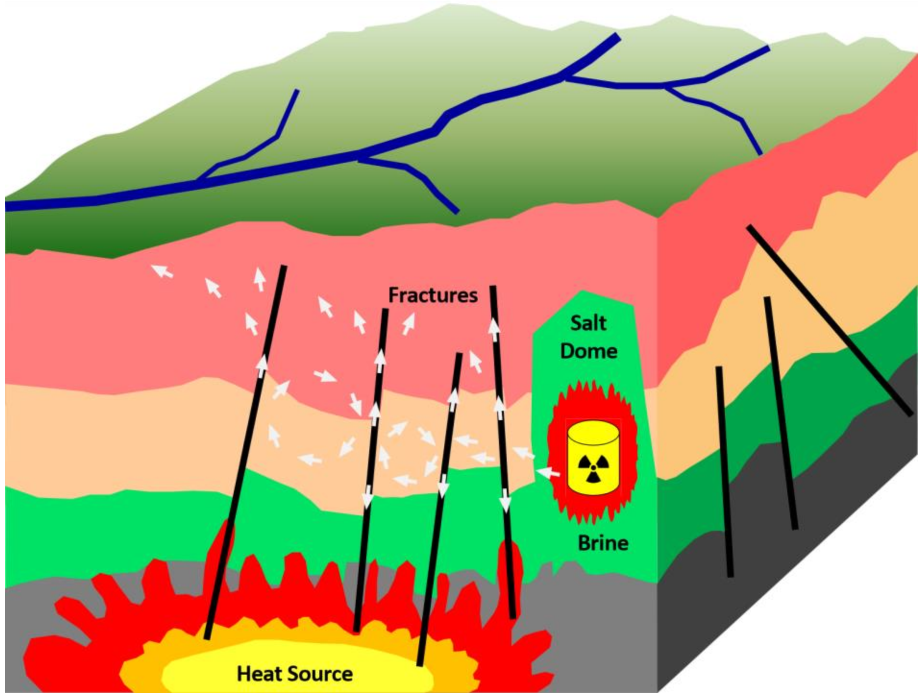
# Risk-based Assessment of Salt Domes as Disposal Sites for Nuclear Waste (RADON)

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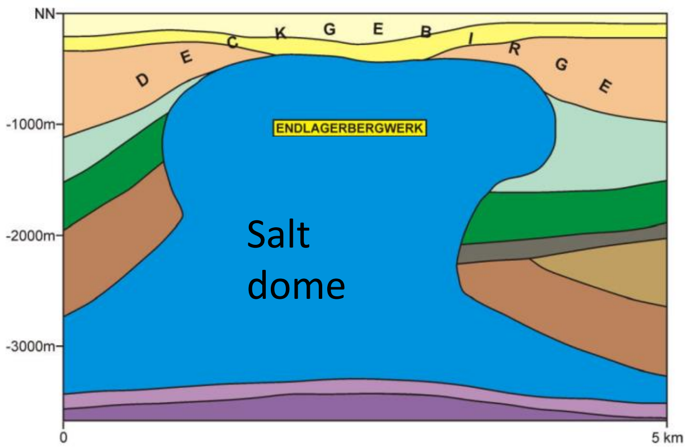
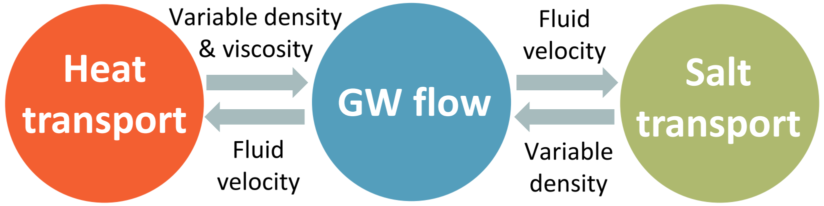
# RADON Project

**Goal**: Develop a **numerical framework** for **risk assessment** of hazardous events of a final nuclear waste deposit in salt dome

- Salt rock (salt domes) have been investigated intensively in Germany (Gorleben)
- Numerical model of radionuclide transport in far field
- Including Groundwater flow
- Including heat and salt transport with water density and viscosity effects
- Including fractured porous media

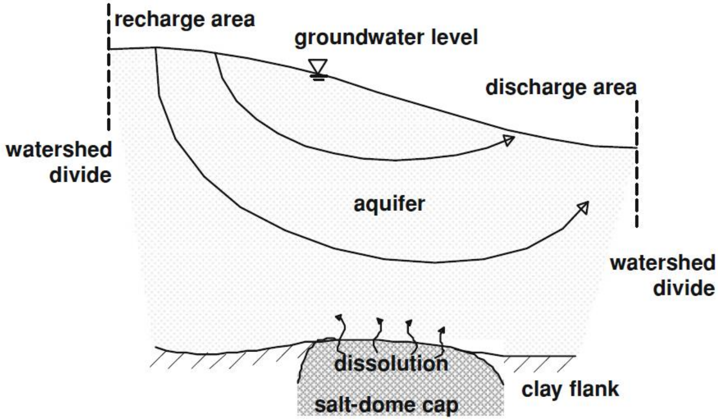



adapted from Brasser et al. 2008

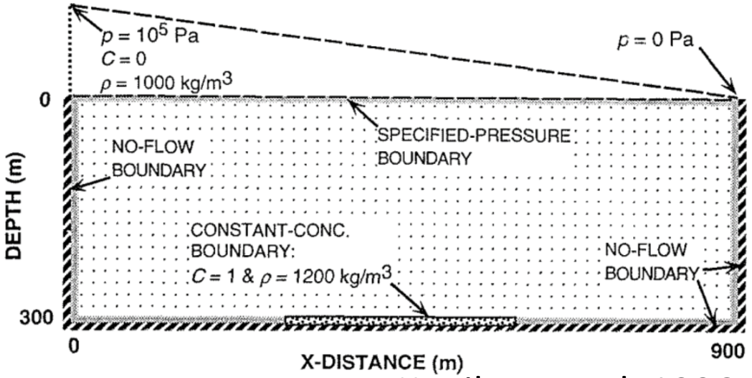


# Salt dome Problem

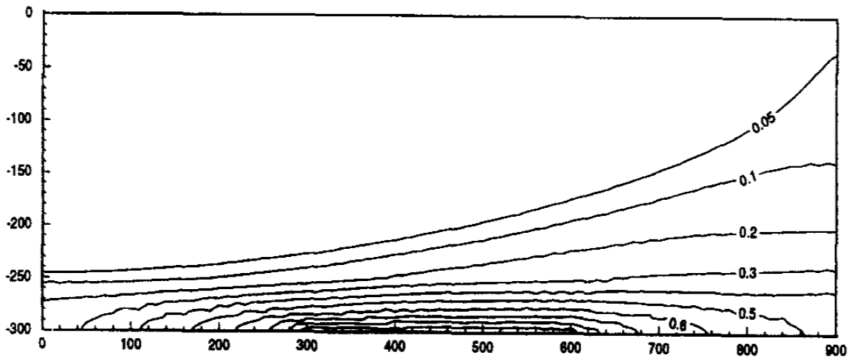
- Density-dependent flow benchmark problem for numerical codes
- Strong coupling of flow and transport (density variation of 20 %)
- Simplied hydrogeological situation above Gorleben saltdome
- Intensively investigated in the 80‘s and 90‘s (Herbert et al. 1988, Oldenburg and Pruess 1995, Kolditz et al. 1998, etc.)
- Different diffusion coefficients and long. & trans. dispersivities used




Holzbecher et al. 2010




Konikow et al. 1996




Kolditz et al. 1998

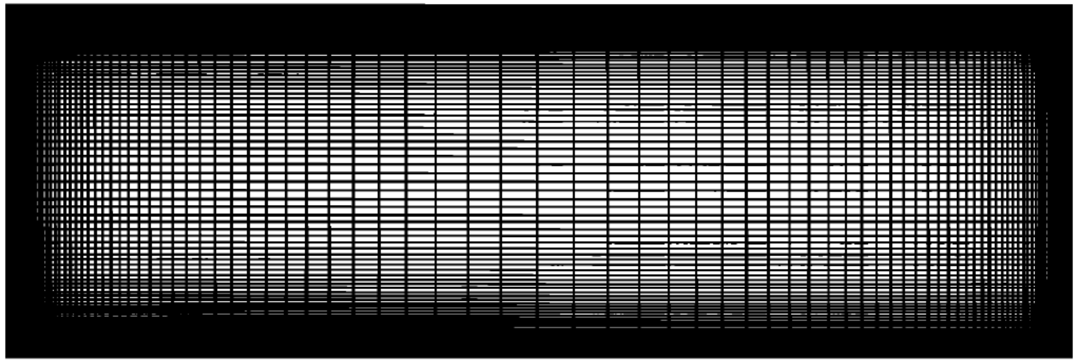
# Research objective

- Further investigate the salt dome problem in terms of **Groundwater age**
- Calculated as transport equation (steady state):
- $\frac{\partial}{\partial x_i}\left(D_{ij}\frac{\partial A}{\partial x_j}\right) - v_i\frac{\partial A}{\partial x_i} + 1 = 0$ (Goode 1996)
- Steady state flow velocities of salt dome problem solution as input for GW-age simulation

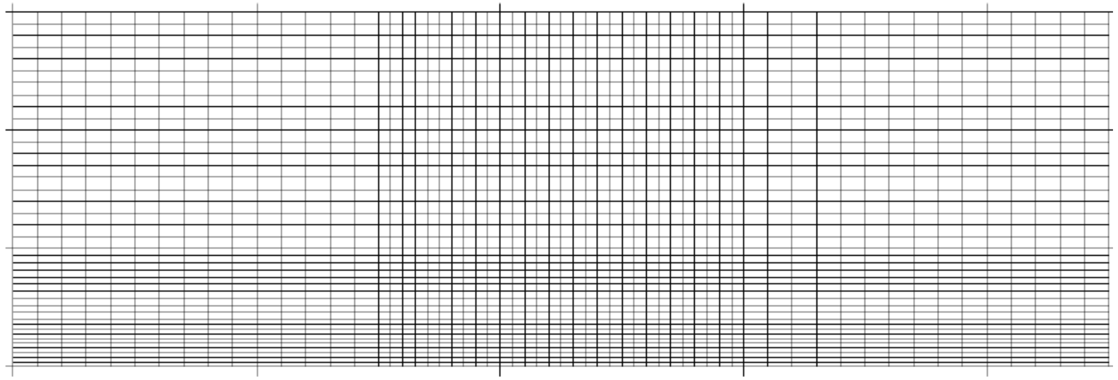
- Sensitvity of long. & trans. **dispersivity** on
  - original salt dome problem (salt concentration in model domain) and
  - GW-age distribution in model domain

# Salt dome Problem

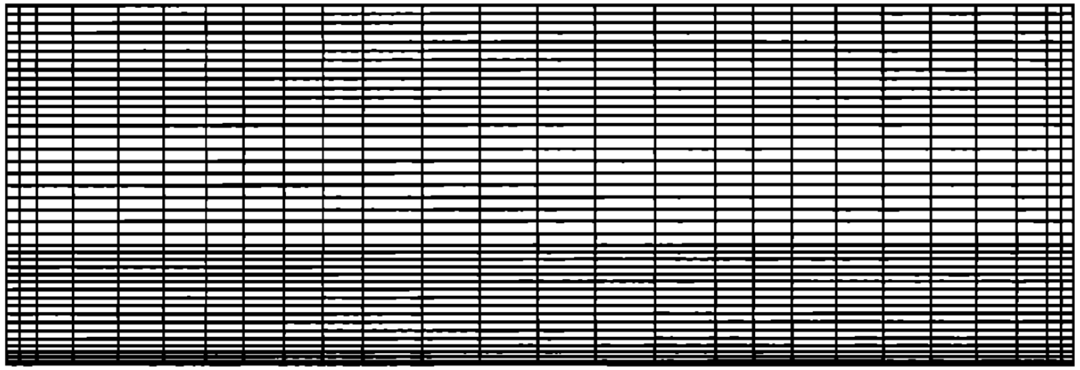
- very different meshes have been used
- systematical grid analysis has never been published



Johns and Rivera et al. 1996



Younes et al. 1999



Herbert et al. 1988

# Salt dome Problem – Grid analysis

- Graded meshes gave no consistent results
  - uniform mesh used here
- Assumption: aspect ratio of elements influences results
- Full grid convergence cannot be achieved
  - focus on specific element size in z-direction and investigate the effect of aspect ratio
- In literature: z-discretization of 4 m is sufficient for grid convergence

  (Konikow et al. 1996, Oldenburg and Pruess 1995, Younes et al. 1999)

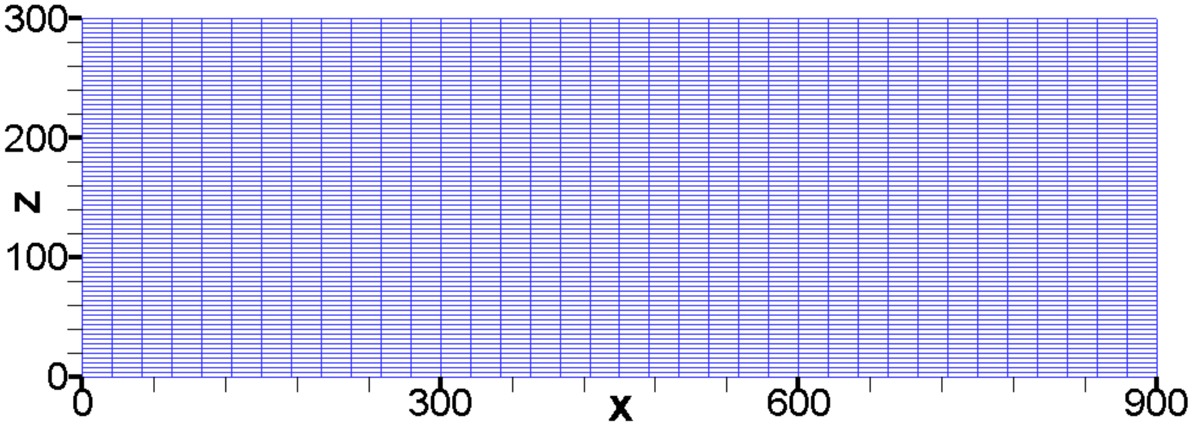
- Determine influence of aspect ratio by changing discretization in x-dimension ($\Delta z$ = 4m, 75 elements)
- Diffusion, Dispersion parameters: D = 1.39e8 $m^2/s$; $\alpha_L$ = 20 m; $\alpha_T$ = 2 m

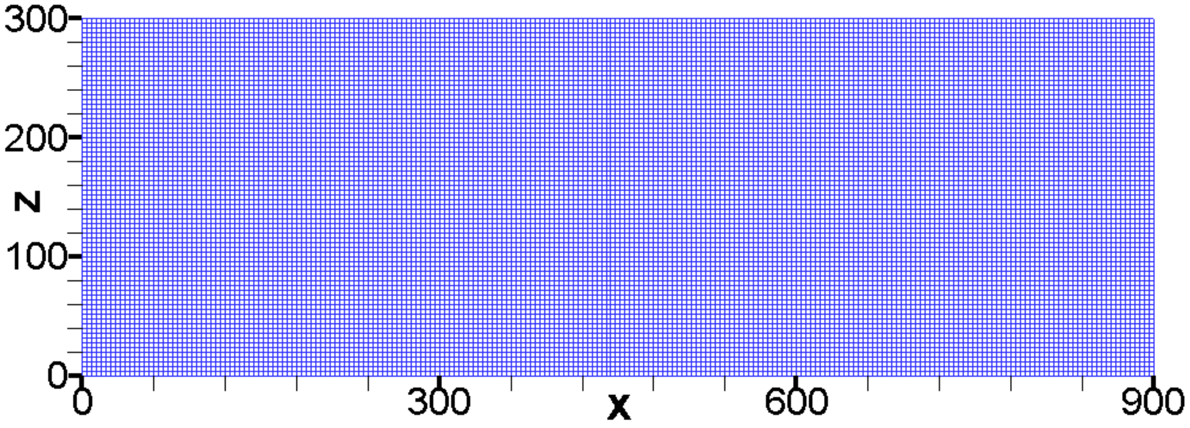
# Salt dome Problem – Grid analysis

- Stepwise reduction of aspect ratio from

**36 x-elements** (2700 in total) to **225 x-elements** (16875 in total)

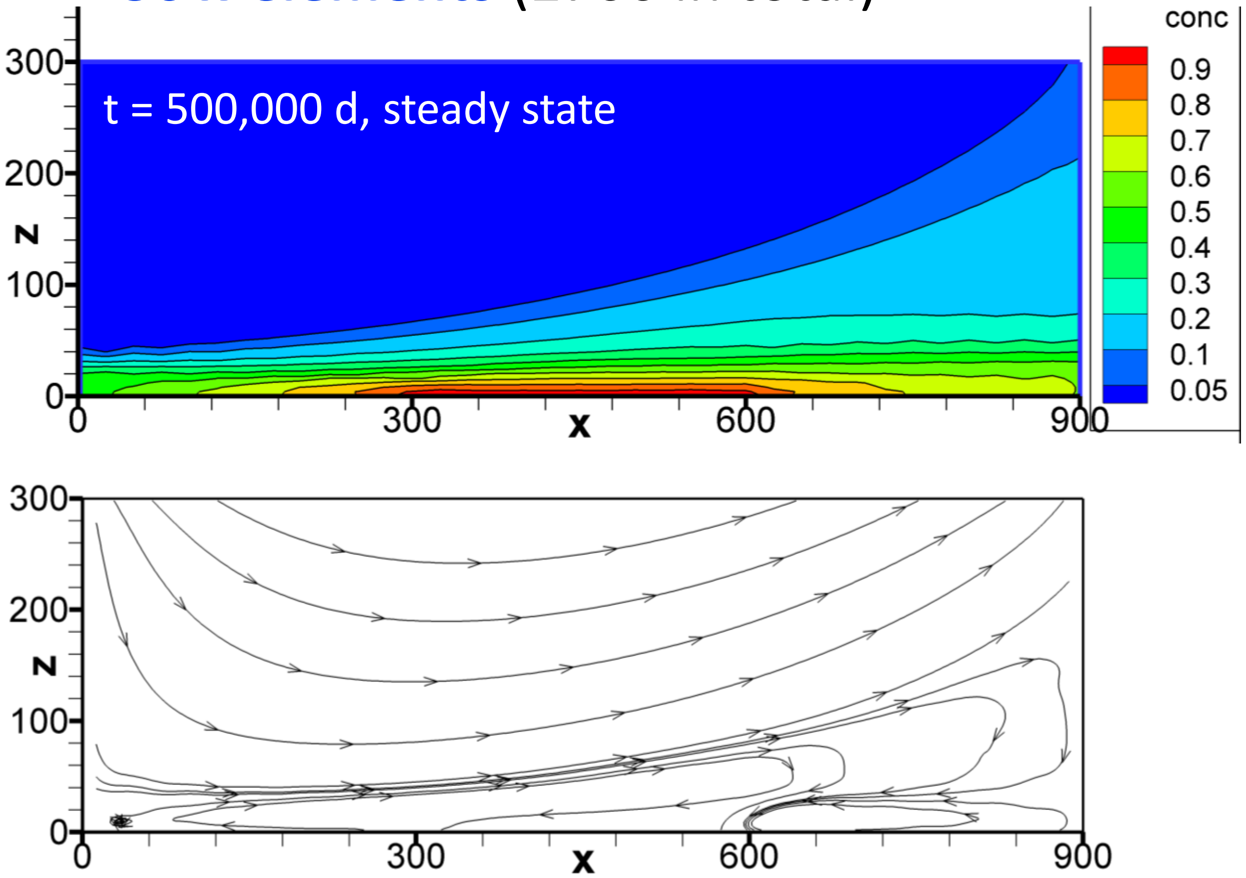
| 36 x-elements | 225 x-elements |
|---|---|
| Δx = 25 m | Δx = 4 m |
| Aspect ratio: 6.25 | Aspect ratio: 1 |



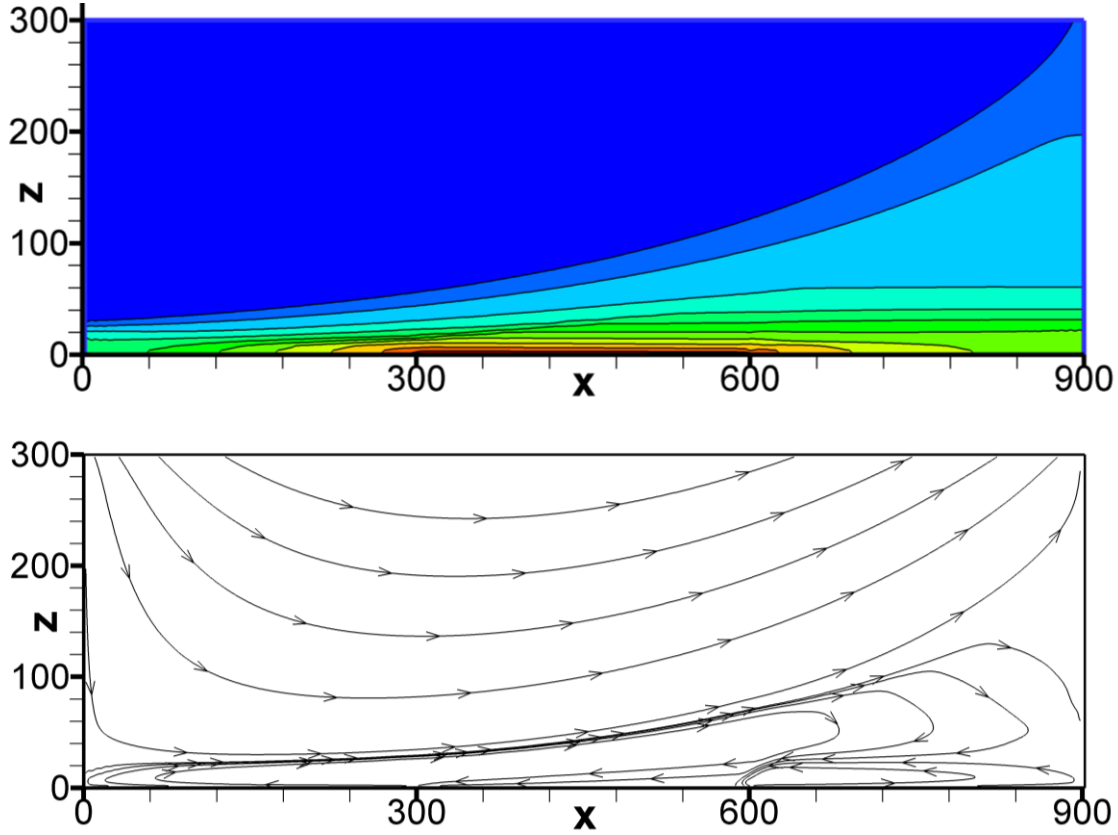



# Salt dome Problem – Grid analysis - Results

**36 x-elements** (2700 in total)

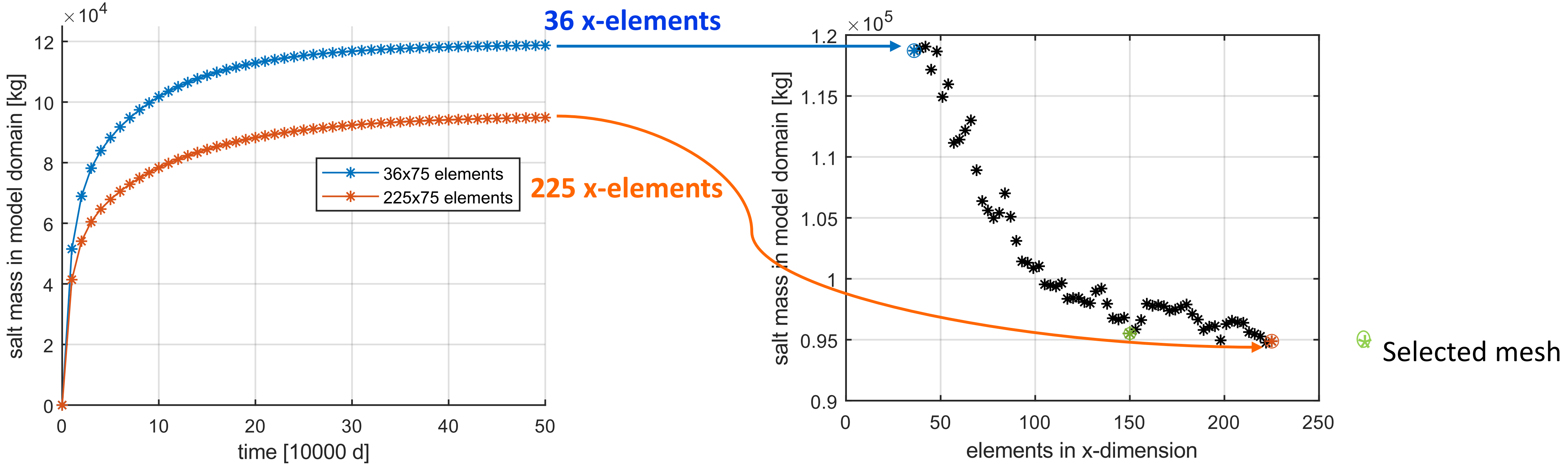



**225 x-elements** (16875 in total)



# Salt dome Problem – Grid analysis

- Results can be compared by total salt mass in model domain




- 150 elements in x-dimension (11250 in total) are chosen (0.79 % deviation in salt mass)
- Aspect ratio 1.5

# Salt dome Problem – Conclusions

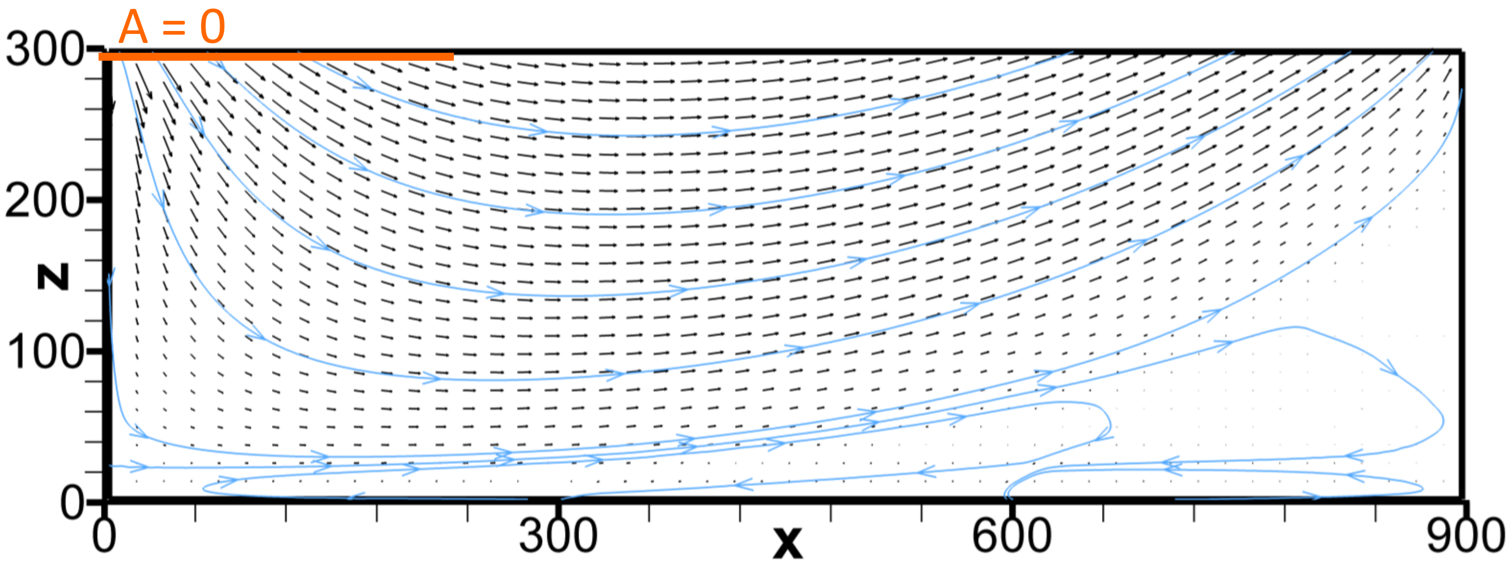
- No grid convergence archieved for discretization in x-dimension
- Clear tendency of reduced total salt mass in model domain for higher element number
- Slope of decreasing salt mass is high until up to ~ 100 elements
- From 100 – 225 elements tendency of gently decreasing salt mass

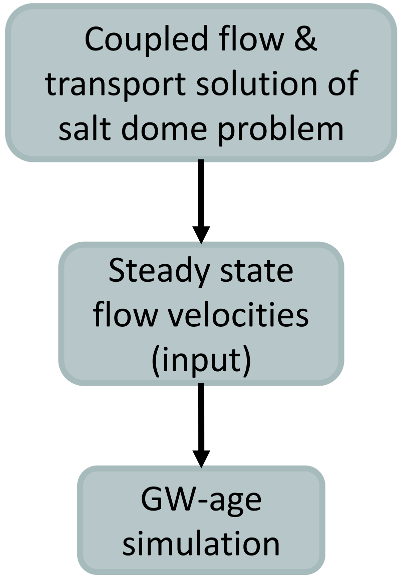
- Values fluctuates locally for all aspect ratios
- Grid dependency of solution is still present at aspect ratios around 1
- Highly complex flow regime, grid may influence the solution
- Grid dependency of density-dependent flow problem solution (as the Elder problem) is a possible explanation

# GW-age simulation - Set up

- GW-Age distribution for 150x75 elements (D = 1.39e8 $m^2/s$; $\alpha_L$ = 20 m; $\alpha_T$ = 2 m)

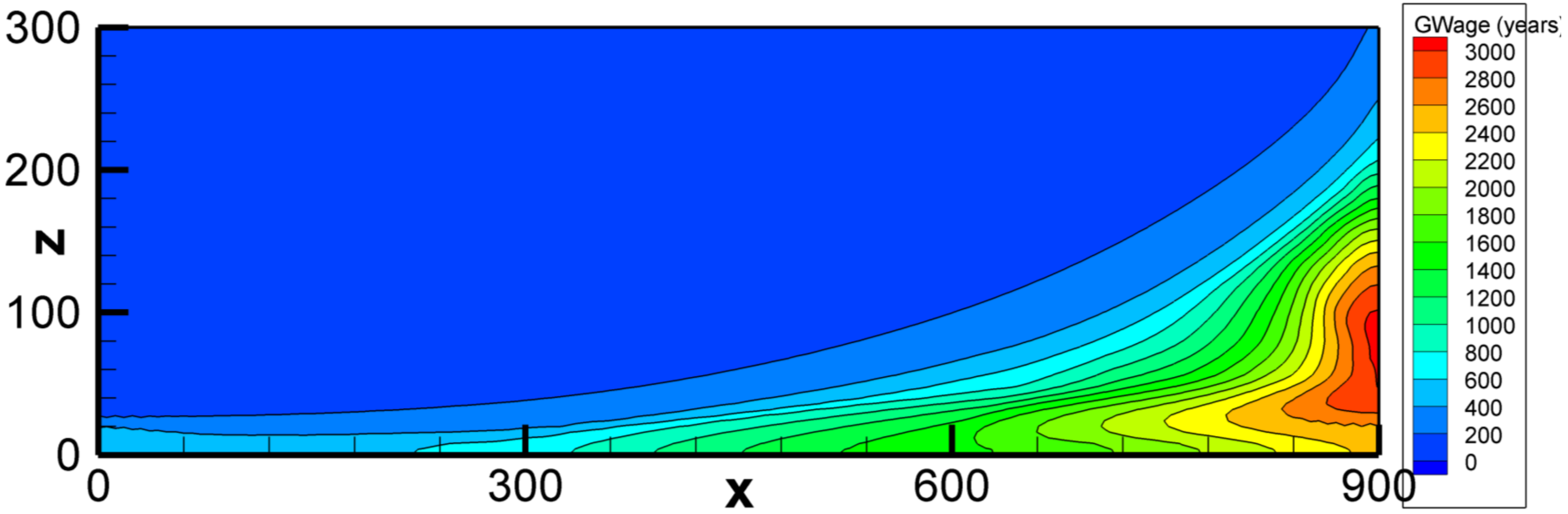
- Steady-state flow velocities as input:
- BC at inflow region: A = 0 (necessary)

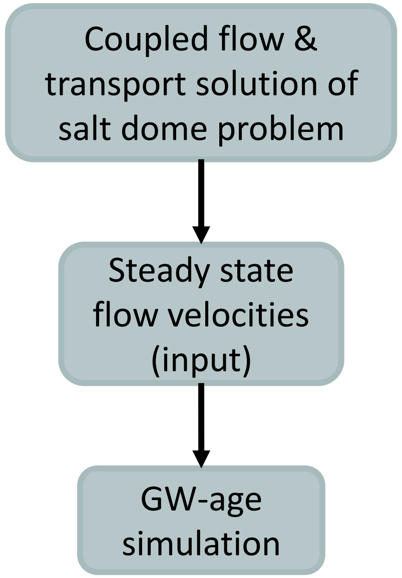


# GW-age simulation - Result

- GW-Age distribution for 150x75 elements (D = 1.39e8 $m^2/s$; $\alpha_L$ = 20 m; $\alpha_T$ = 2 m)




- High GW-age in zones with low flow velocities

# Outlook – Research objective 1

- Sensitvity of long. & trans. dispersivity on
  - Classic salt dome problem (salt concentration in model domain) and
  - GW-age distribution in model domain

- Dispersivities affect steady-state flow solution of salt dome problem (coupling of flow & transport)
- Dispersivities affect GW-age through flow solution and age transport
- Different GW-age distributions expected

# Outlook – Research objective 1

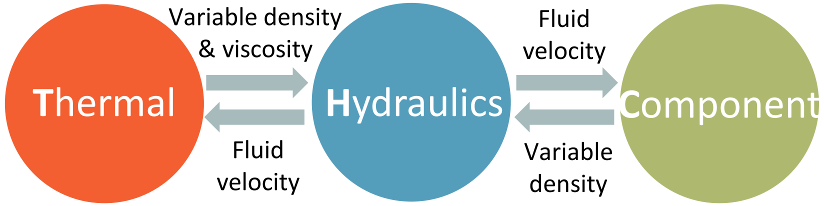
- Sensitvity of long. & trans. dispersivity
- Uncertainty ranges: $\alpha_L$ = [3 - 40] m; $\alpha_T$ = [0.3 - 4] m (scale-dependent)
- $\alpha_T$ as a Gaussian distribution with mean of 1/10 of $\alpha_L$
- **Monte-Carlo-Simulations** using Andrea‘s code

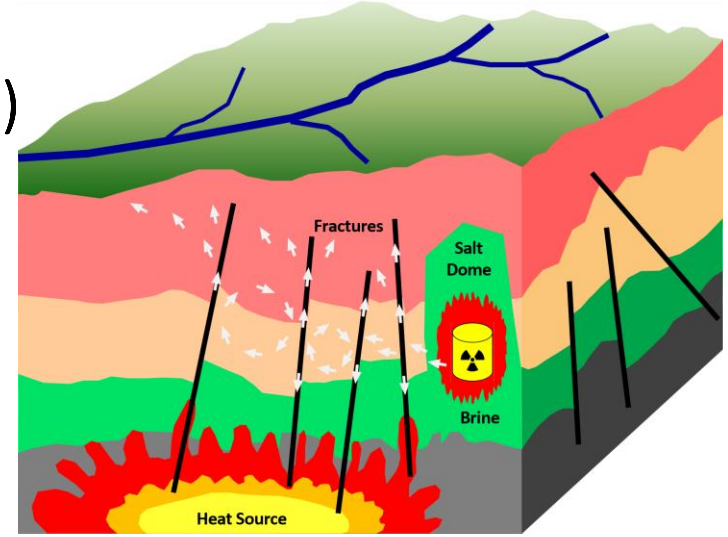
- Calculating first-order & total sensitivity (**Sobol‘ indices**) for characteristic single values
  - e.g. total salt mass, coordinate of specific salt conc. contour line
  - Mean & max. GW-age in model domain
- Marginal effects of parameters
- High variation of GW-age due to double dependency on dispersivities expected

# Outlook – Research objective 2

- Create 2D testcases including a salt dome and thermohaline effects for the simulation of radionuclide propagation through fractures surrounding rock

- Code adaptation of heatflow smoker (Molson & Frind 2023)
- Transport of a second species added (radionuclide)



# Literature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