Methodology of ANAlysis Unified and of management of risks of geological Storage of CO_2

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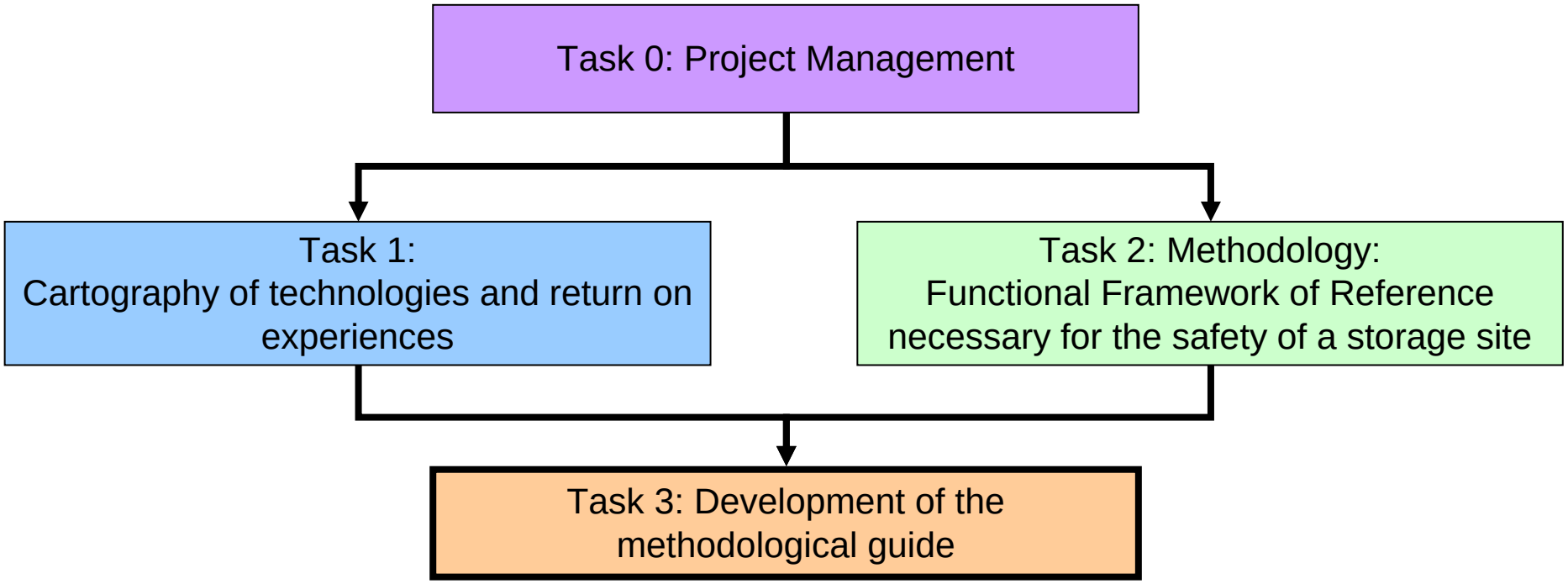
MANAUS - IEAGHG Risk Assesment Network - 21/06/2011

Project objectives

- MANAUS plan to develop a COMMON rational and operational methodology of analysis and of management of risks for the CO_2 geological storage within the French regulatory context.
- The project rely upon the partner experiences on modeling tools and risk analysis projects (R&D and industrials).

Project structure



Project planning

Tasks		2011 2	4	6	8	10	12
Task 0	Project Management						
	Project Management						
Task 1	Cartography of technologies and return on experiences						
sub-task 1.1	Cartography of technologies						
	Software of simulation of the storage						
	Software of management of uncertainties						
	Software of analysis of risks						
sub-task 1.2	Return on experiences from projects						
Task 2	Methodology: Functional Framework of Reference necessary for the safety of a storage site						
sub-task 2.1	Functional analysis of a storage complex						
	Geology (reservoirs, cap rock, overlying aquifers ...)						
	Well (ancient and well of the storage						
	Surface installations for injection						
sub-task 2.2	Identification of the scenarioes of risk and of faults						
sub-task 2.3	Development of a methodology of uncertainties management						
sub-task 2.4	Identification of potential impacts						
	Impacts in surface						
	Impacts in geosphere						
Task 3	Development of the methodological guide						
sub-task 2.4.2	Methodological guide						

Objective of the project: Develop of a reference framework (Task 3)

for Industrial CO_2 Storage Developments and Operations

Methodological Guide

- Review of tools and methods for risk analysis
- Functional analysis for a storage
- Risk and failure scenarios for a CO_2 geological storage
- Uncertainty management for the different scenarios
- Potential impacts potentials
- Guidelines for risk analysis of a geological storage

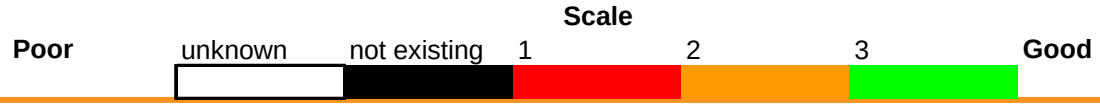
Task 1 : Cartography of technologies and return on experiences

Task 1.1

- Cartography of tools and available methods and analysis of their functionality
  - Task aimed at appraising of software technologies and methods used to map risks according to scenarios for a project
  - A particular attention will be carried on complementarily technologies within the consortium

Qualitative analysis (strengths/weaknesses) of flow modeling software

- DESCRIPTION OF THE GOVERNING PRINCIPLE
- INPUT - EXPECTED OUTPUT
- INTERFACE
  - Friendliness Interface
  - Communication with Geological Modeling software
- PHYSICS of CO_2
  - Compositional Modeling
  - Dynamic temperature
  - Dynamic salinity
  - Dissolution CO2 + impurity in the water
  - Modification of the properties of the water by dissolved CO2 (density, viscosity)
  - Hysteresis Kr&PC
  - Modeling of Salting Out/Drying Out
  - Mineral geochemistry interaction with the rock and k-phi change.
  - PVT Modeling
- WELL
  - Well model / VLP
  - Non Darcy Flow
- BOUNDARY CONDITIONS
  - Numerical aquifer
  - non-neighbor connections
  - Definition of pressure boundary conditions
- CO_2 BALANCE
  - Flux line (lease line)
  - Region definition
- HISTORY MATCH
  - Management uncertainty / sensitivity
  - Wedging debit and pressures
- MISCELLANEOUSES
  - User Guide, Reference manual
  - Cost
  - Speed CPU



Preliminary Results: commercial flow modeling codes

Scale

Poor — unknown — not existing — 1 — 2 — 3 — Good

Critère	A	B	C	D	E
INTERFACE					
Convivialité Interface					
Communication avec Petrel					
Modélisation Compositionnelle Gaz					
PHYSIQUE CO2					
Température dynamique					
Salinité dynamique					
Dissolution CO2 + impuretés dans l'eau avec Constante d'équilibre = F(T, P,S)					
Modification des propriétés de l'eau par CO2 dissous (densité, viscosité)					
Hysteresis Kr&PC					
Modélisation du SaltingOut					
Géochimie minérale Interaction avec la roche et changement k-phi….					
Modélisation PVT					
PUITS					
Modèle puits/VLP					
Non Darcy Flow					
CONDITIONS LIMITES					
Aquifères numériques					
Non neighbor connections					
Définition de Condition Limite en pression					
BILAN CO2					
Ligne de flux (lease line)					
Region					
CALAGE HISTORIQUE					
Gestion incertitude / sensibilité					
Calage débit et pressions					
Divers					
Modélisation Géoméca					
User Guide, Ref man					
Coût					
Rapidité CPU					

Preliminary Results: research flow & reactive transport codes

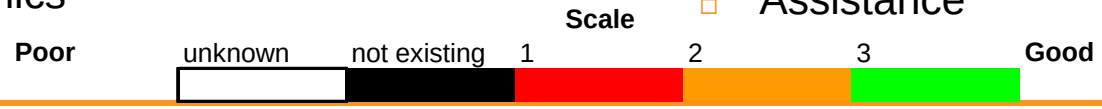
Scale

Poor — unknown — not existing — 1 — 2 — 3 — Good

Critère	A	B	C	D	E
INTERFACE					
Convivialité Interface					
Communication avec Petrel					
Environnement Windows XP64					
Modélisation Compositionnelle Gaz					
PHYSIQUE CO2					
Température dynamique					
Salinité dynamique					
Dissolution CO2 + impuretés dans l'eau avec Constante d'équilibre = F(T, P,S)					
Modification des propriétés de l'eau par CO2 dissous (densité, viscosité)					
Hysteresis Kr&PC					
Modélisation du SaltingOut					
Géochimie minérale Interaction avec la roche et changement k-phi….					
Modélisation PVT					
PUITS					
Modèle puits/VLP					
Non Darcy Flow					
CONDITIONS LIMITES					
Aquifères numériques					
Non neighbor connections					
Définition de Condition Limite en pression					
BILAN CO2					
Ligne de flux (lease line)					
Region					
CALAGE HISTORIQUE					
Gestion incertitude / sensibilité					
Calage débit et pressions					
Divers					
Modélisation Géoméca					
User Guide, Ref man					
Coût					
Rapidité CPU					
Assistance					

Qualitative analysis (strengths/weaknesses) of geomechanical modeling software

- INTERFACE
  - Friendliness Interface
  - Pre / post treatment tools
- LAW of BEHAVIOUR
  - Poro-elastic law
  - Plastic law adapted to porous media
  - Damaging law
  - Big distortion
  - Time dependent effects (fluage, etc.)
  - Possibility of including new laws
- COUPLED PHYSICAL PROCESSES
  - Mechanical, hydraulic
  - Mechanical, hydraulic with gaseous phase
  - Mechanical, hydraulic, thermal
  - Dynamics
- EXTERNAL CONNECTIONS
  - Ease of communication with an external code
  - Include mechanical effect of another physical process
- DISCONTINUITIES (faults, fractures, …)
  - Discreet hydromechanical Elements
  - Spread of fissures
  - Dual porosities / permeabilities
- SPACE HETEROGENEITIES
  - Properties of materials
- MISCELLANEOUSES
  - Easiness of development
  - Employ Guide, Ref man
  - Cost
  - Speed CPU
  - Assistance



Preliminary Results: commercial geomechanics codes

Scale

Poor — unknown — not existing — 1 — 2 — 3 — Good

Critère	A
INTERFACE	
Convivialité Interface	
Outils de pré / post traitement	
LOI de COMPORTEMENT GEOMATRIAUX	
Loi poro- élastique	
Loi plastique adaptée aux milieux poreux	
Loi d'endommagement	
Grande déformation	
Effets dépendants du temps (fluage, etc.)	
Possibilité d'intégrer de nouvelles lois	
PROCESSUS PHYSIQUES COUPLES	
Mécanique, hydraulique	
Mécanique, Hydraulique, Thermique	
Dynamique	
CHAINAGE EXTERNE	
Facilité de communication avec un code externe	
Intégrer l'effet mécanique d'un autre processus physique	
DISCONTINUITES (failles, fractures,…)	
Eléments discrets hydromécaniques	
Propagation des fissures	
Milieux continus double porosités / double perméabilités	
HETEROGENEITES SPATIALES	
Propriétés des matériaux	
Divers	
Facilité de développement	
User Guide, Ref man	
Coût	
Rapidité CPU	
Assistance	

Preliminary Results: research geomechanics codes

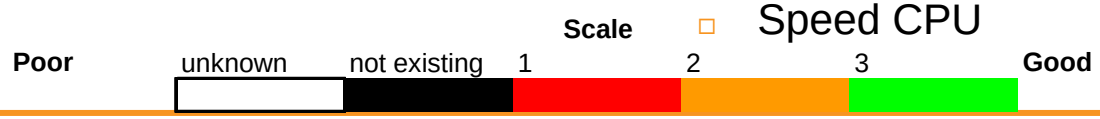
Scale

Poor — unknown — not existing — 1 — 2 — 3 — Good

Critère	A	B
INTERFACE		
Convivialité Interface		
Outils de pré / post traitement		
LOI de COMPORTEMENT GEOMATERIAUX		
Loi poro- élastique		
Loi plastique adaptée aux milieux poreux		
Loi d'endommagement		
Grande déformation		
Effets dépendants du temps (fluage, etc.)		
Possibilité d'intégrer de nouvelles lois		
PROCESSUS PHYSIQUES COUPLES		
Mécanique, hydraulique		
Mécanique, hydraulique avec phase gazeuse		
Mécanique, Hydraulique, Thermique		
Dynamique		
CHAINAGE EXTERNE		
Facilité de communication avec un code externe		
Intégrer l'effet mécanique d'un autre processus physique		
DISCONTINUITES (failles, fractures,...)		
Eléments discrets hydromécaniques		
Propagation des fissures		
Milieux continus double porosités / double perméabilités		
HETEROGENEITES SPATIALES		
Propriétés des matériaux		
Divers		
Facilité de développement		
User Guide, Ref man		
Coût		
Rapidité CPU		
Assistance		

Qualitative analysis of methods and software for uncertainty analysis

- INTERFACE
  - Friendliness Interface
- DATA MODEL
  - Statistical treatment
  - Definition of laws / correlations
  - Non probabilistic approaches
- PHYSICAL MODEL
  - Compatibility with external physical codes
  - Possibility of defining an analytical physical model
  - Meta-models
  - Design of Experiment
- ANALYSIS IN CENTRAL TENDENCY
  - Analysis of distribution
  - Sensitivity analysis
- ANALYSIS OF RELIABILITY
  - Methods of simulation
  - Methods of approximations
- METHODS OF ASSISTED HISTORY MATCHING / REDUCTION OF UNCERTAINTIES BY DATA INTEGRATION
  - Methods of determinist inversion
  - Methods of probabilistic inversion
- MISCELLANEOUSES
  - User Guide, Reference manual
  - Database
  - Cost
  - Speed CPU



Preliminary Results: commercial methods and codes for uncertainty analysis

Scale

Poor unknown not existing 1 2 3 **Good**

Glossaire	A	B	C	D
INTERFACE				
Convivialité Interface				
Modèle de données				
Traitement statistique				
Définition des lois / corrélations				
Approches non probabilistes				
Modèle Physique				
Compatibilité avec des codes physiques externes				
Possibilité de définir un modèle physique analytique				
Méta-modèles				
Plans d'expériences				
Analyse en tendance centrale				
Analyse de distribution				
Analyse de sensibilité				
Analyse de fiabilité				
Méthodes de simulations				
Méthodes d'approximations				
Méthodes de calage assisté/ réduction des				
Méthodes d'inversion déterministe				
Méthodes d'inversion probabiliste				
DIVERS				
User Guide, Ref man				
Base de données				
Coût				
Rapidité CPU				

Preliminary Results: research methods and codes for uncertainty analysis

Glossaire	A	B
INTERFACE		
Convivialité Interface		
Modèle de données		
Traitement statistique		
Définition des lois / corrélations		
Approches non probabilistes		
Modèle Physique		
Compatibilité avec des codes physiques externes		
Possibilité de définir un modèle physique analytique		
Méta-modèles		
Plan d'expériences		
Analyse en tendance centrale		
Analyse de distribution		
Analyse de sensibilité		
Analyse de fiabilité		
Méthodes de simulations		
Méthodes d'approximations		
Méthodes de calage assisté/ réduction des		
Méthodes d'inversion déterministe		
Méthodes d'inversion probabiliste		
DIVERS		
User Guide, Ref man		
Base de données		
Coût		
Rapidité CPU		

Analysis (assets/limitations) of methods and tools for risk analysis

Name Method / tool
AMDE (C) (analysis of modes of failure and their effects (and from their criticity))
HAZOP. (Hazards and Operability Study), possibly preceded by HAZID
Trees of faults
Trees of events
Knot butterfly
ARAMIS (MIMAH)
ARAMIS (RISK INDEX)
QRA (Quantitative Risk Assessment): SAFETI-NL
QRA transport (Quantitative Risk Assessment: France, UNO)
SIGALEA
TOTAL
OSQAR, for example within method EVARISTE
APR (preliminary analysis of risks) and SMA
CFA
What-If or SWIFT (structural technical what-yew tree)
LOPA (Layer of Protection Analysis)
MOSAR (Method organised for systematic analysis of risk)
Asphalès (cf above)
Indicator FEI (fire and explosion index) from Dow
Matrix of risk (ex: ARAMIS, regulation French study of danger)

Name Method / tool
HACCP (Hazard Analysis and Critical Control Points)
MCA / MAUT
ERS (study of health risks)
Coefficient of danger (CD) or Indication of Risk (IR)
Excess of unit risk (ERI)
IEM (Interpretation of the State of Circles)
FEPS (Feature, Events, Processes) or databases " learning from experience"
Cards of vagaries of type PPRM (and other cartographiés tools)
ELECTRE (for the mining sites)
Certification Framework
QRTT (quantitative Risk Through Time)
Cumulative Distribution Functions
SIMEO-STOR
SIMEO-ERM

Task 1.2 Return on experiences

- Return on experiences of the partners on the previous project (CO_2 storage, Oil&Gas, Underground Gas Storage)
  - French R&D, EU
  - US / CANADA RCSP
  - Australia
  - Other

Methods developed/used in various projects

- $CRISCO_2$ – BRGM (Bouc *et al.*, 2010, 2011) ;
- Méthodologie Analyse de risques des projets CCS – Oxand (Botnen *et al.*, 2010 ; Dias *et al.*, 2010) ;
- Méthodologie P&R – Oxand (Le Guen *et al.*, 2008, 2009, 2010 ; Meyer *et al.*, 2009 [a], 2009 [b]) ;
- Démarche Geogreen utilisée pour divers projets commerciaux ;
- Démarche Battelle (Sminchak *et al.*, 2006) ;
- CASSIF – TNO (Yavuz *et al.*, 2009) ;
- Certification Framework – Lawrence Berkeley National Laboratory (Oldenburg *et al.*, 2009 [a], 2009 [b], 2011 ; Dodds *et al.*, 2011) ;
- CO_2PENS – Los Alamos National Laboratory (Stauffer *et al.*, 2009, 2011 ; Viswanathan *et al.*, 2008 ; Pawar *et al.*, 2006) ;
- Démarche Quintessa (Paulley *et al.*, 2011) ;
- RISQUE – CO_2 Cooperative Research Centre (Bowden et Rigg, 2004 ; Dodds *et al.*, 2011 ; Sharma et Cook, 2007 ; Hooper *et al.*, 2005 ; Chevron Australia, 2005) ;
- Decatur Project – Schlumberger (Hnottavange-Telleen *et al.*, 2009, 2011) ;
- Screening and Ranking Framework – Lawrence Berkeley National Laboratory (Oldenburg *et al.*, 2005, 2008) ;
- Approche scenarios – TNO (Wildenborg *et al.*, 2004 ; Svensson *et al.*, 2005) ;
- Vulnerability Evaluation Framework – USEPA (USEPA, 2008 ; Bacanskas *et al.*, 2009) ;
- Early phase risk and uncertainty assessment method – DNV (Sollie *et al.*, 2011).

Synthesis of the Results

The analysis focused among others on the type of the method (site ranking, scenarios construction, scenario appraisal, and vulnerability appraisal) and the functionalities / limits of the method used

	Qualitative	Quantitative		Semi-quantitative	
		Determinitic	Probabilistic	Determinitic	Probabilistic
Site selection	1				
Scenario design	7				
Scenario analysis	1	1	3	3	5
Vulnerability analysis	1				

	Type of storage project	
	R&D	Industrial
Site selection		2
Scenario design	6	1
Scenario analysis	10	3
Vulnerability analysis	1	2

	Site selection Phase	early project design phase	Licencing phase	Operational phase
Operator	8	11	8	8
Regulator			9	9

Task 2 : Methodology: Functional Framework of Reference necessary for the safety of a storage site

Task 2.1 Functional Analysis of a storage complex

- Description of sites and their components (reservoir, cap rock, faults, wells, …), and the safety function of the different components.
- Constitution of a conceptual model which will include different (typical) cases

Task 2.2 Risk scenario Identification: normal and failure modes

- Realistic risk scenario of the storage considering the life cycle of the storage will consider the design evolution and the failure modes based upon the functional analysis

Task 2.3 Uncertainty assessment methodology

- Identify and adapt the best suited methods
- Guide lines for uncertainties management

Task 2.4 Identify the potential impacts

- In coherence with conceptual model and functional analysis, identify the different potential impacts on human and environment, linked to migrations of :
  - CO_2
  - additional substances, mobilized by migration or by disturbances led by injection (e.g. presence of impurity, displacement of brine).

Methodology of ANAlysis Unified and of management of risks of geological Storage of CO_2 (Phase 1)

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