BIOMOVS II

TECHNICAL REPORT No. 5

Long Term Contaminant Migration and Impacts from Uranium Mill Tailings

Comparison of computer models using a realistic dataset

August 1996

BIOMOVS - an international study to test models designed to predict the environmental transfer and bioaccumulation of radionuclides and other trace substances

BIOMOVS II

Preface

BIOMOVS (BIOspheric MOdel Validation Study) is an international cooperative study to test models designed to quantify the transfer and bioaccumulation of radionuclides and other trace substances in the environment. The first phase of BIOMOVS was completed in 1990. The second phase, BIOMOVS II, covers the period from 1991-1996.

The BIOMOVS II study is jointly managed by five organisations:

- The Atomic Energy Control Board of Canada;
- Atomic Energy of Canada Limited;
- Centro de Investigaciones Energéticas Medioambientales y Tecnológicas, Spain;
- Empresa Nacional de Residuos Radiactivos SA, Spain;
- Swedish Radiation Protection Institute.

The primary objectives of BIOMOVS II are threefold, namely:

1. to test the accuracy of the predictions of environmental assessment models for selected contaminants and exposure scenarios;
2. to explain differences in model predictions due to differences in model structure, modelling assumptions and/or differences in selected input data;
3. to recommend priorities for future research to improve the accuracy of model predictions.

A secondary objective of the study is to act as a forum for the exchange of ideas, experience and information in order to improve the confidence with which the environmental behaviour of trace substances in the biosphere can be assessed quantitatively.

Two different approaches are used within BIOMOVS for fulfilling these objectives. One approach of testing (Approach A) involves the formulation of test scenarios based on suitable data and a comparison of model predictions against these independent data sets. The other approach (Approach B) involves the comparison of model predictions and associated estimates of uncertainty for specific test scenarios selected on the basis of assessment priorities.

This report is one of a series of Technical Reports produced within BIOMOVS II and uses Approach B to address the modelling of long term contaminant migration and impacts from uranium mill tailings disposal. The report has been developed in an international context and does not necessarily present the position of the individual organisations represented by contributors.

Executive Summary

The Uranium Mill Tailings Working Group of BIOMOVS II was initiated in Vienna in 1991 with the primary objective of comparing models which can be used to assess the long term impact of contaminant releases from uranium mill tailings piles, involving multiple pathways, multiple contaminants and multiple environmental receptors.

This is the final report of the Working Group describing:

- the enhancement of the previously devised V1 scenario to produce a V2 scenario which includes more detailed source term and other site specific data;
- the application of models in deterministic and probabilistic mode to calculate contaminant concentrations in biosphere media, and related radiation doses, contaminant intakes and health risks, including estimates of uncertainties;
- the comparison and analysis of the resulting calculations.

Following the completion of the V1.07 scenario, it was agreed that a V2 scenario should be developed in a piecewise fashion allowing for the gradual addition of new features. This facilitated comparison of participants' results, interpretation of discrepancies, and identification and removal of ambiguities and inconsistencies. A series of scenarios was developed based on data provided by Working Group members from a range of actual tailings disposal sites, culminating in the V2.2 and V2.3 scenarios. The V2.2 and V2.3 scenarios are identical in all respects, except that the V2.2 considers radioactive (U-238 chain) contaminants, whilst the V2.3 considers stable elements (As, Ni, Pb). Since the scenarios are based on data obtained from a range of actual sites, they should be considered to be generically realistic rather than representative of a particular single site.

In both scenarios, the contaminants of interest are assumed to be released in leachate from a tailings pile into an underlying aquifer. They are transported in groundwater through the aquifer to a well. Water is abstracted from the well and used for: watering beef cattle; human consumption; and irrigating leafy vegetables. The beef and leafy vegetables are consumed by humans living in the area. The same contaminants are also released into the atmosphere due to the wind erosion of the pile and then deposited upon the soil, pasture and leafy vegetables. In addition, for the V2.2 scenario, Rn-222 is assumed to be released to atmosphere from the pile. Unlike the V1 scenario, no consideration is given to surface water exposure pathways.

Results show that there is exceedingly good agreement between participants' deterministic and probabilistic estimates of total dose or intake. They agree within a factor of two to three for both scenarios. This reflects the close agreement between participants' results for the dominant pathways contributing to total dose or intake. Even where there are differences between the minor pathways, these are generally less than an order of magnitude. This good agreement is a function of: the scenarios' relatively unambiguous and limited nature; participants' experience and understanding of the scenarios/models gained through the V1.07 exercise and attending Working Group meetings; and the relatively "tried and tested" nature of most of the models used. Where discrepancies do exist between participants' results, these can generally be explained by differences in the approach used to modelling certain processes, rather than differences in scenario interpretation.

Since the scenarios are considered to be realistic, it is possible to draw some **scenario specific conclusions. Any attempt to apply these conclusions in a wider context must be undertaken with extreme caution.**

1. The dose/intake from the atmospheric release is almost three orders of magnitude higher than that from the groundwater release for the U-238 chain and As, and about an order of magnitude higher for Pb. However, for Ni it is the groundwater release which is dominant by about a factor of 50.

2. For the atmospheric release, the dominant pathway is ingestion of leafy vegetables for all contaminants except As, for which it is ingestion of beef. The dominant radionuclide is Pb-210.

3. For the groundwater release, the dominant pathways are ingestion of leafy vegetables and water for all contaminants except As, for which ingestion of beef is also important. The dominant radionuclides are U-238 and U-234.

4. Although, it is often possible to identify a "dominant" pathway or contaminant, it is rare that any single pathway or contaminant dominates the total dose/intake by more than a factor of five. Thus other pathways/contaminants are always within an order of magnitude of the dominant pathway/contaminant.

5. The probabilistic calculations are consistent with the deterministic results and show a variability in total dose/intake of an order of magnitude or less. They have also been successful in identifying the key sensitive parameters which effect dose/intake for the scenarios.

In so far as the V2 scenarios represent generic sites, the above scenario specific results and conclusions also support the following **generic conclusions** drawn from the V1.07 scenario.

1. A range of pathways and contaminants affect the total dose/intake and so no one single pathway or contaminant is dominant for all scenarios.

2. Peak impacts on individuals from uranium mill tailings piles may not arise for many hundreds of years.

3. Models are available for assessing potential radiological and non-radiological health risks to individuals from releases from tailings piles. However, comparison of health risks arising from radioactive and stable elements is limited in its extent because data for cancer risk per unit intake for the stable elements is not as comprehensive as that for radionuclides.

The following general **recommendations** can be made as a result of the experience gained during the V2 exercise.

1. It is important to ensure that modelling of a scenario is not undertaken in a vacuum (ie one model being used by one person). This can introduce considerable bias and prevents cross verification of the model and its results against other models and their results. The independent use of two or more models on a scenario will help to reduce these problems.

2. Modelling a scenario is not a once through process, it should be iterative. This allows checks to be performed and key features, processes and pathways to be identified and investigated in more detail.

3. It is vital that quality checks are undertaken at all stages of the scenario modelling exercise, not just at the data entry stage.

4. It is often useful to develop a scenario for model intercomparison purposes in a piecewise fashion with full involvement of participants. It facilitates comparison of participants' results and interpretation of discrepancies. It also provides participants with the opportunity to develop their understanding of the scenario and for the scenario to be modified to remove ambiguities and inconsistencies.

5. Participants in the intercomparison exercise should include those providing system characterisation data as well as those developing models and making calculations.

6. Further effort should be spent on collating data to facilitate the comparison of health risks from radionuclides and stable contaminants.

Two specific recommendations can be made relating to the continuation of the work of the Group. Firstly, the V2 scenarios should be extended further to include consideration of surface water pathways. Secondly, more detailed analysis should be undertaken of participants' representation of features, processes and pathways. Such detailed analysis will help to explain further the discrepancies seen between participants' results which, in the case of the V2 scenarios, are relatively minor.

It is hoped that the scenario and model descriptions, as well as the discussion of the process and presentation of results may provide useful insight to those involved in future assessments of uranium mill tailings facilities. If readers wish to use the scenarios to test their own models, it is important that they should follow the scenarios as closely as possible in order to make the comparison of their results with those of the Working Group as valid as possible.

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1. Introduction

Wastes from the processing of uranium ore deposits are often disposed of to surface tailings piles. These piles may present both short and long term pollution hazards due the presence of uranium isotopes and their radioactive daughters, and stable toxic elements. To assist with the assessment of these hazards and any potential impacts upon the environment arising from the release of contaminants from the piles, models[1] have been developed which simulate the release and transport of the contaminants from the piles into the surrounding environment, and their subsequent fate.

It is the primary objective of the Uranium Mill Tailings Working Group to compare such models which have been developed by participants. The comparisons are intended to improve understanding of the processes and how to model them, and to explain the differences in model predictions, including uncertainties, so as to improve overall confidence in model results and their validity. Direct comparison of models in terms of their functionality was not a part of the exercise.

The Uranium Mill Tailings Working Group was initiated in Vienna in 1991 [BIOMOVS II, 1991]. At that first meeting, the Working Group identified a number of tasks for the Group which included:

1. Development of a basic scenario (V1) describing releases of contaminants from a tailings pile.
2. Application of models to the V1 scenario to undertake deterministic calculations of contaminant concentrations in biosphere media, and related radiation doses, contaminant intakes and health risks.
3. 'Type B' comparison[2] of model results and review of the modelling undertaken for the V1 scenario.
4. Enhancement of the V1 scenario to produce a more realistic V2 scenario which includes more detailed source term and other site specific data.
5. Application of models to the V2 scenario to undertake deterministic and probabilistic mode to calculate contaminant concentrations in biosphere media, and related radiation doses, contaminant intakes and health risks, including estimates of uncertainties.
6. 'Type B' comparison of model results and review of the modelling undertaken for the V2 scenario.

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[1] There is a common confusion arising from different uses of the term 'model'. It may mean a conceptual description, or a mathematical realisation of that concept or a specific (generally computer) coded solution of that mathematical realisation. Here we mean the latter.

[2] Within BIOMOVS, a type A comparison is between model predictions and field data. A type B comparison is between different model predictions.

The first three tasks have been reported in BIOMOVS II [1995]. This report discusses the final three tasks within the overall framework of BIOMOVS II's primary objectives:

- testing the accuracy of the predictions of environmental assessment models for selected contaminants and exposure scenarios;
- explaining differences in model predictions due to differences in model structure, modelling assumptions and/or differences in selected input data;
- recommending priorities for future research to improve the accuracy of model predictions.

The scope for obtaining data for a 'Type A' comparison of model predictions with field data was investigated and found to be limited. Tailings management and monitoring of tailings facilities has a history limited to just a few decades, whereas the processes of contaminant migration and accumulation may operate over centuries or even longer. Consideration was also given to using analogue data from ancient mine workings to provide long term data, but without success.

2. Development of the V2 Scenarios

Following the completion of the V1.07 scenario, it was agreed that a V2 scenario, based on data provided by Working Group members from a variety of actual tailings disposal sites, should be developed in a piecewise fashion allowing for the gradual addition of new features. In the light of experience gained during the V1 scenario exercise, it was felt that this piecewise approach of gradually adding more layers of complexity to the scenario was appropriate. It facilitated comparison of participants' results and interpretation of discrepancies. It also provided participants with the opportunity to develop their understanding of the scenario and for the scenario to be modified to remove ambiguities and inconsistencies. The time history of the development of the V2 scenarios is shown in Figure 1 and discussed below.

The first scenario (the V2.0 scenario) only considered the release of U-238 from a tailings pile to groundwater. Both deterministic and probabilistic cases were specified, with three biosphere parameters being assigned probabilistic distributions for the probabilistic case. Whilst allowance was made for the decay of U-238, no explicit consideration was given to long lived U-238 daughters or stable metals. Furthermore, an atmospheric release term was not modelled.

In the light of review comments from participants and discussions at a Working Group meeting, the V2.0 scenario was modified to produce a draft V2.1 scenario. The essential features of the V2.0 scenario were maintained, but parameter values were modified and text was clarified in an attempt to make it less ambiguous. Participants then submitted results for the draft V2.1 scenario which were discussed and analysed at a Working Group meeting. At the meeting, it was agreed that a few modifications should be made to the scenario to produce the final V2.1 scenario for which participants carried out a final set of calculations.

An initial V2.2 scenario was then developed and participants undertook preliminary calculations. Additional features introduced for the V2.2 scenario were the specification of a groundwater source term which included the longer-lived daughters of U-238, and an atmospheric source term. Following a Working Group meeting to discuss the initial scenario and associated results, the V2.2 scenario was finalised and participants undertook the associated calculations.

At the same time as the V2.2 scenario was being finalised, the V2.3 scenario was specified. The scenarios are identical in all respects, except that V2.3 considers stable elements (As, Ni, Pb) rather than radionuclides. Following distribution of the scenario, participants undertook the associated calculations.

Two Working Group meetings were held between the finalisation of the V2.2 and V2.3 scenarios, providing participants with the opportunity to discuss initial results and resubmit them in light of the discussions. The results presented in Section 4 are the finalised results.

Key features of the V2.2 and V2.3 scenarios are as follows. Detailed descriptions of the scenarios and their derivation are given in Appendices A and B.

- A realistic, time variant, source term to groundwater, which, for V2.2, includes both U-238 and its longer-lived daughters (U-234, Th-230, Ra-226, Pb-210 and Po-210). The U-238, Th-230 and Ra-226 source terms are based on the results of detailed modelling of an actual tailings pile. In the absence of detailed modelling results, the U-234 source term is assumed to be the same as U-238, whilst the Pb-210 and Po-210 source terms are assumed to be the same as Ra-226. For V2.3, the release of As, Ni and Pb is considered.

- A realistic, time variant, source term to atmosphere, which, for V2.2 , results from the emission of radioactive gas (Rn-222) and dust from the tailings pile. The contaminants considered to be emitted in the dust are U-238, U-234, Th-230, Ra-226, Pb-210 and Po-210. For V2.3, the emission of As, Ni and Pb in the dust is considered. It is assumed that the cap over the pile prevents any atmospheric release before 200 years, thereafter the cap is assumed to gradually fail until total failure occurs at 1000 years.

- Geosphere and biosphere characteristics based primarily on those of the region around an actual tailings pile.

- Consideration of both deterministic and probabilistic cases. In the probabilistic case, uncertainties associated with five biosphere parameters are considered.

- A significant reduction in the number of end-points and pathways to be considered compared to the V1.07 scenario.

In both scenarios, the contaminants of interest are assumed to be released in leachate from a tailings pile into an underlying aquifer. They are transported in groundwater through the aquifer to a well. Water is abstracted from the well and used for: watering beef cattle; human consumption; and irrigating leafy vegetables. The beef and leafy vegetables are consumed by humans living in the area.

The same contaminants are also released into the atmosphere due to the wind erosion of the pile and then deposited upon the soil, pasture and leafy vegetables. In addition, for V2.2, Rn-222 is assumed to be released to atmosphere from the pile.

Figures 2 and 3 illustrate the main features of the scenarios. Unlike the V1 scenario, no consideration was given to surface water exposure pathways.

Participants were asked to estimate contaminant concentrations in environmental media (well water, soil, air, leafy vegetable and beef) as a function of time, radiation doses, stable element intakes and the associated risks to human health.

If readers wish to use the scenarios to test their own models, it is important that they should follow the scenarios as closely as possible in order to make the comparison of their results with those of the Working Group as valid as possible. To facilitate comparison, compiled results from participants for the two scenarios can be made available.

3. Models Applied to the V2.2 and V2.3 Scenarios

A total of seven models have been applied to the V2.2 and V2.3 scenarios by eight participating organisations:

- GEOS/ABRICOT - Institut de Protection et de Sûreté Nucleaire, Commissariat à l'Energie Atomique (CEA), France;
- IMPACT - applied independently by Beak Consultants Ltd, Canada, and Atomic Energy Control Board (AECB), Canada;
- INTAKE - SENES Consultants Ltd, Canada;
- JAERI model - Japan Atomic Energy Research Institute (JAERI);
- MEPAS - US Department of Energy's Pacific Northwest National Laboratories (PNNL), United States of America;
- RESRAD - US Department of Energy's Argonne National Laboratory, United States of America;
- SONS model - State Office for Nuclear Safety (SONS), Czech Republic (V2.2 scenario only).

Model descriptions, references and comments on the application to the V2 scenarios are given in Appendix C. It is important to recognise that four of the models were modified either shortly before or during the course of this exercise (GEOS/ABRICOT, IMPACT, INTAKE, and RESRAD). Indeed, INTAKE was specifically modified for the exercise. Such developments continue for all models and so the model descriptions given in Appendix C do not necessarily represent the very latest developments.

Most of the models used are fully integrated, ie they allow for atmospheric, groundwater and biosphere modelling. However some participants have used separate models to represent different components of the scenarios. Most of the models are similar conceptually, eg 1D groundwater flow, Gaussian plume for the atmospheric release and linear compartment models for transfer through soils to foodchain, etc. A list of features, processes and pathways modelled by each of the participants is given in Tables 1 - 5. In general there is considerable commonality in the features, processes and pathways modelled, especially in the biosphere processes (Table 3) and exposure pathways (Table 4). There are slightly more differences in the atmospheric and groundwater release features and processes modelled (Tables 1 and 2). It should be noted that a "N" (No) in the tables does not necessarily mean that the model does not have the capability to represent the feature, process or pathway; the user might well have decided not to use the capability for the V2.2 and V2.3 scenarios.

4. Comparison of Results

Tables 6 - 9 show the matrices of final results submitted by participants for the V2.2 (U-238 chain) and V2.3 (stable elements) scenarios. In a model comparison exercise such as this, which involves multiple environmental receptors, multiple pathways and multiple contaminants, a large number of comparisons is possible. It is the aim of this section to focus on certain results which can be used to illustrate key points, rather than to discuss each and every result in turn. The results for V2.2 and V2.3 scenarios are presented together because only the contaminants vary, the biosphere is the same for both scenarios. Indeed, when examining the results, it appears that, in general, the behaviour of the models is the same for radioactive and stable contaminants.

Before analysing the results, it is important to note that the results presented in this report represent the final results submitted by participants. All participants' results have been modified during the course of the exercise and the relatively good agreement shown in the final results has not always been present. Changes have been made because of modifications to the initial scenario description and errors in the initial results submitted by participants. In turn these errors have resulted from:

- ambiguities in the initial scenario descriptions;
- inconsistencies in the initial scenarios;
- inability of models to represent all the features, processes and pathways of the scenarios;
- misinterpretation of the scenarios by the participants;
- incorrect input of data into the models;
- bugs within the models used;
- errors in processing data submitted by participants.

Due to the iterative/piecewise nature of the V2 exercise, many of these factors have been eliminated resulting in the relatively good agreement between participants' results described below. In addition, participants' improved understanding of migration and accumulation processes, and how best to model them, has also contributed.

A further point to note is that the V2.2 and V2.3 scenarios require the participant to calculate the standardised regression coefficient (SRC) and partial correlation coefficient (PCC) for each of the sampled parameters against peak total U-238 chain dose/stable element intake. At a Working Group meeting subsequent to the specification of the final descriptions of the scenarios, it was agreed that they might not be ideal tests for parameters which have a non-linear effect upon the dose/intake since they only test the linear relationship between the parameters and dose/intake. It was felt that sample ranked SRC and PCC tests might have been more suitable given that most of the sampled parameters were considered to have a non-linear impact on dose/intake. However, given the time constraints, it was not considered appropriate to ask participants to recalculate the ranked statistics. This limitation should be borne in mind when analysing the results from these two statistical parameter tests reported below.

4.1 Atmospheric Release

4.1.1 Deterministic Results

The first set of results which should be analysed is contaminant concentrations in air since this is the pathway via which all other biosphere media are contaminated. Participants' results for the V2.2 and V2.3 scenarios show good agreement with all results being within a factor of three of one another (eg Figures 4, 5 and 6). Since the Argonne and JAERI models do not consider plume depletion when calculating air concentrations (Table 1), they estimate slightly higher concentrations than other participants. The lower concentrations for the SONS model results from its consideration of wet deposition in addition to dry deposition and its treatment of the tailings pile as an areal rather than point source term (Table 1). The doses/intakes resulting from the inhalation of contaminated air show the same characteristics as the concentration plots.

The main discrepancies between participants' results for the atmospheric release are observed for soil concentrations of contaminants which at a maximum show two orders of magnitude discrepancy (eg Figure 7). They can be explained by a difference of modelling the interaction between atmosphere and the soil compartment. For example, where as most participants explicitly consider resuspension of soil particles, the IPSN model does not. Instead, the IPSN model directly uses a surface deposition rate which the user has to estimate based on assumptions concerning the dust concentration in air and the deposition velocity. It is interesting to note that for the SONS model the estimated soil concentrations are generally higher than for other participants due to the inclusion of wet deposition. The resulting doses are generally consistent with the concentrations (eg Figure 8).

The discrepancy observed for soil concentrations and doses does not significantly affect other calculational end points (concentrations in vegetables and beef, and doses/intake from vegetables and beef). This is most likely to be because atmospheric related pathways, such as the foliar interception of contaminants by leafy vegetation and pasture, dominate over soil related pathways, such as root uptake. Therefore similar air concentrations result in similar vegetable and beef concentrations (eg Figure 9).

For the V2.2 scenario there is good agreement for participants' estimates of total dose for the U-238 chain with all results being within a factor of two of one another (Figure 10). Figure 11 shows that at the time of peak total dose, leafy vegetables accounts for 71 - 79% of the total dose. The next most important pathways is inhalation of dust (12 - 20%). Figure 12 shows that the radionuclide which contributes most to the peak total dose for all participants is Pb-210 (27 - 49% of peak total dose). Ra-226, Th-230 and Po-210 all contribute between 13% and 34% of the peak total dose.

There is also good agreement for participants' estimates of stable or three element intake for the V2.3 scenario, with all results being within a factor of two or three of one another (eg Figure 13). There is consensus that beef is the dominant exposure pathway for As (Figure 14). For Ni and Pb, it is leafy vegetables which dominate.

4.1.2 Probabilistic Results

All results submitted by participants show relatively good agreement and are consistent with the deterministic results, for both types of contaminants (eg Figures 15 and 16). Argonne's results are about a factor of three higher than other participants. This is because Argonne could not explicitly use the minimum and maximum values specified in the scenarios as cut off points for the sampled parameters. Instead they used three standard deviations about the mean (Table 5). For certain parameters, this means that the range of sampled parameter values is different from other participants which in turn resulted in differences in the range of dose/intake results. Figure 16 shows that the range in total dose for the U-238 chain is greater than other participants. Furthermore doses at the top end of the distribution are higher (almost 10% of probabilistic runs give a total dose in excess of 1E-3 Sv y^{-1}). This in turn gives rise to the higher mean total dose (Figure 15), whilst the median dose is similar to the estimates of the other participants (Figure 16).

The low variability of the IPSN model for the V2.2 scenario (Figures 15 and 16) is primarily due to the model not explicitly considering resuspension and hence not using/sampling a deposition velocity for resuspension soil particles. Instead, it samples a dust concentration (Appendix C.1) which has a little effect on the dose where as, for other models, the deposition velocity has an important impact on the variation in dose (eg Figure 17). The Beak and AECB models do not allow the sampling of the deposition velocity for resuspension soil particles. However, the range of dose/intake results (eg Figures 15 and 16) is much greater than IPSN, suggesting that dose/intake results from the Beak and AECB models are more sensitive to the other sampled parameters (see below).

Figure 17 also shows that other parameters such as the soil to plant concentration factor (TF_{SP}) and soil distribution coefficient (K_d) can affect the peak mean total dose. This is probably due to the fact that Ra-226 is a significant contributor to the peak mean total dose via the leafy vegetable pathway (see below). Evidence from Argonne's analysis of their deterministic results is that soil related pathways dominate over atmospheric pathways for Ra-226 (but not other radionuclides). Thus, parameters such as TF_{SP} and K_d which directly affect soil related pathways will impact on mean total dose.

The variation in the mean total dose/intake is a function of the variation in the dose/intake from the principal pathway contributing to the dose/intake. For example, the approximate order of magnitude variation in the mean intake of As from the dominant pathway (beef) (Figure 18) is reflected in the mean total intake of As (Figure 19). For all other contaminants the variation in the total dose/intake less than or equal to an order of magnitude.

In common with the deterministic results, Figure 20 shows that at the time of the peak mean total dose for the V2.2 scenario, the ingestion of leafy vegetables is the dominant exposure pathway, accounting for 75 - 89% of the dose. The next most important pathway for most participants is inhalation of dust (3 - 16%). Figure 21 shows the contribution of the radionuclides to the mean total dose at the time of peak dose. Pb-210 is the largest contributor to IPSN results (48%) as per the deterministic results, whilst all other participants have Ra-226 as the largest contributor (33 - 80%) and Pb-210 as the second (9 - 33%).

4.2 Groundwater Release

4.2.1 Deterministic Results

The first set of results which should be analysed are contaminant concentrations in well water since this is the pathway via which all biosphere media are contaminated. There is good agreement (a maximum of a factor of two discrepancy) for concentrations in the well of all contaminants for all the participants (eg Figure 22). The doses/intakes resulting from the consumption of well water show the same characteristics as the concentration plots for all participants.

There is some slight variation in the shape of the As and Pb concentration plots (eg Figure 23). IPSN and SENES models give slightly higher peaks than those of Argonne, JAERI and PNNL, although their timing is comparable. The Beak model does not produce a peak, although the equilibrium value is the same as all the other participants. Analysis of Table 2 and discussions at Working Group meetings suggests that, for the V2.2 and V2.3 scenarios, these differences are more a function of the models' solutional methods and the discretisation of the groundwater flow path than the processes include/excluded from the models. For example, although the PNNL results, unlike those of Argonne and JAERI, include the effect of molecular diffusion, all three sets of results are identical. The effect of the discretisation of the groundwater flow path upon results is illustrated by the results from the AECB and Beak models. Both organisations used the IMPACT model (Appendix C), but AECB used a finer discretisation. This resulted in a later break through of As at the well for AECB and an associated peak (Figure 23).

Beef concentration, dose and intake results mimic the well water results (eg Figure 24) since the consumption of well water is the only pathway via which the cattle are exposed for the groundwater release case.

Soil concentrations show similar good agreement, although AECB and SONS model results are a little higher than other participants (eg Figures 25 and 26). Although, AECB and SONS generally consider the same processes as the other participants (Table 3), their models' representation of the processes might vary slightly. For example, the AECB model could not explicitly use the soil erosion rate specified in the scenarios, it had to be approximated. Doses from external irradiation from the soil for the V2.2 scenario are consistent with the concentration results (eg Figure 27).

Some differences can also be observed for concentrations in and resultant doses/intake from air (eg Figure 28). As for the atmospheric release (Section 4.1), these are probably due to the treatment of soil particle resuspension. IPSN and SENES results are generally higher than other participants (by up to an order of magnitude) due to their different treatment of resuspension (Appendix C). These differences for the doses/intake from air have no effect on the total dose/intake because this exposure pathway does not contribute significantly to dose/intake (see below).

Differences were also initially observed for concentrations in and resultant doses/intake from leafy vegetables. Results for certain participants were about a factor of four lower than other participants. This was found to be due to the differences in the assumed irrigation results. Ambiguities in the original scenario description, resulted in AECB, Argonne, Beak and SENES assuming a lower irrigation rate than IPSN and JAERI. These ambiguities were noted at a Working Group meeting and revised results were submitted by participants (Figure 29).

For the V2.2 scenario there is good agreement for participants' estimates of total dose/risk for the U-238 chain with all results being within a factor of two of one another (Figure 30). Figures 31 and 32 show that the dominant radionuclides are U-238 and U-234 both at the time of peak dose and at 10,000 years. It is the leafy vegetable pathway which dominates the dose (55 - 65%) with ingestion of well water being the second most important pathway (35 - 45%) (Figure 33). The same pathways are dominant for the V2.3 scenario (eg Figure 34). It is interesting to note that use of the lower irrigation rate, initially adopted by some participants, resulted in the relative importance of these two pathways being reversed.

4.2.2 Probabilistic Results

Results submitted by participants generally show good agreement and are consistent with the deterministic results, for both types of contaminants (eg Figures 35 and 36). For all contaminants the variation in the total dose/intake is less than or equal to an order of magnitude. As with the atmospheric probabilistic results, Argonne's results are slightly higher than other participants due to their use of different cut off values for the sampled parameters (Section 4.1.2). This resulted in higher intakes at the top end of the distribution (Figure 36) which in turn gives rise to the higher mean total dose (Figure 35).

The sensitivity analysis shows that for all contaminants the foliar interception fraction for irrigation water (N_I) is one of the most important parameters (eg Figure 37). This result is explained by the relative importance of the ingestion of vegetables pathway in the total dose/intake for this scenario and the fact that no parameters affecting the ingestion of well water pathway are sampled (see below). Other parameters which are important for certain contaminants are the soil to plant concentration factor (TF_{SP}) and distribution factor (DF) (eg Figure 37), yet again reflecting the relative importance of their associated pathways in affecting total dose/intake.

In common with the deterministic results, Figure 38 shows that at the time of the peak mean total dose for the V2.2 scenario, leafy vegetables is the dominant pathway accounting for 58 - 79% of the dose. As with the deterministic, U-238 and U-234 are the dominant radionuclides (Figure 39). The leafy vetgetable pathway is also generally dominant for the V2.3 scenario (Figure 40), although Beak results indicate that the dose from ingestion of well water is greater. This is because Beak did not submit any revised probabilistic results for the V2.3 scenario after the meeting at which the ambiguity over the irrigation rate was noted. Thus their V2.3 probabilistic results assume a factor of four less irrigation resulting in lower doses from the leafy vegetable pathway.

5 Conclusions

As with all BIOMOVS scenarios, the V2.2 (U-238 chain) and V2.3 (stable elements) scenarios have benefitted participants through the interchange of ideas and experience, and, in the case of five participants (Section 3), the testing of recently modified models. In the case of one participant, it has directly resulted in the extension of a existing model.

The first key conclusion to be drawn from the analysis of scenario results is that there is exceedingly good agreement between participants' deterministic and probabilistic results for total dose/intake for the V2.2 and V2.3 scenarios. Results agree within a factor of two to three for both scenarios. This reflects the close agreement between participants' results for the dominant pathways contributing to total dose or intake. Even where there are differences between the minor pathways for the scenarios, these are generally less than an order of magnitude, whereas V1.07 results often ranged over three orders of magnitude [BIOMOVS II, 1995]. Why has there been this significant improvement from V1.07 to V2.2 and V2.3? One possible explanation is that, as noted earlier, the results presented in this report are the final results submitted by participants, most participants submitted at least one set of revised results. However, the same iterative process was followed for V1.07. Thus there must be alternative scenario specific explanations.

1. The scenarios were developed in a piecewise fashion to be as realistic and self-consistent as possible, and to minimise any ambiguities in possible interpretation. Each new addition to the scenarios was clearly highlighted on the scenario descriptions issued to participants.

2. The scope and number of parameters to be considered in the scenarios were more limited than the V1.07 scenario. There was tighter specification of the features, processes and pathways and their associated parameter values.

3. All but one of the participants had attended meetings at which the V2 scenarios were discussed and modified, and results presented. Therefore, there was relatively common understanding of the scenarios. Notes of each meeting were distributed to all participants (including those who could not attend) so that they could keep abreast of developments.

4. All but one of the participant organisations had submitted results for the V1 scenarios and so had gained valuable experience from the V1 scenarios which could be directly applied to the V2 scenarios.

5. Although some models were further developed for the V2 scenarios (Appendix C), all but two of them had been used in some form for the V1.07 scenario. Thus the models could be considered to be relatively "tried and tested" and appropriate for the problem to be addressed.

6. All participants have a growing familiarity with their models and the way in which the models are used to represent the key processes. This familiarity resulted either from previous modelling experience, or from direct involvement in the model's development as well as from participation in the BIOMOVS II exercise.

Where discrepancies do exist between participants' results, these can generally, although not exclusively, be explained by differences in the approach used to modelling certain processes and differences in the parameterisation of the processes, rather than differences in scenario interpretation (eg the modelling of resuspension of soil particles).

Comparison of AECB and Beak results is useful since they have independently applied the same model (IMPACT) to the scenarios. Thus any discrepancies between the results reflect differences in the application of the model to the scenarios, resulting from differences in interpretation of the scenarios. Differences in interpretation of the scenarios might result in differences in data values used and processes modelled. In general, there is good agreement between AECB and Beak results. Where discrepancies do occur they are relatively minor (less than a factor of four) and can be explained by differences in the choice of parameter values for certain processes (eg the erosion rate for soil or irrigation rate for leafy vegetables) or the set up of the model (eg the discretisation of the groundwater path lengths). A wider range of user interpretation issues arising where more than one user applies a single model to a given situation has been addressed in another BIOMOVS II Working Group [BIOMOVS II, 1996a].

Since the scenarios are considered to be realistic, it is possible to draw some general conclusions from the results presented in Section 4. Before doing so it is **important to note the following two caveats.**

- Long term assumptions for the biosphere used in the assessment of waste disposal facilities are difficult to justify for many reasons (see discussion in BIOMOVS II [1994]). As such, the **modelling results** for the V2.2 and V2.3 calculational end-points, **presented in this report, should be interpreted only as indicators of the radiological and other environmental impacts and trends, and not as absolute values.**

- The results presented are specific to the scenario assessed. **Any attempt to apply the conclusions in a wider context must be undertaken with extreme caution since any shallow burial facility, whether treated realistically** or **otherwise, is likely to present site specific issues which**

significantly affect the assessment of impacts[3]. Site and scenario specific issues include not only physical features of the system, but also the assessment requirements. For example, although many regulatory regimes require the assessment of individual doses (or risks), the definition of the critical groups varies and the summation of doses over exposure pathways also varies. No single formulation is necessarily correct (see discussion in BIOMOVS II [1994] and in the recent US National Academy of Sciences report on waste disposal criteria [NAS, 1995]).

Key scenario specific conclusions from the analysis of the results are listed below. **It is important to note that these conclusions might not be applicable to alternative scenarios.**

1. The dose/intake from the atmospheric release is almost three orders of magnitude higher than the dose/intake from the groundwater release for the U-238 chain and As, and about an order of magnitude higher for Pb. However, for Ni it is the groundwater release which is dominant by about a factor of 50.

2. For the atmospheric release, the dominant pathway is ingestion of leafy vegetables for all contaminants except As, for which it is ingestion of beef. The dominant radionuclide is Pb-210.

3. For the groundwater release, the dominant pathways are ingestion of leafy vegetables and water for all contaminants except As, for which ingestion of beef is also important. The dominant radionuclides are U-238 and U-234.

4. Although, it is often possible to identify a "dominant" pathway or contaminant, it is rare that any single pathway or contaminant dominates the total dose/intake by more than a factor of five. Thus other pathways/contaminants are always within an order of magnitude of the dominant pathway/contaminant.

5. The probabilistic calculations are consistent with the deterministic results and show a variability in total dose/intake of an order of magnitude or less. They have also been successful in identifying the key sensitive parameters which effect dose/intake for the scenarios.

In so far as the V2 scenarios represent generic sites, the above scenario specific results and conclusions also support the following **generic conclusions** drawn from the V1.07 scenario [BIOMOVS II, 1995].

1. A range of pathways and contaminants affect the total dose/intake and so no one single pathway or contaminant is dominant for all scenarios. This conclusion is consistent with results from an earlier, more generic, BIOMOVS multiple pathway study [BIOMOVS, 1990].

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[3] Note for example the conclusion of a Nuclear Energy Agency study on reference levels for acceptance of long-lived radionuclides in shallow burial facilities [NEA, 1986]. 'The establishment of reference levels in terms of total activity limits (which in turn relate to radiological impacts) for a facility is usually dependent on ... scenarios which are highly site specific'.

2. Peak impacts on individuals from uranium mill tailings piles may not arise for many hundreds of years. Since during this period many possible site and environmental changes might occur, not least because of human actions, a Reference Biosphere approach may be appropriate in developing the scenarios to be modelled for a real site [BIOMOVS II, 1994].

3. Models are available for assessing potential radiological and non-radiological health risks to individuals from releases from tailings piles. However, comparison of health risks arising from radioactive and stable elements is limited in its extent because data for cancer risk per unit intake for the stable elements is not as comprehensive as that for radionuclides.

6. Recommendations

The following general recommendations can be made as a result of the experience gained during the V2 exercise.

1. It is important to ensure that modelling of a scenario is not undertaken in a vacuum (ie one model being used by one person). This can introduce considerable bias and prevents cross verification of the model and its results against other models and their results. The independent use of two or more models on a scenario will help to reduce these problems.

2. Modelling a scenario is not a once through process, it should be iterative. This allows checks to be performed and key features, processes and pathways to be identified and investigated in more detail.

3. It is vital that quality checks are undertaken at all stages of the scenario modelling exercise, not just at the data entry stage.

4. It is often useful to develop a scenario for model intercomparison purposes in a piecewise fashion with full involvement of participants. It facilitates comparison of participants' results and interpretation of discrepancies. It also provides participants with the opportunity to develop their understanding of the scenario and for the scenario to be modified to remove ambiguities and inconsistencies.

5. Participants in the intercomparison exercise should include those providing system characterisation data as well as those developing models and making calculations.

6. Further effort should be spent on collating data to facilitate the comparison of health risks from radionuclides and stable contaminants.

Two specific recommendations can be made relating to the continuation of the work of the Group. Firstly, the V2 scenarios should be extended further to include consideration of surface water pathways. Secondly, more detailed analysis (eg BIOMOVS [1996b]) should be undertaken of participants' representation of features, processes and pathways. Such detailed analysis will help to explain further the discrepancies seen between participants' results which, in the case of the V2 scenarios, are relatively minor.

7. Acknowledgements

This Technical Report has been produced by the Uranium Mill Tailings Working Group of BIOMOVS II chaired by Henri Camus (Commissariat à l'Energie Atomique (CEA), France). The main contributors to the report and the associated work of the Group are listed in Appendix D.

The Working Group members and the BIOMOVS II Steering Committee are grateful for the support and assistance of organisations which have hosted Working Group meetings, namely: Atomic Energy Control Board of Canada; Centro de Investigaciones Energéticas Medioambientales y Tecnológicas, Spain; COGEMA Group; Empresa Nacional de Residuos Radiactivos, Spain; International Atomic Energy Agency; and US Department of Energy's Pacific Northwest National Laboratories.

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Table 1: Atmospheric Release Features/Processes Modelled by Participants

Feature/Processes	AECB	Argonne	Beak	IPSN	JAERI	PNNL	SENES	SONS
Point Source Term	Y	Y	Y	Y	Y	Y	Y	N
Gaussian Plume	Y	Y	Y	Y	Y	Y	Y	Y
Dry Deposition	Y	Y	Y	Y	Y	Y	Y	Y
Wet Deposition	N	N	N	N	N	N	N	Y
Plume Depletion	Y	N	Y	Y	N	Y	Y	Y
Decay/Ingrowth in Plume	Y	N	Y	N	N	N	N	Y
Radon Release Modelled	Y	Y	Y	Y	Y	N	Y	N
σ_z at 1000m	34.5m	32m	34.5m	38m	30m	37.9m	32.1m	32m

Notes:
Y = Yes
N = No

Table 2: Groundwater Release Features/Processes Modelled by Participants

Feature/Processes	AECB	Argonne	Beak	IPSN	JAERI	PNNL	SENES	SONS
Solution Method	Nu	An	Nu	An/Nu (1)	Nu	An/Nu (1)	Nu/An (2)	Nu
1D Advective Flow	Y	Y	Y	Y	Y	Y	Y	Y
Longitudinal Dispersion	Y	Y	Y	Y	Y	Y	Y	Y
Lateral Dispersion	N	N	N	N	N	N	N	N
Molecular Diffusion	Y	N	Y	N	N	Y	N	N
Decay	Y	Y	Y	Y	Y	Y	Y	Y
Ingrowth	Y	Y	Y	Y	Y	Y	Y	Y
Retardation	e	e&t	e	e	e	e	e	e

Notes:
Y = Yes
N = No
An = analytic
Nu = numerical
e = effective porosity used to calculate retardation
t = total porosity used to calculate retardation
(1) = analytic method used with a numerical method to evaluate convolution integrals overtime.
(2) = numerical method used for U-238 chain; analytic method used for stable elements.

Table 3: Biosphere Processes Modelled by Participants

Feature/Processes	AECB	Argonne	Beak	IPSN	JAERI	PNNL	SENES	SONS
PLANT:								
Foliar interception (dust)	Y	Y	Y	Y	Y	Y	Y	Y
Foliar interception (G) (water)	Y	Y	Y	Y	Y	Y	Y	Y
Weathering	Y	Y	Y	Y	Y	Y	Y	Y
Root Uptake	Y	Y	Y	Y	Y	Y	Y	Y
SOIL:								
Resuspension	Y	Y	Y	N(1)	Y	Y	Y	Y
Erosion	Y	Y	Y	Y	Y	N	Y	Y
Leaching	Y	Y	Y	Y	Y	Y	Y	Y
Decay	Y	Y	Y	Y	Y	Y	Y	Y
Ingrowth	Y	Y	Y	Y	Y	Y	Y	N
COW:								
Fodder Ingest (A)	Y	Y	Y	Y	Y	Y	Y	Y
Water Ingest (G)	Y	Y	Y	Y	Y	Y	Y	Y
Soil Ingest (A)	Y	Y	Y	Y	Y	Y	Y	Y
Dust Inhal (A)	Y	N	Y	N	Y	N	Y	N
Radon Inhal (A)	Y	N	Y	N	N	N	N	N

Notes:
Y = Yes
N = No
All processes are assumed to be modelled for both releases unless otherwise stated (A: Atmospheric release only; G: Groundwater release only).
(1) = Not explicitly modelled.

Table 4: Exposure Pathways Modelled by Participants

Pathway	**AECB**	**Argonne**	**Beak**	**IPSN**	**JAERI**	**PNNL**	**SENES**	**SONS**
Beef Ingestion	Y	Y	Y	Y	Y	Y	Y	Y
Leafy Vegetable Ingestion	Y	Y	Y	Y	Y	Y	Y	Y
Water Ingestion (G)	Y	Y	Y	Y	Y	Y	Y	Y
Dust Inhalation	Y	Y	Y	Y	Y	Y (A)	Y	Y
Radon Inhalation (A)	Y	Y	Y	Y	Y	Y	Y	Y
Soil External Irradiation	Y	Y	Y	Y	Y	Y	Y	Y

Notes:
Y = Yes
N = No
All processes are assumed to be modelled for both releases unless otherwise stated (A: Atmospheric release only; G: Groundwater release only).

Table 5: Probabilistic Calculations Undertaken by Participants

	AECB	Argonne	Beak	IPSN	JAERI	PNNL	SENES	SONS
Sampling Technique	MC	LHS	MC	LHS	LHS	N/A	MC	MC
NUMBER OF RUNS:								
V2.2 atmosphere	100	100	500	340	5000	N/A	100	N/A
V2.3 atmosphere	100	100	500	N/A	5000	N/A	100	N/A
V2.2 groundwater	100	100	300	340	5000	N/A	100	100
V2.3 groundwater	100	100	300	440	5000	N/A	100	N/A
Convergence Checks	N	N	N	N	Y	N/A	N	N
Sampling Range	MM	3.1SD	MM	MM	MM	N/A	MM	MM

Notes:
Y = Yes
N = No
MC = Monte Carlo
LH = Latin Hypercube
MM = Maximum/Minimum parameter values specified in scenario used as cut-off points for sampled distribution.
nSD = nStandard Deviations about mean used as cut-off points for sampled distribution.
N/A = Not applicable

Table 6: Results Files Received - V2.2 Deterministic Case

		JAERI		SENES		IPSN		SONS		AECB		Argonne		Beak		PNNL	
Release:		D		D		D		D		D		D		D		D	
Zone:		A	G	A	G	A	G	A	G	A	G	A	G	A	G	A	G
A	C	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨		▨	▨		
	D	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨		
S	C	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		
	D	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨		
V	C	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		
	D	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨		
B	C	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		
	D	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨		
W	C	N/A	▨	N/A	▨	N/A	▨	N/A	▨	N/A	▨	N/A	▨	N/A	▨	N/A	▨
	D	N/A	▨	N/A	▨	N/A	▨	N/A	▨	N/A	▨	N/A	▨	N/A	▨	N/A	▨
T	D	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		
	R	▨	▨	▨	▨					▨	▨	▨	▨	▨	▨		

Key:

1st character - nature of case
D deterministic

2nd character - source term
A atmosphere
G groundwater

3rd character - medium
A atmosphere
S soil
V leafy vegetable
B beef
W well water
T sum over pathways

4th character
C concentration
D dose
R risk

Table 7: Results Files Received - V2.2 Probabilistic Case

		JAERI		SENES		IPSN		SONS		AECB		Argonne		Beak	
Release:		P		P		P		P		P		P		P	
Zone:		A	G	A	G	A	G	A	G	A	G	A	G	A	G
A	D	C	C	C		C	C			C	C	C	C	C	C
S	D	C	C	C	C	C	C			C	C	C	C	C	C
V	D	C	C	C	C	C	C			C	C	C	C	C	C
B	D	C	C	C	C	C	C			C	C	C	C	C	C
T	C	C	C	C	C	C	C		Ra,Th,U8	C	C	C	C	C	C
	D	C,Pb,Po, Ra,Th,U4, U8,Rn	C,Pb,Po, Ra,Th,U4, U8	C,Pb,Po, Ra,Rn,Th, U8	C,Pb,Po, Th,U4, U8,Ra	C,Pb,Po, Ra,Rn,Th, U4,U8	C,Pb,Po, Ra,Th,U8		Ra,Th,U8	C,Pb,Po, Ra,Rn,Th, U4,U8	C,Pb,Po, Ra,Th,U4, U8	C,Pb,Po, Ra,Th,U4, U8	C,Pb,Po, Ra,Th,U4, U8	C,Pb,Po, Ra,Th,U4, U8	C,Pb,Po, Ra,Rn,Th, U4,U8
	R	C	C	C		C	C					C	C	C	C
	S	C	C	C		C	C					C	C		
	P	C	C	C		C	C					C	C		

Key:

1st character - nature of case
P probabilistic

2nd character - source term
A atmosphere
G groundwater

3rd character - pathway
A atmosphere
V leafy vegetable
B beef
S soil
T sum over pathways (total)

4th character - endpoint
C CDF
D dose vs time
R Spearman's rho
S SRC
P PCC

5/6th character - contaminant
C U-238 chain
U8 U-238
U4 U-234
Th Th-230
Ra Ra-226
Rn Rn-222
Pb Pb-210
Po Po-210

Table 8: Results Files Received - V2.3 Deterministic Case

		JAERI		SENES		IPSN		AECB		Argonne		Beak		PNNL	
Release:		D		D		D		D		D		D		D	
Zone:		A	G	A	G	A	G	A	G	A	G	A	G	A	G
A	C	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	
	I	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	
	R	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	
S	C	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
V	C	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	I	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
B	C	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	I	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
W	C	N/A	▨	N/A	▨	N/A	▨	N/A	▨	N/A	▨	N/A	▨	N/A	▨
	I	N/A	▨	N/A	▨	N/A	▨	N/A	▨	N/A	▨	N/A	▨	N/A	▨
T	I	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨

Key:

1st character - nature of case

D deterministic

2nd character - source term

A atmosphere
G groundwater

3rd character - medium

A atmosphere
S soil
V leafy vegetable
B beef
W well water
T sum over pathways

4th character - end point

C concentration
I intake
R risk

Table 9: Results Files Received - V2.3 Probabilistic Case

		JAERI		SENES		IPSN		AECB		Argonne		Beak	
Release		P		P		P		P		P		P	
Zone:		A	G	A	G	A	G	A	G	A	G	A	G
A	I	▨	▨	▨			▨	▨		▨	▨	▨	▨
V	I	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨
B	I	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨
T	C	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨
	I	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨
	R	▨	▨	▨	▨		▨			▨	▨		
	S	▨	▨	▨	▨					▨	▨		
	P	▨	▨	▨	▨		▨			▨	▨		

Key:

1st character - nature of case

P probabilistic

2nd character - source term

A atmospheric
G groundwater

3rd character - pathway

A atmosphere
V leafy vegetable
B beef
T sum over pathways (total)

4th character - end point

C CDF
I intake vs time
R Spearman's rho
S SRC
P PCC

Figure 1: The Development of the V2 Scenarios

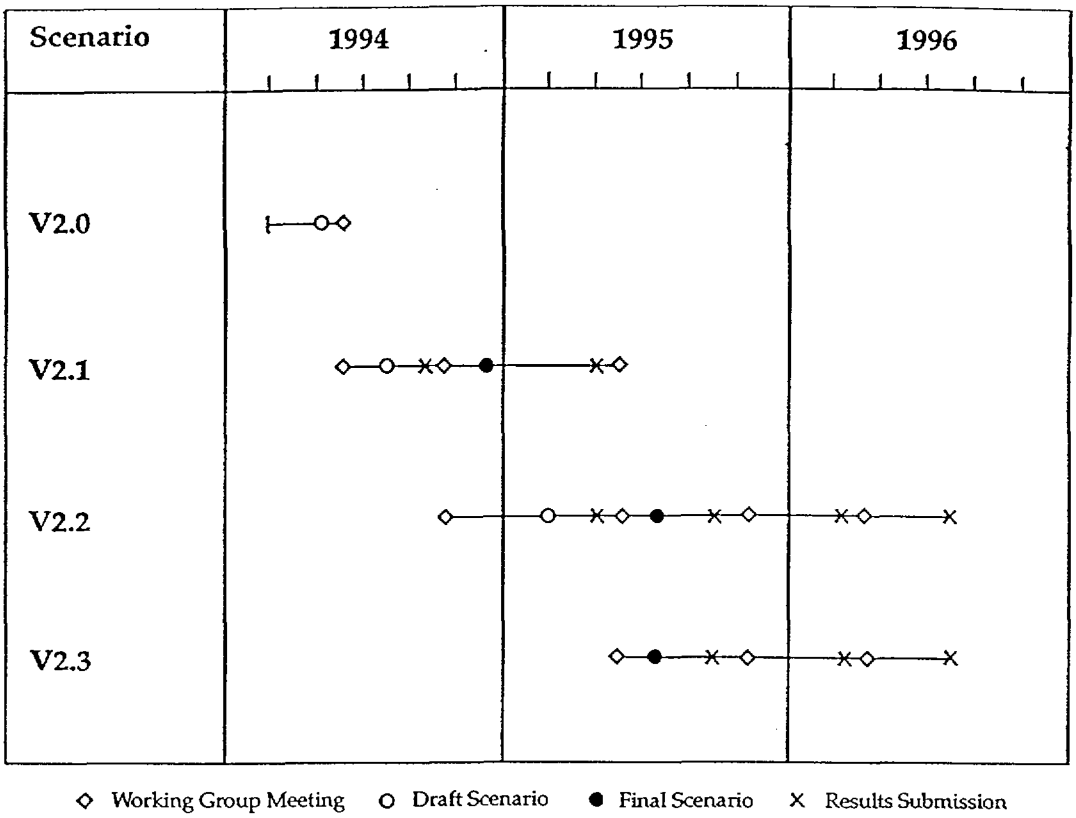


Figure 2: Plan View Representation of the V2.2 and V2.3 Scenarios

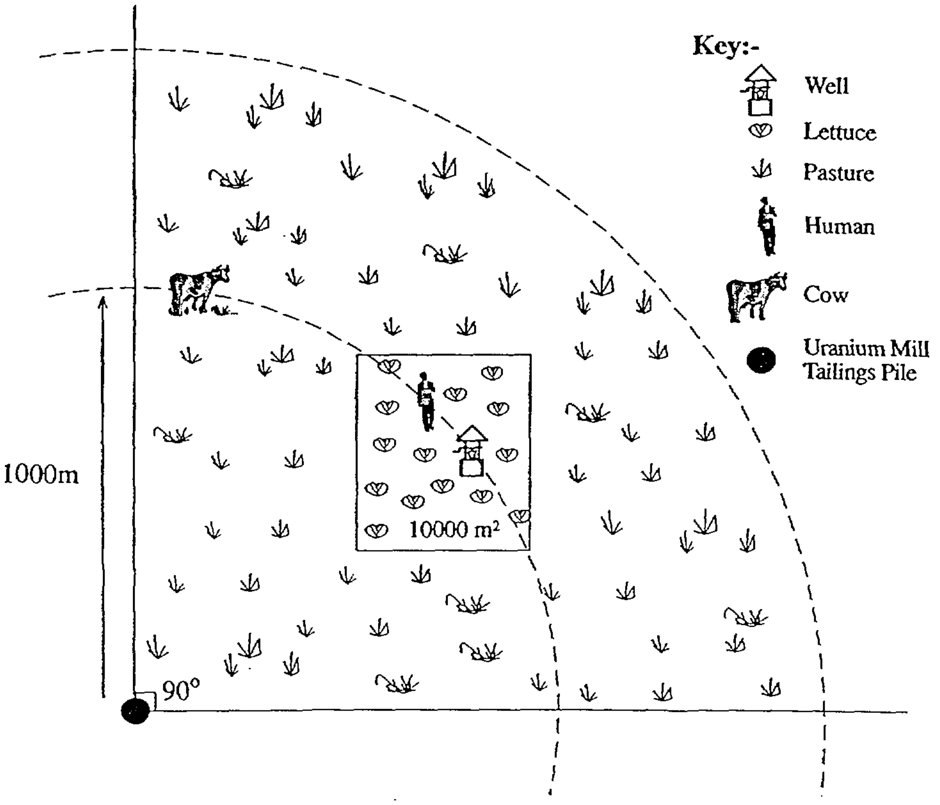


Figure 3: Cross Sectional Representation of the V2.2 and V2.3 Scenarios

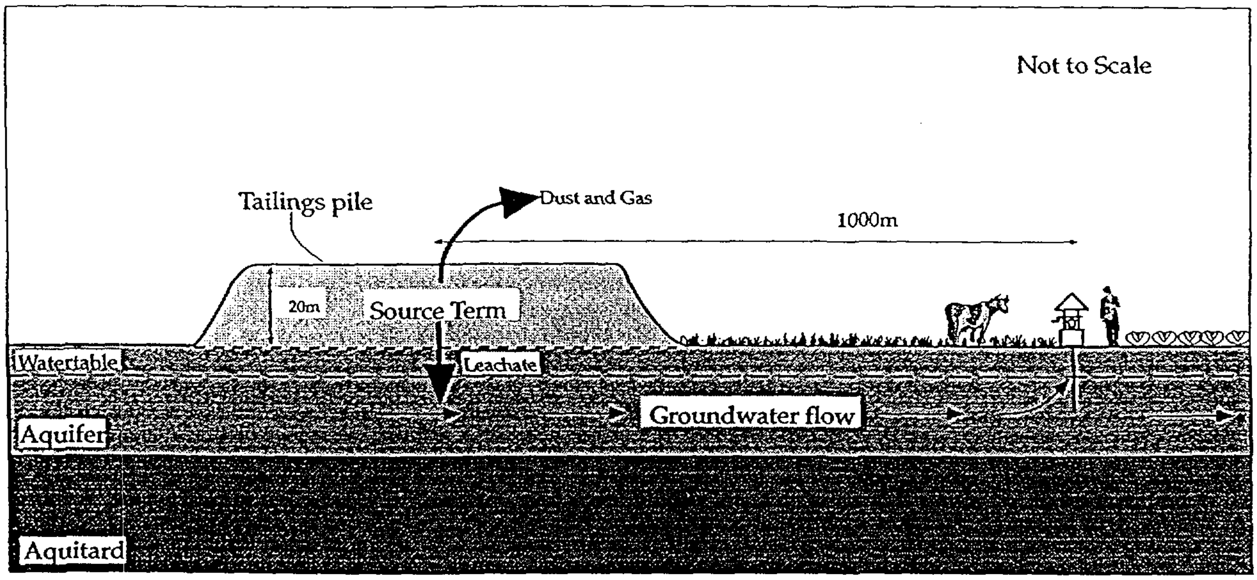


Figure 4: Deterministic U-238 Air Concentration from Atmospheric Release

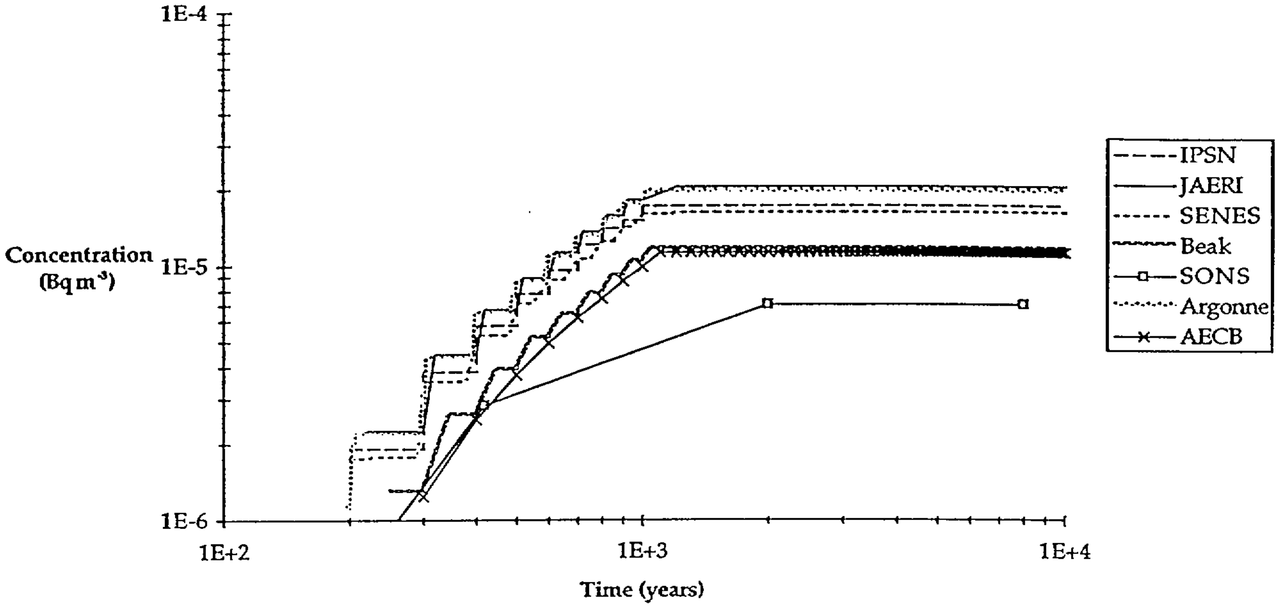


Figure 5: Deterministic Pb-210 Air Concentration from Atmospheric Release

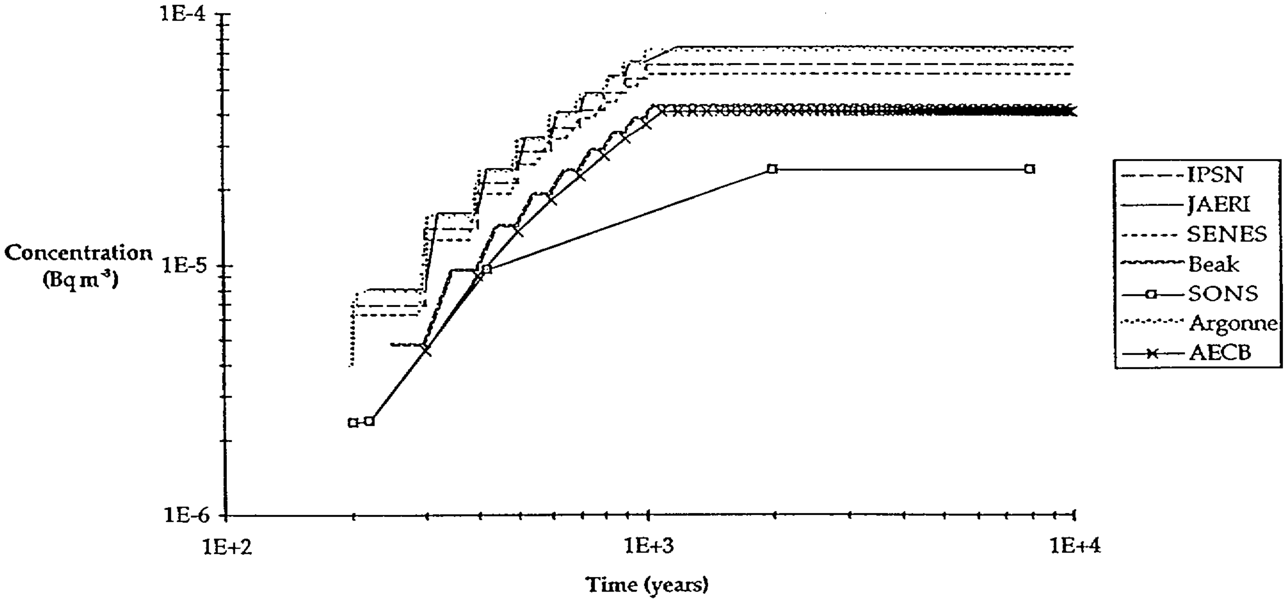


Figure 6: Deterministic Pb Air Concentration from Atmospheric Release

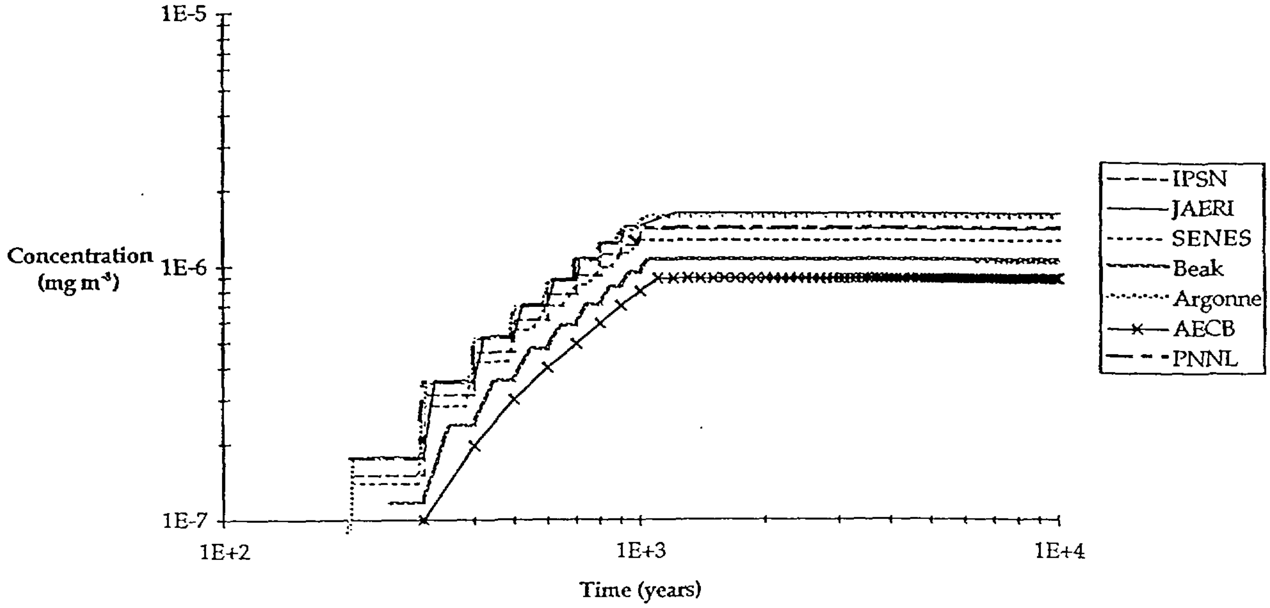


Figure 7: Deterministic U-238 Soil Concentration from Atmospheric Release

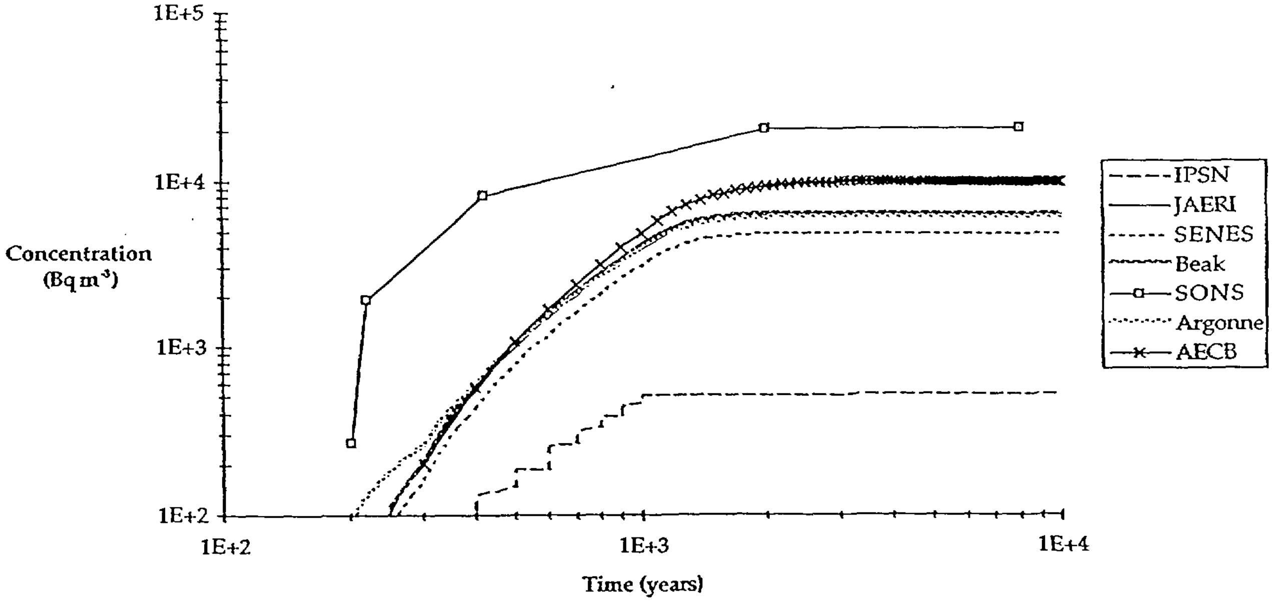


Figure 8: Deterministic Ra-226 Dose via Soil External Irradiation Pathway from Atmospheric Release

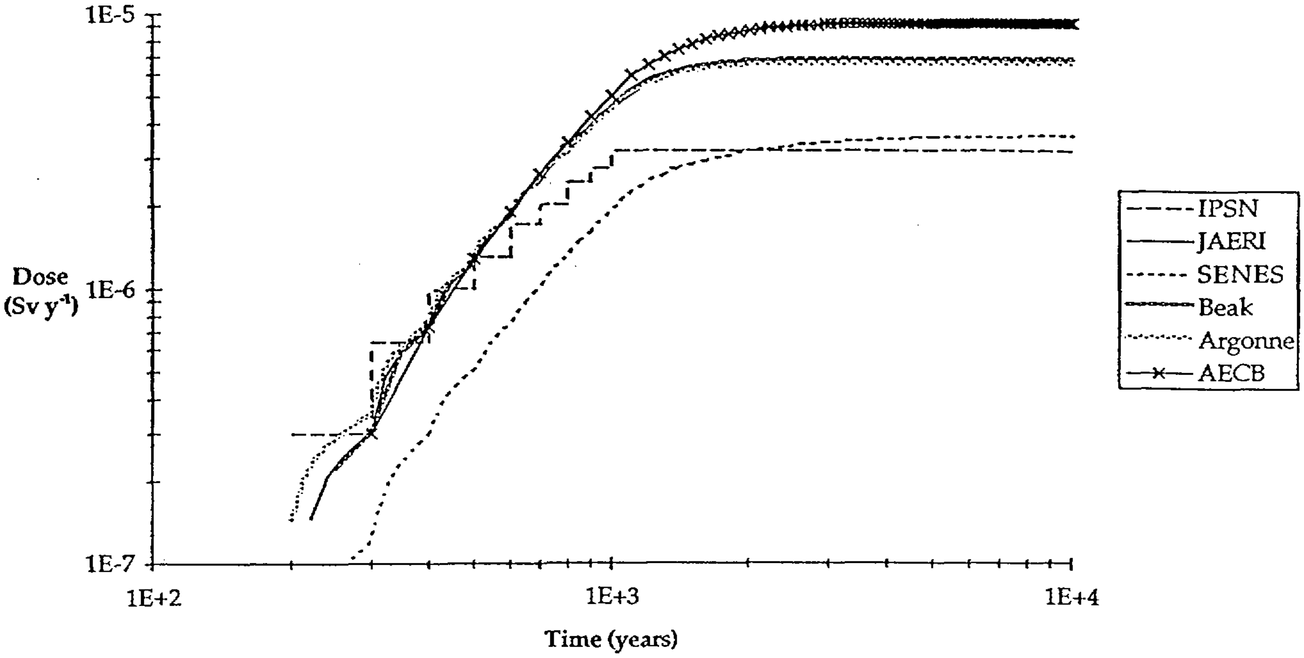


Figure 9: Deterministic Pb Beef Concentration from Atmospheric Release

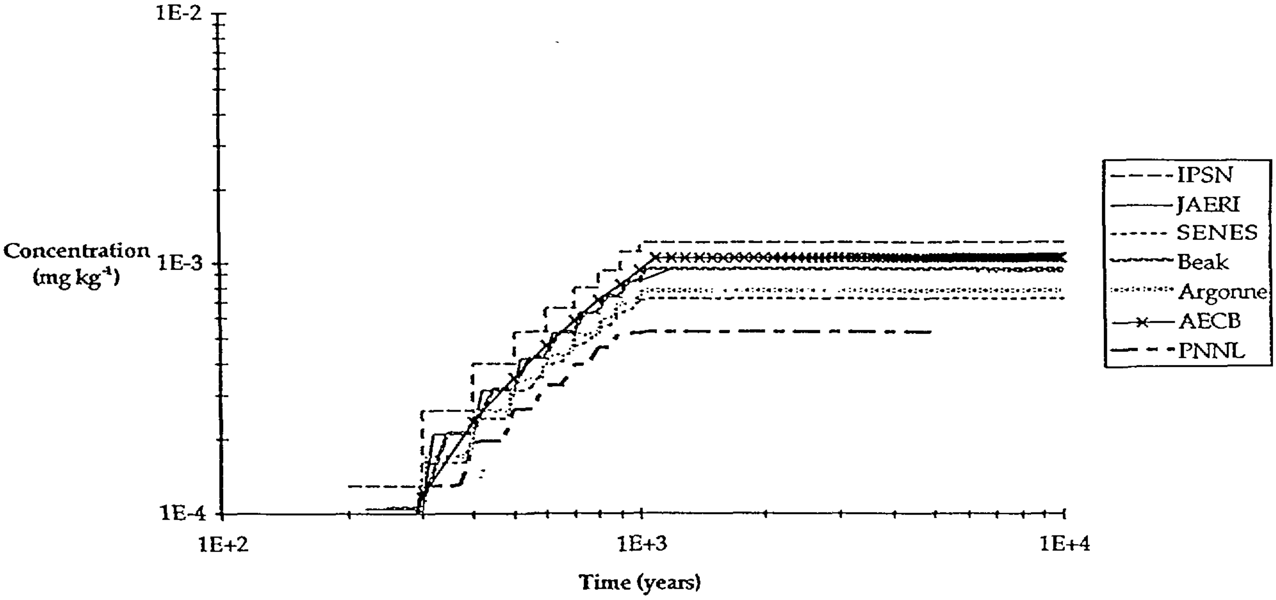


Figure 10: Deterministic Total U-238 Chain Dose from Atmospheric Release

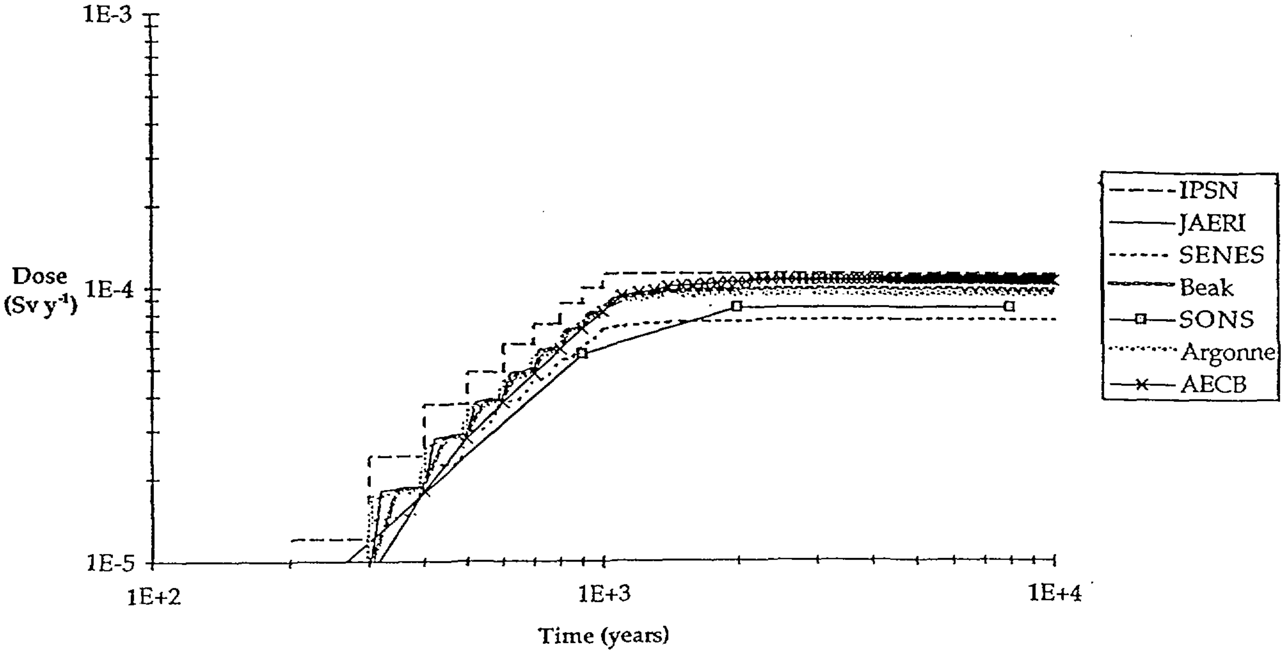


Figure 11: Pathway Contribution to Peak Deterministic Total U-238 Chain Dose from Atmospheric Release

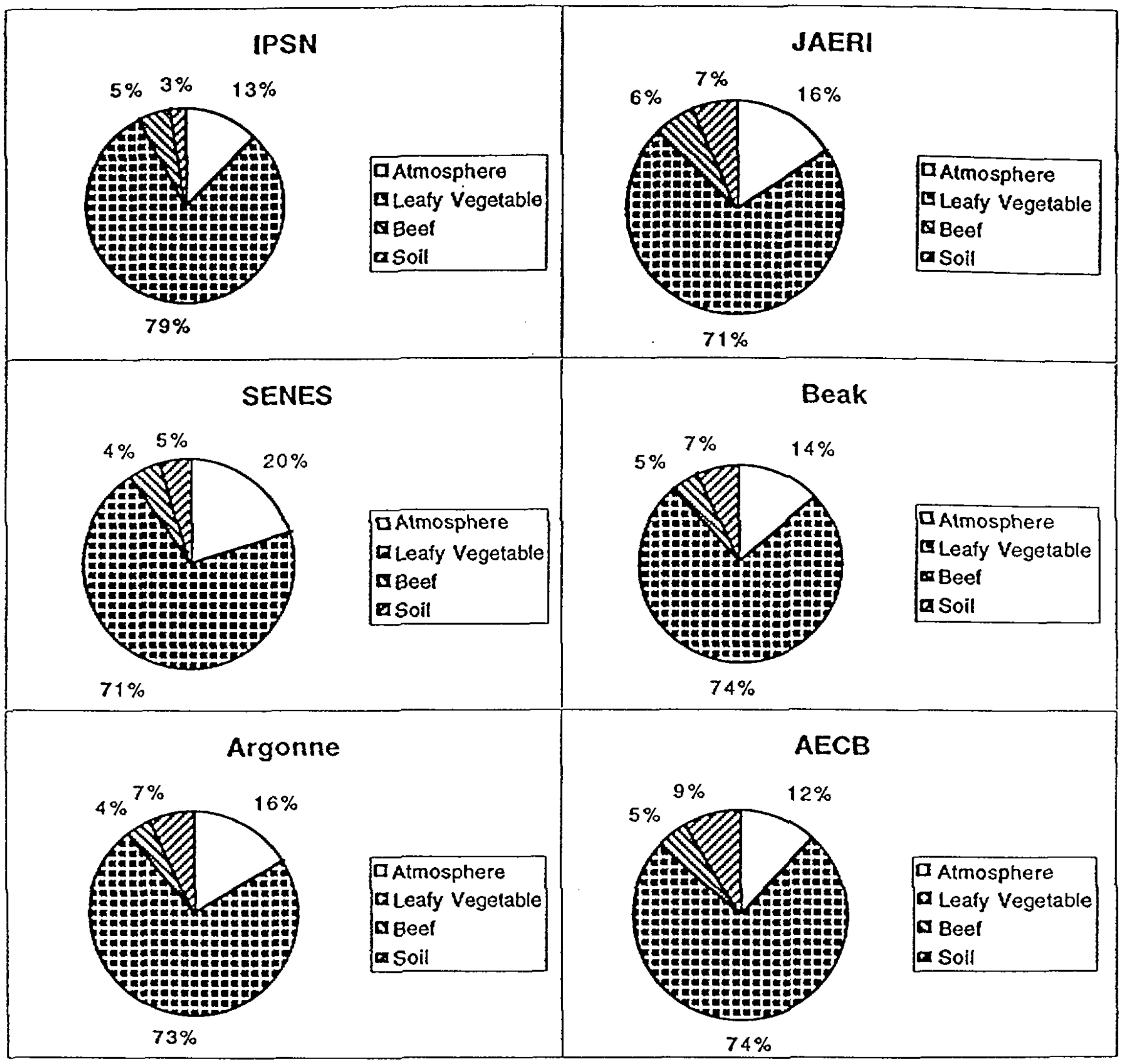


Figure 12: Radionuclide Contribution to Peak Deterministic Total U-238 Chain Dose from Atmospheric Release

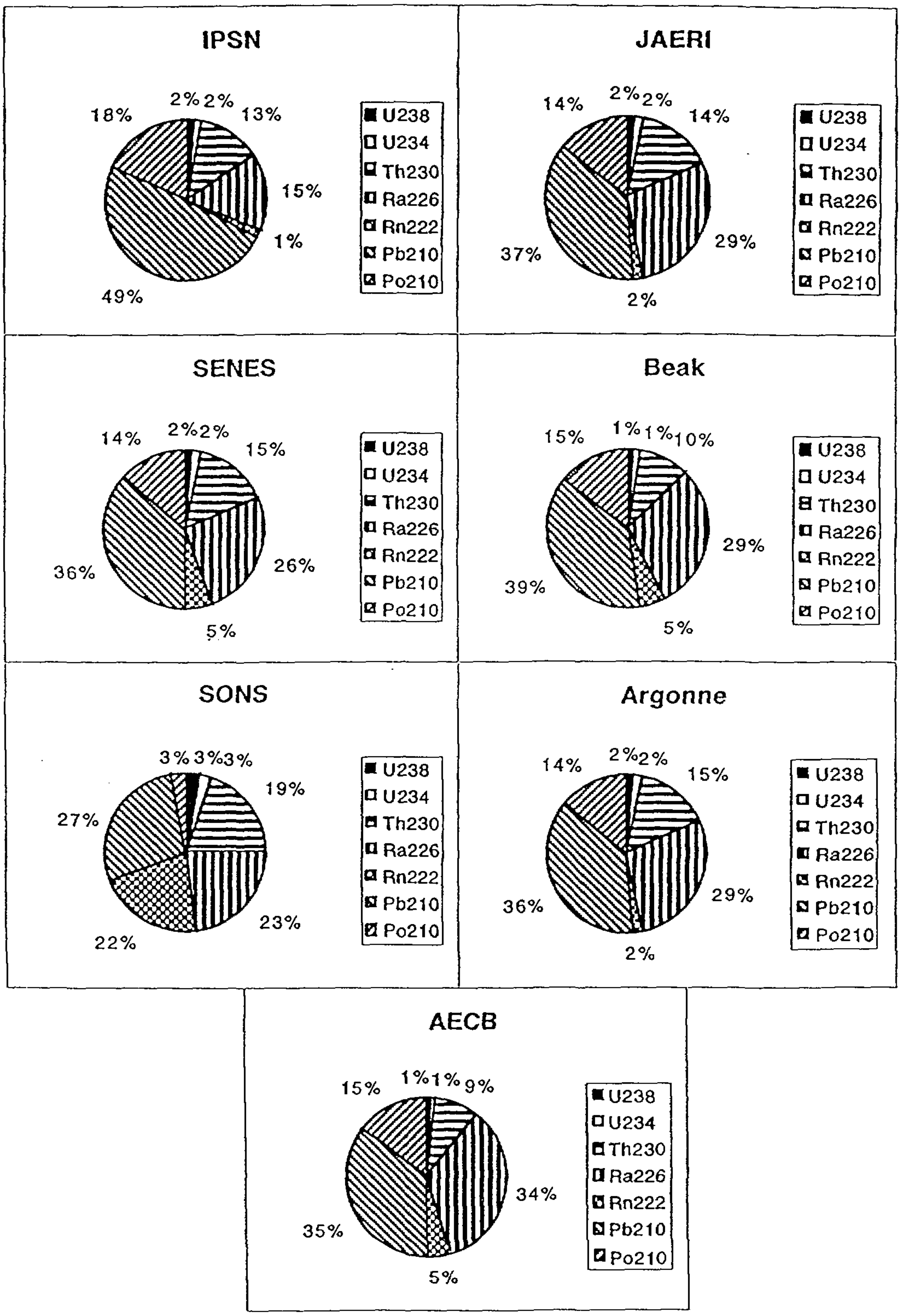


Figure 13: Deterministic Total As Intake from Atmospheric Release

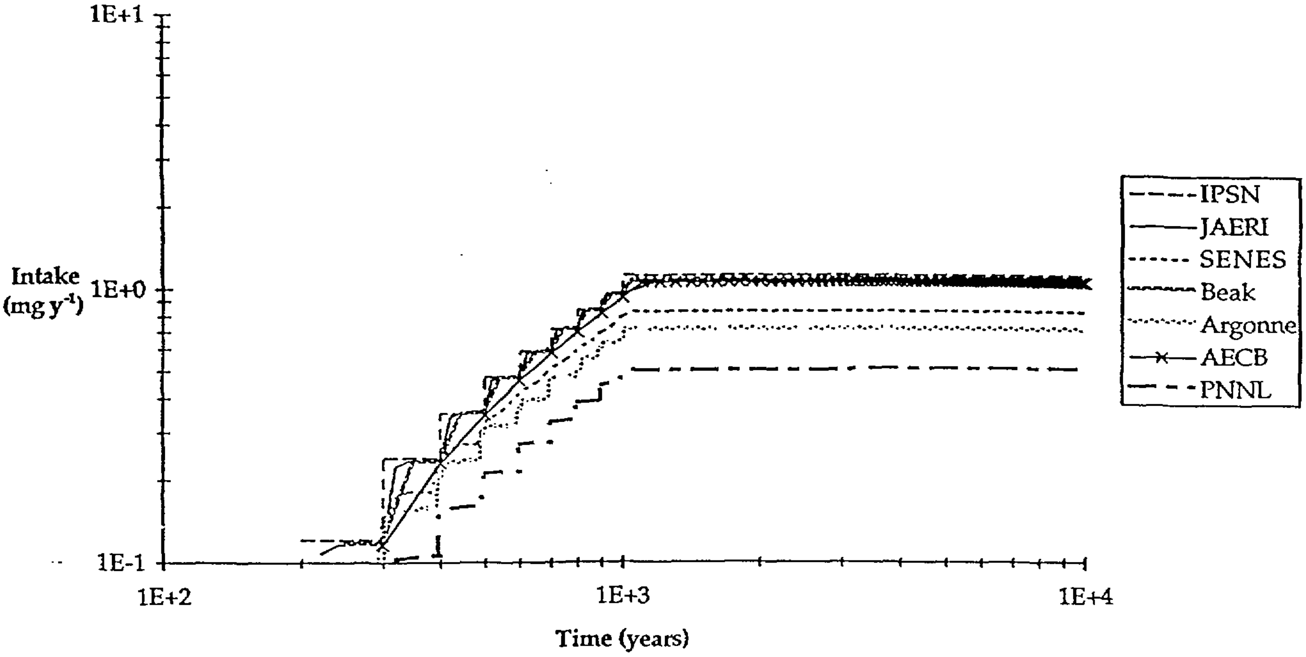


Figure 14: Pathway Contribution to Peak Deterministic Total As Intake from Atmospheric Release

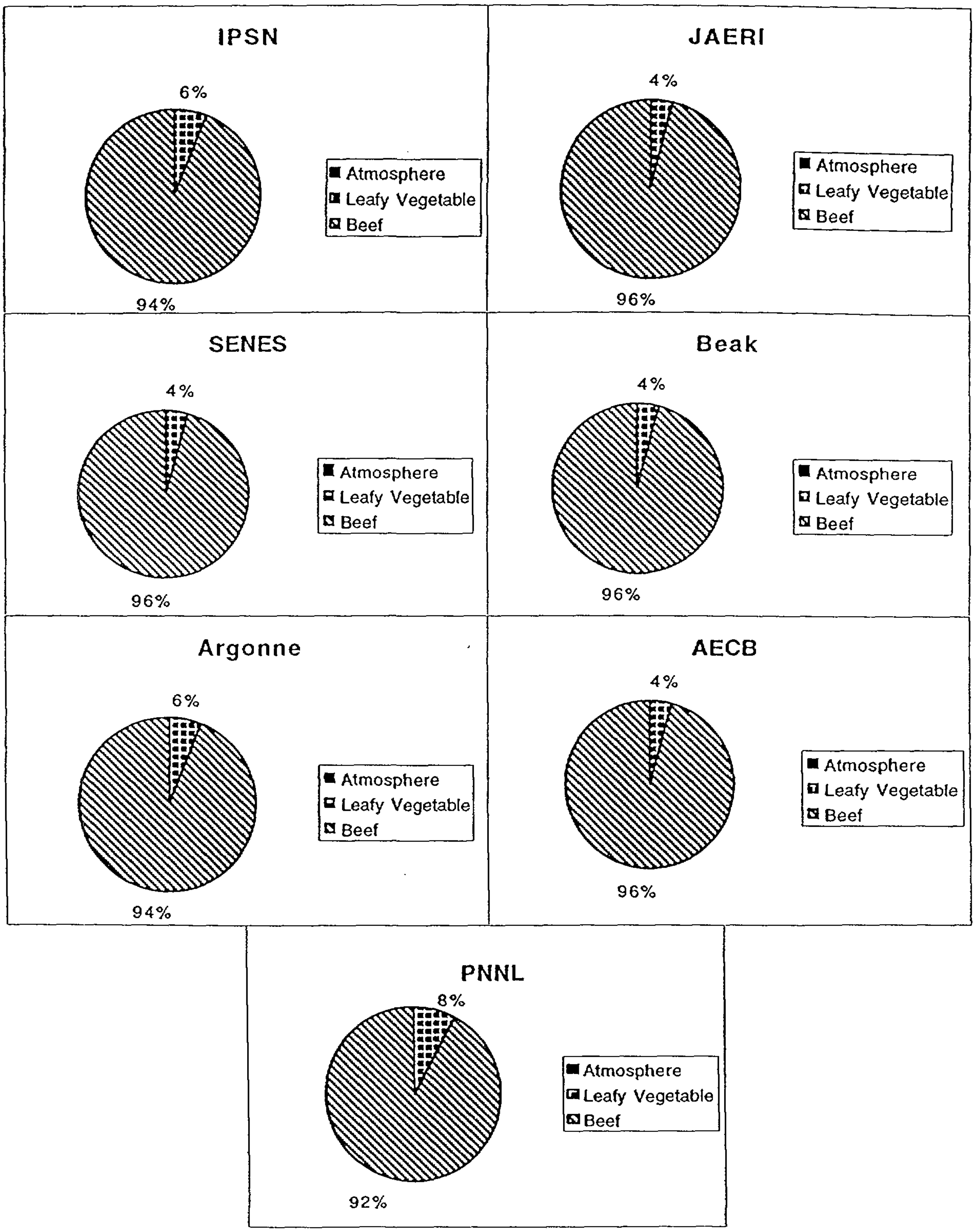
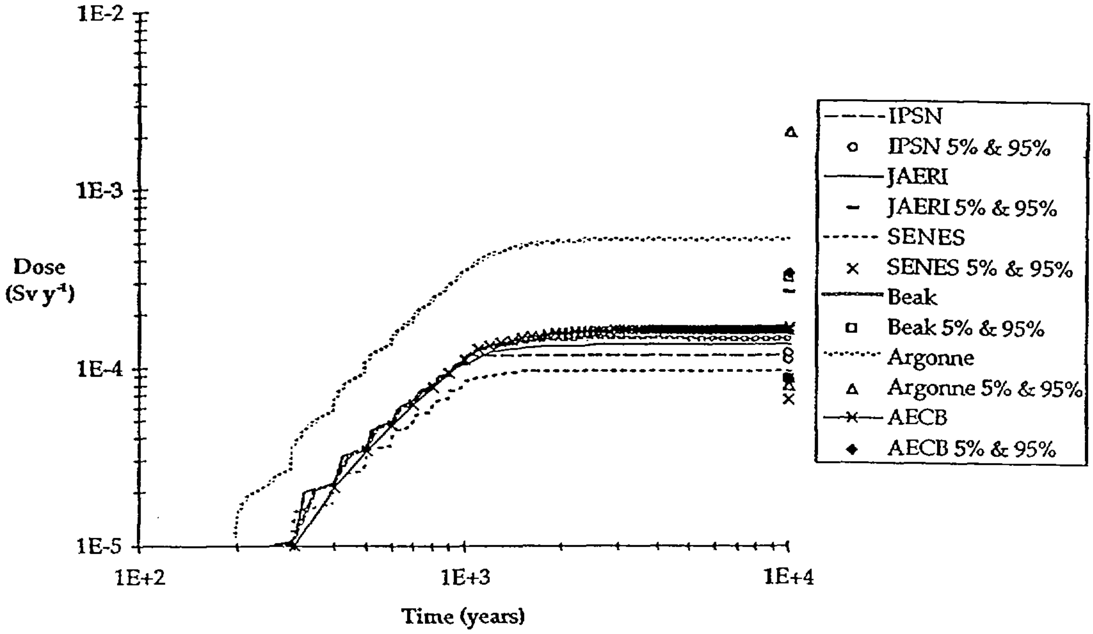


Figure 15: Probabilistic Total U-238 Dose from Atmospheric Release



Note:
Percentiles shown represent the lower and upper endpoints of the 90% confidence interval. The 5th percentile represents the value of dose below which 5% of the sampled total doses lie.

Figure 16: Cumulative Distribution Function for Total U-238 Chain Dose from Atmospheric Release

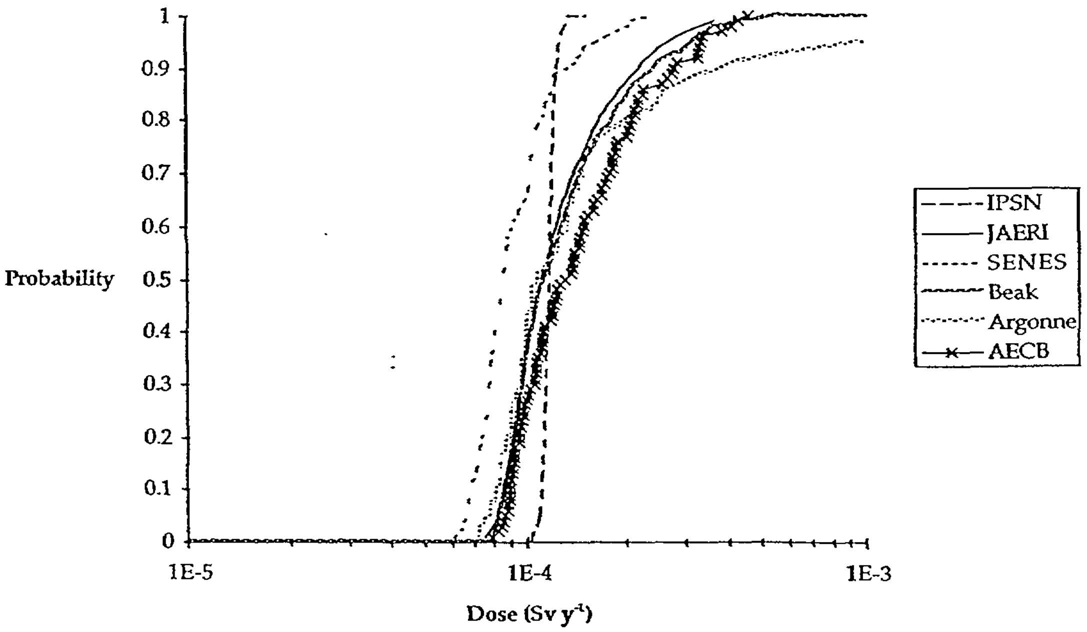
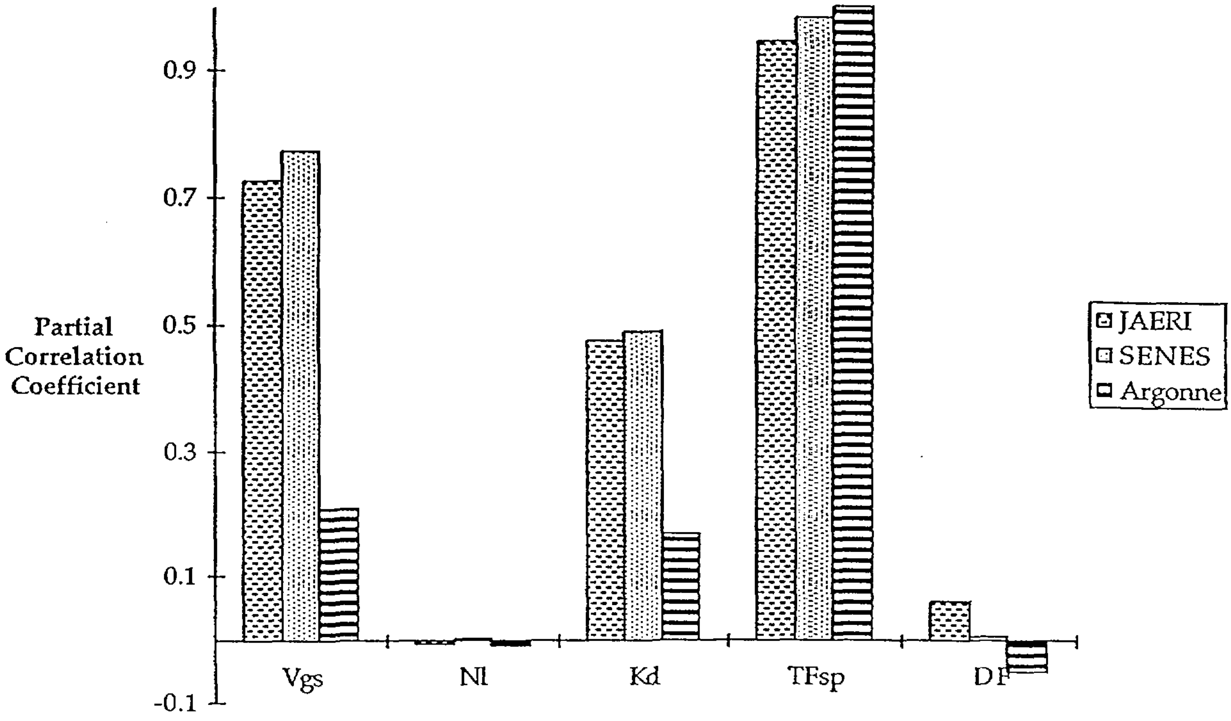


Figure 17: Partial Correlation Coefficent for Ra-226 Sampled Parameters Against Peak Total U-238 Chain Dose from Atmospheric Release



Note:
Vgs = deposition velocity of resuspended soil particles
N1 = foliar interception fraction for irrigation water
Kd = soil distribution coefficient
TFsp = soil to plant concentration factor
DF = distribution factor for beef

Figure 18: Probabilistic As Intake via Beef Ingestion Pathway from Atmospheric Release

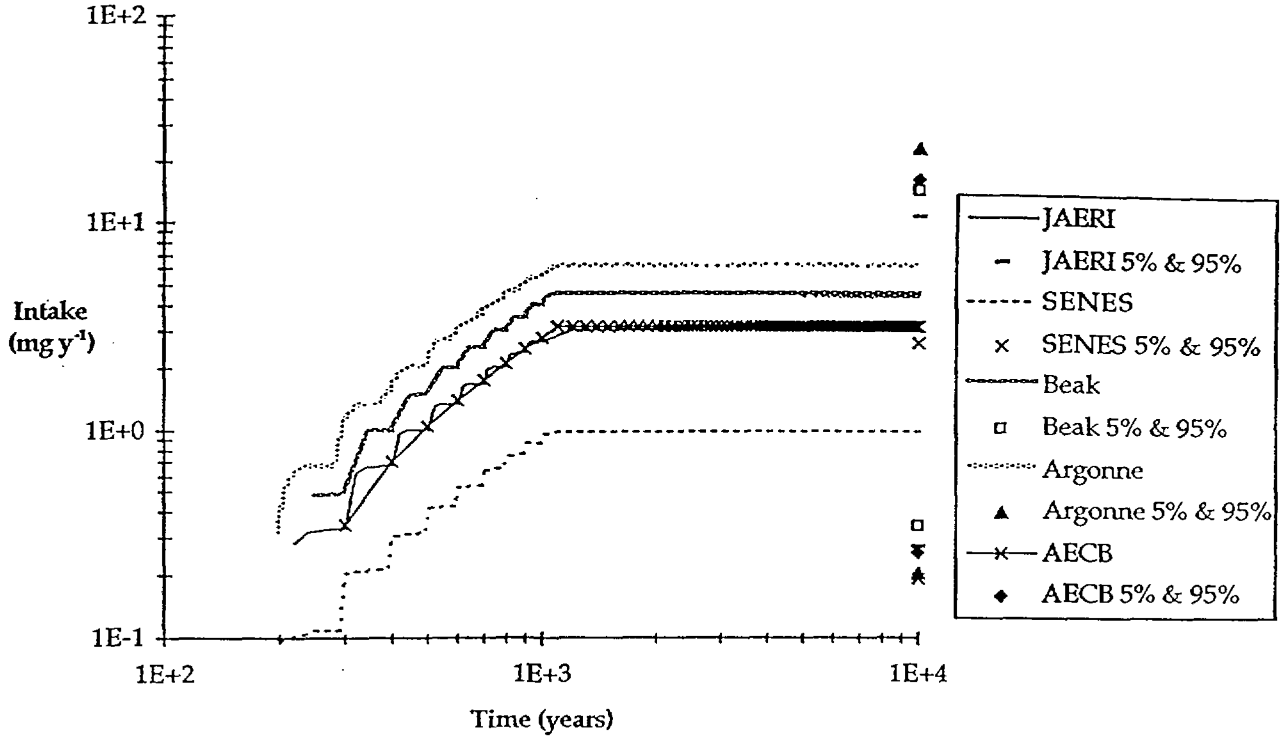


Figure 19: Probabilistic Total As Intake from Atmospheric Release

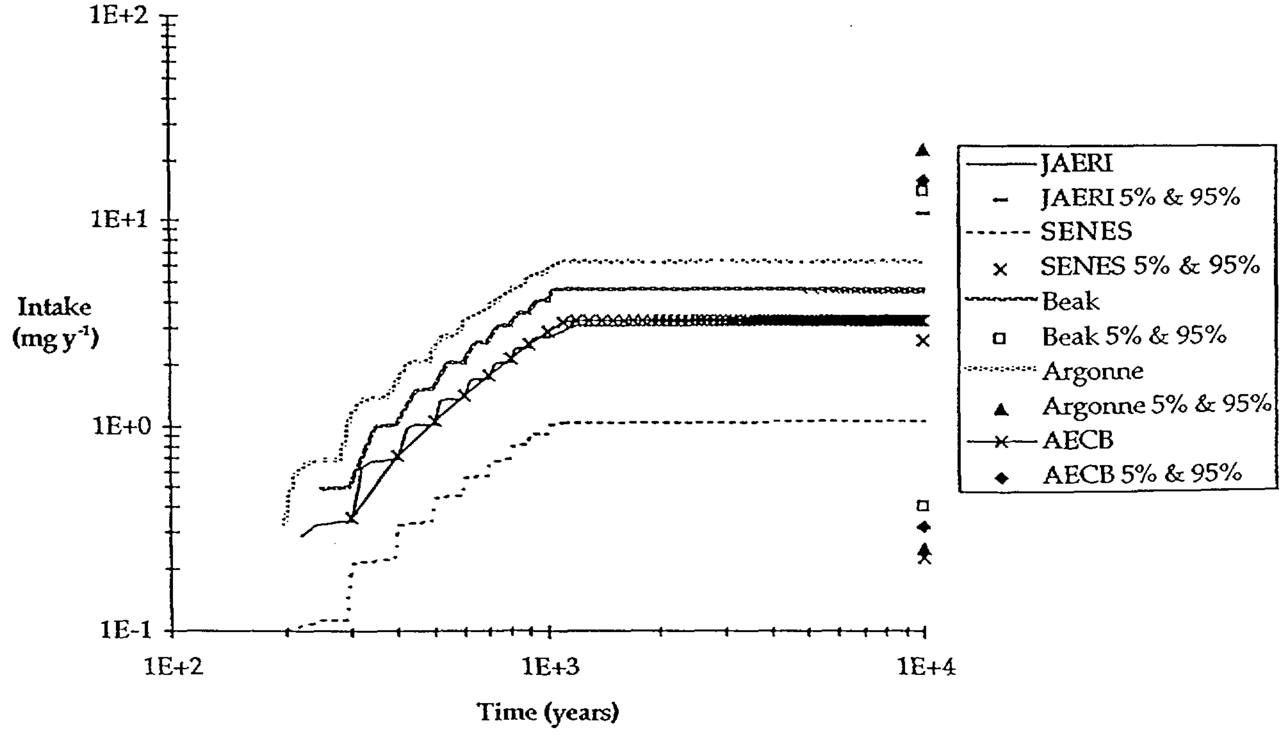


Figure 20: Pathway Contribution to Peak Probabilistic Total U-238 Chain Dose from Atmospheric Release

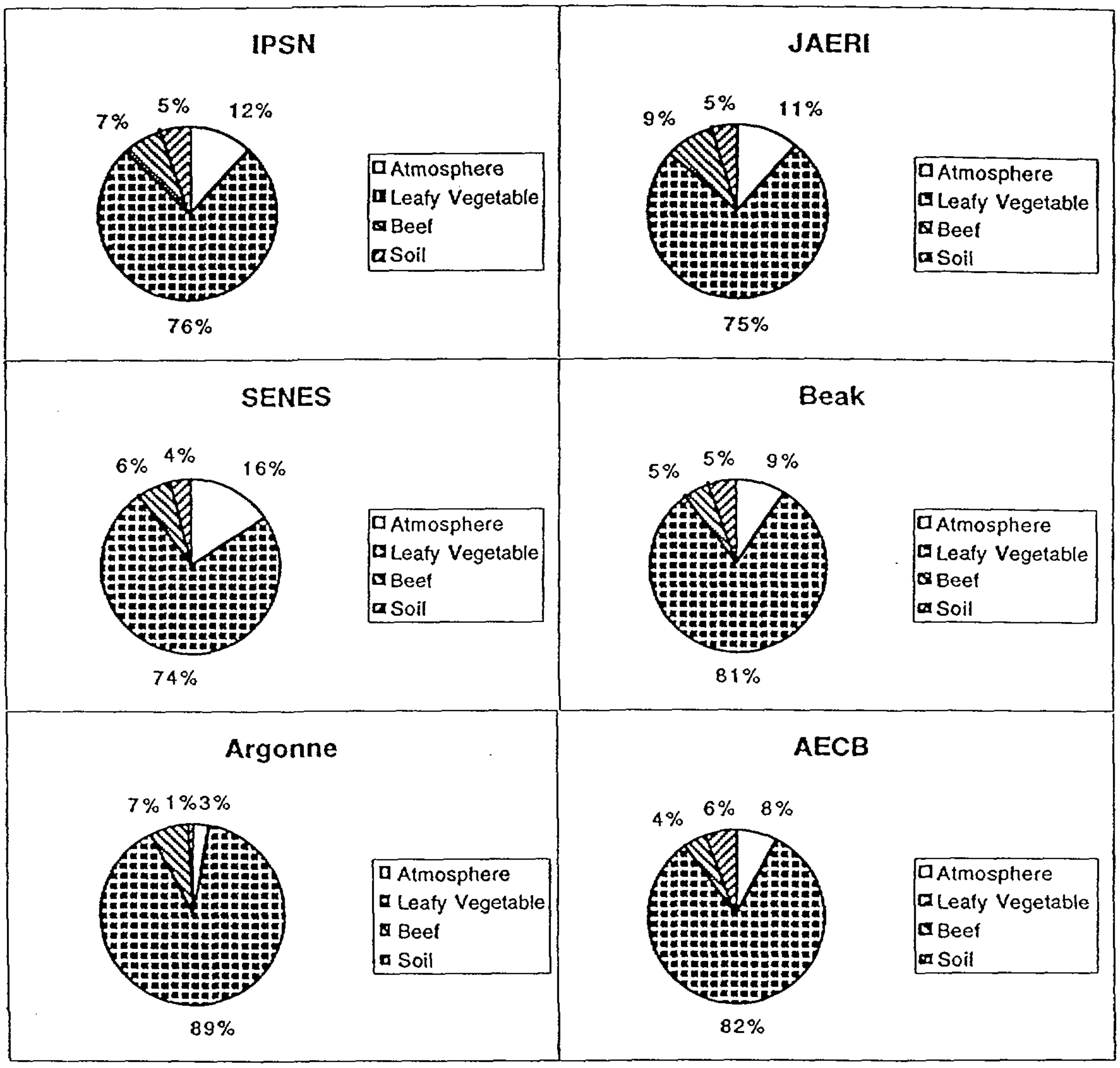


Figure 21: Radionuclide Contribution to Peak Probabilistic Total U-238 Chain Dose from Atmospheric Release

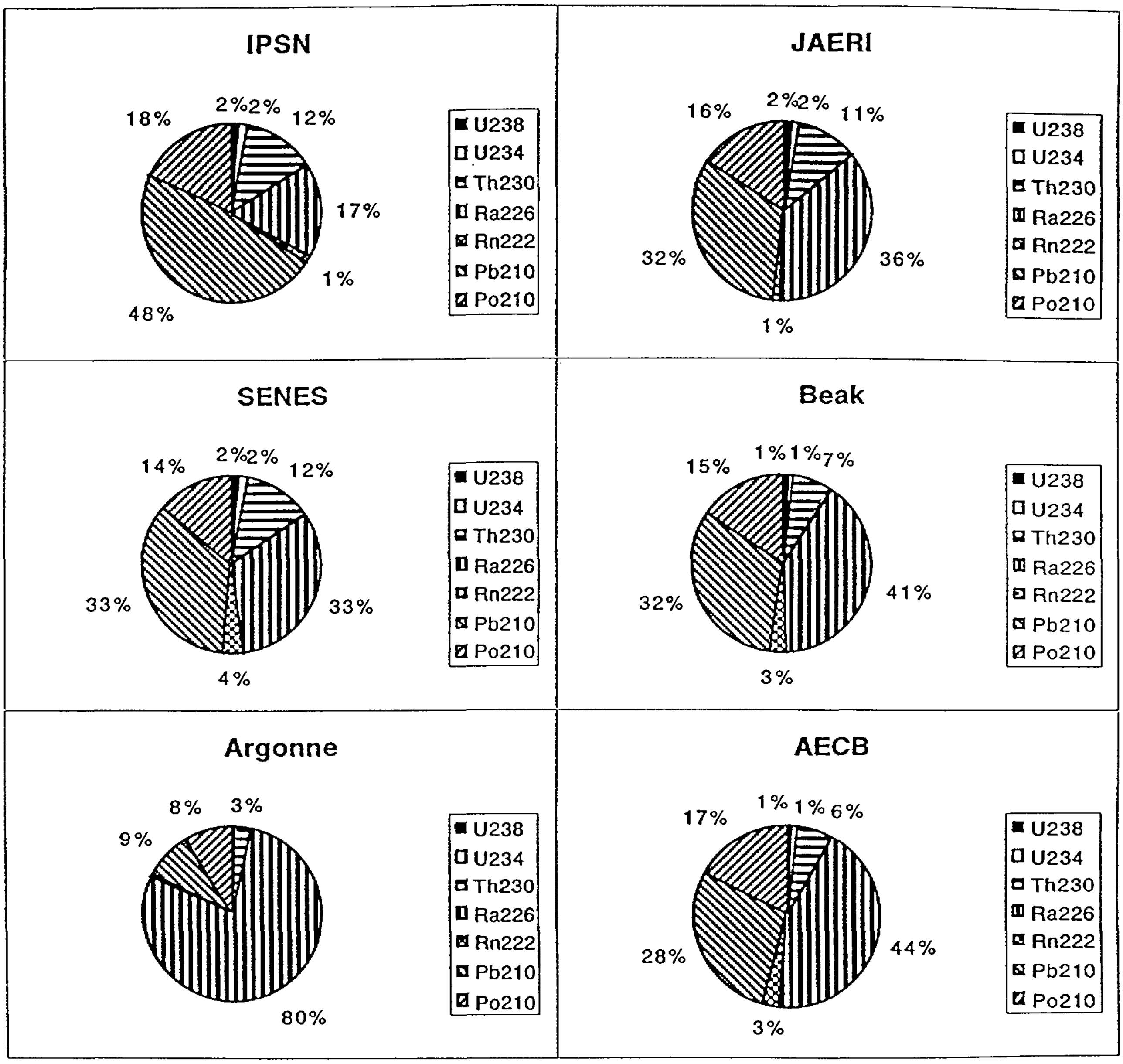


Figure 22: Deterministic Th-230 Well Water Concentration from Groundwater Release

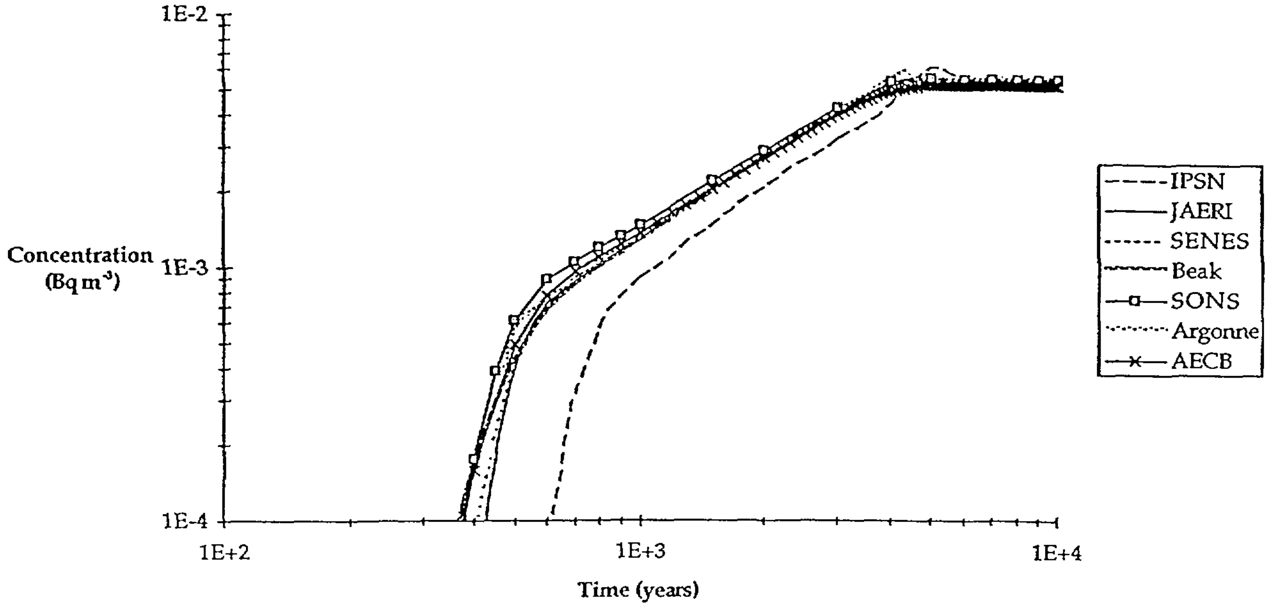


Figure 23: Deterministic As Well Water Concentration from Groundwater Release

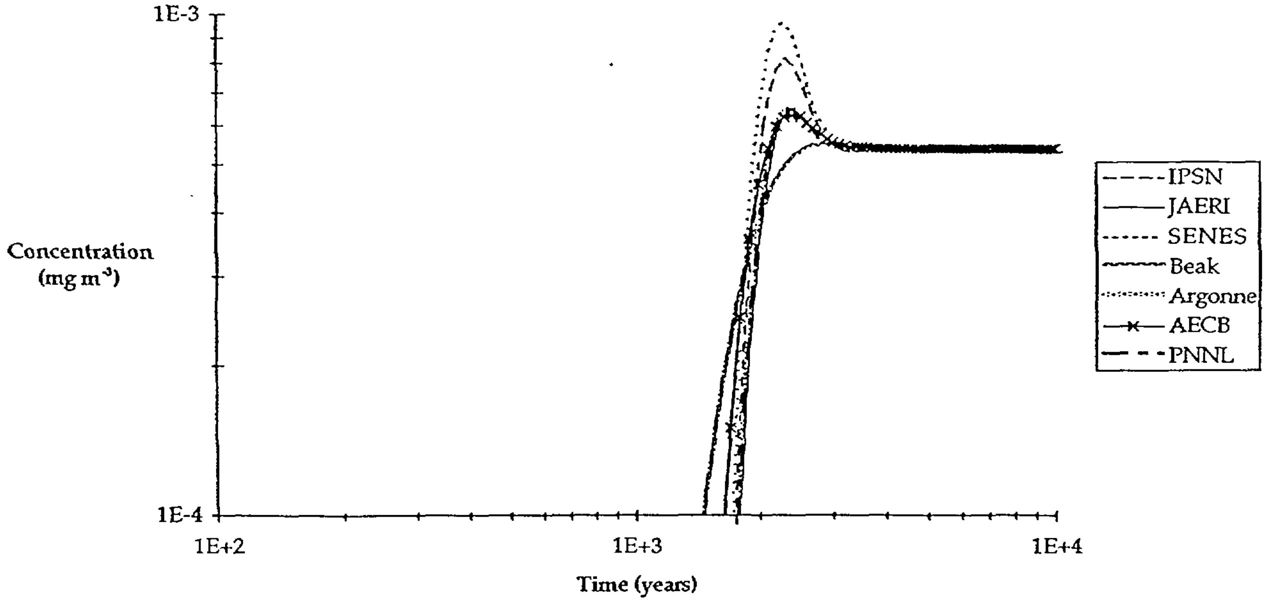


Figure 24: Deterministic Th-230 Beef Dose from Groundwater Release

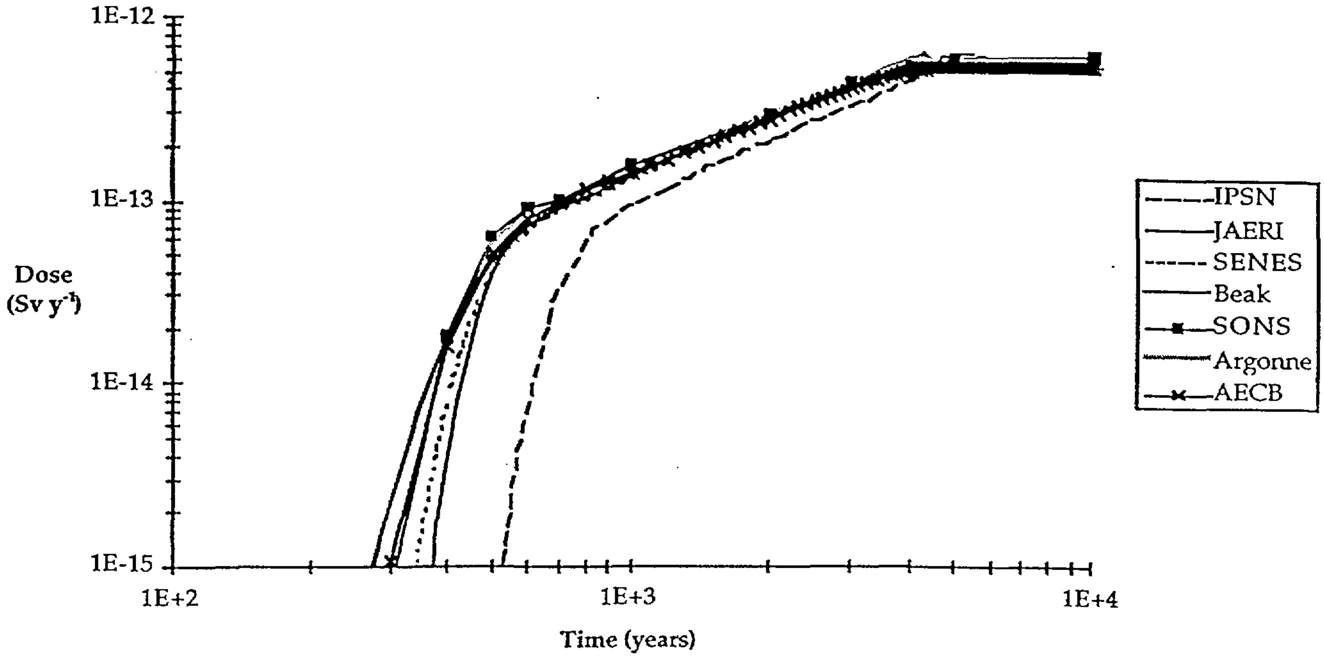


Figure 25: Deterministic U-238 Soil Concentration from Groundwater Release

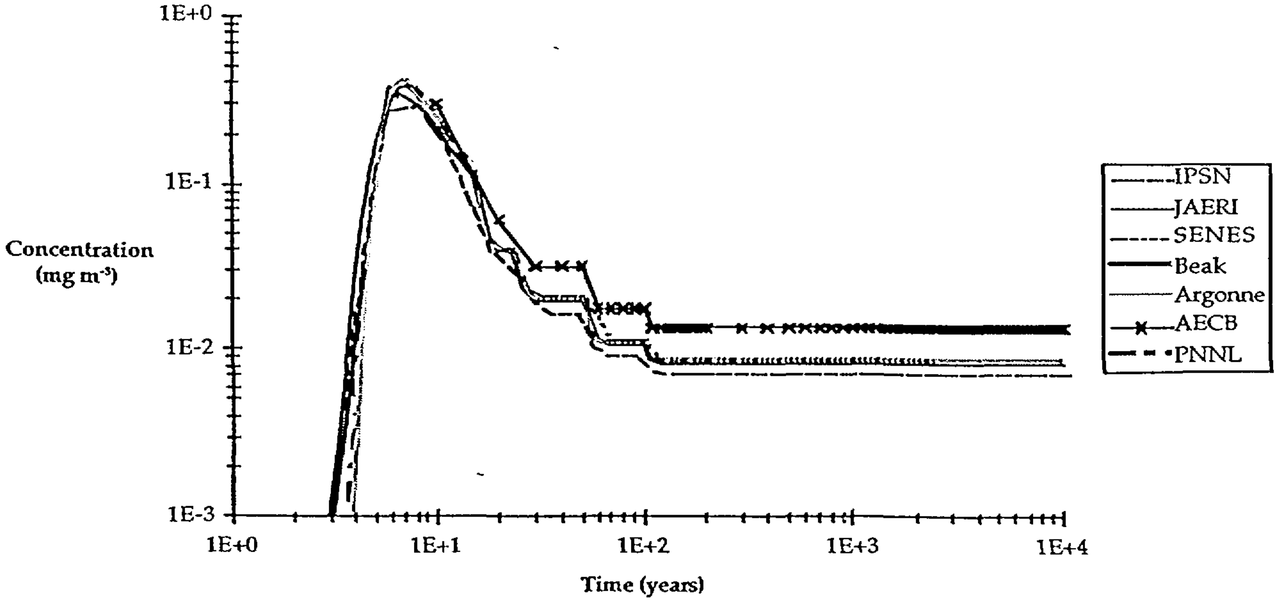


Figure 26: Deterministic Ni Soil Concentration from Groundwater Release

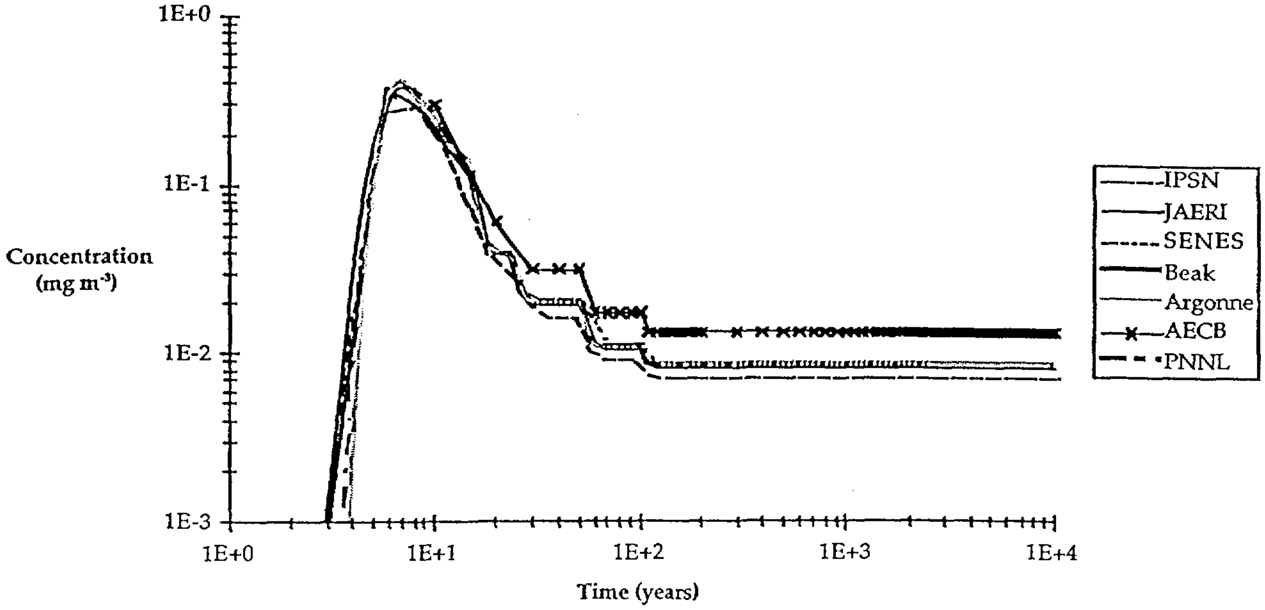


Figure 27: Deterministic Th-230 Soil Dose via Soil External Irradiation Pathway from Groundwater Release

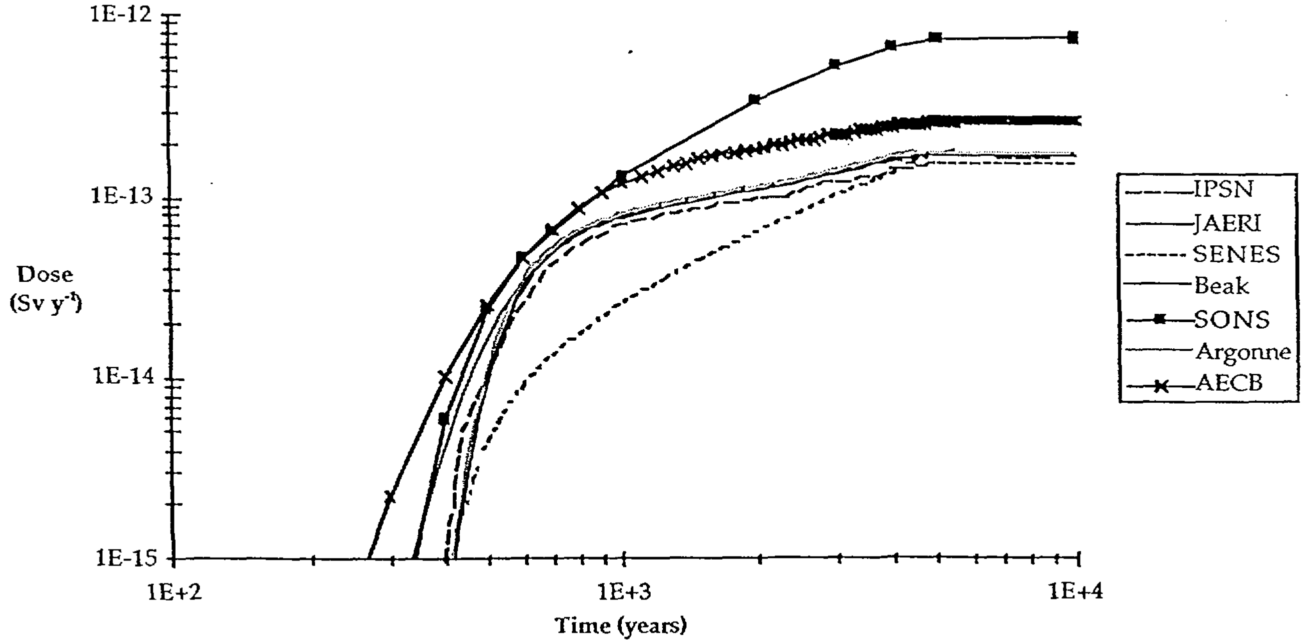


Figure 28: Deterministic Ni Intake via Air Inhalation Pathway from Groundwater Release

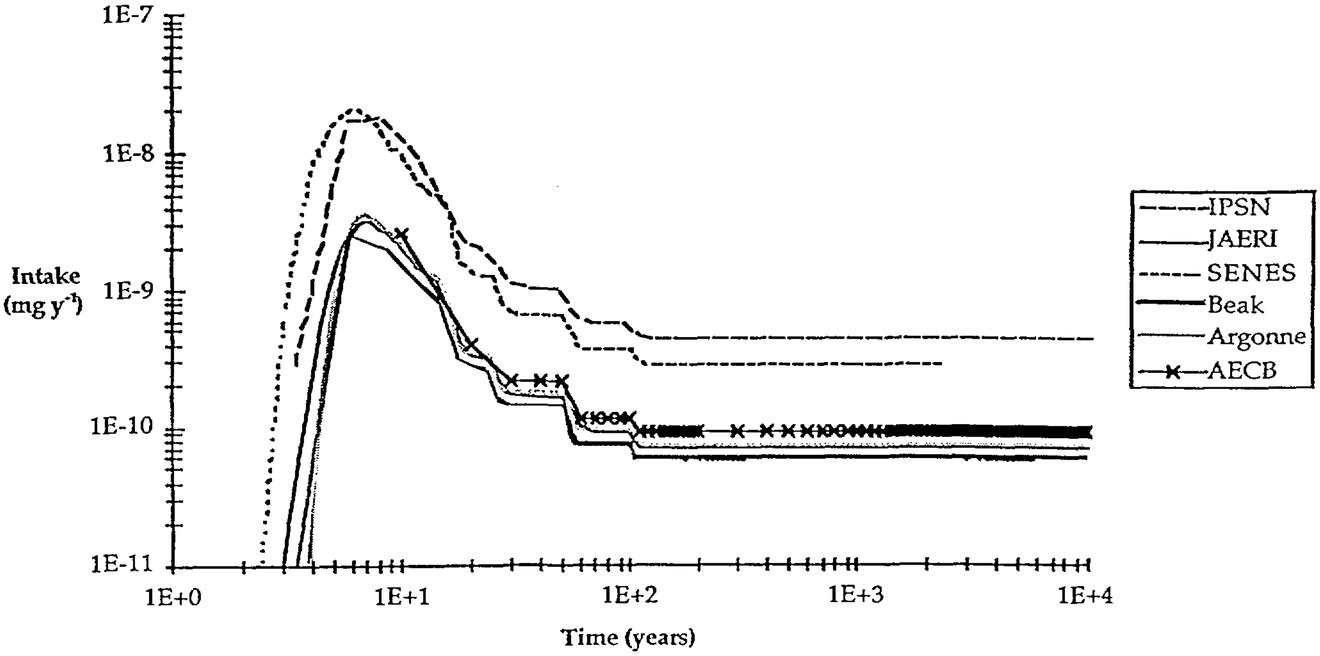


Figure 29: Deterministic Pb Intake via Vegetable Ingestion Pathway from Groundwater Release

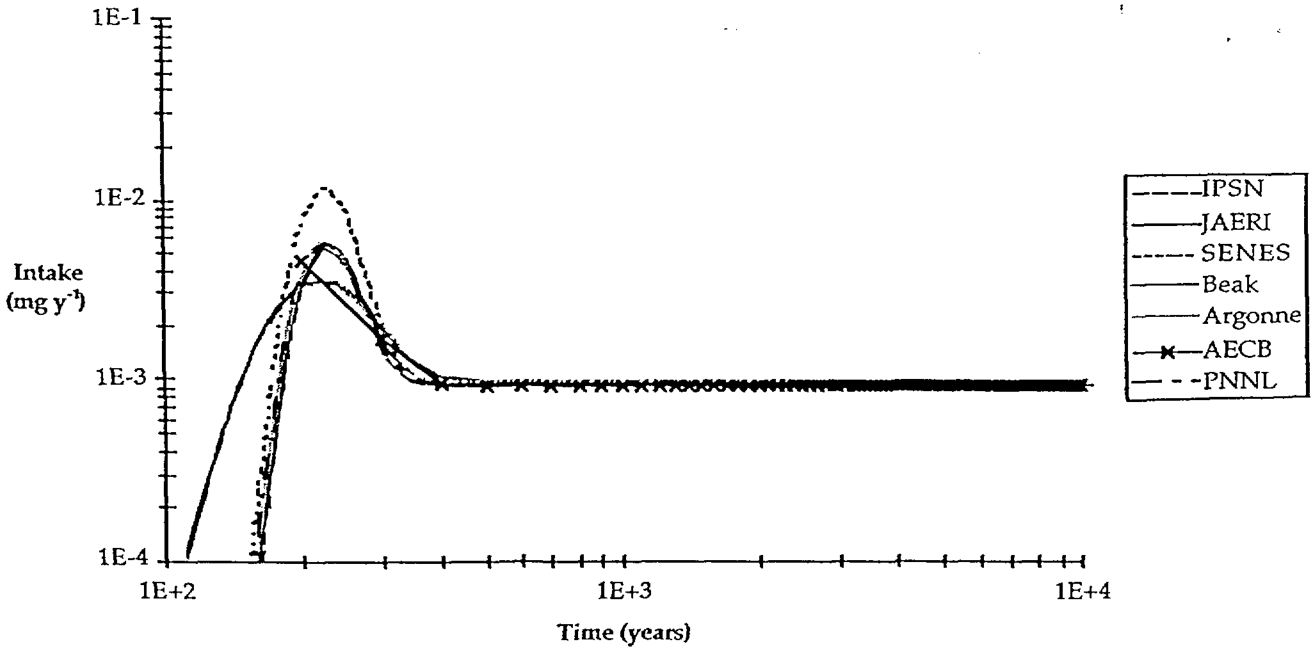


Figure 30: Deterministic Total U-238 Chain Dose from Groundwater Release

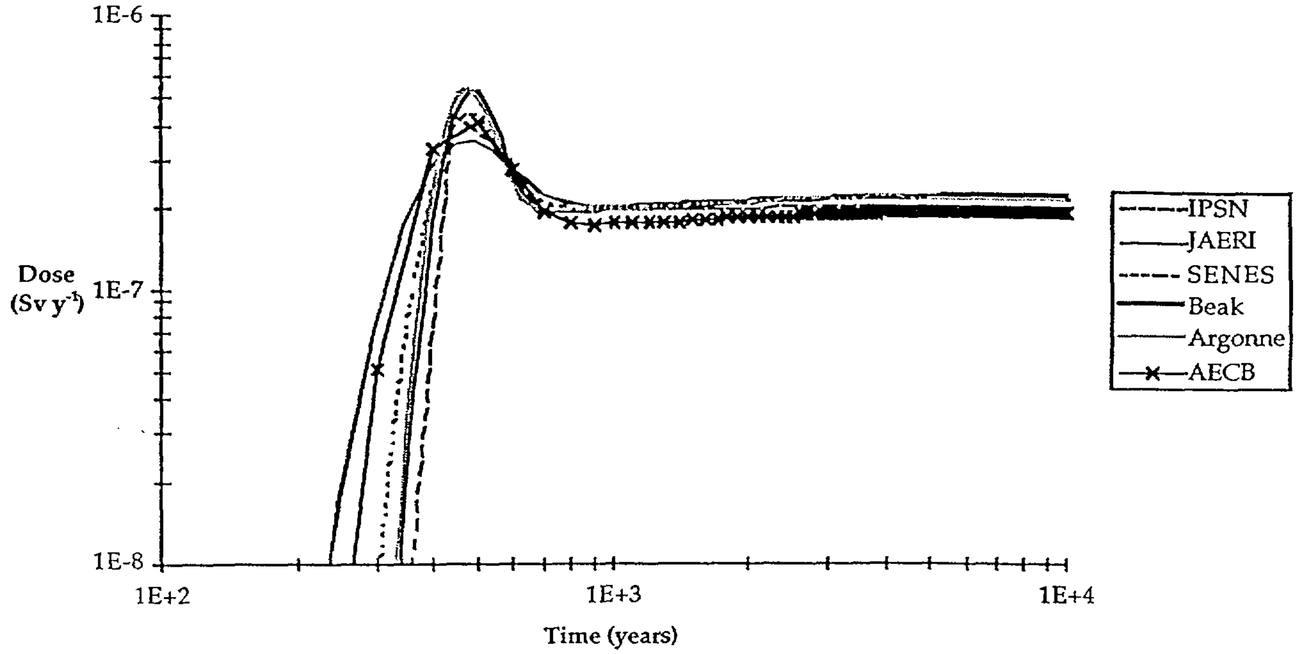


Figure 31: Radionuclide Contribution to Peak Deterministic Total U-238 Chain Dose from Groundwater Release

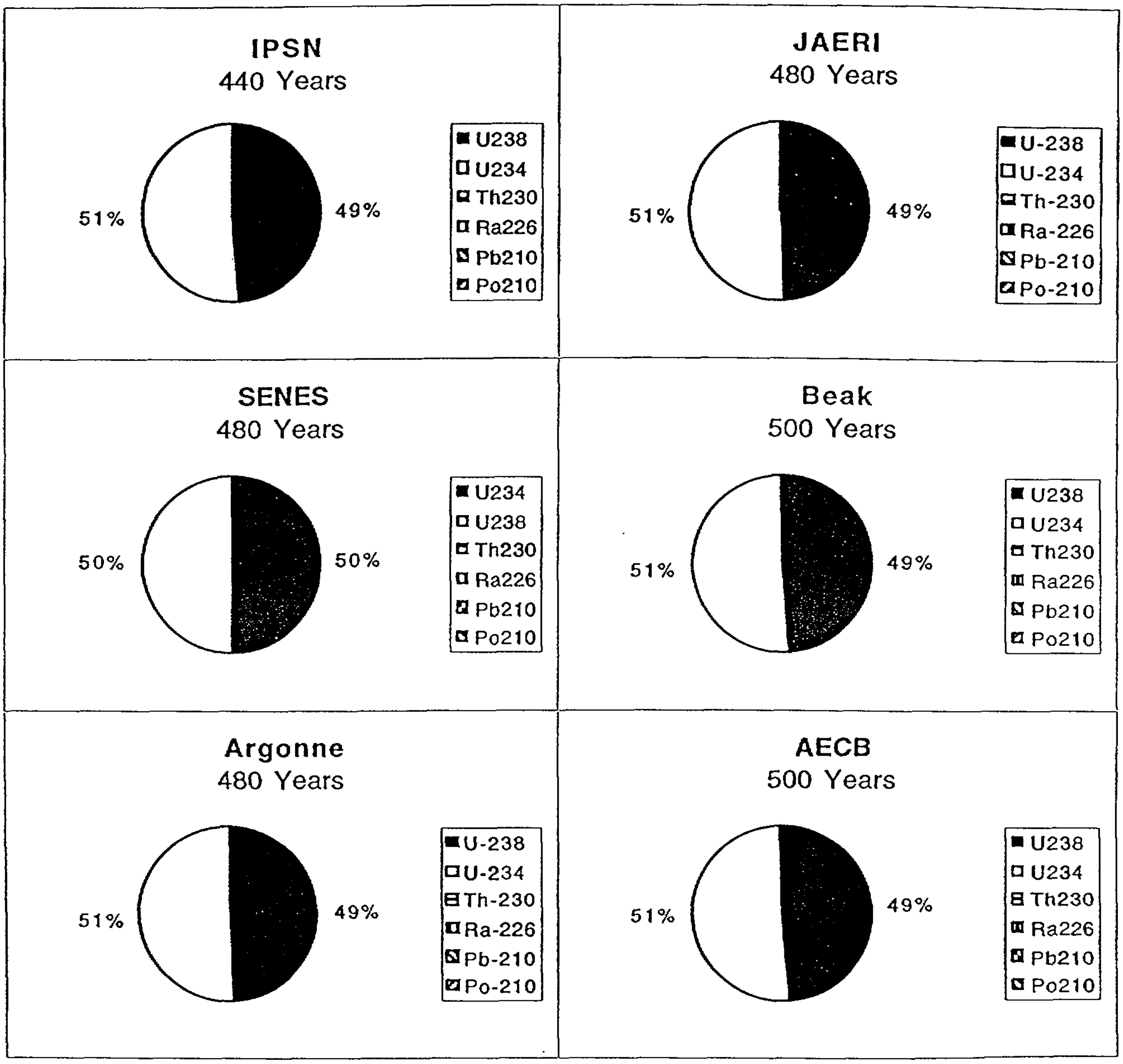


Figure 32: Radionuclide Contributions to Deterministic Total U-238 Chain Dose at 10000 years from Groundwater Release

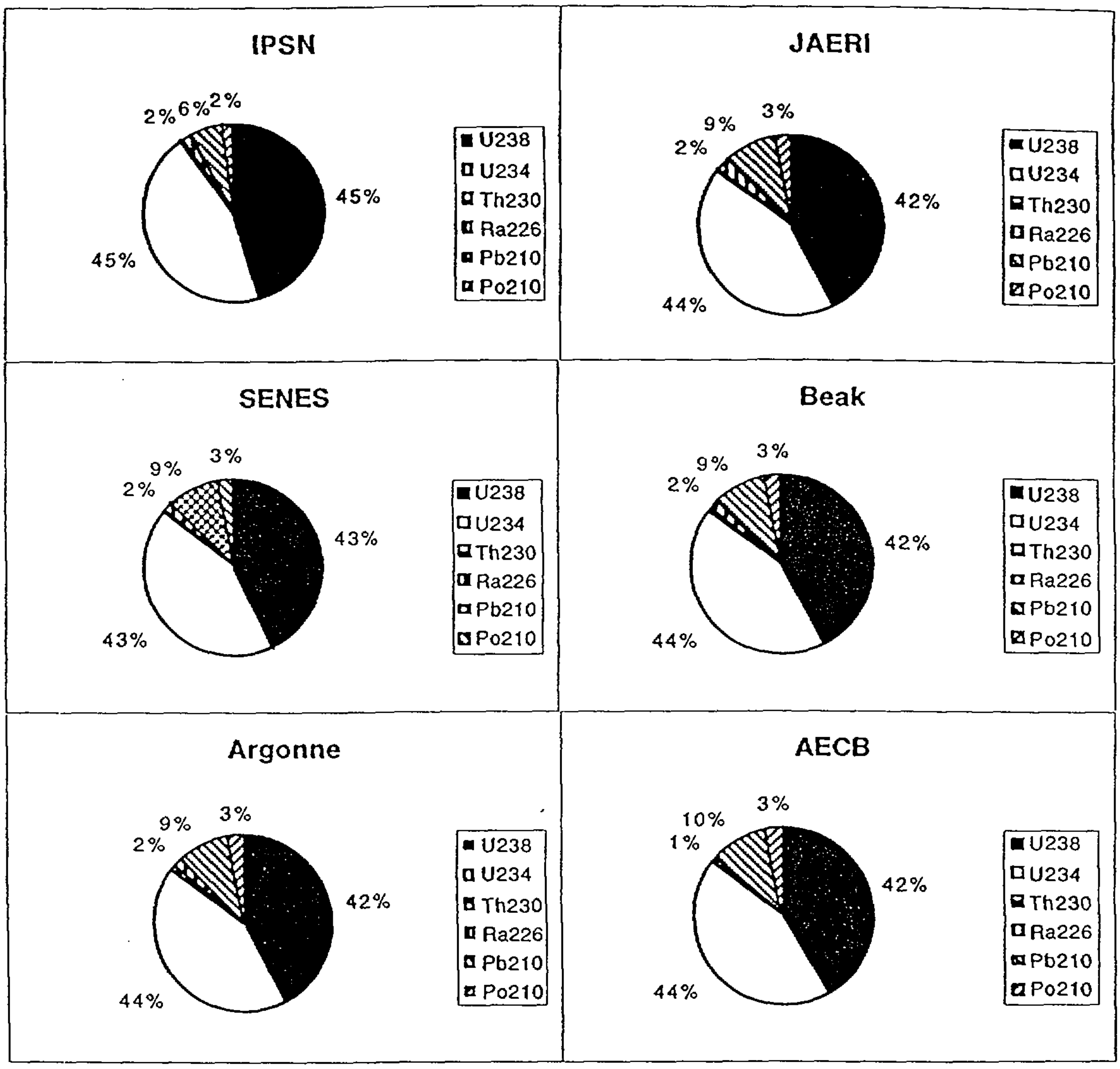


Figure 33: Pathway Contributions to Peak Deterministic Total U-238 Chain Dose from Groundwater Release

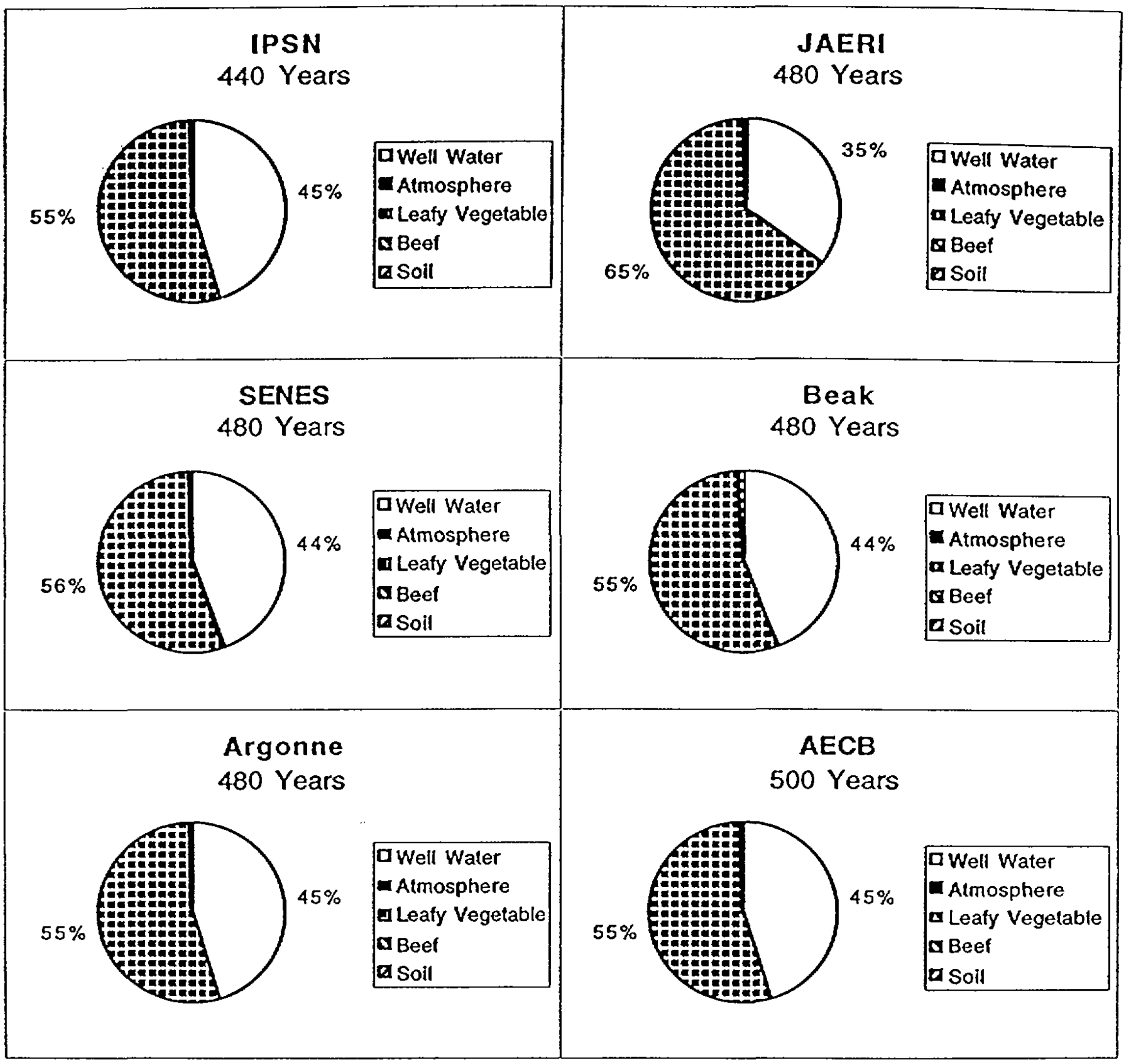


Figure 34: Pathway Contributions to Peak Deterministic Total Ni Intake from Groundwater Release

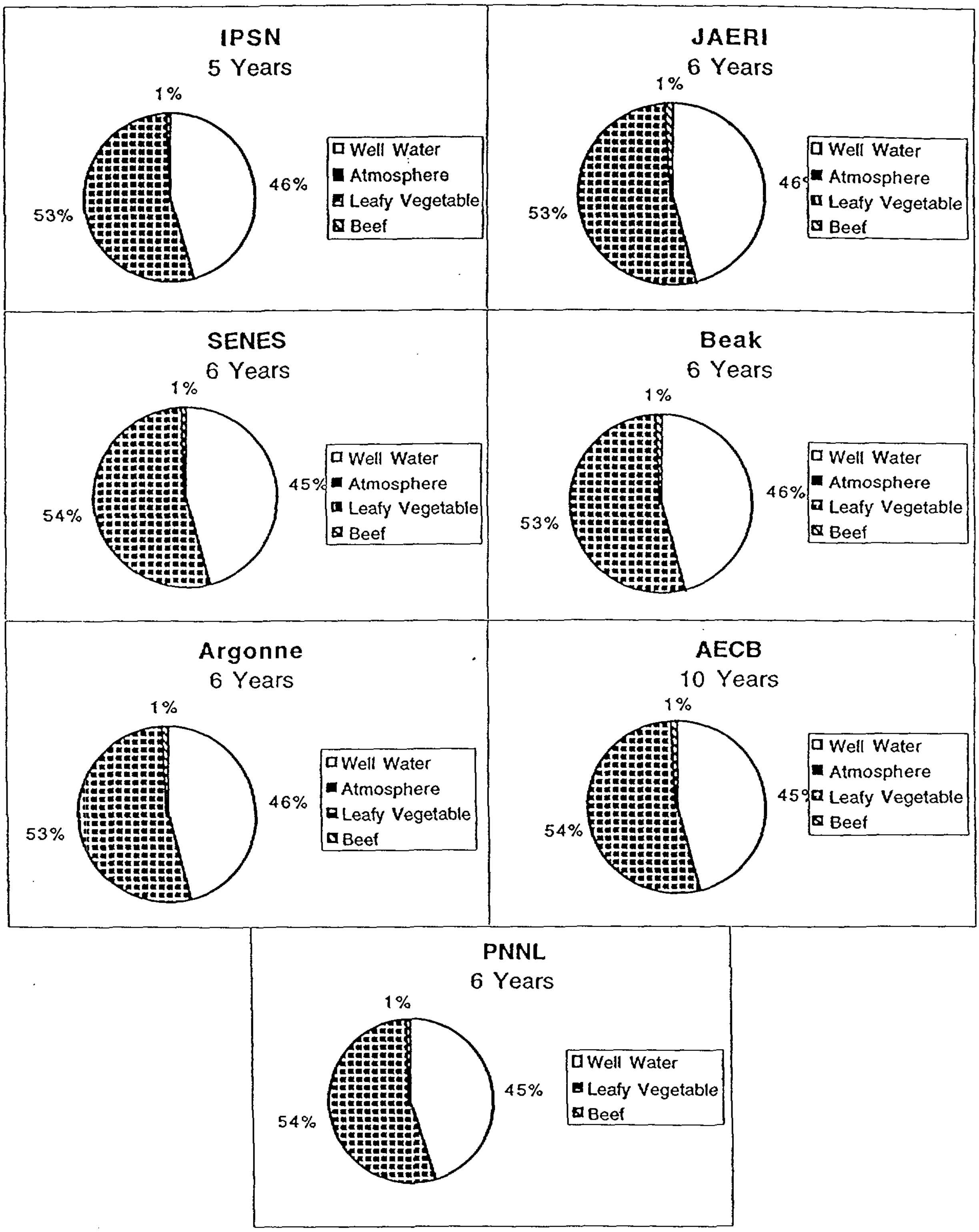
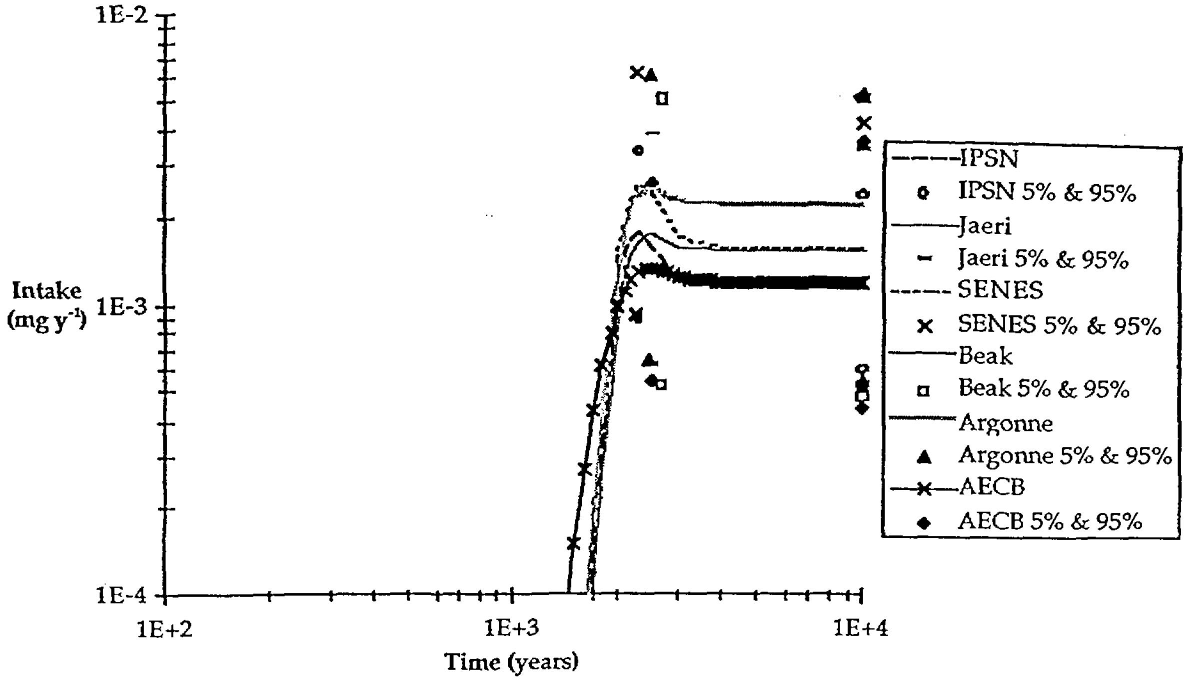


Figure 35: Probabilistic Total As Intake from Groundwater Release



Note:
Percentiles shown represent the lower and upper endpoints of the 90% confidence interval. The 5th percentile represents the value of dose below which 5% of the sampled total doses lie.

Figure 36: Cumulative Distribution Function for Total As Intake from Groundwater Release

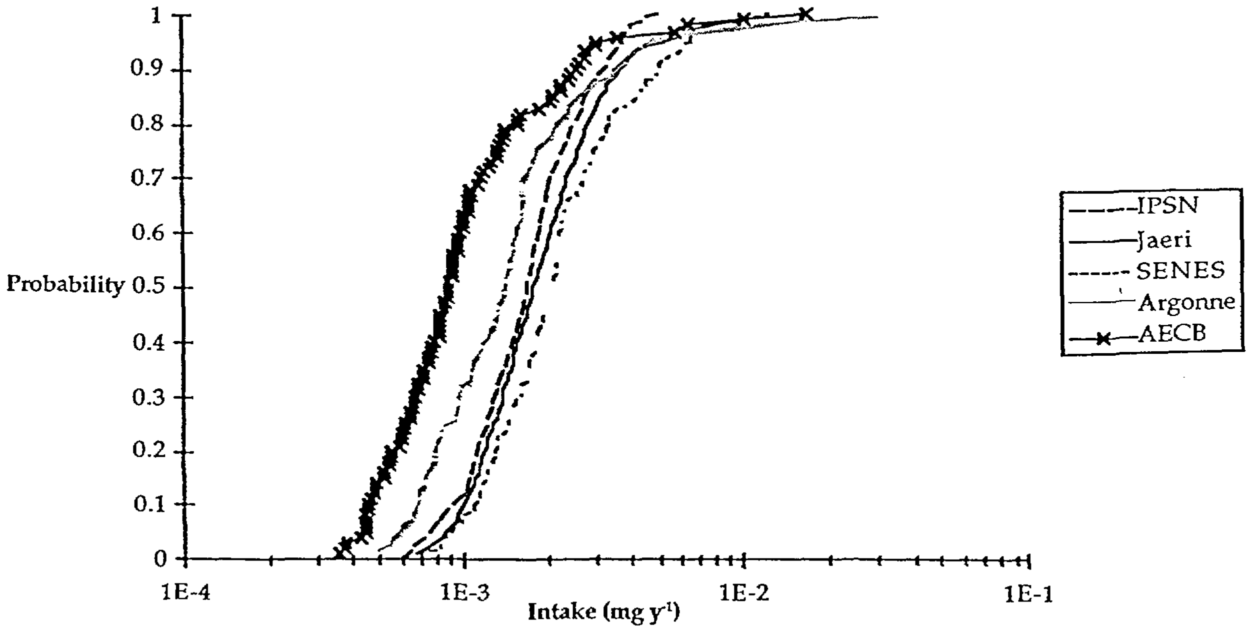
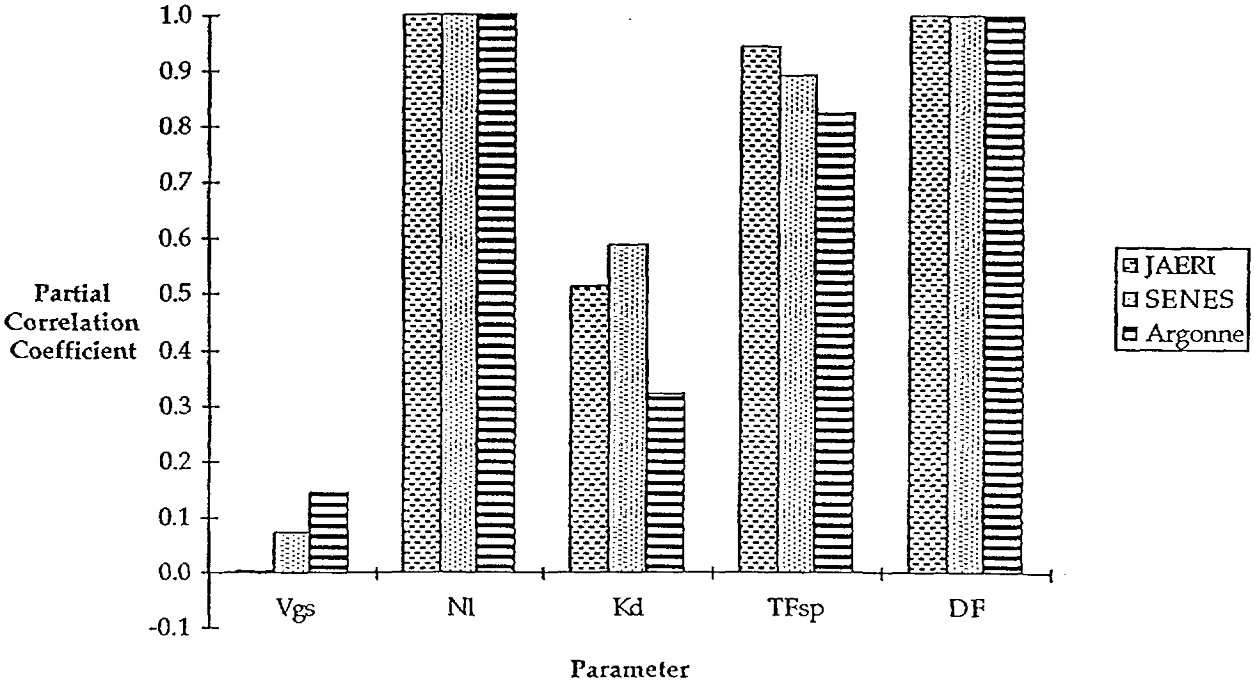


Figure 37: Partial Correlation Coefficient for Sampled Parameters Against Peak Total Ni Intake from Groundwater Release



Note:
Vgs = deposition velocity of resuspended soil particles
NI = foliar interception fraction for irrigation water
Kd = soil distribution coefficient
TFsp = soil to plant concentration factor
DF = distribution factor for beef

Figure 38: Pathway Contributions to Peak Probabilistic Total U-238 Chain Dose from Groundwater Release

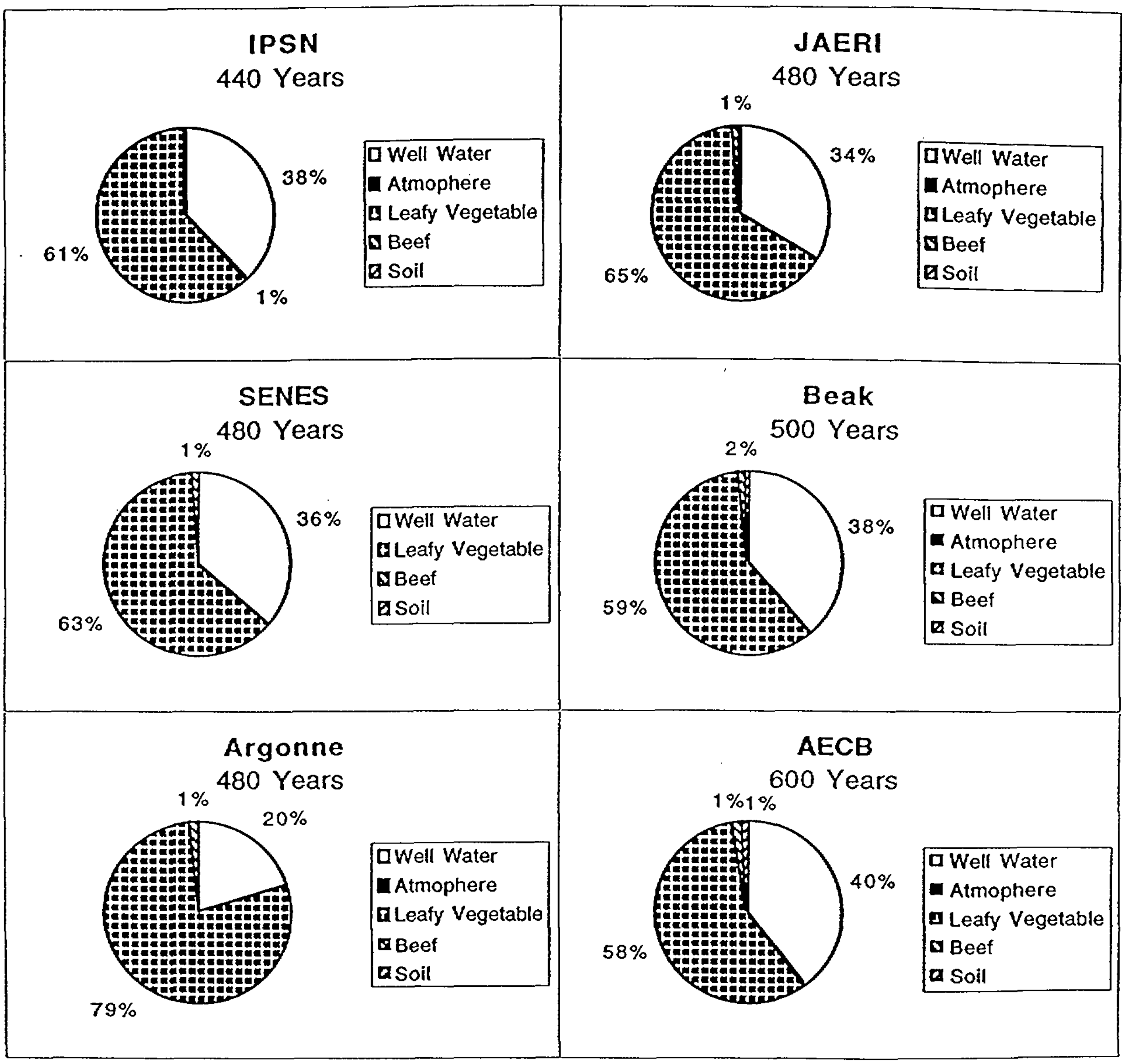


Figure 39: Radionuclide Contributions to Peak Probabilistic Total U-238 Chain Dose from Groundwater Release

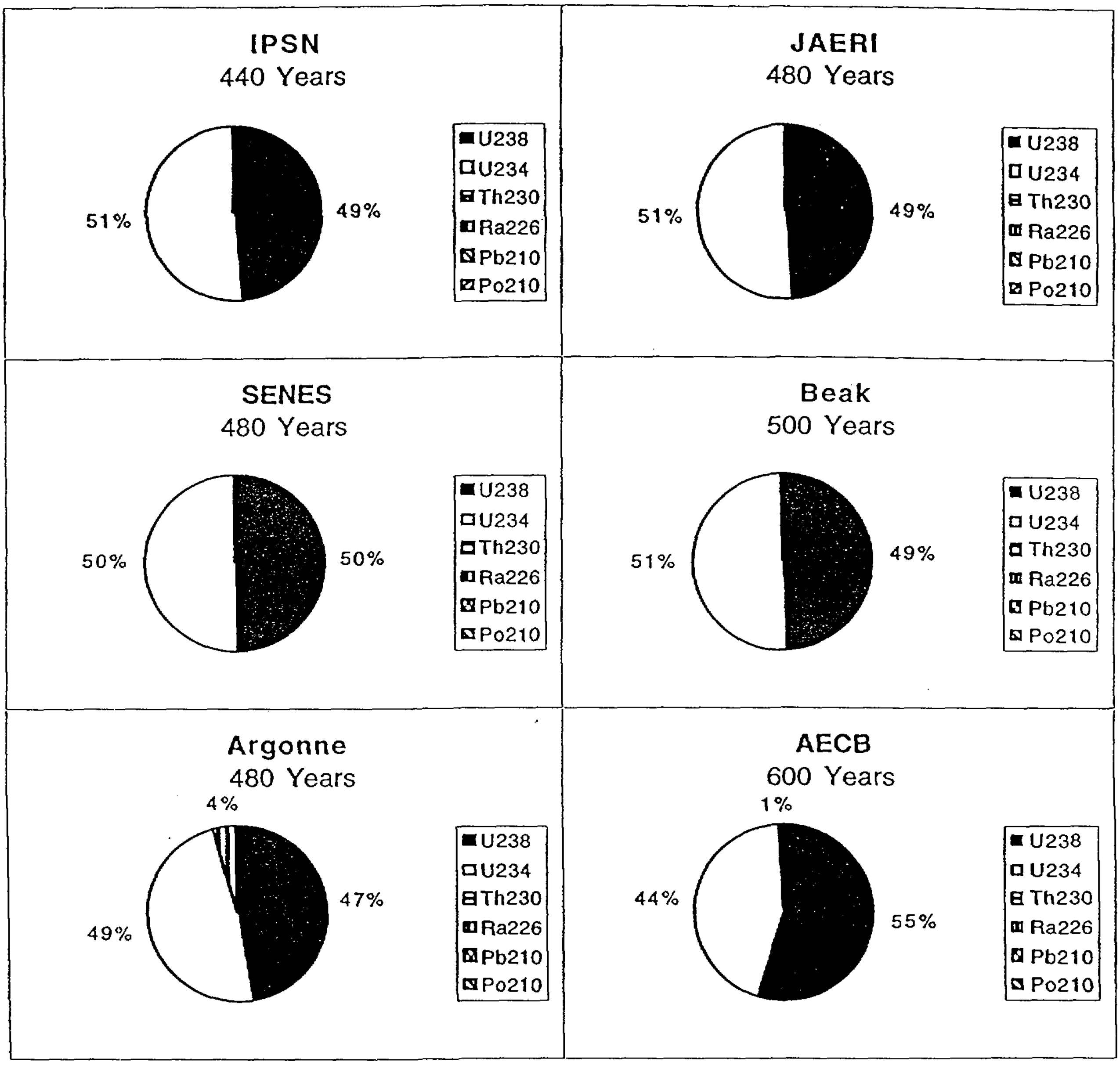
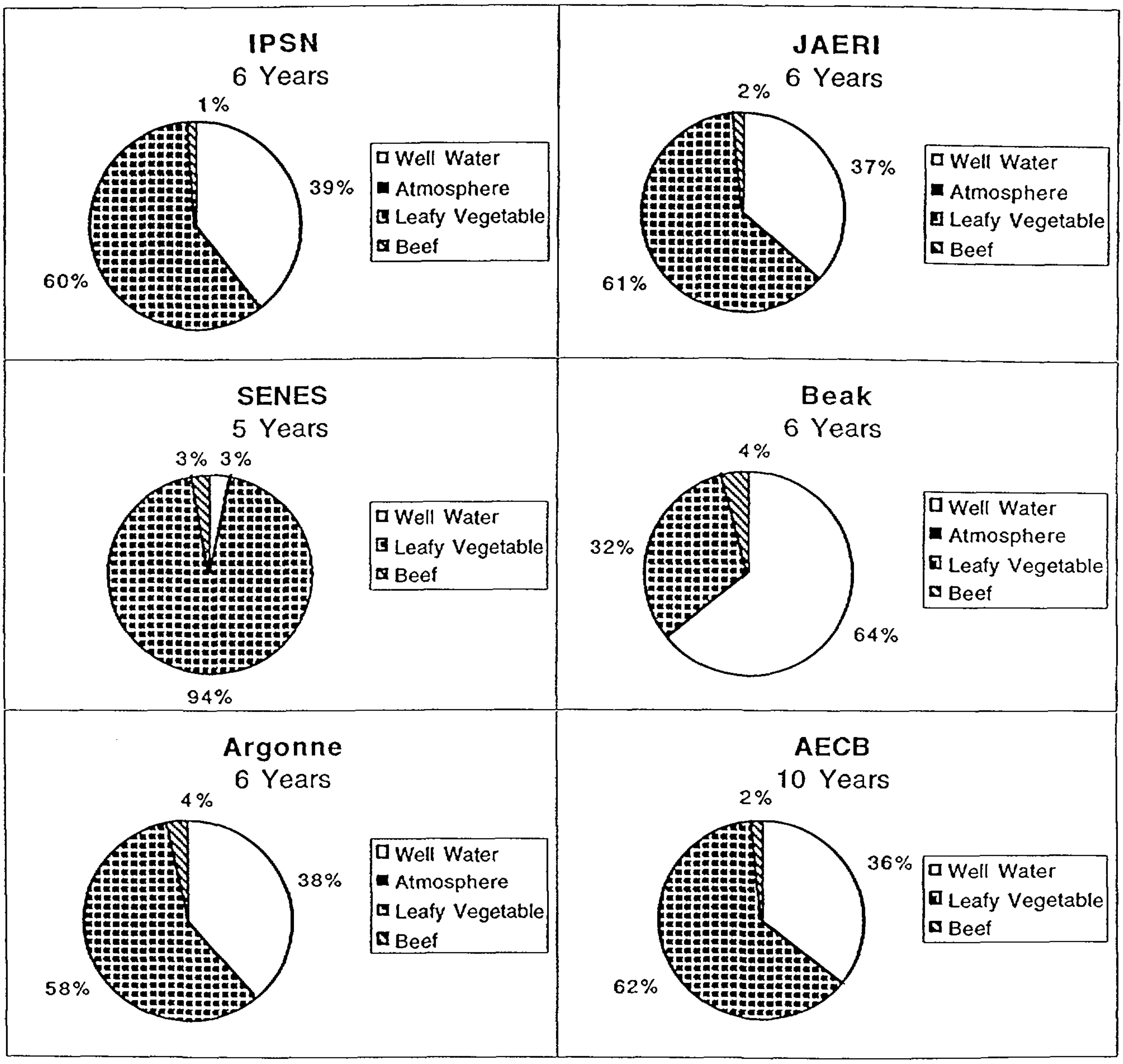


Figure 40: Pathway Contributions to Peak Probabilistic Total Ni Intake from Groundwater Release



Appendix A: V2.2 Scenario Description

A1. BACKGROUND

This V2.2 scenario description has been produced following discussions at the Uranium Mill Tailings Working Group meeting at the October 1994 Workshop of BIOMOVS II in Vienna, and the May 1995 meeting in Saskatoon. It is based on contributions provided by Working Group members and is designed to be a logical extension to the V2.1 scenario.

The two main features which have been added to the V2.1 scenario to create this new scenario are as follows.

- A source term to groundwater which includes both U-238 and its longer-lived daughters (U-234, Th-230, Ra-226, Pb-210 and Po-210). The U-238, Th-230 and Ra-226 source terms are based on the results of detailed modelling of a uranium mill tailing. In the absence of detailed modelling results, the U-234 source term is assumed to be the same as U-238, whilst the Pb-210 and Po-210 source terms are assumed to be the same as Ra-226.
- A source term to atmosphere which results from the emission of radioactive gas (Rn-222) and dust from the tailing. The contaminants considered to be emitted in the dust are U-238, U-234, Th-230, Ra-226, Pb-210 and Po-210.

A2. BASIC SCENARIO DESCRIPTION V2.2

U-238 and its daughters (U-234, Th-230, Ra-226, Pb-210 and Po-210) are released in leachate from a uranium mill tailings pile into an aquifer underlying the pile. These contaminants are transported in groundwater through the aquifer to a well. Water is abstracted from the well and used for: watering beef cattle; human consumption; and irrigating leafy vegetables. It is assumed that the well water contains no particulates. The beef and leafy vegetables are consumed by humans living in the area.

The same contaminants are also released into the atmosphere due to the wind erosion of the pile and then deposited upon the soil, pasture and leafy vegetables. In addition, Rn-222 is released to atmosphere from the pile.

The scenario is shown in Figures A1 and A2.

Detailed source term, aquifer and biosphere data for a deterministic case are given in Appendix A1, whilst data for a probabilistic case are given in Appendix A2. Many parameter values are taken from an actual uranium mill tailing site. Non site specific values have (NSS) next to them. Parameters have been given algebraic names, for example erosion rate is called "e". Please use the same names in any discussions/correspondence.

The short lived daughters of the U-238 chain (ie those members of the chain not specified above) are assumed to be in equilibrium with their parent in all parts of the system. The radiological effects of these short lived daughters, ie contributions to external and internal radiation doses, are allowed for in the data provided for their parents.

Figure A1: Plan View Representation of the V2.2 Scenario

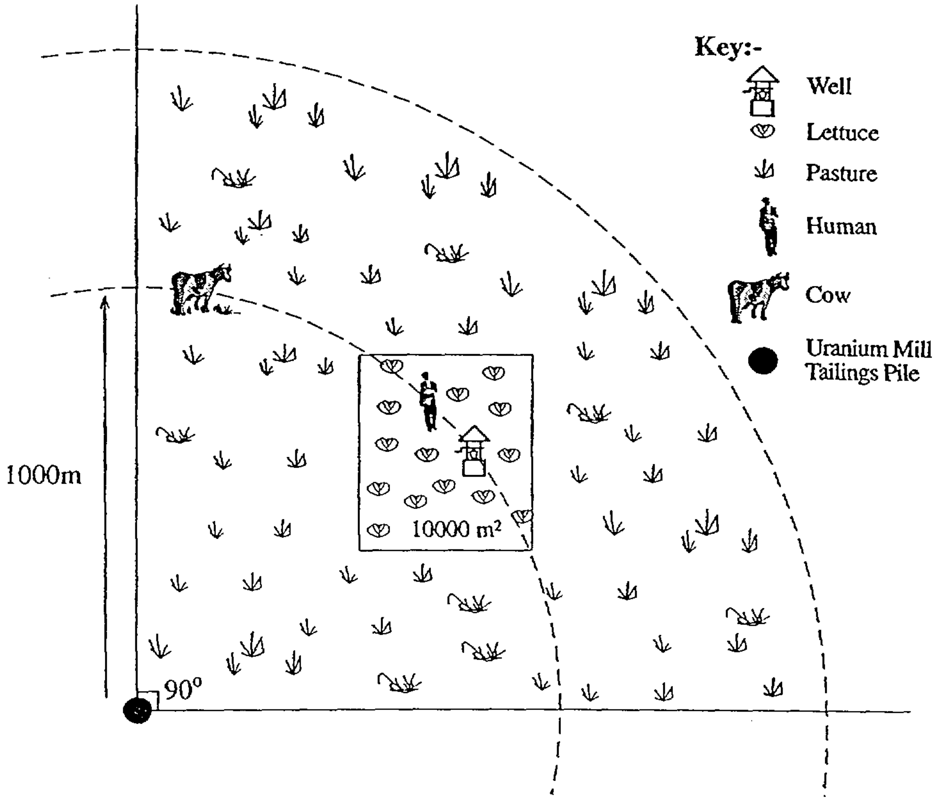
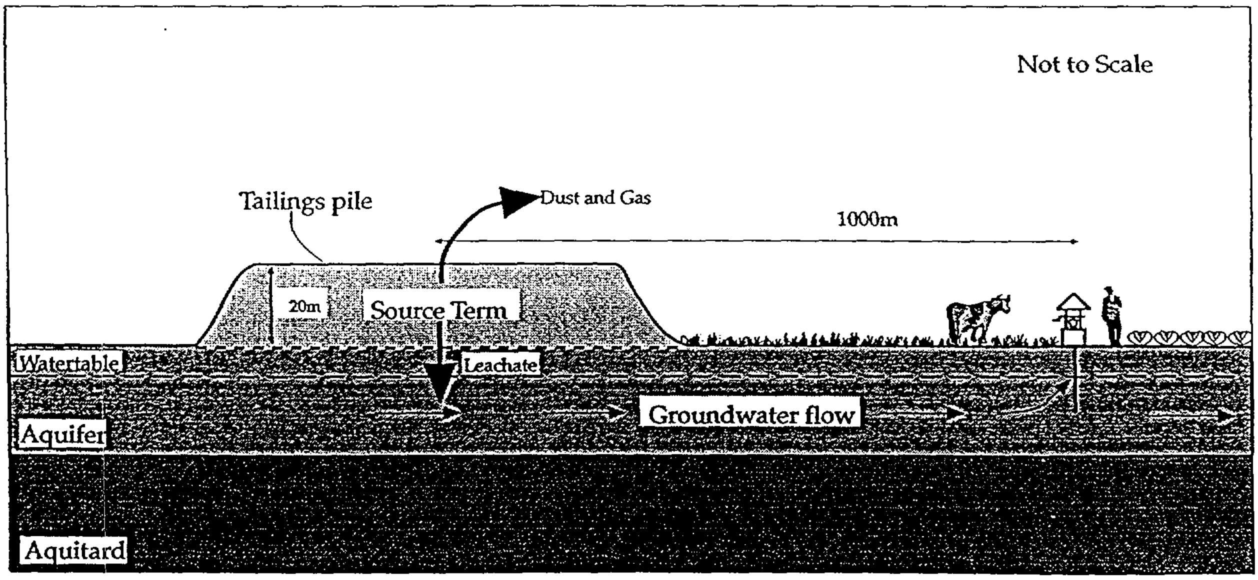


Figure A2: Cross Sectional Representation of the V2.2 Scenario



A3. MATERIAL REQUESTED FROM PARTICIPANTS

A3.1 DETERMINISTIC CASE

Assuming the characteristics specified in Appendix A1 for the various scenario components, the data itemized below are requested. Please present results as a function of time from time zero and in the units requested. Please truncate the calculations at 10000 years and ensure that results are given for no more than 100 output times.

For the atmospheric source term, calculations of concentration, dose and risk should be undertaken on the basis that deposition and exposure occurs 1000 m from the source.

(1) For each release type (groundwater and atmospheric), calculate the concentration of each contaminant in the following media:

- well water (Bq m^{-3}) (groundwater source term only);
- air above the land used for growing leafy vegetables (Bq m^{-3}) (atmospheric source term only);
- leafy vegetables (Bq kg^{-1} fresh weight);
- beef (Bq kg^{-1} fresh weight);
- soil used for growing leafy vegetables (Bq m^{-3} wet weight).

Although contaminant concentrations in the pasture soil and air above the pasture land should be calculated, participants should not report these concentrations.

(2) For each release type and contaminant, calculate the annual individual effective dose equivalent (Sv a^{-1}) to an adult for the following exposure pathways:

- ingestion of well water (groundwater source term only);
- * inhalation of dust (including resuspended dust);
- * inhalation of Rn-222 (atmospheric source term only);
- ingestion of vegetables (assumed to be leafy vegetables);
- ingestion of meat (assumed to be beef);
- * external irradiation from the soil (exclude any external dose received from suspended soil or dust).

Factors to convert annual intake into effective dose equivalent are provided in Appendix A1.

* For pathways marked with an asterix, the dose reported should represent doses received from both the pasture land and the land used for growing leafy vegetables.

(3) For each release type and contaminant, calculate the annual individual effective dose equivalent (Sv a^{-1}) to an adult summed across all the relevant pathways specified in (2).

(4) For each release type and contaminant, calculate the lifetime cancer incidence risk from one year's exposure summed over all the relevant pathways specified in (2). Factors to convert annual intake (Bq a^{-1}) into this quantity are provided in Appendix A1, along with the equivalent data for the external irradiation pathway. (The breakdown of risks among pathways can be derived from the other results provided and so need not be provided.)

(5) Participants are also requested to provide:

- a brief description of the application of their code(s) to the scenario, noting any ways in which they added to or had to modify the description of site characteristics and/or their code(s). In particular, participants should explain their approach to modelling the (re)suspension of soil particles into the air (for example do they assume that only the dry fraction of the soil is suspended);
- a diagram, for each of the groundwater and atmospheric source terms, indicating the components of the model and contaminant transfers;
- a brief commentary on the results produced;
- a reference for the code(s) used.

Please provide all these data as hard copy and on PC or Macintosh floppy disk in ASCII format. Please use a common file name structure for the results files, as explained below.

1st character identifies the nature of the case (ie deterministic)		D
2nd character, the source term		
	groundwater	G
	atmospheric	A
3rd character, the medium:		
	well water	W
	atmosphere	A
	leafy vegetable	V
	beef	B
	soil	S
	sum over pathways (total)	T
4th character, concentration, dose or risk		C, D, or R
5th character, contaminant:		
	U-238 chain	U

As examples, the doses from each member of the U-238 chain released in groundwater due to ingestion of leafy vegetable would be in the file DGVDU.DAT. Risk from all pathways from the atmospheric source term for U-238 chain members would be in the file DATRU.DAT. **It is very important to check that your results are in the correct units and that the files are correctly named.**

The following is the required layout for the data.

Line one. A title line, eg DGVDU, also giving the units in which results are reported. These should be as requested above, but respecifying them is intended to provide an additional check.

Line two. A header line as follows:

Time, a |U-238 |U-234 |Th-230 |Ra-226 |Pb-210 |Po-210 |Rn-222 |chain sum

Rn-222 results are put to the end since they are only required for calculations involving the emission of Rn-222 from the tailings. The chain sum values should only be given in dose and risk files.

Line three. The results at each time, eg

4E2 |1.2E-6 |1.8E-6 |1.2E-8 |1.2E-9 |1.8E-6 |4.2E-6 |0.0 |1E-5

A3.2 PROBABILISTIC CASE

Assuming the characteristics specified in Appendix A2 for the various scenario components, the data itemized below are requested. These calculational end-points are mostly taken from BIOMOVS II Technical Report No. 1 "Guidelines for Uncertainty Analysis"(Most, if not all current participants will already have received a copy. Further copies are available from the Secretariat). Relevant details are given in Sections 7 and 9 of TR1. As with the deterministic case, please truncate all calculations at 10000 years and, where appropriate, ensure that results are given for no more than 100 output times.

For the atmospheric source term calculations of concentration, dose and risk should be undertaken on the basis that deposition and exposure occurs 1000 m from the source.

(1) For each release type (groundwater and atmospheric) produce a graph of the cumulative distribution function (CDF) showing "peak total U-238 chain dose" against cumulative probability (see Figure 2a of BIOMOVS II TR1). "Peak total U-238 chain dose" is taken to be the peak annual individual effective dose equivalent (Sv a^{-1}) to an adult due to the release of the U-238 chain members summed across all the pathways assessed.

(2) For each release type, produce a graph showing mean total U-238 chain dose against time. At the time of peak mean total dose and at 10000 years, mark on the 5th and 95th percentiles which represent the lower and upper endpoints of the 90% confidence interval (see Section 9 of BIOMOVS II TR1). The 5th percentile represents the value of dose below which 5% of the sampled doses lie.

(3) For each release type and radionuclide, produce a graph of mean dose summed across all the pathways assessed against time. At the time of peak mean dose and at 10000 years, mark on the 5th and 95th percentiles.

(4) For each release type and each of the pathways listed below produce a graph of U-238 chain mean dose from the pathway against time. At the time of peak mean dose and at 10000 years, mark on the 5th and 95th percentiles. The pathways to be considered are: ingestion of leafy vegetables; ingestion of beef; external irradiation from the soils used for growing leafy vegetables and pasture (exclude any dose received from suspended soil or dust); and inhalation of dust (including resuspended dust) and Rn-222 from the soils used for growing leafy vegetables and pasture. The inhalation pathways should only be assessed for the atmospheric release.

(5) For each release type provide Spearman's rank correlation coefficient (RCC) for each of the sampled parameters against peak total U-238 chain dose. Details on how to calculate Spearman's rank correlation coefficient are given in IAEA Safety Series 100. Spearman's rank correlation coefficient measures the strength of an increasing or decreasing relationship between two variables.

(6) For each release type provide the standardised regression coefficient (SRC) and partial correlation coefficient (PCC) for each of the sampled parameters against peak total U-238 chain dose (see Sections 7.2 and 7.3 of BIOMOVS II TR1). These coefficients will provide a measure of the relative importance of the sampled parameters in affecting peak total U-238 chain dose.[1]

(7) Participants are also requested to provide:

- details of the sampling technique(s) used (eg Monte Carlo, Latin Hypercube);
- details of the convergence test(s) and stopping rule(s) used;
- a brief commentary on the results produced.

Please provide all these data as hard copy and on PC or Macintosh floppy disk in ASCII format. Please use a common file name structure for the results files, as explained below.

1st character identifies the nature of the case (ie probabilistic)	P
2nd character, the source term	
groundwater	G
atmospheric	A

---

[1] At a Working Group meeting subsequent to the specification of the final descriptions of the scenarios it was agreed that SRC and PCC tests might not be ideal tests for parameters which have a non-linear effect upon the dose since they only test the linear relationship between the parameters and dose. It was felt that sample ranked SRC and PCC tests might have been more suitable given that most of the sampled parameters were considered to have a non-linear impact on dose. However, given the time constraints, it was not considered appropriate to ask participants to recalculate the ranked statistics. This limitation should be borne in mind when analysing the results from the tests reported in the main text.

3rd character, the pathway:

atmosphere	A
leafy vegetable	V
beef	B
soil	S
sum over pathways (total)	T

4th character, the endpoint:

CDF	C
dose vs time	D
Spearman's rho	R
SRC	S
PCC	P

5th/6th character, the contaminant:

U-238 chain	C
U-238	U8
U-234	U4
Th-230	T
Ra-226	R
Rn-222	Rn
Pb-210	Pb
Po-210	Po

As examples, data relating to the cumulative distribution function showing "total U-238 chain dose" against cumulative probability for released in groundwater would be in the file PGTCC.DAT. The standardised regression coefficient for each of the sampled parameters against peak total U-238 chain dose from the atmospheric source term would be in the file PATSC.DAT. **It is very important to check that your results are in the correct units and that the files are correctly named.**

The following is the required layout for the CDF data files.

Line one. A title line, eg PGTCC, also giving the units in which results are reported. These should be as requested above, but respecifying them is intended to provide an additional check.

Line two. A header line as follows:

Peak total U-238 chain dose Cumulative probability

Line three. The result at each cumulative probability step, eg:

4E-9 1.2E-3

The following is the required layout for the **mean dose against time data files.**

Line one. A title line, eg PGTPC, also giving the units in which results are reported. These should be as requested above, but respecifying them is intended to provide an additional check.

Line two. A header line as follow:

Time, a	Mean dose	5%tile of dose	95%tile of dose

Line three. The results at each output time, eg:

1E1	1.2E-9	4.5E-11	7.9E-7

Note that 5th and 95th percentiles should only be given at the time of peak mean dose and at 10000 years.

The following is the required layout for the **Spearman's rho, SRC and PCC data files**.

Line one. A title line, eg PGTPC, also giving the units in which results are reported. These should be as requested above, but re-specifying them is intended to provide an additional check.

Line two. A header line as follows:

Sampled parameter	Coefficient value

Line three. The result for each sampled parameter, eg

Distribution factor for beef	0.345

APPENDIX A1

Deterministic Case:

Source Term, Aquifer and Biosphere Data

A1.1 GROUNDWATER SOURCE TERM

The source term is the engineered uranium mill tailings pile. The time dependent flux of the U-238 chain members to the underlying aquifer is given in Table 1 (note that the flux is given in units of Bq a^{-1}). The U-238, Th-230 and Ra-226 data are derived from detailed site modelling and are consistent with flow and concentration data from the site. In the absence of detailed modelling results, the U-234 source term is assumed to be the same as U-238, whilst the Pb-210 and Po-210 source terms are assumed to be the same as Ra-226.

Table 1:
Flux (Bq a^{-1}) of U-238 chain members to the aquifer as a function of time

Time(a)	Flux (Bq a^{-1})					
	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210
0-1	1.87E+8	1.87E+8	8.34E+4	6.44E+4	6.44E+4	6.44E+4
1-2	1.14E+8	1.14E+8	3.21E+4	2.01E+4	2.01E+4	2.01E+4
2-5	6.62E+7	6.62E+7	4.88E+3	3.54E+3	3.54E+3	3.54E+3
5-10	3.86E+7	3.86E+7	1.49E+3	1.09E+3	1.09E+3	1.09E+3
10-20	1.00E+7	1.00E+7	5.24E+2	3.76E+2	3.76E+2	3.76E+2
20-50	5.27E+6	5.27E+6	1.66E+2	1.35E+2	1.35E+2	1.35E+2
50-100	2.84E+6	2.84E+6	4.49E+1	3.53E+1	3.53E+1	3.53E+1
100-10000	2.21E+6	2.21E+6	1.47E+1	1.17E+1	1.17E+1	1.17E+1

A1.2 ATMOSPHERIC SOURCE TERM

The source term is the engineered uranium mill tailings pile. The time dependent flux of the U-238 chain members to the atmosphere is given in Table 2 (note that the flux is given in units of Bq s^{-1}). For all contaminants, other than Rn-222, the flux is due to wind erosion of the pile. The flux has been calculated by multiplying the measured concentration of each contaminant in the pile (Bq kg^{-1}) by the area of the pile (m^2) and a time dependent wind erosion rate (kg m^{-2} s^{-1}). The flux of Rn-222 is due to the direct emission of radon gas from the pile. It has been derived from fluxes measured prior to the emplacement of a cap over the pile.

The time dependent nature of the fluxes reflects the impact of the erosion of the cap covering the pile. It is assumed that the cap is fully intact for the first 200 years and hence prevents any emissions. Thereafter the cap gradually fails until it has totally failed at 1000 years.

Table 2:
Flux (Bq s^{-1}) of U-238 chain members to the atmosphere as a function of time

Time(a)	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	Rn-222
0-200	0.0	0.0	0.0	0.0	0.0	0.0	0.0
200-300	1.16E+0	1.16E+0	4.16E+0	4.16E+0	4.16E+0	4.16E+0	7.34E+4
300-400	2.31E+0	2.31E+0	8.31E+0	8.31E+0	8.31E+0	8.31E+0	1.47E+5
400-500	3.47E+0	3.47E+0	1.25E+1	1.25E+1	1.25E+1	1.25E+1	2.20E+5
500-600	4.62E+0	4.62E+0	1.66E+1	1.66E+1	1.66E+1	1.66E+1	2.94E+5
600-700	5.78E+0	5.78E+0	2.08E+1	2.08E+1	2.08E+1	2.08E+1	3.67E+5
700-800	6.93E+0	6.93E+0	2.49E+1	2.49E+1	2.49E+1	2.49E+1	4.41E+5
800-900	8.09E+0	8.09E+0	2.91E+1	2.91E+1	2.91E+1	2.91E+1	5.14E+5
900-1000	9.24E+0	9.24E+0	3.32E+1	3.32E+1	3.32E+1	3.32E+1	5.88E+5
1000-10000	1.04E+1	1.04E+1	3.74E+1	3.74E+1	3.74E+1	3.74E+1	6.61E+5

A1.3 AQUIFER

Hydraulic conductivity	k	= 1.0E+5 m a^{-1}
Hydraulic gradient from below pile to well	i	= 4.0E-3
Cross sectional area of flow	A	= 4.2E+3 m^2
Total porosity	ε_t	= 3.5E-1
Effective porosity	ε_e	= 2.0E-1
Dispersion coefficient*	D_L	= 1.46E+4 m^2 a^{-1}
Distribution coefficient for U	K_d	= 1.06E-1 m^3 kg^{-1}
Distribution coefficient for Th	K_d	= 1E+0 m^3 kg^{-1} (NSS)
Distribution coefficient for Ra	K_d	= 2.17E-1 m^3 kg^{-1}
Distribution coefficient for Pb	K_d	= 5E-2 m^3 kg^{-1} (NSS)
Distribution coefficient for Po	K_d	= 5E-2 m^3 kg^{-1} (NSS)
Dry bulk density	ρ_b	= 1.76E+3 kg m^{-3}
Abstraction rate from well**	a	= 1.0E+4 m^3 a^{-1}

*This term represents longitudinal dispersion only. Diffusion and transverse dispersion are assumed to be insignificant. From the data provided, a longitudinal dispersity (α_L) of 7.3 m can be calculated.

**This abstraction rate is assumed to meet all requirements for drinking water for humans and cows, as well as crop irrigation needs.

The flux of groundwater contaminants (given in Table 1) is assumed to be an instantaneously diluted vertical planar source which enters the aquifer 1000 m upstream from the well. The product of k, i and A gives an annual flow rate in the aquifer of 1.68E+6 m^3.

A1.4 BIOSPHERE

A1.4.1 Atmospheric Data

Note that for the atmospheric source term, calculations of concentration, dose and risk should be undertaken on the basis that deposition and exposure occurs 1000 m from the source.

The following conditions are assumed during the atmospheric release:

Wind Rose:

Stability category	D
Average windspeed	2.1 m s^{-1}
Release height	20 m

Wind blows into chosen 90° sector 30% of the time

Radon daughters sorbed on the Aitken nuclei:

Deposition velocity V_{gr} = 1E-3 m s^{-1} (NSS)

The radon equilibrium factor is assumed to be 0.2.

Resuspended soil particles (NSS):

Resuspension layer R_l = 1E-2 m
Resuspension factor R_{fs} = 1E-9 m^{-1}
Deposition velocity V_{gs}= 1E-2 m s^{-1} (~1μm median aerodynamic diameter)

A1.4.2 Farming Land Data

Ploughing depth for vegetable growing land P_d= 3.0E-1 m
Ploughing frequency for vegetable growing land P_f= 1 a^{-1}
Total porosity ε_t = 4.2E-1
Effective porosity ε_e = 3.4E-1
Fraction of total porosity filled with water f_w= 0.81
Distribution coefficient for U K_d= 9.97E-1 m^3 kg^{-1}
Distribution coefficient for Th K_d= 1E+0 m^3 kg^{-1} (NSS)
Distribution coefficient for Ra K_d= 1.28E+0 m^3 kg^{-1}
Distribution coefficient for Pb K_d= 5E-2 m^3 kg^{-1} (NSS)
Distribution coefficient for Po K_d= 5E-2 m^3 kg^{-1} (NSS)
Dry bulk density ρ_b= 1.35E+3 kg m^{-3}
Erosion rate e = 8.5E-1 kg m^{-2} a^{-1}

It is assumed that the farming land is used for the growing of leafy vegetables (Veg) and pasture (Past) and that only the land used for growing leafy vegetables is ploughed. The relevant parameters are as follows:

	Y	N_S	N_l	Tv	V	A	I	I_n
Veg	1.57	0.7	0.1	14	90	1E+4	8.76E-3	0.520
Past	1.85	0.5	N/A	14	180	3E+6	0.0	0.125

where:

Y	annual yield (kg fresh weight m^{-2})
N_s	foliar interception fraction for dust (-) (NSS)
N_I	foliar interception fraction for irrigation water (-) (NSS)
T_v	weathering half life for intercepted dust and irrigation water (d) (NSS)
V	growing period (d) (NSS)
A	cultivated area (m^2)
I	irrigation rate* ($m^3\ m^{-2}\ d^{-1}$)
I_n	net infiltration through soil** ($m^3\ m^{-2}\ a^{-1}$)

*Irrigation is assumed to occur only during the vegetable growing period. Thus 7.88E+3 m^3 is applied over a period of 90 days and so the effective irrigation rate if extrapolated over 365 days is 3.20E+4 $m^3\ y^{-1}$. It is this rate that participants should use when calculating the concentration on the vegetables. However, 7.88E+3 $m^3\ y^{-1}$ should be used when calculating the concentration in soil.

**Takes into consideration precipitation, evapotranspiration and, for irrigated land, irrigation. Note that only the land used for growing leafy vegetables is irrigated. Two factors result in the infiltration value being higher for the irrigated land. Firstly, irrigating at the site specific irrigation rate results in a surplus of irrigation water even after evapotranspiration losses and the water required to restore the soil to field capacity have been taken into account (the implied irrigation efficiency is about 50%). The surplus water is assumed to infiltrate through the soil. Secondly, irrigation prevents a soil moisture deficit from developing during the summer which in turn results in the field capacity being restored more rapidly in the winter period, resulting in higher winter infiltration rates.

The soil to plant concentration factors (TF_{SP}, Bq kg^{-1} fresh weight plant/Bq kg^{-1} dry weight soil) for each contaminant (NSS) are:

U	4E-3
Th	4E-4
Ra	5E-2
Pb	2E-3
Po	5E-3

Soil splash, translocation of activity from external to internal plant surfaces, and losses due to harvesting and food preparation should be ignored. However, losses due to weathering should be considered. The soil to plant concentration factors given above should be used for both leafy vegetables and pasture, and represent the fraction of activity which is transferred from the soil to the plant via root uptake (foliar uptake is considered separately).

Loss of activity from the soil is assumed to occur due to radioactive decay, erosion of the soil, and net infiltration of water through the soil. Other loss processes should be ignored.

A1.4.3 Animal Data (beef cattle)

Individual Diet (NSS):

Drinking water from the well	0.05 $m^3\ d^{-1}$
Pasture grass	50 kg (wet weight) d^{-1}
Soil	0.5 kg (wet weight) d^{-1}

Occupancy and Inhalation (NSS):

Occupancy: pasture	24 h d^{-1}
Inhalation rate	150 $m^3\ d^{-1}$

For the groundwater release, it is assumed that the beef cattle are contaminated by consumption of well water only. For the atmospheric release, it is assumed that they are contaminated only by consumption of contaminated pasture, soil, and inhalation of contaminated soil and air.

The transfer of individual contaminants to beef is quantified by a distribution factor (DF). The distribution factors (d kg^{-1} fresh weight) for beef for each contaminant (NSS) are:

U	2E-3
Th	4E-4
Ra	5E-4
Pb	2E-3
Po	4E-3

A1.4.4 Human Data (adults)

Individual Diet:

Meat (beef)	3.35E+1 kg (fresh weight) a^{-1}
Vegetables (leafy vegetables)	3.9E+1 kg (fresh weight) a^{-1}
Drinking water from the well	3.7E-1 $m^3\ a^{-1}$ (NSS)

Occupancy and Inhalation (NSS):

Occupancy: pasture land	8.76E+2 h a^{-1}
: leafy vegetable land	8.76E+2 h a^{-1}
Inhalation rate	9.6E-1 $m^3\ h^{-1}$

It is assumed that humans dwell in an uncontaminated area and therefore only receive external and inhalation doses whilst working on the pasture land and the land used for growing leafy vegetables.

A1.4.5 Factors for Converting Annual Intake and Concentrations to Radiation Dose (NSS)

These self-consistent factors have been provided by Charley Yu (Argonne National Laboratories) and represent effective dose equivalent values. "+D" after a radionuclide means that the contribution from daughters with half lives less than 30 days are included in the factor given for the parent. These short lived daughters are assumed to be in equilibrium with the parent in all parts of the system.

The inhalation and ingestion data are taken from Federal Guidance Report No. 11 (K F Eckerman, A B Wolbarst and A C B Richardson, 1988 "Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion - Derived Guides for Control of Occupational Exposure and Exposure-to-Dose Conversion Factors for General Application, Based on the 1987 Federal Radiation protection Guidance" Oak Ridge National Laboratory and Office of Radiation Programs,United States Environmental Protection Agency).

The external irradiation dose factors have been calculated using RESRAD Version 5.60. The pasture land external irradiation dose factors assume exposure is from a 1 cm depth of uniform contamination, whilst the leafy vegetable land factors assume exposure is from a 30 cm depth of uniform contamination.

	Inhalation Sv/Bq	Ingestion Sv/Bq	External Irradiation Sv h^{-1}/Bq kg^{-1} (soil)	
			Pasture Land	LeafyVegetable Land
U-238+D	3.2E-5	7.3E-8	9.9E-13	4.2E-12
U-234	3.6E-5	7.7E-8	5.5E-15	1.2E-14
Th-230	8.8E-5	1.5E-7	1.3E-14	3.7E-14
Ra-226+D	2.3E-6	3.6E-7	6.2E-11	3.4E-10
Rn-222+D*	3.9E-9	N/A	N/A	N/A
Pb-210+D	3.7E-6	1.5E-6	8.0E-14	1.9E-13
Po-210	2.5E-6	5.1E-7	3.1E-16	1.6E-15

*Only used for dose calculations involving the emission of Rn-222 from the tailings.

A1.4.6 Factors for Converting Annual Intake to Risk (NSS)

These self-consistent risk factors have been provided by Charley Yu (Argonne National Laboratories) and represent the lifetime total excess cancer risk per unit intake or exposure. If the intake occurs over one year, then the risk calculated is the lifetime risk from that year's intake. Likewise, for unit activity concentration in the soil, then the figures represent the lifetime risk from one year of exposure. The factors have been taken from "Health Effects Assessment Summary Table FY 1994, Supplement Number 2" United States Environmental Protection Agency, EPA/540/R-94/114, PB94-921102. "+D" after a radionuclide means that the contribution from daughters with half lives less than 30 days are included in the factor given for the parent. These short lived daughters are assumed to be in equilibrium with the parent in all parts of the system.

The external irradiation risk factors have been calculated by multiplying the risk factor for infinite depth by the ratio of the dose conversion factors at respective depth to infinite depth. The pasture land external irradiation risk factors assume exposure is from a 1 cm depth of uniform contamination, whilst the leafy vegetable land factors assume exposure is from a 30 cm depth of uniform contamination.

	Inhalation Risk/Bq	**Ingestion Risk/Bq**	**External Irradiation Risk $a^{-1}/Bq\ kg^{-1}$ (soil)**	
			Pasture Land	**Leafy Vegetable Land**
U-238+D	3.3E-7	1.7E-9	3.5E-10	1.5E-9
U-234	3.8E-7	1.2E-9	2.7E-13	5.8E-13
Th-230	4.6E-7	1.0E-9	4.3E-13	1.2E-12
Ra-226+D	7.4E-8	8.0E-9	3.2E-8	1.8E-7
Rn-222+D*	6.8E-10	N/A	N/A	N/A
Pb-210+D	4.6E-8	1.8E-8	1.3E-12	3.0E-12
Po-210	5.8E-8	8.8E-9	1.7E-13	8.9E-13

*Only used for risk calculations involving the emission of Rn-222 from the tailings.

APPENDIX A2

Probabilistic Case:

Source Term, Aquifer and Biosphere Data

A2.1 GROUNDWATER SOURCE TERM

As for the deterministic case. It is proposed that uncertainty analysis should be restricted to certain biosphere parameters, given that BIOMOVS II is concerned primarily with biosphere modelling.

A2.2 ATMOSPHERIC SOURCE TERM

As for the deterministic case. It is proposed that uncertainty analysis should be restricted to certain biosphere parameters, given that BIOMOVS II is concerned primarily with biosphere modelling.

A2.3 AQUIFER

As for the deterministic case. It is proposed that uncertainty analysis should be restricted to certain biosphere parameters, given that BIOMOVS II is concerned primarily with biosphere modelling.

A2.4 BIOSPHERE

In selecting the biosphere parameters to be sampled, it is proposed that one or more of the following criteria are met:

- the parameter values have a range of at least an order of magnitude;
- the parameter has a non-linear effect on dose;
- the parameter values are distributed non-uniformly.

In order to calculate the mean, standard deviation, minimum and maximum (on a log scale) of parameters which are specified as having a log normal distribution, the log of the appropriate parameter value specified below should be taken. For example, if the standard deviation of a distribution is given below as 2.5, then its standard deviation on a natural log scale is 0.9 (ie ln 2.5), or, if you wish to use a $\log_{10}$ scale, 0.4 (ie $\log_{10}$ 2.5).

At a Working Group meeting subsequent to the specification of the final description of the scenario, it was noted that none of the sampled parameters listed below are assumed to be correlated. It was felt that perhaps a negative correlation between TF_{SP} and K_d should have been introduced. However, it was agreed that the scenario should not be modified but that this possible "error" in the scenario description should be brought to the attention of readers.

A2.4.1 Atmospheric Data

As for the deterministic case except:

- The deposition velocity of resuspended soil particles (m s^{-1}) (NSS)

Distribution type	Normal
Arithmetic mean	1E-2
Arithmetic standard deviation	1E-3
Minimum	5E-3
Maximum	2E-2

A2.4.2 Agricultural Land Data

As for the deterministic case except:

- The foliar interception fraction for irrigation water (-) (NSS)

Distribution type	Log normal
Geometric mean	0.1
Geometric standard deviation	2.5
Minimum	0.01
Maximum	0.99

- The soil distribution coefficient (m^3 kg^{-1}) (NSS)

	U	Th	Ra	Pb	Po
Distribution type	<----------------------		Log normal		--------------------->
Geometric mean	9.97E-1	1E+0	1.28E+0	5E-2	5E-2
Geom. Stand. Dev.	2.5	2.15	2.15	1.9	1.73
Minimum	2.5E-1	1E-1	5E-1	1E-2	1E-2
Maximum	2.5E+1	1E+1	5E+1	5E-1	3E-1

- The soil to plant concentration factor (Bq kg^{-1} fresh weight plant/Bq kg^{-1} dry weight soil) (NSS)

	U	Th	Ra	Pb	Po
Distribution type	<----------------------		Log normal		--------------------->
Geometric mean	4E-3	4E-4	5E-2	2E-3	5E-3
Geom. Stand. Dev.	8.9	9	10	9	12
Minimum	5E-5	5E-6	5E-4	2E-5	5E-5
Maximum	3E-1	3E-2	1E+0	2E-1	5E-1

A2.4.3 Animal Data (beef cattle)

As for the deterministic case except:

- The distribution factor (d kg^{-1} fresh weight) for beef (NSS)

	U	Th	Ra	Pb	Po
Distribution type	<---------------------		Triangular		--------------------->
Minimum	2E-4	1E-4	1E-4	5E-4	1E-3
Mode	2E-3	4E-4	5E-4	2E-3	4E-3
Maximum	2E-2	1E-3	2E-3	6E-3	1E-2

A2.4.4 Human Data (adults)

As for the deterministic case.

A2.4.5 Factors for Converting Annual Intake to Radiation Dose

As for the deterministic case.

A2.4.6 Factors for Converting Annual Intake to Risk

As for the deterministic case.

Appendix B: V2.3 Scenario Description

B1. BACKGROUND

This V2.3 scenario description has been produced following discussions at the Uranium Mill Tailings Working Group meeting at the May 1995 meeting in Saskatoon. It is based on contributions provided by Working Group members and is designed to be a logical extension to the V2.2 scenario. It differs from the V2.2 scenario only in so far as the release of stable elements (As, Ni and Pb) is considered rather than the U-238 chain members. Unless stated otherwise, element dependent transport and uptake data for Pb are taken from the V2.2 scenario, whilst the As and Ni data are taken from the V1.07 scenario.

B2. BASIC SCENARIO DESCRIPTION V2.3

As, Ni and Pb are released in leachate from a uranium mill tailings pile into an aquifer underlying the pile. These contaminants are transported in groundwater through the aquifer to a well. Water is abstracted from the well and used for: watering beef cattle; human consumption; and irrigating leafy vegetables. It is assumed that the well water contains no particulates. The beef and leafy vegetables are consumed by humans living in the area.

The same contaminants are also released into the atmosphere due to the wind erosion of the pile and then deposited upon the soil, pasture and leafy vegetables.

The scenario is shown in Figures B1 and B2.

Detailed source term, aquifer and biosphere data for a deterministic case are given in Appendix B1, whilst data for a probabilistic case are given in Appendix B2. Many parameter values are taken from an actual uranium mill tailing site. Non site specific values have (NSS) next to them. Parameters have been given algebraic names, for example erosion rate is called "e". Please use the same names in any discussions/correspondence.

Figure B1: Plan View Representation of the V2.3 Scenario

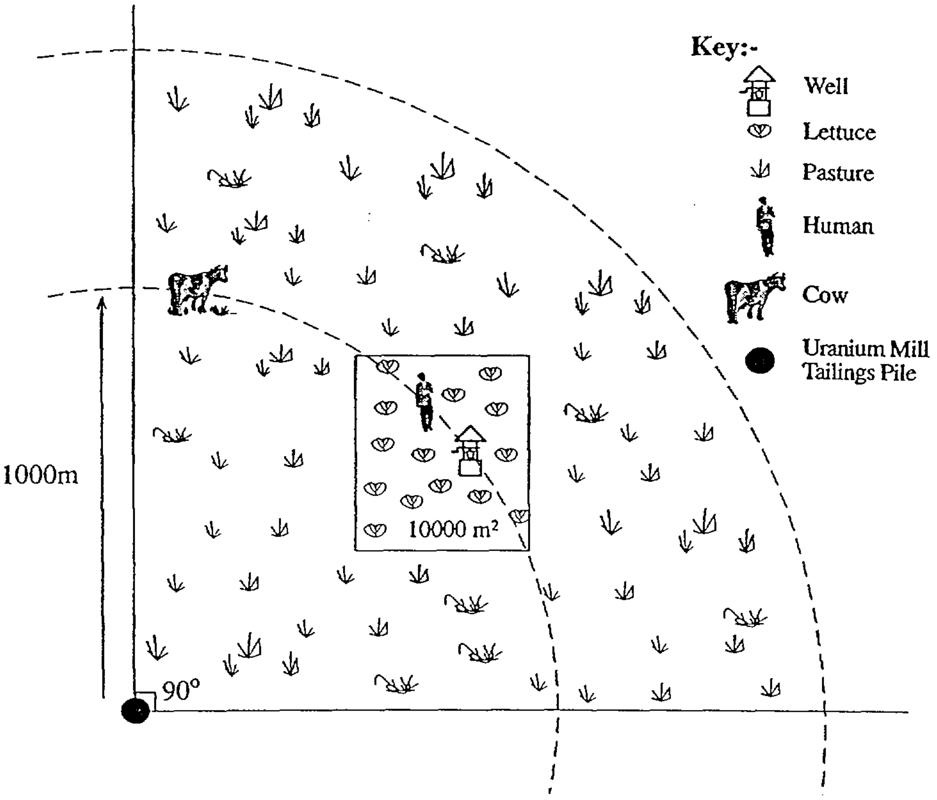
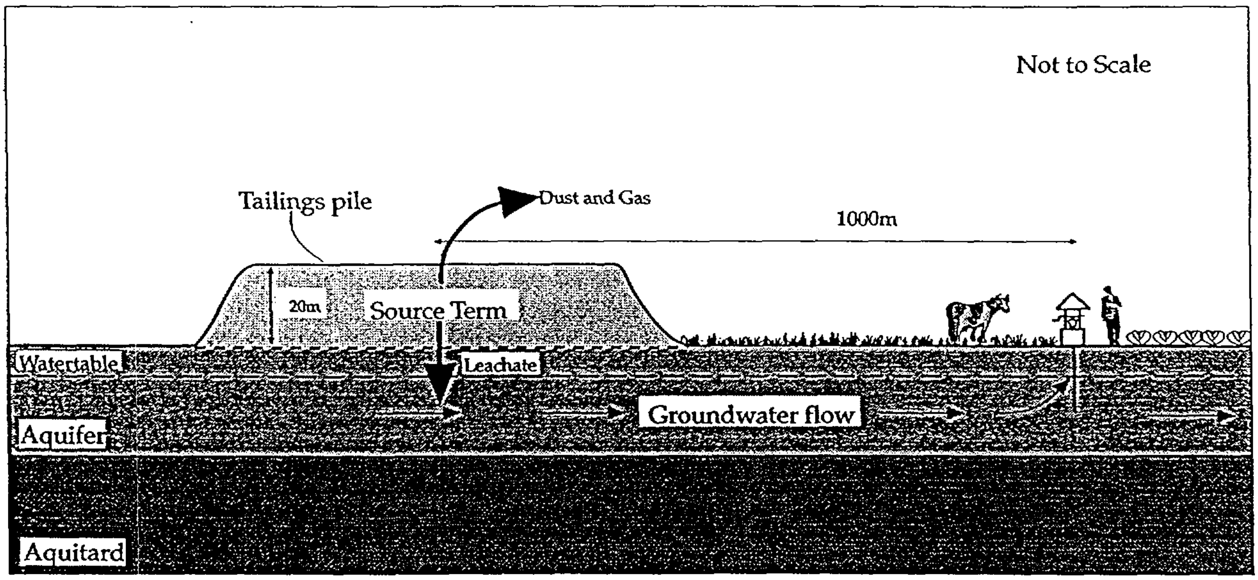


Figure B2: Cross Sectional Representation of the V2.3 Scenario



B3. MATERIAL REQUESTED FROM PARTICIPANTS

B3.1 DETERMINISTIC CASE

Assuming the characteristics specified in Appendix B1 for the various scenario components, the data itemized below are requested. Please present results as a function of time from time zero and in the units requested. Please truncate the calculations at 10000 years and ensure that results are given for no more than 100 output times.

For the atmospheric source term, calculations of concentration, intake and risk should be undertaken on the basis that deposition and exposure occurs 1000 m from the source.

(1) For each release type (groundwater and atmospheric), calculate the concentration of each contaminant in the following media:

- well water (mg m^{-3}) (groundwater source term only);
- air above the land used for growing leafy vegetables (mg m^{-3}) (atmospheric source term only);
- leafy vegetables (mg kg^{-1} fresh weight);
- beef (mg kg^{-1} fresh weight);
- soil used for growing leafy vegetables (mg m^{-3} wet weight).

Although contaminant concentrations in the pasture soil and air above the pasture land should be calculated, participants should not report these concentrations.

(2) For each release type and contaminant, calculate the annual intake (mg a^{-1}) by an adult for the following exposure pathways:

- ingestion of well water (groundwater source term only);
- * inhalation of dust (including resuspended dust);
- ingestion of vegetables (assumed to be leafy vegetables);
- ingestion of meat (assumed to be beef);

* For pathways marked with an asterix, the intake reported should represent intakes received from both the pasture land and the land used for growing leafy vegetables.

(3) For each release type and contaminant, calculate the annual intake (mg a^{-1}) by an adult summed across all the pathways specified in (2).

(4) For each release type and for As and Ni only, calculate the lifetime cancer incidence risk from one year's inhalation of each contaminant. Factors to convert annual intake (mg a^{-1}) into this quantity are provided in Appendix B1. Data are not available to allow the calculation of inhalation risk for Pb and ingestion risk for As, Ni and Pb.

(5) Participants are also requested to provide:

- a brief description of the application of their code(s) to the scenario, noting any ways in which they added to or had to modify the description of site characteristics and/or their code(s). In particular, participants should explain their approach to modelling the (re)suspension of soil particles into the air (for example do they assume that only the dry fraction of the soil is suspended);

- a diagram, for each of the groundwater and atmospheric source terms, indicating the components of the model and contaminant transfers;

- a brief commentary on the results produced;

- a reference for the code(s) used.

Please provide all these data as hard copy and on PC or Macintosh floppy disk in ASCII format. Please use a common file name structure for the results files, as explained below.

1st character identifies the nature of the case (ie deterministic)	D
2nd character, the source term	
groundwater	G
atmospheric	A
3rd character, the medium:	
well water	W
atmosphere	A
leafy vegetable	V
beef	B
soil	S
sum over pathways (total)	T
4th character, concentration, intake or risk	C, I, or R
5th character, contaminant:	
Stable elements	S

As examples, the intake from each stable element released in groundwater due to ingestion of leafy vegetable would be in the file DGVIS.DAT. Risk from inhalation from the atmospheric source term for As and Ni would be in the file DAARS.DAT. **It is very important to check that your results are in the correct units and that the files are correctly named.**

The following is the required layout for the data.

Line one. A title line, eg DGVIS, also giving the units in which results are reported. These should be as requested above, but respecifying them is intended to provide an additional check.

Line two. A header line as follows:

Time, a | As | Ni | Pb

Line three. The results at each time, eg

4E2 | 1.2E-6 | 1.8E-6 | 1.2E-8

B3.2 PROBABILISTIC CASE

Assuming the characteristics specified in Appendix B2 for the various scenario components, the data itemized below are requested. These calculational end-points are mostly taken from BIOMOVS II Technical Report No. 1 "Guidelines for Uncertainty Analysis" (Most, if not all current participants will already have received a copy. Further copies are available from the Secretariat). Relevant details are given in Sections 7 and 9 of TR1. As with the deterministic case, please truncate all calculations at 10000 years and, where appropriate, ensure that results are given for no more than 100 output times.

For the atmospheric source term calculations of concentration, intake and risk should be undertaken on the basis that deposition and exposure occurs 1000 m from the source.

(1) For each release type (groundwater and atmospheric) and each stable element (As, Ni and Pb) produce a graph of the cumulative distribution function (CDF) showing "peak total intake" against cumulative probability (see Figure 2a of BIOMOVS II TR1). "Peak total intake" is taken to be the peak annual intake (mg a^{-1}) by an adult due to the release of the stable element summed across all the pathways assessed.

(2) For each release type and each stable element, produce a graph showing mean total intake against time. At the time of peak mean total intake and at 10000 years, mark on the 5th and 95th percentiles which represent the lower and upper endpoints of the 90% confidence interval (see Section 9 of BIOMOVS II TR1). The 5th percentile represents the value of intake below which 5% of the sampled intakes lie.

(3) For each release type, each stable element, and each of the pathways listed below, produce a graph of mean intake from the pathway against time. At the time of peak mean intake and at 10000 years, mark on the 5th and 95th percentiles. The pathways to be considered are: ingestion of leafy vegetables; ingestion of beef; and inhalation of dust (including resuspended dust) from the soils used for growing leafy vegetables and pasture. The inhalation pathways should only be assessed for the atmospheric release.

(4) For each release type and each stable element, provide Spearman's rank correlation coefficient (RCC) for each of the sampled parameters against peak total intake. Details on how to calculate Spearman's rank correlation coefficient are given in IAEA Safety Series 100. Spearman's rank correlation coefficient measures the strength of an increasing or decreasing relationship between two variables.

(5) For each release type and each stable element, provide the standardised regression coefficient (SRC) and partial correlation coefficient (PCC) for each of the sampled parameters against peak total intake (see Sections 7.2 and 7.3 of BIOMOVS II TR1). These coefficients will provide a measure of the relative importance of the sampled parameters in affecting peak total intake.[1]

(6) Participants are also requested to provide:

- details of the sampling technique(s) used (eg Monte Carlo, Latin Hypercube);
- details of the convergence test(s) and stopping rule(s) used;
- a brief commentary on the results produced.

Please provide all these data as hard copy and on PC or Macintosh floppy disk in ASCII format. Please use a common file name structure for the results files, as explained below.

1st character identifies the nature of the case (ie probabilistic)	P
2nd character, the source term	
groundwater	G
atmospheric	A
3rd character, the pathway:	
atmosphere	A
leafy vegetable	V
beef	B
sum over pathways (total)	T
4th character, the endpoint:	
CDF	C
intake vs time	I
Spearman's rho	R
SRC	S
PCC	P
5th character, the contaminant:	
As	A
Ni	N
Pb	P

---

[1] At a Working Group meeting subsequent to the specification of the final descriptions of the scenarios it was agreed that SRC and PCC tests might not be ideal tests for parameters which have a non-linear effect upon the intake since they only test the linear relationship between the parameters and intake. It was felt that sample ranked SRC and PCC tests might have been more suitable given that most of the sampled parameters were considered to have a non-linear impact on intake. However, given the time constraints, it was not considered appropriate to ask participants to recalculate the ranked statistics. This limitation should be borne in mind when analysing the results from the tests reported in the main text.

As examples, data relating to the cumulative distribution function showing "total As intake" against cumulative probability for released in groundwater would be in the file PGTCA.DAT. The standardised regression coefficient for each of the sampled parameters against peak total Pb intake from the atmospheric source term would be in the file PATSP.DAT. It is very important to check that your results are in the correct units and that the files are correctly named.

The following is the required layout for the **CDF data files.**

Line one. A title line, eg PGTCA, also giving the units in which results are reported. These should be as requested above, but respecifying them is intended to provide an additional check.

Line two. A header line as follows:

Peak total As intake	Cumulative probability

Line three. The result at each cumulative probability step, eg:

4E-9	1.2E-3

The following is the required layout for the **mean intake against time data files.**

Line one. A title line, eg PGTIA, also giving the units in which results are reported. These should be as requested above, but respecifying them is intended to provide an additional check.

Line two. A header line as follow:

Time, a	Mean intake	5%tile of intake	95%tile of intake

Line three. The results at each output time, eg:

1E1	1.2E-9	4.5E-11	7.9E-7

Note that 5th and 95th percentiles should only be given at the time of peak mean intake and at 10000 years.

The following is the required layout for the **Spearman's rho, SRC and PCC data files.**

Line one. A title line, eg PGTPN, also giving the units in which results are reported. These should be as requested above, but re-specifying them is intended to provide an additional check.

Line two. A header line as follows:

Sampled parameter	Coefficient value

Line three. The result for each sampled parameter, eg

Distribution factor for beef	0.345

APPENDIX B1

Deterministic Case:

Source Term, Aquifer and Biosphere Data

B1.1 GROUNDWATER SOURCE TERM

The source term is the engineered uranium mill tailings pile. The time dependent flux of the stable elements to the underlying aquifer is given in Table 1 (note that the flux is given in units of mg a^{-1}). The flux data are derived from leachate concentration data collated from several tailings sites. The concentration data were converted to fluxes at time zero assuming the same water flux through the tailings as used in the V2.2 scenario. A time series was then generated by direct scaling with the V2.2 scenario U-238 fluxes.

Table 1:
Flux (mg a^{-1}) of stable elements to the aquifer as a function of time

Time(a)	Flux (mg a^{-1})		
	As	Ni	Pb
0-1	7.62E+4	4.57E+5	3.05E+5
1-2	4.65E+4	2.79E+5	1.86E+5
2-5	2.70E+4	1.62E+5	1.08E+5
5-10	1.56E+4	9.38E+4	6.26E+4
10-20	4.07E+3	2.49E+4	1.63E+4
20-50	2.15E+3	1.29E+4	8.62E+3
50-100	1.16E+3	6.98E+3	4.66E+3
100-10000	9.08E+2	5.44E+3	3.63E+3

B1.2 ATMOSPHERIC SOURCE TERM

The source term is the engineered uranium mill tailings pile. The time dependent flux of the stable elements to the atmosphere is given in Table 2 (note that the flux is given in units of mg s^{-1}). For all contaminants, the flux is due to wind erosion of the pile. The flux has been calculated by multiplying the measured concentration of each contaminant in the pile (mg kg^{-1}) by the area of the pile (m^2) and a time dependent wind erosion rate (kg m^{-2} s^{-1}). The concentration of each contaminant in the pile has been taken from data collated from several tailings sites.

The time dependent nature of the fluxes reflects the impact of the erosion of the cap covering the pile. It is assumed that the cap is fully intact for the first 200 years and hence prevents any emissions. Thereafter the cap gradually fails until it has totally failed at 1000 years.

Table 2:
Flux (mg s^{-1}) of stable elements members to the atmosphere as a function of time

Time(a)	As	Ni	Pb
0-200	0.0	0.0	0.0
200-300	7.94E-3	4.77E-3	9.21E-2
300-400	1.59E-2	9.53E-3	1.84E-1
400-500	2.38E-2	1.43E-2	2.76E-1
500-600	3.18E-2	1.91E-2	3.68E-1
600-700	3.97E-2	2.38E-2	4.61E-1
700-800	4.77E-2	2.86E-2	5.53E-1
800-900	5.56E-2	3.34E-2	6.45E-1
900-1000	6.36E-2	3.81E-2	7.37E-1
1000-10000	7.15E-2	4.29E-2	8.29E-1

B1.3 AQUIFER

Hydraulic conductivity	k	= 1.0E+5 m a^{-1}
Hydraulic gradient from below pile to well	i	= 4.0E-3
Cross sectional area of flow	A	= 4.2E+3 m^2
Total porosity	ε_t	= 3.5E-1
Effective porosity	ε_e	= 2.0E-1
Dispersion coefficient*	D_L	= 1.46E+4 m^2 a^{-1}
Distribution coefficient for As	K_d	= 5E-1 m^3 kg^{-1} (NSS)
Distribution coefficient for Ni	K_d	= 1E-3 m^3 kg^{-1} (NSS)
Distribution coefficient for Pb	K_d	= 5E-2 m^3 kg^{-1} (NSS)
Dry bulk density	ρ_b	= 1.76E+3 kg m^{-3}
Abstraction rate from well**	a	= 1.0E+4 m^3 a^{-1}

*This term represents longitudinal dispersion only. Diffusion and transverse dispersion are assumed to be insignificant. From the data provided, a longitudinal dispersity (α_L) of 7.3 m can be calculated.

**This abstraction rate is assumed to meet all requirements for drinking water for humans and cows, as well as crop irrigation needs.

The flux of groundwater contaminants (given in Table 1) is assumed to be an instantaneously diluted vertical planar source which enters the aquifer 1000 m upstream from the well. The product of k, i and A gives an annual flow rate in the aquifer of 1.68E+6 m^3.

B1.4 BIOSPHERE

B1.4.1 Atmospheric Data

Note that for the atmospheric source term, calculations of concentration, intake and risk should be undertaken on the basis that deposition and exposure occurs 1000 m from the source.

The following conditions are assumed during the atmospheric release:

Wind Rose	Stability category	D
	Average windspeed	2.1 m s^{-1}
	Release height	20 m
	Wind blows into chosen 90° sector 30% of the time	

The radon equilibrium factor is assumed to be 0.2.

Resuspended soil particles (NSS):

Resuspension layer	R_l =	1E-2 m
Resuspension factor	R_{fs} =	1E-9 m^{-1}
Deposition velocity	V_{gs} =	1E-2 m s^{-1} (~1μm median aerodynamic diameter)

B1.4.2 Farming Land Data

Ploughing depth for vegetable growing land	P_d = 3.0E-1 m
Ploughing frequency for vegetable growing land	P_f = 1 a^{-1}
Total porosity	ε_t = 4.2E-1
Effective porosity	ε_e = 3.4E-1
Fraction of total porosity filled with water	f_w = 0.81
Distribution coefficient for As	K_d = 5E-1 $m^3\,kg^{-1}$ (NSS)
Distribution coefficient for Ni	K_d = 1E-3 $m^3\,kg^{-1}$ (NSS)
Distribution coefficient for Pb	K_d = 5E-2 $m^3\,kg^{-1}$ (NSS)
Dry bulk density	ρ_b = 1.35E+3 kg m^{-3}
Erosion rate	e = 8.5E-1 kg $m^{-2}\,a^{-1}$

It is assumed that the farming land is used for the growing of leafy vegetables (Veg) and pasture (Past) and that only the land used for growing leafy vegetables is ploughed. The relevant parameters are as follows:

	Y	N_S	N_l	Tv	V	A	I	I_n
Veg	1.57	0.7	0.1	14	90	1E+4	8.76E-3	0.520
Past	1.85	0.5	N/A	14	180	3E+6	0.0	0.125

where:

Y	annual yield (kg fresh weight m^{-2})
N_s	foliar interception fraction for dust (-) (NSS)
N_l	foliar interception fraction for irrigation water (-) (NSS)
T_v	weathering half life for intercepted dust and irrigation water (d) (NSS)
V	growing period (d) (NSS)
A	cultivated area (m^2)
I	irrigation rate* ($m^3\,m^{-2}\,d^{-1}$)
I_n	net infiltration through soil** ($m^3\,m^{-2}\,a^{-1}$)

*Irrigation is assumed to occur only during the vegetable growing period.

Thus 7.88E+3 m^3 is applied over a period of 90 days and so the effective irrigation rate if extrapolated over 365 days is 3.20E+4 m^3 y^{-1}. It is this rate that participants should use when calculating the concentration on the vegetables. However, 7.88E+3 m^3 y^{-1} should be used when calculating the concentration in soil.

**Takes into consideration precipitation, evapotranspiration and, for irrigated land, irrigation. Note that only the land used for growing leafy vegetables is irrigated. Two factors result in the infiltration value being higher for the irrigated land. Firstly, irrigating at the site specific irrigation rate results in a surplus of irrigation water even after evapotranspiration losses and the water required to restore the soil to field capacity have been taken into account (the implied irrigation efficiency is about 50%). The surplus water is assumed to infiltrate through the soil. Secondly, irrigation prevents a soil moisture deficit from developing during the summer which in turn results in the field capacity being restored more rapidly in the winter period, resulting in higher winter infiltration rates.

The soil to plant concentration factors (TF_{SP}, mg kg^{-1} fresh weight plant/mg kg^{-1} dry weight soil) for each contaminant (NSS) are:

As	4E-3
Ni	5E-3
Pb	2E-3

Soil splash, translocation of activity from external to internal plant surfaces, and losses due to harvesting and food preparation should be ignored. However, losses due to weathering should be considered. The soil to plant concentration factors given above should be used for both leafy vegetables and pasture, and represent the fraction of each element which is transferred from the soil to the plant via root uptake (foliar uptake is considered separately).

Loss of elements from the soil is assumed to occur due to erosion of the soil, and net infiltration of water through the soil. Other loss processes should be ignored.

B1.4.3 Animal Data (beef cattle)

Individual Diet (NSS):

Drinking water from the well	0.05 m^3 d^{-1}
Pasture grass	50 kg (wet weight) d^{-1}
Soil	0.5 kg (wet weight) d^{-1}

Occupancy and Inhalation (NSS):

Occupancy: pasture	24 h d^{-1}
Inhalation rate	150 m^3 d^{-1}

For the groundwater release, it is assumed that the beef cattle are contaminated by consumption of well water only. For the atmospheric release, it is assumed that they are contaminated only by consumption of contaminated pasture, soil, and inhalation of contaminated soil and air.

The transfer of individual contaminants to beef is quantified by a distribution factor (DF). The distribution factors (d kg^{-1} fresh weight) for beef for each contaminant (NSS) are:

As	5E-1
Ni	5E-3
Pb	2E-3

B1.4.4 Human Data (adults)

Individual Diet:

Meat (beef)	3.35E+1 kg (fresh weight) a^{-1}
Vegetables (leafy vegetables)	3.9E+1 kg (fresh weight) a^{-1}
Drinking water from the well	3.7E-1 m^3 a^{-1} (NSS)

Occupancy and Inhalation (NSS):

Occupancy: pasture land	8.76E+2 h a^{-1}
: leafy vegetable land	8.76E+2 h a^{-1}
Inhalation rate	9.6E-1 m^3 h^{-1}

It is assumed that humans dwell in an uncontaminated area and therefore only intake stable elements via the inhalation pathway whilst working on the pasture land and the land used for growing leafy vegetables.

B1.4.5 Factors for Converting Annual Intake to Risk (NSS)

These self-consistent risk factors represent the lifetime total excess cancer risk per unit intake. If the intake occurs over one year, then the risk calculated is the lifetime risk from that year's intake. The factors have been derived from data in "Health Effects Assessment Summary Table FY 1994, Supplement Number 2" United States Environmental Protection Agency, EPA/540/R-94/114, PB94-921102.

	Inhalation Risk/mg	**Ingestion Risk/mg**
As	2.8E-5	No data
Ni	4.7E-7	No data
Pb	No data	No data

APPENDIX B2

Probabilistic Case:

Source Term, Aquifer and Biosphere Data

B2.1 GROUNDWATER SOURCE TERM

As for the deterministic case. It is proposed that uncertainty analysis should be restricted to certain biosphere parameters, given that BIOMOVS II is concerned primarily with biosphere modelling.

B2.2 ATMOSPHERIC SOURCE TERM

As for the deterministic case. It is proposed that uncertainty analysis should be restricted to certain biosphere parameters, given that BIOMOVS II is concerned primarily with biosphere modelling.

B2.3 AQUIFER

As for the deterministic case. It is proposed that uncertainty analysis should be restricted to certain biosphere parameters, given that BIOMOVS II is concerned primarily with biosphere modelling.

B2.4 BIOSPHERE

In selecting the biosphere parameters to be sampled, it is proposed that one or more of the following criteria are met:

- the parameter values have a range of at least an order of magnitude;
- the parameter has a non-linear effect on intake;
- the parameter values are distributed non-uniformly.

In order to calculate the mean, standard deviation, minimum and maximum (on a log scale) of parameters which are specified as having a log normal distribution, the log of the appropriate parameter value specified below should be taken. For example, if the standard deviation of a distribution is given below as 2.5, then its standard deviation on a natural log scale is 0.9 (ie ln 2.5), or, if you wish to use a $\log_{10}$ scale, 0.4 (ie $\log_{10}$ 2.5).

At a Working Group meeting subsequent to the specification of the final description of the scenario, it was noted that none of the sampled parameters listed below are assumed to be correlated. It was felt that perhaps a negative correlation between TF_{SP} and K_d should have been introduced. However, it was agreed that the scenario should not be modified but that this possible "error" in the scenario description should be brought to the attention of readers.

B2.4.1 Atmospheric Data

As for the deterministic case except:

- The deposition velocity of resuspended soil particles (m s^{-1}) (NSS)

Distribution type	Normal
Arithmetic mean	1E-2
Arithmetic standard deviation	1E-3
Minimum	5E-3
Maximum	2E-2

B2.4.2 Agricultural Land Data

As for the deterministic case except:

- The foliar interception fraction for irrigation water (-) (NSS)

Distribution type	Log normal
Geometric mean	0.1
Geometric standard deviation	2.5
Minimum	0.01
Maximum	0.99

- The soil distribution coefficient (m^3 kg^{-1}) (NSS)

	As	Ni	Pb
Distribution type	<---------Log	normal---------	>
Geometric mean	5E-1	1E-3	5E-2
Geom. Stand. Dev.	2.5	2.5	1.9
Minimum	8E-2	2E-4	1E-2
Maximum	3E+0	6E-3	5E-1

- The soil to plant concentration factor (mg kg^{-1} fresh weight plant/mg kg^{-1} dry weight soil) (NSS)

	As	Ni	Pb
Distribution type	<---------Log	normal---------	>
Geometric mean	4E-3	5E-3	2E-3
Geom. Stand. Dev.	16	4.6	9
Minimum	2E-5	2E-4	2E-5
Maximum	1E+0	1E-1	2E-1

B2.4.3 Animal Data (beef cattle)

As for the deterministic case except:

- The distribution factor (d kg^{-1} fresh weight) for beef (NSS)

	As	Ni	Pb	
Distribution	<--Log normal-->		Triangular	
Geometric mean	5E-1	5E-3	Mode	2E-3
Geom. Stand. Dev	2.5	5		
Minimum	8E-2	2E-4	Minimum	5E-4
Maximum	3E0	1E-1	Maximum	6E-3

B2.4.4 Human Data (adults)

As for the deterministic case.

B2.4.5 Factors for Converting Annual Intake to Radiation Intake

As for the deterministic case.

B2.4.6 Factors for Converting Annual Intake to Risk

As for the deterministic case.

Appendix C: Descriptions of Models Applied to the V2.2 and V2.3 Scenarios

The following are summaries of information on the models supplied by participants relevant at the time when calculations were done. The summaries include comments on how the models have been applied to the V2.2 and V2.3 scenarios. Where the models have been adapted to allow inclusion of features in the scenarios, these adaptions are noted. Where features in the scenarios have had to be modified to allow the application of the model, these modifications are also noted.

C1 GEOS/ABRICOT

For the V2.2 and V2.3 scenarios, the GEOS V2.0 code was used to calculate the transfer of radionuclides through the aquifer, and ABRICOT V2.0 [C1.1] was used to calculate the transfers into the biosphere. GEOS was developed in 1994 to replace the code used in the V1.07 scenario, GEOLE, but the basic concepts are the same [C1.2].

C1.1 Groundwater Release

For the V2.2 scenario, it was necessary to introduce the ingrowth of daughters into GEOS. To deal with daughters, some approximations were made. Indeed, GEOS is based on the analytical solution of the transport equation (transport by advection-dispersion affected by radioactive decay and sorption) in an homogeneous medium. It is not possible to use this type of solution for daughters. To keep this method of solution, it is necessary to approximate the transport of daughters. Some simplifications have been made. For simple cases (dependent on the radioactive decays of the parent and the daughter, and on the retardation factor), it is supposed that there is equilibrium between parent and daughter. For other cases, the quantity of daughter produced by decay during the travel of the parent through the aquifer is estimated and it is injected as a source term (adding this quantity to the initial source term of daughter). For the final set of results this procedure was improved by discretising the aquifer into a series of intermediate at which the daughter could be injected (Figure C1.1).

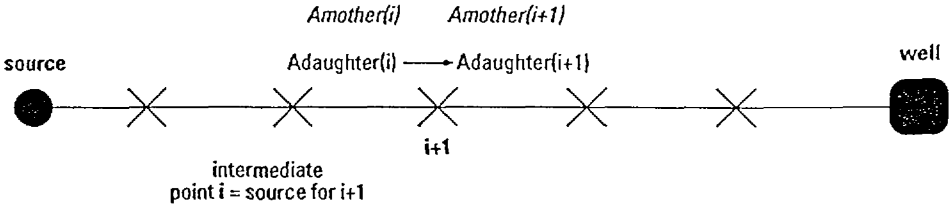


Figure C1.1: Aquifer Discretisation in GEOS for the V2.2 Scenario

C1.2 Atmospheric Release

For the V2.2 and V2.3 scenarios, the atmospheric source term model was based on the formula used by Martin [C1.3]. The formula used is the semi-empirical solution of the dispersion equation in the atmosphere. It calculates the mean concentration in the air at a given point, due to a point source with a continuous flux:

$$C(V,S,d)=\frac{0.399\cdot Q}{u\cdot\sigma_z\cdot d\cdot\omega}\times\left\{\exp\left[-\frac{(hs-h)^2}{2\cdot\sigma_z^2}\right]+\exp\left[-\frac{(hs+h)^2}{2\cdot\sigma_z^2}\right]\right\}\quad\text{, with}$$

C, concentration of radon or dust in the air (Bq.m^{-3}) or (mg m^{-3}),
h, the height of the point,
V,and S, classes of wind and atmospheric stability,
d, distance between the source and the point (m),

w, direction of the wind (radian),
u, wind's speed ($m.s^{-1}$),
σ_Z, standard deviation (m) of the concentration's distribution (Briggs),
hs, the release height (m).

In this formula, radioactive decay and ingrowth is ignored.

The annual mean concentration (Cm) is obtained by multiplying C by the frequency of occurrence (f):

$$Cm = f.C$$

To calculate the impact due to the atmospheric source term, the mean concentration of each contaminant in the air is calculated and the annual surface deposition of dust (Bq m^{-2} y^{-1}) or (mg m^{-2} y^{-1}) for each steady release step. For each step of release, these two constant values are introduced into ABRICOT V2.0 to calculate the concentrations in each compartment and the doses/intakes received for each pathway.

C1.3 Biosphere Modelling

The compartments and pathways modelled in ABRICOT V2.0 are shown in Figure C1.2. The resuspension of soil particles is not explicitly modelled. For all cases a concentration of dust in the air equal to 1 E-07 kg m^{-3} is assumed. It is assumed that both the dry and wet fraction of the soil is suspended.

A deposition velocity of 1 E-03 m s^{-1} for the particles is used.

C1.4 Probabilistic Modelling

Latin Hypercube sampling was used to generate a sample size of 340 for the V2.2 scenario and 440 samples for the V2.3 scenario. No convergence test was used to select these values.

Resuspension is not explicitly modelled in ABRICOT and so it was not possible to sample the resuspended soil particles. To simulate variability in the deposition velocity, variability in the concentration of dust in air was introduced. This parameter (kg m^{-3}) was assumed to have a lognormal distribution, with minimum equal to 1E-08 and maximum equal to 1E-06. Sensitivity analysis was undertaken on the ranked and not on the direct values of the parameters.

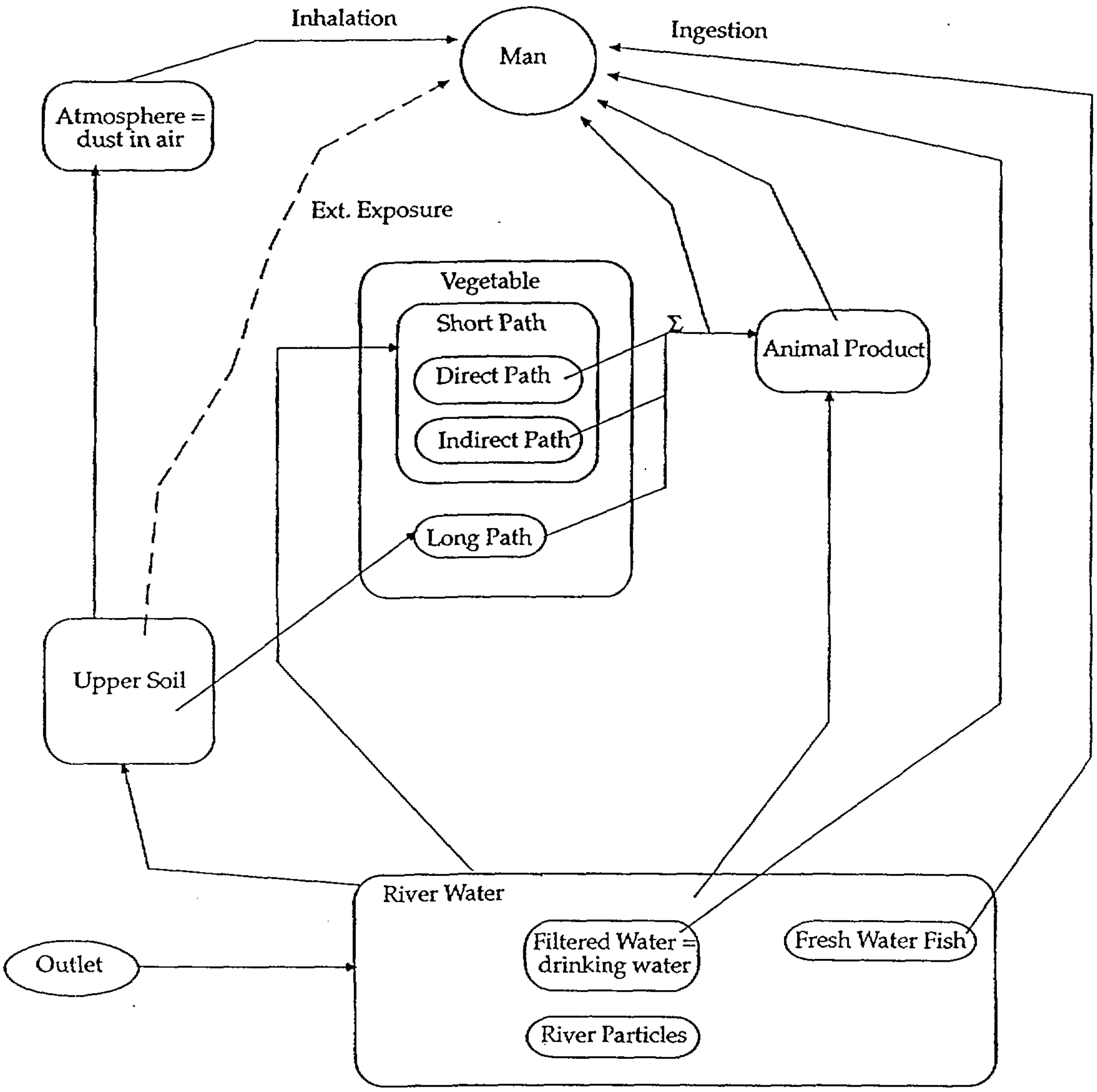


Figure C1.2: ABRICOT V2.0 Compartments and Pathway

C1.5 References

[C1.1] Santucci P (1995). Conceptual and Mathematical Modelling of the Biosphere: ABRICOT Version 2.0. IPSN/DPEI/SERGD/95/04.

[C1.2] Ferry C (1995). GEOS V1.0: Transfer of Radionuclides through the Geosphere from Near-Surface Radioactive Waste Disposals. IPSN/DPEI/SERGD/95/14.

[C1.3] Martin D O (1971). An Urban Diffusion Model for Estimating Long Term Average Values of Air Quality. J. Air Poll. Control Assoc. 21 (1), p 16-19.

C2 IMPACT (as used by Beak Consultants)

C2.1 Model Description

Environmental IMPACT (Integrated Model for the Probabilistic Assessment of Contaminant Transport) has evolved from the ETP model that was developed by Beak on behalf of the Atomic Energy Control Board (AECB). It simulates multimedia contaminant fate and transport, calculates contaminant uptake and transfer through the food chain, and estimates dose and risk to man and other biota. It accepts time-varying contaminant fluxes to air, water, groundwater, soil or sediment, at multiple locations, and predicts exposure concentrations, dose and risk to multiple receptors at specified locations. It also includes radionuclide decay and ingrowth, a soil weathering model and a probabilistic option.

Groundwater transport is represented by a choice of either a steady-state flow and transport or dynamic 1-D model, which includes adsorption, dispersion, radioactive decay and ingrowth. Atmospheric dispersion is represented by a Gaussian plume model using triple joint frequency meteorological data, including radioactive decay and ingrowth, deposition to soil and resuspension from soil. Soil weathering in response to precipitation is represented by separate erosion and leaching processes which respond to site features such as topography and cover. Aquatic transport is represented by a steady-state mixing model, with deposition to sediment, two-way diffusional exchange between the sediment and water column, burial and radionuclide decay and ingrowth. The sediment model contains shallow and deep layers which can have different characteristics.

Contaminant uptake and transfer through the food chain are represented as a linear, steady-state process. Routes of exposure for man and biota include ingestion, inhalation, dermal absorption, external irradiation by air and water immersion, and groundshine.

The model contains an extensive database of default chemical contaminant properties, and human and ecological receptor properties, to permit rapid completion of a wide variety of screening level risk assessments. Its graphical user interface permits rapid construction of contaminant release, transport and exposure scenarios, using cut and paste features, and visual display of scenarios and results in a spatially explicit (GIS) format. All user input values are directly traceable and referenceable within a the model database.

Simulations can be performed in deterministic or probabilistic model. In probabilistic simulations, uncertainty distributions can be defined for any model input parameter. Means and percentiles over multiple iterations are reported for each predicted concentration, dose or risk, at each receptor location and time step.

A user manual for the version used for the V2.2 and V2.3 scenarios (Version 2.0) [C4.1], documents all contaminant dispersion and transfer equations and dose and risk calculations. These are based on standard screening level conceptual models [C4.2, C4.3, C4.4, C4.5] with addition of special features such as decay and ingrowth. Figure B2.1 illustrates the human exposure pathways.

C2.2 Application to V2.2 and V2.3 Scenarios

The site was descretized into three "polygons": a tailings area containing the uranium mill tailings; a "pasture" polygon containing forage grass and the beef cow; and a "garden" polygon containing the leafy vegetables. The human receptor was assumed to inhabit both polygons.

The groundwater source term for V2.2 scenario was converted from annual flux rates in Bq y^{-1} to porewater concentrations in Bq l^{-1} by assuming a flow rate of 1.68E9 l y^{-1} (53.3 l s^{-1}) from the tailings into the aquifer (i.e all flow in the aquifer orginates as infiltration through the tailings). The calculated porewater concentrations in the tailings were used as initial boundary conditions for a one-dimensional finite-difference groundwater flow and transport model. This model calculated the concentration of contaminants in groundwater over a 10,000 year period in the well 1000 m from the tailings. The concentrations in the well were then used as input values for the subsequent food chain calculations.

A similar technique was used to derive the groundwater source term for the V2.3 scenario.

The atmospheric source term for the V2.2 scenario was used for input to a Gaussian plume air dispersion model that incorporates the effects of plume depletion due to settling and radioactive decay. The wind rose was divided into 16 sectors, with the frequency in the sector containing the receptor = 7.5% (30% for 90° quadrant containing 4 sectors).

As specified in the scenario description, the well water was applied to leafy vegetables and garden soil at a rate of 8.76E-3 m^3 m^{-2} d^{-1}, from which an average annual irrigation rate of 7.88E+2 l m^{-2} y^{-1} was calculated.

For the purposes of dose calculation due to external soil irradiation in the V2.2 scenario, the human receptor was assumed to spend 876 hours per year outdoors in each polygon exposed to the contaminated soil. Dust resuspension was modelled using an empirical resuspension factor of 1E-9 m^{-1} and a resuspension layer thickness of 1E-2 m. For the purposes of inhalation dose calculations, only the sorbed fraction of contaminants in the soil was assumed to be available for resuspension as dust. The partitioning of contaminants between the solid phase and liquid phase was calculated using the distribution coefficients (K_d) specified in the scenario for soil.

For probabilistic calculations, due to a limitation in the IMPACT model, it was not possible to vary the deposition velocity of resuspended soil particles as specified in the scenario description. Instead, a constant value of 1E-2 m s^{-1} was assumed for the deposition velocity.

The atmospheric release scenarios were run in probabilistic mode for 500 iterations using a Monte Carlo sampling technique, whilst the groundwater release scenarios were run for 300 iterations. The deposition velocity was not sampled because it was not explicitly used by the model. No convergence criteria were used - simulations were stopped after the specified number of iterations was complete.

C2.3 References

[C4.1] Beak Consultants (1995). Environmental IMPACT Revised Draft User Manual, Version 2.0.

[C4.2] Canadian Standards Association (CSA) (1987). Guidelines for Calculating Derived Release Limits for Radioactive Material in Airborne and Liquid Effluents for Normal Operation of Nuclear Facilities. CAN/CSA-N288.1-M87.

[C4.3] IAEA (1989). The Application of the Principles for Limiting Releases of Radioactive Effluents in the Case of the Mining and Milling of Radioactive Ores, Safety Series No. 90.

[C4.4] U.S. Environmental Protection Agency (EPA) (1989). Risk Assessment Guidance for Superfund Volume I Human Health Evaluation Manual (Part A). EPA/540/1-89/002. Washington, D.C.

[C4.5] U.S. Environmental Protection Agency (EPA) (1992). Framework for Ecological Risk Assessment. EPA/630/R-92/001. Washington, D.C.

C3 IMPACT (as used by AECB)

C3.1 Model Description

See Section C2.1 for model description.

C3.2 Application to V2.2 and V2.3 Scenarios

Calculations were based on the scenario descriptions provided in Appendices A and B of this report. Results were calculated for 10,000 years at time steps of 1 year.

The Gaussian plume atmospheric model used the concept of a single virtual-point source. A 16-sector wind rose was modified to approximate the atmospheric stability and wind frequency data provided in the scenario descriptions. A particulate size fraction of 10-20 µm was chosen to approximate the specified deposition velocity of 1.0E-2 m s^{-1}.

The groundwater source term was converted from the specified annual flux rates to porewater concentrations in Bq (mg) l^{-1}, by assuming a flow rate of 1.68E+9 l y^{-1} in the aquifer. The groundwater transport model used a darcy velocity value of 1.27E-5 m s^{-1} (ie., k*i), and an effective porosity value of 0.2.

The model calculates soil concentrations as Bq (mg) m^{-2}. Output was converted to Bq (mg) m^{-3} to conform with the scenario output specification. Consequently, the external irradiation dose conversion factors (DCFs) required conversion from units of Sv h^{-1}/Bq kg^{-1} to Sv y^{-1}/Bq m^{-2}.

An effective irrigation rate of 3.197 m y^{-1} (1.014 l m^{-2} s^{-1}) was used.

For probabilistic calculations, it was not possible to vary the deposition velocity of resuspended soil particles as specified in the scenario description. Instead, the value used in the deterministic calculations was used as a constant. All probabilistic simulations were run for 100 iterations.

C4 INTAKE

C4.1 Model Description

The INTAKE model for environmental transfer, uptake and risk used by SENES to assess the V2.2 and V2.3 scenarios is a modified version of the environmental pathways portion of the UTAP (Uranium Tailings Assessment Program) model.

The original UTAP model was developed by SENES under contract to the National Uranium Tailings Program (NUTP) established by Energy Mines and Resources Canada [C4.1 - C4.3]. During the development of the UTAP code the following issues, amongst others, were addressed: characterization of a typical reference tailings site; selection of key pathways of radionuclide exposure of receptors; assessment of probability distributions used to specify physical, chemical and behaviourial parameters; and evaluation of sensitivity and uncertainty analysis techniques for analyzing results. The result of this work was a flexible probabilistic assessment code (implemented in FORTRAN) which can aid in the evaluation of impacts resulting from tailings both during operation and following close out. The UTAP model consists of several component modules or sub-programs which implement mathematical models specifying processes occurring in both the tailings and their surrounding environment.

The original program was modified [C4.4 - C4.9] to incorporate modelling of Po-210 and stable metals and to allow matrices of certain values calculated external to the model (eg air concentrations or water source term concentrations) to be input if desired instead of using values calculated from models built into the code. The SENES pathways program models radionuclides (natural uranium, Th-230 or total thorium, Ra-226, Rn-222, Pb-210 and Po-210), stable metals and other ions dissolved in the aqueous phase. Other species can be added as needed.

Other modifications made to the model in recent studies include the addition of small game (hare, fowl) pathways, inhalation pathways for animals, soil ingestion by animals and the ability to model total concentrations in the environment (and doses) as opposed to incremental affects [C4.4 - C4.7].

C4.2 Application to V2.2 and V2.3 Scenarios

For the V1.07 scenario, the pathways model used had been modified to include: groundwater modelling of stable metals; human intake of metals, irrigation, beef cattle (rather than wild game and including pasture, soil, water and inhalation pathways); the option for direct consumption of well water by both human receptors and cattle; (resuspension of dust; and soil erosion). Risk estimation had also been incorporated into the model as a result of the V1.07 scenario.

The only alterations made to INTAKE for the V2 application were minor adjustments in array dimensions to allow for varying infiltration rates depending on the use of irrigation and to allow for a receptor to reside outside of the study area, in an unimpacted zone.

Figures C4.1 and C4.2 show the exposure pathways modelled for the V2 application for the groundwater and air source terms, respectively.

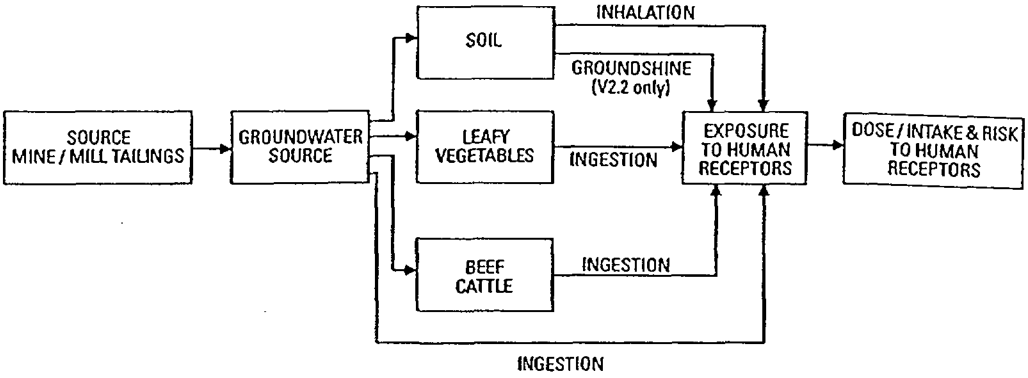


Figure C4.1: Groundwater Source Exposure Pathways in INTAKE

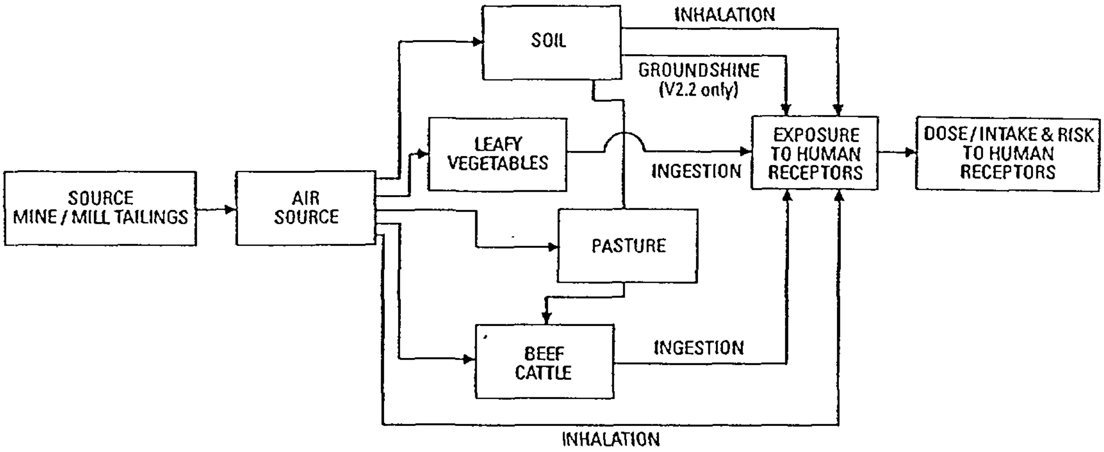


Figure C4.2: Atmospheric Source Exposure Pathways in INTAKE

INTAKE is built within RANSIM (RANdom SIMulation), a model framework developed by SENES for probabilistic modelling. The technique employed involves Monte Carlo sampling of specified distributions.

The probability integral transformation, which makes use of the cumulative probability function, is used to generate random variables from triangular and normal distributions. (RANSIM allows for sampling from numerous other distributions that are not used in the present application.) The normal distribution is approximated by a rational function developed by [C4.10].

A number of key assumptions and variations from the V2.2 and V2.3 scenario descriptions were made. These are outlined as follows.

1. The SENES model contains a detailed two layer soil model which incorporates atmospheric depostion, irrigation water application, leaching in soil water, erosion, surface runoff and radioactive decay and ingrowth. For the purpose of this application, the upper layer, typically modelled as a thin

layer of organic material, was modelled as consisting of the same topsoil as the lower layer. The ploughing depth was used as the depth of the first soil layer for the vegetable crop area, having a depth of 0.3m. Ploughing frequency was not directly accounted for in the modelling; however, a uniform concentration was assumed over the 0.3m layer (the depth of ploughing).

2. The model assumes that 50% of suspended particulate is from resuspended dust [C4.11] and does not specifically employ the resuspension factor given in the scenario description.

3. U-238 and U-234 are modelled as natural uranium with average properties of the two isotopes.

C4.3 References

[C4.1] SENES Consultants Limited (1987). Uranium Tailings Assessment Program (UTAP. 3): Component Model Documentation. Research Report Prepared for the National Uranium Tailings Program, CANMET, EMR, under Supply and Services Contract No. 23317-6-1728/01 SQ.

[C4.2] SENES Consultants Limited (1986). Probabilistic Model Development for the Assessment of the Long-Term Effects of Uranium Mill Tailings in Canada - Phase III. Research Report prepared for the National Uranium Tailings Program, CANMET, EMR, under supply and Services Canada Contract No. OSQ85-00182.

[C4.3] SENES Consultants Limited (1985). A Study to Develop and Demonstrate Techniques for the Probabilistic Assessment of the Long-Term Effects of Uranium Mill Tailings in Canada - Phase II. Research Report prepared for the National Uranium Tailings Program, CANMET, EMR, under Supply and Services Canada Contract No. OSQ84-00207.

[C4.4] SENES Consultants Limited, SENES Oak Ridge Inc. And Terrestrial and Aquatic Environmental Managers Ltd (1994). Screening Level Ecological Risk Assessment - McArthur River Project. Prepared for Cameco Corporation.

[C4.5] SENES Consultants Limited (1994). Human Health and Environmental Pathways Analyses, McArthur River Project Operating Phase. Draft, June.

[C4.6] SENES Consultants Limited (1991). McClean Lake Project Environmental Impact Statement. Prepared for Minatco Ltd, August.

[C4.7] SENES Consultants Limited (1991). Environmental Impact Statement for a Proposed Uranium Mine and Mill. Prepared for Midwest Joint Venture, August.

[C4.8] SENES Consultants Limited (1989). Open Pit Decommissionin Collins Bay A-Zone, B-Zone and D-Zone - Pathways Analysis of Decommissioning Alternatives. Prepared for Cameco Corporation. April.

[C4.9] SENES Consultants Limited, Boojum Research Ltd and Steffen, Robertson and Kirsten (Canada) Inc (1993). Collins Bay B-Zone Decommissioning - Year 1. Proposed Target Levels. Prepared for Cameco Corporation Rabbit Lake Operation.

[C4.10] Abramowtiz and Stegun (1964). Handbook of Mathematical Functions. US Department of Commerce.

[C4.11] Hawley J K (1985). Assessment of Health Risk from Exposure to Contaminated Soil. Risk Analysis, 5 (4): 289-302.

C5 JAERI Model

C5.1 Groundwater Release

The conceptual model of aquifer used is shown in Figure C5.1. The transport of the contaminants through aquifer was analysed by using a numerical solution of a mass transport equation involving 1D-advection, 1D-dispersion, retardation and decay. A condition of no flow at the upstream boundary (point A), and a condition of zero gradient concentration at the downstream boundary (point B) is assumed. The migration lengths of region 1 and region 3 were determined such that the boundary conditions have no effect on output values.

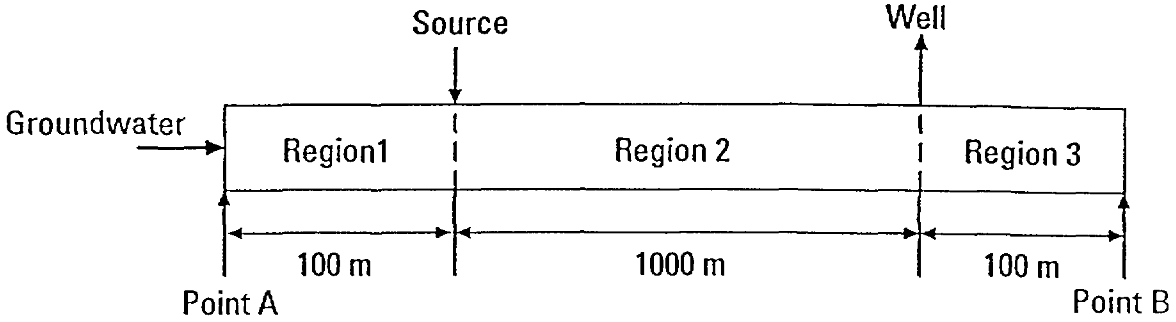


Figure C5.1: Conceptual Model of the Aquifer in the JAERI Model

C5.2 Atmospheric Release

The concentration of the contaminants in air was calculated by a Gaussian plume model.

C5.3 Biosphere Modelling

Schematic pathways of contaminants transport in the biosphere are shown in Figures C5.2 and C5.3. A linear dynamic compartment model for biosphere is used and a set of differential equations by using the Runge-Kutta method is solved. It is assumed that both dry and wet fraction take part in resuspension.

C5.4 Probabilistic Modelling

The Latin Hypercube was used method for parameter sampling. The convergence of results was checked by the dispersion of mean values of peak total dose as a function of sample size. Additionally, the results of CDF curves obtained under different sample sizes were compared. 5,000 runs were used for analysis for the V2.2 scenario, and 5,000 runs were used for the V2.3 scenario. If a generated parameter-set included the parameter whose value was out of the range defined by the scenario, the parameter-set was rejected.

SAS software was used to analyse the results.

Figure C5.2: Groundwater Source Exposure Pathways in the JAERI Model

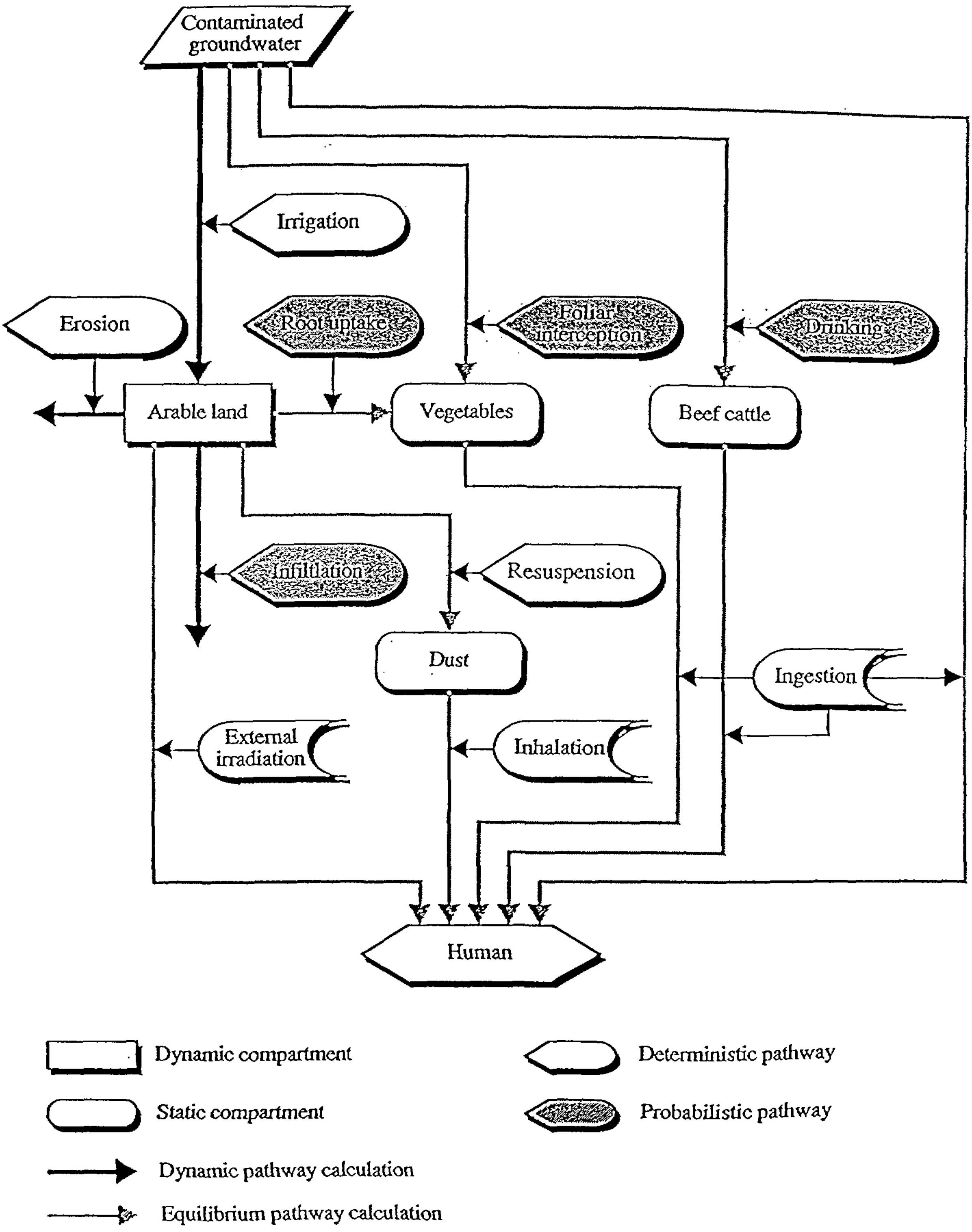
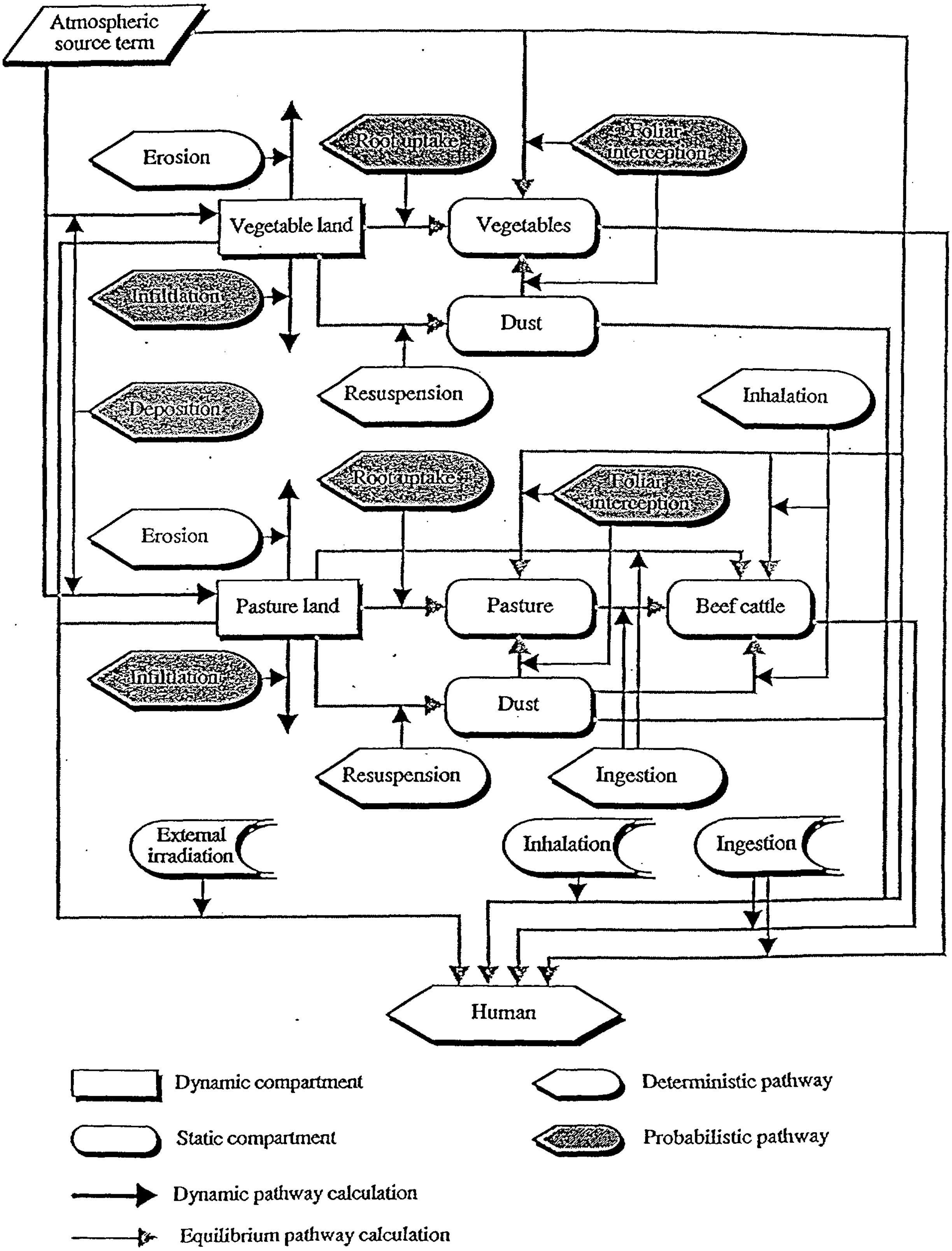


Figure C5.3: Atmospheric Source Exposure Pathways in the JAERI Model



C6 MEPAS

C6.1 Model Description

The Multimedia Environmental Pollutant Assessment System (MEPAS) is a risk computational tool that evaluates impacts to exposed individual and surrounding populations [C6.1 - C6.6]. MEPAS considers the release of chemical and radioactive contaminants into the environment and the their migration and fate in the groundwater, surface water, overland, and atmospheric pathways. This fate and transport software was developed at the US Department of Energy's Pacific Northwest National Laboratory (PNNL).

MEPAS is an integrated system of analytical, semi-analytical, and empirically based mathematical models that simulates source-term release rates, transport processes, exposure and uptake, and human-health effects. The source term component include overland flow, infiltration, particle suspension, and gaseous loss processes. Transport components include airborne, surface water, and groundwater pathways. Linkages between transport pathways are incorporated between transport media (e.g. vadose zones to groundwater, groundwater to surface water).

MEPAS is designed to make optimal use of site-specific information. Whenever available, MEPAS software allows (and the documentation encourages) the use of site-specific data. When such data are unavailable, guidance is provided for estimating inputs based on general site characteristics.

Four main exposure pathways are evaluated in MEPAS; inhalation, ingestion, direct contact, and external exposure. Inhalation includes both ambient air and resuspension intakes, as well as inhalation of volatiles from showering. Ingestion includes drinking water, showering, direct ingestion, and agricultural intakes. Direct contact occurs from swimming and showering, and external exposure occurs from proximity to radioactive contaminants via fishing, swimming, atmospheric plumes. Residential, recreational, agricultural, and industrial land use activities can be evaluated. The health effects computation allows the user to select from methodologies suggested by the International Atomic Energy Agency, US Nuclear Regulatory Agency, and US Environmental Protection Agency. Both carcinogenic and noncarcinogenic impacts are considered. The user is allowed a wide latitude in customizing the details of dose and effects computations.

MEPAS includes a database with chemical, physical, uptake, and human health effects parameters for over 550 radioactive, organic, and inorganic materials. A citation data field defines the source of each database entry.

The main MEPAS outputs are maximum individual and population impacts. Spacial and time-varying environmental concentrations are provided as intermediate outputs. Detailed supporting information on the emission rates, media flux computations, etc. are provided in intermediate output files.

MEPAS includes the capability of conducting Monte-Carlo sensitivity and uncertainty studies. Once a run is made with the MEPAS deterministic interface, a MEPAS probabilisitic interface allows the selection of stochastic variables from all input and database variables, definition of probability distributions for selected variables, and running of a selected number of samples. Outputs include a table of samples, summary statistics, and plots of probability distributions.

C6.2 Application to V2.2 and V2.3 Scenarios

Both scenarios were modeled using the released version of MEPAS at the time of the comparisons (Version 3.1g). The software was configured to match the conditions defined for the scenario. This version provides outputs that include a time series of water concentrations, a single average air concentration, and impacts at the time of peak exposure. The impacts are listed by specific inhalation and ingestion exposures (water intake, beef, leafy vegetables, etc.).

To meet the specific output requirements of the scenarios, it was necessary to use post-processor programs on the output files of the runs with MEPAS Version 3.1g. An "annual risk module" that expands the MEPAS outputs to a series of annual impacts was used. This module is not distributed with Version 3.1g but will be available in a future version of MEPAS. Other post-processor programs were used to extract the MEPAS concentrations in individual exposure media.

The application of MEPAS to the V2.2 and V2.3 Scenarios requires assumptions for the groundwater transport computation. For groundwater modeling the following assumptions were made:

1. The shape of the source was assumed to be square with a side dimension of 65 m (213 ft).
2. The aquifer was modeled with a thickness of 65 m (213 ft).
3. A vertical dispersivity value of 3.05E+19 m (1E+20 ft) to simulate instantaneous vertical dilution. A lateral dispersivity of 0.0 m was used.
4. The withdrawal point for the receptor well was assumed to be at the middle of the aquifer at a depth of 32.5m (107 ft).

Groundwater decay-product ingrowth during transport is not handled by Version 3.1g (all ingrowth is assumed to occur at the receptor). A model update to handle decay-product ingrowth during transport is being developed but was not available at the time of these computations.

The standard version of MEPAS provides atmospheric results for three default particle sizes. For the airborne computation, a special run was made for the particle size defined in the scenarios. Also a very low precipitation rate was assumed to simulate the case with no wet deposition.

Because of time and resource limitations, only a partial set of the requested products could be submitted. The submitted products include a selected subset of the deterministic case results and no data for the probabilisitic case results.

C6.3 References

[C6.1] Droppo J G and Buck J W (1996). Multimedia Environmental Pollutant Assessment System (MEPAS): Atmospheric Pathway Formulations. PNNL 11080, Pacific Northwest National Laboratory, Richland, Washington.

[C6.2] Strenge D L and Chamberlain P J (1995). Multimedia Environmental Pollutant Assessment System (MEPAS): Exposure Pathway and Human Health Impact Assessment Models. PNL-10523, Pacific Northwest Laboratory, Richland, Washington.

[C6.3] Whelan G and McDonald J P (1996). Multimedia Environmental Pollutant Assessment System (MEPAS): Groundwater Environment. PNNL 10907, Pacific Northwest National Laboratory, Richland, Washington.

[C6.4] Streile et al. (1996). Multimedia Environmental Pollutant Assessment System (MEPAS): Source-Term Release Formulations. PNNL 11248, Pacific Northwest National Laboratory, Richland, Washington.

[C6.5] Whelan G and McDonald J P (1996). Multimedia Environmental Pollutant Assessment System (MEPAS): Riverine Environment. Pacific Northwest National Laboratory, Richland, Washington. (To be Published)

[C6.6] Whelan G and McDonald J P (1996). Multimedia Environmental Pollutant Assessment System (MEPAS): Surface Hydrology. Pacific Northwest National Laboratory, Richland, Washington. (To be Published)

C7 RESRAD

C7.1 Model Description

RESRAD is a computer code developed at Argonne National Laboratory (ANL) for the U.S. Department of Energy (DOE) to calculate site-specific residual radioactive materials guidelines and radiological dose/risk to an on-site individual at a radioactively contaminated site [C7.1]. The code is continuously improved and updated in response to suggestions from users and to incorporate new features that facilitate user interaction and increase the capabilities and flexibility of the code. RESRAD-CHEM, which was derived from RESRAD, calculates risks from chemical contaminants. The RESRAD-CHEM database includes 151 chemicals. A recent improvement to RESRAD (available in ß test version) is the addition of a Latin Hypercube-Monte Carlo preprocessor that allows statistical distributions to be specified in place of single values for input parameters. The code is being also extended to include off-site modeling capability.

RESRAD uses a pathway analysis method in which a pathway sum is calculated to relate the radiological dose/risk to the concentration of the radionuclide in soil. The pathway sum is the sum of pathway factors for each of the applicable pathways. The pathway factor accounts for radioactive decay and ingrowth, transport, transfer, (bio)accumulation, and radiological potency of the contaminant. RESRAD considers the pathways listed below as depicted in Figure C7.1.

- External radiation from ground.
- Inhalation of dust, radon and radon progeny, and gaseous airborne radionuclide.
- Ingestion of plant food contaminated by root uptake, foliar deposition, and irrigation water.
- Ingestion of meat and milk contaminated by fodder, livestock water, and soil ingestion.
- Ingestion of fish and aquatic foods contaminated by lake water.
- Ingestion of drinking water from contaminated well water or surface water.
- Ingestion of contaminated soil.

The pathways that were used to model the V2.2 and V2.3 scenarios are shown in Figure C7.2.

C7.2 Application to V2.2 and V2.3 Scenarios

This scenario was modelled on a Prototype version of RESRAD-OFFSITE (Monte Carlo) based on version RESRAD V5.60M (β). The changes to version 5.60M(β) are as follows.

1). Provision was made to accept user specified (inputs of) groundwater and atmospheric releases. If the user specifies the time variation of the release, the standard RESRAD calculations of release are suppressed.
2). Inclusion of longitudinal and lateral dispersion. Longitudinal dispersion of contaminants released into the aquifer are accounted for. However, longitudinal dispersion for a transformation product formed in transit (in the aquifer), is considered only if it travels at the same speed as all its parents, i.e. only if all members of the chain from the parent released into the aquifer to the transformation product being considered have the same distribution coefficient. When they do not travel at the same velocity, the effects of the differential rates of transport were considered and the effects of longitudinal dispersion on the transformation product formed in transit were ignored. Lateral dispersion in the horizontal direction is considered for all nuclides (parents and daughters), but was not used in this scenario because the scenario stipulates that this is insignificant.
3). Inclusion of an offsite accumulation module to consider agriculture and grazing at offsite (off the primary contaminated zone) locations. The accumulation model considers (a) time dependent influx of contaminants, due to atmospheric deposition of dust and irrigation with contaminated water; (b) uniform mixing in a mixing zone (e.g due to ploughing); (c) first order (radioactive) transformations (decay and ingrowth); (d) surface erosion at a constant rate; and (e) adsorption equilibrium controlled release from the mixing zone.
4). Provision to accept user inputs of formally hardwired parameter relating to agriculture: e.g. annual yield, foliar interception fraction for dust and irrigation, weathering half life, growing period, agricultural area specific irrigation, evapotranspiration and runoff rates.
5). Performing calculations and outputting the results to a DOS file, at 'graphical time points' (a user specified number of time points, ranging from 32 to 1024 in the power of 2) for the probabilistic runs; instead of, only at the user specified times (maximum of ten). 128 points were used for this scenario.
6). Outputting concentrations in offsite soils.

The situation modelled by RESRAD departed from the specified scenario in two respects:

- The cattle inhalation sub pathway was not included.

- The minimum and maximum values specified for the probabilistic parameters with normal or log-normal distributions was not used. RESRAD sets these limits to 3.09 times the specified standard deviation about the mean.

C7.3 Probabilistic Modelling

Latin hypercube-Monte Carlo with $n_r \times n_o$ (100 for this scenario) sample sets consisting of n_r (=10, user changeable) repetitions of n_o (=10, user changeable) observations. That is, each of the user specified probability distributions were partitioned into n_o equally probable segments and an observation was made from each segment in accordance with the probability distribution of that segment. The n_o observations of the different variables were combined at random, by not specifying any correlation between input variables, to make n_o sets of inputs. This procedure was repeated n_r times to obtain the $n_r \times n_o$ sample sets. Different sample set sizes were not attempted; hence stopping rules and convergence test were not applicable.

C7.4 References

Yu, C., et al (1993). Manual for Implementing Residual Radioactive Material Guidelines Using RESRAD, Version 5.0, ANL/EAD/LD-2, Argonne National Laboratory, Argonne, Ill.

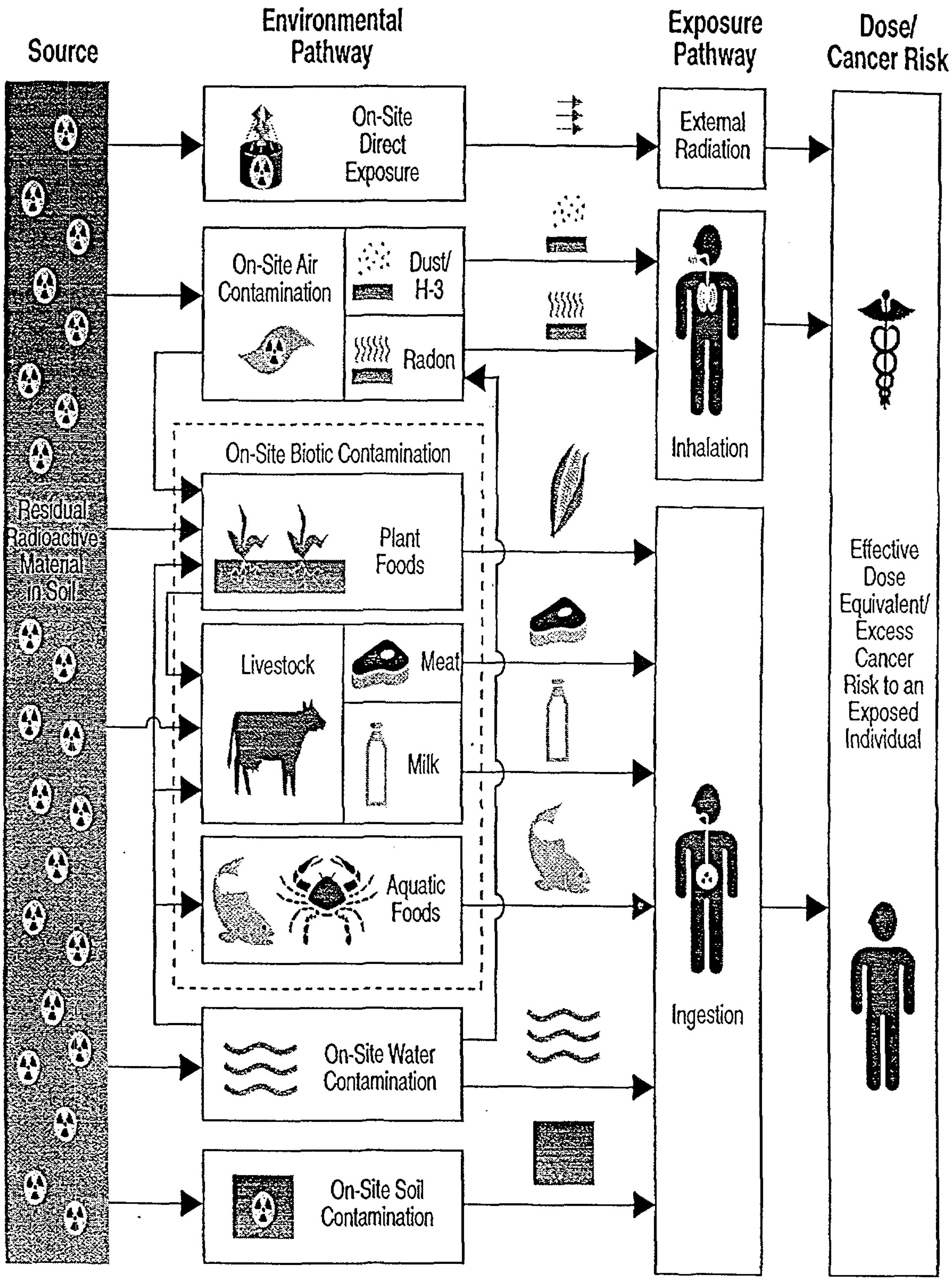


Figure C7.1: Generic Exposure Pathways in RESRAD

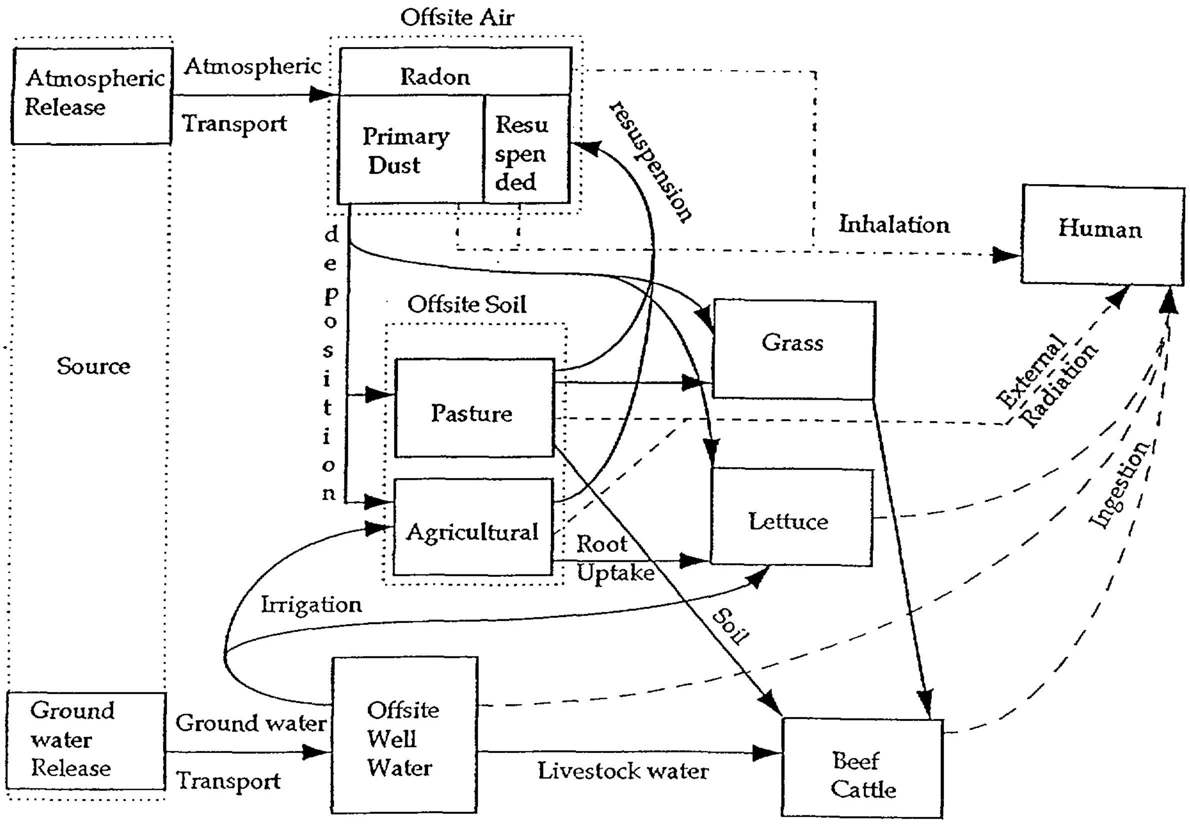


Figure C7.2: Contaminant Transfer and Exposure Pathways Used by RESRAD for the V2.2 and V2.3 Scenarios

C8 SONS Model

The V2.2 Scenario has been modelled using three separate computer codes. The first one has been used for the groundwater contamination, the second for the foodstuff contamination and the third for the atmospheric dispersion. They are similar to the codes used in the BIOMOVS V1.06 and V2.1 exercises. The results of calculations are stored as ASCII text files.

C8.1 Groundwater Release

The transport model simulates radionuclide migration by computing radionuclide fluxes and concentrations throughout the aquifer. The processes considered are mass flow and radioactive decay. The model assums that the retardation of radionuclide migration velocity relative to that of groundwater can be represented by linear, equilibrium and reversible adsorption.

The transport of the contaminants through aquifer was calculated by using of a numerical solution of a 1D mass transport equation including dispersion, advection, retardation and activity changes due to radioactive decay.

The concentration in the well water is assumed to be the same as in the groundwater.

The output concentration of the contaminant has been used as the input for the biosphere transport calculations.

C8.2 Atmospheric Release

The atmospheric transport has been simulated by a Gaussian plume model. The dispersion coefficients have been approximated using Hosker's formula [C8.1]. The corrections for radioactive decay, plume depletion, rain scavenging and source dimension has been included also. These corrections decrease airborne activity for the low or the ground level source.

A commonly used computer code designated for calculation of radionuclide dispersion from nuclear power plants has been used.

C8.3 Biosphere Modelling

The biospheric transport has been modelled by a linear compartment model. The terrestrial food chains included are shown in the Figure C8.1.

Two computer codes have been used for calculating biospheric transport. The slight differences are metioned below.

For plants, milk and meat contamination assessment, a steady state model has been used.

For the case of irrigation from groundwater, two soil compartment are assumed to be time dependent. The contamination has been calculated using lineaer differential equations solved by the Runge-Kutta method. In this case, an activity increase in soil can be found in comparison to a single compartment model.

For the case of atmospheric dispersion, only one soil compartment is used in the model.

The resuspension of soil particles has been taken into account as well as the external exposure from the soil surface.

C8.4 Probabilistic Modelling

The code enables the user to perform uncertainty analysis using the simple random sampling method. The results are given in the form of mean value, standard deviation and cumulative distribution function for irrigation from groundwater.

C8.5 References

[C8.1] Hosker R P. Estimates of Dry Deposition and Plume Depletion over Forests and Grassland. IAEA-SM-181/19, Oak Ridge

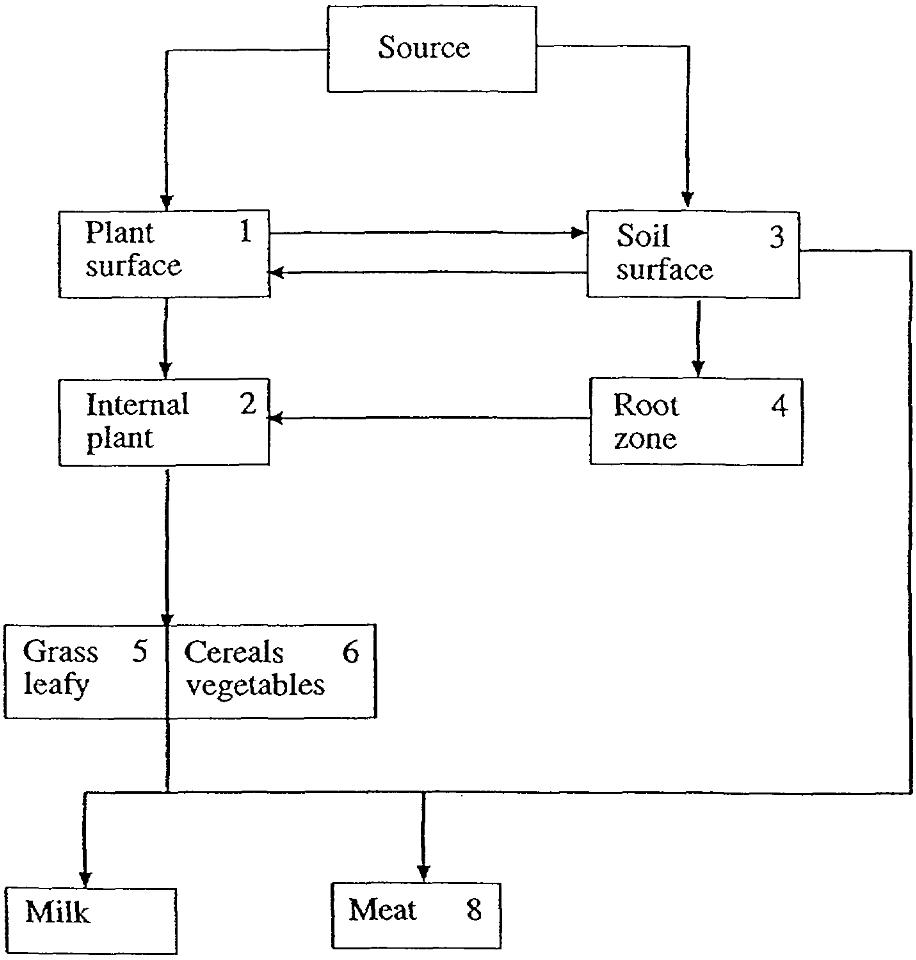


Figure C8.1: Flow Chart through the Terrestrial Food Chain in the SONS Model

Appendix D: List of Contributors to the V2 Exercise

Considerable interest has been shown in the Uranium Mill Tailings Working Group from many organisations throughout the world. Contributions have been made in several forms: in the development of the scenario descriptions, as comments on discussion material and preliminary results, and in provision of those modelling results. All these contributions are much appreciated. The following is a list of the main contributors:

Henri Camus (Chairman)	CEA (DAM/DQS), France
Richard Little (Secretariat)	QuantiSci Ltd, United Kingdom
*Dan Acton, Don Hart, Don Lush	Beak Consultants Limited, Canada
Almudena Agüero	CIEMAT/IMA, Spain
*Larry Chamney	Atomic Energy Control Board, Canada
Jean-Louis Daroussin	COGEMA, France
*Jim Droppo, Kathryn Higley, Keith Shield, Dennis Strenge	US Department of Energy's Pacific Northwest National Laboratory
*Cecile Ferry	CEA/IPSN, France
*Emmanuel Gnanapragasam, Charley Yu	US Department of Energy's Argonne National Laboratory
*Cecile Hallam, Bruce Halbert	SENES Consultants Limited, Canada
*Jan Horyna	State Office for Nuclear Safety, Czech Republic
*Tomoyuki Takahashi	Japan Atomic Energy Research Institute

* indicates a participant submitting model calculation results for the V2.2 and/or V2.3 scenarios.

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