L：個人研究

L.1 Slides - The Application of GoldSim

The application of GoldSim

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Institute of Nuclear Energy Research

Contents

(I) Fundamental research

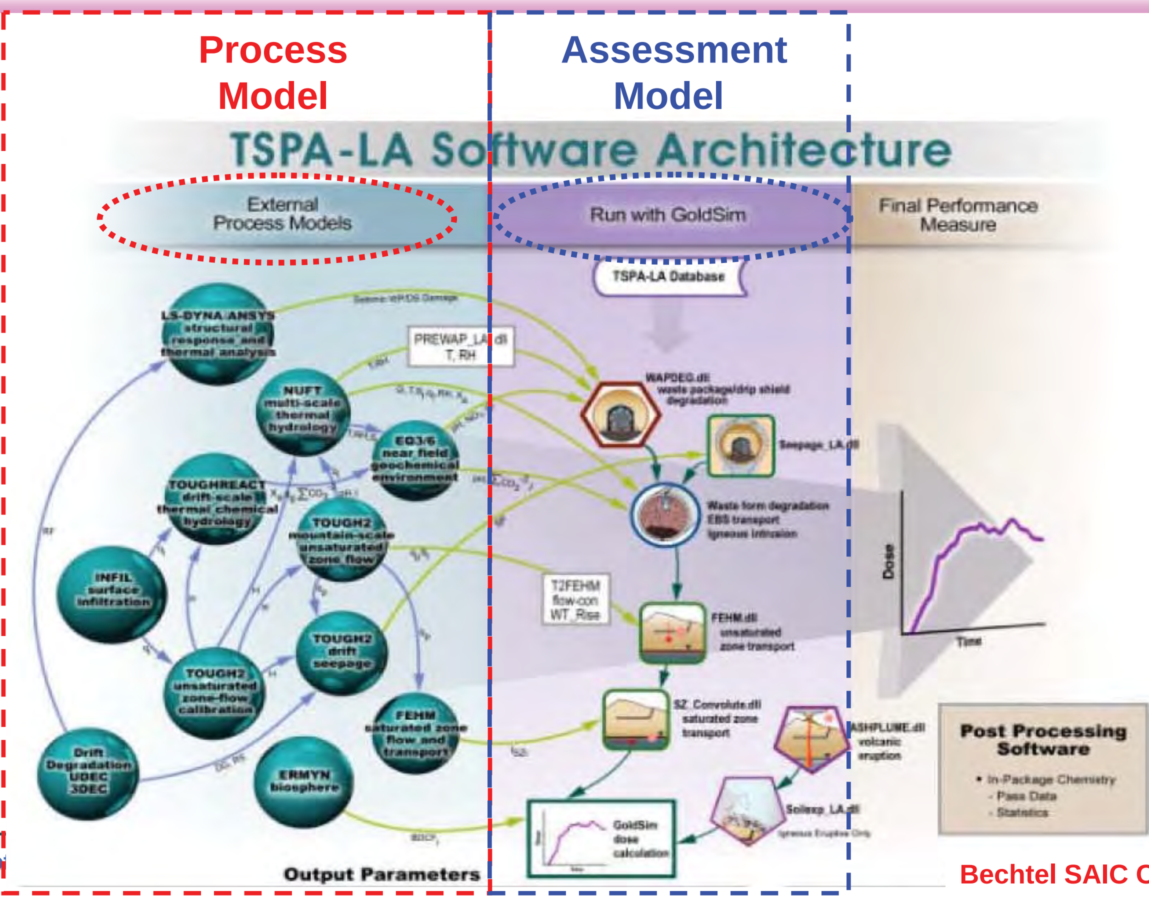
- Verification and modification of the pipe module in GoldSim
- Comparison of GoldSim and AMBER
- Characteristic study on pipe module and cell module in GoldSim

} safety assessment in porous

- Connection between GoldSim and FracMan/PA Works → safety assessment in fracture
- GoldSim-Dashboard application → public communicate

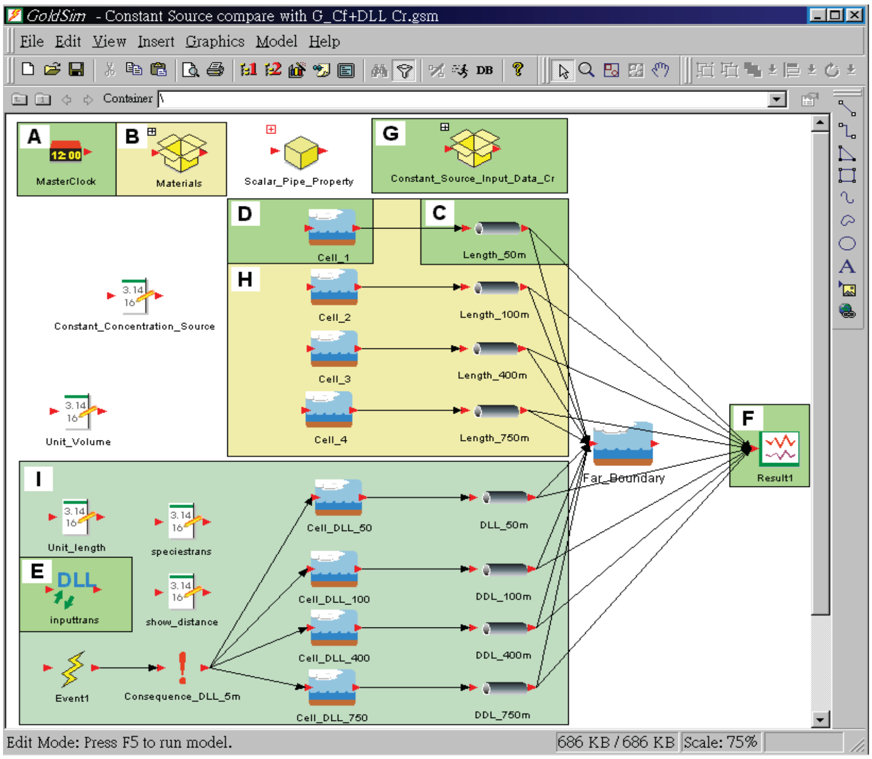
(II) Developing representative assessment model for radwaste disposal → safety assessment in porous

Why GoldSim ?



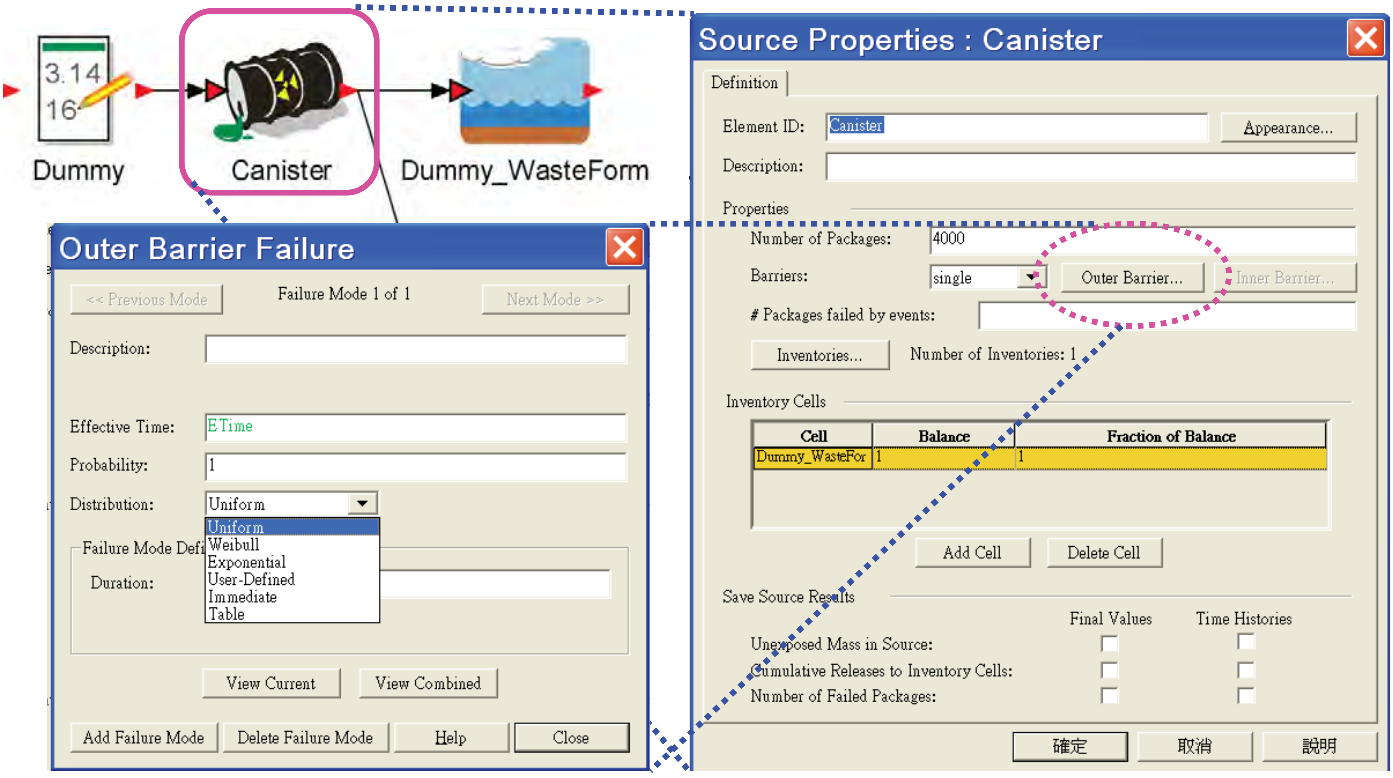
Bechtel SAIC Company (2003)

What is GoldSim ?

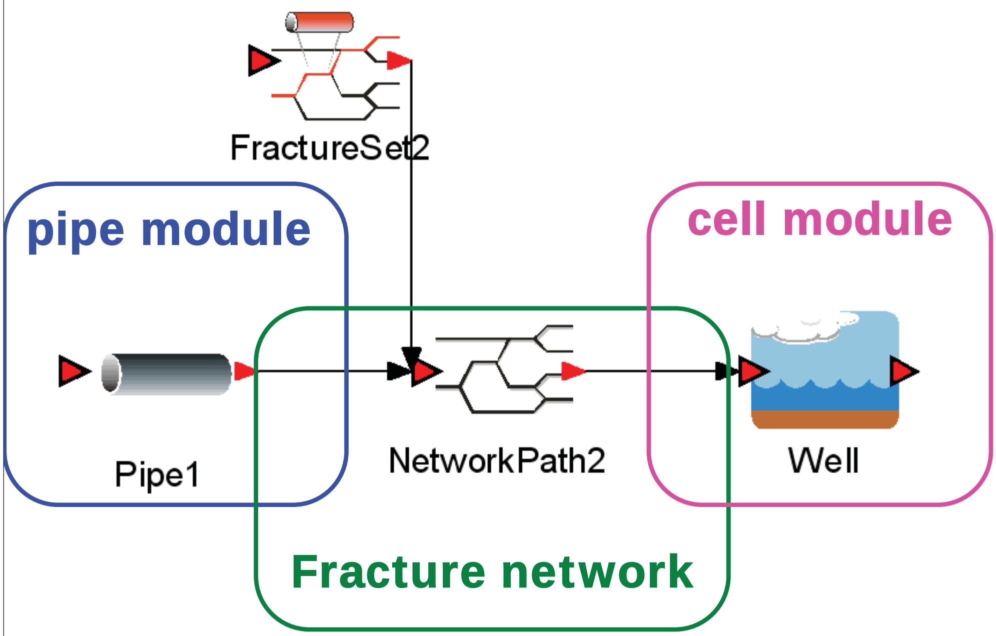


GoldSim was developed by Golder Associates Inc. It is a modular and iconified software. User can simulate nuclide/mass transport easily. The probabilistic analysis is one of its powerful functions.

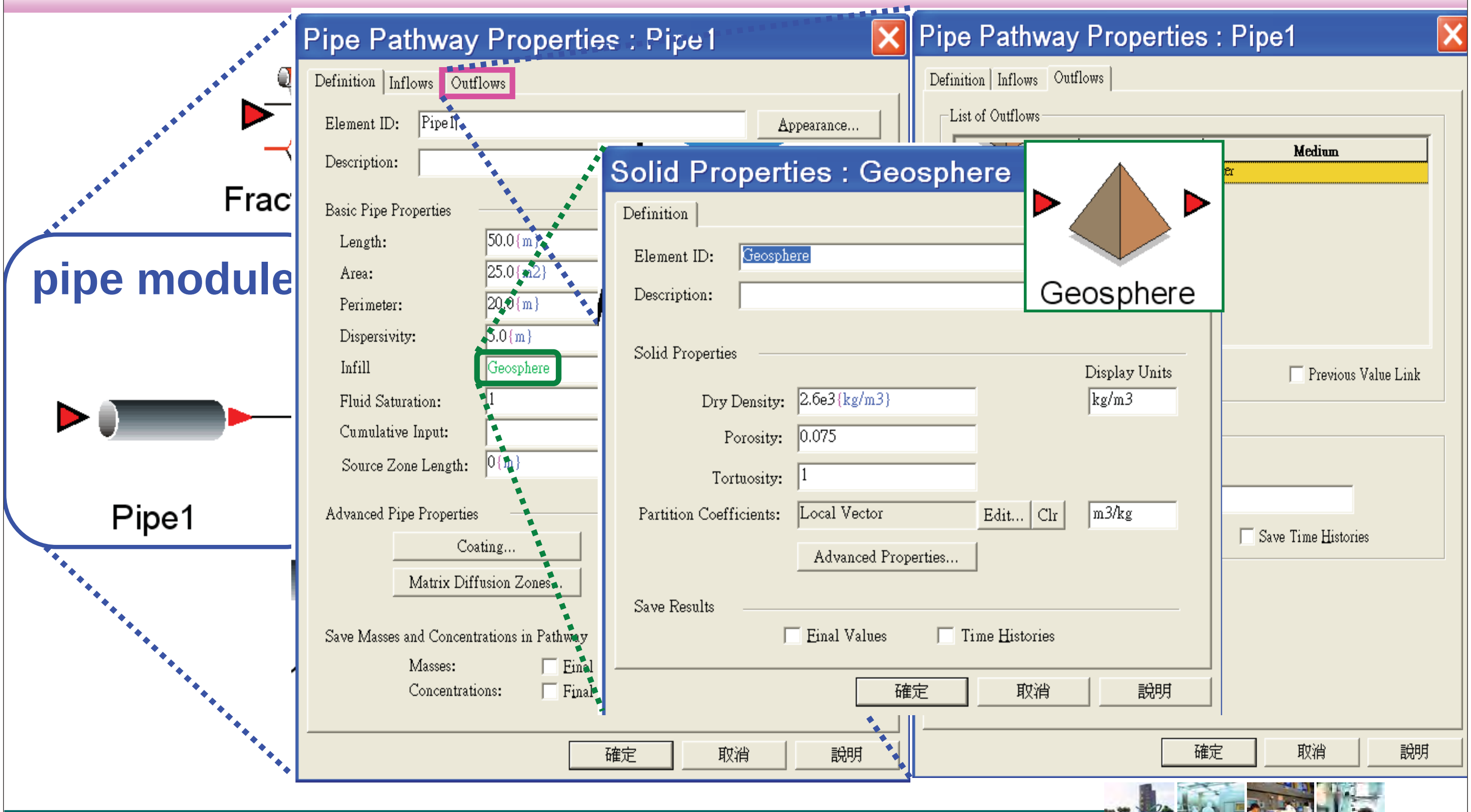
What is GoldSim - Source



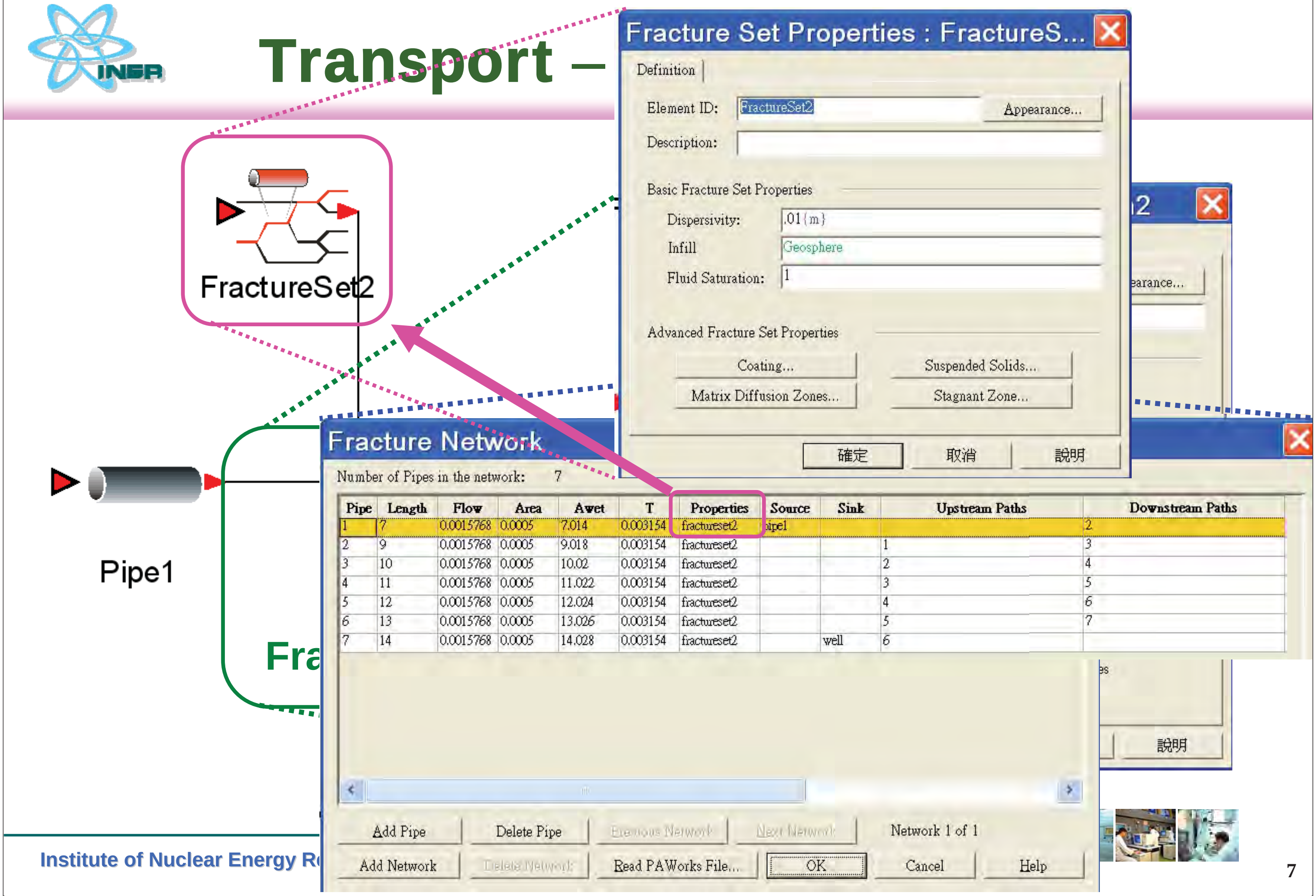
What is GoldSim - Transport



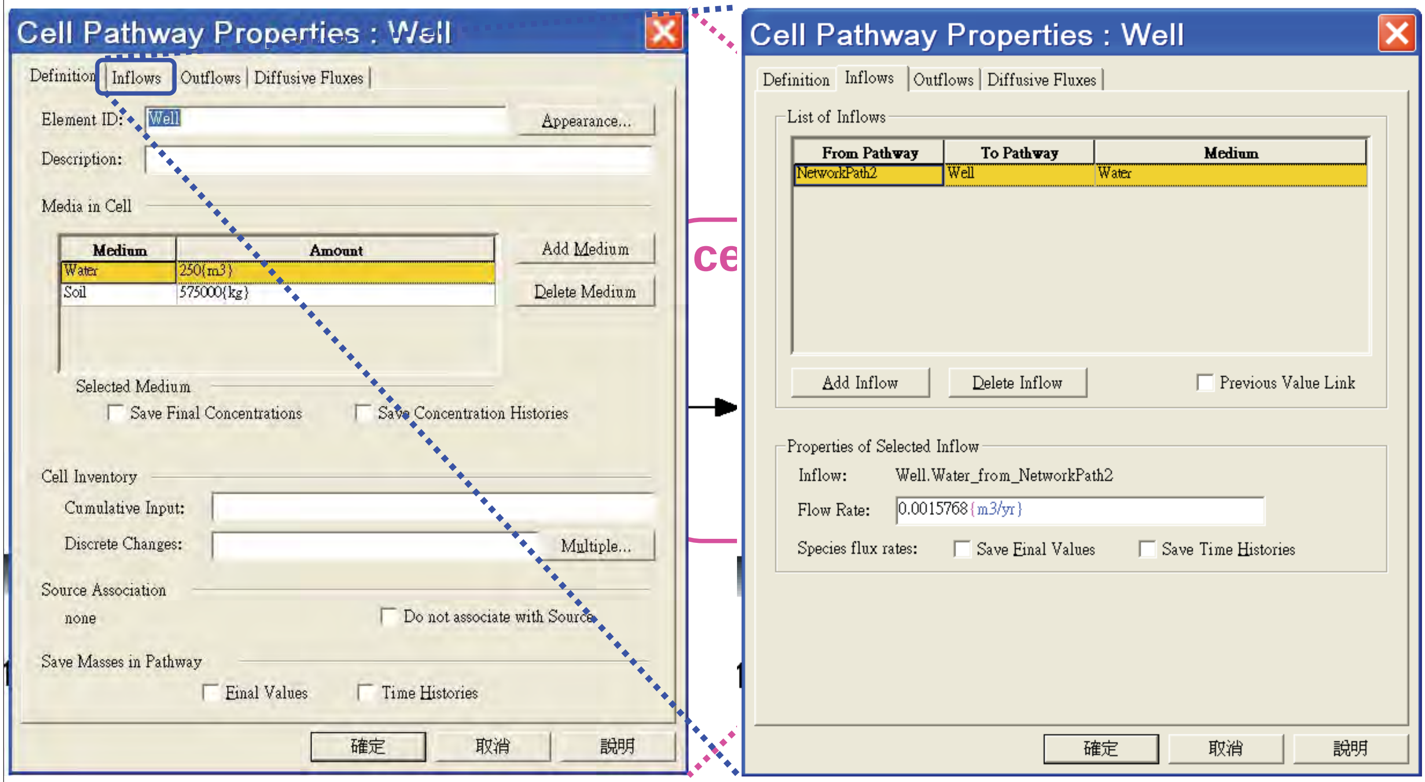
Transport – Pipe module



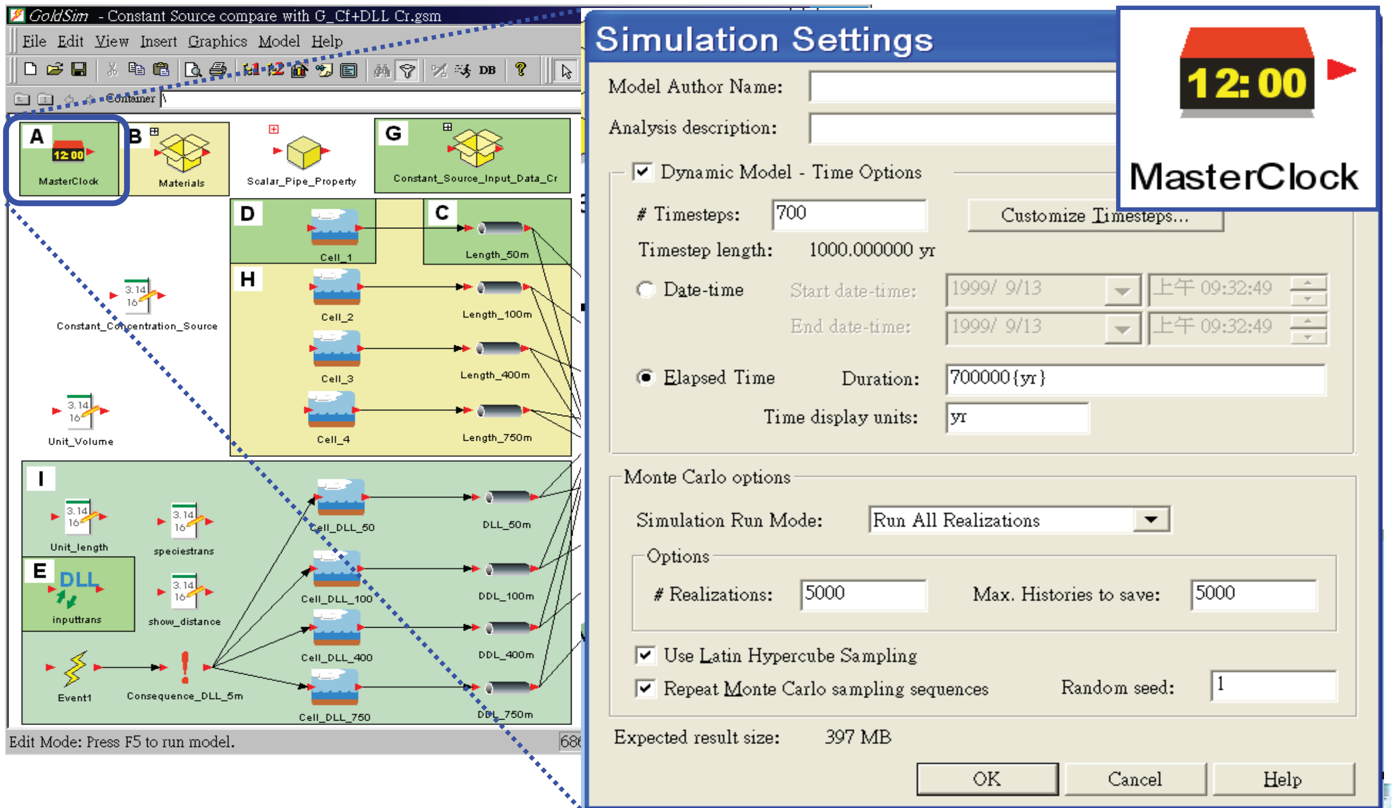
Transport –



Transport – Cell module



What is GoldSim - Probability



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- GoldSim-Dashboard application

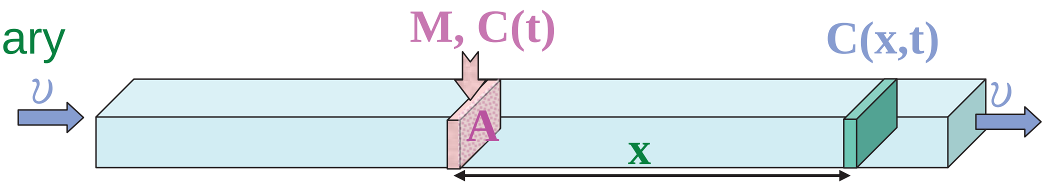
purposes

1. The characteristics of pipe module
2. Developing DLL technology

(II) Developing representative assessment model for radwaste disposal

1-D mass transport

(A) Infinite boundary



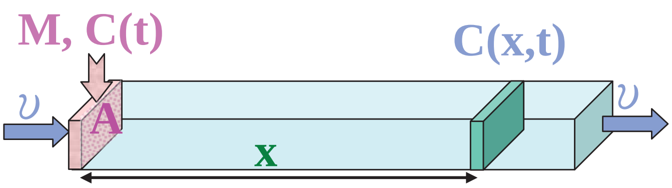
Pulse source

$$C(x,t)=\frac{M}{nA}\frac{1}{\sqrt{4\pi t D_x}}\exp\left(-\frac{(x-\upsilon t)^2}{4D_x t}\right)$$

n : porosity[-]

D_x : dispersivity in x direction [L^2/T]

(B) Semi-infinite boundary



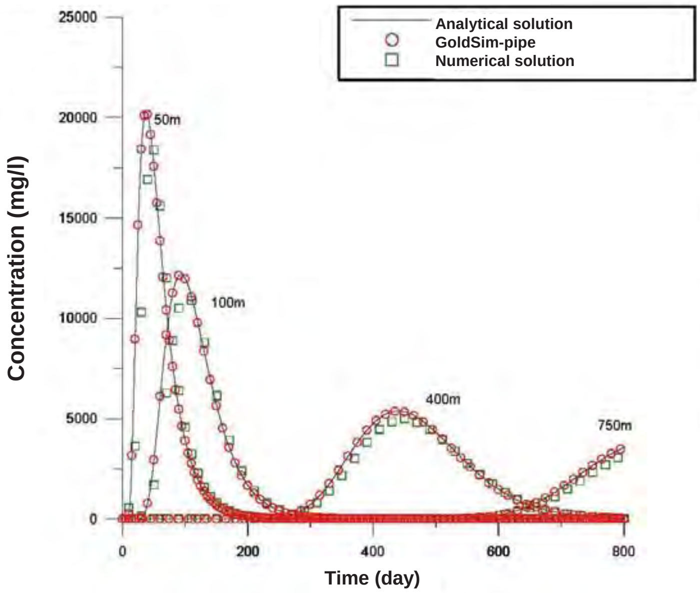
$$C(x,t)=\frac{M}{nA}\frac{1}{\sqrt{4\pi t D_x}}\frac{x}{\upsilon t}\exp\left(-\frac{(x-\upsilon t)^2}{4D_x t}\right)$$

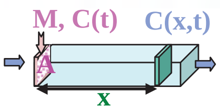
Chen et al.(2005)

1-D mass transport

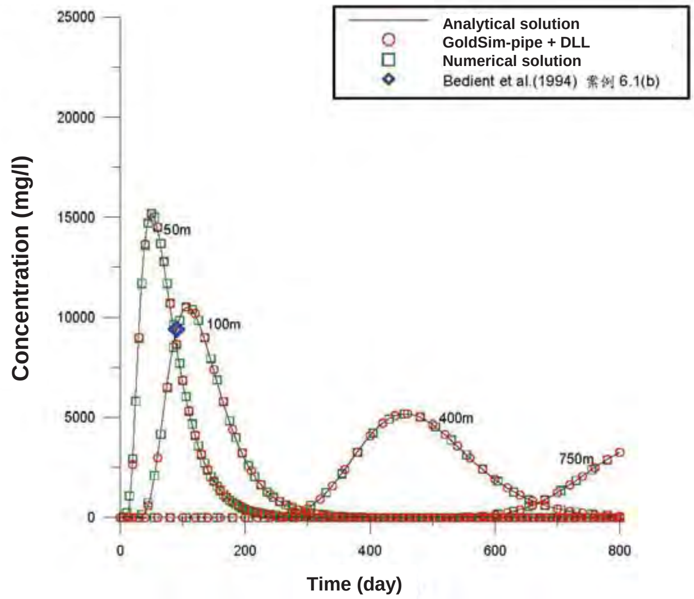
Pulse source

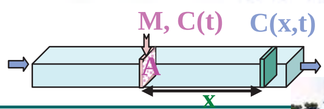
(A) Semi-infinite boundary





(B) Infinite boundary

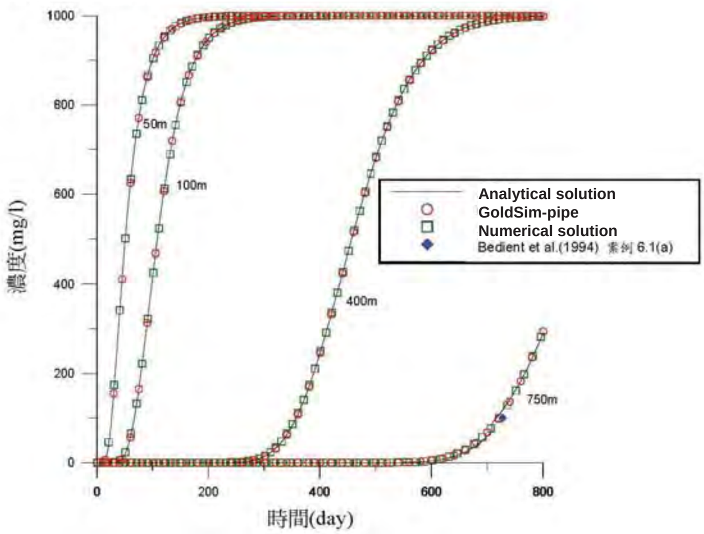


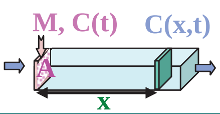


1-D mass transport

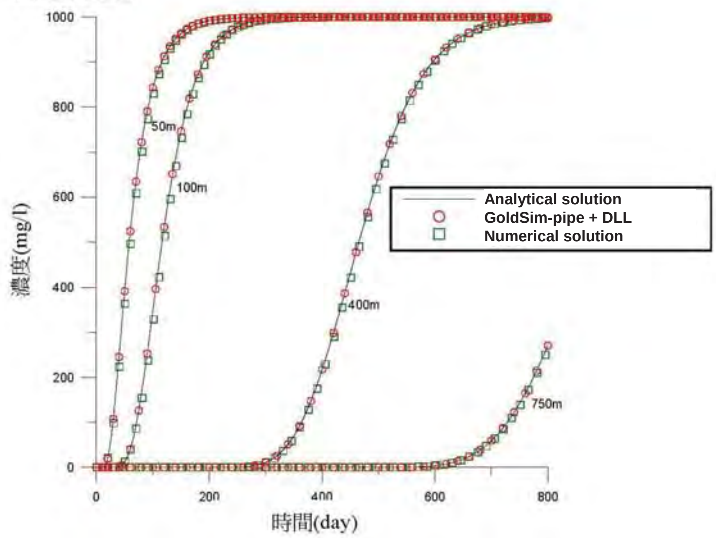
Constant Concentration source

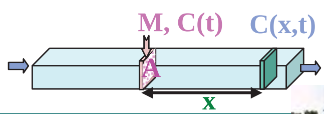
(A) Semi-infinite boundary





(B) Infinite boundary





Conclusion(1)

- Boundary condition of GoldSim pipe module is a semi-infinite boundary
- Developing and confirmed the Dynamic Link Library (DLL) function in GoldSim can help user to connect other software (ex. AMBER)
- Applied DLL of GoldSim to enhance pipe module [Semi-infinite boundary→infinite boundary]

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- Connection between GoldSim and ... Works
- GoldSim-Dashboard application

(II) Developing representative model for radwaste disposal

purposes

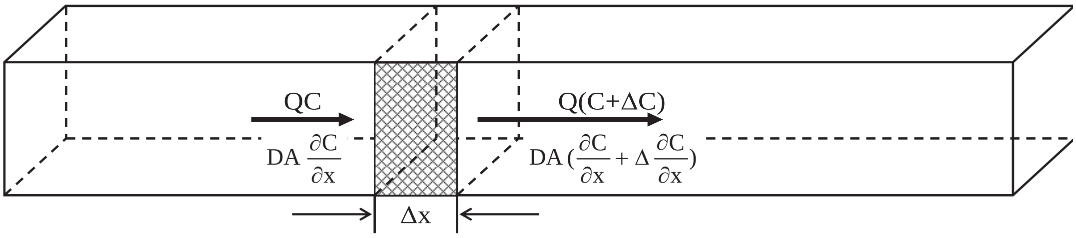
1. Study on the characteristics of pipe module and cell module in GoldSim
2. The characteristics of compartment module in AMBER

Advection-Dispersion (pipe module)

Advection-Dispersion Model (AD Model)

---Continuous model

– Based on mass balance principle. The governing equation derived from finite difference method. It is not necessary to assume a well mixed volume element. Generally used to simulate nuclides/ contaminant transport behavior in groundwater.



Q：flux
C：concentration
D：dispersivity
A：cross-section

Governing equation

$$\frac{\partial C_1(x,t)}{\partial t} = D_x \frac{\partial^2 C_1(x,t)}{\partial x^2} - \upsilon \frac{\partial C_1(x,t)}{\partial x} - \lambda_1 C_1(x,t)$$

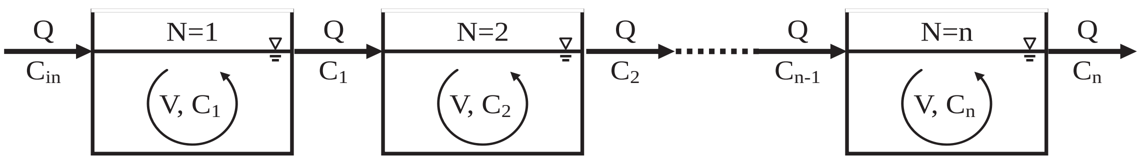
Chen and Lai (2008a)

Compartment Model (cell module)

Multi-Compartment model (MC model)

---Multi-box model, Tank-in-series model, Discrete model

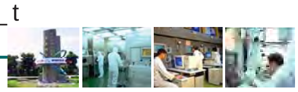
– Based on mass balance principle, too. It sliced the pathway into several element with equal volume or not. It assumed that mass flow into the volume element, it mix well immediately. Generally used to simulate nuclides/contaminant transport behavior in river or lake.



Q：flux
V：element volume
C_{in}：boundary conc.
C_n：n-th element conc.

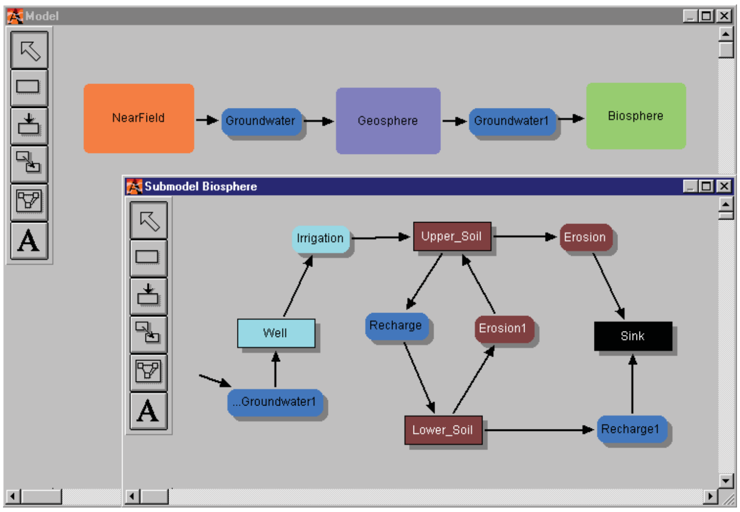
Governing equation

$$\frac{d(V\phi C_{n\_t})}{dt} = -\lambda(V\phi C_{n\_t}) + Q\ C_{n-1\_t} - Q\ C_{n\_t}$$

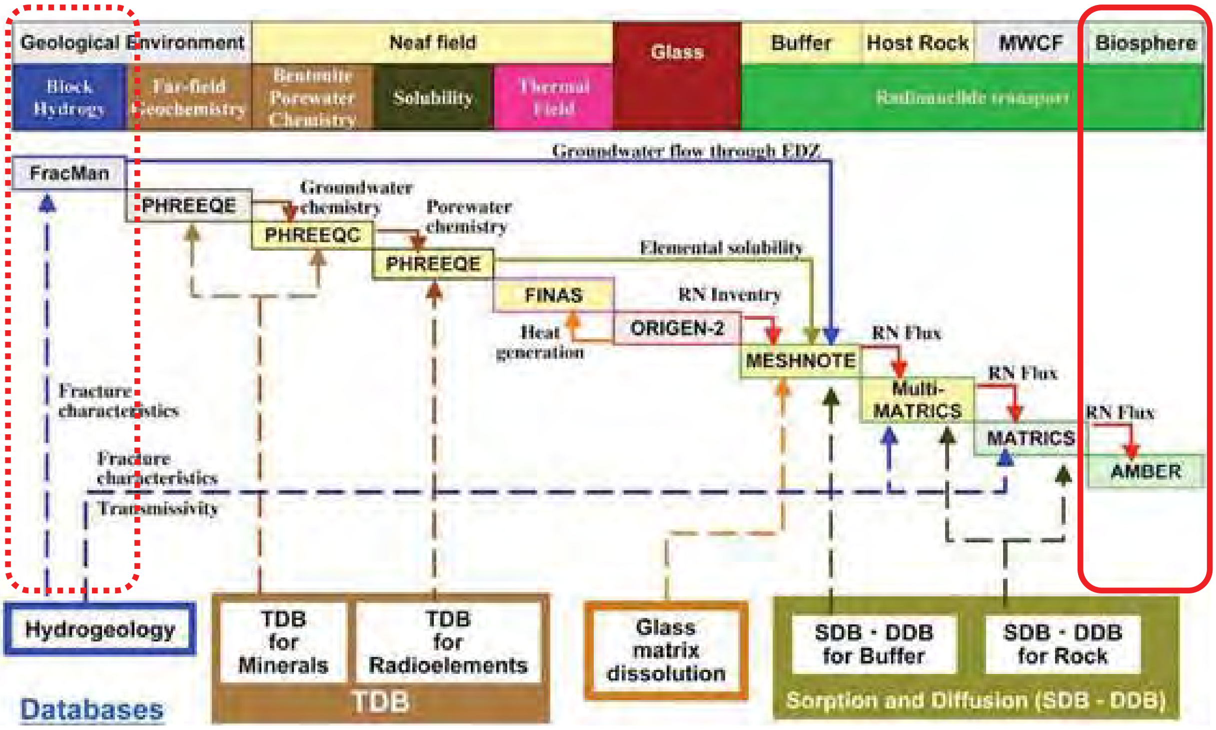


AMBER

- AMBER was develpoed by Enviros and Quintessa, and supported by ENRESA, JAEA and SKI etc.
- Nuclides/contaminant migration in Biosphere are simulated by compartment model
- It can apply to the three phases (solid, liquid and gas) simulation and perform probabilistic analysis



H17 model chain

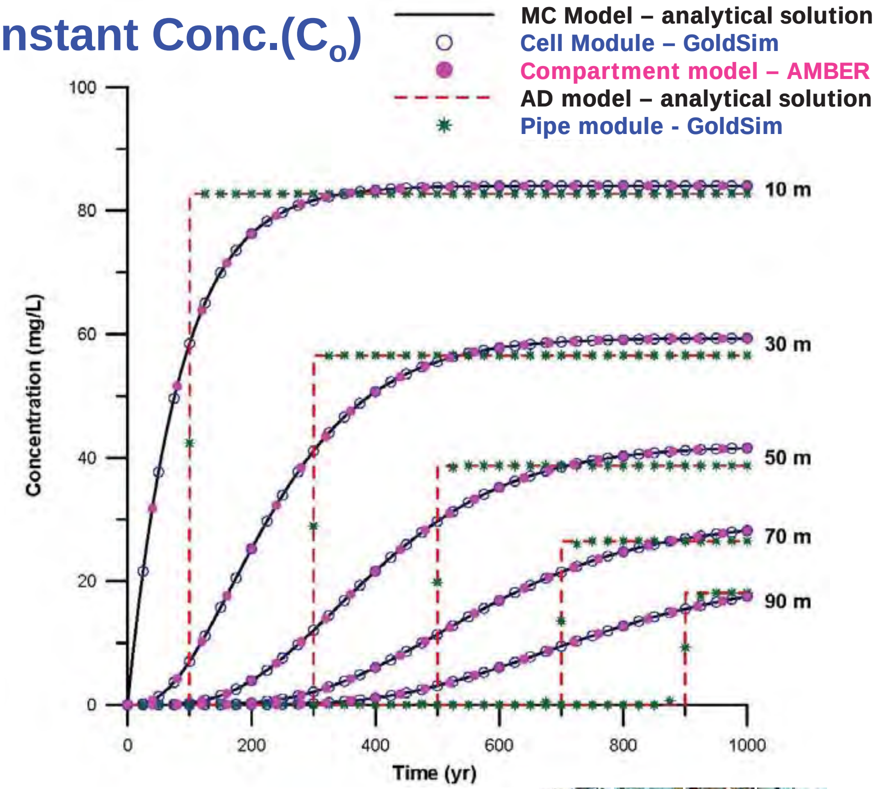


JNC (2005)

GoldSim V.S. AMBER (1)

No dispersion and diffusion
Only advection

Constant Conc.(C_o)



Governing equation

$$-\bar{v}_x \frac{\partial C_{xt}}{\partial x} - \lambda C = \frac{\partial C_{xt}}{\partial t}$$

Initial condition

$$C_{xt}(x, t = 0) = 0$$

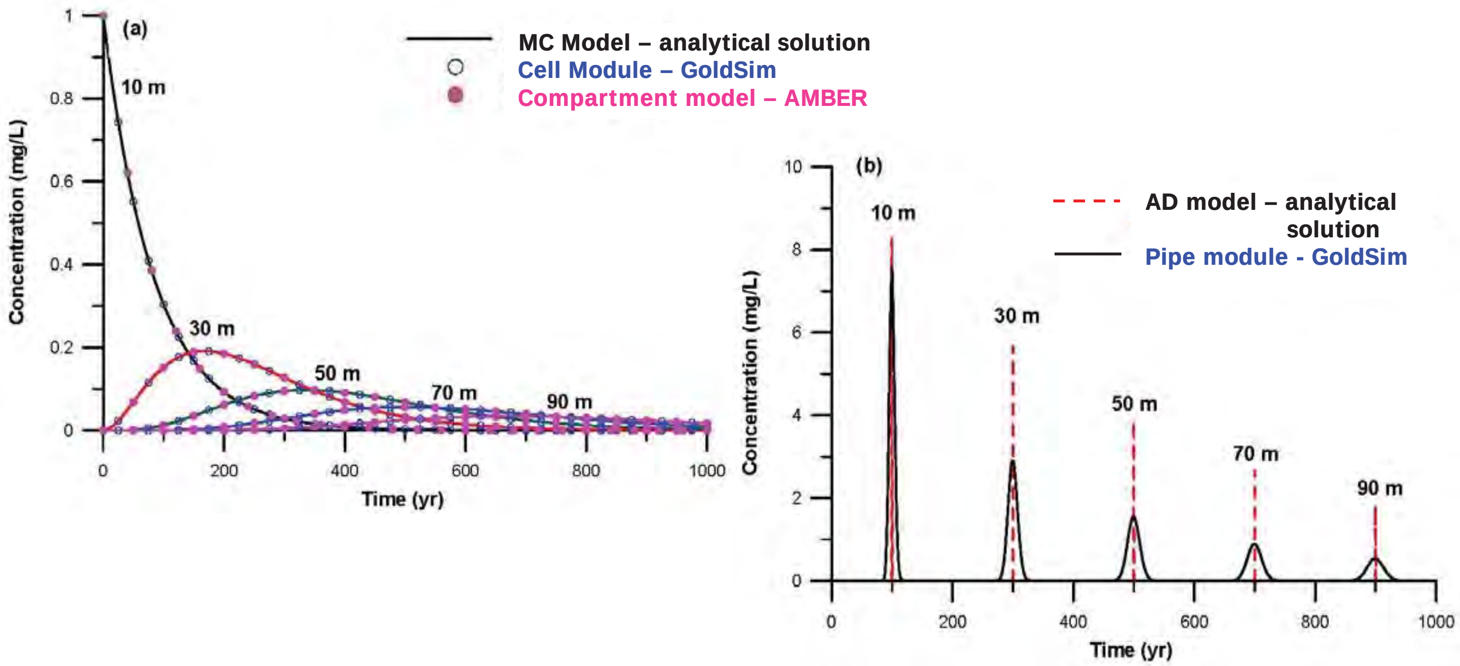
Boundary condition

$$C_{xt}(x = 0, t) = C_o$$

$$C_{xt}(x \to \infty, t) = 0$$

GoldSim V.S. AMBER (2)

Pulse source



Conclusion (2)

- AMBER is a compartment model that is similarly as cell module in GoldSim. In viewpoint of safety assessment, the biosphere assessment were simulated by AMBER can be done by GoldSim cell module directly. This will avoid the difficult or mistake between two software.
- The compartment model is different from the advection-dispersion model. When we performed safety assessment, we should choice reasonable model corresponding to environmental condition.

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(II) Developing representative model for radwaste disposal

purposes

1. Many cells can simulate the phenomenon of advection-dispersion?
2. What relationship between pipe module and cell module in GoldSim?

MC model V.S. AD model

Q : Many cells can simulate the phenomenon of advection-dispersion?

Van Ommen (1985) — $N = \dfrac{2\alpha L}{u\Delta t}$

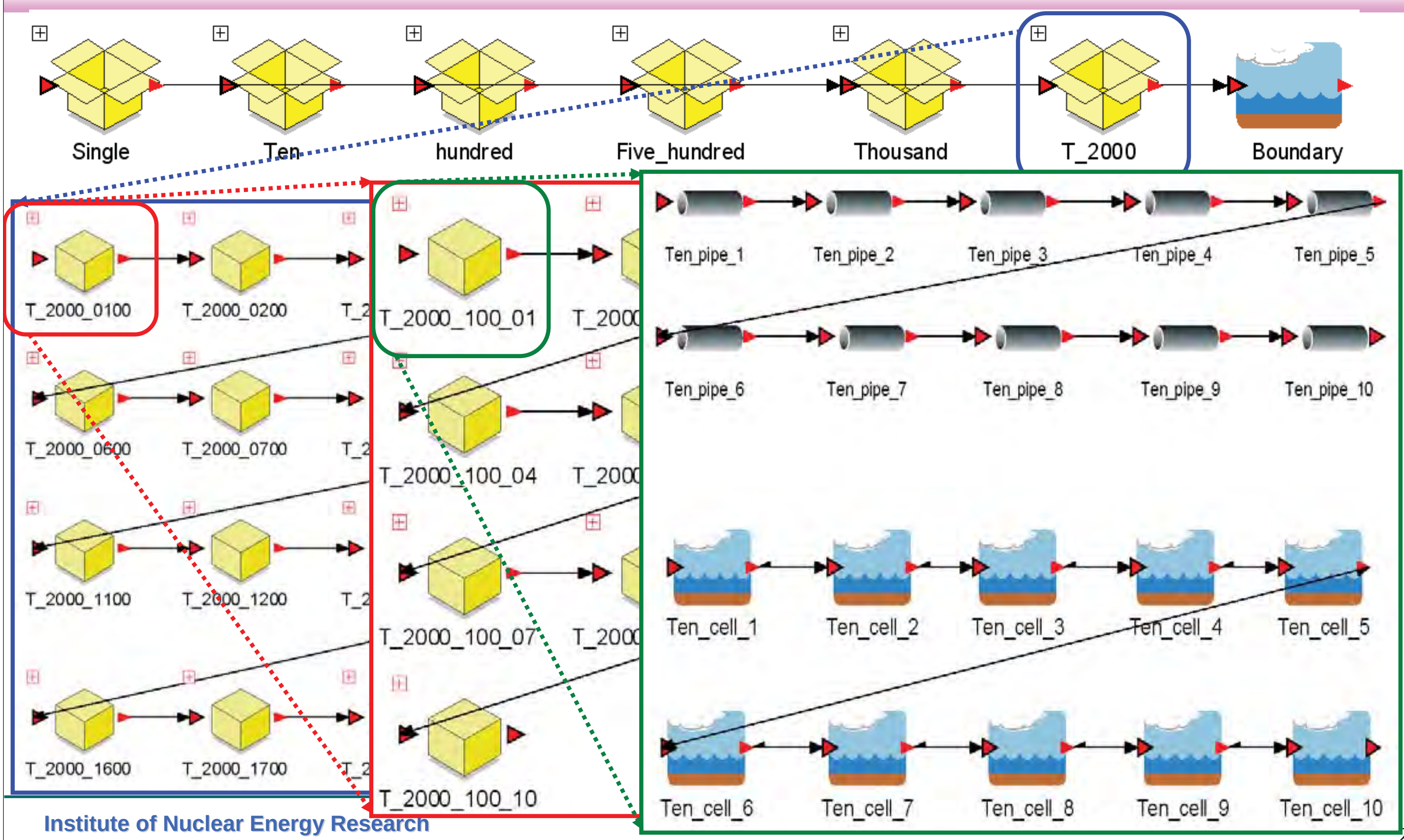
Wang and Chen (1996)
Bajracharya and Barry (1992)
Sardin et al. (1991)
Shanahan and Harleman (1984)

$$N = \frac{Lu}{2D}$$

N : Cell number
α : Dispersivity
L : Length(position)
u : velocity
Δt : time interval
D : Dispersion coef.(α*u+D_f)
D_f : Diffusion coef.

Chen (2012)

GoldSim model



Case study

Common parameters：

- – Porosity : 0.1
- – Cross-section : 1 m^2
- – Diffusion coef. : 10^{-9} m^2/day
- – Not consider decay effect

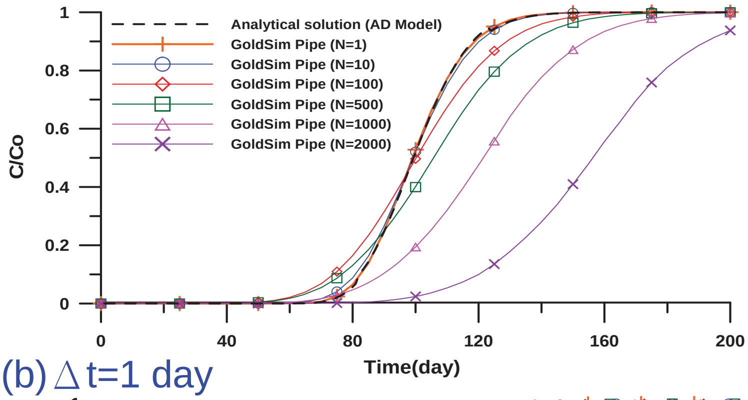
Case (A) – time interval

The influence of the time interval (△t) [distinctness] to the numbers (N) of pipes or cells

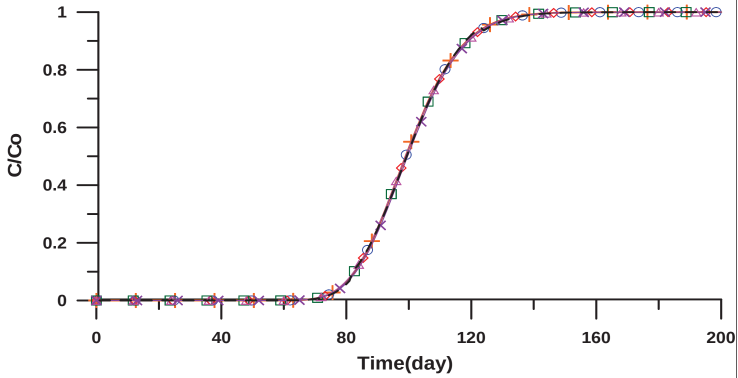
- – Length : 100 m
- – Velocity : 0.1 m/day
- – Dispersivity : 1 m

Case (A) – time interval

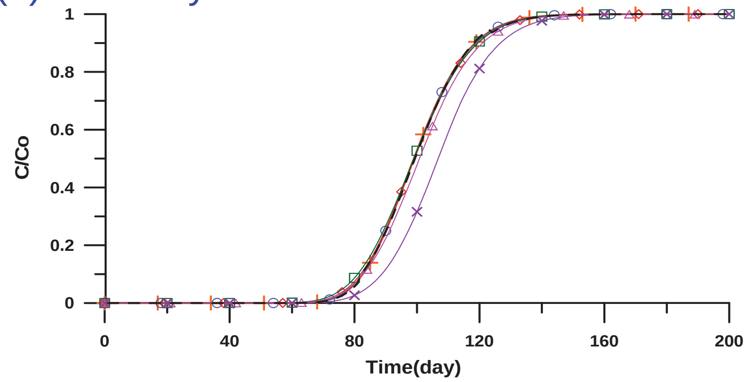
(a) △t=5 day



(c) △t=0.2 day



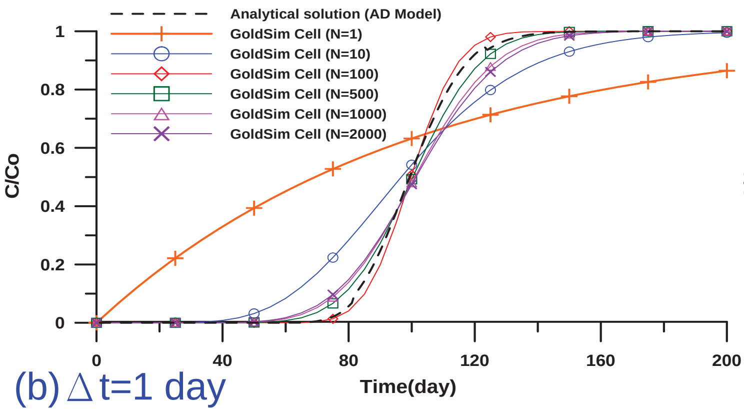
(b) △t=1 day



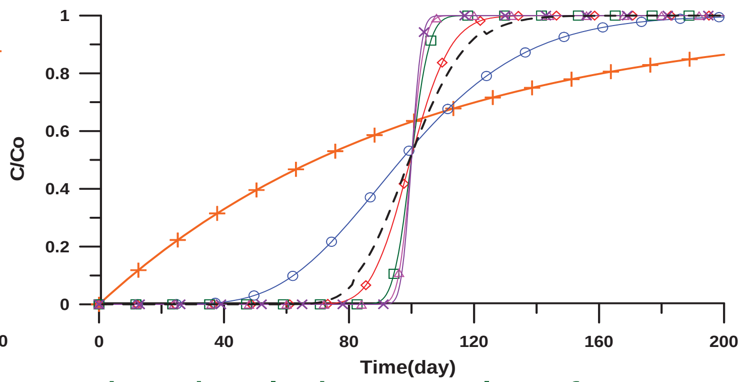
Increasing **pipe number**, it needs small time interval to gain similarly simulation results.

Case (A) – time interval

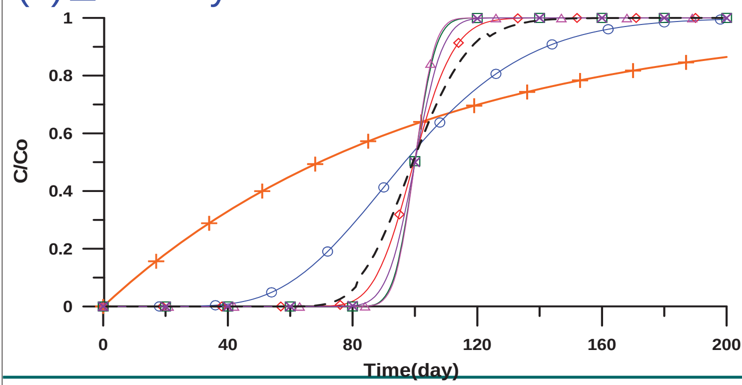
(a) △t=5 day



(c) △t=0.2 day



(b) △t=1 day



The simulation results of a specific cell number may close to the results of AD model. The simulation results from cell module did not be influenced by time interval.

Case (B) – velocity

The influence of groundwater velocity (u) [mixing degree] **to the numbers (N) of pipes or cells**

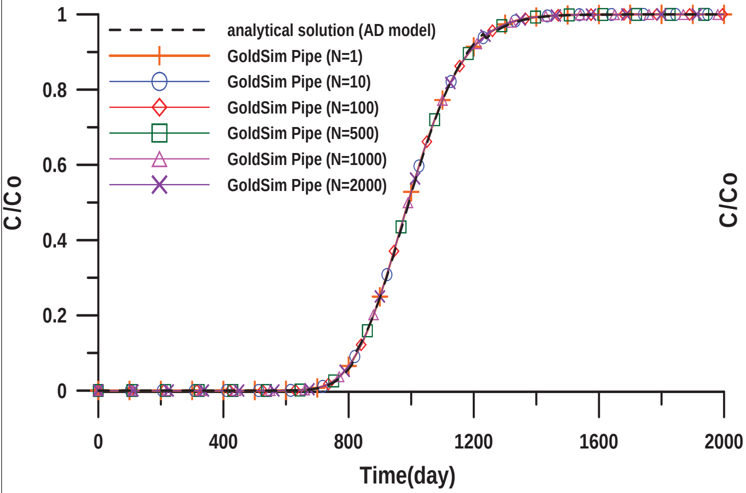
– Length : 200 m

– Dispersivity : 1 m

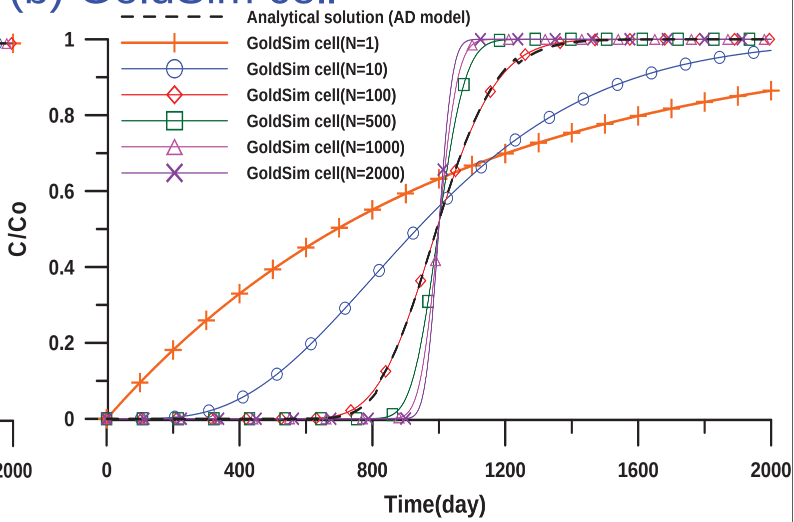
Case (B) – velocity

Δt=0.5 day，u=0.02 m/day

(a) GoldSim pipe



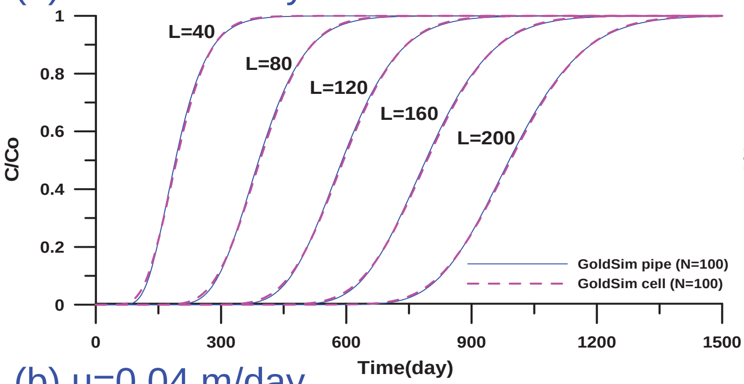
(b) GoldSim cell



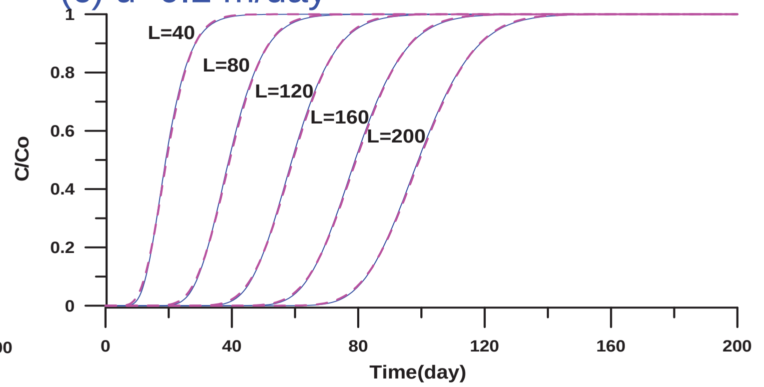
The simulation results of 100 cells close to the results of AD model

Case (B) – velocity

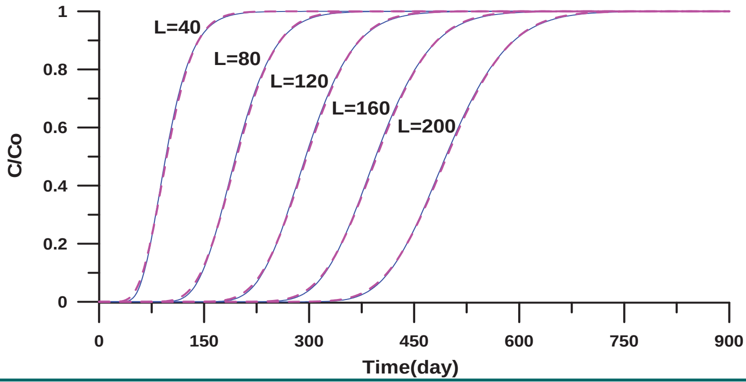
(a) u=0.02 m/day



(c) u=0.2 m/day



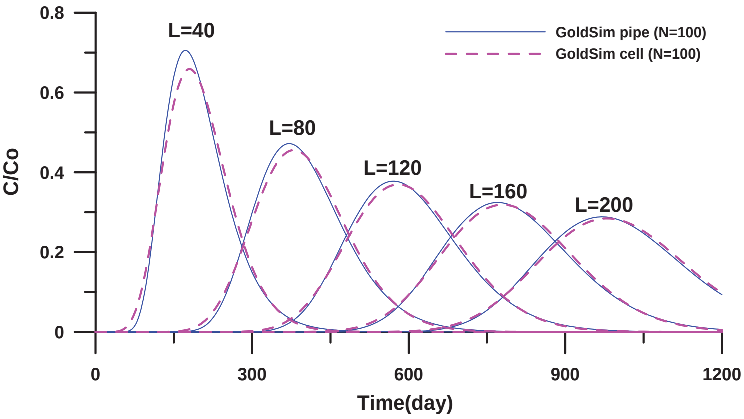
(b) u=0.04 m/day



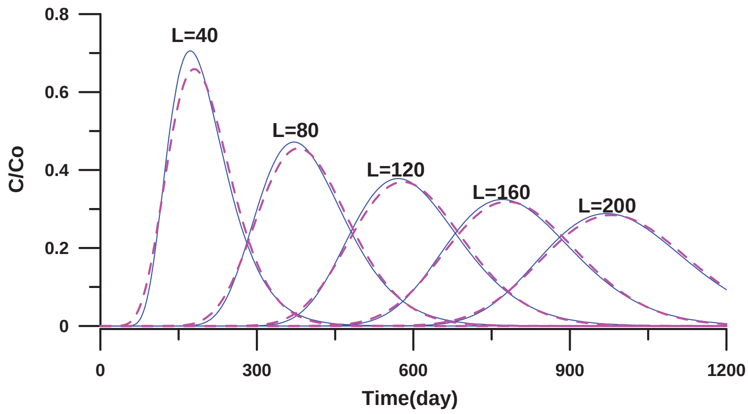
100 cells with different velocity, it shows the simulation results are similarly with AD model. It means velocity did not influence the suitable cell number.

Case (B) – velocity

(a) ∆t=1 day



(b) ∆t=0.5 day



Although under different source condition, the simulation results of specific cell number (N=100) are still close to the results of AD model and it is not influenced by time interval.

Case (C) – complex

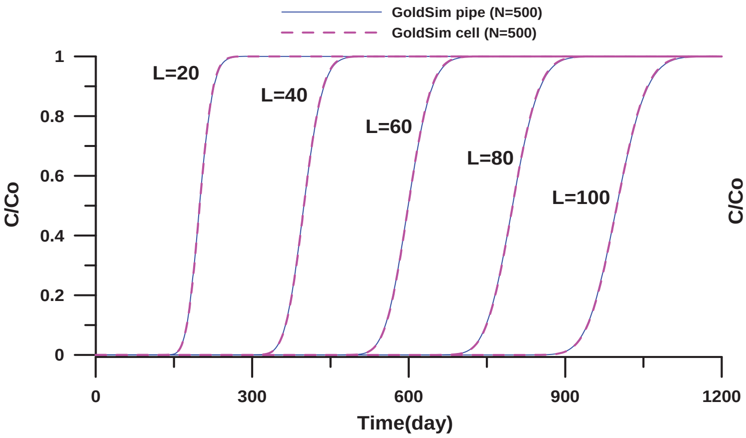
According to the previous results, we get the relationship (N＝Lu/2D) between cell and pipe modules. Here, we assumed two sets parameters to prove the formula.

(a) Length (L) : 100 m
Velocity (u) : 0.01 m/day
Dispersivity (α) : 0.1 m
Numver (N) : 500

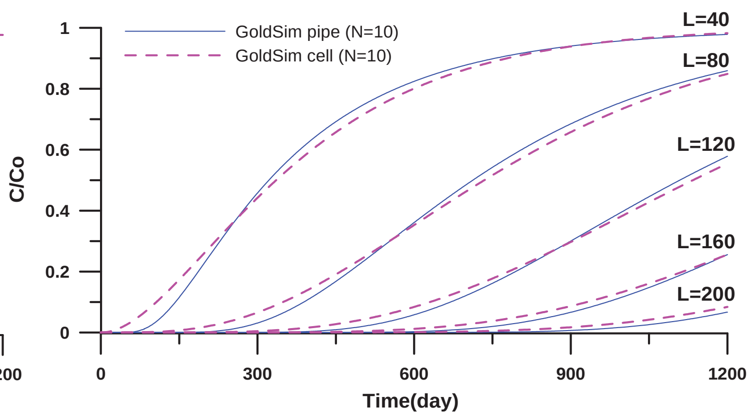
(b) Length (L) : 200 m
Velocity (u) : 0.01 m/day
Dispersivity (α) : 10 m
Numver (N) : 10

Case (C) – complex

(a) N＝500



(b) N＝10

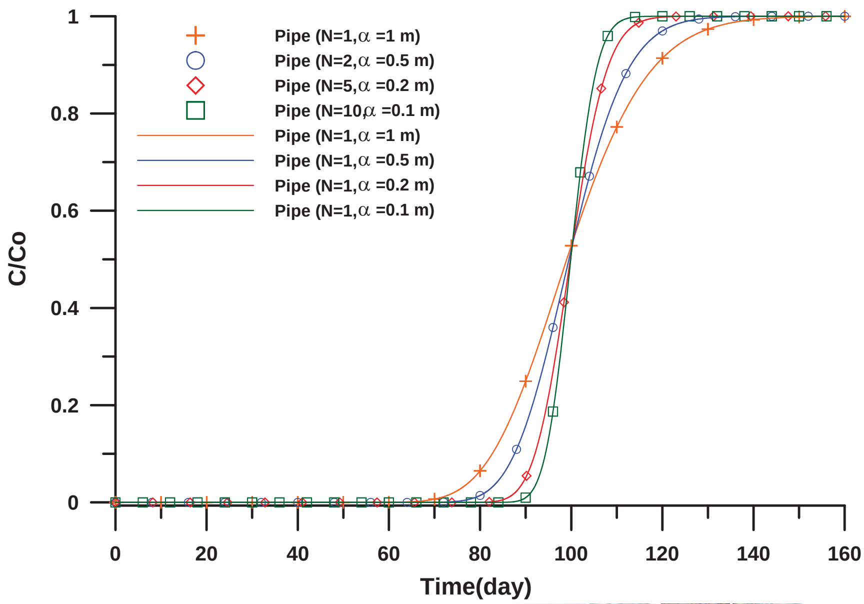


It proved the relationship between cell and pipe modules is Lu/2D.

Dispersivity

Q : Does dispersivity value change with the pipe number?

- physics：dispersivity(1 m) means the degree of dispersion in migration length (100 m). If it apply two 50 m pipes for simulating, it means in this 100 m (2*50 m) migration length, the dispersivity is still 1 m in each 50 m pipe.
- The dispersivity does not have a linear superposition characteristic.



Cell number

Q : more cell number is more accurate !

- Cell number≠element number in Finite Element Analysis。
- The results of more cell number does not close to the results of the pipe.

  -pipe module (AD model)：mainly be used for groundwater or fracture mass transport.

  -cell module (MC model)：mainly be used in river, ocean or air mass transport.
- In GoldSim, cell module and pipe module have the relationship ,Lu/2D. More cell number does not benefit for the accurate of results but only time-consuming.

Conclusion(3)

- By case (A) : specific cell number is necessary. More cells is just time-consuming.
- By case (B) : the velocity or source type does not change the simulation results of specific cell numbers to AD model.
- By case (C) : if someone wants to simulate mass migration **behavior in groundwater by** GoldSim **cell module**, the cell number **should match the formula of** Lu/2D.

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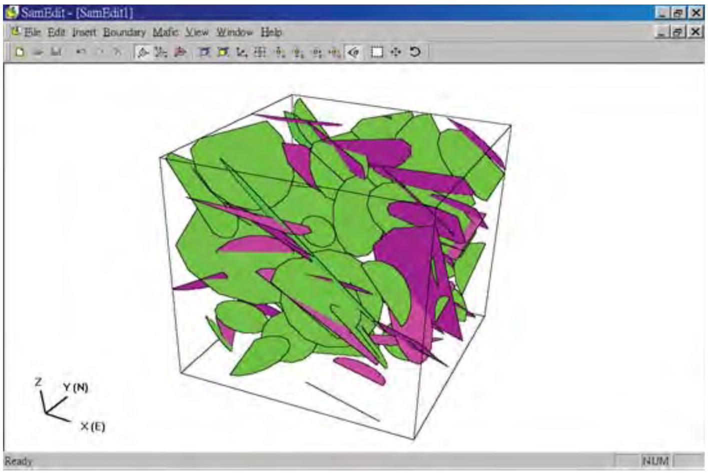
} safety assessment in porous

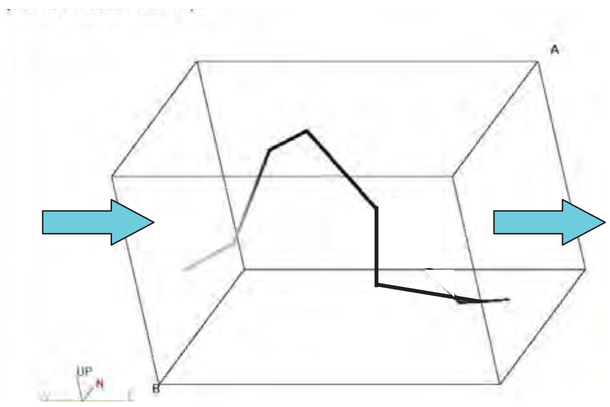
- **Connection between GoldSim and FracMan/PA Works** → **safety assessment in fracture**
- GoldSim-Dashboard application → public communicate

(II) Developing representative assessment model for radwaste disposal → safety assessment in porous

GoldSim - FracMan

GoldSim can connect PAWorks module of FracMan to simulate nuclide migration in fracture networks. PAWorks includes all major pathways which were analyzed by FracMan.





Chen and Lai (2008b)

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→ safety assessment in porous

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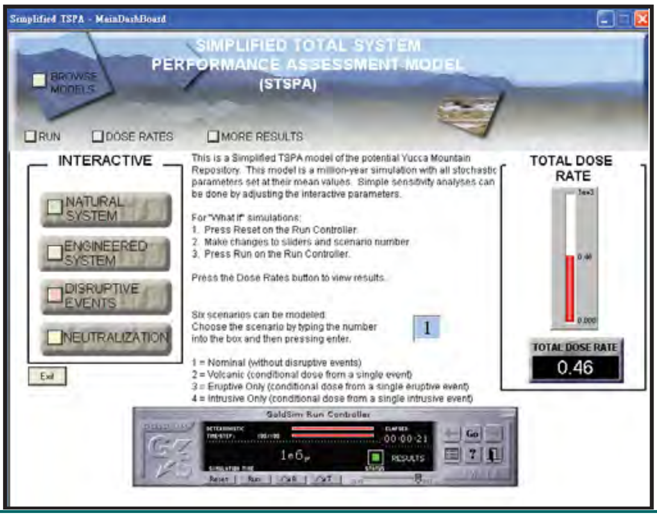
- **GoldSim-Dashboard application** → public communicate

(II) Developing representative assessment model for radwaste disposal

→ safety assessment in porous

GoldSim-Dashboard

Safety assessment model in GoldSim can transfer into a dashboard that let people to change parameters by themselves and gain the analysis result immediately. This can help people to increase their confidence of safety assessment.



Chen and Lai (2007)

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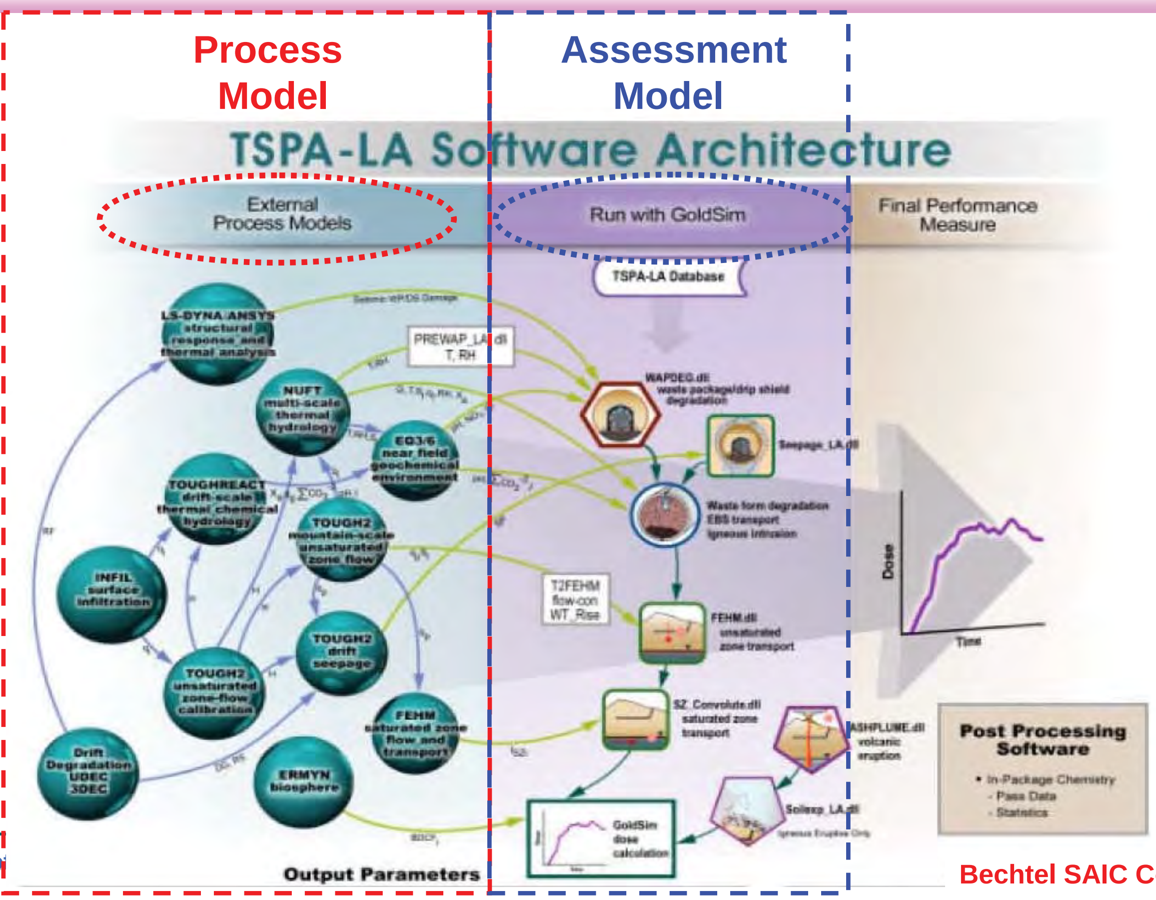
purposes

1. What relationship between process model and assessment model
2. How to develop a representative safety assessment model

(II) Developing representative assessment model for radwaste disposal

→ safety assessment in porous

Process v.s. Assessment Model



Bechtel SAIC Company (2003)

Process model V.S. assessment model

■ Process model

- Focus on performance assessment of partial system
- To gain material characteristics by software detail calculation or experiment
- FEHM : a finite element analysis software to simulate a saturated groundwater flow field and nuclide migration

■ Assessment model

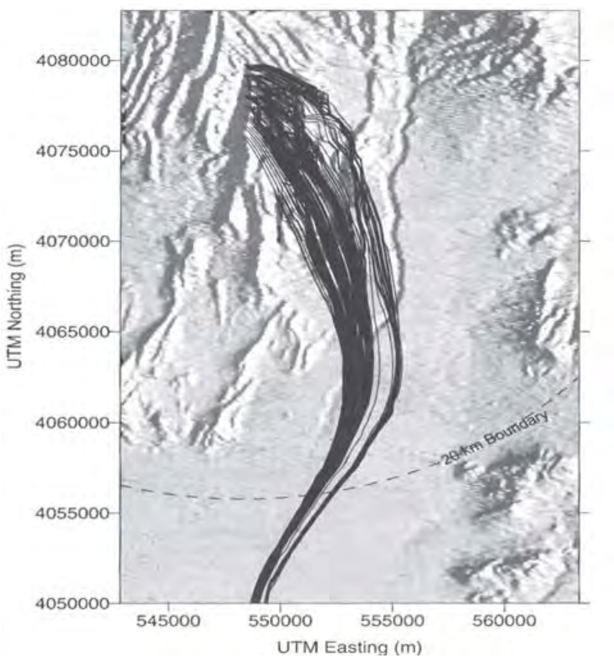
- Focus on probability analysis of total system
- Calculate potential max. dose rate (concentration) by multi-running
- GoldSim : a probability analysis software

Chen (2009)

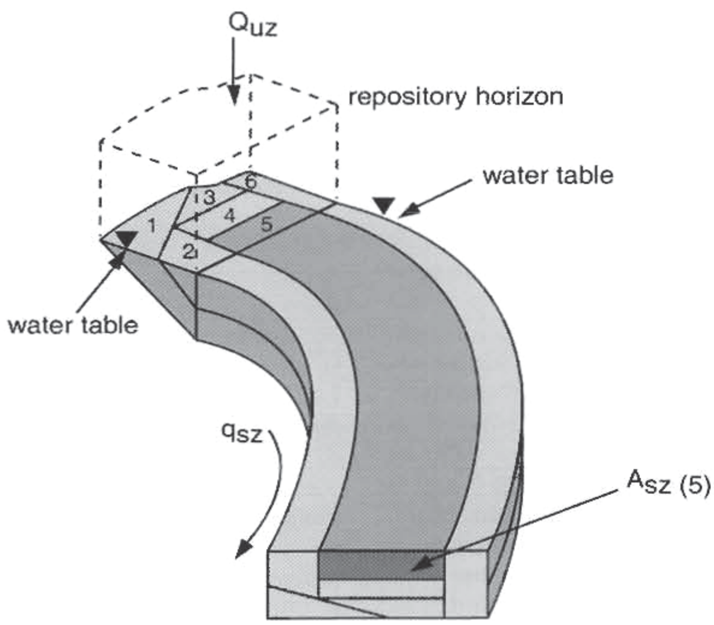
Key point of assessment model

- Assessment model can not simulate a complicate condition and get a accurate result. It just runs on many realizations of a simplified and representative model.
- How to construct a representative assessment model is a key point to perform a total system safety assessment.

Yucca Mt. Project



Particle tracking of nuclide migration in aquifer (FEHM)

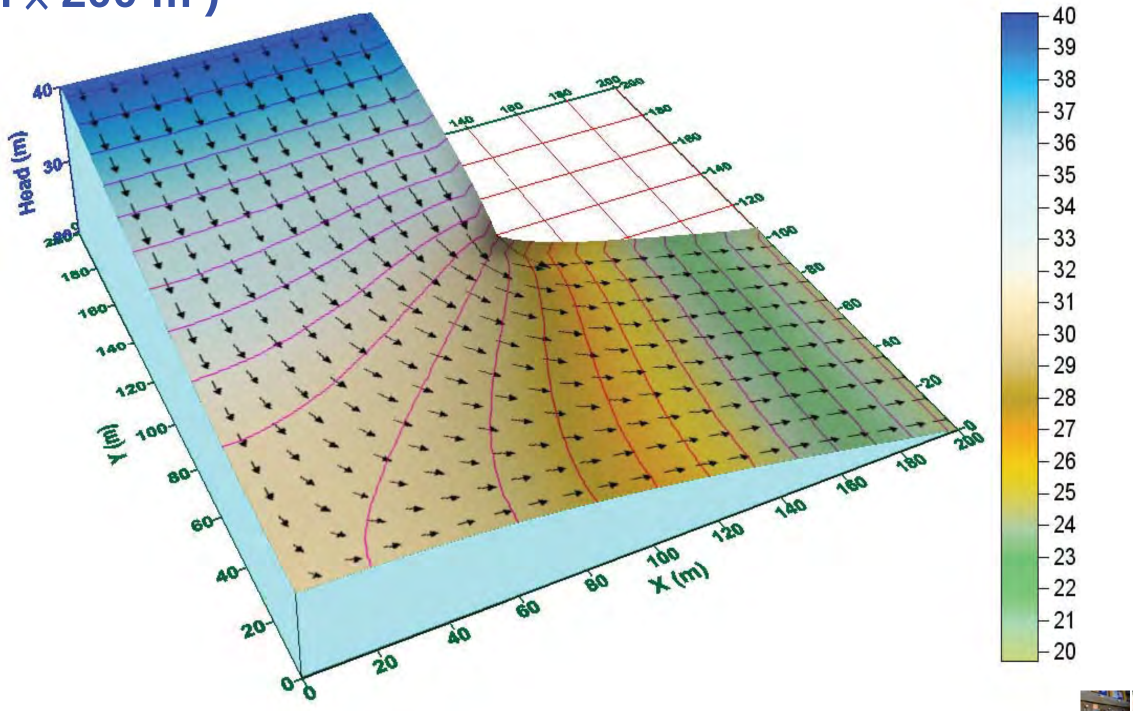


1-D nuclide transport (GoldSim)

DOE (1998)

FEHM process model

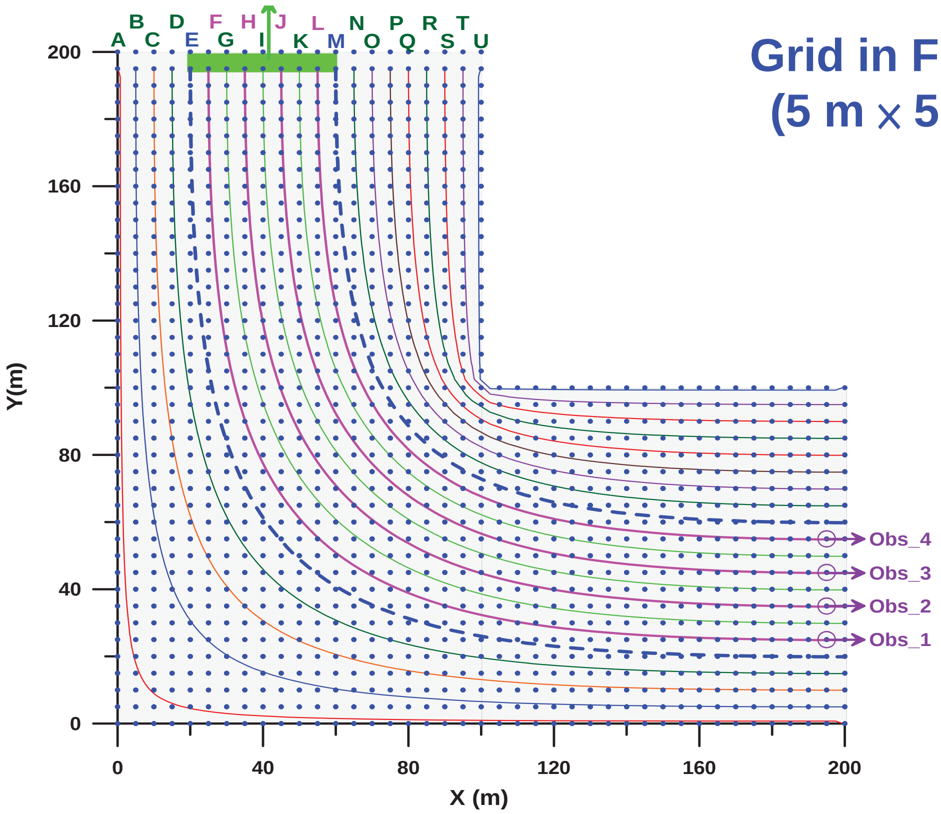
Hydrogeological model
(200 m × 200 m)



FEHM process model

Source(nuclides) - No decay

Grid in FEHM
(5 m × 5 m)



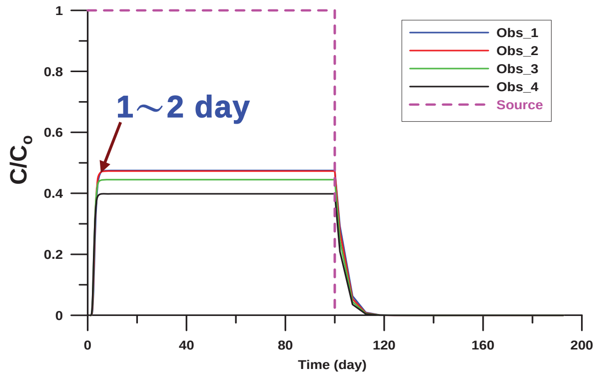
Particle tracking of FEHM

Flow line		F	H	J	L
Travel time (day)	Case A ($k=10^{-9}$ m^2)	2.066	1.778	1.553	1.369
	Case B ($k=10^{-10}$ m^2)	20.660	17.780	15.530	13.690
	Case C ($k=10^{-10.5}$ m^2)	41.320	35.560	31.070	27.380
	Case D ($k=10^{-11}$ m^2)	206.600	177.800	155.300	136.900
	Case E ($k=10^{-12}$ m^2)	2066.000	1778.000	1553.000	1369.000
	Case F ($k=10^{-12.5}$ m^2)	4132.000	3556.000	3107.000	2738.000
Path length (m)	Case A ～ Case F	297.8	278.2	260.8	244.8

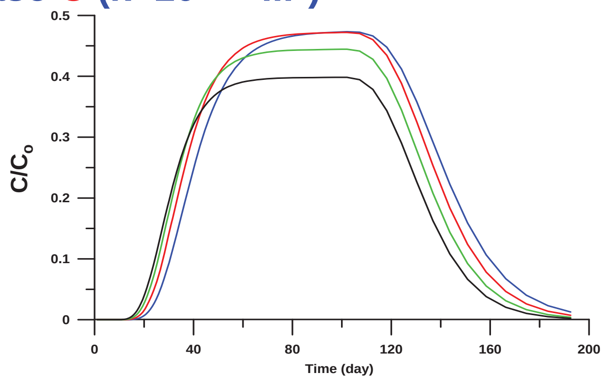
$$\text{velocity}(V) = \frac{k\,\rho\,g}{\mu}\cdot\frac{\Delta h}{\Delta L}$$

Concentrations

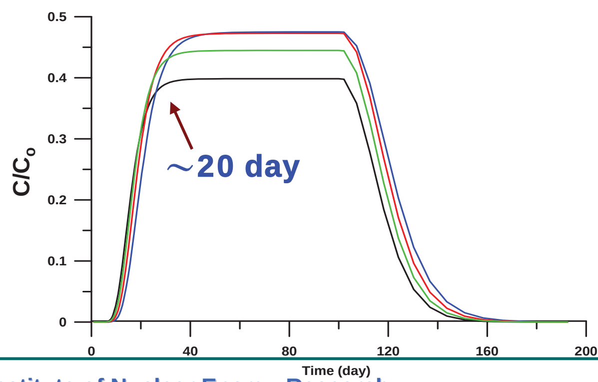
Case A ($k=10^{-9}$ m^2)



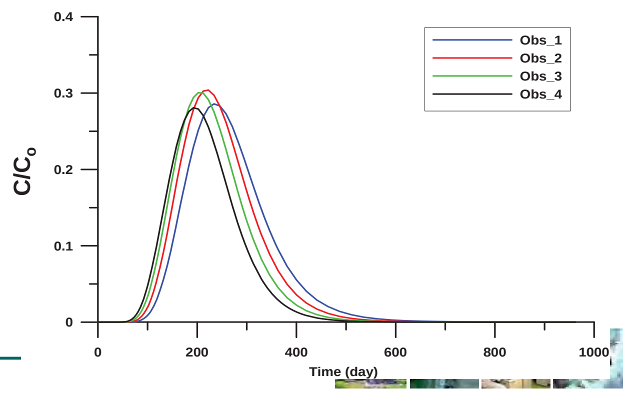
Case C ($k=10^{-10.5}$ m^2)



Case B ($k=10^{-10}$ m^2)



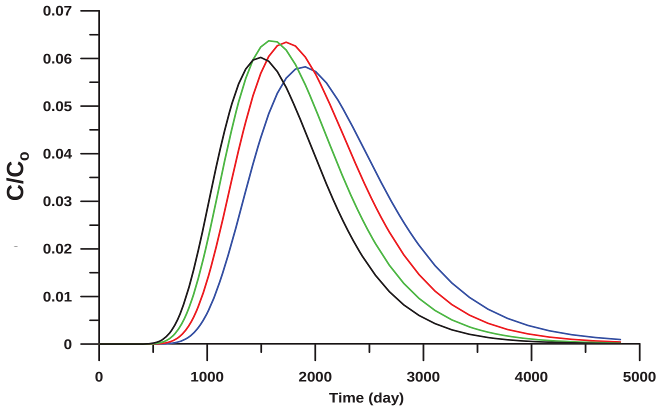
Case D ($k=10^{-11}$ m^2)

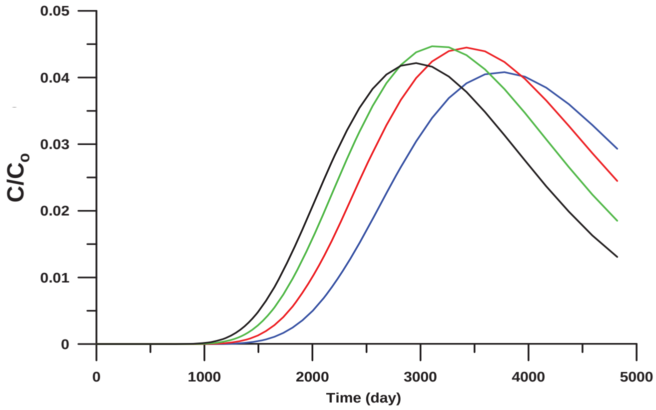


Concentrations

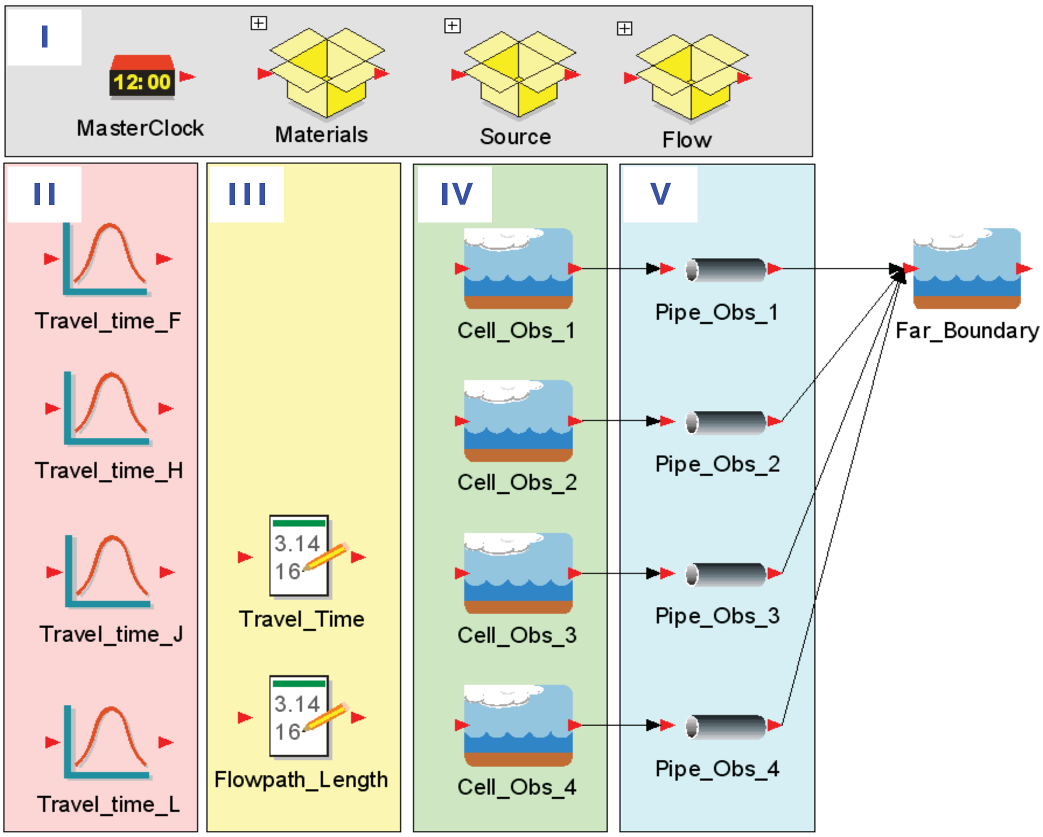
Case E (k=10^{-12} m²)

Case F (k=$10^{-12.5}$ m²)





GoldSim assessment model

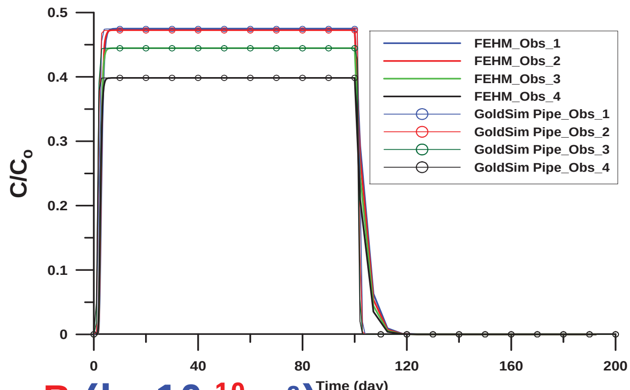


Modified cross section in Goldsim

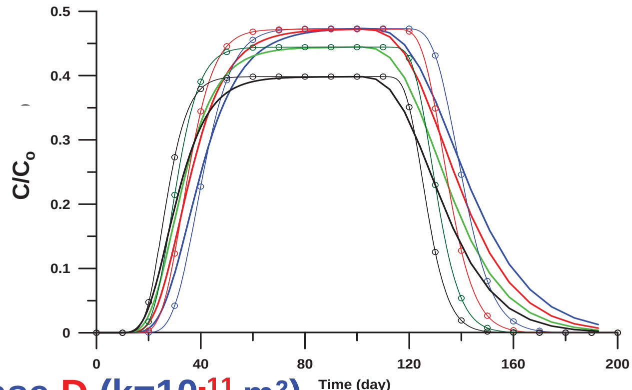
Pipe module		Pipe_Obs_1	Pipe_Obs_2	Pipe_Obs_3	Pipe_Obs_4
Cross section (m^2)	Case A ($k=10^{-9}$ m^2)	10.540	10.590	11.250	12.550
	Case B ($k=10^{-10}$ m^2)	10.500	10.500	11.300	12.500
	Case C ($k=10^{-10.5}$ m^2)	10.566	10.592	11.255	12.550
	Case D ($k=10^{-11}$ m^2)	13.000	13.100	14.000	15.700
	Case E ($k=10^{-12}$ m^2)	7.800	8.100	8.900	10.500
	Case F ($k=10^{-12.5}$ m^2)	5.570	5.770	6.383	7.467

Comparison of concentration

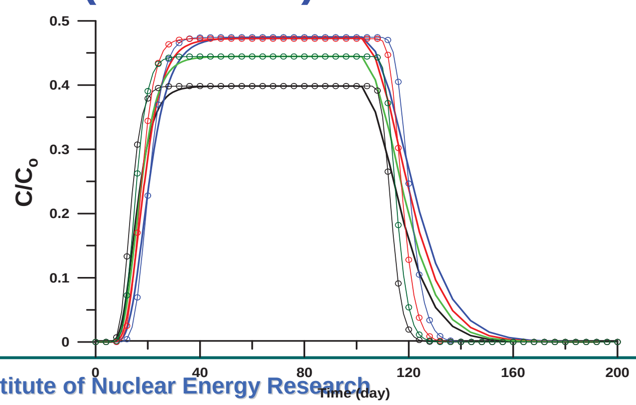
Case A ($k=10^{-9}$ m^2)



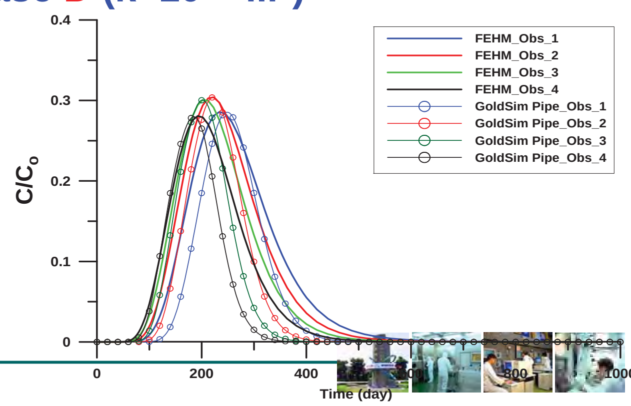
Case C ($k=10^{-10.5}$ m^2)



Case B ($k=10^{-10}$ m^2)

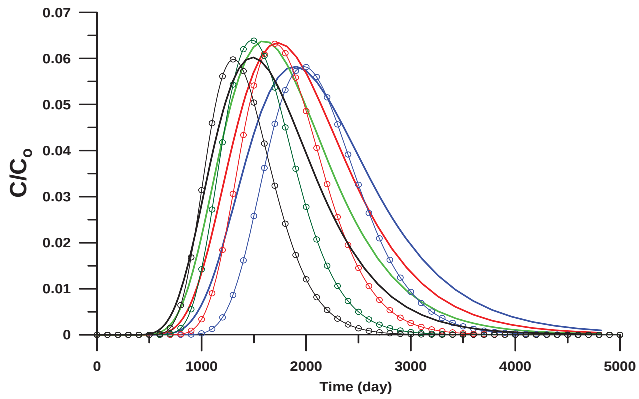


Case D ($k=10^{-11}$ m^2)

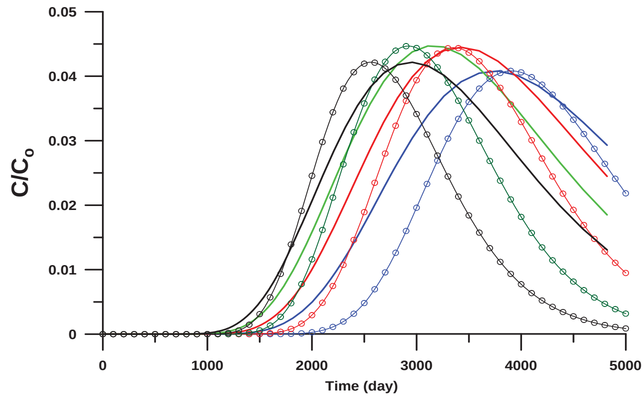


Comparison of concentration

Case **E** (k=10^{-12} m^2)

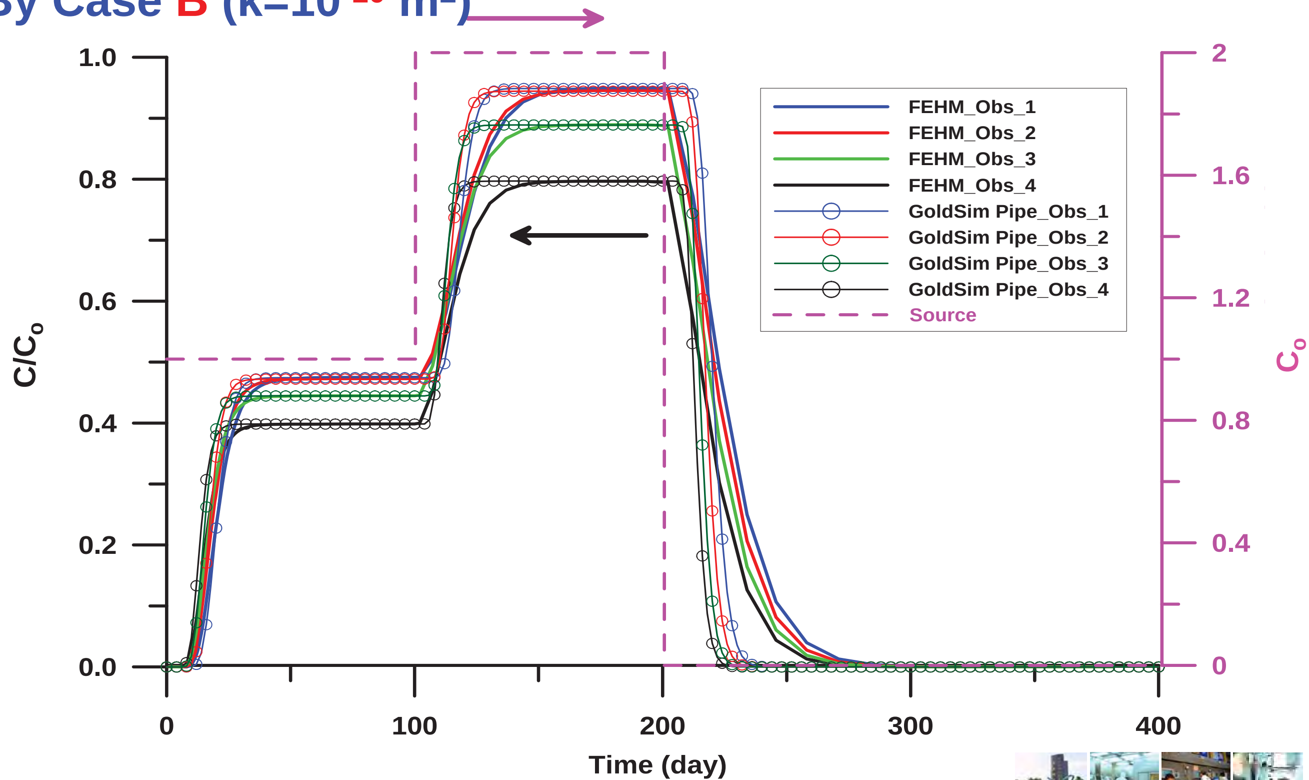


Case **F** (k=$10^{-12.5}$ m^2)



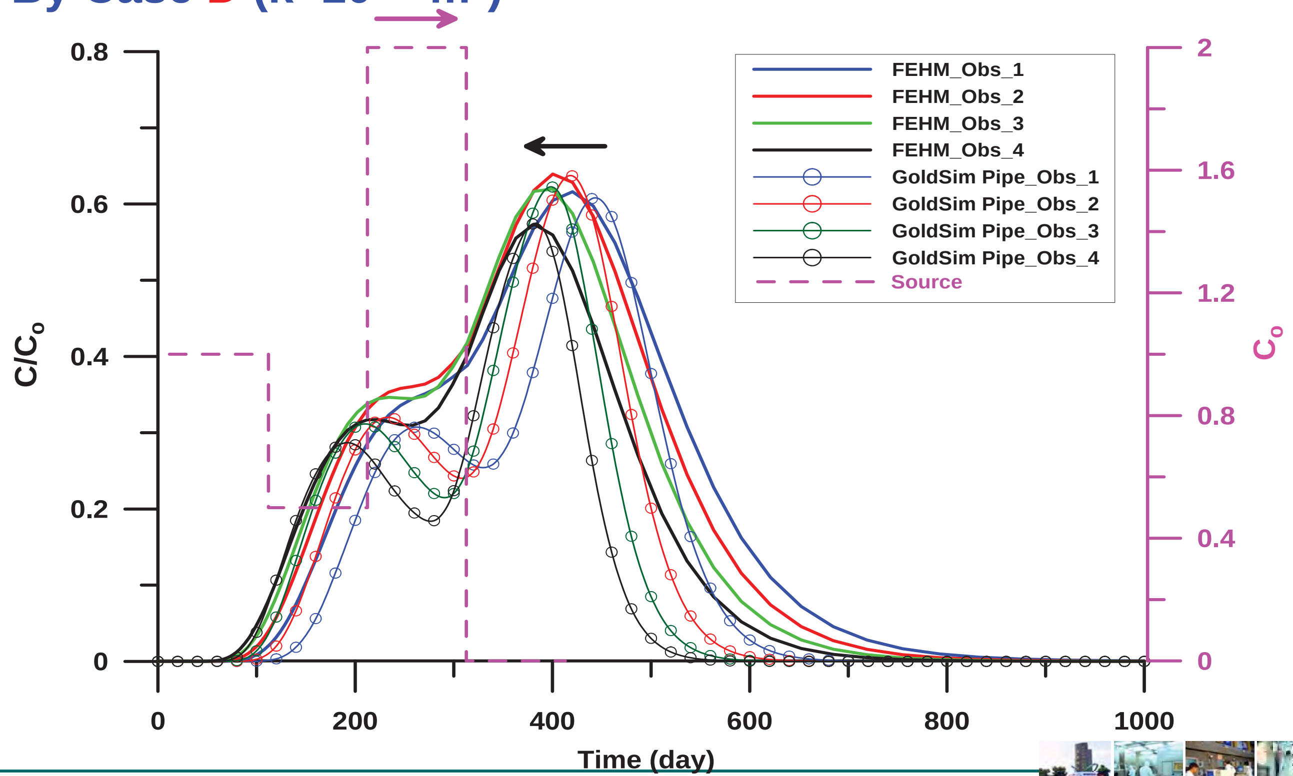
Verification

(1) By Case **B** (k=10^{-10} m^2)



Verification

(2) By Case D (k=10^{-11} m^2)



Representative ?

Process model (FEHM)

Hydrogeological parameters

- Conductivity
- GW velocity
- Dispersivity
- . . .

Observed position (Receptor)

Particle traveling time
Max. concentration

Assessment model (GoldSim)

Probability analysis

- Conductivity-Log normal distribution
- GW velocity -Uniform distribution
- Dispersivity -Log normal distribution
- . . .

Modified research

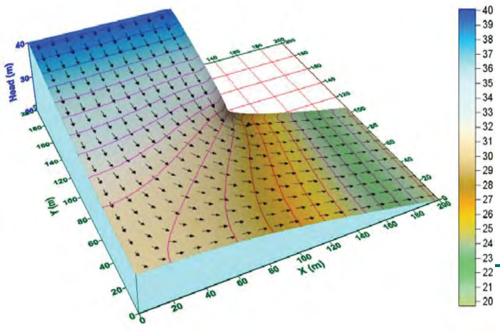
- Chen(2009) did not consider decay effect
- Each nuclide with different decay half-life. After migration, the nuclides concentration will be different because of decay effect.
- Does the assessment model of daughter nuclide (which is producted from its parent nuclide) be same with the assessment model of parent nuclide?

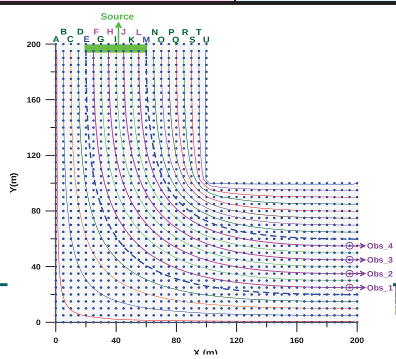
Co-60[5.27 yr]
Cs-137[30.04 yr]
Sr-90[28.74 yr] → Y-90[64.01 hr]
Pu-241[14.70 yr] → Am-241[432 yr] → Np-237[2.14×10^{6} yr]

Chen (2010)

Cross section- Case B ($k=10^{-10}$ m^2)

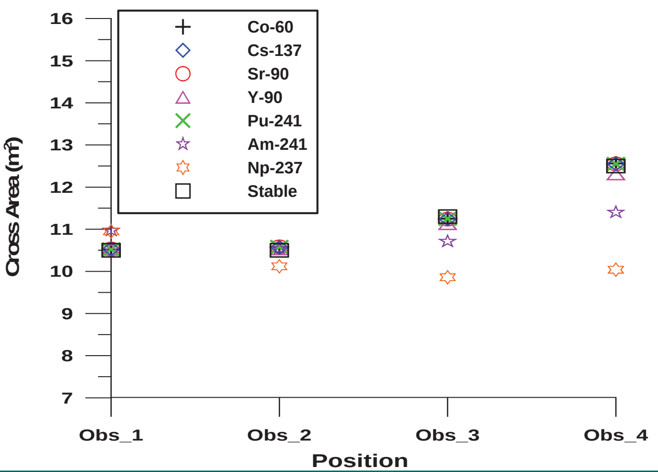
Nuclides	Half-life	Pipe_Obs_1	Pipe_Obs_2	Pipe_Obs_3	Pipe_Obs_4
Co-60	5.27 yr	10.52	10.58	11.25	12.56
Cs-137	30.04 yr	10.53	10.57	11.24	12.55
Sr-90	28.74 yr	10.53	10.58	11.24	12.55
Y-90	64.01 hr	10.52	10.53	11.13	12.31
Pu-241	14.70 yr	10.52	10.58	11.25	12.55
Am-241	432 yr	10.97	10.54	10.71	11.40
Np-237	2.14×10^{6} yr	10.95	10.12	9.86	10.04

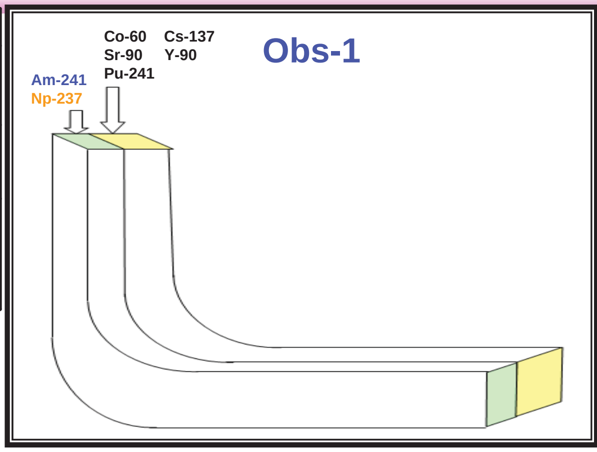


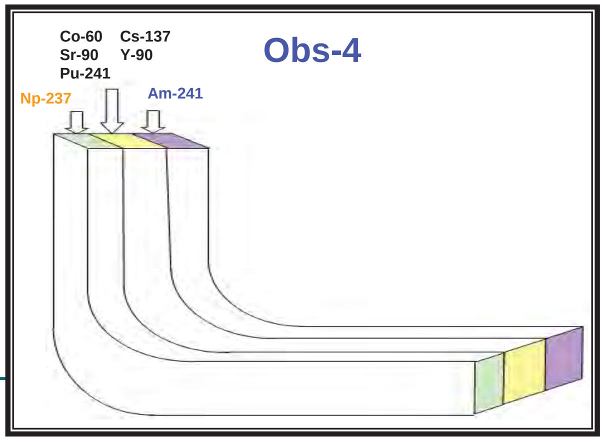


Model differences- Case B ($k=10^{-10}$ m^2)

nuclides	Half-life	Pipe_Obs_1	Pipe_Obs_2	Pipe_Obs_3	Pipe_Obs_4
Co-60	5.27 yr	10.52	10.58	11.25	12.56
Cs-137	30.04 yr	10.53	10.57	11.24	12.55
Sr-90	28.74 yr	10.53	10.58	11.24	12.55
Y-90	64.01 hr	10.52	10.53	11.13	12.31
Pu-241	14.70 yr	10.52	10.58	11.25	12.55
Am-241	432 yr	10.97	10.54	10.71	11.40
Np-237	2.14×10^{6} yr	10.95	10.12	9.86	10.04







Conclusion (4)

- Even it has different concentration distribution between process model (FEHM) and assessment model (GoldSim). But they have same maximum concentration value.
- GoldSim pipe module by justified cross section can simplify complicate process model of FEHM. It is validated by cases study to prove this methodology which can construct a representative assessment model.

References

- Bajracharya, K. and D.A. Barry, 1992, Mixing cell models for nonlinear equilibrium single species adsorption and transport, Journal of Contaminant Hydrology, Vol. 12, p.227-243.
- Bechtel SAIC Company, 2003, Total System Performance Assessment-License Application Methods and Approach,TDR-WIS -PA-000006 REV 00 ICN 01
- Chen, C.L., S.I. Su and Y.C. Liu, 2005, Verification and modification of the mass transfer pipe module in GoldSim, monthly journal of Taipower's engineering, vol.688, p.100-110. (In Chinese)
- Chen, C.L. and J.C. Lai, 2007, Application of Dashboard in GoldSim platform to Public Communication, Taipower Nuclear, Vol.295, p.26-38. (In Chinese)
- Chen, C.L. and J.C. Lai, 2008a, Study on compartment mass transport model(AMBER) and pipe mass transport model(GoldSim), Taipower Nuclear, Vol.302, p.28-43. (In Chinese)
- Chen, C.L. and J.C. Lai, 2008b, Development and Verification the simulation technology of Discrete Fracture Network in GoldSim platform, Taipower Nuclear, Vol.307, p.38-57. (In Chinese)
- Chen, C.L., 2009, Technology Verification of Develop Representative Assessment Model for Radioactive Waste Disposal, Taipower Nuclear, Vol.317 p.21-38. (In Chinese)
- Chen, C.L., 2010, Technical Development of Multiple Radioactive Nuclides Assessment Model for Radioactive Waste Disposal, monthly journal of Taipower's engineering, vol.750, pp.41-51. (In Chinese)
- Chen, C.L., 2012, Analysis of Character Difference of Cell Module and Pipe Module in GoldSim, monthly journal of Taipower's engineering, vol.762, pp.1-13. (In Chinese)

References

- DOE, 1998, Viability Assessment of a Repository at Yucca Mountain, Volume 3: Total System Performance Assessment, DOE/RW-0508/V3.
- JNC, 2005, H17: Development and management of the technical knowledge base for the geological disposal of HLW -- Knowledge Management Report, JNC TN1400 2005-022.
- Sardin, M., D. Schweich, F.J. Leij and M.T. Van Genuchten, 1991, Modeling the nonequilibrium transport of linearly interacting solutes in porous media: a review, Water Resources Research, Vol. 27, No.9, p.2287-2307.
- Shanahan, P. and D.R.F. Harleman, 1984, Transport in lake water quality modeling, Journal of Environmental Engineering, Vol. 110, No.1, p.42-57.
- Van Ommen, H.C., 1985, The "mix-cell" concept applied to transport of non-reactive and reactive components in soils and groundwater, Journal of Hydrology, Vol. 78, p.201-213.
- Wang, G.T. and S. Chen, 1996, A new model describing convective-dispersive phenomena derived by using the mixing-cell concept, Appl. Math. Modelling, Vol.20, p.309-320.

Thank you for your attention

M：JNFL 現況說明

M.1：Slides－Outline of JNFL Facilities

Outline of JNFL Facilities

December,2012

Uranium Enrichment Plant

- Start of Operation : March,1992
- Design Capacity : 1,500 tSWU/y
- Current Status :
  - ·Running Capacity 1,050 tSWU/y
- Building completion "Centrifuge Machinery Factory" (October,2009)
- "Advanced type of centrifuges" Start operation: December,2011
- Total production of enriched uranium 1,698tUF6 (as of November 30,2012)

Prospects for total demand of Japan in 2010; approx.5,800 tSWU

Low-Level Radioactive Waste Disposal Center

- Start of Operation : December,1992
- Design Capacity : 600,000 m^3 (equivalent to 3 million 200 liter drums)
- Current Status: (as of November 30,2012)
  - ·The number of drums are stored
  - No.1 approx. 147,000
  - No.2 approx. 103,000

Approx 650,000 drums in total are stored at Nuclear Power Stations in 2009

Vitrified Waste Storage Center

- Start of Operation : April,1995
- Design Capacity : 2,880 canisters
- Current Status :
  - ·Received 1,414 canisters (as of November 30,2012)
  - 1,310 canisters from France (Completed on March 31,2007)
  - 104 canisters from Britain

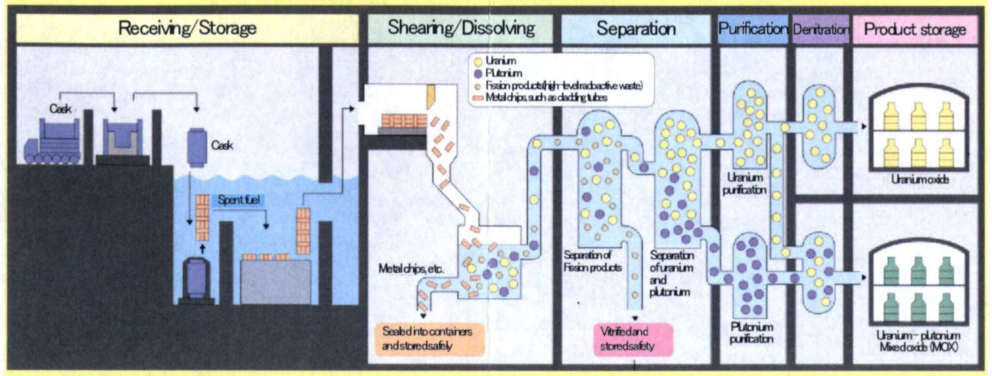
Spent Fuel Receiving and Storage Facility

- Start of Operation : December,1999
- Design Storage Capacity : 3,000 tU
- Current Status :
  - ·Receive 3,344tU S/F (Cumulative total) (as of October 31,2012)
  - ·Storing 2,919tU S/F (as of October 31,2012)

- ·Annual quantities of S/F discharged from Reactors in Japan; 900 - 1,000tU
- ·Approx 14,000tU S/F in total are stored at reactor sites as of March 31,2011

Reprocessing Plant (under final commissioning test)

- Reprocessing Capacity : Max.800 tU/y
- Expected Start of Commercial Operation October,2013
- Reprocessed 425tU S/F (Cumulative total)



MOX Fuel Fabrication Plant (MOX:Mixed Oxide Fuel)

- Design Capacity : Max.130 t-HM / y
- Number of employee : approx 300
- Start of construction : October2010
- Start of operation : March2016 (planned)