Modelling an Underground Nuclear waste Repository

From the Near Field
To
a Far Field Model

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Modelling an Underground Nuclear waste Repository

- What is a Nuclear waste site (exemple)
- Near Field versus Far Field modelling
- Some problems for Scaling Up the source terms

Geological Storage

where

- Host rock: Brine, Clay, Granite, Argilite, …

Who (high level, long lived)

- high level of activity and/or long lived elements
  - B Type : low or medium activity level, but long life time
  - C Type : high activity level, T° > 80 °C
- come mainly from industrial activities(power plants)

Question before deciding a Geological Storage for Nuclear waste

- What is the possible **evolution**, and **impact** on the biosphere, of such an underground storage ?
  - Real experiments are not possible at these scales : time (> 500 years)

    and space (1X25 X 25 km^3)
  - Only predictions based on numerical simulations are possible

Could predictions be based on numerical simulations **??**

- There are well established models, but they were derived from the usual scales of measurement (meters, years)

- Two types of simulations are done:
  - Ones based on **Near Field** models (mainly for *Performance Assessement*)
  - and ones based on **Far Field** models (mainly for *Safety Analysis*)

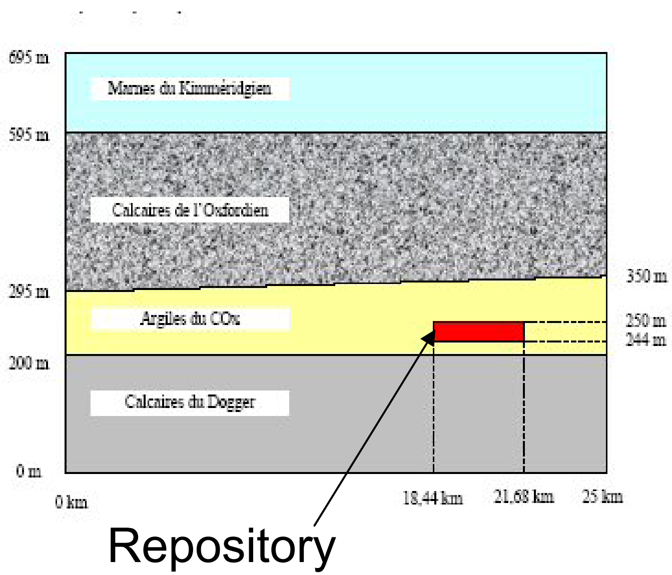
Far Field

1X25 X 25 km^3 and > 500 years

Far field region

Site region

Far field domain of computation

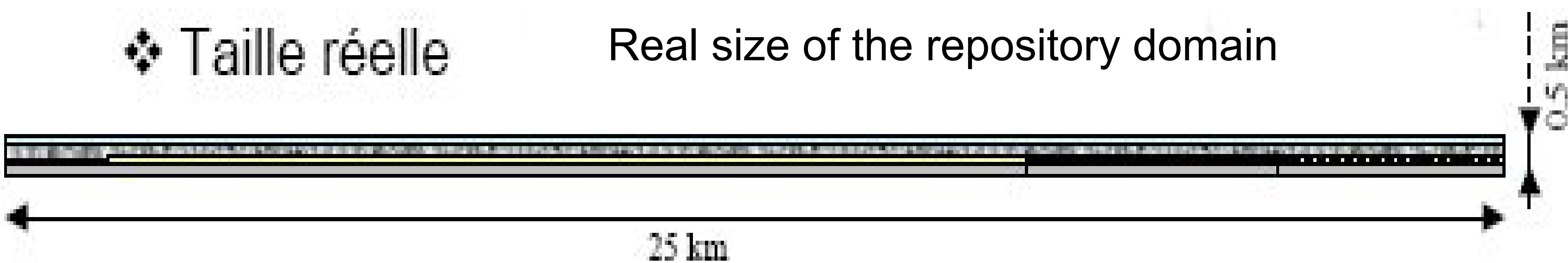


Far Field
1X25 X 25 km^3 and > 500 years

– Numerical simulations and predictions are based on **MACROmodels**:
  - Diffusion/Dispersion, Convection, Reaction (by mean of a Retardation factor)
  - The repository is reduced to a very thin homogeneous « source » zone

❖ Taille réelle

Real size of the repository domain



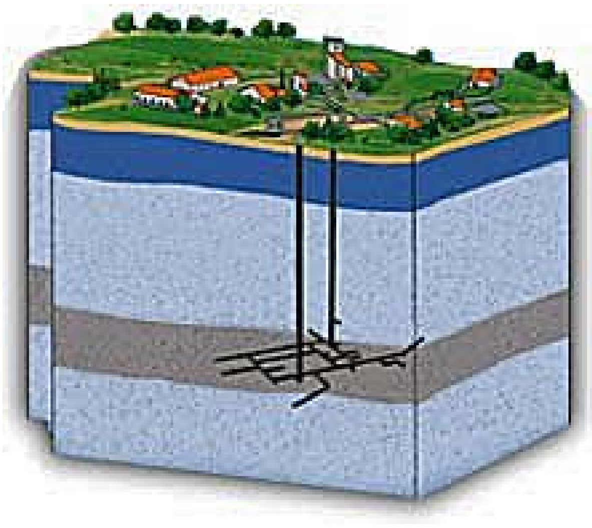
Far Field Simulations

– MACRO model:
- Diffusion/Dispersion, Convection, Reaction (by mean of a Retardation factor)

1 General Equations

$$R\omega\frac{\partial\rho}{\partial t} - \nabla\cdot(\mathbf{A}\nabla\rho) + (\mathbf{V}\cdot\nabla)\rho + \lambda R\omega\rho = 0 \qquad (1)$$

- R the latency retardation factor,
- ω the porosity,
- v the Darcy's velocity
- $\lambda = \frac{\log 2}{T}$; T the element radioactivity half life time
- Iodine ^{129}I has half life time $T = 1.57\ 10^7$ years and is releasing during a time $t'_m = 8\ 10^3$ years, with intensity $\Phi' = 10^{-1}$.



Far Field Models

– **MACROSCOPIC** (Far Field) models need to be derived from the **mesoscopic** (Near Field) level, which could include :

- geochimical effects with highly contrasted rock properties for various velocity ratio (reaction / diffusion/flow)
- geomechanical effects after drilling shafts and tunnels
- emission from each container or vault
- ETC…….

Near Field

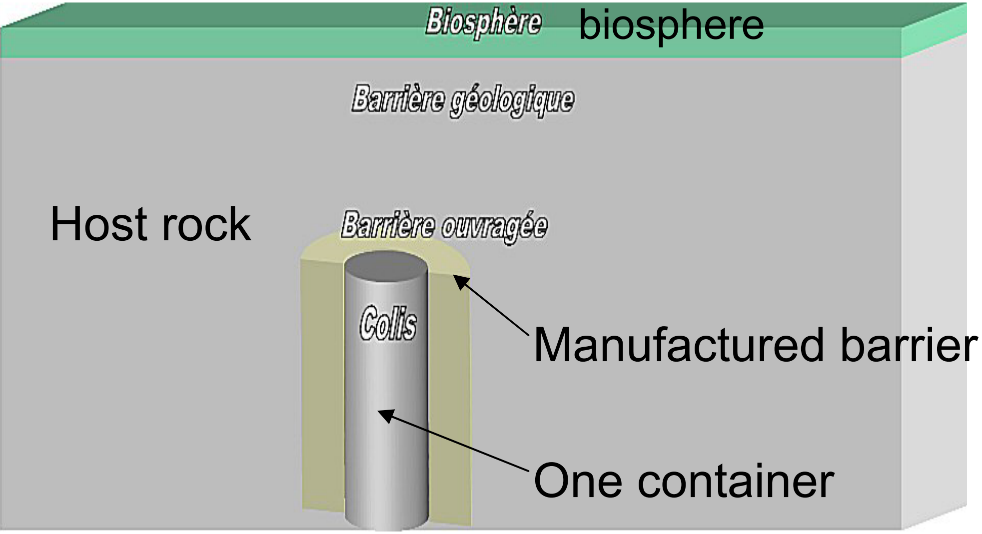
The **Waste** is:

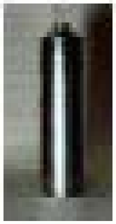
- Inside a matrix (glass, concrete, tar,…)
- Protected by a container (steel, concrete,…)
- Surrounded by manufactured barriers (bentonite, concrete, …)

Containers are grouped in Vaults

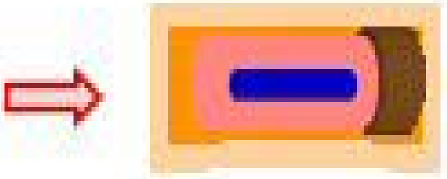
Vaults are connected by tunnels, galleries, drifts and shafts

Near Field (Containers)

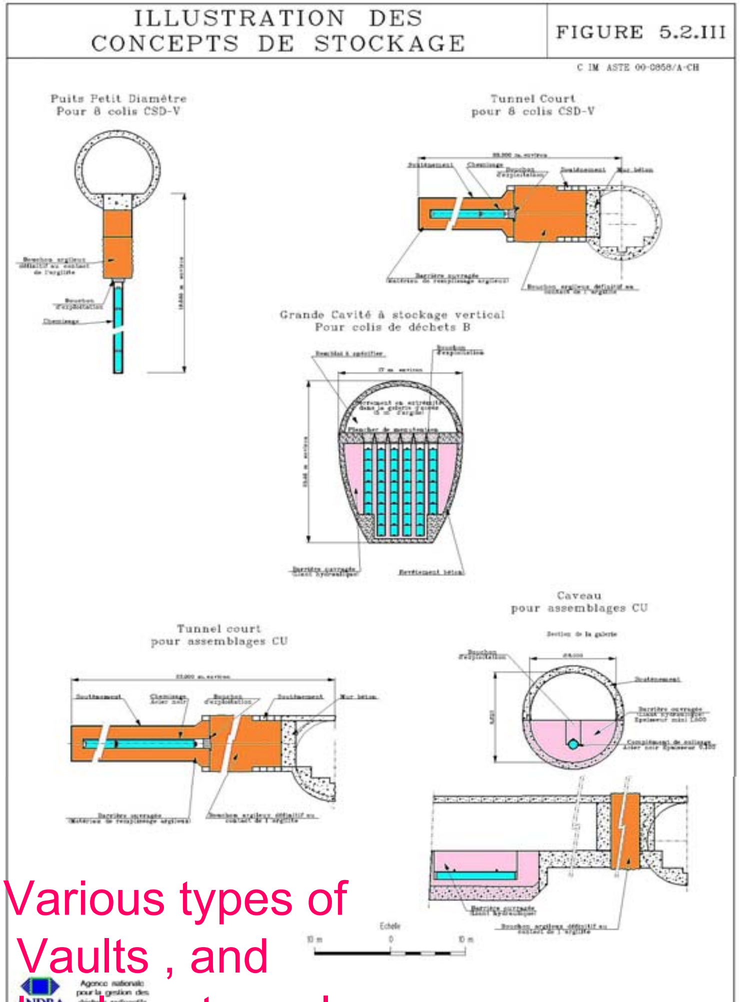




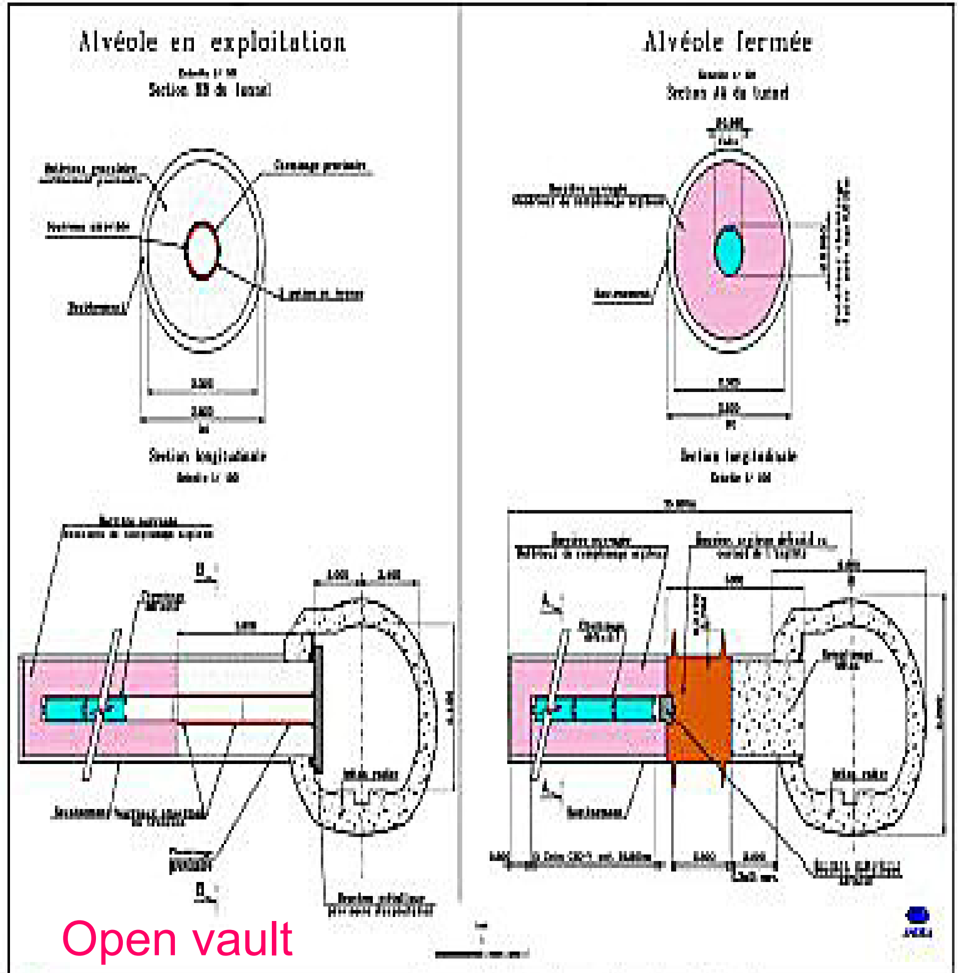
A container inside a vault



Near Field (Vaults)



Various types of Vaults , and haulage tunnels



Open vault with a set of containers

closed vault

Near Field Modelling

- Vault dimensions $\approx$ 1 m diameter, length: 10m
- **Numerical simulations** and **predictions** based on **mesoscopic** (Near Field) **models** including:
  - T-H-M-C couplings
  - Coupling of different materials (steel, glass, concrete, bentonite, clay, ….)
  - Adsorption / desorption
  - …..

Near Field Models

– These **MESOSCOPIC** (**Near Field**)models need to be derived from the **microscopic** level(e.g. pores), specially :

- geomechanical properties of rocks
- coupling transport/reaction
- adsorption/desorption
- swelling of bentonites

…….

Far Field versus Near Field

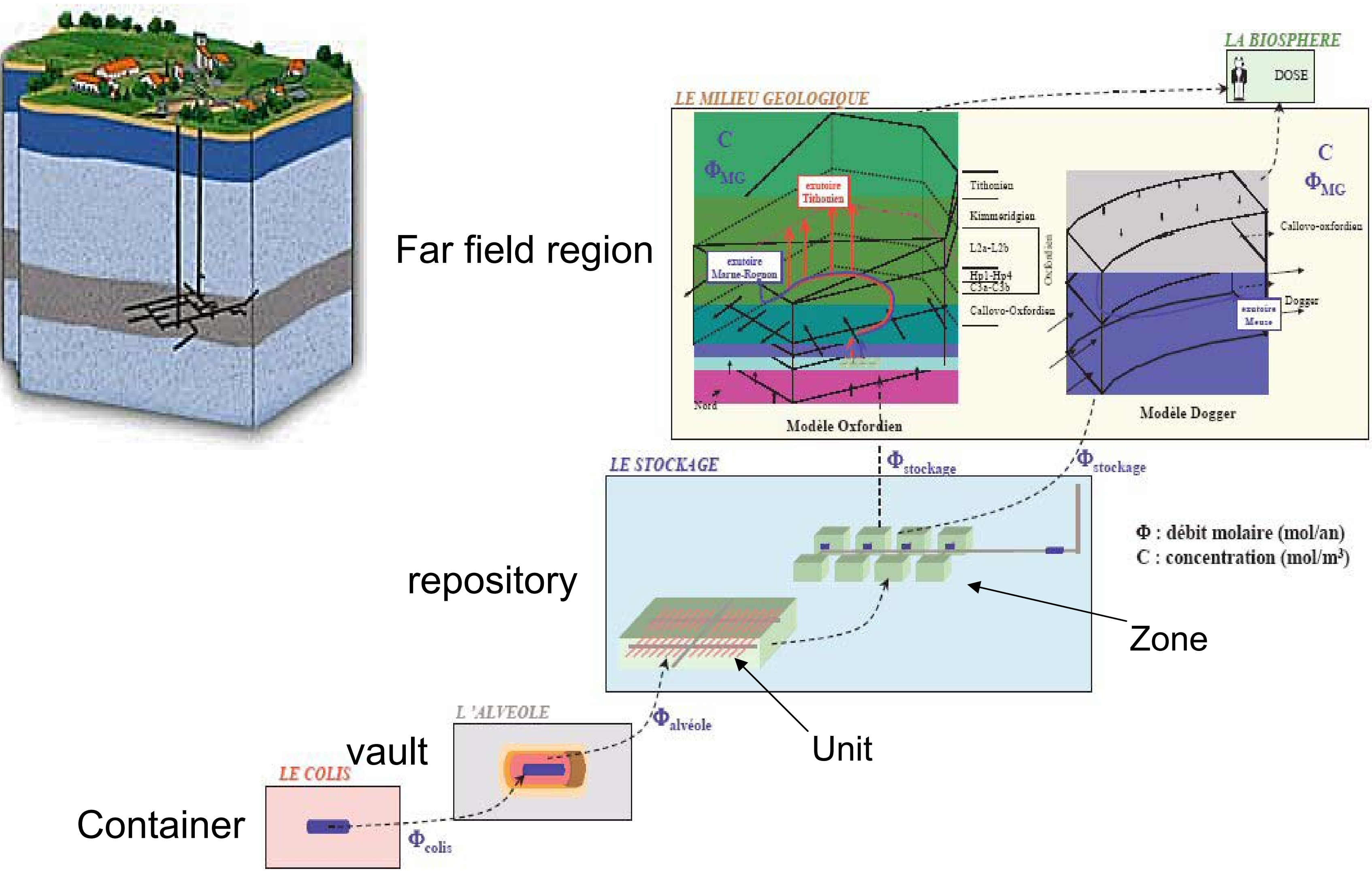
Near Field model

- to be derived from « microscopic » models

Far Field model

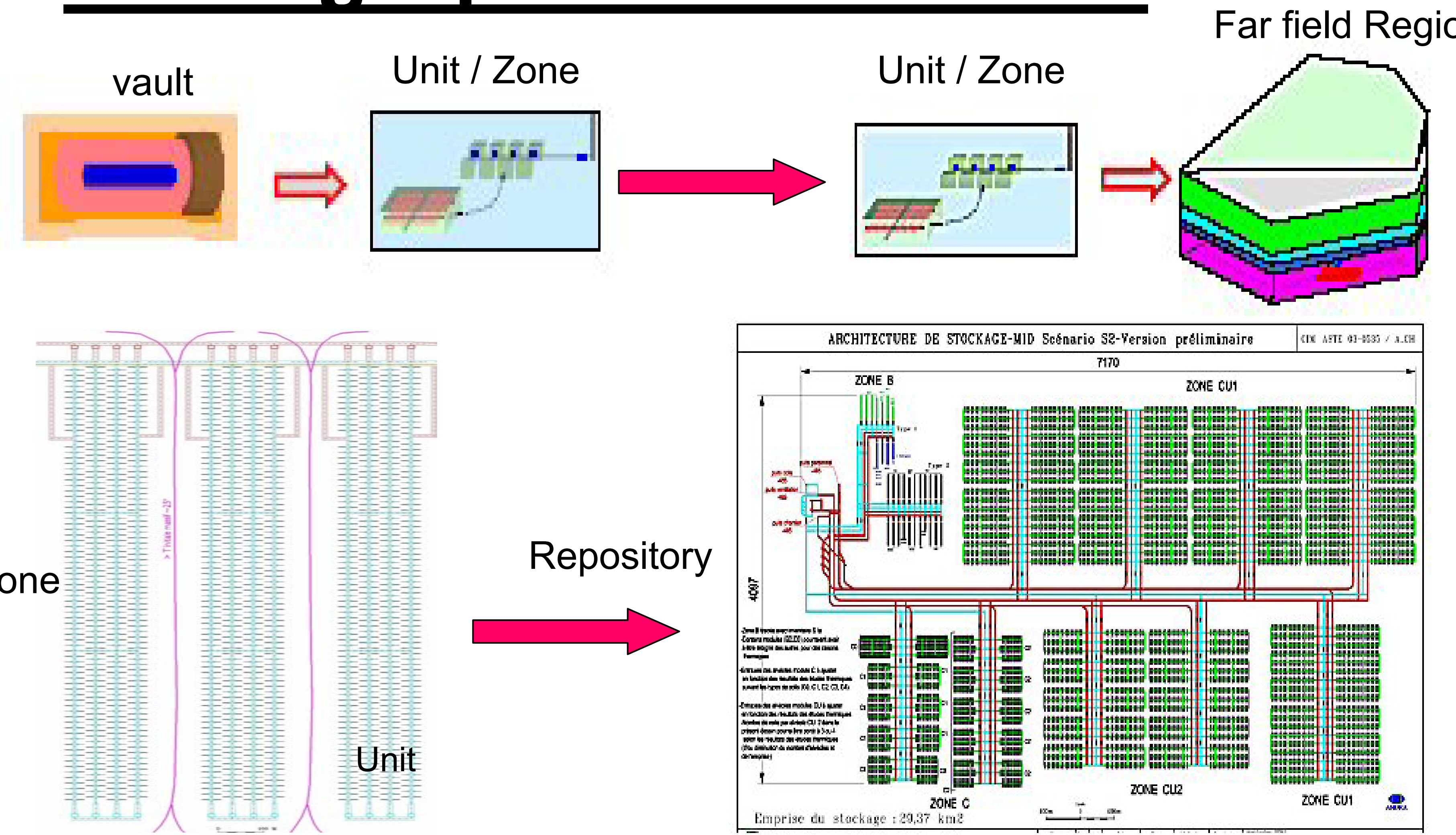
- to be derived from Near Field models

Far Field vs. Near Field



Far Field vs. Near Field

Scaling Up the Sources ??



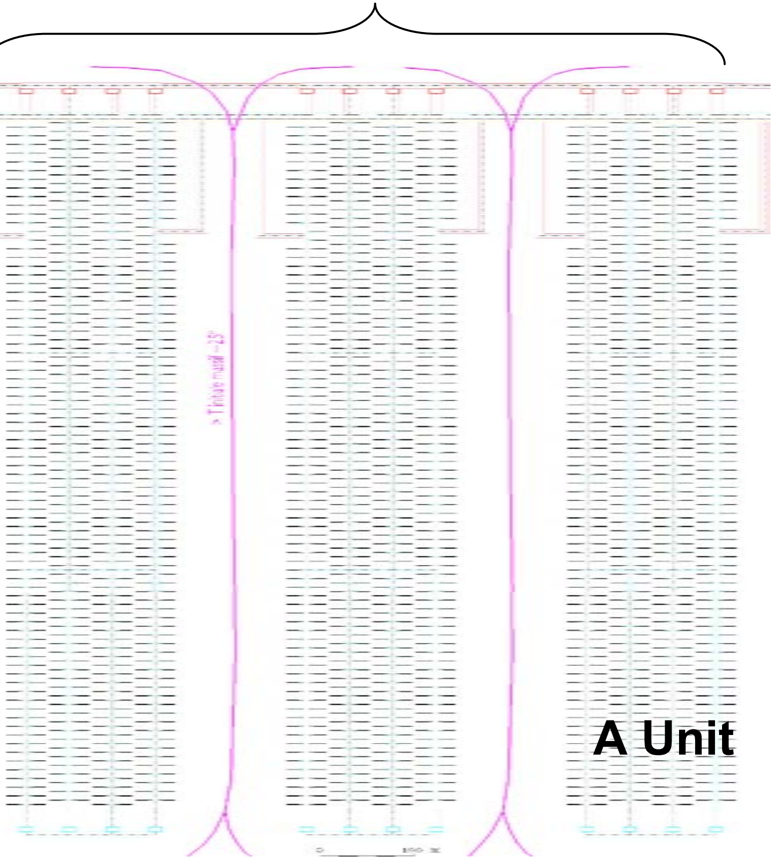
Scaling Up the Sources

There are several levels of possible scaling up:

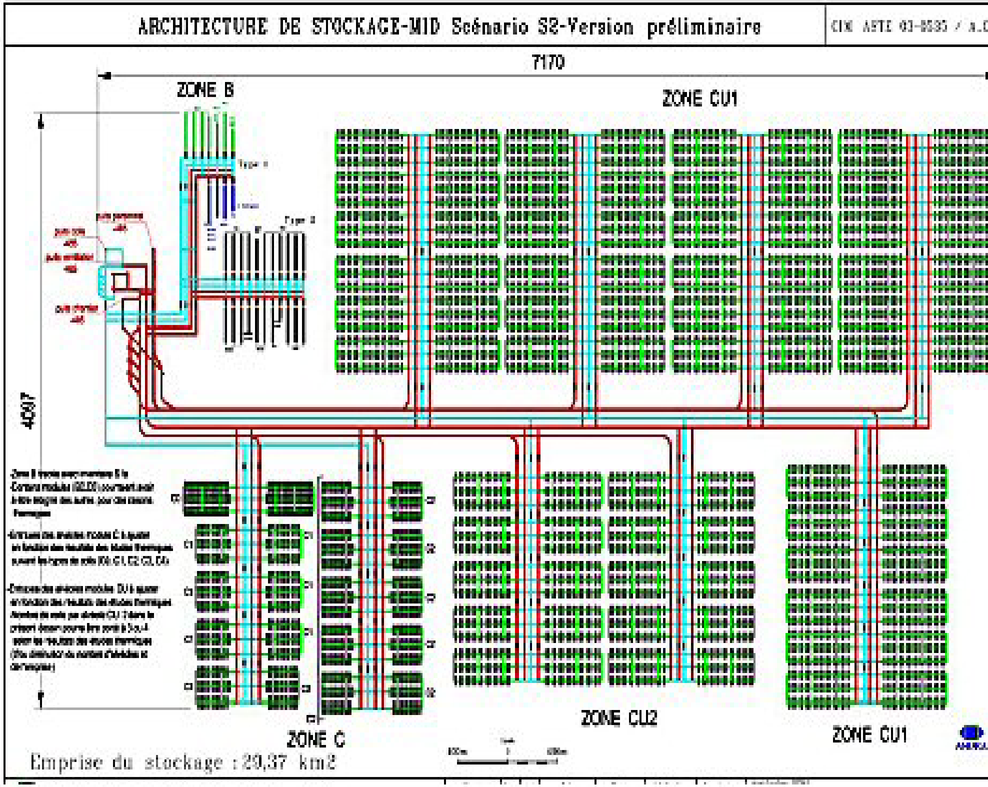
1. from the **waste packages** to a **storage unit** global model
2. from the **storage units** to a **zone** global model
3. from **similar zones** to the **repository** global model

First example of Scaling Up the Sources:

A Zone



The Repository



First example of Scaling Up the Sources:

From the STORAGE UNITS to a "ZONE global model"

OR, From Similar ZONES to the "REPOSITORY global model"

.B., O. Gipouloux, E. Marusic-Paloka. Mathematical Modeling of an underground wast disposal site by upscaling. Math. Meth. Appli. Sci., Volume 27, Issue 4; March 2004, p 381-403.

from **storage units** to a **zone** model (or from **similar zones** to the **repository**)

Avoiding cumbersome computations, we choose:

- a simplified geometry for the units (or zones)
- a simplified model of transport

But same things (methodology and simulations) could be done for real situations

from storage units to a zone model (or from similar zones to the repository)

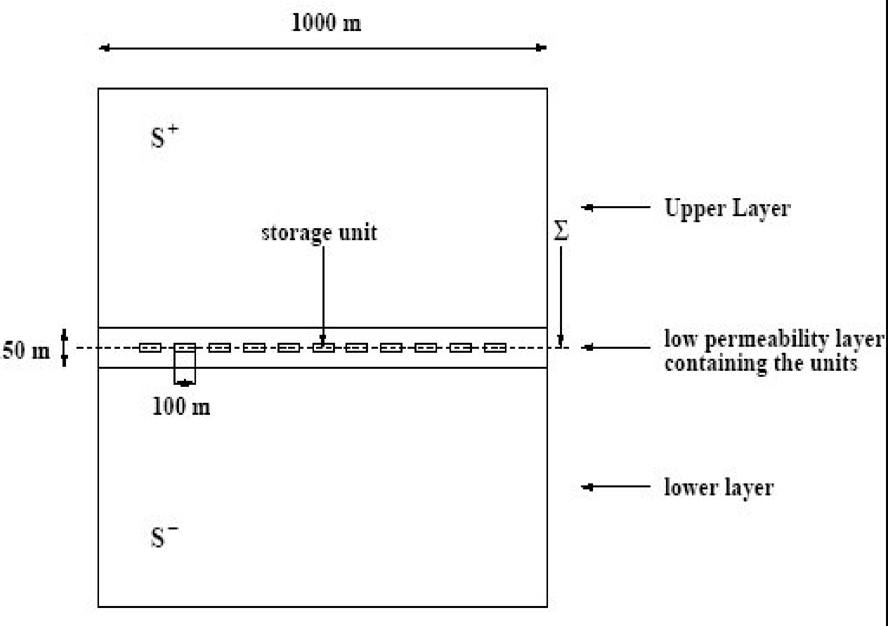
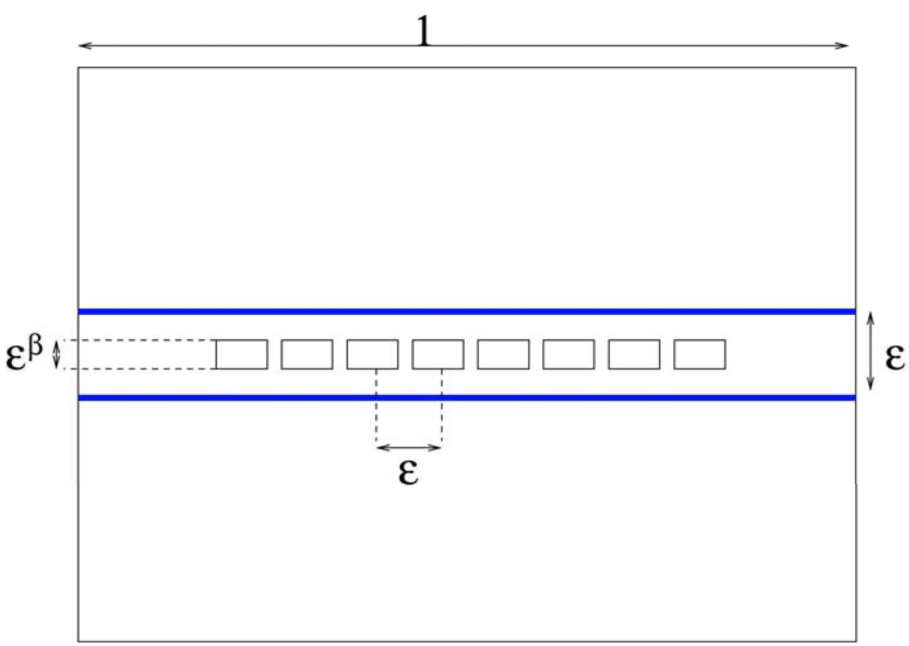


Figure 4: The three geological layers containing the Storage Units



Real domain section

Rescaled domain section

from storage units to a zone model (or from similar zones to the repository)

2 The Equations

$$\omega^{\varepsilon}\frac{\partial\varphi_{\varepsilon}}{\partial t}-\mathrm{div}\,(\mathbf{A}^{\varepsilon}\nabla\varphi_{\varepsilon})+(\mathbf{v}^{\varepsilon}\cdot\nabla)\varphi_{\varepsilon}+\lambda\omega^{\varepsilon}\varphi_{\varepsilon}=0 \quad \text{in} \quad \Omega_{\varepsilon}^{T} \qquad (2)$$

$$\varphi_{\varepsilon}(0,x)=\varphi_0(x) \quad x\in\Omega_{\varepsilon} \qquad (3)$$

$$\mathbf{n}\cdot\sigma=\mathbf{n}\cdot(\mathbf{A}^{\varepsilon}\nabla\varphi_{\varepsilon}-\mathbf{v}^{\varepsilon}\varphi_{\varepsilon})=\Phi(t) \quad \text{on} \ \Gamma_{\varepsilon}^{T} \qquad (4)$$

$$\varphi_{\varepsilon}=0 \quad \text{on} \quad S_1, \qquad (5)$$

$$\mathbf{n}\cdot(\mathbf{A}^{\varepsilon}\nabla\varphi_{\varepsilon}-\mathbf{v}^{\varepsilon}\varphi_{\varepsilon})=0 \quad \text{on} \quad S_2 \qquad (6)$$

with

$$\mathbf{A}^{\varepsilon}(x_2)=\mathbf{A}(\frac{x_2}{\varepsilon});\ \mathbf{v}^{\varepsilon}(x,t)=\mathbf{v}(x,\frac{x_2}{\varepsilon},t);\ \omega^{\varepsilon}(x_2)=\omega(x_2/\varepsilon). \qquad (7)$$

from storage units to a zone model (or from **similar zones** to the **repository**)

By homogenisation (asymptotic analysis) we obtain a corresponding <u>Zone « global model »</u>

$$\omega^2 \frac{\partial \varphi}{\partial t} - \mathrm{div}\,(\mathbf{A}^2 \nabla \varphi) + (\mathbf{v}^2 \cdot \nabla)\varphi + \lambda \omega^2 \varphi = 0 \text{ in } \tilde{\Omega}^T \qquad (8)$$

$$\varphi(x,0) = \varphi_0(x) \quad x \in \tilde{\Omega} = \Omega \backslash \Sigma \qquad (9)$$

$$\varphi = 0 \quad \text{on} \quad S_1 \qquad (10)$$

$$\mathbf{n} \cdot (\mathbf{A}^2 \nabla \varphi - \mathbf{v}^2 \varphi) = 0 \quad \text{on} \quad S_2 \qquad (11)$$

$$[\varphi] = 0 \quad , \quad [\mathbf{e}_2 \cdot (\mathbf{A}^2 \nabla \varphi - \mathbf{v}^2 \varphi)] = -|\tilde{M}| \Phi \quad \text{on} \quad \Sigma \quad , \qquad (12)$$

where $[\cdot]$ denotes the jump over Σ, and $|\tilde{M}|$ stands for the limit of a normalized unit $\mathcal{M}_\varepsilon$ area.

from **storage units** to a **zone** model
(or from **similar zones** to the **repository**)

n order to check the quality of this **zone**
‹ **global model »:**

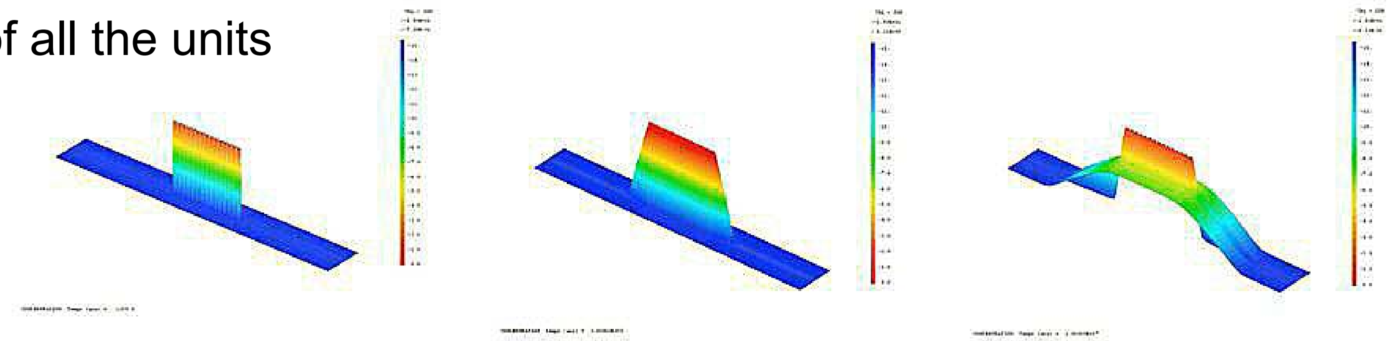
We compute the resulting contaminant
ransport from all the sources terms
eaking,

using first a detailed model (near field
nodelling of all the units)

and compare these simulations to the
ones obtained, using the zone « global
model »

from **storage units** to a **zone** model
(or from **similar zones** to the **repository**)

imulation of all the units



Niveaux de concentration aprés1209, 300 000 et 1 000 000 d'années; obtenus par simulations à partir du modèle détaillé (en haut) et du modèle « homogénéisé » (en bas)

imulation of the zone « global model »

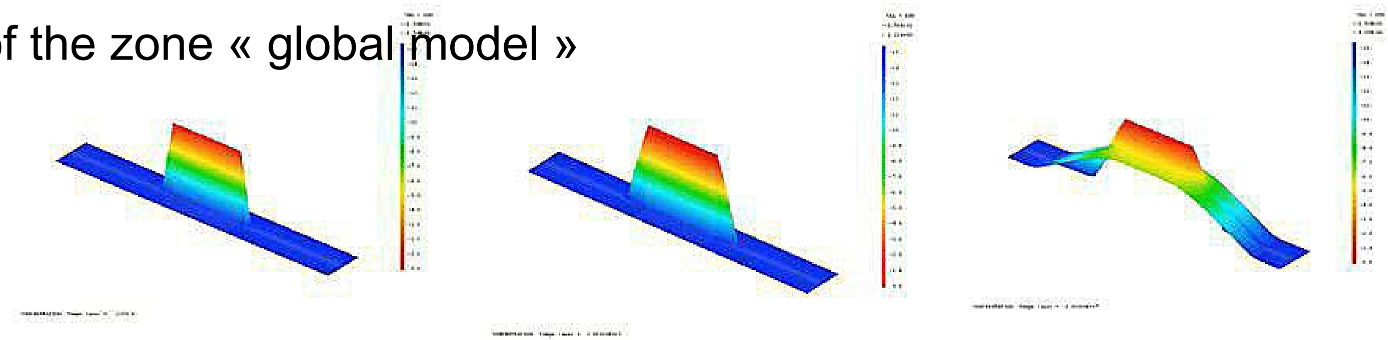


Fig.10 : ***Comparaison des niveaux de concentration en Iode129,*** *obtenus par une simulation détaillée à une échelle fine et ceux obtenus par une simulation basée sur le modèle « homogénéisé » correspondant. Malgré son caractère « global », cette dernière simulation, moins détaillée, rend cependant bien compte des pics de concentration, au voisinage des conteneurs.*

A Random scenario ??

=The contents, and the leaking starting time of the Waste Packages are Random

.B., jointly with A. Piatnitski; work in progress

The "local sources" $\boldsymbol{f}_{\varepsilon}$ are periodically repeated, on a plan Σ
Associated to the randomness of the **contains**, the **leaking starting time** and the **emission time evolution**, of each local source, there is a random dynamical system T characterizing $\boldsymbol{f}_{\varepsilon}$:

$$f^{\varepsilon}(x,t) = \mathbb{I}_{B_{\varepsilon}} \frac{1}{\varepsilon^{\gamma}} f(T_{x'/\varepsilon}\omega, t)$$

$$\partial_t u^{\varepsilon} - \operatorname{div}(a(x)\nabla u^{\varepsilon}) + \operatorname{div}(b(x)u^{\varepsilon}) = f^{\varepsilon};$$

$$u^{\varepsilon}\big|_{t=0} = 0, \qquad \frac{\partial}{\partial n_a} u^{\varepsilon} \cdot n(x) - b(x) \cdot n(x) u^{\varepsilon} + \lambda u^{\varepsilon} = 0.$$

A Random scenario ??

The contents, and the leaking starting time of the Waste Packages are Random

A.B., jointly with A. Piatnitski; work in progress

Under the assumptions :
The "local sources" f^e are statistically homogeneous and the associated random dynamical system T is ergodic

We may then characterize the global model:

$$\partial_t u^0 - \operatorname{div}(a(x)\nabla u^0) + \operatorname{div}(b(x)u^0) = F(t)\delta_\Sigma(x);$$

$$F(t) = \mathbf{E}\{f(\cdot, t)\}.$$

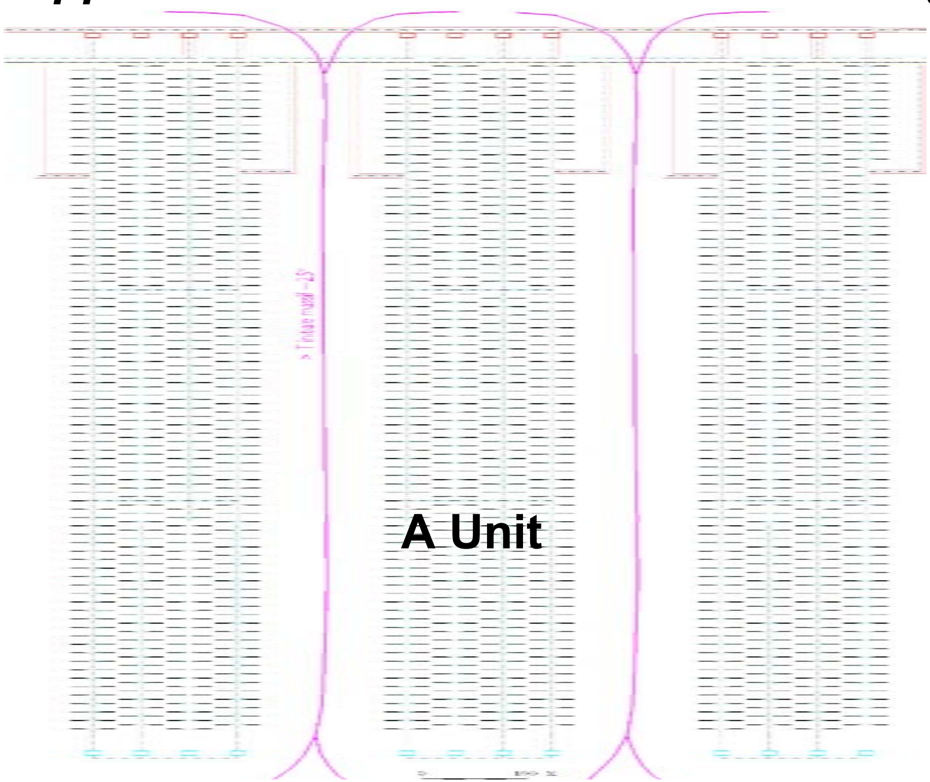
Application of Scaling up to obtain global model in situations where the near field is damaged

How a global (far field) model could be affected by the damaged zones in the near field models

On the following two examples of scaling up, our goal will be to characterize the influence of the degree of damaging (in the EDZ zone) on the global (or far field) mathematical model

Second example of Scaling Up:

From a " WASTE PACKAGES model" to a "**Storage UNIT** Global model", **including a possibly damaged zone** (*A. B, E. Marusic-Paloka. A homogenized model of an underground waste repository including a disturbed zone. To appear in SIAM J.on Multiscale Modeling and Simulation, 2005.)*



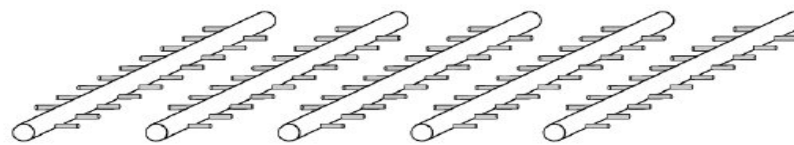
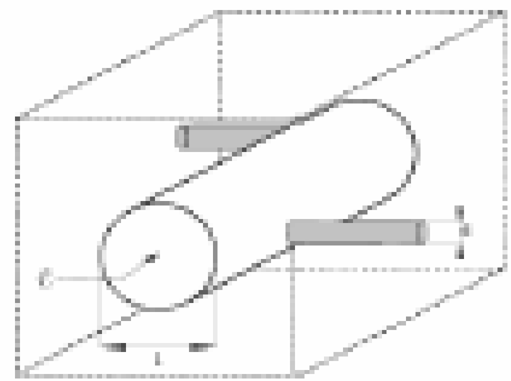


Figure 13: A part of a Storage Unit, with 5 rows of waste packages (or containers sets) along shafts



From a " WASTE PACKAGES model" to a "Storage UNIT Global model", including a possibly damaged zone

The "Mesoscospic" model of a storage unit

$$\omega^{\varepsilon}\,\frac{\partial \varphi_{\varepsilon}}{\partial t} - \mathrm{div}\,(\mathbf{A}^{\varepsilon}\nabla\varphi_{\varepsilon}) + (\mathbf{v}^{\varepsilon}\cdot\nabla)\varphi_{\varepsilon} + \lambda\,\omega^{\varepsilon}\,\varphi_{\varepsilon} = 0 \quad \text{in } \Omega_{\varepsilon}^{T} \qquad (13)$$

$$\varphi_{\varepsilon}(0,x) = \varphi_0(x) \quad x \in \Omega_{\varepsilon} \qquad (14)$$

$$\mathbf{n}\cdot(\mathbf{A}^{\varepsilon}\nabla\varphi_{\varepsilon} - \mathbf{v}^{\varepsilon}\,\varphi_{\varepsilon}) = \Phi_{\varepsilon}(t) \quad \text{on } \Gamma_{\varepsilon}^{T} \qquad (15)$$

$$\mathbf{n}\cdot(\mathbf{A}^{\varepsilon}\nabla\varphi_{\varepsilon} - \mathbf{v}^{\varepsilon}\,\varphi_{\varepsilon}) = \kappa\,(\varphi_{\varepsilon} - g_{\varepsilon}) \quad \text{on } \mathcal{K}_{\varepsilon}^{T}\cup\mathcal{H}_{\varepsilon}^{T} \qquad (16)$$

$$\varphi_{\varepsilon} = 0 \quad \text{on } \mathcal{Z}_{\varepsilon}^{T}\;. \qquad (17)$$

$\mathcal{Z}_{\varepsilon}^{T}$ the Drifts Bottoms (sealed), $\mathcal{H}_{\varepsilon}^{T}$ the drifts tops and $\mathcal{K}_{\varepsilon}^{T}$ the rest of the exterior boundary of Ω,Γ_{ε} the Waste Packages boundary $\times(0,T)$;

g_{ε} measure the concentration entering at the drifts tops. A parameter β is introduced for characterizing the degree of damaging by mean of the Darcy's velocity range .

From a " WASTE PACKAGES model" to a "Storage UNIT Global model", including a possibly **damaged zone**

Modelling all range of damaging

($\varepsilon^{-\beta}$ characterize the Darcy's velocity range inside the drifts)

$$\mathrm{v}^{\varepsilon}(x) = \begin{cases} \mathrm{v}^{h}(x) \text{ in the host rock } \Omega_{\varepsilon} \backslash \mathcal{S}_{\varepsilon} \\ \varepsilon^{-\beta}\, \mathrm{v}^{d}(x', x_2/\varepsilon; x_3/\varepsilon) \text{ in the drifts } \mathcal{S}_{\varepsilon} \end{cases} .$$

The Diffusion/Dispersion

$$\mathrm{A}^{\varepsilon}(x) = \begin{cases} \mathrm{A}^{h}(x) \text{ in the host rock } \Omega_{\varepsilon} \backslash \mathcal{S}_{\varepsilon} \\ d(x)\,\mathrm{I} + \varepsilon^{-\beta}\, \mathrm{A}^{d}(x_2, x_2/\varepsilon, x_3/\varepsilon) \text{ in the drifts } \mathcal{S}_{\varepsilon} \end{cases} .$$

THEN:

in the corresponding Macroscopic model *Depending on* β*(characterizing the degree of damaging, i.e. the Darcy's velocity range) we have three different cases.*

From a " WASTE PACKAGES model" to a "Storage UNIT Global model", including a possibly damaged zone

ccording to the range of damaging, we see 3 storage unit global models

- $0 \leq \beta < 1$; The storage site is undisturbed.

The drifts do not make any contribution, i.e. the repository behaves as if they were not there. $\varphi_\varepsilon \rightarrow \varphi$ the solution of an equation, similar to the one associated to the mesoscopic model.

- $\beta = 1$; galleries and drifts with damaged sealings.

The transport processes, inside and outside the "damaged" drifts are comparable and there are interactions between them.

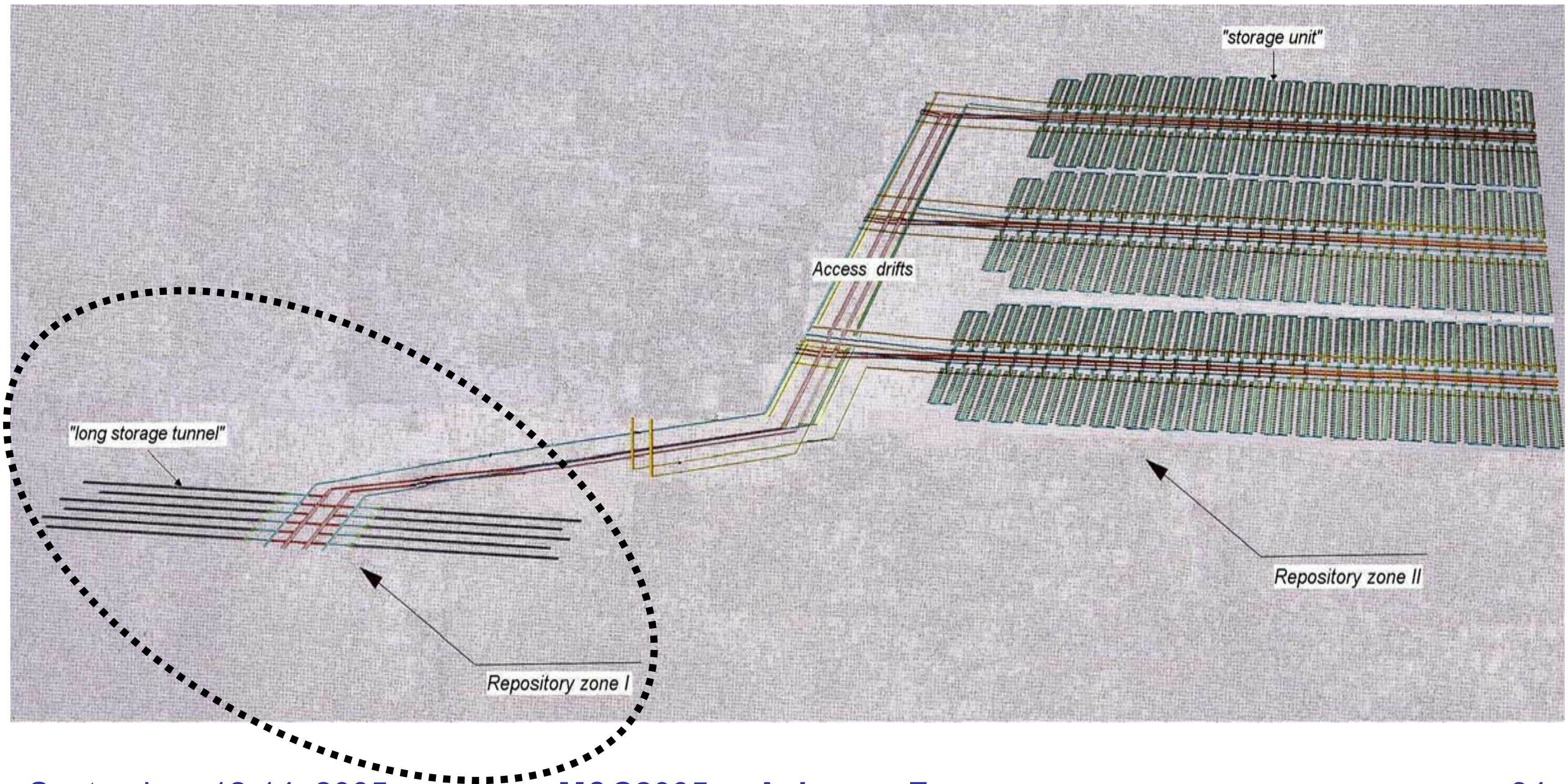
- $2 > \beta > 1$; The storage site is highly disturbed.

The Transport process in the drifts is dominant and we do not see anything else outside the drifts in the corresponding global model .

Third exemple of Scaling Up:

From the **LONG STORAGE UNITS** to a "**ZONE** global model"

.B., jointly with A. Piatnitski and E. Marusic-Paloka. ; work in progress.



Third exemple of Scaling Up:

From the **LONG STORAGE UNITS** to a "**ZONE** global model" (***A.B., jointly with A. Piatnitski and E. Marusic-Paloka. ; work in progress.***)

The repository **zone**, is made of a high number of similar long waste filled storage units, linked by backfilled working and haulage drifts. .

Like previously, **the parameter β characterize de degree of damaging** (scaling the Darcy's velocity range)

Third exemple of Scaling Up:

From the LONG STORAGE UNITS to a "ZONE global model" (*A.B., jointly with A. Piatnitski and E. Marusic-Paloka. ; work in progress.*)

In the first example there was no damaged zone at all, while in the second one the damaged drifts were periodically repeated, allowing to use the technique of singular measures.

The main difference compared to the 2 previously studied situations, is the singular behavior of the only one damaged drift which reduces to a 1-D object in the scaled up model, leading to technical difficulties

Third exemple of Scaling Up:

From the LONG STORAGE UNITS to a "ZONE global model" (*A.B., jointly with A. Piatnitski and E. Marusic-Paloka. ; work in progress.*)

Finally we prove:

- ***The Zone global model is independent of the choice of β and only higher order correctors terms differ, according to β.***

THE END

- *Thank you for your attention*