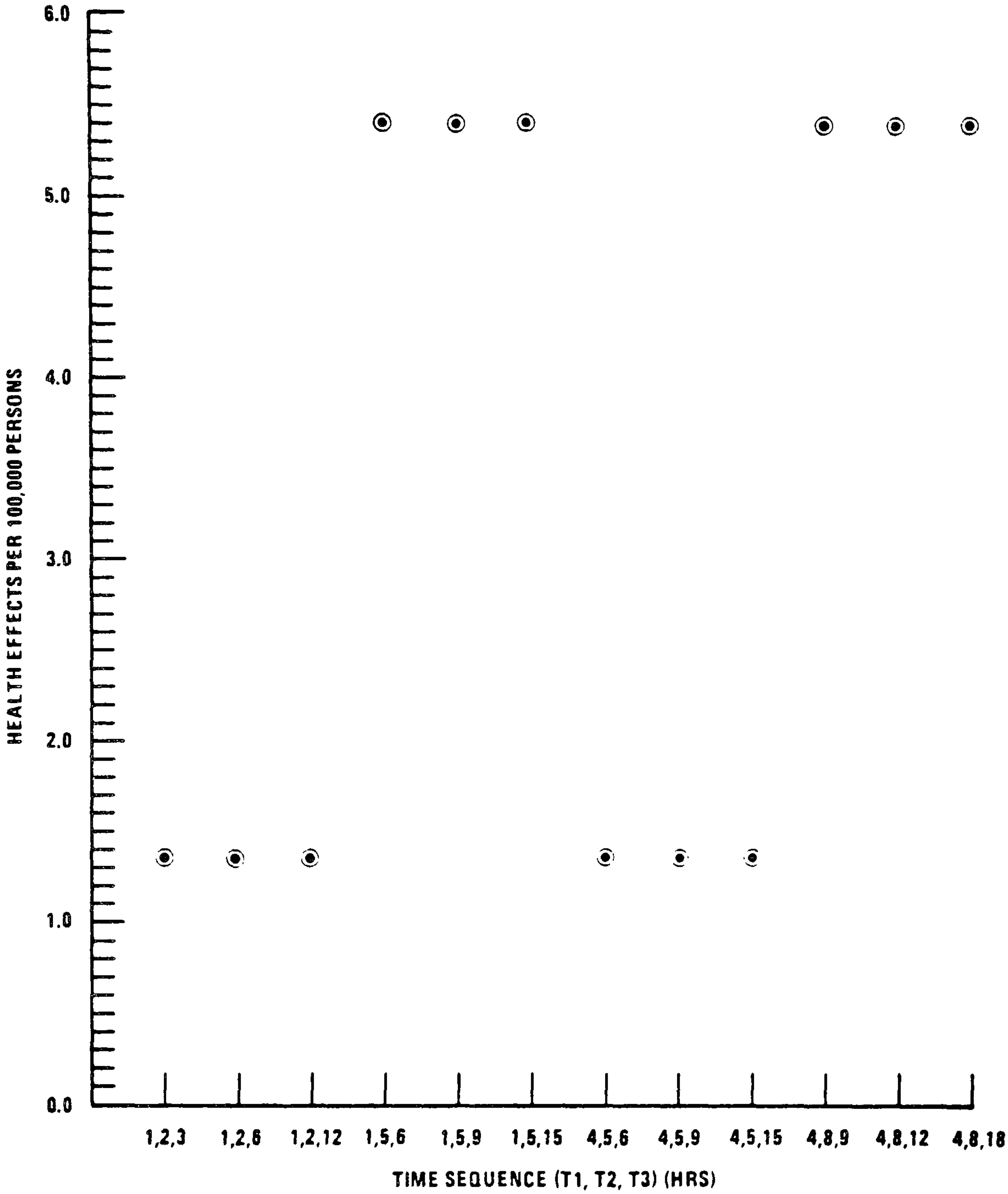

Figure A-4a. Health Effects with No PA for Contaminated Personnel.

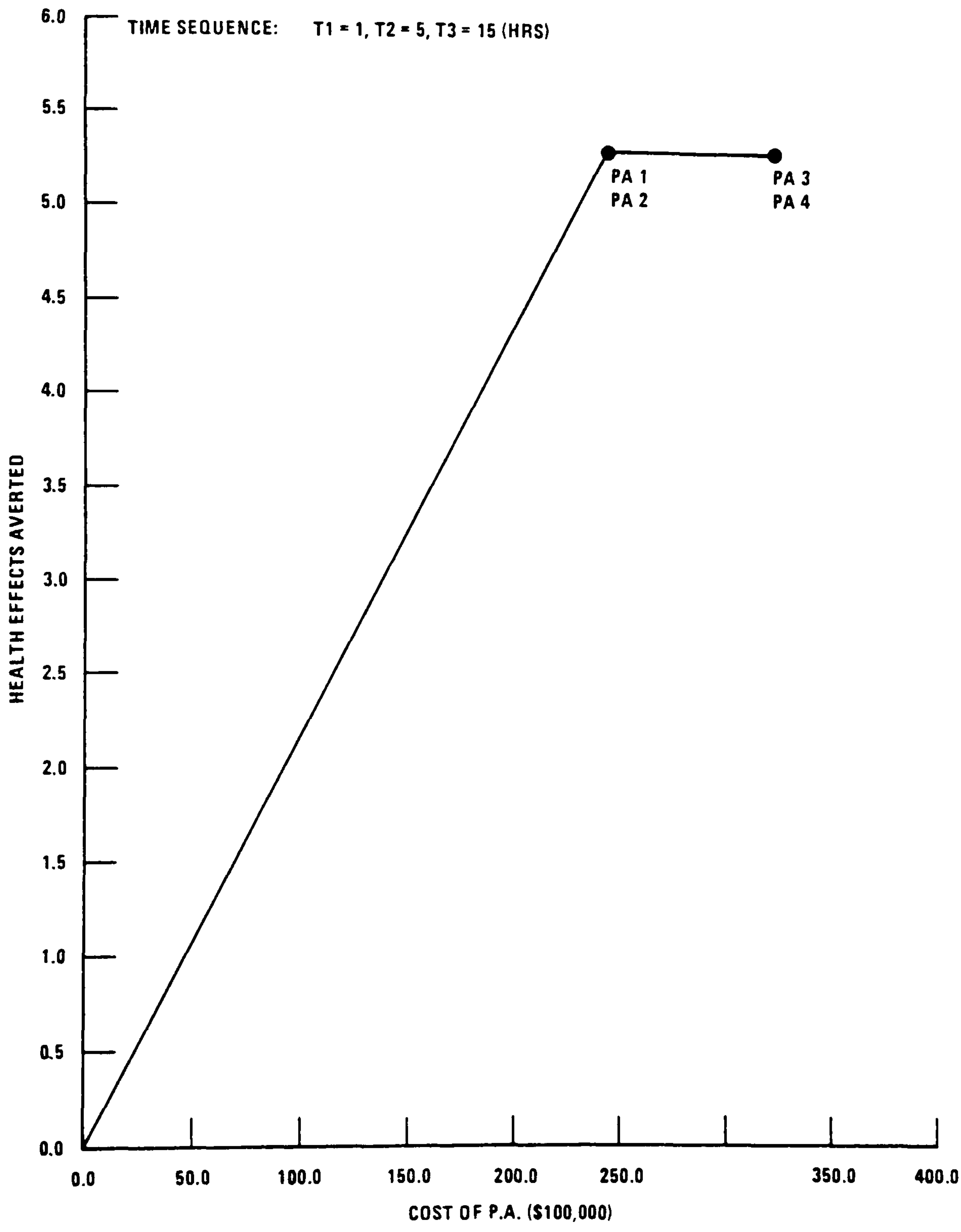

Figure A-4b. Critical Pathway Component for Contaminated Personnel.

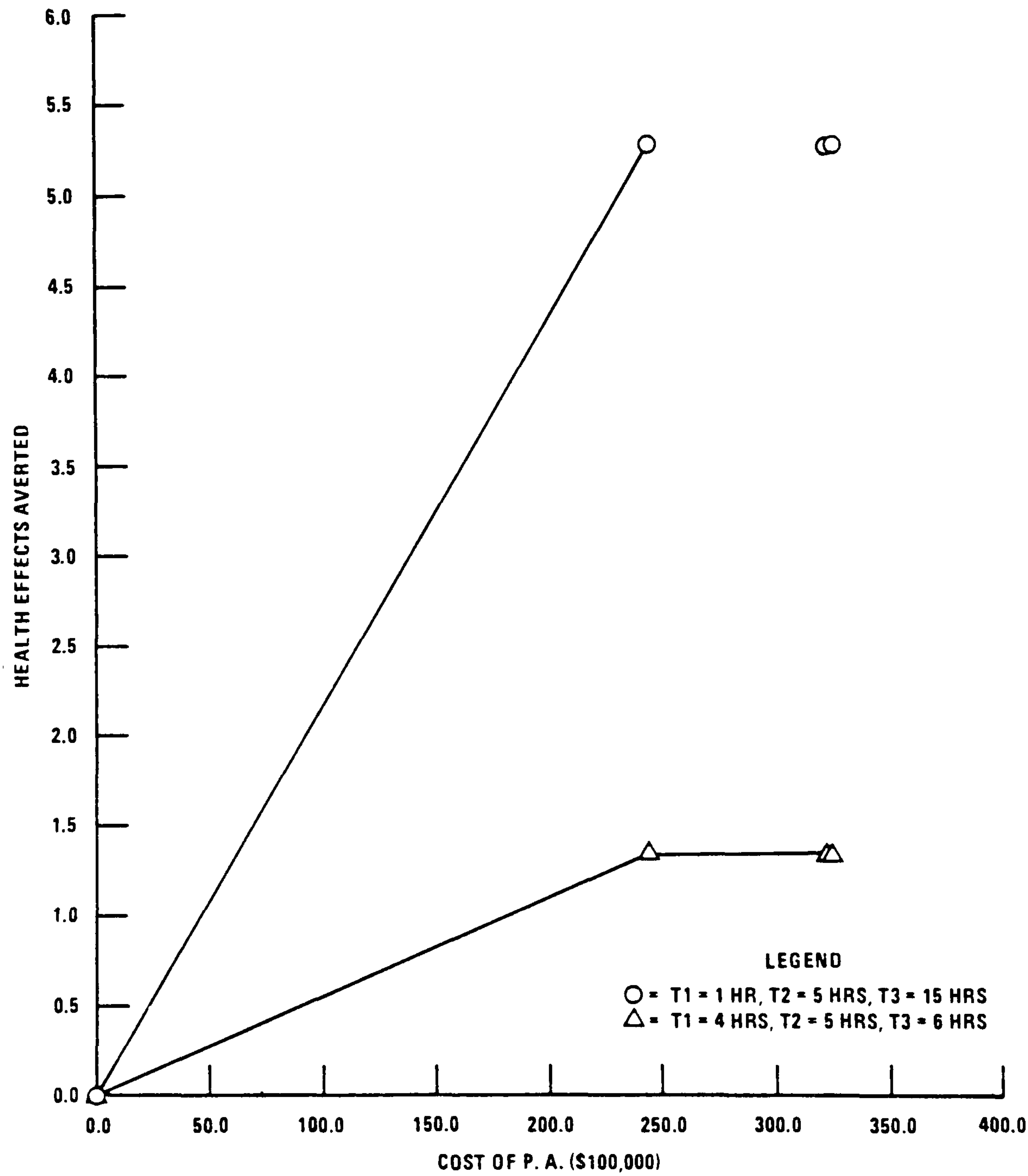

Figure A-4c. Protective Actions for Contaminated Personnel.

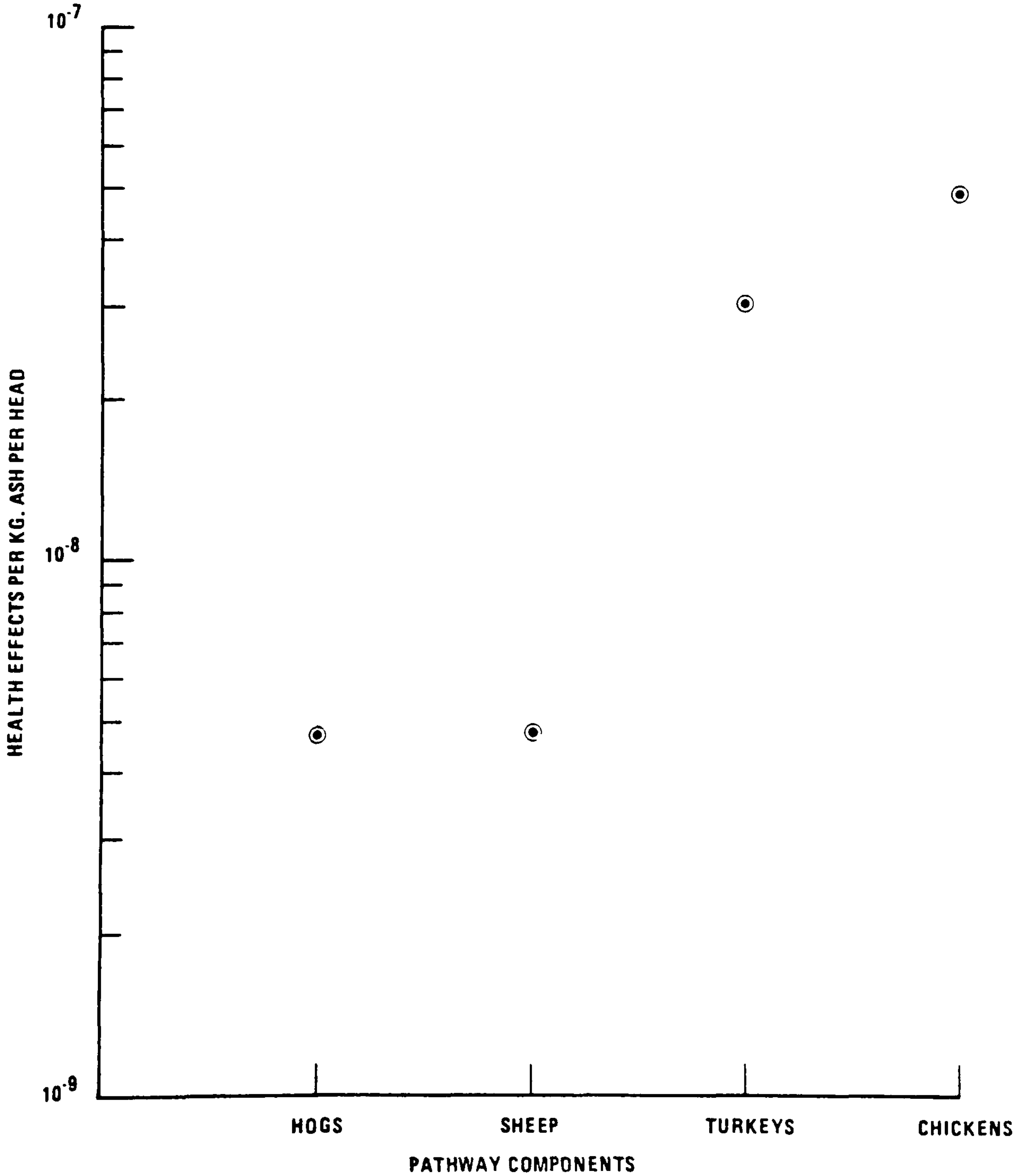

Figure A-5a. Health Effects with No PA for Pathway Components of Contaminated Biota.

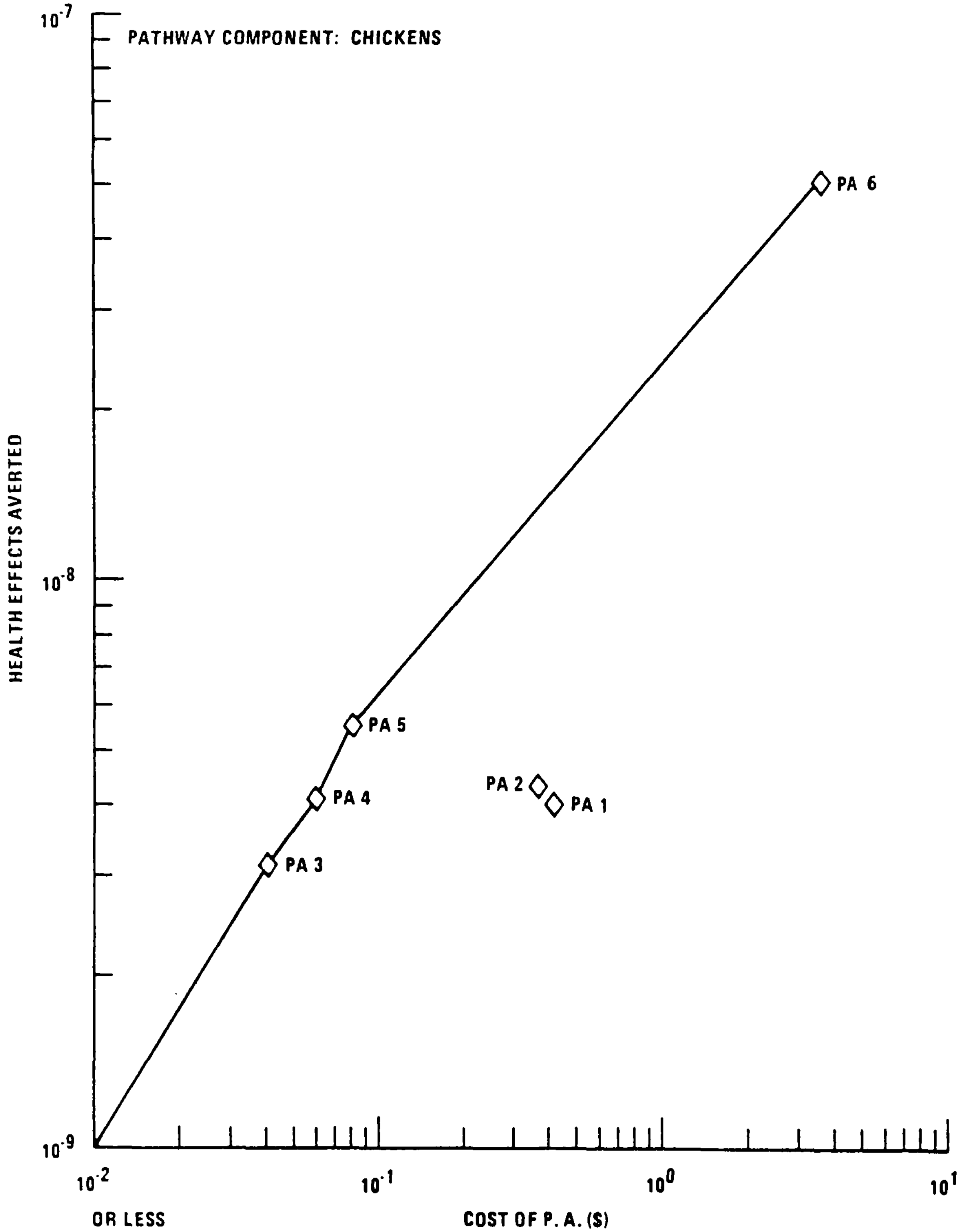

Figure A-5b. Critical Pathway Component for Contaminated Biota.

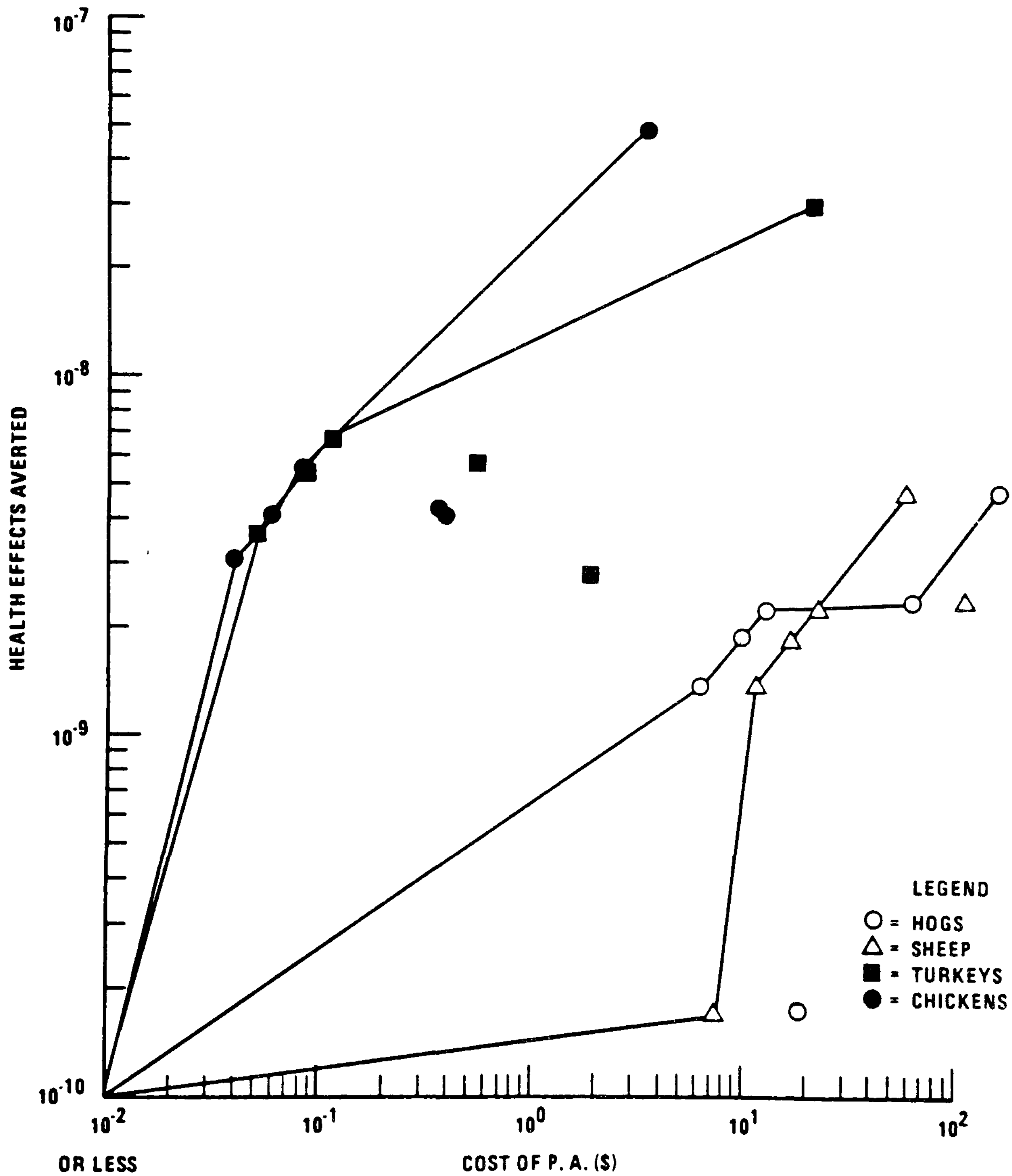

Figure A-5c. Protective Actions for Pathway Components of Contaminated Biota.

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