Modelling increased soil radon emanation caused by instantaneous and gradual permafrost thawing due to global climate warming

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INTRODUCTION

Radon is a naturally occurring radioactive gas which accounts for approximately 9% of lung cancer deaths in Europe and 12% in the USA, and is considered to be the most serious environmental carcinogen by the EPA.

The diffusive and advective transport of radon through the soil is controlled by the porosity, fluid saturations, diffusion coefficients and relative permeabilities of the soil. All of these parameters are significantly reduced in the permafrost that makes up one fifth of the Earth's terrestrial surface.

We have extended the 2D numerical modelling of radon transport through soil and permafrost reported at EGU2006 to include gradual as well as instantaneous melting, different designs of ventilated and unventilated building, and diffusive or convective-diffusive transport.

We find that the presence of the permafrost acts as an effective radon barrier. For the world average Ra^{226} activity of 40 Bq/kg, the permafrost seems to reduce the domestic radon concentrations by 80 to 90% (5 to 10 Bq/m^3) while leading to an increase in the concentration in the radon behind the barrier by 10 to 15 times (500 to 750 Bq/m^3).

However, when we modelled the thawing of the permafrost that is beginning to occur as a result of global climate change the radon in the building increased transiently by up to 100 times (1000 Bq/m^3) over a timescale of several years before decreasing once again. It is therefore possible that a significant number of people could be exposed to levels of radon in excess of the 200 Bq/m^3 threshold that many countries adopt.

The inclusion of advection has a time compression effect that has little or no effect on the maximum and final concentrations of radon, or the overall shape of the curve describing the mean radon in the building as a function of time. The inclusion of gradual melting slightly reduces the maximum value of radon present in the building, but not sufficiently to reduce it to a safe level. The form of the radon concentration-time curve is surprisingly similar to the instantaneous case.

METHODS

All modelling was carried out by the finite element solution of linked partial differential equations in 2D as a function of time using FemLab 3.3.

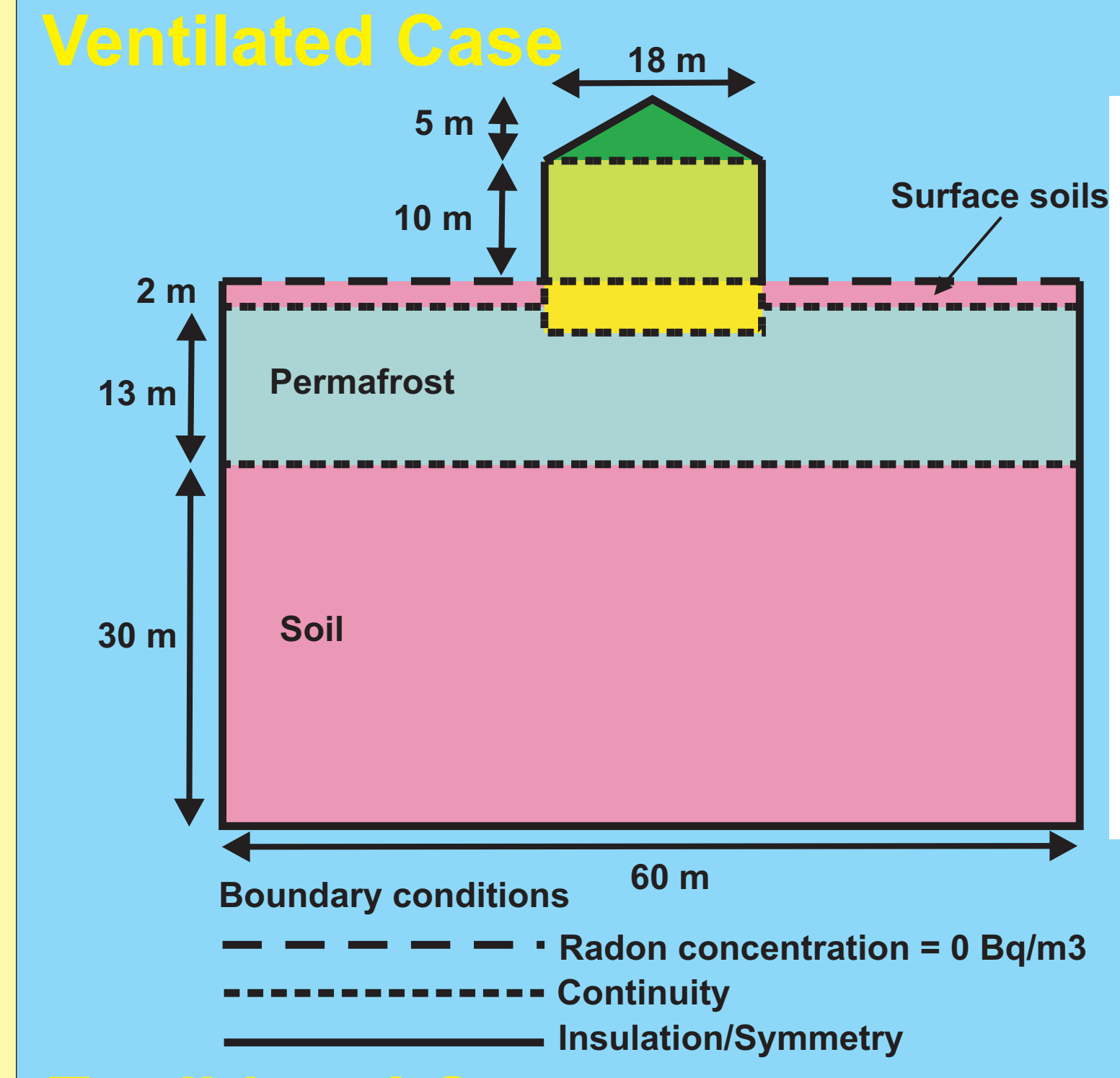
The models are 60 m wide with a 45 m depth of soil. The permafrost layer is of variable thickness starting not less than 2 m below the surface. There are 4 soil domains; (a) soil below the permafrost layer, (b) the permafrost layer, (c) the soil above the permafrost layer on each side of the building.

Unventilated (modern) buildings are split into three domains, (i) a rectangular basement (4 m high, 18 m wide), which is just below the surface of the soil and penetrates into the permafrost layer, (ii) a rectangular main living space (10 m high, 18 m wide), and (iii) a triangular roof space (5 m high, 18 wide). **Traditional (ventilated) buildings** are similar except their ‘basement’ is above the surface of the soil and admits air representing the space between the piles upon which the buliding stands.

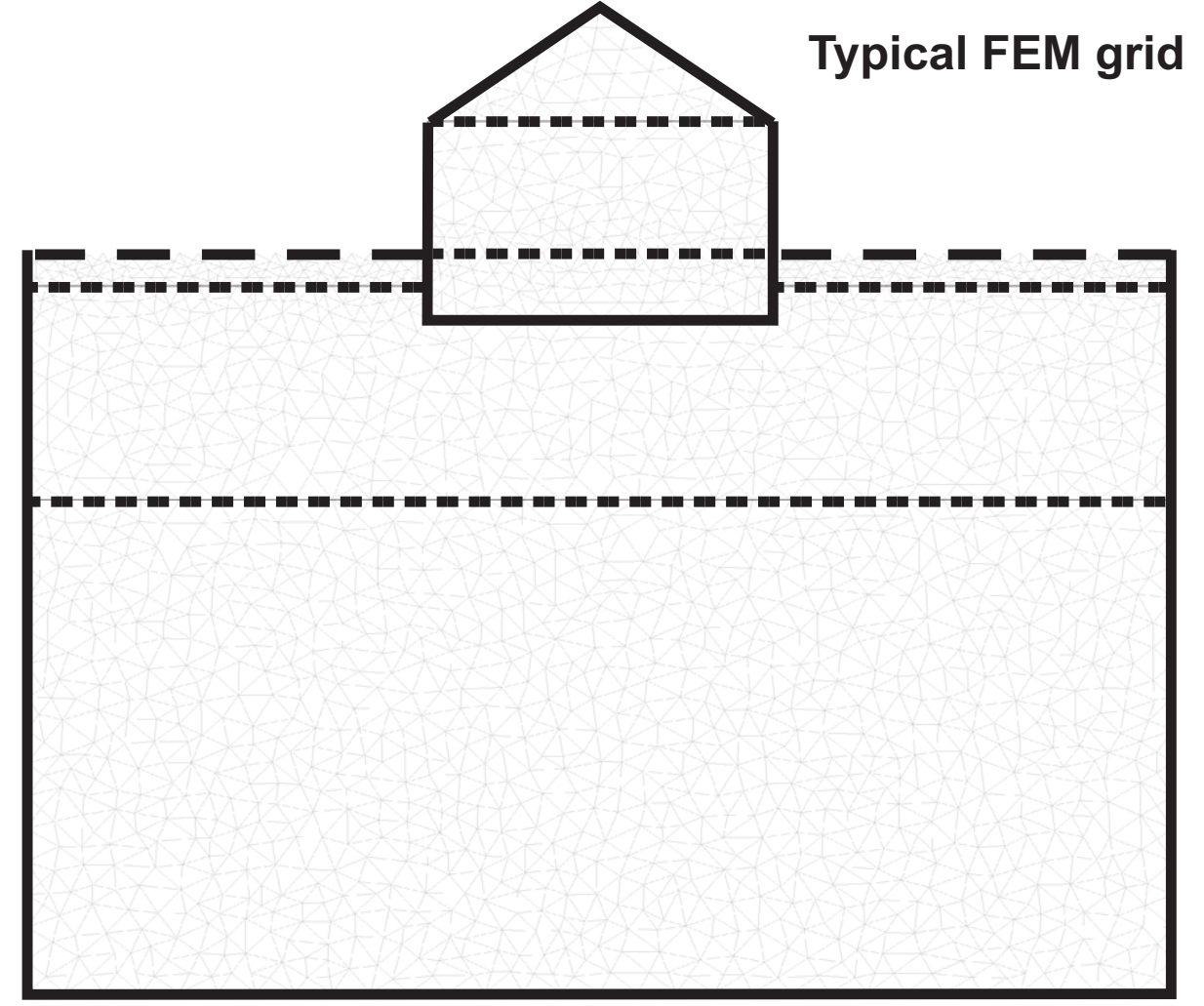
A two dimensional mesh is created and refined in all domains of the model. The mesh consists of triangles which are no larger than 2 m in the body of the model, and no larger than 1 m along all boundaries except those where the boundary conditions of insulation and symmetry are applied. There are over 4000 elements in the final model. The number of elements controls the speed of the final solution. We found that the solutions were reached within several minutes on a standard 3 GHz laboratory PC, and hence retain the described geometry for clarity even though the model is symmetric and could be reduced to half of its size.

MODEL GEOMETRY AND BCs

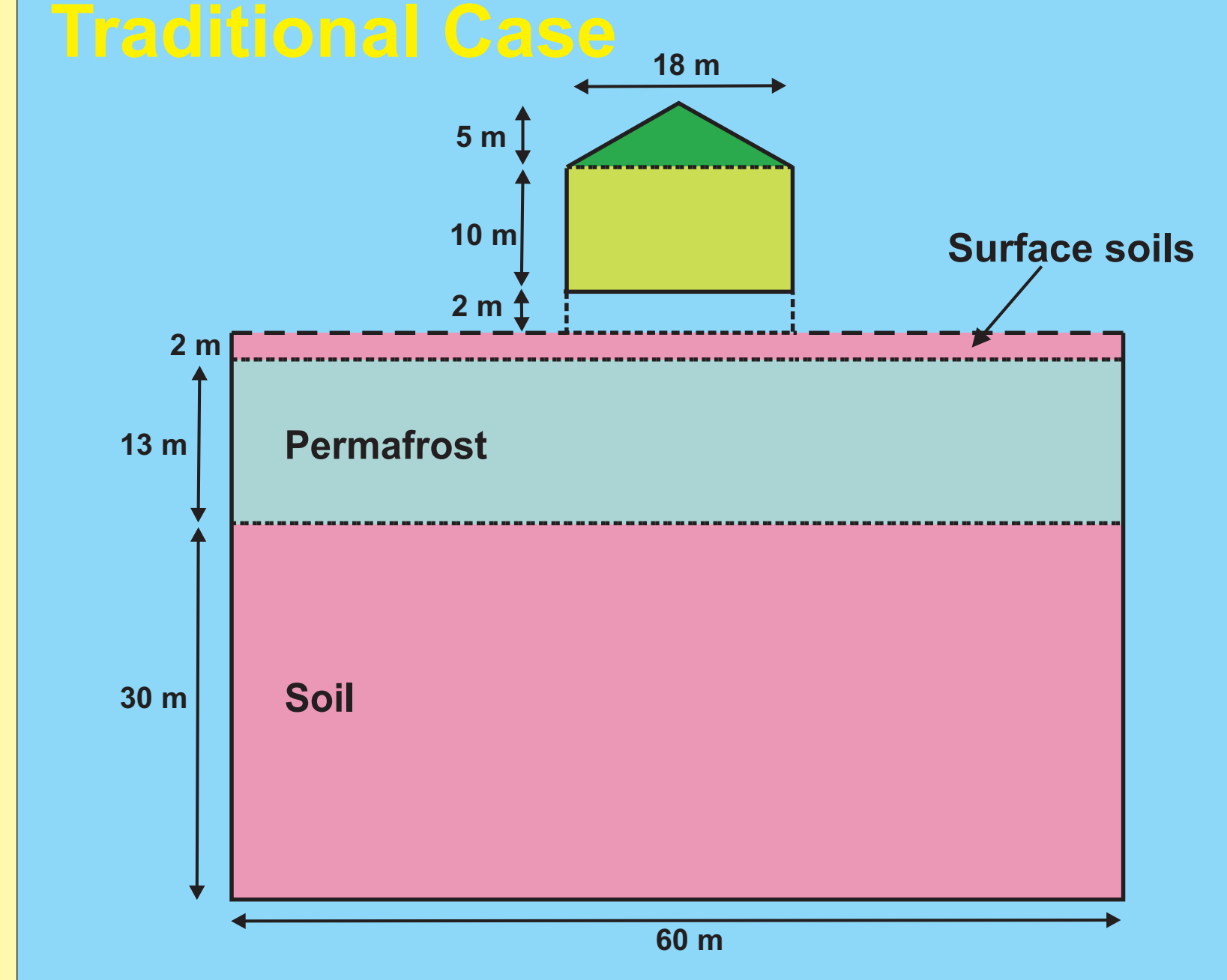
Ventilated Case

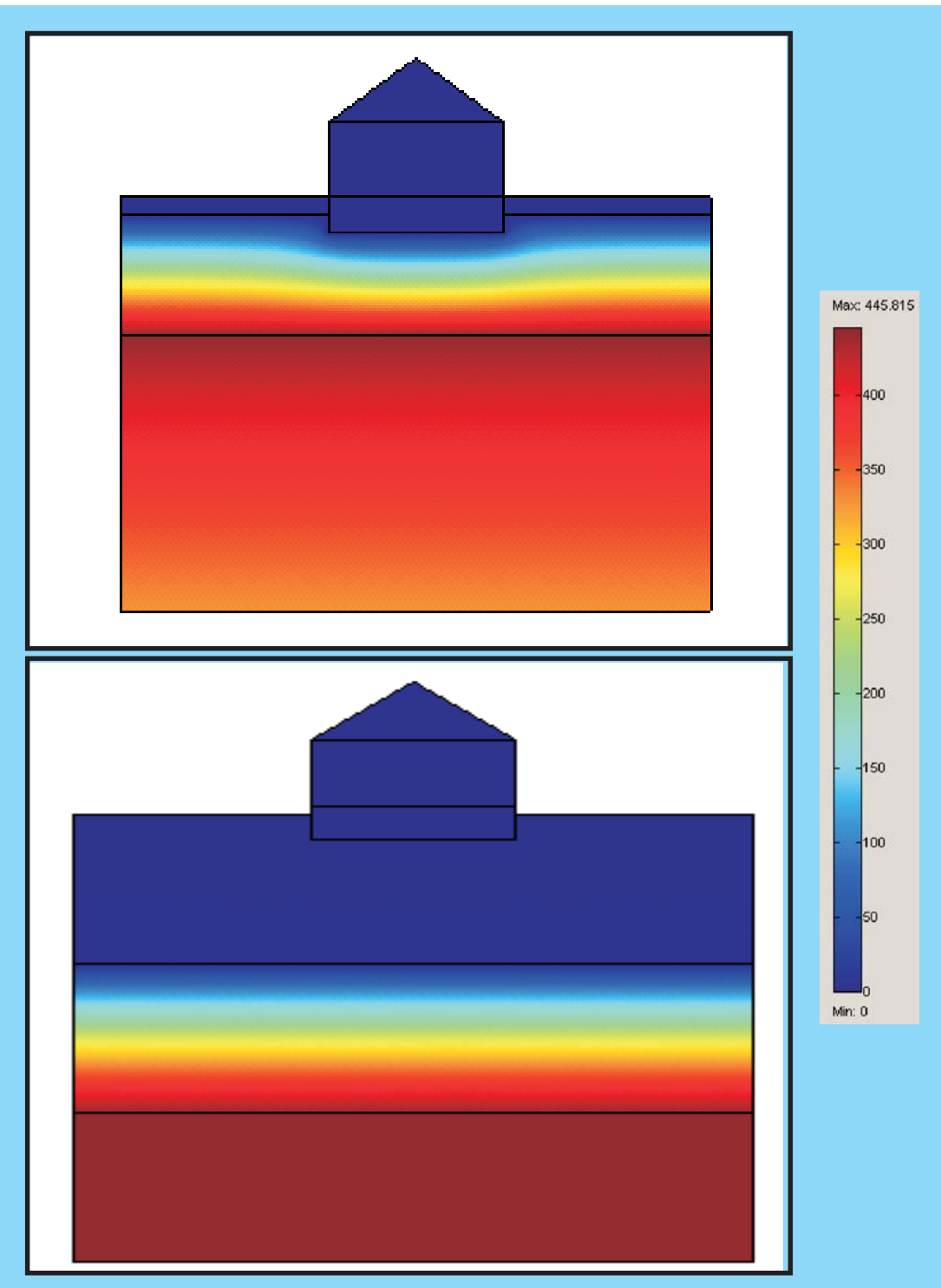


Boundary conditions
- - - - Radon concentration = 0 Bq/m3
-------- Continuity
—— Insulation/Symmetry



Traditional Case



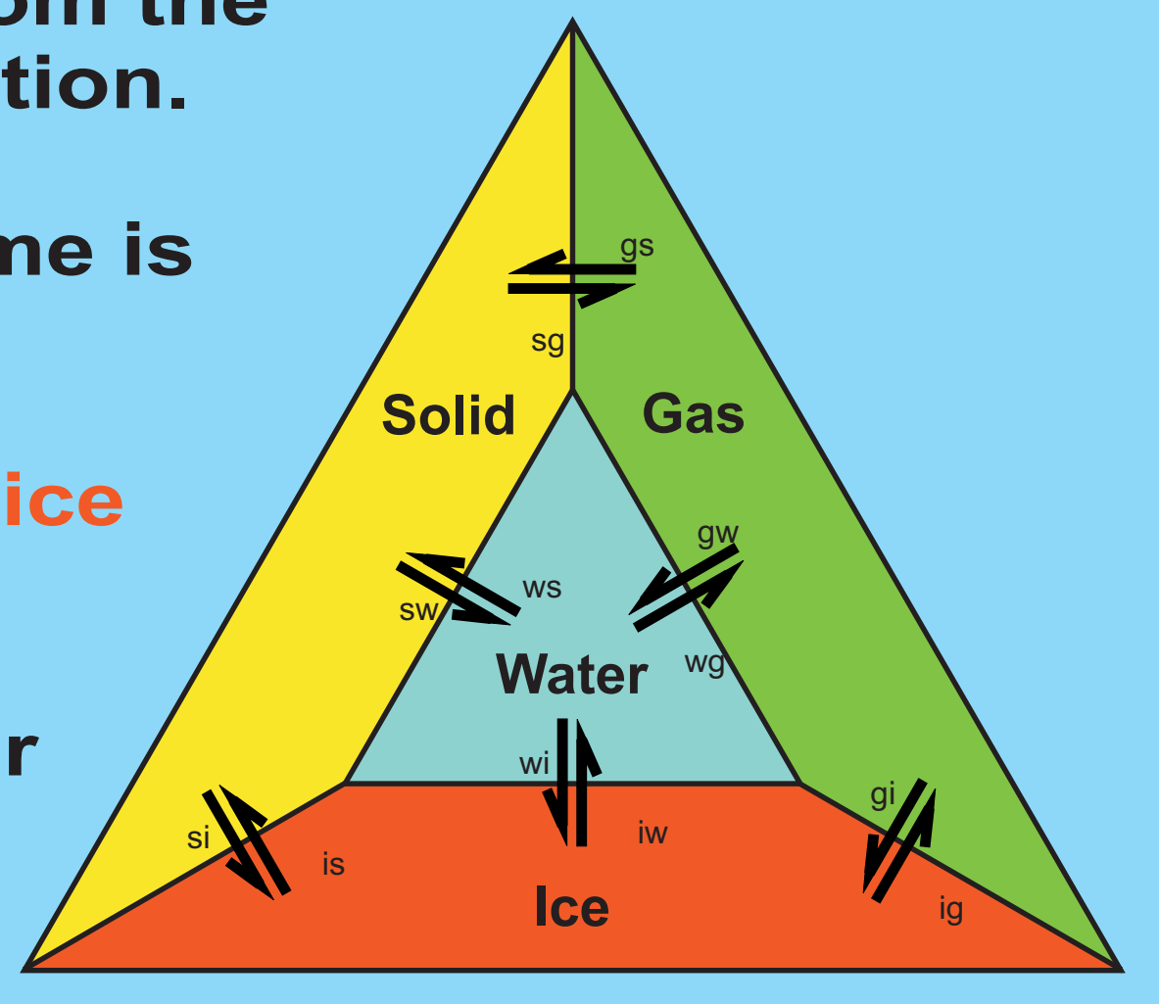


Initial concentrations

DIFFERENTIAL EQUATIONS

There is a radioactive source of radon and a radioactive loss of radon as well as losses of radon from the system due to diffusion and advection.

The available radon at any given time is partitioned between four phases.
The phases are: The solid minerals, Pore gases, Pore waters and Pore ice



The triangular diagram shows reaction coefficients for the transfer of radon between these phases. The partitioning is important because radon is not as **MOBILE** in some phases as in others. The differential equations for flow can then be *simplified* to include only the mobile fractions.
THUS:

$$\frac{C_a}{t} \quad D \quad C_a \quad \frac{K_a}{a} \quad P \quad C_a \quad C_a$$

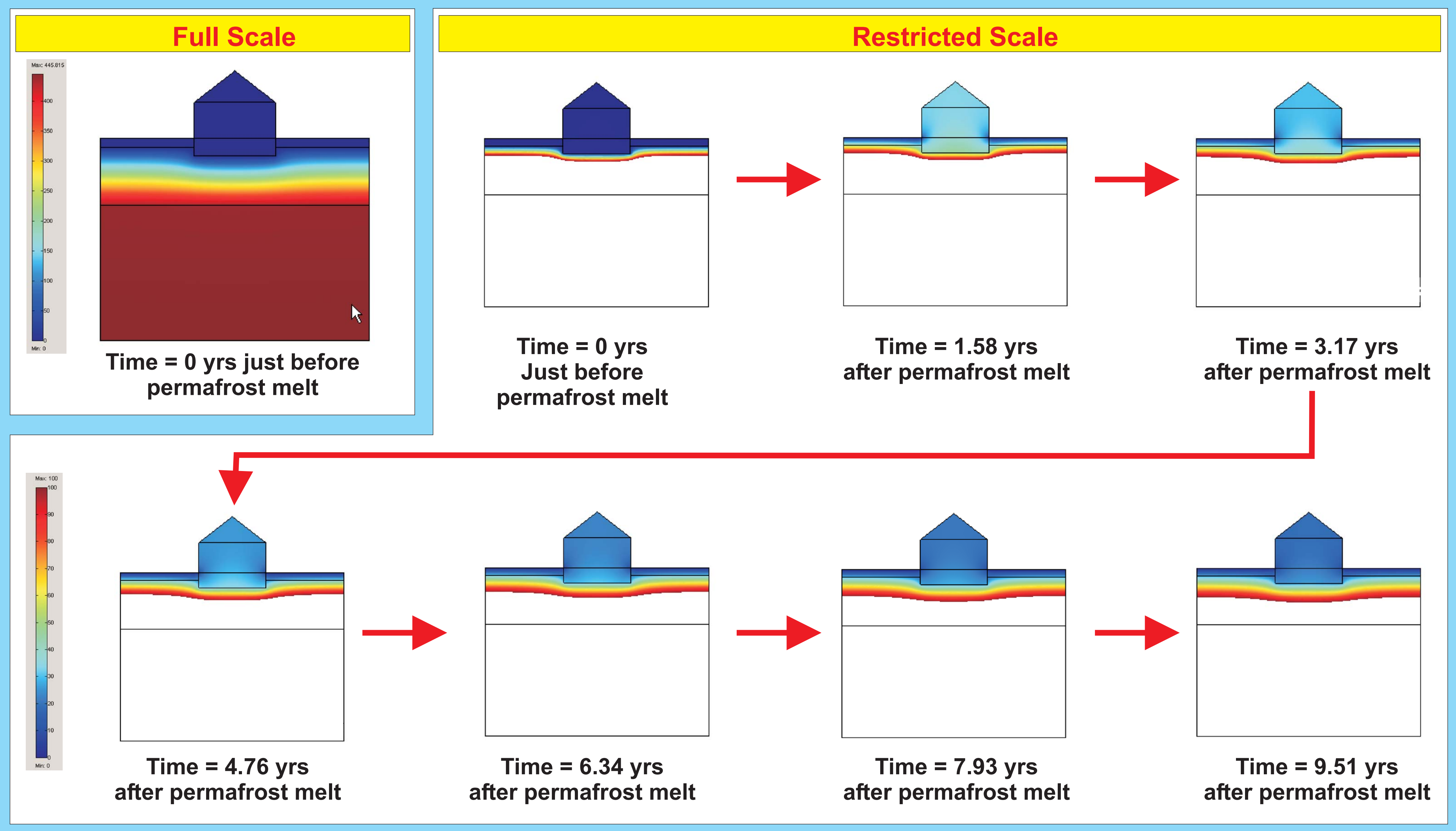
where: $1 \quad S_w \quad S_i \quad S_w L_{aw} \quad S_i L_{ai} \quad {}_b K_{as}$ is the operating porosity

$D \quad 1 \quad S_w \quad S_i \quad {}_a D_a \quad S_w \; {}_w D_w L_{aw} \quad S_i \; {}_i D_i L_{ai}$ is effective diffusion coeff.

${}_b \; C_{Ra}$ is the source term

The parameters L_{aw} and L_{ai} are Ostwald coefficients, ${}_j$ are tortuosities, D_j are diffusion coefficients and S_j are phase fractions for each phase.

TIME DEVELOPMENT



Time = 0 yrs just before permafrost melt

Time = 0 yrs
Just before
permafrost melt

Time = 1.58 yrs
after permafrost melt

Time = 3.17 yrs
after permafrost melt

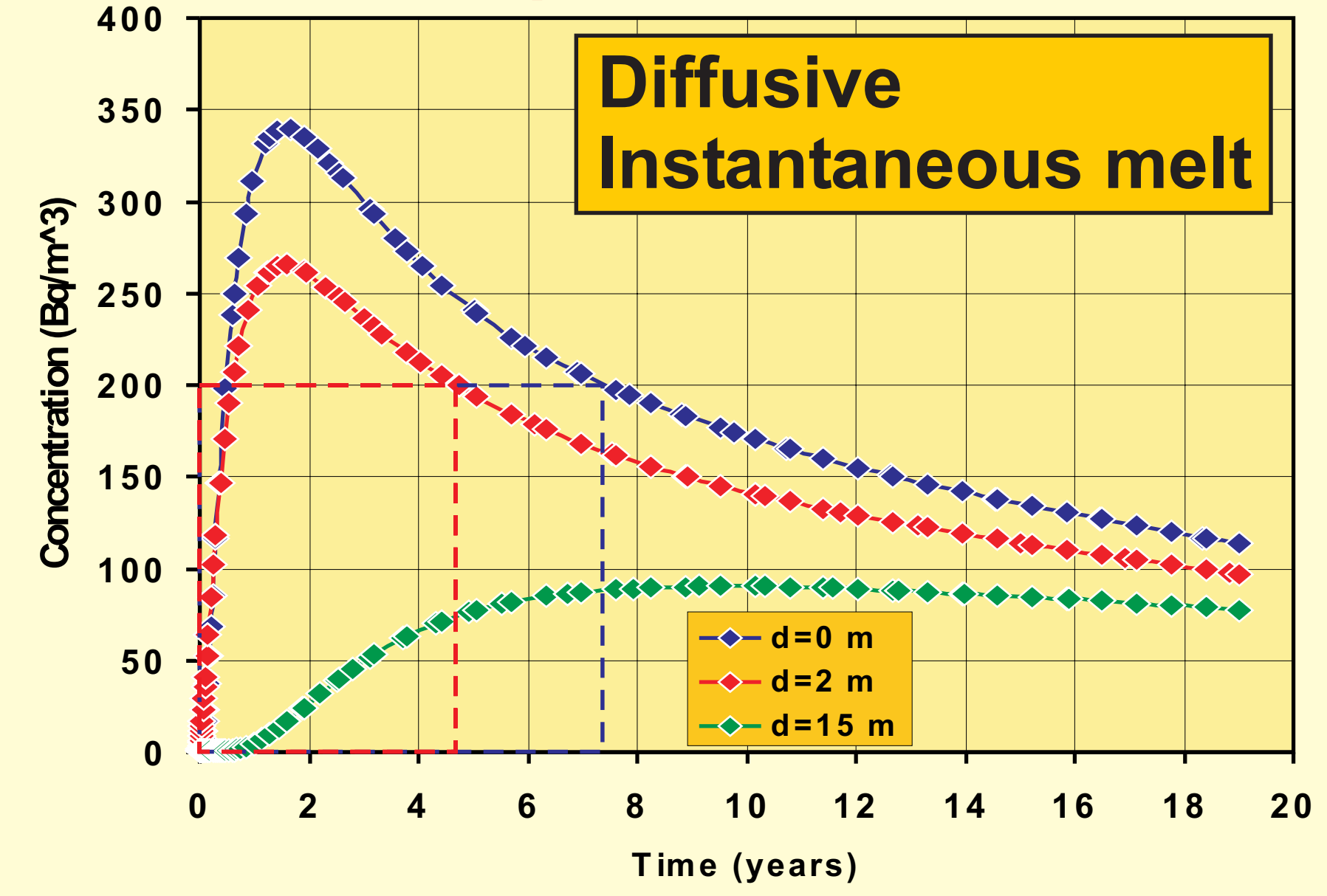
Time = 4.76 yrs
after permafrost melt

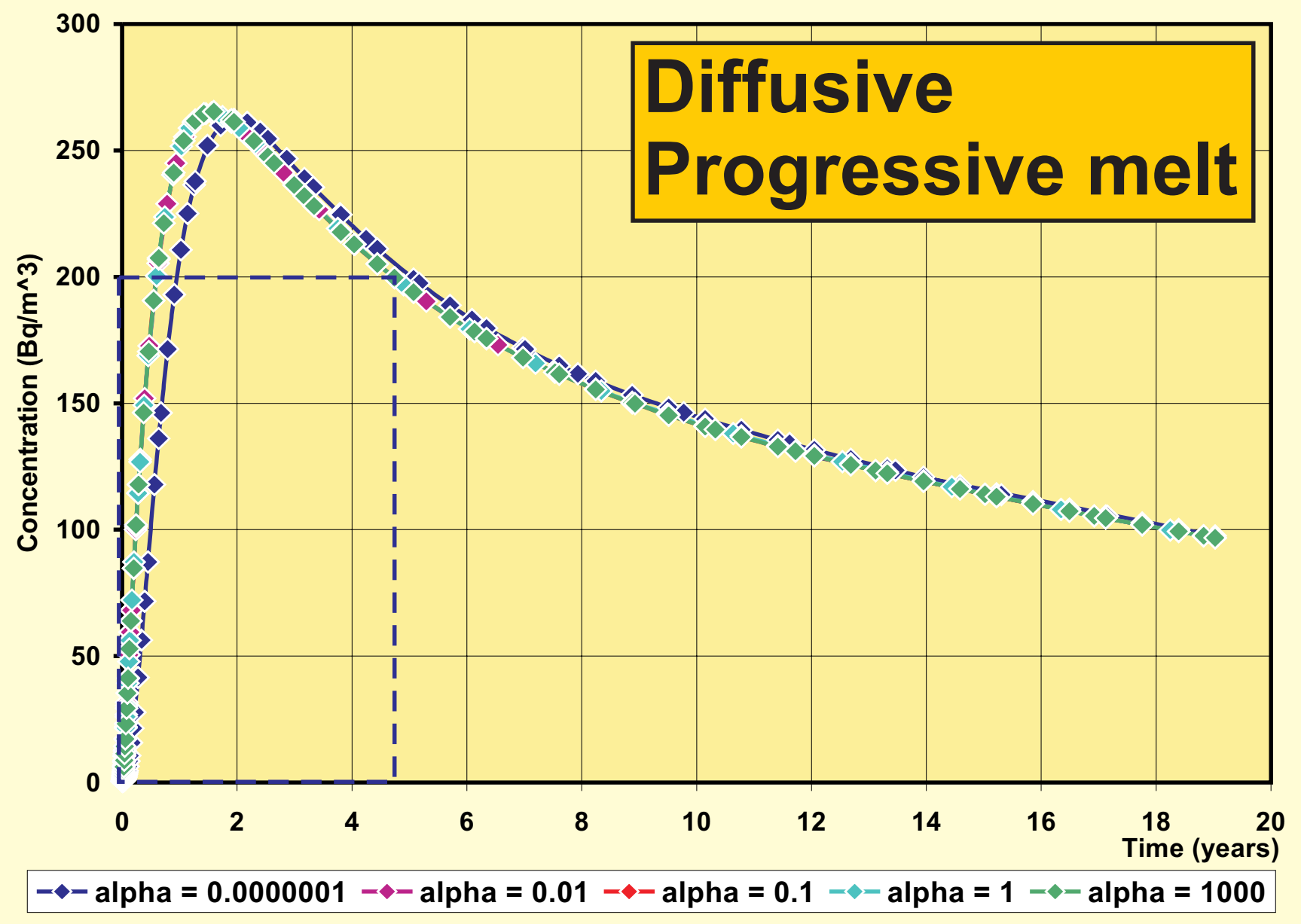
Time = 6.34 yrs
after permafrost melt

Time = 7.93 yrs
after permafrost melt

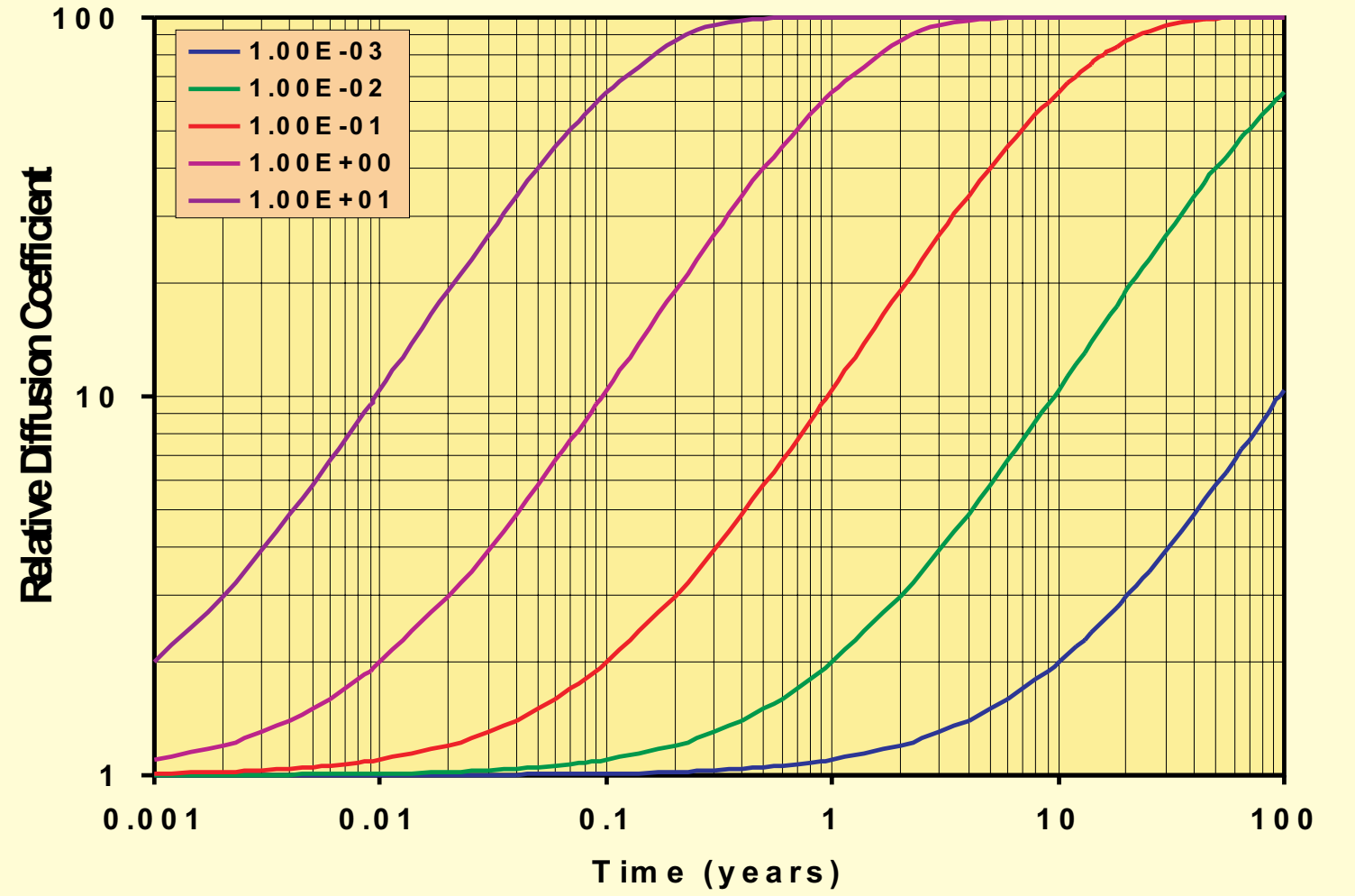
Time = 9.51 yrs
after permafrost melt

Diffusive Transport

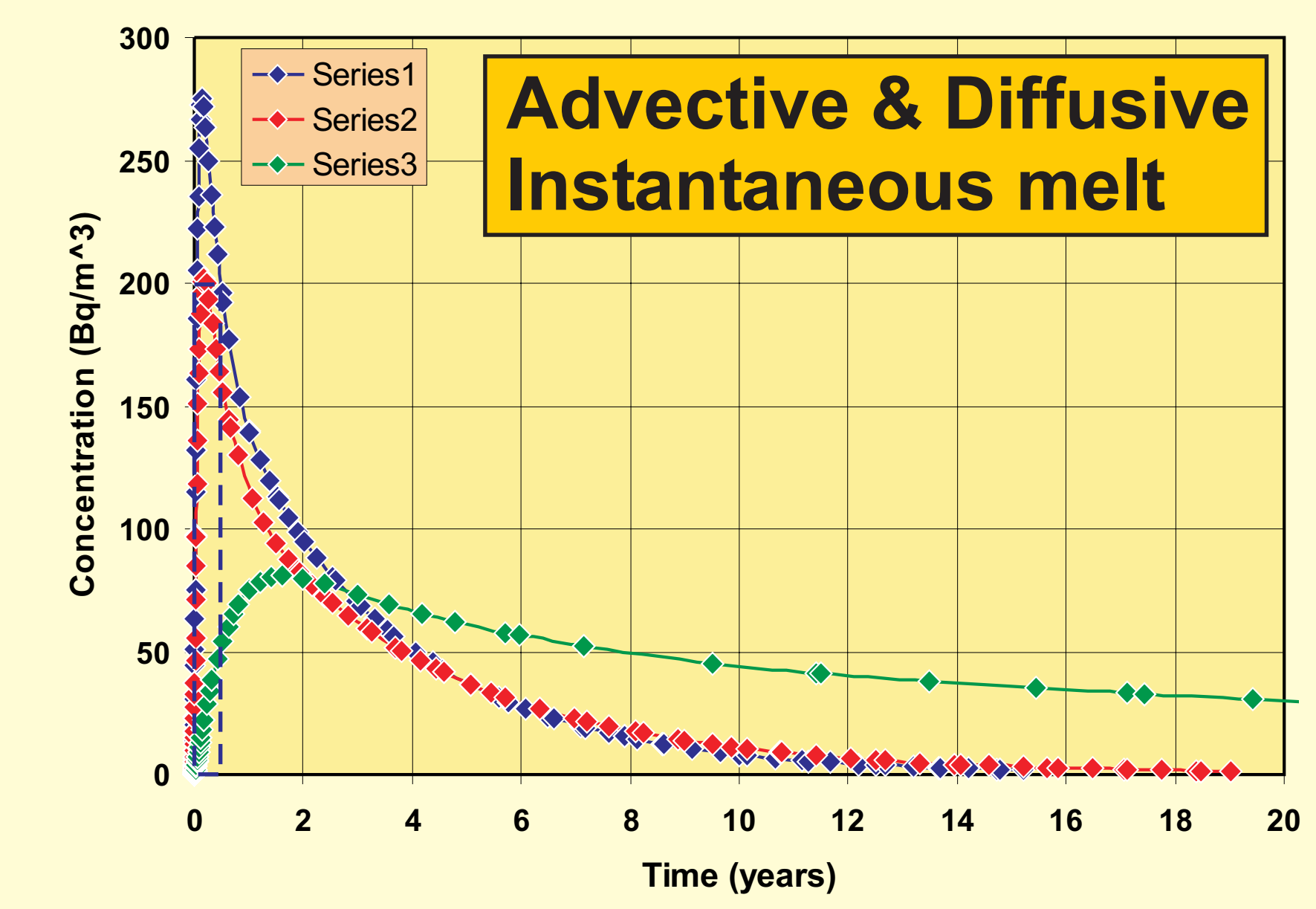


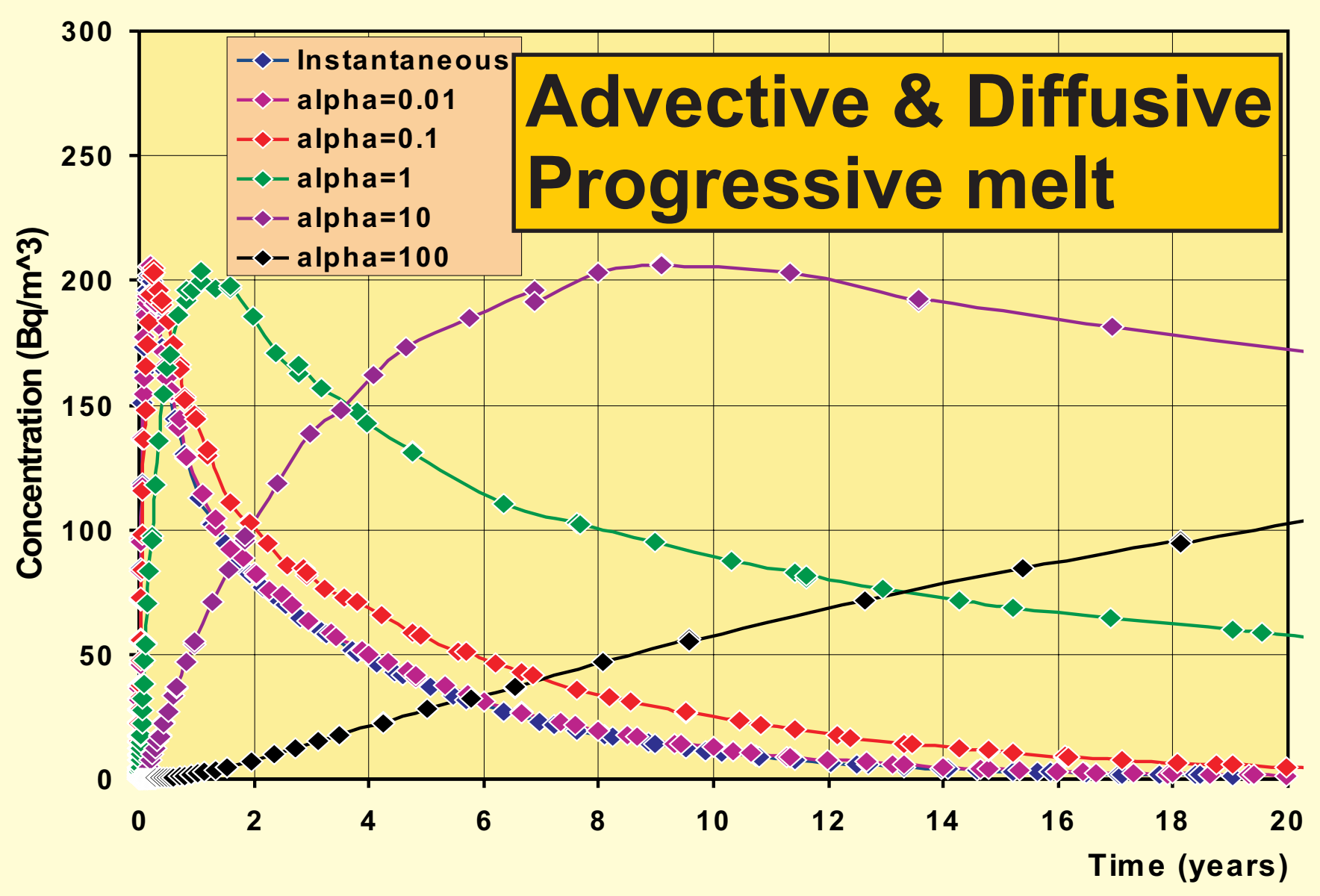


Modelling of the variation of the diffusion coefficient of partially molten permafrost



Diffusion coefficient of unfrozen soil = 100 units
Diffusion coefficient of 100% frozen soil = 1 unit





Modelling runs were also carried out on buildings with a traditional design consisting of the main rooms arranged on piles above the surface of the ground.

In all cases (advective, diffusive, gradual and sudden melt etc.) there were no increases in Rn within the dwelling.

Even though many traditional buildings enclose the piles to stop the ingress of snow, it is likely that Rn does not build up.

By comparison, newer buildings built with concrete basements are significantly at risk.

CONCLUSIONS

1. The permafrost acts as an effective radon barrier.
2. The sudden loss of the permafrost due to melting caused by climate change leads to about a 100 fold increase in the exposure to radon.
3. The radon level remains over the 200 Bq per cubic metre action level for over 3.5 years.
5. The radon level eventually falls to a lower level after more than 6 years.
6. This level is the natural radon level for the area without the protective permafrost barrier.
7. The level of Rn in houses built traditionally is extremely low.
8. If Rn is transported advectively as well as diffusively, the Rn levels fall significantly, and so does the duration of the peak surge.
9. Gradual melting has little effect on the intensity of the peak surge, but can increase the duraction of the peak and delay it.

For additional information, please contact:
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