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Safety Aspects of Offshore CO_2 Storage in Depleted Levels of Hydrocarbon Cultivation Fields

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The article is aimed at representing the activities of technical evaluation carried out on the examination of the experimental program for the geological storage of carbon dioxide. The paper describes the experimentation program and the related plants, focusing attention on the assessment of the relevant risks for the environment and health, with specific aspects related to the safety, prevention and mitigation plans for significant releases of CO_2. In particular, the corrective measures of prevention and protection are specified, connected both to purely technical and plant aspects, as well as to management and organizational aspects. The discussion ends with a series of assessments about the strengths of this experimental installation.

1. Introduction

As part of the experimental program for the geological storage of carbon dioxide in the depleted levels of a field in concession for the cultivation of offshore hydrocarbons, carried out by multinational company operating in the oil & gas sector (Operator) and located in the Adriatic Sea in Italy, a technical evaluation activity was carried out by a specific Technical Working Group (TWG), within ISPRA, in charge of supporting the CCS (Carbon Capture Storage) Technical Secretariat of the Italian ETS (Emissions Trading System) Commission. The authorization of the project, in charge of the Ministry of the Environment, falls within the scope of application of Legislative Decree no. 162/2011 (GU. 2011), which, in implementation of Directive 2009/31 / EC (EU. 2009), contains the rules on the geological storage of carbon dioxide. The technical assessment dealt with various aspects, related to the static geological model, the tsunami risk, the monitoring of soil deformations and related risks, the safety analysis and emergency management, the emissions in the off-shore and on-shore environment, geophysical monitoring and any risks associated with the injection of CO_2 into the subsoil (EC. 2011).

2. The experimental project

2.1 Description of activities and new installations

The experimental project presented by the Operator, as shown in the following Figure 1, provides for: 1. Casalborsetti CO_2 capture plant: sized to capture and treat the CO_2 present in the exhaust fumes of one of the 4 existing Turbocompression units located within the Casalborsetti on - shore power plant area (an area of 44,900 m2 to the north of Ravenna, consisting of a Natural Gas compression and treatment plant). The nominal size of the capture plant will be approximately 25,000 tons of CO_2 per year; 2. Compression and CO_2 reception station in Casalborsetti: the Casalborsetti plant provides for the compression of the captured CO_2 for sending to the pipeline. Also included in the experimental program is a system for receiving CO_2 from tankers, storage, pressurization and vaporization (initially foreseen but later abandoned); 3. CO_2 transport and injection system: a new 4" line will be built inside an existing gas line with a “pipe in pipe” system, for the transport of CO_2 from the Casalborsetti station to the existing offshore platform and the permanent injection of CO_2 into the reservoir (located in the Adriatic Sea); 4. CO_2 Storage Fields: the platform will be adapted and will house the necessary equipment in order to allow the reception and subsequent injection of CO_2, without any impact on the current gas production of the field; 5. CO_2 monitoring system: a well, micro-seismic, soil deformation and environmental monitoring system will be created.

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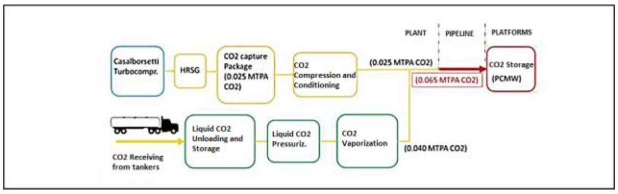

Figure 1: New Plant scheme

The selection of materials for the CO_2 service is functional to the water content, for the corrosion phenomena: The section with wet CO_2 from the capture system up to the dehydration unit includes stainless steels, duplex or higher; The downstream section of the dehydration unit up to the reinjection well, where the CO_2 is dehydrated, involves the use of carbon steel with suitable corrosion excess thickness (the use of carbon steel is also envisaged for the pipeline and platform equipment).

2.2 On-shore auxiliary and process units

The interventions relating to the new plant will be carried out by the Operator in order to guarantee the operational continuity of the Casalborsetti plant and the planned production capacity. As regards the safety aspects, the following investigations were conducted by the TWG on the main units that make up the new installations: 1. Hydrogen storage. The unit consists of two packs of two hydrogen cylinders, inside the CO_2 dehydration package. In any case, the storage will be carried out according to the technical data sheets of the substance, at ambient temperatures, in suitable and adequately ventilated areas and away from sources of heat, ignition and electrical discharges; 2. Chemists. As regards chemists, these are substances generally used in natural gas treatment plants, i.e. oxigen scavengers, pH neutralizers, amines, caustic soda; 3. Vent system (cold spark plug). The vent system will work together with a blocking and isolation system which, by means of block valves, will be able to isolate the different process units or equipment. For all the simulated scenarios there are no fallout of the CO_2 concentrations at the monitored thresholds.

2.3 New installations in the pipeline

As part of the experimental project, the Operator provides for the transport of CO_2 between the Casalborsetti plant and the PCWC platform, through the reuse of existing pipelines in order to minimize environmental impacts and avoid new occupations of the subsoil. The new connection can be divided into the following four sections, as shown in the following Figure 2, a brief description of which is given below: Section 1: Onshore pipeline approximately 1.5 km long which starts from the Casalborsetti gas plant up to the shoreline (guide tube: 20”); Section 2: Pipeline approximately 7.3 km long which starts from the shoreline and reaches the vicinity of the PCWT platform (guide tube: 20”); Section 3: Pipeline approximately 1.5-2.5 km long which extends from the vicinity of the PCWT platform to the foot of the PCWC platform; Section 4: ascent and transit on the PCWC.
The route of the line in the section between the Casalborsetti plant and the PCWT platform is the same as the 20" gas line, as the new 4" pipeline will be inserted inside it, while between the PCWT and the PCWC platform a new 4" pipeline will be laid in parallel to the existing 14" pipelines. In order to guarantee continuity of operation, it is planned to convey the gas from the "Porto Corsini" field on the 10" pipeline connecting the PCWT platform to the Casalborsetti plant since, in fact, the 20" pipeline will be used as a "jacket" of the 4" pipeline for the transport of CO_2.

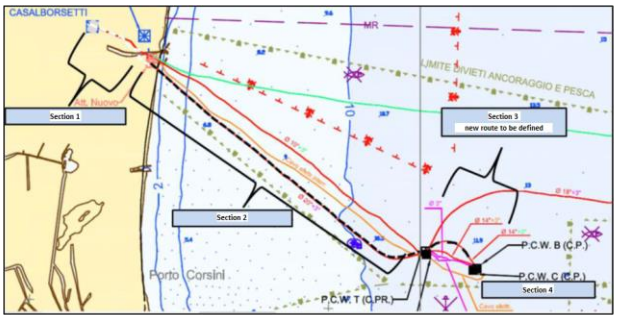

Figure 2: Link pipeline sections

2.4 New installations on the platform

For the new CCS plant in Casalborsetti, the Operator provides for the dedicated transport of CO_2 through a 4" pipeline which will connect the Casalborsetti plant to the existing platform. The installation of the new CO_2 injection equipment is planned on the platform, as follows: New riser installation; Reception trap from Casalborsetti plant; Dielectric joint; Installation of SDV (Shut Down Valve) block valve and relative local panel; Measurement package to measure the total CO_2 flow injected into the well; New wellhead equipped with specific automatic valves for CO_2 reinjection; Installation of new pipes and new piping supports; Control and safety instrumentation and associated systems; Venting circuit.
As regards the Electro-Instrumental Engineering, the following additions and modifications are foreseen within the project: Measurement package to measure the total CO_2 flow injected into the well; Installation of SDV block valve and relative local panel; New wellhead equipped with specific automatic valves for CO_2 reinjection; Control and safety instrumentation and associated systems; CO_2 detection systems and related connections; Multi - cable installation of instrumentation. In-depth analyses were carried out by the TWG on the management of the emergency: all new signals, measurements, controls related to the process, valve status and environmental sensors related to the platform will be remoted to the ground.

2.5 Main changes to existing plants

At the Casalborsetti plant, the Operator has made the following process changes to the existing plants: Existing turbochargers; Launch traps; Demi water and drinking water circuit; Drains. With regard to the safety aspects inherent to the aforementioned interventions, the design criteria identified for the tie-in to the chimney (turbochargers) are highlighted. The design of the heat recovery system, as well as of the downstream system, must have the objective of minimizing the back pressure imposed on the machine, in order to limit the impact on the performance of the compression train. For this purpose, an exhaust fumes blower will be installed inside the capture package. All the changes introduced to the chimney and to the logic must not introduce new danger scenarios. The deviation of the fumes towards the new system must be designed in such a way as to guarantee the possibility of keeping the Turbocharger in operation both in the event of an emergency stop of the capture system and in the event of a stop of the capture system for maintenance, exploiting the old chimney as a "by-pass" chimney. As regards the modifications to the pipeline, there will be the opening, sectioning and removal of some portions of the existing 20" pipeline in correspondence with the curves in the land section, the pulling areas in the coastal area, the areas of insertion near the platform. With regard to the changes introduced to the chimney, with specific regard to the operating logic and possible block, in the event of an anomaly, investigations were conducted by the TWG which confirmed that there are no additional danger scenarios and releases that affect the existing system.

3. Evaluation of the effects of accidental CO_2 releases

3.1 Preliminary assessments on the marine ecosystem

The analysis of the entire system, conducted by the Operator, led to the study and evaluation of hypothetical and exemplary accidental releases of CO_2 along the pipeline (pipeline leak) connected to the transport phase. The project variant taken into consideration (as well as the one of greatest interest) envisages a stretch of pipeline without interruptions, from the shore to the platform, with a length of approximately 11 km. The two hypotheses consist of: 1. A worst case that concerns the complete rupture of the pipe (pipe break) which would open an exit path for the CO_2 with a section equal to the diameter of the pipe, that is 4"; 2. A mild case that would occur with a minor leak (pipe leak) in the vicinity of a flange (cautiously considered a weak point), for example, due to a slow corrosion that would lead to the creation of an exit route, arbitrarily established by the measure of 1". As for the Pipe Break, it is to be considered exceptional as it is associated with an external factor that causes its complete break (in the form of truncation or tearing). In order to support this scenario, an external cause was assumed, for example that of a ship in transit on a route that crosses the route of the pipeline and that undergoes the release of the anchor chain, with the latter being dragged to the bottom go to intercept and break the conduct. This hypothesis has been considered since it falls within the series of naval accidents with similar effects. With regard to Pipe Leak, a less drastic scenario, it develops around the hypothesis, albeit unlikely, of a small perforation of the pipeline due to wall corrosion. The most plausible point for this event was identified at the base of the platform, an area in which flanged connections will be installed to connect the subsea pipeline and the risers towards the platform. The flanges, although they meet high quality standards, due to their nature of coupled elements, are in this case assumed as potentially weak points with respect to the linear section of the pipeline. In this case a 1" hole was assumed as a parameter of the CO_2 dispersion modelling.
The receptors were selected on the basis of an analysis of the receptors likely to be present in the study area, their main characteristics and the significance of the effects linked to an increase in CO_2 and / or a decrease in

pH on them. On the basis of the analyses performed and the considerations set out, the effects associated with a hypothetical and accidental release of CO_2 from the conduct on the analysed receptors is to be considered negligible, both for the limited range of interest, and for the limited exposure time to which it subjects the receptors.

3.2 Preliminary health and environmental assessments

Following the preliminary assessments on the effects of accidental CO_2 releases on the marine environment, the Operator proceeded to evaluate the releases in the plant. It is important to remember that CO_2 is asphyxiant in high concentrations and contact with liquid phase can cause frostbite. In high concentrations, CO_2 rapidly causes respiratory failure: symptoms are headache, nausea and vomiting which can lead to unconsciousness (EIGA. 2011). For the Risk Analysis the Operator defines the DTL (Dangerous Toxic Load) to evaluate a particular level of damage in the population as a function of the concentration in the air and duration of exposure, as shown in the Table 1 (HSE. 2022): SLOT (Specified Level Of Toxicity); SLOD (Specified Level Of Death).

Table 1: Limiting concentration of CO_2 as a function of exposure time

Exposure time (min)	CO2 concentration in air by volume			
	SLOT (%)	SLOT (ppm)	SLOD (%)	SLOD (ppm)
0,5	11,5	115000	15	150000
1	10,5	105000	14	140000
5	8,6	86000	11,5	115000
10	7,9	79000	10,5	105000
20	7,2	72000	9,6	96000
30	6,9	69000	9,2	92000
60	6,3	63000	8,4	84000

The exposure times analysed by the Operator are 1, 5, 20, 60 minutes. These exposure times were selected in order to evaluate the immediate effects of the releases on the operators (1 minute), for the analysis of escape routes and adjacent areas of the existing plant (5 and 20 minutes) and to quantify the impacts on assembly points inside the plant, outside the plant area and along the pipeline (60 minutes). Furthermore (DNV. 2009), the Operator has selected a CO_2 concentration level of 40000 ppm. Exposure to this concentration for a few minutes (5 minutes) does not prevent operators from escaping or from implementing safety systems (discomfort area). The results of the releases in the plant are as follows: 1. Capture & Compression - Gas phase releases: The threshold values of SLOT (Specified Level Of Toxicity - Dangerous Toxic Load) and SLOD (Specified Level Of Death - Dangerous Toxic Load) and 40000 ppm (discomfort) are not reached for persistence times required to cause damage to operators, since the releases have a short duration; in terms of lowering the temperature, the phenomenon is limited to a few meters from the breaking point; 2. Pipeline – onshore section: Total breakages 4” (simulated underground pipeline): the SLOT and SLOD values are not reached for the relative exposure times considered. 1” hole (conservative simulation with non-buried pipeline): the SLOT and SLOD values are reached within about 10 meters. The cloud covers an area that tends to be rural or in any case with a low population density. In the stretch where there is an area already destined for tourist use (camping), a preliminary risk estimate was also conducted which is less than 10-6ev/year and therefore acceptable; 3. Pipeline - offshore section (Precautionary case not considering the solubility of CO_2): Maximum reduction in sea density of the order of 1%: no problems related to the stability of the vessels are expected; The SLOT and SLOD values are reached for distances of about 10 m near the pipeline. Discomfort values (i.e. 40000 ppm) reached only in the first 5 minutes, within an area of 200 meters; 4. Platform: SLOD and SLOT values are not achieved in any of the platforms; the discomfort values (i.e. 40000 ppm) are reached around the release point, guaranteeing an escape route that is always free. Thermal effects: the results are acceptable and will be investigated with a dedicated CFD study, capable of identifying the temperature profiles inside the structures in order to verify whether dedicated protection / shielding may be necessary.

4. Corrective prevention and protection measures and related safety plans

4.1 Instrumentation and automation

The general design philosophy of the Operator is aimed at making the new plant as independent as possible from the existing plant. The Integrated Control and Safety System (ICSS) will be designed as a new system, consisting of: PCS (Process Control System), which will manage the process control; SIS (Safety Instrumented System), which will manage the new safety locks and the part relating to smoke, fire and gas detection.

The ICSS will perform supervisory functions, control and safety functions, and will provide operators with the ability to manage the various plant units in an agile and continuous manner. The ICSS will consist of the following subsystems: 1. PCS process control system; 2. SIS Safety Instrumented System (ESD/F&G); 3. Operator Interface (HMI-Human Machine Interface); 4. Workstation for engineering station (EWS-Engineering Work Station); 5. Printer and Server.
The PCS must be able to provide the following functions: Control and monitoring of plant processes and auxiliary services; Communicate with third-party control systems, to allow a complete overview of these, allowing control from existing operator stations; Manage all alarms (process and system) through visual and sound activation, recording and logging, reporting (generic print and event report in sequence "SOE - Sequence of Event report").
The SIS is the control system that returns the process to a safe state from conditions that could be dangerous or could possibly give rise to a danger if no action is taken. This system performs the safety instrumented functions (SIF) by acting to prevent the danger or mitigate its consequences.
The F&G system will provide the following functions for the new CCS plant: Detect flammable gases and fires that could compromise the safety of personnel, cause damage to the system and the environment; Interface with third-party control systems, for emergency stop of equipment where required; Interface with the ESD (Emergency Shut Down) system for the system blocks, and with the telecommunication and security systems for the activation of acoustic / visual alarms; Allow a total control and view of the plant to the operators, from the operating station (HMI). With regard to the Human Machine Interface (HMI), all the information required by the operators, whether it be for monitoring, alarming, displaying, archiving control or system protection, etc., must be viewable through the ICSS operator interface.

4.2 Fire -fighting system and fire / gas detection system

The CCS plant will have CO_2 as its main fluid, therefore the Operator has not foreseen any increase in the fire risk for the existing plant. Where necessary, the new active fire protection systems will be integrated, after verification, with the existing fire protection system and engineered in order to minimize the risk and consequences of a possible accident, while ensuring the operating conditions that are as intrinsically safe as possible for the new installation and for the system in which it is inserted. Preliminarily, it is expected that the following devices will be integrated / installed: suppression systems for electro -instrumental cabinets; portable and wheeled fire extinguishers; water and / or water / foam systems.
The Fire & Gas (F&G) system was engineered by the Operator on the basis of the substances present in the CCS plant and on the new fire scenarios. It is planned to install: smoke detectors inside the electro-instrumental cabinets; H2 detectors in battery rooms; asphyxiating, toxic and / or flammable gas detectors where necessary; heat and / or flame detectors where necessary; MCP (Manual Call Point); Sirens and flashing lights.

4.3 Electrical systems and civil structures

The Operator has foreseen that, for the electrical systems serving the new equipment, the power distribution, the protection system of the electricity network, the earth network and equipotential system, the lighting system, UPS and emergency systems are included. The design and construction of electrical systems will be based on the philosophy of designing a functional and efficient electrical network and guaranteeing the maximum safety of the systems. Since it will operate in an operational plant, it will be of fundamental importance to study solutions to minimize interference with existing plants and avoid service interruptions. The new installations and related earthing system will be interconnected to the earth network of the Casalborsetti plant and the existing grid will be integrated with both new horizontal and vertical earth electrodes and with new manifolds, maintaining the same philosophy and grid dimensions as the existing one.
With regard to the supply of electricity, and the necessary adjustments to the needs of the new plants for greater available power, the TWG has examined the aspects of safety management in the event of an electricity blackout and the related plant and management implications on the new on-shore and off-shore installations. With regard to the management of emergency stops due to blackout scenarios, for ground installations relating to the CCS system, it is envisaged that, in the event of a power failure from the grid, the system will be completely de-energized (unless vital loads under UPS) proceeding to a safe stop. Similarly, in the event of an off-shore blackout on the platform, the plant will be secured automatically and without the need for depressurization.
With regard to the safety aspects in the construction of civil works and structures, the floorings, to be made of concrete in areas where leaks or spills of pollutant liquid (typically oil from pumps, etc.) may occur, have been carefully considered by the Operator. Adequate anti-acid coating will be provided where necessary in areas close to chemical additive systems. In relation to this, the TWG investigated the possible scenarios for the release of dangerous substances on the ground, with the related areas and basins concerned, for the purpose of the correct perimeter and connected waterproofing covering of these.
The drainage system of the capture plant envisaged by the Operator can be schematized through: drainage of the capture unit containing amine; dispatch of the acidic water of the plant; dispatch of the HRSG (heat recovery

steam generator) purge water; collection of rainwater from areas not contaminated as well as from areas potentially contaminated by dangerous chemicals, for subsequent treatment and disposal using suitable means for transport.

4.4 Emergency management flows on the platform

The Operator has reported a series of diagrams relating to the emergency management flow, for the Drilling / Workover / Completion / Simultaneous phases, also for the purpose of coordinating the parties operationally involved in the Site, differentiating them into: 1st level found externally; 2nd level; 3rd level; Civil protection emergency. In particular, the TWG conducted in-depth analysis of the emergency management aspects, on the basis of the flow diagrams identified, with the relative support of procedures and operating instructions, in terms of men, means, methods, systems, etc. (general site emergency plan), also with reference to the reports of real emergency drillings and training sessions conducted by the Operator on the existing natural gas compression station and platform.

5. Conclusions

At the conclusion of the analysis conducted by the ISPRA TWG, a series of considerations and criticalities, in terms of safety management, emerged from the technical assessment of the project are reported below. These elements, connected to the risk analysis and emergency management, resulted in particular in requests for compliance, for the Operator, for the construction of this experimental CO_2 capture plant (UK. 2021):
In light of the results of the simulations following the releases of the various plant sections, it is necessary that: the emergency plans will be updated taking into account the Pipeline (offshore) and Platform sections (achievement of SLOT, SLOD and discomfort values); a CFD (Computational Fluid Dynamics) study will be carried out, in order to identify any protections / shields for all sections of the system affected by thermal effects, following the release of CO_2, on the platform.
Starting from the methods of inspection, on the pipeline, of the corrosion mechanisms, also with reference to the implemented asset integrity management procedures, the specific procedures and / or operating instructions for controlling the losses along the CO_2 transport pipeline will be made available. These methods must be based on the continuous control of the process variables (pressure and flow rate), with specific attention to the management method in the event of malfunction or anomaly or failure, with the consequent blocking logic and management of the foreseen emergencies.
On the basis of the methods and types of waste produced following activation of the drainage system of the capture plant, the types of liquid effluent produced will be characterized, from the point of view of the characteristics of environmental hazard and / or flammability and / or of toxicity.
2nd level emergency drillings will be scheduled and carried out such as to include all the accident scenarios hypothesized in those plans, in a suitable period of time (including several years), which are representative of the risk analysis conducted for the site.

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