Idaho National Engineering and Environmental Laboratory

Methodology for Conducting Probabilistic Risk Assessment of CO_2 Sequestration in Coal Beds

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Fossil Energy Technologies
Idaho National Engineering & Environmental Laboratory

INEEL
Home of Science and Engineering Solutions

Funding Source

Joint Industry Project (JIP) for

Next Generation CO_2 Capture & Geological Sequestration

JIP Member List

DOE, European Union, BP, ChevronTexaco, Den Norske Stats Oljeselskap AS, ENI S.p.A., Norsk Hydro ASA, Pancanadian Resources, Shell, Suncor Energy

Project Goal

- Provide a methodology acceptable to regulators and the public alike by which to conduct a meaningful probability based risk assessment of CO_2 injection and storage in coal beds.
  - The work will develop the necessary knowledge, tools, and strategies for risk evaluation, risk mitigation, and monitoring and verification.
  - The work will be conducted within the context of an actual field demonstration of the technology at BP's Tiffany field.

Outline

- Background Information
- Tiffany Project Overview
- Risk Analysis Methodology

CO_2 Sequestration in Geologic Formations

- Oil & Gas Reservoirs
  - EOR*
  - Depleted oil & gas reservoirs
  - Reservoir pressure maintenance*
- Saline Aquifers
- Coal Beds
  - Enhanced coal bed methane recovery*

* income generating

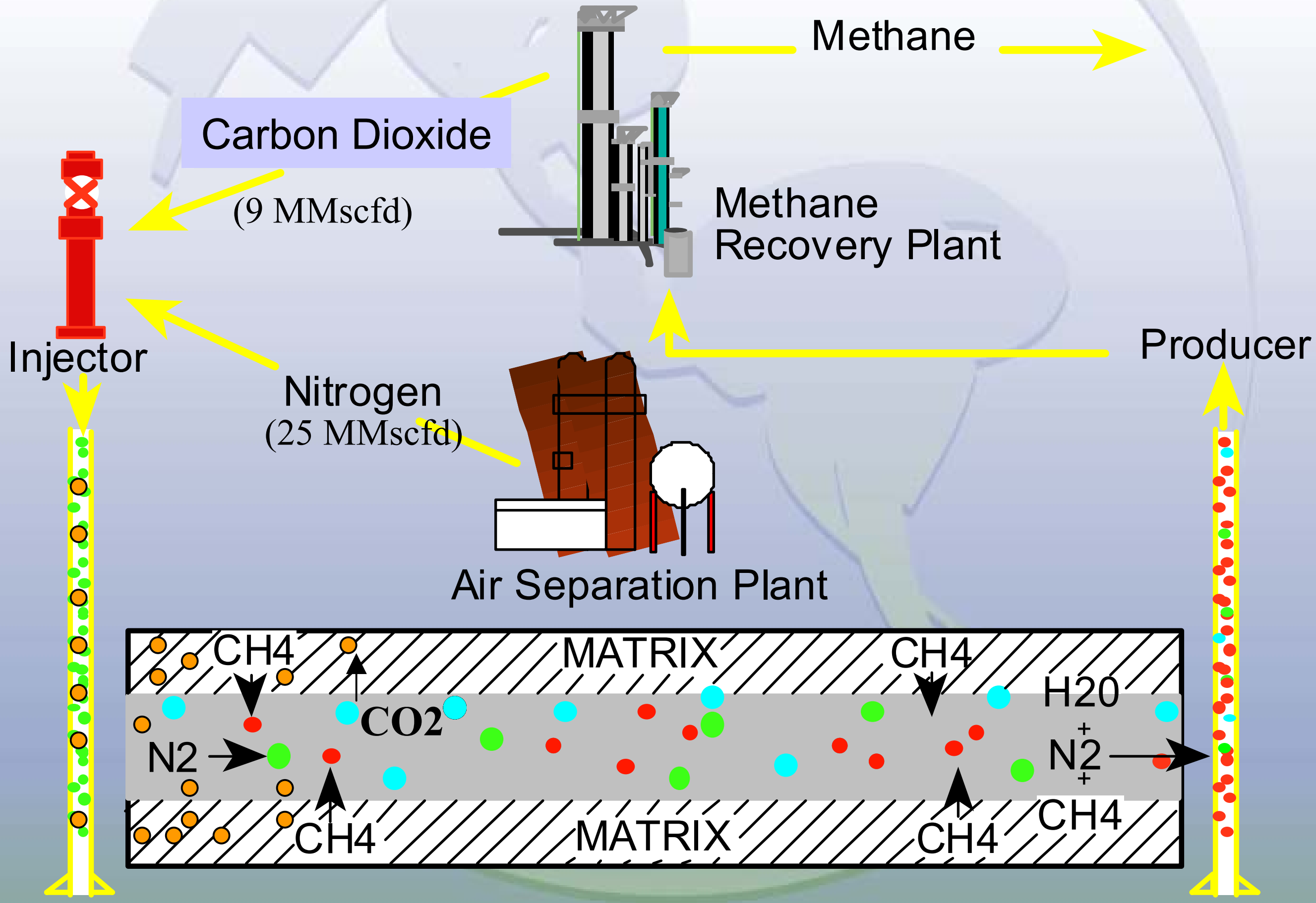
Why is CO_2 Sequestration in Coal Beds Attractive?

- Coal beds typically contain a large amount of methane gas that is adsorbed on coal surface.
- Injection of CO_2 can enhance methane recovery by efficiently displacing methane from coal matrix.
- CO_2 is roughly twice as adsorbing on coal as methane and therefore, giving coal beds the potential for large-scale CO_2 sequestration.
- Worldwide sequestration potential in unmineable coal seams is 350 billion metric tons of CO_2

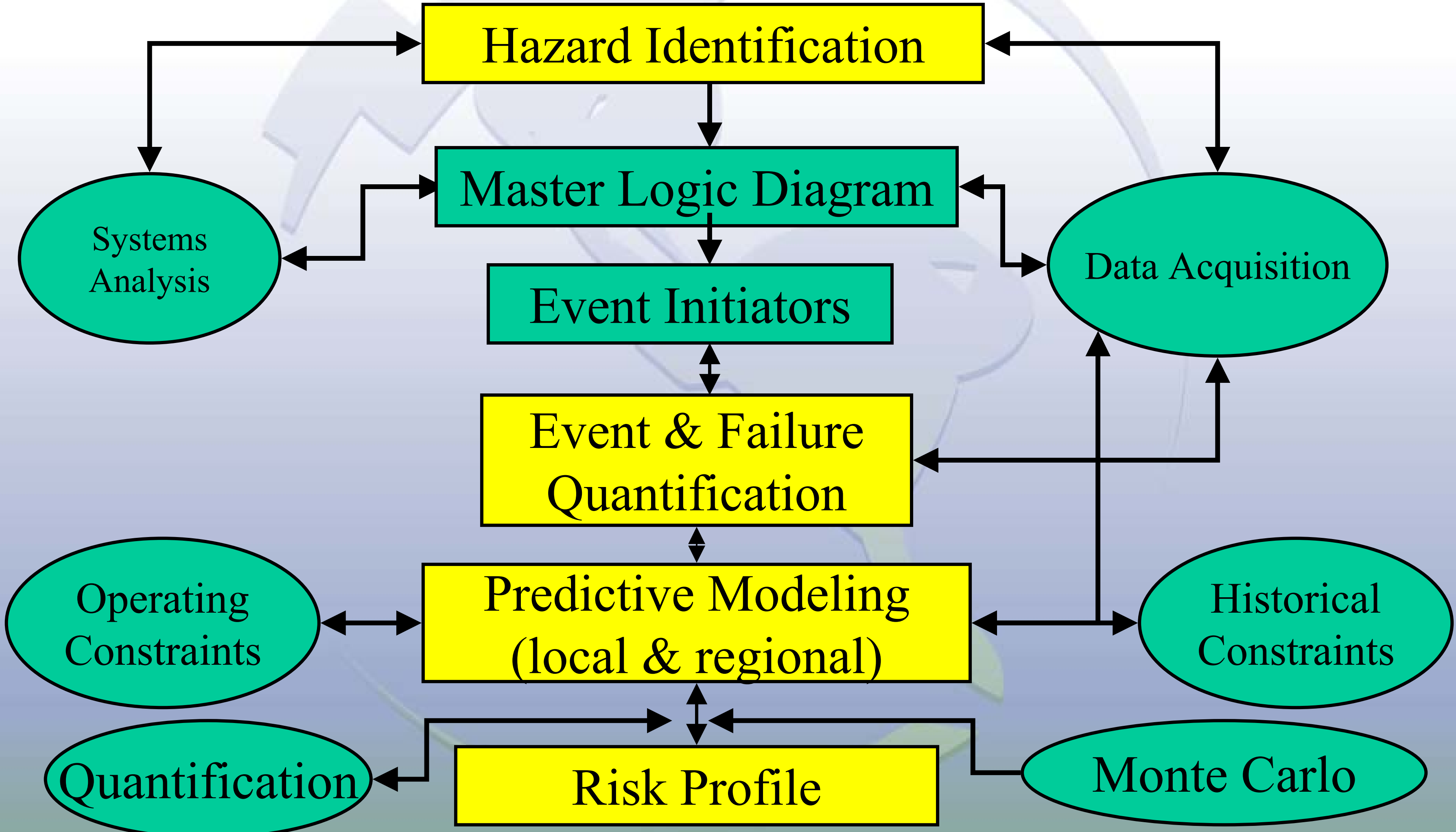
Tiffany Field Overview

- Located in San Juan Basin, CO
- Existing commercial scale nitrogen flood
  - 10,000-acre unit with 12 injectors and 36 producers
  - Data available
    - Geological description of field and basin
    - Production history(primary & N_2 injection)
    - Case history
    - Field Models
  - Monitoring in-place
- Potential for large scale CO_2 disposal

CO_2 Capture & Sequestration with Enhanced Methane Recovery



Risk Analysis Methodology



Monitoring & Verification

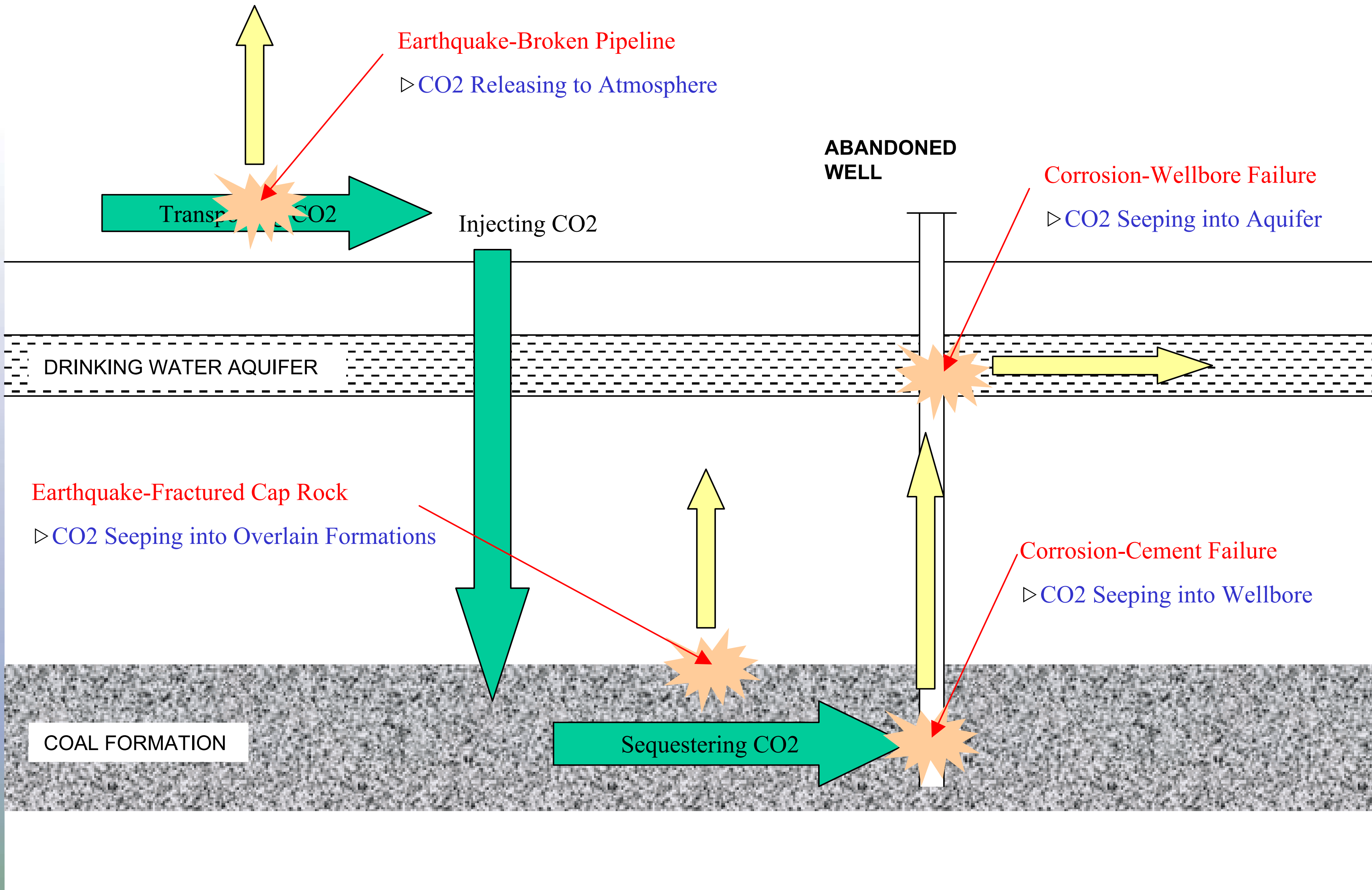
- Identify likely CO_2 releasing paths
- Verify the current monitoring plan
  - includes all identified release points
  - monitors at an acceptable frequency

Mitigation Strategies

- Based on risk profile, propose a strategy for risk mitigation. For example,
  - limit injection into center layers; provide buffer zone above and below
  - recommended completion practice for injectors and/or producers
- Determine impact on risk profile

Risk Assessment of CO_2 Sequestration in Geological Formations

Information/Data Acquisition	Representation & Implementation	System Analysis
Project Plan Possible CO_2 Releasing Paths Hazard Identification Expert Knowledge Regulations & Policies Simulation Forecast	Processes Failure Modes Initiators Consequences (effects) Risk Quantification Indicators	Inference Logic Based on Set Theory Scenario Testing Consistence of Risk Scales


Earthquake-Broken Pipeline
▷ CO2 Releasing to Atmosphere
Transp CO2
Injecting CO2
ABANDONED WELL
Corrosion-Wellbore Failure
▷ CO2 Seeping into Aquifer
DRINKING WATER AQUIFER
Earthquake-Fractured Cap Rock
▷ CO2 Seeping into Overlain Formations
Corrosion-Cement Failure
▷ CO2 Seeping into Wellbore
COAL FORMATION
Sequestering CO2

Processes = Planned CO_2 Paths
+ Possible CO_2 Releasing Paths

THE FIRST SCHEMA

A REFINED SCHEMA

$$\{\text{sequester } CO_2 \text{ in coal seam}\} \rightarrow \left\{ \begin{array}{c} \text{prevent } CO_2 \text{ seeping from cap rock} \\ \text{prevent } CO_2 \text{ seeping from outcrop} \\ \text{prevent cement corrosion in old wells} \\ \ldots \end{array} \right\}$$

Initiator Table Fields

Initiator ID	Initiator Name	Project ID

Affected Process ID	Affected Process Name

Numerical Likelihood Value	Fuzzy Likelihood Value

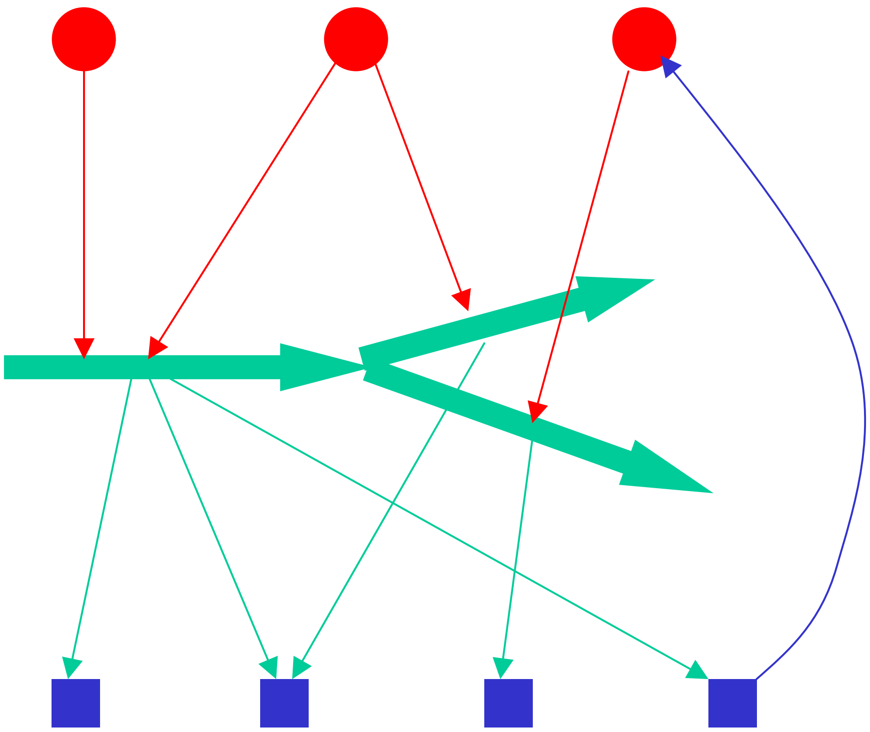
Activation Status

Spatial Scale (km)	Time Scale (year)

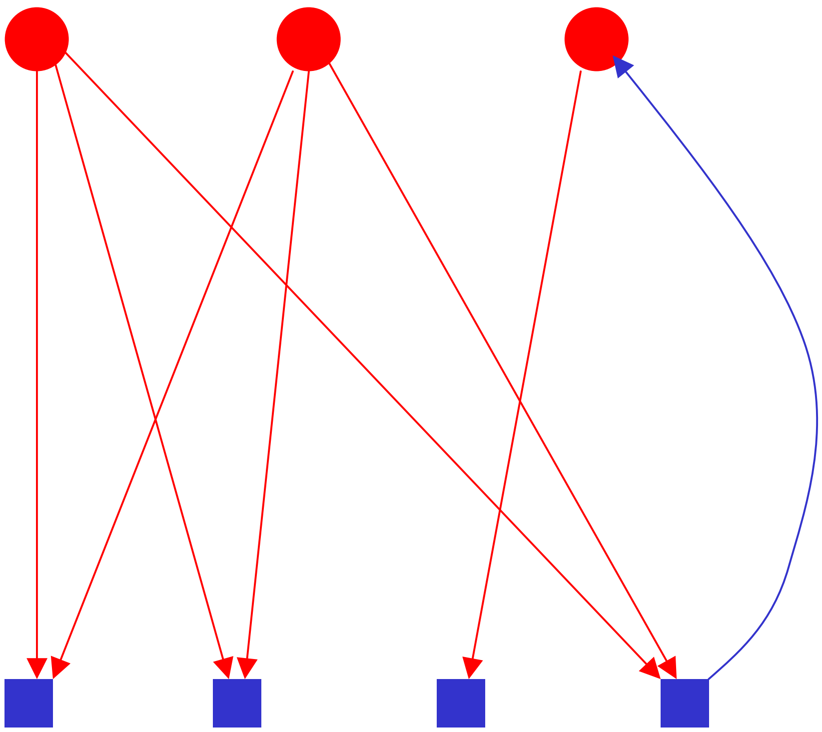
Initiators

Processes

Consequences



Initiators



Consequences

Scenario Simulation

- Activate selected initiators
- Identify affected processes
- Look into the failure mode tables
- Find the consequences and calculate their severity measures
- Repeat the process if new initiators have been invoked by resulting consequences

The Failure Modes – A Set of Triplets at Process Level

- What can go wrong?
- What is the likelihood of that happening?
- What are the consequences?

Example

Initiator	Affected Process	Likelihood of Broken Pipeline	Effect
Earth quake	CO_2 transportation (CO_2 pipeline)	seldom	CO_2 releasing to atmosphere

Defining a quantitative/qualitative severity scale matrix for a failure mode

			Likelihood		
Consequence	Unlikely Pr<0.01	Seldom 0.01<Pr<0.05	Occasional 0.05<Pr<0.1	Likely 0.1<Pr<0.5	Frequent 0.5<Pr<1
Cons. 1	s11	s12	s13	s14	s15
Cons. 2	s21	s22	s23	s24	s25
…					

Where S_{ik} are the aggregate severity measures of the consequence severity and the likelihood interval defined by the geometric average

$$S_{ik} = \sqrt{(Severity\ of\ Cons.\ i) \times (Likelihood\ of\ the\ \mathrm{k}th\ Interval)}$$

Criteria for Rating the Severity of Consequences

- Adverse Effect to Human Health
- Adverse Effect to Animals
- Potentiality of Violating Regulations
- Duration
- Cascading Effect
- Undetectability
- Uncontrollability
- Irreversibility

Numerical Ranking: 0~1

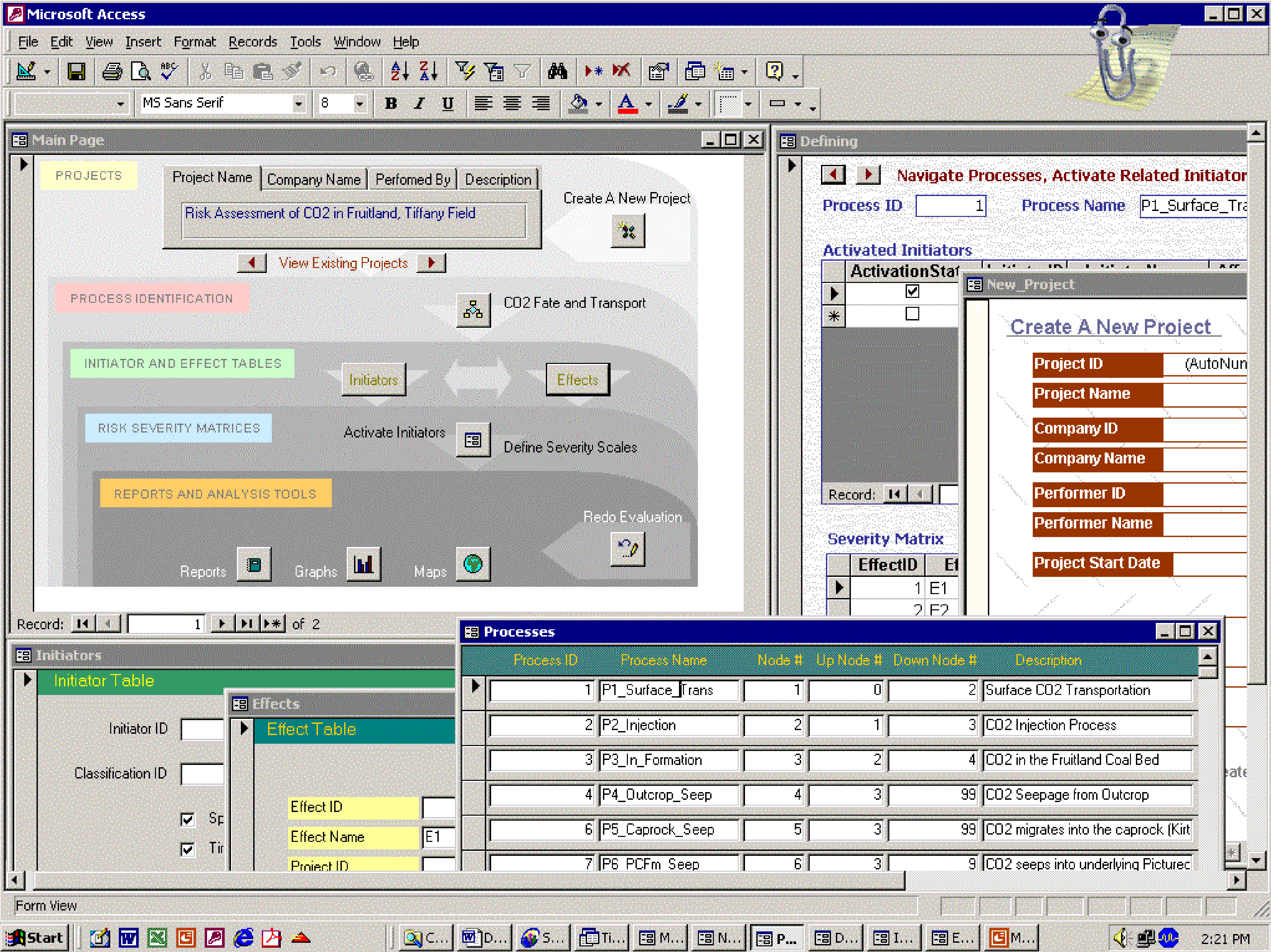
Fuzzy Ranking: Sever, High, Medium, Low, or Not Applicable

Indicators

- Activated Initiators
- Affected Processes (Failure Modes)
- Possible Consequences and Their Severity Scales

- Process Tree
- Initiator-Process-Consequence Diagram (One to Many)
- Consequence-Process-Initiator Diagram (One to Many)
- Initiator-Consequence Diagram (Many to Many)

- Overall Risk Index
- Sensitivity of Initiators to the Overall Risk
- Sensitivity of Consequences to the Overall Risk



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Main Page
PROJECTS
Project Name
Company Name
Perfomed By
Description
Risk Assessment of CO2 in Fruitland, Tiffany Field
Create A New Project
View Existing Projects
PROCESS IDENTIFICATION
CO2 Fate and Transport
INITIATOR AND EFFECT TABLES
Initiators
Effects
RISK SEVERITY MATRICES
Activate Initiators
Define Severity Scales
REPORTS AND ANALYSIS TOOLS
Redo Evaluation
Reports
Graphs
Maps
Record: 1 of 2
Defining
Navigate Processes, Activate Related Initiator
Process ID 1
Process Name P1_Surface_Tra
Activated Initiators
ActivationStat
Record:
Severity Matrix
EffectID
1 E1
2 E2
New_Project
Create A New Project
Project ID (AutoNun
Project Name
Company ID
Company Name
Performer ID
Performer Name
Project Start Date
Initiators
Initiator Table
Initiator ID
Classification ID
Sp
Tir
Effects
Effect Table
Effect ID
Effect Name E1
Project ID
Processes
Process ID | Process Name | Node # | Up Node # | Down Node # | Description
1 | P1_Surface_Trans | 1 | 0 | 2 | Surface CO2 Transportation
2 | P2_Injection | 2 | 1 | 3 | CO2 Injection Process
3 | P3_In_Formation | 3 | 2 | 4 | CO2 in the Fruitland Coal Bed
4 | P4_Outcrop_Seep | 4 | 3 | 99 | CO2 Seepage from Outcrop
6 | P5_Caprock_Seep | 5 | 3 | 99 | CO2 migrates into the caprock (Kirt
7 | P6_PCFm_Seep | 6 | 3 | 9 | CO2 seeps into underlying Picturec
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Features of This Approach

- Designed for Implementing on A Relational Database
- Transparency and Adjustability of the Severity Ranking Method
- Risk Profiles Resulted from Scenario Simulations
- Reduced Complexity by Defining Failure Modes at Process Level
- Inference Rules Can be Converted to And Verified by Set Operations