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Long-term contaminant migration and impacts from uranium mill tailings

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Abstract

As part of the BIOMOVS II study, a Working Group was established with the primary aim of comparing computer models used to assess the long-term impacts of contaminants released from uranium mill tailings piles, involving multiple pathways, multiple contaminants and multiple environmental receptors. The application of models to two scenarios (V1 and V2) allowed participants to gain an improved understanding of important processes and to compare the representation of these processes in the models. Partly as a result of this, new models were developed and the functionality of existing models was enhanced. Model results for the scenarios were compared quantitatively and agreed well (often within a factor of three) for the more tightly specified V2 scenario. In so far as the scenarios represent generic sites, the following generic conclusions can be drawn.

- A range of pathways and contaminants affect the total dose/intake and so no single pathway or contaminant is dominant for all scenarios to the exclusion of all other pathways or contaminants.
- Peak impacts on individuals may not arise for many hundreds of years.
- Simplification of the ²³⁸U decay chain, by assuming ²¹⁰Pb and ²¹⁰Po are in secular equilibrium in the biosphere with the long-lived parent, ²²⁶Ra, is inappropriate.
- Whilst models are available for assessing potential radiological and non-radiological health impacts, comparison of health impacts is limited by the absence of comprehensive data for health impacts of stable elements. © 1998 Elsevier Science Ltd. All rights reserved.

1. Introduction

Wastes from the processing of uranium ore deposits have historically been disposed of in surface tailings piles. These tailings may present both short- and long-term pollution hazards due to 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, computer models have been developed which simulate the release and transport of the contaminants from the tailings into the surrounding environment, and their subsequent fate.

Whilst such models have been widely used in the deterministic and probabilistic assessment of the long-term environmental impacts of both proposed new uranium mine developments (see e.g., Cigar Lake Mining Corporation, 1995) and proposed decommissioning of existing uranium mill tailings (see e.g., SENES, 1995), intercomparison of model results has been limited, especially in an international context. Therefore, the Uranium Mill Tailings Working Group was initiated as part of BIOMOVs II with the primary objective of comparing the models developed by participants. The comparisons were intended to improve understanding of the contaminant transport 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. The value of such model intercomparisons is increasingly being recognised (see e.g., Joint Federal-Provincial Panel, 1997).

In order to meet the objectives of the Working Group, it was decided to divide the exercise into two parts; the first part was to develop an understanding of models and processes using a hypothetical scenario, the second was to compare results using a more realistic scenario. The Working Group identified a number of tasks to accomplish this.

1. Development of a hypothetical scenario (V1) describing releases of contaminants from a tailings pile.
2. Application of models to the V1 scenario to undertake illustrative deterministic calculations of contaminant concentrations in biosphere media, and related radiation doses, contaminant intakes and health risks.
3. Review of the modelling approaches used for the V1 scenario through the examination of model results and Working Group discussions.
4. Use of the experience gained in developing and undertaking calculations for the V1 scenario to produce a more realistic V2 scenario which included more detailed source term and other site-specific data.
5. Application of models to the V2 scenario to undertake deterministic and probabilistic calculations of contaminant concentrations in biosphere media, and related radiation doses, contaminant intakes and health risks, including estimates of uncertainties.
6. Comparison of model results and review of the modelling undertaken for the V2 scenario.

The scope for obtaining data for a comparison of model predictions with field data

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.

Most of the models used by participants were fully integrated, i.e. they allow for atmospheric, groundwater and biosphere modelling (BIOMOVS II, 1995, 1996a). However some participants used separate models to represent different components of the scenarios. Most of the models were similar conceptually, for example one-dimensional groundwater flow, Gaussian plume for the atmospheric release, and linear compartment models for transfer through soils to foodchain. In general, there was considerable commonality in the features, processes and pathways modelled, especially in the exposure pathways and biosphere processes. There were slightly more differences in the atmospheric and groundwater release features and processes modelled.

The purpose of this paper is to provide a summary of the work undertaken and to highlight some of the key technical conclusions from the work which are relevant to the use of computer models used to assess the long-term impacts of contaminants released from uranium mill tailings. First the main features of the two scenarios are summarised, then the associated results are discussed, and finally the general conclusions from the exercise are presented. Full descriptions of the two scenarios and more detailed discussions of the associated technical findings of the Working Group are provided in BIOMOVS II (1995) (V1 scenario) and BIOMOVS II (1996a) (V2 scenario).

2. V1 scenario

A hypothetical scenario was developed for contaminant releases from a uranium mill tailings pile in order to test participants' models. The assumptions and parameter values for the tailings and its environs were chosen to test and facilitate the evaluation of potentially important processes incorporated into models. The site description was therefore idealised and did not represent any particular site. Atmospheric and groundwater release source terms and associated environmental parameters were chosen to facilitate the review of models and were not necessarily considered to be realistic.

Seven iterations of the V1 scenario were required because the description of the hypothetical mine tailings system and its environment in terms relevant to modelling multiple pathways and multiple contaminant migration was found to be a complex matter. Progressively simplified and less ambiguous iterations of the scenario description were produced. The final version of the V1 scenario had the following key features:

- constant atmospheric release source terms lasting 1000 years, including release of radon (with daughters) and contaminated dust, assuming no cover over tailings material to limit releases;
- constant groundwater release source term lasting 1000 years, with no engineered barriers limiting the release;

- releases of radionuclides in the ^{238}U decay chain;
- releases of arsenic, chromium and nickel;
- deposition from atmosphere onto agricultural land used for crop and livestock production;
- abstraction from an aquifer via a well and use of the water for drinking and agricultural purposes; and
- discharge from the aquifer into a river and lake system, with consumption of fish from the lake and use of the water for drinking and agricultural purposes.

Participants were asked to predict contaminant concentrations in environmental media as a function of time, radiation doses, stable element intakes, and the associated risks to human health from radionuclides and stable elements.

Nine sets of models from seven countries were applied to the final version of the V1 scenario (Table 1). Participating organisations were: Atomic Energy Control Board (AECB); United States Department of Energy's Argonne National Laboratory (ANL); Beak Consultants Ltd (Beak); Instituto de Medio Ambiente (now Departamento de Impacto Ambiental de la Energía), Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (IMA/CIEMAT); Institute of Public Health and Medical Research (IPHMR); Institut de Protection et de Sûreté Nucleaire, Commissariat à l'Energie Atomique (IPSN/CEA); Japan Atomic Energy Research Institute (JAERI); SENES Consultants Ltd (SENES); and State Office for Nuclear Safety (SONS).

3. V2 scenario

Following the completion of the V1 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

Table 1
V1 scenario participants

Organisation and country	Model(s)	Contact
AECB, Canada	ETP/AECB	Larry Chamney
ANL, United States of America	RESRAD v5.13	Charley Yu
Beak, Canada	IMPACT	Donald Lush
IMA/CIEMAT, Spain	SACO, MILDOS-AREA, BIOPATH and DOSCAL	Almudena Agüero
IPHMR, Romania	ECOSR	Laszlo Toro
IPSN/CEA, France	GEOLE and ABRICOT	Denise Stammose
JAERI, Japan	JAERI Model	Tomoyuki Takahashi
SENES, Canada	SENES Model	Douglas Chambers
SONS, Czech Republic	SONS Model	Jan Horyna

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.

Following several iterations, two scenarios (V2.2 and V2.3) were derived with the following key features.

- A realistic, time-variant, source term to groundwater, which, for V2.2, included both ^{238}U and its longer-lived daughters (^{234}U , ^{230}Th , ^{226}Ra , ^{210}Pb and ^{210}Po) was considered. Potential changes to the chemical and physical conditions within the pile, resulting from gradual processes such as cap degradation, were considered when deriving data for the time-variant source term. The ^{238}U , ^{230}Th and ^{226}Ra source terms were based on the results of detailed modelling of an actual tailings pile. In the absence of detailed modelling results, the ^{234}U source term was assumed to be the same as ^{238}U , whilst the ^{210}Pb and ^{210}Po source terms were assumed to be the same as ^{226}Ra . For V2.3, the release of arsenic, nickel and lead was considered.
- A realistic, time-variant, source term to atmosphere, which, for V2.2, resulted from the emission of radioactive gas (^{222}Rn) and dust from the tailings pile was considered. The contaminants considered to be emitted in the dust were ^{238}U , ^{234}U , ^{230}Th , ^{226}Ra , ^{210}Pb and ^{210}Po . For V2.3, the emission of arsenic, nickel and lead in the dust was considered. For the purpose of illustration, it was assumed that the cap over the tailings prevents any atmospheric release before 200 years, thereafter the cap was assumed to deteriorate gradually until total failure occurred at 1000 years.
- Geosphere and biosphere characteristics were based primarily on those of the region around an actual tailings pile.
- Consideration was given to both deterministic and probabilistic cases. In the probabilistic case, participants used their models to sample values from specified distributions for five biosphere parameters (soil to plant concentration factor, deposition velocity of resuspended soil, soil distribution coefficient, foliar interception factor for irrigation water, and transfer factor for beef). Single value best estimates were used for non-sampled parameters.
- There was a significant reduction in the number of end-points and pathways to be considered compared with the V1 scenario.

In both V2 scenarios, the contaminants of interest were assumed to be released in leachate from a tailings pile into an underlying aquifer. They were transported in groundwater through the aquifer to a well. Water was abstracted from the well and used for watering beef cattle; human consumption; and irrigating leafy vegetables. The beef and leafy vegetables were consumed by humans living in the area.

The same contaminants were also assumed to be released into the atmosphere due to the wind erosion of the tailings and then deposited upon the soil, pasture and leafy vegetables. In addition, for V2.2, ^{222}Rn was assumed to be released to atmosphere from the tailings.

Figs. 1 and 2 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

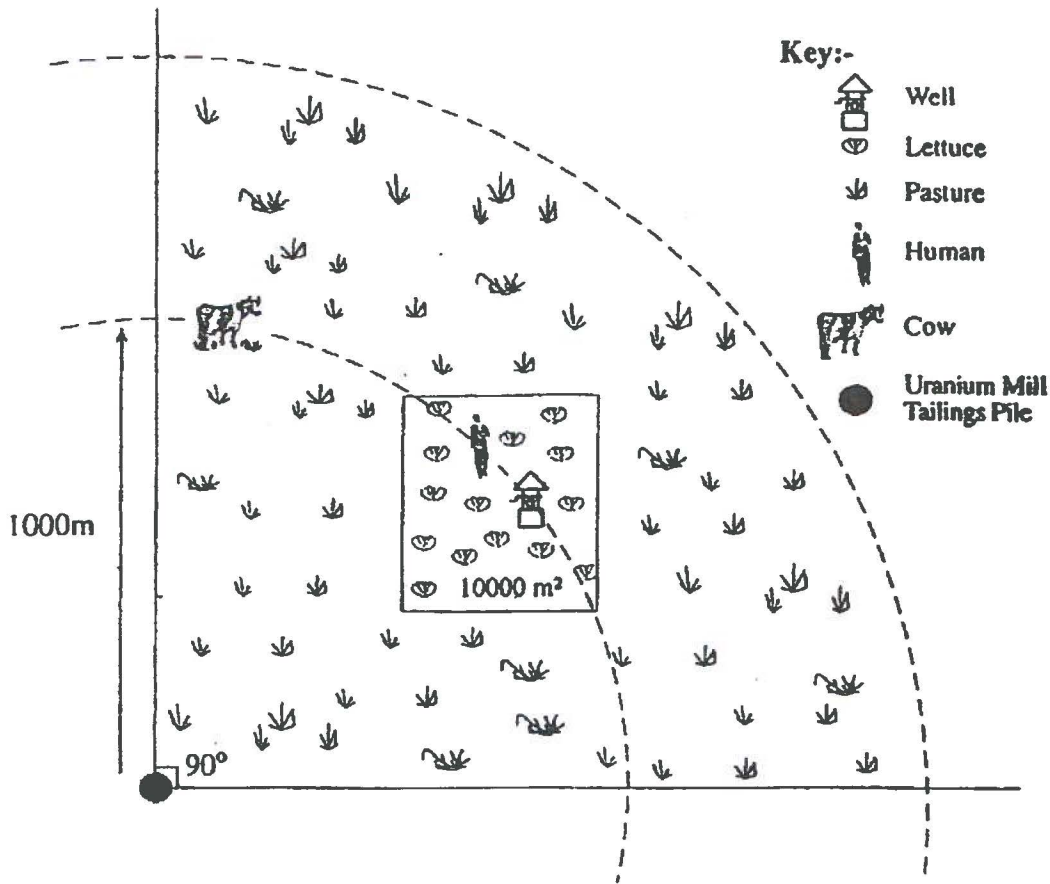


Fig. 1. Plan view representation of the V2.2 and V2.3 scenarios.

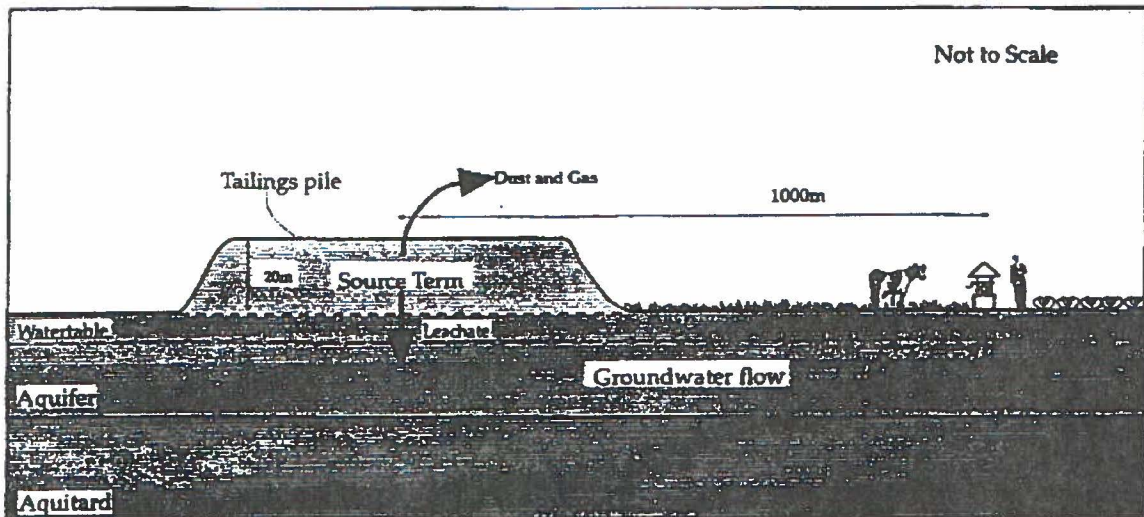


Fig. 2. Cross-sectional representation of the V2.2 and V2.3 scenarios.

doses, stable element intakes and the associated risks to human health from radionuclides and stable elements.

A total of seven sets of models were applied to the scenarios by eight participating organisations from five countries (Table 2). Participating organisations were: AECB;

Table 2
V2 scenario participants

Organisation and country	Model(s)	Contact
AECB, Canada	IMPACT v2.0	Larry Chamney
ANL, United States of America	RESRAD v5.60M(β)	Emmanuel Gnanapragasam
Beak, Canada	IMPACT v2.0	Dan Acton
IPSN/CEA, France	GEOS v2.0 and ABRICOT v2.0	Cecile Ferry
JAERI, Japan	JAERI Model	Tomoyuki Takahashi
PNNL, United States of America	MEPAS v3.1g	Jim Droppo
SENES, Canada	INTAKE	Cecile Hallam
SONS, Czech Republic	SONS Model	Jan Horyna

ANL; Beak; IPSN/CEA; JAERI; United States Department of Energy's Pacific Northwest National Laboratories (PNNL); SENES; and SONS.

4. Scenario results and discussion

Before considering the results from the V1 and V2 scenarios, it is important to note the following caveats.

- V1 is a hypothetical scenario, whilst the V2 scenario is more realistic.
- 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 (NEA, 1986). 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 US National Academy of Sciences report on waste disposal criteria (NAS, 1995)).

4.1. V1 scenario

Results for the V1 scenario often range over several orders of magnitude (see e.g. Figs. 3–5). This is due to a number of reasons such as ambiguities in the scenario, differences in participant interpretation of certain information given in the

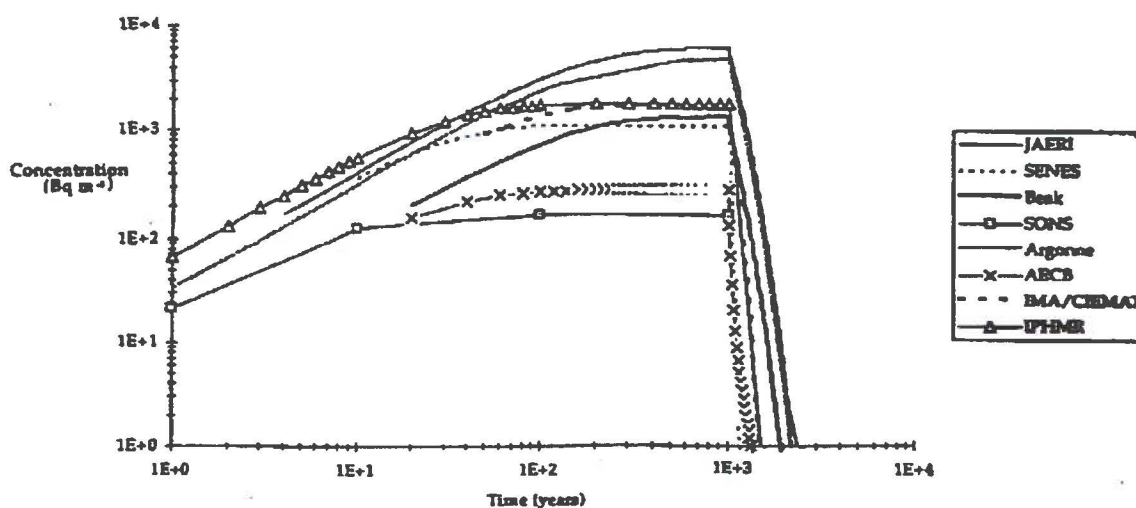


Fig. 3. ^{210}Pb soil concentrations from atmospheric release for the V1.07 scenario.

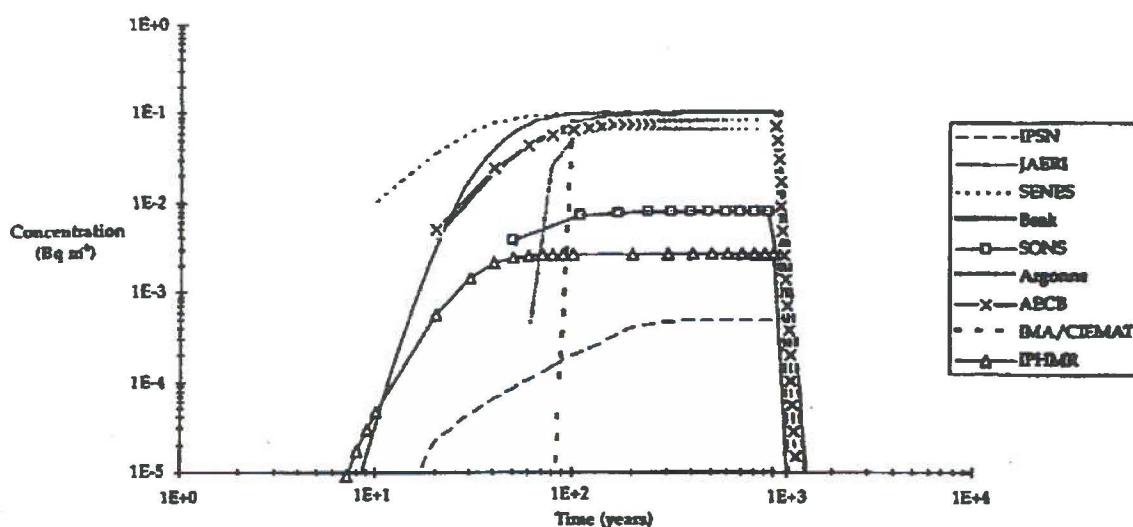


Fig. 4. ^{238}U well water concentrations from groundwater release for the V1.07 scenario.

scenario description, and differences in the approach used to model relevant processes. For example, consider the migration and accumulation of contaminants in soil. Initially, as contaminants first reached the soil, different assumptions were used in different models for the thickness of the surface soil in which rapid mixing occurs resulting in different estimates of initial concentrations in soil. Not all models took account of the given data for ploughing depth. In the longer term, variations in results should have been reduced because of the specified 100 year residence time in the total soil column. However, the SENES and IPSN/CEA models used a sorption coefficient related function to determine the residence time in soil.

Results, especially for the atmospheric release, also show that as the cumulative number of processes affecting the migration of radionuclides through the environment increases, the difference in participants' results also increases. Thus, whilst the difference in most participants' estimates for radionuclide concentrations in air resulting

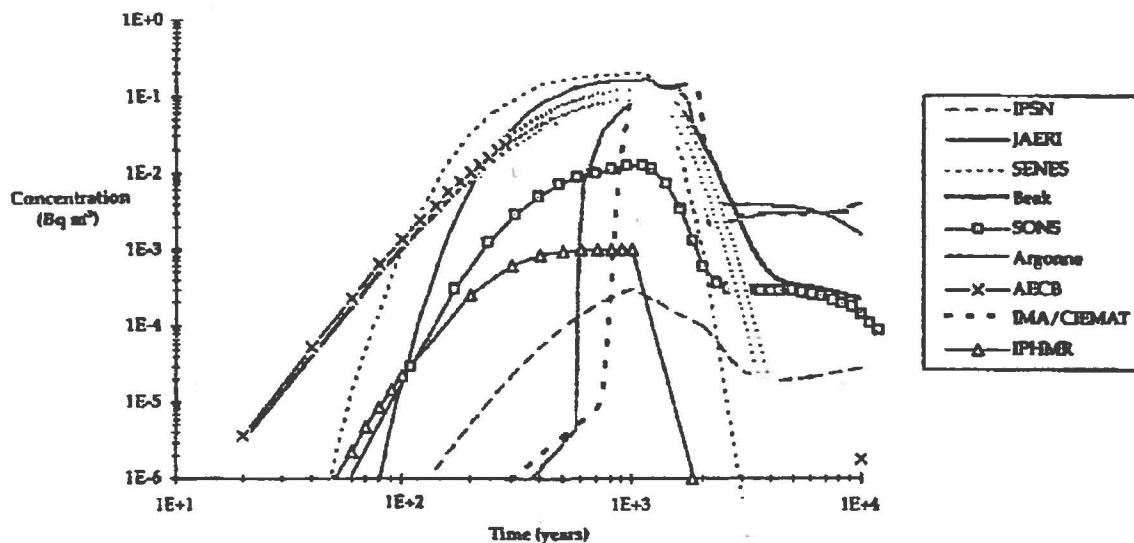


Fig. 5. ^{226}Ra well water concentrations from groundwater release for the V1.07 scenario.

from the release of radionuclides to the atmosphere is about a factor of two, results for the associated doses from ingestion of various foodstuffs can differ by in excess of two orders of magnitude.

By comparing participants' results, it is possible to identify and gain an insight into potentially important processes. Fig. 3 indicates the slow accumulation of contamination in surface soil arising due to continuing deposition from the atmosphere. Most models indicate continued accumulation until a few hundred years, after which gains to the soil are matched by losses. This result corresponds to the specified 100 year physical half-life in soil. Fig. 3 also shows that, although ^{210}Pb is relatively short-lived (half-life of 22.3 years), concentrations in soil continue to rise over a comparatively long period. This is due to in-growth from deposited ^{226}Ra in the soil.

Fig. 4 shows ^{238}U concentrations in well water. Most models show the eventual climb to concentration levels similar to those in the source term. The lower results for the SONS model are due to inclusion of dilution of contamination in the aquifer, not allowed for in the scenario description. The low IPSN/CEA result is due to inclusion of lateral dispersion in a way which reduces contaminant abstraction from the well. As a process this is realistic, though the scale of the effect is not certain. It would depend on how abstraction from the well affects the flow in the aquifer. The low IPHMR result is also thought to be due to allowance for lateral dispersion. Other models assumed that the well abstraction captured all activity at 1000 m from the source, as pessimistically suggested in the scenario specification.

Fig. 5 illustrates the spread in results for ^{226}Ra due to inclusion or exclusion of longitudinal dispersion in the geosphere, and due to different treatments of lateral dispersion. For example, the ANL and IMA/CIEMAT models show the same shape because of the exclusion of a longitudinal dispersion.

A number of observations can be drawn from the V1 results which are relevant to modelling uranium mill tailings.

1. It is difficult to exclude from consideration particular contaminants or migration and exposure pathways in advance of detailed assumptions for source terms and other site- and assessment specific features.
2. Peak impacts on individuals from uranium mill tailings may not arise for many hundreds of years.
3. Simplifications to modelling of contaminant accumulation in soil (e.g. using a 100 year residence time for all contaminants) are inappropriate since the long-term accumulation potential of the different contaminants may be substantially different.
4. Simplification of the ^{238}U decay chain, by assuming ^{210}Pb and ^{210}Po are in secular equilibrium with the long-lived parent, ^{226}Ra , is inappropriate for the biosphere component of a uranium mill tailings assessment.

4.2. V2 scenario

Illustrative results are given in Figs. 6–9. Analysis of the scenarios' results shows that there is good agreement between participants' results for the V2.2 and V2.3 scenarios. For example, results for total dose/intake agree within a factor of two to three for both scenarios (Figs. 6 and 7). This reflects the close agreement between participants' results for the dominant pathways contributing to total dose or intake (Fig. 8). Even where there are differences between the minor pathways for the scenarios, these are generally less than an order of magnitude.

This significant improvement in the agreement between participants' results can primarily be attributed to the division of the exercise into two parts (V1 and V2 scenarios). This had three key benefits.

1. It allowed participants to review and, if necessary, modify the representation of processes in their models. Thus, the models could be considered to be relatively 'tried and tested' and appropriate for the scenarios.

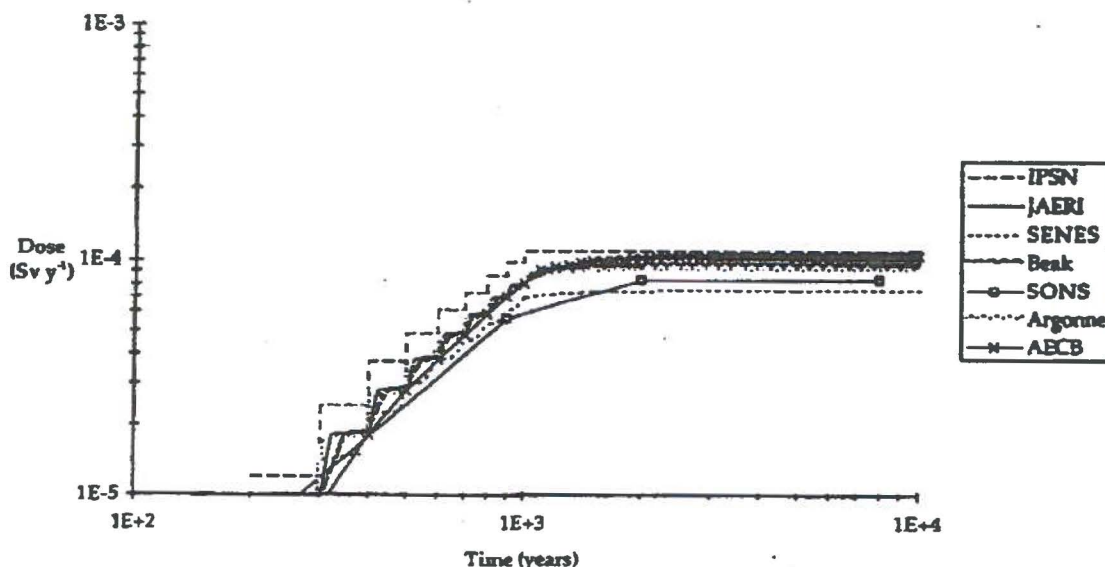


Fig. 6. Deterministic total ^{238}U chain dose from atmospheric release for the V2.2 scenario.

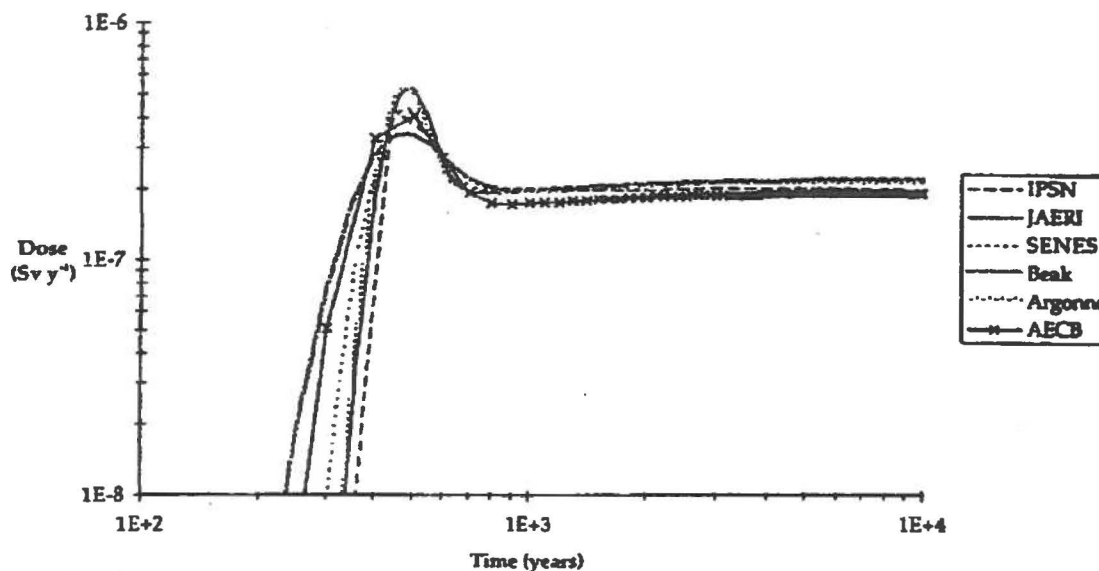


Fig. 7. Deterministic total ^{238}U chain dose from groundwater release for the V2.2 scenario.

2. It allowed participants to become more familiar with their models and their use to represent the scenarios.
3. It allowed the V2 scenario to be developed in a way to minimise possible ambiguities in the interpretation of the scenario, for example through the tighter specification of the features, processes and pathways and their associated parameter values.

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

Where minor discrepancies existed between participants' results for the V2 scenario, these could generally, although not exclusively, be explained by differences in the approach used to modelling certain processes and by differences in the parameterisation of the processes, rather than differences in scenario interpretation. For example, a discrepancy between participants' results for soil concentrations was observed for the atmospheric release. This was due to a difference of modelling the interaction between atmosphere and the soil compartment. Whereas most participants explicitly considered resuspension of soil particles, the IPSN/CEA and SENES models did not. Instead, the IPSN/CEA model accounted for resuspension by using a lower deposition velocity than the one specified in the scenario description, whilst the SENES model assumed that 50% of the suspended particulate was from resuspension.

Comparison of AECB and Beak results is useful since they independently applied the same model (IMPACT) to the V2 scenario. Thus, any discrepancies between the results reflect differences in the application of the model to the scenario, resulting from differences in interpretation of the scenario. Differences in interpretation of the scenario might have resulted in differences in data values used and processes

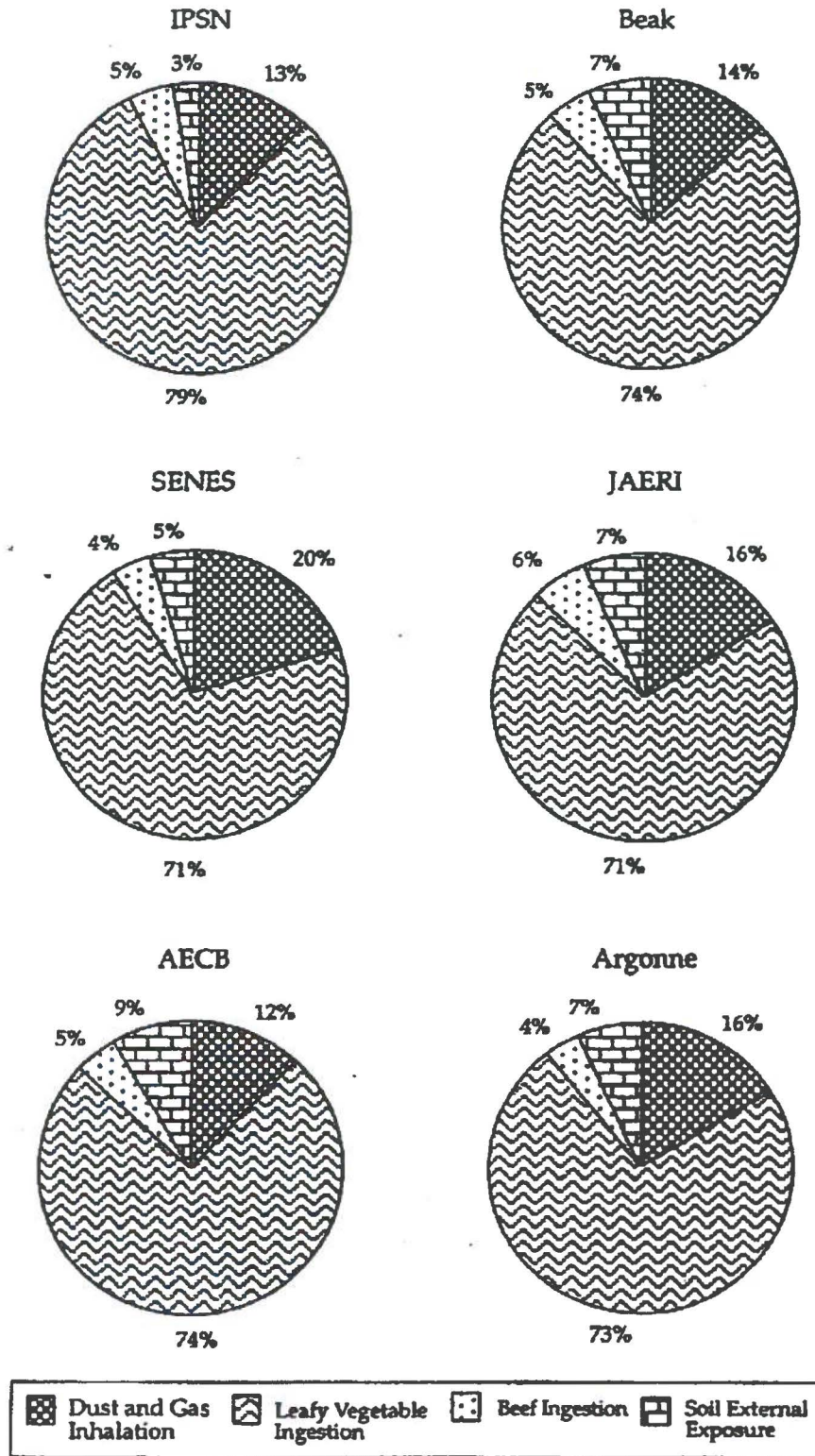


Fig. 8. Pathway contribution to peak deterministic total ^{238}U chain dose from atmospheric release for the V2.2 scenario.

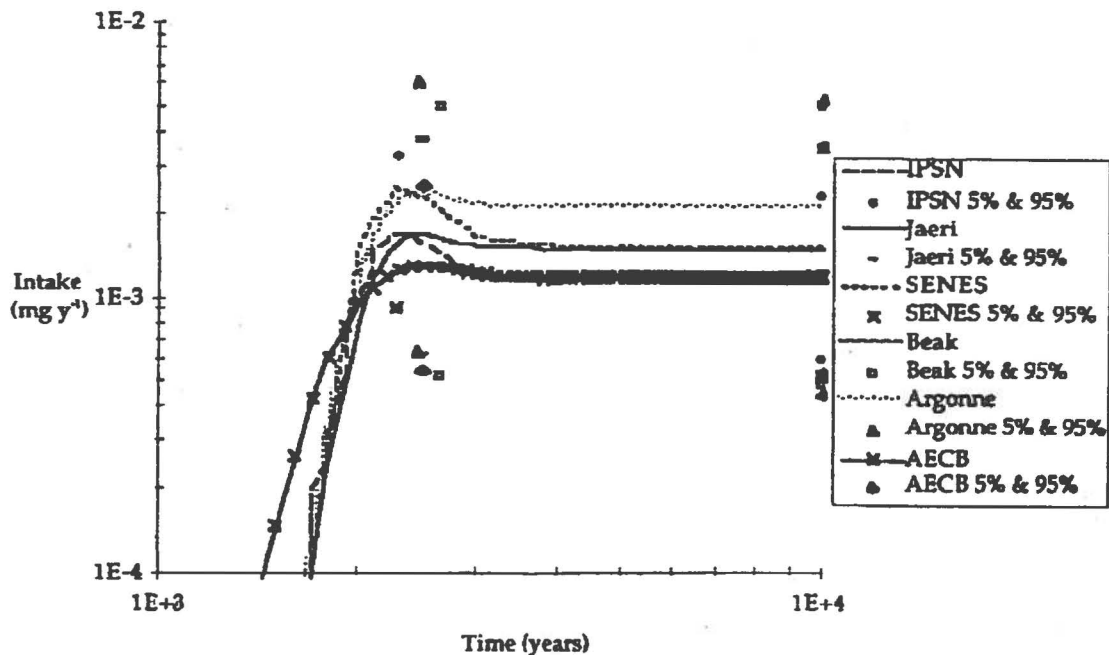


Fig. 9. Probabilistic total arsenic intake from groundwater release for the V2.3 scenario. Note: Percentiles shown represent the lower and upper endpoints of the 90% confidence interval. The 5th percentile represents the value of dose below which 5% of the sampled total doses lie. The continuous lines represent the mean intakes.

modelled. In general, there was good agreement between AECB and Beak results (see e.g. Figs. 6–9). Where discrepancies occurred they were relatively minor (less than a factor of four) and could be explained by differences in the choice of parameter values for certain processes (for example the erosion rate for soil or irrigation rate for leafy vegetables) or the set up of the model (for example the discretisation of the groundwater flowpath lengths).

Key scenario-specific conclusions from the analysis of the V2 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 was almost three orders of magnitude higher than the dose/intake from the groundwater release for the ^{238}U chain and arsenic (cf. e.g. Figs. 6 and 7), and about an order of magnitude higher for lead. This was primarily due to the atmospheric source term being greater than the groundwater source term for these contaminants. However, for nickel, it was the groundwater release which was dominant by about a factor of 50 due to its relatively large groundwater source term and the associated high concentrations in groundwater.
2. For the atmospheric release, the pathway contributing most to dose/intake was ingestion of leafy vegetables for all contaminants (see e.g. Fig. 8), except arsenic, for which it was ingestion of beef due to its relatively high beef transfer factor. The radionuclide contributing most to total dose was ^{210}Pb due to its high ingestion dose factor.

3. For the groundwater release, the pathways contributing most to dose/intake were ingestion of leafy vegetables and water for all contaminants except arsenic, for which ingestion of beef was also important due to its relatively high beef transfer factor. The radionuclides contributing most to total dose were ^{238}U and ^{234}U due to their large groundwater source terms.
4. Although, it is often possible to identify a 'primary' pathway or contaminant, it was rare that any single pathway or contaminant dominated the total dose/intake by more than a factor of five (see e.g. Fig. 8). Thus, other pathways/contaminants were nearly always within an order of magnitude of the primary pathway/contaminant.
5. The probabilistic calculations were consistent with the deterministic results and showed a variability in total dose/intake of an order of magnitude or less (see e.g. Fig. 9). They were also successful in identifying the key sensitive parameters which affect dose/intake for the scenario (soil to plant concentration factor, deposition velocity of resuspended soil, soil distribution coefficient, foliar interception factor for irrigation water, and transfer factor for beef).

5. Conclusions

As with all BIOMOVS II scenarios, the Uranium Mill Tailings' scenarios benefitted participants through the interchange of ideas and experience. In addition, the time and effort taken over derivation of the scenario descriptions and the initial modelling was an important and valuable learning exercise. It allowed participants to become more familiar with their models and to gain an improved understanding of the important processes to be considered and represented in such models when assessing uranium mill tailings. It also emphasised the importance of gaining a clear understanding of the scenario to be assessed. These are all important factors which facilitate the comparison of results from different models applied to the same model intercomparison exercise.

Both scenarios allowed participants to compare the representation of migration and accumulation processes in their models for both atmospheric and groundwater releases to the biosphere. Partly as a result of this, new models were developed, such as the SONS and IPHMR models, whilst the ability of existing models to represent certain processes was enhanced. For example, the SENES model was modified to include several additional exposure pathways, such as direct consumption of well water by humans, whilst the ANL model was modified: to provide results for contaminant concentrations, in addition to doses and risks; to provide results for radionuclides giving rise to dose as opposed to doses due to disposal of (parent) radionuclides; to allow for the effect of lateral dispersion; and to allow for calculation of 'off-site' impacts arising outside facility boundaries.

The scenarios allowed the influence of different modelling approaches to particular migration and accumulation processes to be demonstrated. However, firm but generic conclusions about the best approach cannot be drawn because of different site-specific features and regulatory requirements, and because model results for the hypothetical scenarios considered cannot be compared against field observations. Furthermore,

conclusions about the absolute or even relative importance of particular migration or exposure pathways cannot be drawn without reference to site and assessment specific issues. Nevertheless, insofar as the scenarios represent generic sites, the following generic conclusions can be drawn.

1. Features which need to be considered when using computer models to assess the long-term impacts of contaminants released from uranium mill tailings include: the chemical features of the tailings themselves; the nature of any engineered barriers present and their effect on the evolution of the tailings chemistry; long-term degradation effects on both engineered barriers and tailings material; the hydrogeological system; the conditions and features of the local biosphere; the assessment end points of interest; and the particular contaminants of interest.
2. A range of pathways and contaminants affect the total dose/intake and so no single pathway or contaminant is dominant for all scenarios to the exclusion of all other pathways or contaminants. This conclusion is consistent with results from an earlier, more generic, BIOMOVs multiple pathway study (BIOMOVs, 1990).
3. 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, 1996b; van Dorp et al., 1999). Furthermore, over such timescales, modelling results should be interpreted only as indicators of potential impacts and trends, rather than absolute values.
4. Simplification of the ^{238}U decay chain, by assuming ^{210}Pb and ^{210}Po are in secular equilibrium with the long-lived parent, ^{226}Ra , is inappropriate for the biosphere component of a uranium mill tailings assessment.
5. Models are available for assessing potential radiological and non-radiological health impacts to individuals from releases from tailings piles. However, comparison of health impacts arising from radioactive and stable elements is limited in its extent because data for health impacts (carcinogenic and non-carcinogenic) per unit intake for the stable elements is not as comprehensive as that for radionuclides.

The exercise provided participants with a most valuable model intercomparison opportunity. Now, there is a need to test the application of the models further through the use of field data from ancient mine workings and/or existing mill tailings.

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