PAPER FOR
BIOMOVS II REFERENCE BIOSPHERES WORKING GROUP

Nirex Approach to the Definition and Application of Critical Groups in the Context of Post-Closure Performance Assessment for Deep Geological Disposal of Long-lived Solid Radioactive Wastes

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Note: The views expressed in this paper are those of the authors and do not neccessarily represent the views of UK Nirex Ltd.

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Summary:

John Kessler of the US Electric Power Research Institute (EPRI) gave a presentation at the latest meeting of the BIOMOVS II Reference Biospheres Working Group on the definition of Critical Groups in the context of the deep geological disposal of radioactive waste.

This note provides a short summary of the approach adopted by UK Nirex Ltd in addressing the definition of critical groups in post-closure performance assessments for a deep geological repository in the United Kingdom. It is intended that the note should be circulated by Nirex to members of the BIOMOVS II Working Group.

Distribution:

M C Thorne, Electrowatt
Project Workfile

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1. BACKGROUND TO THIS NOTE

John Kessler of the US Electric Power Research Institute (EPRI) gave a presentation at the latest meeting of the BIOMOVS II Reference Biospheres Working Group on the definition of Critical Groups in the context of the deep geological disposal of radioactive waste.

This note provides a short summary of the approach adopted by UK Nirex Ltd in addressing the definition of critical groups in post-closure performance assessments for a deep geological repository in the United Kingdom. Further information on the overall approach to treatment of the biosphere in Nirex assessments is available [1].

2. UK REGULATORY GUIDANCE AND REQUIREMENTS

The earliest formal guidance on requirements provided in the UK was published in 1984 [2]. This contains the general principles that the relevant Government Departments proposed to apply in considering authorization for a proposed disposal facility for low- and intermediate-level radioactive wastes, under the general legislative control of the Radioactive Substances Act 1960. The relevant general principle is that:

> *"... the site should be chosen and the facility should be designed so that the risk or probability of fatal cancer, to any member of the public, from any movement of radioactivity from the facility, is not greater than 1 in a million in any one year".*

There is no additional exposition of this statement. However, more explicit formal guidance was provided by the National Radiological Protection Board (NRPB) in 1992 [3]. Although the advice of NRPB does not represent official regulatory policy, its guidance was taken into account in a recent consultation document issued by the relevant Government Departments [4]. The NRPB document outlines an approach to the calculation of individual risk that changes as the timescale of assessment increases, with a reduced amount of detail being justified for longer timescales. The NRPB therefore recommends that, for the purpose of carrying out and presenting risk calculations, the future should be divided into a series of timeframes.

Up to 100 years after repository closure, the NRPB statement suggests that institutional control over the site may be assumed to remain in place. This implies that potential radiological exposures can be controlled, so risk calculations are of little relevance. Beyond one million years, the NRPB considers that the scientific basis for any calculation of risk is highly questionable and that numerical risk criteria are therefore inappropriate. Hence it is recommended that assessments beyond, at most, a few million years should concentrate on qualitative discussions. The definition of the critical group for the purposes of calculating individual risks therefore relates only to timeframes between 10^2 and 10^6 years after closure. General principles underlying the definition of critical groups are dealt with by the NRPB in its discussion of the time period from 10^2 to 10^4 years after repository closure.

For the purposes of assessment, the NRPB recommends that hypothetical critical groups should be assumed to exist, at any given time in the future, "at the place where the relevant environmental concentrations are highest, and to have habits such that their exposure is *representative* of the highest exposures which might *reasonably* be expected" (NRPB [3] §30, our italics). In defining hypothetical critical groups for the timeframe 10^2 to 10^4 years after repository closure, the NRPB's position is that such groups may be selected "on the basis of currently observed behaviour" with the group's habits being "broadly representative of a type of area" (§32). The rationale for this is that assumptions about the existence and location of the group are sufficiently conservative to preclude the need for assuming behaviour based on particular extreme habits observed at a particular time in a particular place.

For the time period from 10^4 to 10^6 years after repository closure, the NRPB considers that:

> *"The emphasis of the assessment should ... be changed so that ... calculations relating to the biosphere and human activity are simplified by calculating the nominal risk to hypothetical 'reference communities' in a 'reference biosphere'. Thus, calculations will provide an indicator of risk, based on the estimated radionuclide releases into the biosphere, rather than a prediction of the risk".*

In its characterization of reference biospheres and reference communities, NRPB suggests that calculations should be based on present-day climate conditions and need not necessarily be matched to the environmental conditions assumed (e.g. in terms of effects on groundwater flow) for geosphere modelling. The argument for basing reference biospheres on present-day conditions is that differences between biomes and human behaviour will be of relatively minor importance compared to the overall level of uncertainty implicit in long-term radiological assessments and the difference between releases into the terrestrial and marine environments.

The difference between a 'reference community' defined for 10^4 to 10^6 years and the critical group defined for the earlier timeframe is largely one of emphasis rather than substance. Thus, for example, the need for an internally consistent set of assumptions regarding habits and behaviour that is not extreme, and is based on present-day and historical information, is largely consistent with the requirements for the hypothetical critical group. However, it is suggested that, for simplicity, the community could be considered as "perhaps a few families who produce a range of food to feed themselves". This may be compared with an approach based on "currently observed behaviour", as referred to above, for 10^2 to 10^4 years. It is suggested that a small number of 'reference communities' may be appropriate to reflect a range of conditions (such as those appropriate to different sea levels at a coastal site), with the most pessimistic being considered when making comparisons with the risk criteria.

3. NIREX APPROACH

A key feature of the approach taken by the Nirex Disposal Safety Assessment Team (DSAT) is the emphasis placed on climate change and its consequences as a principal factor in post-closure radiological performance assessment for a deep geological repository. This has involved the adoption of five broad climate states (Mediterranean, Temperate, Boreal, Periglacial and Glacial) as being appropriate for the characterization of the range of climate conditions likely to occur over the next 10^6 years at Sellafield, Cumbria (the site currently being investigated by Nirex). The biosphere component of the Nirex Safety Assessment Research Programme (NSARP) has, since its inception in 1987, contributed the results of climate research to the development of an assessment approach [5] based on timeframes identical to those adopted by the NRPB [3].

The approach to defining critical groups within the Nirex programme is generally congruent with that recommended in the NRPB guidance. Consistent with the NRPB approach, the results of risk calculations are subject to assumptions regrading insitutional control over the site in the period 0 to 10^2 years. For subsequent timeframes, the methods are again similar, but Nirex has tended to adopt a more uniform approach to the definition of critical groups over time (i.e. there is no distinction between 'critical groups' and 'reference communities'). Beyond 10^6 years, although risks have been presented in the context of a risk target, the emphasis of the analysis has been to demonstrate that risks do not increase significantly during this period, thereby implicitly identifying with NRPB's observations concerning the basis for risk calculations in this timeframe.

The Nirex methodology is based on the understanding that potential critical groups for present-day effluent discharges are identified from within communities living in the vicinity of a licensed site. Although there can be no direct analogue of such communities for the situation pertaining to future discharges from a waste repository, the methodology adopted to date is based on the assumption that critical groups will similarly be representative of particular habits and behaviours within a hypothetical future community. Hence the identification of critical groups begins with the assumption of a community with the following characteristics:

- It is located such that its primary area of resource utilisation includes those localities and environmental materials that exhibit the highest concentrations of repository-derived radionuclides;
- It is constrained to be a subsistence community, to ensure that maximum use is made of locally derived materials, including foodstuffs;
- It is required to exhibit habits and behaviour patterns consistent with those observed in the present day in corresponding climates (e.g. in South-east Iceland for Boreal conditions).

In this methodology, once hypothetical communities appropriate to each of the climate states have been defined, potential critical groups are identified, their radiation exposures calculated and the critical group then defined as the most exposed of the potential critical groups. For the purpose of the calculations, all persons within the community with similar habits and behaviour are assumed to make use of the contaminated resources to the same extent. In this approach, if the contamination were inhomogeneously spread across the primary resource area, individuals with the same habits and behaviour constitute a group within the hypothetical community that is homogeneous with respect to risk, but not necessarily with respect to dose. In practice, this effect is minimised by selecting a subsistence community that is as small as is reasonable for a stable long-term socio-economic structure.

4. CRITICAL GROUP PARAMETERS FOR THE GROUNDWATER RELEASE PATHWAY

4.1 Community Size

As has been noted above, all persons within the community with similar habits and behaviour are assumed to make use of the contaminated resources to the same extent. One of the most important parameters used to define the critical group in biosphere assessments is therefore the size of the community that is assumed to make use of the contaminated primary resource area. By contrast with the approach recommended by NRPB ("perhaps a few families"), the Nirex DSAT has typically adopted hypothetical communities that are somewhat larger. This arises because a "community" is defined as a closely-linked socio-economic structure, not through commonality of behaviour alone. Hence a distinction is maintained between local communities and the potential critical groups that they contain (as is the case in present-day practice for routine discharges).

For Temperate and Mediterranean conditions, the size of the hypothetical future subsistence community is taken to be 300 persons, utilizing a primary resource area of 10 km^2 (1000 ha). This choice is based on a survey of Parish sizes in West Cumbria at the present day, because the Parish is regarded as the smallest socio-economic unit that can reasonably be considered as a relatively permanent subsistence community. A historical analysis shows that, when account is taken of the impact on some Parishes of industrial developments in the region (notably Windscale/Sellafield), the size of Parish populations has been remarkably stable over a period of some 80 years.

For Boreal conditions, the size of the hypothetical community was again taken as 300 persons, a figure that is judged to be close to the minimum for long-term viability of an agricultural community. However, in order to allow for the lower primary productivity in Boreal conditions, and an increased emphasis on pasture rather than arable crops, the primary resource area was increased from 10 km^2 to 30 km^2.

The subsistence community adopted for Periglacial conditions was based on the quasi-nomadic lifestyle observed in northern European countries, Alaska and the North-western Territories of Canada, as such a lifestyle is well-adapted to the low terrestrial primary productivity that occurs in such climatic conditions. Thus a coastal community was envisaged, utilising an inland resource area of 1000 km^2 for herding/hunting.

The Glacial state has not been modelled in biosphere studies undertaken to date, because the whole of the region of interest is considered to lie beneath an ice sheet in such conditions.

4.2 Critical Group Habits

Within the hypothetical subsistence community defined for a Temperate climate, the potential critical groups considered are those that would typically be addressed in the context of liquid and atmospheric effluent discharges at the present day. The groups considered typically exhibit one or more aspects of behaviour, or components of their assumed diet, that are somewhat in excess of the community average. Thus, for the Sellafield region, preliminary assessments have considered beef and sheep farmers, bait diggers and houseboat dwellers, all with their families, as potential critical groups.

Rather than identifying each of the wide range of parameter values used to characterize habits and dietary intake in these assessments, it is simply noted here that the intention is to adopt values that are, as far as possible, consistent with descriptions appropriate to average members of the public. Particular emphasis is then placed on specific pathways of exposure for each potential critical group by enhancing certain aspects of their diet and/or behaviour. Thus, for example, beef and sheep farmers and their families have an increased meat consumption at the expense of marine foods, whereas bait diggers have an increased intake of molluscs and spend a greater proportion of their year at the tidal margin of the sea. Data values assumed in the definition of critical group parameters are currently under review.

At present, Nirex does not differentiate between the hypothetical communities and potential critical groups appropriate to Temperate and Mediterranean conditions. Although there will be some distinctions between these conditions, a consideration of soil types and the agricultural potential of the region under consideration, together with the relatively limited sea-level rise that is anticipated in a Greenhouse-gas-warmed world, indicates that the pattern of land use in Mediterranean conditions would not change substantially from that observed at the present day.

For Boreal conditions, the potential critical groups comprise inland and coastal farmers, fishermen and their families. This more limited range of groups reflects the fact that Boreal conditions are not likely to occur in the region of interest for at least the next 10,000 years, so justifying a somewhat simplified assessment approach.

In a Periglacial climate, little differentiation is made in terms of occupations or diet within the assumed subsistence community, so the only distinction made between potential critical groups for assessments performed to date has been on the basis of age.

4.3 Treatment of Uncertainties

Changes in human habits and behaviour are not addressed in post-closure radiological assessments undertaken by Nirex, except in so far as such habits and behaviour are assumed to be consistent with changing climate. It is clear, therefore, that the individual risk estimates generated are necessarily indicators of repository performance rather than predictions of impact. Specifically, the defined communities and the potential critical groups within them are considered to be artificial constructs, which have been developed in order to translate calculated radionuclide concentrations in the environment into a single measure of impact ("individual risk").

If it is accepted that the communities and potential critical groups considered in post-closure performance analyses are indeed artificial constructs, it follows that it is inappropriate to incorporate uncertainties into the parameter values that characterize those communities and groups. Rather, such parameters form part of the assessment basis and Nirex considers it appropriate to assign single, point values to them in any one set of calculations. This does not preclude investigation of the implications of using alternative bases of assessment in variant calculations.

One particular basis of the assessment approach adopted to date is that of a subsistence community, making maximum use of locally derived materials, including foodstuffs. It would perhaps be more reasonable to define hypothetical communities that make a great deal of use of local resources, but which are not entirely dependent on them. An alternative basis of assessment might be to consider potential exposures associated with more industrialized development in the region local to the discharge.

5. CRITICAL GROUPS FOR OTHER RELEASE PATHWAYS

The transport of radionuclides in groundwater has been viewed as resulting, almost inevitably, in their eventual entry to the biosphere. In this respect, the biosphere does not represent a "barrier" between waste and the accessible environment. Rather, it is in the biosphere that the mixing of ground and meteoric (or marine) waters mainly takes place, leading to a dilution of radionuclide concentrations. It is nevertheless also recognized that other general routes exist whereby radionuclides may be released from a repository and result in radiation exposures of humans. These include:

- Migration of radionuclides in bulk gases evolved as a consequence of microbial degradation and chemical corrosion of the wastes and associated materials;
- Human intrusion into the repository or its contaminated environs;
- Disruption of the repository or its contaminated environments by natural events such as deep erosion or seismic activity.

The basic principle adopted here is that, in making assessments of post-closure radiological performance, a consistent approach should be adopted in the definition of critical groups for all potential release pathways, including groundwater. In this respect, the position taken is the same as that adopted by NRPB [3], in so far as the characteristics of any potential critical group are defined by relative homogeneity of habits and behaviour and not by the doses received as a consequence of those habits and behaviour.

Thus, for example, in assessments for the gas pathway, where scoping calculations suggest that radiological impacts will arise primarily over the first few hundred, or at most few thousand, years after repository closure, it is appropriate to adopt the same hypothetical community approach as that used for the groundwater pathway.

With respect to intrusion, two broad cases have been considered:

- Intrusion into the repository, or its immediate surroundings, resulting in the transfer of wastes, or contaminated materials, directly to the surface environment;
- Intrusion into the overlying aquifer, intercepting contaminated groundwaters migrating from the repository towards the surface.

The second of these is readily addressed in combination with the standard groundwater pathway, since contaminated groundwaters can be assumed to be abstracted and used for purposes such as domestic and agricultural supply, or river augmentation, within the primary resource area of the hypothetical future community. Indeed, small, agricultural-type wells are an intrinsic feature of the types of subsistence, agricultural communities defined for Temperate, Mediterranean and Boreal climate conditions. Exposure scenarios involving water abstraction from an agricultural well, with little or no impact on the underlying groundwater fluxes and flow pathways, are therefore incoporated into treatment of the normal groundwater pathway.

A slightly different approach is required in order to consider the case of larger wells penetrating deep into the regional aquifer, which would be expected to have yields considerably in excess of the requirements of a subsistence community. This demands the definition of a different basis for the selection of potential critical groups from a collection of subsistence communities and/or from a single larger centre of population.

In considering the direct transfer of contaminated materials to the surface environment as a result of intrusion, a hypothetical community is not as easily defined as for the groundwater and gas pathways, because the community is not necessarily associated with a particular, spatially limited resource area. The Nirex response has been to adopt a simple scoping approach, based on robust assumptions regarding the probability that individuals may come into contact with the contaminated material and the potential pathways of exposure that are associated with such contact.

Thus, for example, it may be considered that a particular community at risk from possible future intrusion events are the geotechnical workers who, at some time in the future, could be called upon to examine cores and cuttings from exploratory drilling activities in the vicinity of the repository. In the calculation of individual risks it is necessary to consider the probability that an individual member of the group at risk receives a radiation exposure, given that such exploratory drilling has occurred. To date, Nirex has adopted the pessimistic approach of setting this probability at unity. It is then necessary to adopt suitably robust modelling assumptions and parameter values in order to determine the effective dose that would be received by a representative exposed individual from within the group.

REFERENCES

1. UK Nirex Ltd, *Post-closure Performance Assessment: Treatment of the Biosphere*, Nirex Report No. S/95/002, 1995.

2. HMSO, *Disposal Facilities on Land for Low and Intermediate-level Radioactive Wastes: Principles for the Protection of the Human Environment*, 1984.

3. NRPB, *Radiological Protection Objectives for the Land-based Disposal of Solid Radioactive Wastes: Statement by the National Radiological Protection Board and Recommendations for the Practical Application of the Board's Statement*, Documents of the NRPB, 3(3), 1992.

4. HMSO, *Consultation Document - Disposal Facilities on Land for Low and Intermediate Level Radioactive Wastes: Guidance on Requirements for Authorisation*, 1994.

5. D.E. Billington, D.A. Lever and S.J. Wisbey, *Radiological Assessment of Deep Geological Disposal: Work for UK Nirex Ltd*, Proceedings of the Symposium on Safety Assessment for Radioactive Waste Repositories, Paris, 9–13 October 1998, pp. 271–281, OECD/NEA, 1989.

BIOMOVS-II Critical Groups Report

Description of Approach and Content

(adapted from Oct. 1995 BIOMOVS-II Reference Biospheres Working Group comments)

John Kessler, Electric Power Research Institute
(Graham Smith, Intera Information Technologies)

NRC/EPA presentation, 13 November 1995

ATTACHMENT 4

Approach

Properly defining the critical group(s) is essential

A single definition for critical groups is not adequate

- Differences in regulatory guidance
- Fundamental differences in future biospheres
- Differences in preferred modeling approaches

This report will be more than a compilation of current practices

BIOMOVS-II can provide guidance on choosing the "correct" approach(es) to critical groups for a given application

MAIN THEME: Regulations and implementation *must all* be consistent

Regulatory philosophy

Specific regulatory guidance:

Critical groups;

Approaches to biosphere definition and modeling.

Application of critical groups

How large? How homogeneous?

How conservative?

What level of detail?

FEPs and modeling approach

Do the FEPs and models support the pathways important to the critical group?

Regulatory philosophy: Options

"Cautious" (Conservative):

Radioactive waste disposal is an involuntary risk from a man-made source for which future generations will derive no benefit.

Furthermore, it is radioactivity and society dreads all things radioactive.

Consequently, regulators feel justified to make much more stringent regulations regarding HLW disposal than for other activities involving health risk.

Conclusion: make sure *nobody* will ever receive anything more than a tiny dose/health risk from HLW disposal.

Examples:

US Environmental Protection Agency: 40CFR191 ("maximally exposed individual" should get less than 0.04 mSv/yr)

ICRP 26 ("representative of individuals ... who ... would receive the highest dose")

Regulatory philosophy options (continued)

"Equitable":

HLW disposal constitutes a health risk to present and future generations, just like innumerable other risks society broadly tolerates (i.e., takes no extraordinary measures to avoid or reduce).

Therefore, regulate it to the same level as other 'tolerable' risks.

In addition, the levels of 'tolerable' risk are based on a society-wide *averages*, rather than on specific usually ill-defined, higher risk subgroups."

Examples:

Those using health risk limits close to "tolerable" levels ($\sim 10^{-6}$ to 10^{-5} per year): ICRP, US NAS, NRPB, others.

NRPB's "reference communities" language.

RWMAC/ACNSI "Tolerability of Risk"

Why are the 10^{-6} to 10^{-5}/yr health risk limits "tolerable"?

They are based on "accepted" risk levels. Examples:

Risk (*average for entire US population*)	Annual risk per million persons[1]	
Motor vehicle accidents	240	
Home accidents	110	
Motor vehicle pedestrian collisions	42	
Firearms	10	↑
Poisonings (not drugs/medications)	6.0	↑
Electrocution	5.3	**(~10^{-6} to 10^{-5}/yr range)**
Tornadoes	0.6	↓
Lightning	0.5	↓
FDA food additive regulatory "floor"	1	
EPA general risk limit range[2]	1-1000	

[1] [Adapted from Wilson, R. and Crouch, E., *Risk/Benefit Analysis*. Cambridge: Ballinger, 1982.]
[2] Statement by William K. Reilly, US EPA Administrator on Environmental Tobacco Smoke, Jan. 7, 1992. "Merely for comparison, EPA generally sets its standards or regulations so that risks are below 1-in-1,000 to 1-in-1,000,000."

Risks for subsets of the population can be higher

Annual risk of death by tornado (US average): 0.6 per million[3]

Annual risk of death by tornado (Midwest average): 2.2 per million[4]

What if "critical group" who is "most at risk" is only a few tens of people?

Tornadoes: Midwestern people in mobile homes at the top of exposed hills located in a "tornado alley"?

Risk for this hypothetical critical group probably much higher than even 10^{-5} per year.

Society "accepts" this (i.e., won't take extraordinary measures to reduce risk to these mobile home dwellers)

3 Adapted from Wilson, R. and Crouch, E., *Risk/Benefit Analysis.* Cambridge: Ballinger, 1982.

4 Adapted from Dinman, G. D., "The Reality and Acceptance of Risk," *Journal of the American Medical Association,* Vol. 244(11), 1126-1128, 1980.

Conclusion: A truly "equitable" philosophy is based on what society "broadly tolerates" for all kinds of risks.

10^{-6} to 10^{-5} per year health risk range.

Averaged over a very large group.

Large, within-group heterogeneity in risk/exposure is accepted.

Problem: Many regulations and guidance apply "equitable" health risk limits in a "cautious" manner.

This approach is inconsistent.

Inevitably leads to confusion in interpretation and enforcement.

Regulatory implementation (continued)

Most regulators try for something between "cautious" and "equitable"

Standards frequently set in the 10^{-6} to 10^{-5} per year range.

"Critical group": those "most exposed" (i.e., fairly small).

Critical group should be relatively homogeneous.

But are these 'in-between' approaches self-consistent?

This report will try to identify the inconsistencies and approaches to dealing with them.

Regulatory implementation (continued)

Report will:

- Survey existing guidance and regulations *and the basis for them.*
- Characterize the levels of conservatism used in the guidance or regulations.
- Identify conflicting levels of conservatism within the same document (i.e., are they being self-consistent?).
- Identify what is missing from the regulations/guidance to make implementation possible.

BIOMOVS-II recommendations on a self-consistent regulatory/guidance philosophy:

"Cautious" philosophy should employ:

- a deterministic approach (e.g., specific dose *limits* rather than health *risk* limits or guidance; "bounding" calculations)
- use a single, "maximally exposed" individual
- upper limits on all biosphere and human characteristics

"Equitable" philosophy should employ:

- a probabilistic approach (health risk criteria, not dose rate limits)
- risk comparison to a risk *goal*. Implementor provides illustrations
- use individual characteristics representative of a larger population
- use averages or "best estimates" of all biosphere and human characteristics

Implementation of critical group guidance or regulations

Survey current approaches to implementation

Identify where approaches are consistent and inconsistent

Identify areas where the implementor:

- has insufficient guidance
- is "extreme" in the interpretation

FEPs that are used in conjunction with the critical group definition

Summary of general approaches to implementation

Critical group size

approaches to determining it

Relevant critical group characteristics (use today's habits, or something else?)

eating habits

age differences

"susceptibility" differences

Common features requiring *major* user interpretation

Geosphere/biosphere interface (point or area release?)

BIOMOVS-II recommendations on approaches to implementation

- **Must be consistent with regulatory guidance *and philosophy***
  - Increases the likelihood the regulator will accept the implementation approach
  - Smoothes the way for public acceptance
- **In the face of uncertainty, alternate critical group definitions may be necessary (assuming they are all consistent with the regulations)**
- **Biosphere FEPs must support the critical group**

CONCLUSIONS AND RECOMMENDATIONS:

A wide range in regulatory philosophies gives rise to a wide range of approaches to critical groups.

However, given a specific regulatory approach, the choice of consistent critical group approaches is more limited.

Examples, not an all-inclusive list, will be given.

Identify generic areas where apparently "consistent" interpretations yield wildly different and incomparable results.

Report Schedule

Draft of final version will be completed by Spring 1996

Final report issued October 1996.

BIOMOVS-II Reference Biospheres Working Group
"Critical Groups" Report Outline

I. INTRODUCTION

- BIOMOVS Reference Biosphere's interest in critical groups
- Critical group definition must be properly linked to regulations and the regulatory philosophy
- The members of the Reference Biospheres Working Group have lots of experience with critical groups
- Purpose:
  1) investigate different regulatory/guidance approaches to public health protection, and identify (generally, if necessary) regulatory/guidance approaches to critical group definitions that are consistent with the regulatory philosophy (get into how much or little detail there is on critical group definition within regulations or regulatory guidance).
  2) investigate different approaches to implementing the regulations/guidance on critical groups. What's doable? What is left for interpretation? Problems in defining critical groups and how to overcome them.
  3) make recommendations on approaches to regulations and their interpretation that are consistent with the overall regulatory philosophy.

II. REGULATORY PHILOSOPHY AFFECTING THE CHOICE OF CRITICAL GROUPS

Introduction on prescriptive and non-prescriptive approaches, followed by "illustrative" range of possibilities, but with example text taken from real regulations/guidance. Ends of the potential regulatory philosophy spectrum:

A. "Cautious": Disposal constitutes an involuntary risk from a man-made source for which future generations will derive no benefit. Fear and distrust of anything to do with radiation lead to very strict regulation, i.e., beyond that associated with other risks. Therefore, strict regulatory risk *limits* (not guidance) are in order. The implementor must make quantitative predictions, not illustrations, so well documented, conservative calculations are required (rather than best estimate projections and heavy reliance on expert judgment).

B. "Equitable": Disposal constitutes a health risk to present and future generations just like many other risks society broadly tolerates. Levels of risk on the order of that broadly tolerated are appropriate for regulatory guidance. In addition, the levels of broadly tolerable risk are generally calculated on a society-wide basis, rather than on specific considerations of usually ill-defined, higher risk subgroups. Therefore, risk guidance based on risk levels broadly tolerated by society should be the form of the regulation. The regulator requires a risk comparison to a risk "goal". The implementor provides "illustrations". Critical group sizes may be large and heterogeneous in risk. Probabilistic approaches to analysis using best estimates partially derived from expert judgment are appropriate.

III. SURVEY OF GUIDANCE AND REGULATIONS

A. A dispassionate survey devoid of any form of editorialization (perhaps some).
B. Identify common themes.
C. Identify consistent and inconsistent approaches found in the common themes. If it doesn't work on the purely generic level, then we will have to be specific.

IV. SURVEY OF IMPLEMENTATION

A. Dispassionate survey
B. Common themes
C. Compare to guidance/regulatory themes. This may not work at all on the generic level, but we should try before getting too specific.

V. CONCLUSIONS

- "equitable" approach is not generally recognized, but is viable
- consistency makes an approach hang together an be more defensible to public
- not much TECHNICAL basis for the level of detail on groups
- regulator may be able to mix and match philosophies, but the implementor can't. Mixed philosophies will be difficult to properly implement without a tremendous amount of detailed guidance from the regulator.
- subjective decision on both the period of institutional control, and when one switches to a lower level of critical group detail. We recommend that studies of the sensitivity of the final analysis to the level of detail assumed in the critical groups definitions should be performed.
- when guidance is unclear (as it usually IS) it is necessary for the regulator and implementor to work closely together throughout the process

Biosphere FEP List Development

Specific to Yucca Mountain

A summary of work performed by BIOMOVS II and INTERA Environmental Division

John Kessler
Manager, Spent Fuel and HLW Disposal Program
Electric Power Research Institute

presented to NRC/EPA, 13 November 1995

ATTACHMENT 5

Outline

Importance of biosphere FEPs and the FEP-making process

International FEP lists (including BIOMOVS)

The RES matrix approach

Intera work on a Yucca Mountain-specific FEP list

Importance of biosphere FEPs

Biosphere is the new link required to assess doses

Release portion of 40CFR191 circumvented the need for biosphere considerations

Biosphere FEPs: Features, Events, and Processes of the biosphere

- within the Yucca Mountain vicinity
- from farther afield that affect the Yucca Mountain vicinity

Importance of the FEP-making process: FEPs need to be systematically identified

Important to be able to understand the relationships between FEPs

Important to the regulator to show what has been included

If done intelligently, one can use a FEP list to

- list the FEPs
- show the linkages between related FEPs
- document the choices of the FEPs that have been included (and excluded)
- document the models and parameter values chosen

EPRI's interest in FEP lists

Lots of international FEP lists out there

Is one "better" than another?

Are they robust enough to include ALL features important to YUCCA MOUNTAIN?

Many different ways of presenting the FEPs and their relationships

Looking for an approach that:

- can make Yucca Mountain-specific FEPs
- is reasonably simple to understand
- documents the decisions made that generated the FEP list

International FEP lists for deep, geologic disposal (not all-inclusive)

BIOMOVS (Biosphere Modeling Validation Studies)

"I" group

- Ad hoc approach (just write them down and organize them)
- List more appropriate for European continental settings

Sweden (outgrowth of SKB's SITE 94 work)

- Event tree analysis
- Influence diagrams
- *RES ("Rock Engineering Systems") Methodology*

United Kingdom (Nirex)

- "Fanfare": a hierarchical/relational data base approach

International FEP lists (continued)

Joint French/Spanish effort (MICE Project)

- Geared toward climate evolution studies
- FEPs included that may be more like Yucca Mountain climates

PAAG (Performance Assessment Advisory Group)

- International FEP list

BIOMOVS II

- "International" FEP list, but focusing on details similar to conditions in Switzerland
- Initial effort: ad hoc effort; FEPs organized by category; some linakges identified
- More recently, adopted the RES matrix approach

The RES Matrix Approach

Leading Diagonal Elements (LDEs): main features of the system to be modeled

- Source term (assumed to come from the "geosphere" and is located at the "geosphere/biosphere interface")
- Aquifer
- Surface Water
- Sediments
- Variably Saturated Zone (includes deep soil)
- Surface Soil
- Atmosphere
- Flora
- Fauna
- Human Activities
- Dose to Critical Group

The RES Matrix Approach (continued)

Off Diagonal Elements (ODEs): interactions between the LDEs

most of the FEPs lie in the ODEs

Size of matrix is somewhat subjective

generally limited to about 13X13 to make all the ODE interactions manageable

The RES Matrix Approach (continued): Description of the LDEs

Source term

Flux of radionuclides from the geosphere into the biosphere

Assumed abstracted from a deep well

Aquifer (or Permanent Saturated Zone)

Unconfined aquifer immediately beneath the unsaturated zone)

Not a big player for Yucca Mountain *biosphere*

Surface Water

Rivers, streams, canals, ditches, lakes, reservoirs, and lagoons

May be relevant for Yucca Mountain if surface ponds and ditches assumed

Sediment

Bed sediments (perhaps only marginally applicable at YM)

The RES Matrix Approach: Description of the LDEs (continued)

Variably Saturated Zone

Deep soil generally below the root zone

All the way down to the saturated zone

Surface Soil

Root zone soil

Lots of biological activity in this zone including crop growth

Includes solid soil, soil water and gases

Flora

All plants, fungi, crops, and crop products (e.g., cotton clothing, wood for furniture and housing materials)

Fauna

All animals (water and land). Includes animals eating animals.

The RES Matrix Approach: Description of the LDEs (continued)

Human Activities

All relevant activities in the vicinity of the release to the environment including modifications to the environment:

- agricultural practices
- building practices (excavation, use of soils for building, etc.)
- hunting and fishing
- water usage
- more............

Dose to Critical Group

Radiation exposure pathways for the critical group (linked by ODEs)

Partially defined by the assessment context

Figure 1: Generic Biosphere RES Matrix for an Inland Groundwater Release Source Term Taken from BIOMOVS II [1995].

BIOSPHERE MATRIX: DESCRIPTION AND QUESTIONNARIE

SOURCE TERM	1. Contaminati-on	1. Contaminat.	1. Contaminat.	1. Contaminat.	1.	1. No(No a gaseous release)	1. Yes (Special local release)	1.	1.1 B.C. (No media tion - release)	1. Yes (Posibly)
2.	PERMANENT SATURATED ZONE (Aquifer	2. Flow water + solute (...	2. Flow water + solute (...	2. Water trans-port	2. Irrigation Capillary rise	2.	2. Not (main for our system...	Not (main for our situation...	2.1 Use of water	2.1 Ingestion Other (...
3.	3. Recharge	SURFACE WATER	3. Sedimentat., Erosion, ...	3. Recharge (...	3. Flooding, Diffusion, ...	3. Aerosols format. ...	3. Uptake Irrigation	3. Uptake	3.1 Water supply	3.1 Uptake External ...
4.	4. Water + solutes	4. Sediment, Resuspension	SEDIMENTS	4. Conversion	4. Conversion, Dredging	4. Aerosols format ...	4. Uptake External ...	4. Uptake External ...	4.1	4.1 External and direct ...
5.	5. Percolation, Solid transp.	5. Exfiltration, Discharge, ...	5. Bank collapse	VARIABLE SATURATE ZONE	5. Gas Capillary ...	5.	5. Deep root Species	5. Burrowing Species	5.1 Builders Land use ?	5. External (Digging)
6.	6.	6. Transport of eroded ...	6. Bank collapse	6. Infiltration, Chem. eff., ...	SURFACE SOIL (Top Soil)	6. Resuspensio Evaporation..	6. Uptake Rain splash	6. Soil consup-tion ...	6.10 Land uses	6.1 External Dermal ...
7.	7.	7. Deposition; Precipitation	7. Wind erosion Rainfal (if dry)	7.	7. Wind Erosion Deposition. ...	ATMOS-PHERE (AIR)	7. Deposition Rain snow	7. Inhalation Deposition	7.1 Minimal on Weather ...	7. Inhalation External. ...
8. Not or very small	8. Only for spe-cial plants	8. Contaminatio (by leaves)	8. Bioturbation, Death	8. Deep rooting	8. Death Organic bio...	8. Exhalation Transpirat...	FLORA	8.	8.1 Viability (Diet and ...	8.1 Ingestion External
9.	9.	9. Contaminatio Drums	9. Bioturbation	9. Burrowing	9. Burrowing, Excretion, ...	9. Exhalation	9. Consumption Fertilising, ...	FAUNA	9.1 Depend. on boun...	9.1 Ingestion External
10. Intrusion(Not considered)	10. Water extrac-tion, ...	10. Water Rechar Water Ext., ...	10. Dredging, Removal	10. Pollution, Civil engi., ...	10. Agriculture, Pollution, ...	10. Pollution Filtration	10. Recycling Storage...	10. Farming Storage	HUMAN ACTIVI-TIES	10. Depending on bound...
11.	11.	11.	11.	11.	11.	11.	11.	11.	11.	DOSE TO CRITICAL GROUP

Intera work (in progress) on Yucca Mountain-specific biosphere FEPs

Performed by Intera Environment Division (UK) for EPRI.

Authors: Graham Smith (lead), Barbara Watkins, Richard Little

Purpose:

- Adapt the RES matrix developed by BIOMOVS II to make it Yucca Mountain-specific
- Provide a few examples of how to "bottom out" the FEPs using the RES software developed by CIEMAT (for BIOMOVS II)

1.1 **SOURCE TERM** (Contaminated well water)	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10 Water supply	1.11 Direct exposure
2.1	2.2 **PERMANENT SATURATED ZONE** (Aquifer)	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11
3.1	3.2	3.3 **SURFACE WATER**	3.4 Sedimentation Erosion Diffusion Advection	3.5 Recharge Erosion	3.6 Flooding Diffusion Sedimentation Erosion Irrigation	3.7 Aerosols formation Degassing Evaporation	3.8 Interception Uptake Irrigation / flooding External contamination	3.9 Consumption	3.10 Water supply	3.11 Direct exposure
4.1	4.2	4.3 Resuspension Diffusion	4.4 **SEDIMENTS**	4.5 Conversion Advection	4.6 Conversion Dredging Advection	4.7	4.8 Uptake	4.9 Uptake External contamination	4.10	4.11 Direct exposure
5.1	5.2 Percolation	5.3	5.4 Conversion Bank collapse	5.5 **VARIABLE SATURATED ZONE**	5.6 Gas transfer Capillary rise Weathering	5.7	5.8 Deep root uptake	5.9	5.10 Materials resource	5.11 Direct exposure
6.1	6.2	6.3 Erosion Run-off	6.4 Conversion Bank collapse	6.5 Infiltration	6.6 **SURFACE SOIL (Topsoil)**	6.7 Suspension Evaporation Gas transfer *Volatilization*	6.8 Uptake Rain splash	6.9 Soil contamination	6.10 Land uses Materials resource	6.11 Direct exposure
7.1	7.2	7.3 Precipitation Deposition	7.4	7.5	7.6 Deposition Precipitation Wind erosion Weathering *Condensation*	7.7 **ATMOSPHERE (Air)**	7.8 Deposition Precipitation Gaseous uptake Seasonality *Condensation*	7.9 Inhalation External contamination Seasonality	7.10 Weather influences	7.11 Direct exposure
8.1	8.2	8.3 Desorption	8.4 Weathering Desorption Sediment processes	8.5 As 8.6 but for deep rooted flora	8.6 Weathering Desorption Soil processes *Residues*	8.7 Transpiration Respiration Volatilisation / Desorption Morphological effects Burning	8.8 **FLORA**	8.9 Consumption	8.1 Materials Resource	8.11 Direct exposure
9.1	9.2	9.3 Excretion	9.4 Bioturbation Excretion	9.5 Bioturbation	9.6 Excretion Bioturbation Soil structure	9.7 Exhalation Flatulence	9.8 Fertilisation Direct contamination	9.9 **FAUNA**	9.10	9.11 Direct exposure
10.1	10.2	10.3 Engineering works Extraction Discharge *Water treatment*	10.4 Dredging *Construction*	10.5 Excretion *Construction*	10.6 Agricultural practices on soil processes Excretion Construction	10.7 Filtration Ventilation	10.8 Agricultural practices and ecosystems *Construction* *Furniture* *Energy source* Clothing	10.9 Agricultural practices and ecosystems *Furniture* Clothing	10.10 **HUMAN ACTIVITIES**	10.11 Definition of exposure pathways *Food preparation*
11.1	11.2	11.3	11.4	11.5	11.6	11.7	11.8	11.9	11.10	11.11 **DOSE TO CRITICAL GROUP** (Exposures)

Intera work-in-progress on YM-specific FEP list

Review LDEs and ODEs for appropriateness

Choose a few ODE components to "bottom out"

Examples (completely arbitrary - illustrative only):

- Ingestion of Np-237 in winter wheat (ODE 10.11 and 8.11)
  - Literature search
  - Document choice of gut transfer model and parameters (why one model? why not another model or set of data?)
- Methods of growing and harvesting winter wheat (ODE 10.8)
- Root/soil uptake of Np-237 in winter wheat (ODE 6.8)

Preliminary conclusion

RES matrix approach to biosphere FEP generation for Yucca Mountain looks promising

- Relative visual clarity in presenting FEPs and the relationship between FEPs
- Flexibility in being able to alter matrix, if deemed necessary
- Associated RES software (developed by CIEMAT) allows documentation of FEP choices

40CFR191, NAS, and HR1020 "Standards"

A Preliminary Comparison of Potential Regulatory Standards for Yucca Mountain

John Kessler
Manager, Spent Fuel and HLW Disposal Program
Electric Power Research Institute (EPRI)

Presented to the Nuclear Waste Technical Review Board, 17 October 1995

ATTACHMENT 6

Outline

Electric Power Research Institute (EPRI) involvement with the "Standards"

EPRI's TSPA code, IMARC

Preliminary comparison of the "Standards"

- Basic "Standard" form (release rate; dose rate; health risk)
- 10,000 year versus peak dose or health risk sensitivities
- "Critical groups"
- "Moving the fence post"

Preliminary conclusions

EPRI involvement

EPRI conducts research for US nuclear utilities

US utility view: The "Standard" must

- protect the health of present and future generations
- be licensable (i.e., not ask for more than science can deliver)

EPRI actively participated in the NAS TYMS Committee public meetings

- analysis of 40CFR191
- analysis of alternate Standards
- recommended a Standard

Assessment of NAS recommendations, HR1020 underway

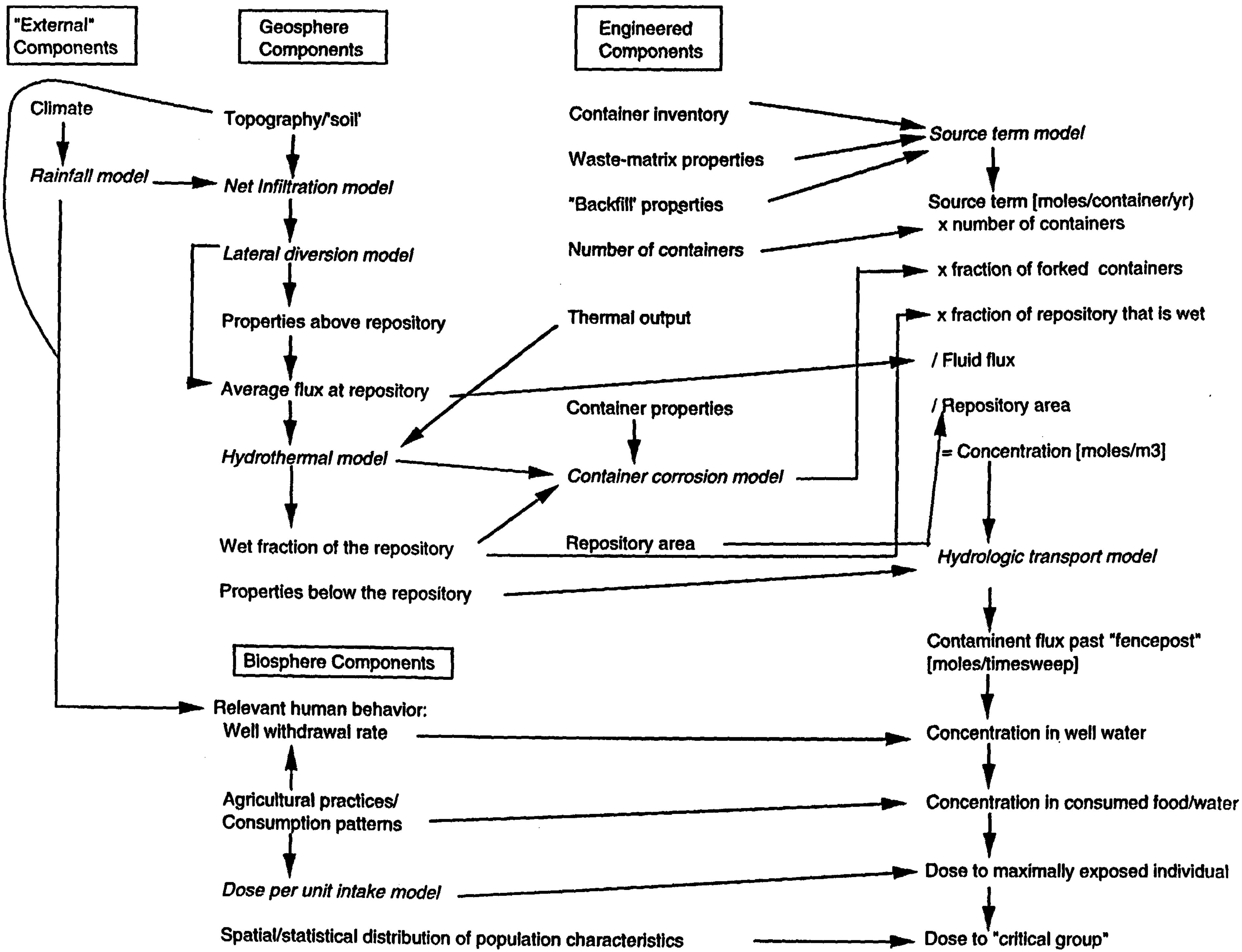
EPRI's primary assessment tool -- TSPA code, IMARC

Developed by Risk Engineering and a small team of experts

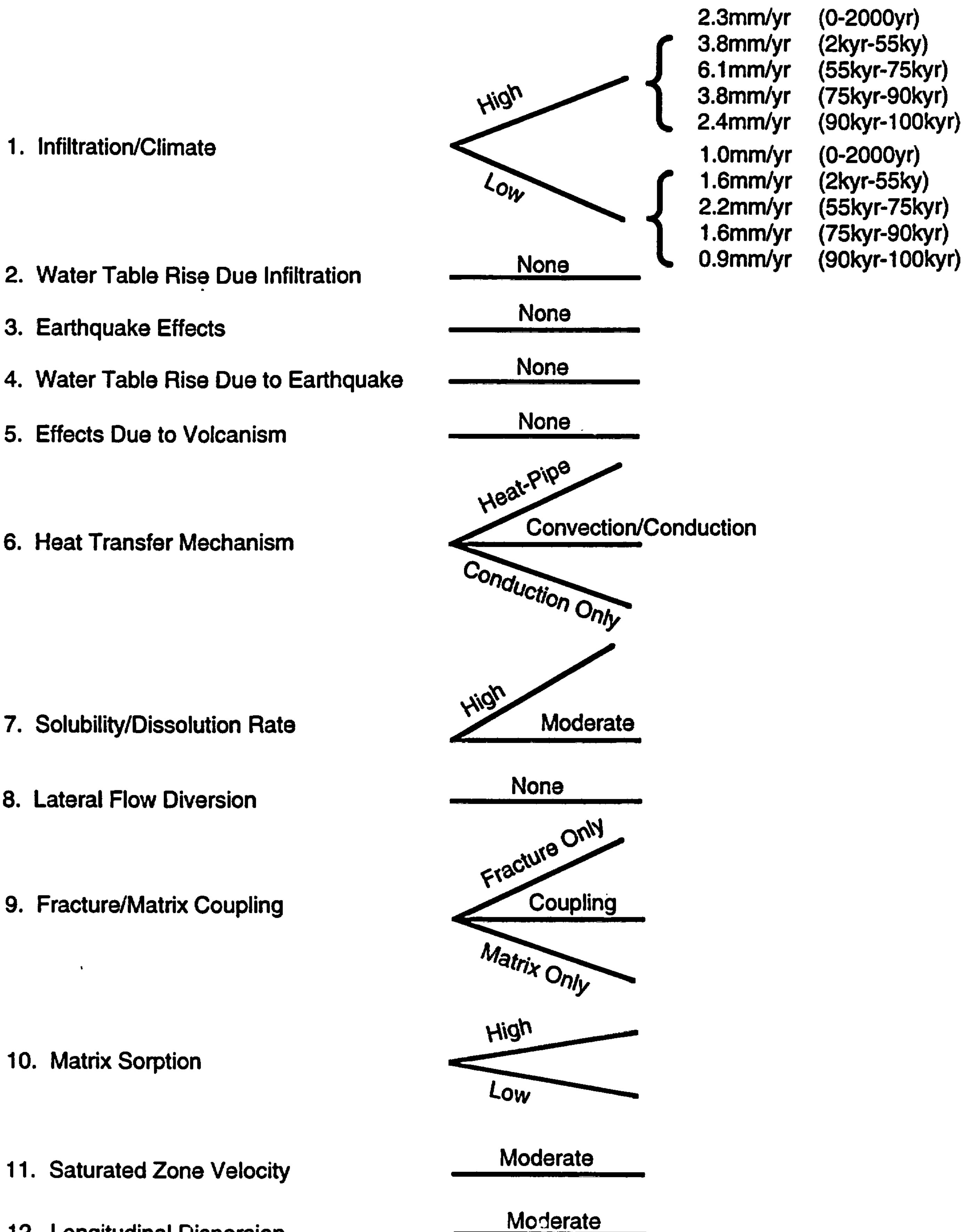
Event tree approach

Recent additions:

- Extend to 1,000,000 years
- Time-varying infiltration rate (pluvials)
- Hydrology model: 3-D in saturated zone, 1-D in unsaturated zone; fracture/matrix coupling; dispersion; daughter ingrowth


"External" Components
Geosphere Components
Engineered Components
Climate
Rainfall model
Topography/'soil'
Net Infiltration model
Lateral diversion model
Properties above repository
Average flux at repository
Hydrothermal model
Wet fraction of the repository
Properties below the repository
Container inventory
Waste-matrix properties
"Backfill' properties
Number of containers
Thermal output
Container properties
Container corrosion model
Repository area
Source term model
Source term [moles/container/yr)
x number of containers
x fraction of forked containers
x fraction of repository that is wet
/ Fluid flux
/ Repository area
= Concentration [moles/m3]
Hydrologic transport model
Contaminent flux past "fencepost" [moles/timesweep]
Biosphere Components
Relevant human behavior:
Well withdrawal rate
Agricultural practices/
Consumption patterns
Dose per unit intake model
Spatial/statistical distribution of population characteristics
Concentration in well water
Concentration in consumed food/water
Dose to maximally exposed individual
Dose to "critical group"

EVENT TREE BRANCHES USED IN THE PRELIMINARY ANALYSES (IMARC PHASE 3)



Preliminary comparison of the "Standards"

Basic "Standard" form (release rate vs. dose rate or health risk)

10,000 year versus peak dose or health risk

"Critical Groups"

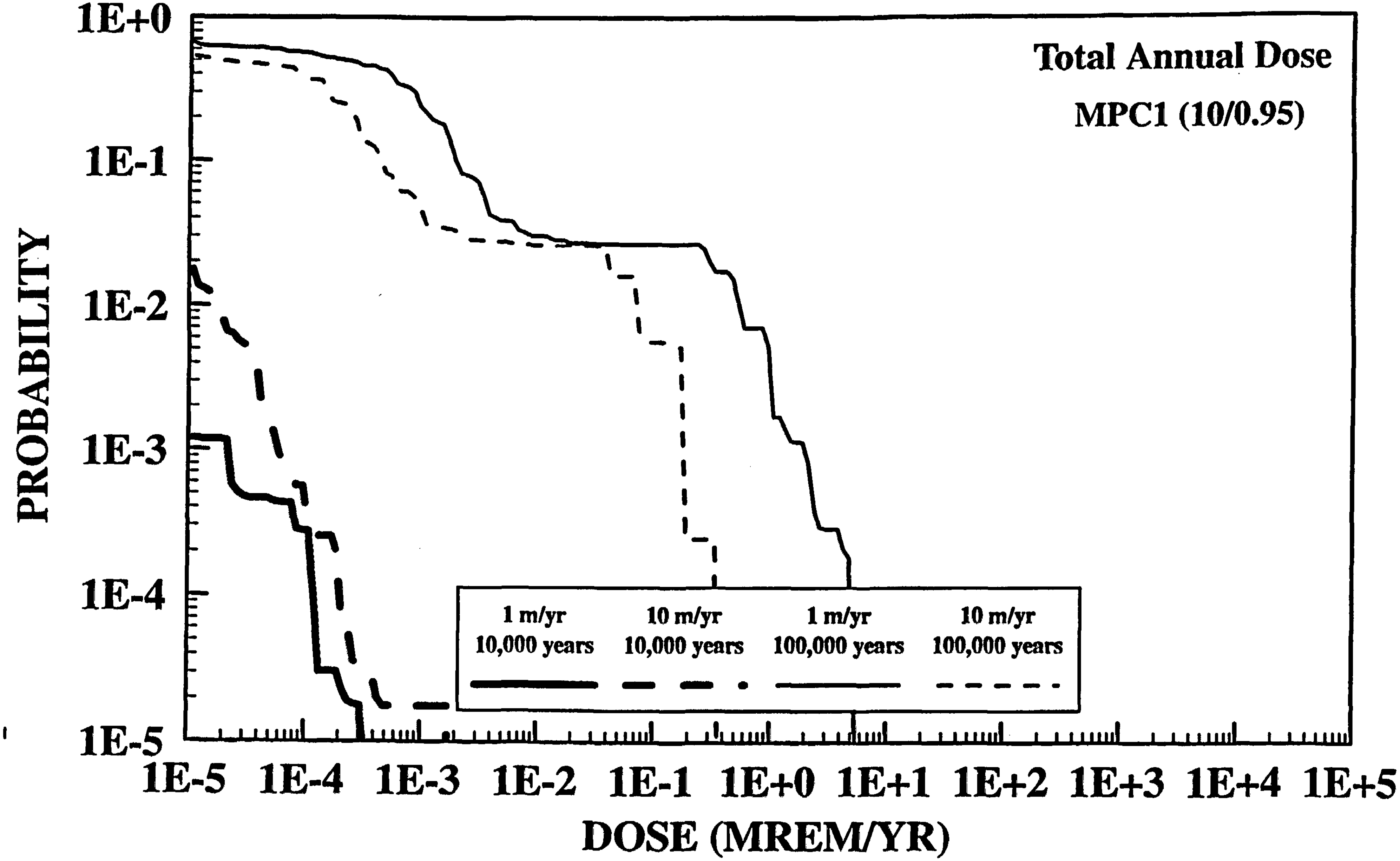
"Moving the fence post"

Parameter sensitivity - release rate vs. dose/health risk criteria

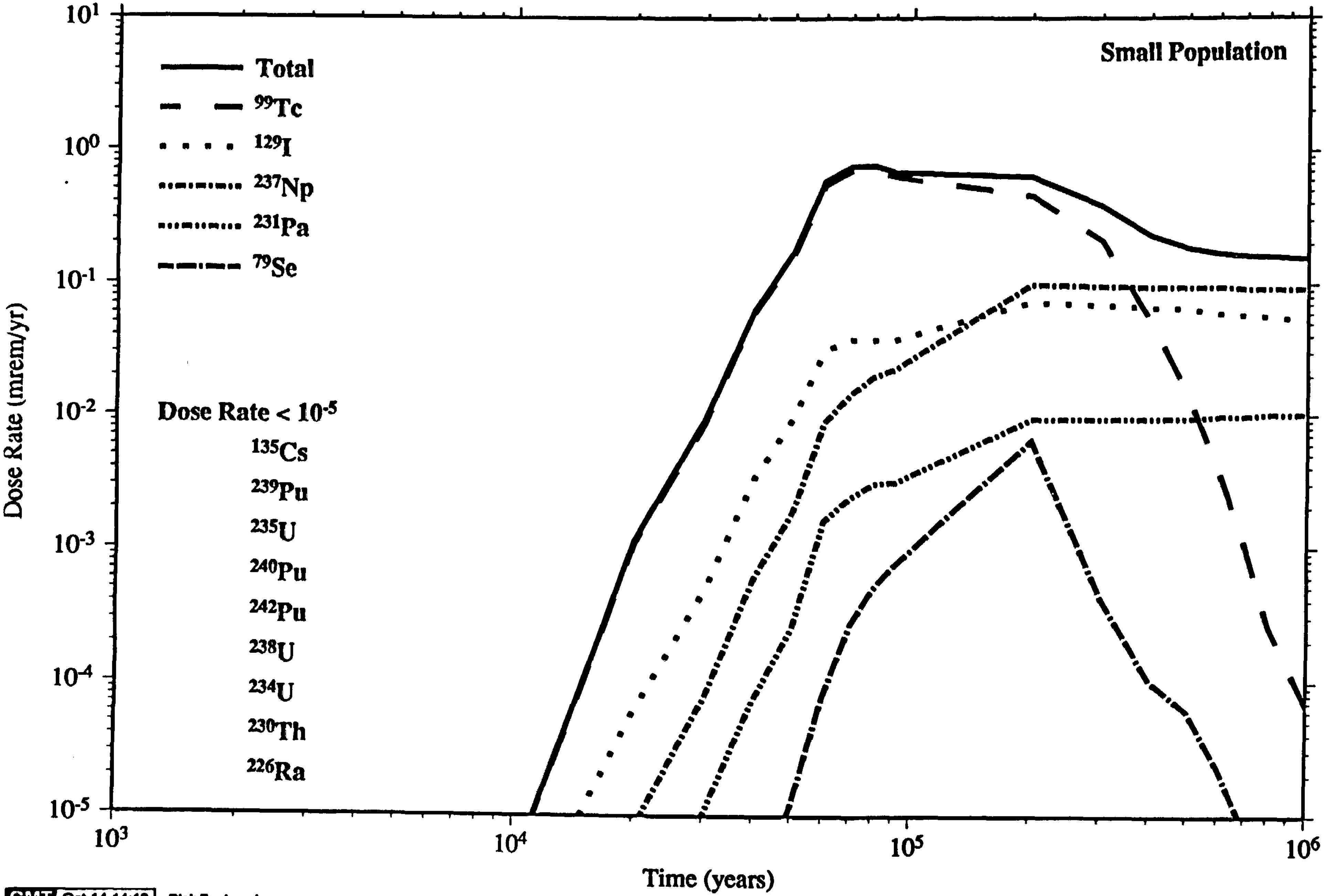
Saturated zone flow velocity

Higher velocity *increases* "release" past boundary

Higher velocity can cause more dilution - so *reduces* dose


Total Annual Dose
MPC1 (10/0.95)
PROBABILITY
1E+0
1E-1
1E-2
1E-3
1E-4
1E-5
DOSE (MREM/YR)
1E-5
1E-4
1E-3
1E-2
1E-1
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1 m/yr 10,000 years
10 m/yr 10,000 years
1 m/yr 100,000 years
10 m/yr 100,000 years

EXPECTED ANNUAL DOSE VS. TIME FOR INDIVIDUAL NUCLIDES



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Time period of Standard can significantly impact the waste isolation strategy

0-~10^4 years - transient period. Important factors:

- Hydrothermal behavior
- Container corrosion resistance
- Number of leaking containers
- Matrix alteration/dissolution rate
- Fast flow paths
- Longitudinal dispersion
- Saturated zone dilution
- Biosphere components

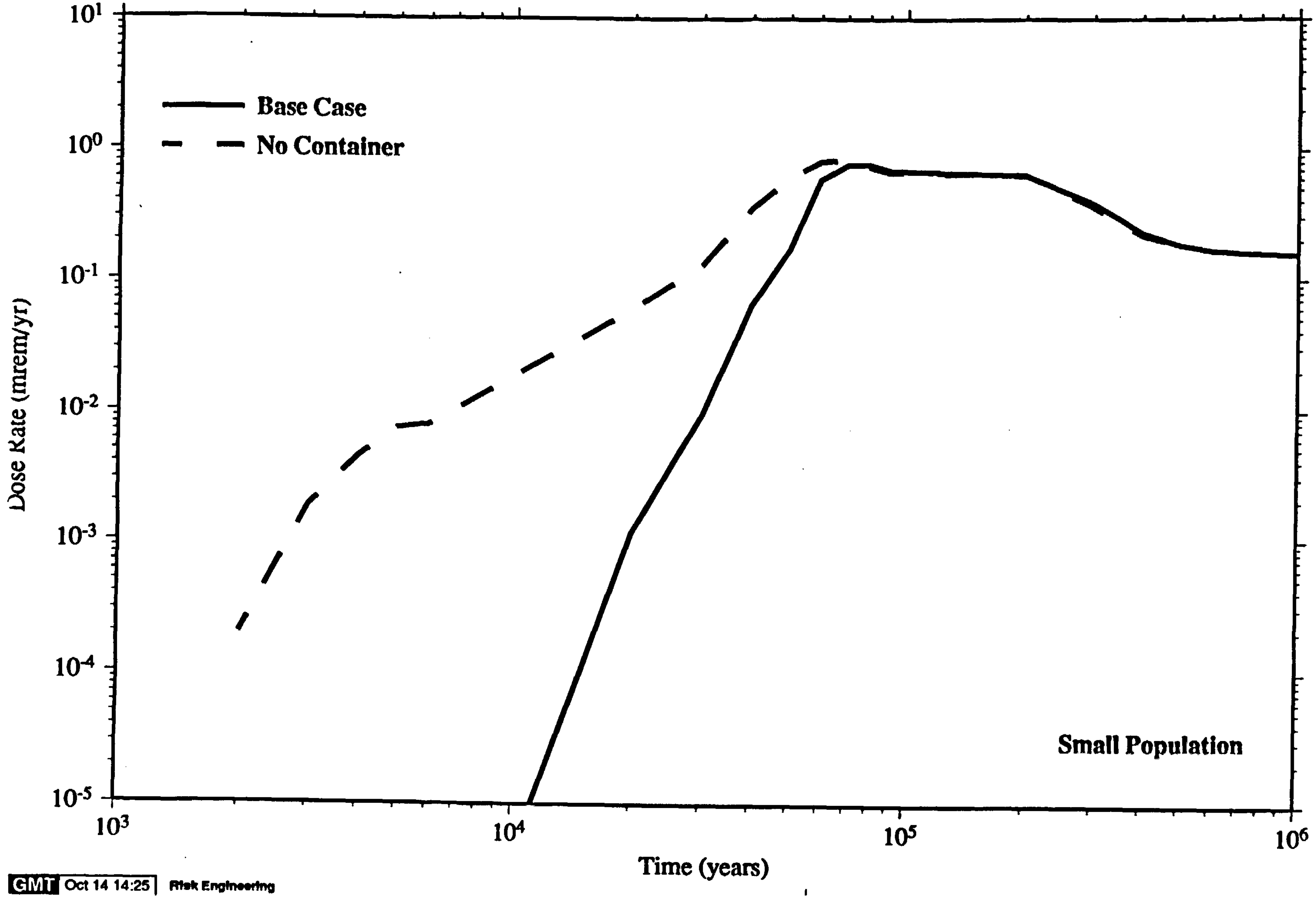
Time period of Standard can significantly impact the waste isolation strategy (continued)

~10^5 years and beyond - peak dose or health risk period. Important factors:

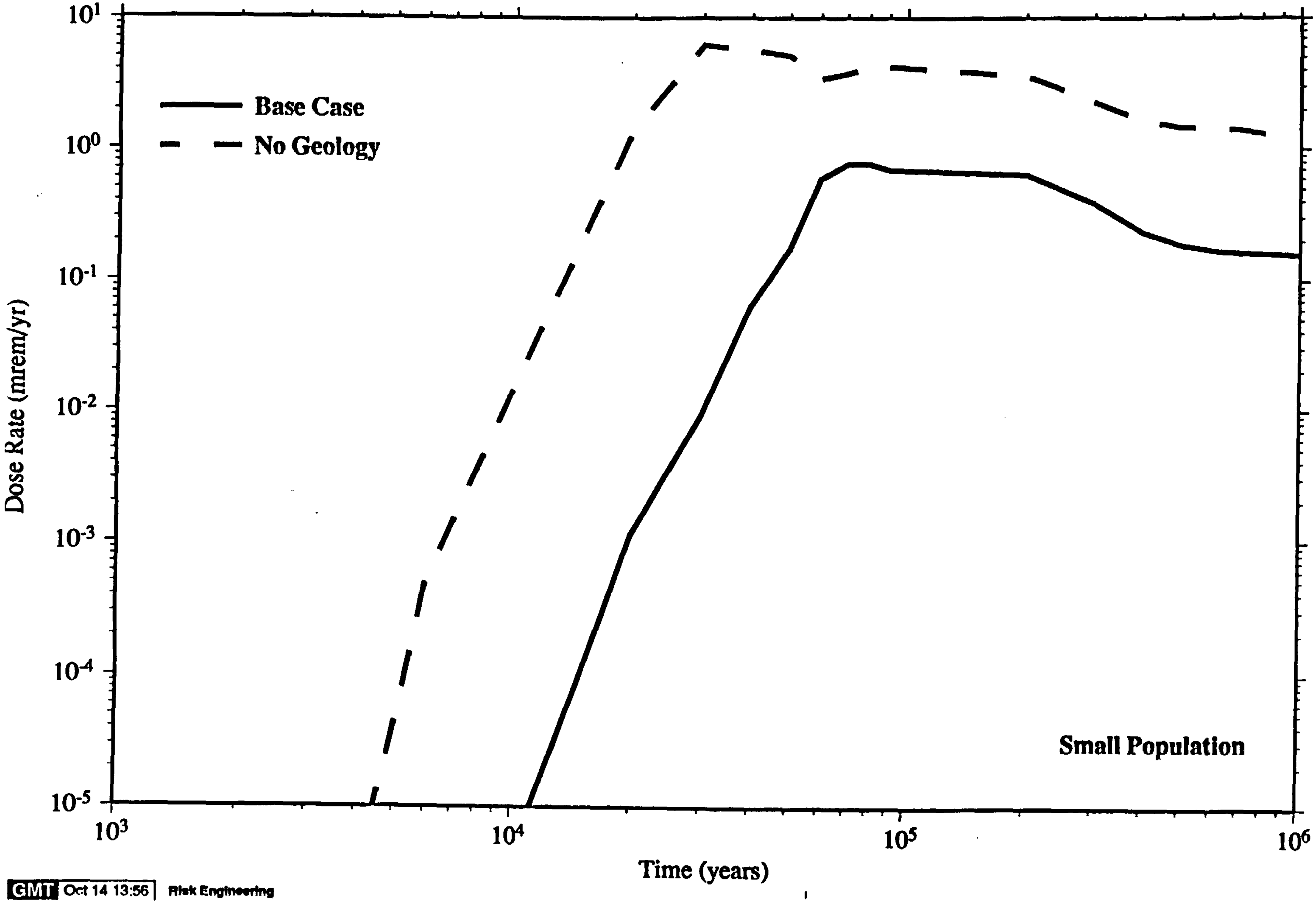
Saturated zone dilution

Biosphere components

TOTAL EXPECTED ANNUAL DOSE VS. TIME



TOTAL EXPECTED ANNUAL DOSE VS. TIME



Comparison of health risk limits

NAS

Suggested annual individual risk limits of 10^{-6} to 10^{-5}

Risk to an average member of a "critical group"

HR1020

100 mrem/yr equals an annual individual risk limit of $5x10^{-5}$

Risk to an average individual in the local population

40CFR191 (based on 1,000 deaths in 10,000 years)

Annual, *population-averaged* individual risk limits of:

- $<10^{-10}$ for C-14 (world population of 10 billion assumed)
- $<10^{-5}$ if 10,000 people (drinking water only)
- $<10^{-3}$ If 100 people (agricultural - groundwater source)

Critical Groups - NAS approaches

1. Probabilistic critical group

- a group that is at greatest risk
- should be small in number (less than a few tens)
- homogeneous in risk (within a factor of 10 or less) w.r.t. "diet and other aspects of behavior"
- "Risks can be homogeneous even when outcomes are quite diverse"
- compare Standard to the mean of the critical group

2. Subsistence farmer critical group

- assumed to represent maximally exposed individual
- must assume individual is at the worst place all of the time
- can be adjusted for realistic well locations and water withdrawal rates

Critical Groups (continued)

40CFR191

Population-based approach neglects risk heterogeneity

Therefore, no special protection of those at greatest risk (beyond 1,000 years)

HR1020

Average individual in the local population

- spatially averaged population distribution
- average of distributions in consumption rates

Explore the basis for a limit between 10^{-6} to 10^{-5} per year:

Involuntary risks or risk limits (annual individual average):

Source	Risk
Being struck by a crashing airplane[1]	$4x10^{-6}$
Extra fatal cancer risk living in Denver[2]	$1x10^{-5}$
US FDA food additive regulatory risk "floor"[3]	$1x10^{-6}$
US EPA general risk limit range[4]	10^{-6}-10^{-3}

[1] Harvard Center of Risk Analysis, 1992 Annual Report, pg. 3.
[2] (relative to living in New York) Wilson, R., 1980, Risk/Benefit Analysis for Toxic Chemicals, "Ecotoxicology and Environmental Safety", Vol. 4, pg. 370-383.
[3] Wilson and Crouch, Science, Vol. 236, pg. 293, 1987.
[4] Statement by William K. Reilly, US EPA Administrator on Environmental Tobacco Smoke, Jan. 7, 1992. "Merely for comparison, EPA generally sets it standards or regulations so that risks are below 1-in-1,000 to 1-in-1 million."

Health risk limit - "critical group" link conclusions

Involuntary health risks of 10^{-6} to 10^{-5} are broadly tolerated by society

Group sizes are often orders of magnitude larger than a few tens of individuals

Risk heterogeneity within existing "critical groups" can be large

Implications for "critical groups" at Yucca Mountain:

Applying a 10^{-6}/yr limit to a maximally exposed individual is inconsistent and *very* conservative

A ~10^{-5}/yr limit to an average individual in the local population (HR1020 approach) is still conservative

- present and future local Yucca Mountain populations probably much smaller than Denver (or populations near airports)

US FDA's risk "floor" of 10^{-6}/yr implies

- averaging of food consumption habits over a large population is acceptable

Illustration of the "average individual" concept

EPRI first proposed this approach to the NAS[5]

"Statistical" components (i.e., based on present day behavioral distributions)

- Water and food consumption
- Agricultural/urban mix
- Agricultural practices

Probabilistic components

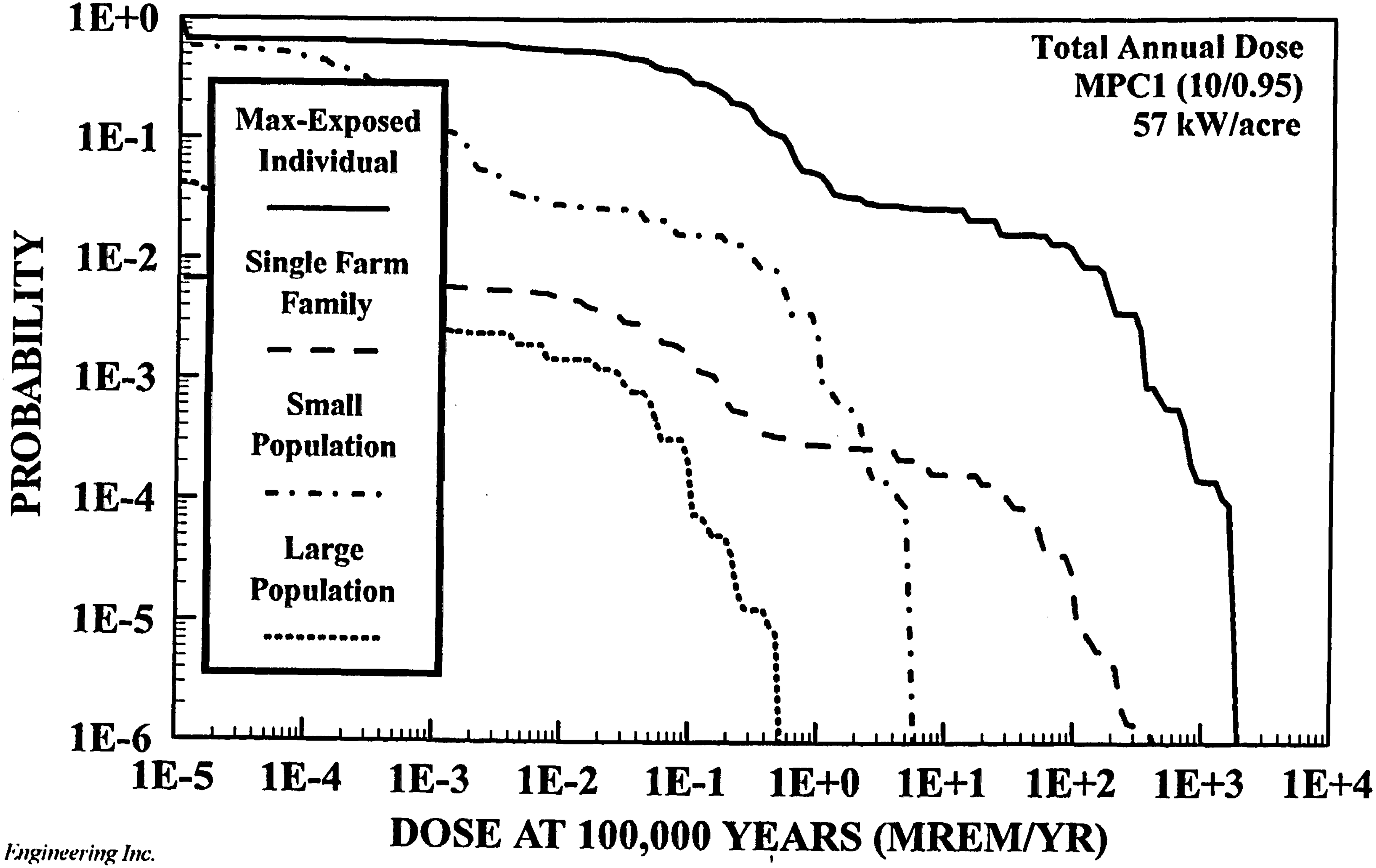
- Water source (local or distant)
- Well depth (base on known hydrogeologic properties)
- Well location (can assume random placement)
- Contamination detection and remediation

---

[5] EPRI TR-104012, "A Proposed Public Health and Safety Standard for Yucca Mountain", Electric Power Research Institute, Palo Alto CA, December 1994.

SENSITIVITY TO POPULATION

FOR AN AVERAGE PERSON IN THE CRITICAL POPULATION



Risk Engineering Inc.

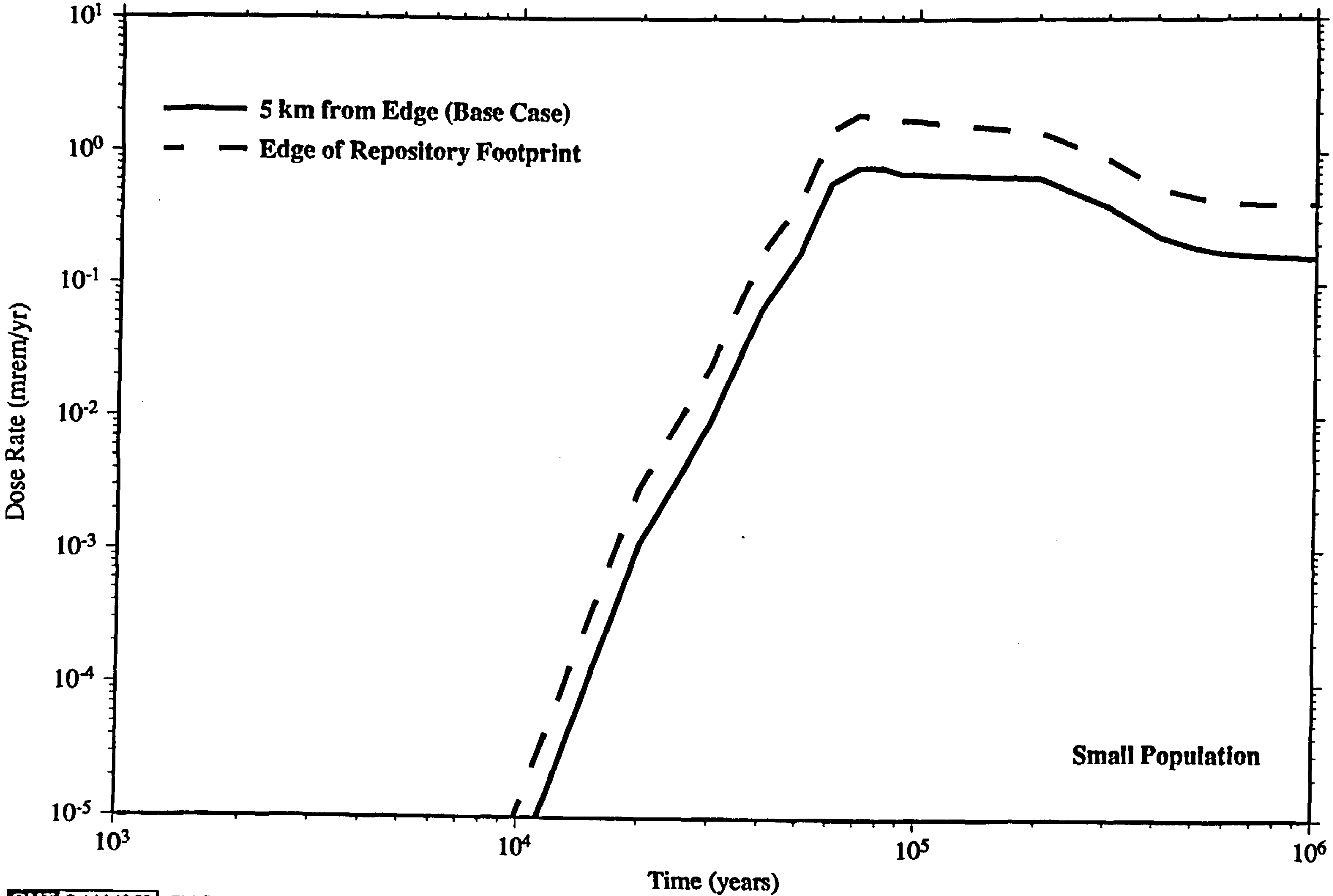
The “fence post”: Downstream position assumed for licensing calculations

NAS: Edge of the repository footprint

40CFR191: 5 km from edge of repository

HR1020: edge of the withdrawn land

TOTAL EXPECTED ANNUAL DOSE VS. TIME



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Conclusions

Both NAS recommendations and HR1020 are a significant improvement over 40CFR191

- They both directly regulate health effects (i.e., they are dose- or health risk-based)
- Their limits are based on broadly tolerable individual risk values

Individual risk limits and "critical groups" should be consistent

- Annual individual risk range of 10^{-6} to 10^{-5} is broadly tolerable
- Inconsistent approach if applied to a maximally exposed individual
- Most consistent if applied to average individual in the local population

Conclusions (continued)

- **Time of regulatory cutoff affects the amount of work to be done**
  - Many parameters/processes are important if regulations set at ~10,000 years only
  - Fewer affect peak doses or health risks
- **Location of "fence post" not very critical**