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System Functions and Informatic Programs for Integrated Digital Monitoring of CO2 Storage

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Introduction

These articles present the system functions and programs for integrated digital monitoring of CO2 storage. The authors and a team are involved in an international project that aims to create a configurable system for monitoring CO2 deposits. The overall objective of the DigiMon project is to materially accelerate the implementation of Carbon Capture System by developing and demonstrating an affordable, smart, flexible and societally embedded Digital Monitoring early-warning system, for monitoring any CO2 storage reservoir and subsurface barrier system. The system will be done flexible and interchangeable with respect to the environment (offshore or onshore) and to new system components provided by market-driven technology development.Key component of any Carbon Capture System (CCS) project is measurement, monitoring and verification (MMV), which must demonstrate that projects are planned and executed in a societally acceptable and cost-effective manner, ensuring safety and security and will have a particular focus on knowledge communication and dissemination with the public and policy makers.

Security and chemical alarm system

A hierarchical system was conceived, openly distributed with the possibility of development in stages, with the possibility of further integration of other subsystems. The subsystems that are the object of the present documentation, being security systems, must be implemented the concrete ways of safety supply. When designing the subsystems, the need to achieve a distributed, reliable, redundant system that allows easy calibration and maintenance of the monitored sensors and equipment in the system was considered. The implemented schemes consider the need for fast transmission of information to the decision makers of the Technological Platform subject to the technological risk in the impact region. The described system lays the foundations for the realization of the INTRANET of the technological platform through its components of monitoring / analysis of the factors that determine the chemical alarm plan and informing social partners / decision makers. The documentation made during the phase highlights the need, the purpose of the functional blocks, the equipment, the purpose of the system according to the identification of risk factors, determines the decision factors that are informed in order to objectify the response in case of potential accident, identifies the implemented equipment, as well as the tests performed on the beneficiary to prove the technical capacity of the system.

The potential risk represented by the technological platform comes from the storage and circulation of important quantities of CO2. Based on the analysis of the technological process, of the operative management and its operation, of the conditions and impositions regarding the safety in operation, an integrated IT system solution of type Decision Support System / Management Support System - SCADA was proposed and implemented which leads to an increased safety in operation of the technological process.

We proposed a modular, configurable, open system for monitoring and control of the technological process, monitoring the utilities and informing the decision and information factors (inside and outside the technological unit), in a format specific to the attributions and the workplace.

From a constructive point of view, the system, the software packages ensure:

- Risk assessment through the System I and II module

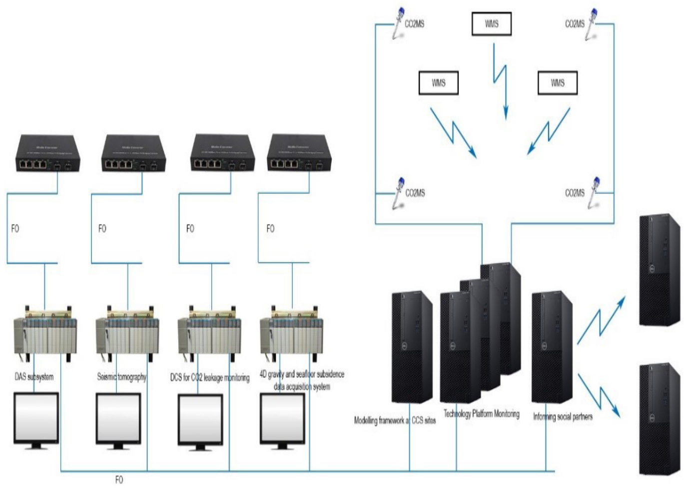

Figure 1: *Block diagram of the informatics system (presented by the author into the paper "Integrated informatics system structure for digital monitoring of the CO2 storage")*

• Risk management through the module Monitoring system of the technological process related to risk areas,

• Analysis and management of risk situations through the Data Communication Modules, information, analysis, Decision Factors.

• Data security; Firewall. WAN communications.

By implementing the system and the software packages, the increase of the safety in operation in units subject to the technological risk is ensured.

The application program package also includes the compatibility with the other subsystems, data communications in the LAN network and in the WAN network.

By decision factors we mean the internal compartments of the unit as well as units outside the Technological Platform / the social partners: The Inspectorate of Environmental Protection and the Inspectorate of Civil Protection and other information units.

With these units we have provided wired or radio data connection, through dedicated lines.

System functions provided:

a. Taking over the characteristic data from the Technological Platform

b. Monitoring and control

c. Simulation and virtualization

d. Determining the possible chemical outbreak, monitoring accidents, determining the causes and potential effects

e. Informing decision makers including the social partners in the potential risk area.

The factors that contribute to the fulfillment of the chemical alarm plan are:

I. The local dispatcher who determines and remedies the cause of the chemical outbreak;

II. The chemical alarm dispatcher who applies the chemical alarm plan in case of an accident affecting a larger area inside or outside the plant;

III. The Civil Protection Inspectorate involved in case the accident spreads and affects areas outside the plant;

IV. The Environmental Protection Inspectorate as a control body, ascertaining;

V. In order to control the technological process, the industrial management, in safe conditions in operation on the Technological Platform, it is necessary to interconnect the SCADA type subsystems in a unique system of acquisition, processing, monitoring and data transmissions to form the basis for the Intranet of the Technological Platform.

Through this concept, the unitary view of the concepts of technological risk, industrial safety, prevention of accidents by real-time monitoring of the technological process is achieved.

The role of the system is to prevent risk situations through the security component and to support the human factor in order to make optimal decisions within the chemical alarm plan by providing adequate information in a format specific to the duties and the workplace.

The system that is the object of this documentation considers these aspects, its forecast and information component realizing:

a) determining the place where the outbreak occurred;

b) determining the amount of leaked gas;

c) determination and presentation of meteorological parameters;

d) determining the shape of the cloud and its evolution;

e) presentation of the evolution on the map of the region;

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f) real-time information of decision makers inside and outside the plant;

By coupling the sensor system, the origin of the leak can be determined precisely.

By correlation, the gas escape cone from the technological platform can be determined, as well as the evolution of the gas cloud. The proposed systems are based on the concept of distributed and open system, and can be adapted and extended in successive stages and interfaced with applications so as to cover the requirements of a security and emergency response system, operating in conditions of technological risk.

The systems provide information to the departments that contribute both to the operative management of the technological process and to the follow-up and decision-making regarding the impact of a chemical event on the area inside or in the vicinity of the Technological Platform. Within the chemical alarm plan, depending on the location of the chemical outbreak and the amount of gas escaped, a certain scenario is chosen.

In the final stage, the system could provide, as an operator guide, the information necessary to choose the intervention scenario, each scenario leading to the choice of the appropriate action plan.

The structure of the functional blocks of the informatics system is shown in the figure below.

Gas Dispersion, Impact Zone Forecast, and Simulation

Atmospheric dispersion of CO2 is in many cases very fast. However, there is a time when the atmosphere is very stable and does not lead to dispersion.

The factors involved in atmospheric dispersion are:

• Extremely unstable atmospheric conditions lead to a rapid mixing and dispersion of airborne particles, while stable atmospheric conditions inhibit mixing;

• Mechanical turbulence due to wind, uneven terrain and forests;

• Existing temperature gradient up to 30 m in the atmosphere;

• The most unfavourable condition for dispersal is the calm atmosphere of quiet nights or early morning, as well as a not too high cloud ceiling;

• The best condition for dispersal is the strong sun and wind breezes in the upper layers of the atmosphere.

• During container explosions, leaks or gas pipes, the area that is affected is not fixed, but depends on many parameters, among which are:

• Direction of the exhaust gas (vertical or horizontal); Wind direction and speed;

• General environmental conditions: day / night, clear / dark, sun / cloud, rain / humidity;

• Gas emission speed; Gas and ambient temperature;

• CO2 concentration of the gas; Topography of the land;

The potential risks presented by the storage and transport of chemicals are realized in three stages: Risk identification; Impact analysis; Risk analysis.

Gas (CO2) leaks into the atmosphere can be simultaneous or successive. The main parameters considered in the modelling are: initial gas density; type of escape: instantaneous / continuous; the type of terrain in the impact area.

Industrial security - system

The DigiMon project is part of the priorities of the Technology Platform with components:

• Risk prevention by monitoring and controlling the technological process;

• Industrial security and computerization of the internal and external risk management of the unit;

• Prevention of ecological accidents and monitoring of environmental factors in air and water;

The environment and industrial security are global issues and particularly essential for the countries of Central and Eastern Europe. EC legislation (SEVESO treaty) imposes more and more constraints on industries and requires them to have technologically efficient equipment for the control and surveillance of leakage sources. The system is a modular system, distributed, configurable, open, security, risk reduction, monitoring of the technological process, assisted decision in conditions of technological risk, analysis of impact and risk on populated areas. By implementing the system, the technological risk in potentially polluting units with potentially dangerous substances will be reduced to a level imposed by the legislation in force, the management of crisis situations will be ensured in real time and the risk will be anticipated.

The present chapter has as object the reconsideration of the current technical level of the data acquisition and processing system from the technological process, in order to achieve a unitary computer system for monitoring and managing the process in the technological installations using the calculation technology at the current technological level. This system will be integrated in the IT system of the Technology Platform in order to achieve efficient management at platform level.

The aim is that, based on the analysis of the technological process, its operational management and operation, conditions and requirements on chemical alarm, to propose an integrated IT system solution that combined with action strategies in case of chemical alarm leads to greater operational safety of the Technology Platform.

Through this concept, the unitary view of the concepts of technological risk, real-time monitoring of toxins, prevention of accidents by real-time monitoring of the technological process, simulation, forecast depending on weather and climatic conditions and information of social decision makers is achieved.

Monitoring is perceived as useful towards ensuring site safety, protecting groundwater resources, safeguarding the environment, minimizing the possibility of induced seismicity, identifying possible leakage, and providing information on CO2 emissions reductions.

The project allows the treatment with a single computer system of the security aspects of the industrial unit, of the surroundings of the industrial places subject to technological risks and of the environmental protection aspects. As a finality of the system will be the creation of a unitary and operative database, which will provide the support for making the optimal decisions in order to lead the technological process, to prevent and / or to diminish the risks for the unit and the neighboring areas.

Globally, the unified system must provide the following functions:

- to prevent the risk by keeping the installations within technological limits;
- to constantly monitor, in real time, the state of utilities and energy consumption;
- to monitor gas leaks in and around installations;
- provide information to decision makers for optimal decision making;
- to ensure the IT flows necessary for the management and the economic-financial course;

Considering these general considerations, the project analyzed and proposed a unitary solution for the following subsystems:

DAS subsystem. DigiMon will investigate how classic, currently in use, micro seismic event detection techniques perform on synthetic and real DAS data. These methods will then be extended to investigate how machine learning techniques can assist or replace the current workflows. A similar approach will be applied to event location, magnitudes and mechanisms. The algorithms will be optimized to enable near real-time processing.

DigiMon will also investigate how ANI techniques can be extended to DAS data to improve subsurface imaging capabilities. The results will be interpreted to improve understanding of geological structure and geomechanically responses to CO2 injection. This will provide input to the geomechanically modeling.

The DAS subsystem has two subsystems:

Seismic tomography subsystem. DigiMon will develop a new SV-wave source which will be tested in the field for comparison with existing technology (SH-wave and P-wave sources) and suitability for tomographic surveys. Data will be collected using conventional and DAS technology and monitoring designs tested for their ability to provide results with the required resolution.

The task will investigate the best deployment methods and set-ups for DAS cables in offshore settings to achieve good data quality - what type of cable should be deployed and how should it be coupled to the seafloor. The possibility coupling fiber deployments to refraction surveys and full-waveform inversion will be investigated using synthetic data, feasibility studies and, if available, field data. Existing datasets from time-lapse seismic reflection surveys and the Oseberg PRM will be investigated to determine how these surveys could be further optimized for monitoring.

DCS for CO2 leakage monitoring. The sensors will provide the in-line measurement we need, to the desired accuracy, to exercise control over technological processes. The CO_2 sensors will provide feedback on the CO_2 in the process, without the need for sampling.

Dissolved CO_2 is a harmful and unwanted by-product that occurs naturally during cell culture processes. High dissolved CO_2 levels cause unwanted metabolic changes, growth inhibition and low productivity. The dissolved CO_2 sensor provides real-time CO_2 analysis, allowing rapid reaction to extra-specific changes in CO_2 concentration.

4D gravity and seafloor subsidence data acquisition system. Information obtained from 4D gravity and subsidence monitoring provides improved decision-making in the exploitation of offshore reservoirs.

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Field cases demonstrate the impact of this technology in the estimation of hydrocarbon volumes, the evaluation of risk of water breakthrough, understanding of drive mechanisms and identification of untrained compartments, the identification of infill-well targets or by the optimization of compression facilities. The technology has been used in eight fields on the Norwegian continental shelf (NCS).

4D gravity is sensitive to changes in the mass distribution in the reservoir. Gas depletion and water influx from surrounding aquifers produce an observable time-lapse gravity signal. The observed signals are independent of seismic velocities, which make this technology complementary to seismic monitoring. In addition, gravity provides a more precise quantification of mass changes than 4D seismic, and it can provide a better sensitivity to the movement of the gas-water contact.

Seafloor subsidence is also sensitive to important reservoir and overburden properties. It is directly related to compartmentalization, and it can be a key factor for the safety of installations.

It is an observable effect of geotechnical changes. Seafloor subsidence is used to identify non-depleted compartments; determine the drilling-window for in-fill wells; understand aquifer properties; and improve the geotechnical model hence the interpretation of seismic time-shifts.

Modeling framework at CCS sites. Modeling of CO2 capture, transport and storage allows the modeling of CO2 pipelines and pipeline networks.

The CO2 capture and storage (CCS) assessment includes the capture of CO2 from both existing and new CO2 storage facilities. The pipelines in the updated model are endogenously configured to be optimally consistent with the latest capacity and cost data for the storage resource base.

The model allows the analysis of different combinations of sources, in different economic and technological scenarios. DigiMon will develop a software application of the model to assess the role of CO2 capture, transport and storage.

Industrial management subsystem - is the core of optimal management of the industrial process, informing decision makers, creates the necessary infrastructure for information flows. The subsystem comprises 3 servers: general, for Internet and external communications, for management.

Technology Platform Monitoring - has the role of monitoring technological parameters, framing between functional limits, pre-alarm and alarm in case of exceeding limits, displaying information on synoptic schemes and database management, in order to prevent accidents and breakdowns. Database analysis can provide criteria for optimal operation of the installation.

The subsystem follows the quantities that characterize the technological process (pressures, differential pressures, liquid level, flows, temperatures, PHS, in areas established by the risk study, etc.). The Technological Process Subsystem could integrate:

Utilities subsystem - has the role of monitoring the parameters that characterize the technological utilities. Considering the fact that the technological process is correlated with the functioning of the utilities, the subsystem can be included both in the function of accident prevention and in monitoring the efficiency of the technological process by highlighting the internal consumptions.

Sensors subsystem from the technological process - has the role of monitoring the technological parameters and the concentrations of CO2 gases escaped inside and in the immediate vicinity of the technological installations.

Sensors subsystem on the perimeter of the technological process - has the role of monitoring the amounts of CO2 gases released around the installations, monitoring environmental factors and forecasting the evolution of the toxic cloud in case of an accident.

The subsystem estimates the location of the accident as well as the amount of gas escaped. It allows the detection, control and identification of various emission sources as well as fugitive leaks.

Analytical, meteorological and cartographic data are considered, which allows establishing a forecast of the diffusion of pollutants and the evolution of the CO2 cloud according to the information taken automatically.

Independent Sensors Subsystem - Independent sensors are located next to the critical points established by the impact study, the channel mouths which by their nature allow CO2 leaks or leaks. The adapters to which the sensors are connected ensure a local audible alarm (hoop) and light alarm (beacon) in case of accidental leaks above the preset limit. The monitoring subsystem ensures the automatic acquisition of the quantities that characterize the independent sensors, the transmission of this information to a dispatcher, their presentation and management in a database.

Environmental monitoring and forecasting subsystem. Environmental monitoring and forecasting subsystem. It is a subsystem made up of all the environmental sensors (CO_2) located underwater and above the water, perimeter of the technological platform that analyses the potential pollution (CO_2). Together with 3 automatic stations for measuring the weather parameters (temperature, atmospheric pressure, wind direction and speed, amount of precipitation) it can make the forecast of potential pollution.

Informing social partners; **Subsystem Data transmissions to social decision makers** - Civil Protection Inspectorate and Environmental Protection Inspectorate - Data obtained by acquisition and processing, from transducers and sensors as well as data characterizing the evolution of the possible gas cloud are transmitted as they are transmitted specifically to social decision makers.

These data are presented on the map of the region highlighting: the place of the accident, estimating the amount of gas escaped, weather parameters in the immediate vicinity of the outbreak, estimating the shape of the cloud and its speed, highlighting possible scenarios and intervention measures.

Due to the complexity of the system, special attention will be paid one hand to the performance of redundancy functions to solve the degraded operation of the system, the operators' access being pass worded to the various partial or global databases of the system and even to the maintenance functions of each subsystem and on other hand to the power of computing, data bases and data communication.

Data flows between subsystems and social partners

Package programs "data transmissions to social partners"

The necessary information, which is transmitted, is:

a) the quantity of gases emitted into the atmosphere;

b) framing between technological limits of operation;

c) wind direction and intensity;

d) the evolution of the gas cloud superimposed on the map of the region.

The system allows the detection and modelling of accidental gas discharges that may occur in the vicinity of technological installations.

• Detection and surveillance of gas discharges in the vicinity of technological installations;

• Monitoring of METEO parameters in the meteorologically significant neighborhood;

• Gas cloud modelling based on both real-time data taken from subsystems and performance algorithms for modelling and estimating cloud evolution.

• Remote reporting of information to decision-makers inside and outside the unit (informing the social partners) in order to make optimal decisions.

Package programs "detection and forecasting"

The system forecasting and information component performs:

• determining where the defect/outbreak occurred;

• determination of the amount of gas dropped;

• determination and presentation of meteorological parameters;

• determining the shape of the cloud and its evolution;

• presentation of evolution on the map of the region;

• real-time information to decision-makers on and off the perimeter (informing the social partners);

• presenting information in a format that allows optimal decisions to be made

Package programs "chemical analysis and alarm"

The chemical alarm component achieves:

• Communication with Sensor /Translator/Analyzer subsystems,

• Retrieval of data on state overshoots, functional limits,

• Toxic gas monitoring;

• Monitoring of meteorological parameters

• Determination of escapes, quantities, concentrations

• Determination in points / areas, on the map of the region or inside the perimeter,

• Determination of the affected area according to weather conditions;

• Correlation escapes – quantities – concentrations – weather conditions – evolutions;

• Monitoring on synoptic schemes and map of the region in the GIS sleeve;

• Alarm in case of exceeding the limits;

• Generating acoustic/visual signals (gyro far) for punctual or local accidents;

• Generating acoustic signals, gyroscope, operating barriers in case of zonally accidents;

• Management of databases on inventory of activities at risk of chemical accident;

• Management database data obvious properties, quantities risky substances punctual installation;

• Management of chemical alarm scenarios;

• Simulation

Activities with a chemical accident risk factor require that, in addition to the measures that are currently being taken, safe operation, there is a control and a continuous assessment of the risk, the possible consequences, and a system for monitoring the state of operation of installations, environmental emissions and concentrations of pollutants.

Packages of programs specific to the emergency plan

An emergency plan must cover all requirements in terms of both the indoor and outer emergency plan of the chemical unit.

The program packages specific to the emergency plan must ensure a secure and up-to-date database, in real time, in the field of input and output data that changes currently over time.

Data purchased in real time and processed with these software packages will have to update databases in which there are also constant data whose update will be done only when necessary because they are generally evidence of different factors constant over time.

In this sense, the following program packages are identified:

1. Monitoring of technological parameters, for detecting the beginnings of the exit from the limits of technological processes and possible trends of evolution towards a major chemical accident; special attention, in this case, is given to parameters that energize safety and protection systems;

2. Location of the chemical outbreak with identification of the type and quantity of the toxic substance escaped. The program will present, on a map of the toxic unit:

• Place of escape, based on quotas with reference to a system of general coordinate axes;

• Nature of the toxic substance escaped, with its identification in SNAP code;

• Total amount of toxic substance dropped and its condition (liquid or gas).

3. Determining the characteristics of the chemical outbreak. The programe will present:

• Total amount of evaporated toxic substance, i.e. escaped liquid that wets a surface;

• The effective, measured concentration of the toxic substance in the atmosphere, with the warning of the program user on its lethal or toxic character;

4. Determining the weather conditions both in the toxic unit and in its surrounding area up to about 10 km, at the time of the escape. Consideration shall be given to:

Wind direction; Wind speed on the ground with an indication of the wind stability index; Atmospheric temperature; atmospheric humidity; Atmospheric pressure;

5. Determining the characteristics of the toxic cloud and the type of alarm, i.e.:

• Persistence of the toxic substance in the infected area. It refers to the duration of how long there is still a toxic substance in liquid form with a higher concentration than THE CMA. Not applicable to gases;

• The duration of action of the toxic cloud, as it has a higher concentration than the CMA. It is approximated according to: the amount of toxic substance, its properties, the mode of storage, the characteristics of the land;

• Area of infected area;

• Radius of the lethal zone, i.e. intoxication, in atmospheric calm;

• Length and width of the lethal zone, i.e. intoxication, toxic cloud action in wind conditions with a speed greater than zero. Like the concentration and persistence of the toxic cloud, the length and width of the toxic area are influenced by the meteorological factors specific to the area, its relief and vegetation by the intervention of the phenomenon of convection or inversion, respectively the height of some obstacles and the density of vegetation;

• The arrival time of the toxic cloud at different distances included in the toxic zone, especially on its directions of travel on which localities and/ or economic units meet;

6. Determine the type of alarm to be decreed (local or general), by entering a message on the general command commander's screen on the unit to decide whether or not to trigger the local alarm or the general alarm;

7. Presentation of the list of objects (installations, buildings) interiors of the toxic unit affected by the escape of the toxic substance that will be affected by the toxic cloud and that

will have to be alarmed;

8. Presentation of the list of units and/or localities that will be affected by the toxic cloud and that will need to be alarmed;

9. Integration of the data set out by the above programs.

The integration program will allow the presentation of all this data together with those that will be the subject of a static database relating to the toxic unit.

Risk Analysis and Management

The function of analysis and management of risk situations is carried out through the Modules Communications Data, Information, Analysis, Information social partners

Through the software packages the unified system provides the following functions:

• prevent risk by keeping installations within technological limits;

• constantly monitor the condition of the installations in real time;

• monitor gas leakage in and around installations within the monitored perimeter;

• provides information to decision-makers for optimal decision-making;

• provide information flows necessary for the technical management of the unit;

• inform the social partners with the status of the monitored perimeter to confirm the state of operation

In the informational exchange between consumer factors and information producers the number of information is different depending on the task and the role that each factor has in the response structure in case of event [1-12].

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