



LESSONS LEARNED AFTER THE 2012 EMILIA EARTHQUAKES (ITALY) IN MATTER OF HYDROCARBON E&P AND GAS STORAGE MONITORING

I. Antoncetti^{(1) (2)}, F. Cappelletti⁽³⁾, C. Chiarabba⁽⁴⁾, C. Doglioni⁽⁵⁾, P. Gasparini⁽⁶⁾, R. Lanari⁽⁷⁾, E. Priolo⁽⁸⁾, A. Zollo⁽⁹⁾, D. Di Bucci⁽¹⁰⁾, F. Terlizzese⁽¹⁾, G. Dialuce⁽¹⁾, L. Panei⁽¹⁾

(1) Ministry of Economic Development ilaria.antoncetti.ext@mise.gov.it; franco.terlizzese@mise.gov.it; gilberto.dialuce@mise.gov.it; liliana.panei@mise.gov.it;

(2) Bicocca University of Milan – Interuniversity Research Centre for Economy and Territory ilaria.antoncetti@unimib.it

(3) RSE S.p.A. - Ricerca sul Sistema Energetico, francesca.cappelletti@rse-web.it

(4) INGV – Earthquakes Structure, claudio.chiarabba@ingv.it

(5) Earth Science Department, Sapienza University of Rome, carlo.doglioni@uniroma1.it

(6) University of Naples “Federico II”; Environmental Risk Analysis and Monitoring – AMRA, gasparin@na.infn.it

(7) CNR – Institute for the Electromagnetic Sensing of the Environment- IREA, lanari.r@irea.cnr.it

(8) OGS – Scientific Section Seismological Research Center, epriolo@inogs.it

(9) University of Naples “Federico II- Physics Department”, aldo.zollo@unina.it

(10) National Department of Civil Protection, daniela.dibucci@protezionecivile.it

Abstract

After the seismic events occurred in Emilia (Italy) on May 20th and May 29th, 2012, the International Commission on Hydrocarbon Exploration and Seismicity in the Emilia Region (ICHESE) evaluated the possible links between E&P activities and the seismic activity in the area affected by the earthquakes. The Commission could not rule out the possibility of a link and emphasized the need of further analyses, in order to exclude the correlation of seismic events of May 2012 to waste-water injection activities performed at the Cavone field. The Ministry of Economic Development (MiSE), the Emilia-Romagna Region and the Operator with the patronage of Assomineraria¹ carried out such analyses and found new elements against the possibility that operations could affect the seismic events. Furthermore, the Commission recommended developing new integrated monitoring systems for seismicity, ground deformations and pore pressures that were able to provide high-quality data in real time, in order to support the analysis of the possible link between the human activities and the detected seismicity. In our presentation, we describe the lessons learned after the 2012 seismicity with reference to the initiatives undertaken by MiSE to improve and optimize knowledge and management of E&P sector in a seismically active territory as Italy is.

Keywords: Earthquake; Seismic monitoring; ground deformation monitoring; E&P safety; E&P best practice;

1. Introduction

Due to its geodynamic setting, Italy is among the most seismic regions in Europe and in the Mediterranean area. From the beginning of the last century (1900) up to now, 30 very strong earthquakes ($M_w \geq 5.8$) occurred in Italy, some of which catastrophic¹.

Focusing on the last 30 years, the recent seismicity is localized in specific areas along the Apennines and the Alps, and population often perceive seismic events. More than 45 events since 1985 have $ML \geq 5.0$ (Richter).

¹ <https://ingvterremoti.wordpress.com/i-terremoti-in-italia/>.

The most recent strong earthquakes [2] are those occurred in the Abruzzo Region (6th April 2009, ML 5.9) and in Emilia Romagna and neighboring Regions (20th May 2012, ML 5.9).

The present paper is focused on the lessons learned after the 2012 Emilia earthquake sequence, after which several actions were developed by the Italian Ministry of Economic Development in order to improve and better control some aspects of E&P activities.

The 2012 seismic sequence in the Emilia Region was characterized by two main events, occurred on 20th and 29th May 2012 (Fig.1.1). After these events, the Emilia-Romagna Region requested to the Italian Department of Civil Protection to designate an International Commission to investigate the possible correlations between seismicity and human activities related to hydrocarbon production and storage. The two questions posed to the International Commission on Hydrocarbon Exploitation and Seismicity in Emilia Region (hereinafter-ICHESE Commission) were:

1. Is it possible that the seismic crisis in Emilia has been triggered by the recent researches at the Rivara site, particularly in the case of invasive research activities, such as deep drilling, fluids injections, etc.?
2. Is it possible that the Emilia seismic crisis has been triggered by activities for the exploitation and utilization of reservoirs carried out in recent times in the close neighborhood of the seismic sequence of 2012?

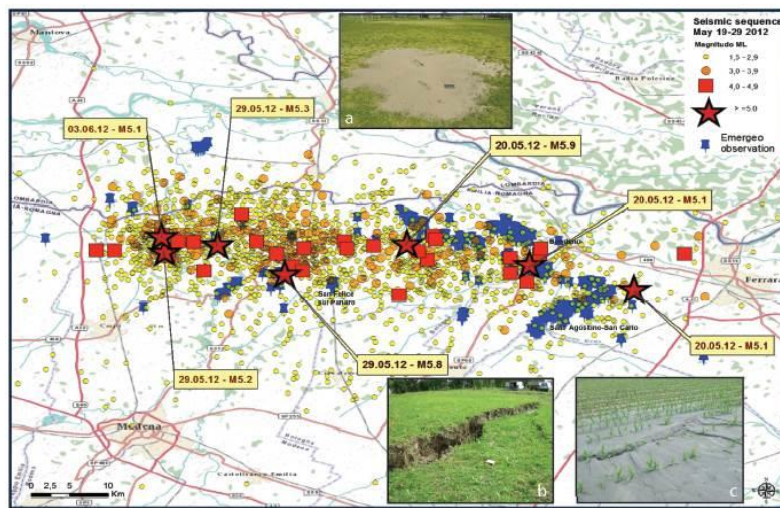


Figure 1.1 Seismic sequence in the Emilia Po Plain from May 19th to June 19th, 2012 (<http://iside.rm.ingv.it/>). In a month, more than 2000 seismic events occurred, 7 of which with $ML \geq 5.0$ (red stars).

The answers of the ICHESE Commission are contained in a Report [3], based on the technical-scientific knowledge available at that moment. In particular, the Commission studied an area of about 4000 km², encompassing the entire seismic sequence and including:

- 3 exploitation licences (Mirandola, Spilamberto and Recovato oil fields);
- the geothermal field of Casaglia (near Ferrara);
- the area considered in the Rivara Storage project

The Report take note, considering the first question, that the Rivara storage project was rejected by the Ministry of Economic Development², (DGS-UNMIG³) and, no kinds of mining activities have been performed at the

² On June 19, 2013 the DGS-UNMIG presented an official statement (Appendix D) providing a declaration in which it is officially stated that, with respect to the Rivara storage project, the Ministry has not authorized any kind of mining activity (“[...] it is evident that this Administration has not authorized any mining activity in the area related to the Rivara storage project”) and that no mining activities were carried out in the past 30 years (“[...] The central and the territorial offices of the DGS-UNMIG have no evidence of mining activities carried out in the past 30 years and that the last well drilled in the area has been the “Bignardi 1 DIR” in 1981, but with complete shutoff of well in June 1982”). The DGS-UNMIG also provided the Commission with a complete report on the Rivara permit procedure.



Rivara site in the recent years, so the answer to this first question was therefore that it is not possible that seismic crisis in Emilia has been triggered by the researches at the Rivara field.

Answering the second question, the analysis was conducted in particular on two licenses: Mirandola (Cavone field) and Casaglia. The other ones were ruled out based on their location with respect to the seismic sequence and on the lack of continuous operations of waste-water injection before and during the 2012 seismicity.

The methodology used for establishing/excluding the possible correlation between E&P activities and seismic events consisted of the following steps:

- in-depth review of the state of knowledge of the historical seismicity and geological setting;
- critical review of the literature on induced and triggered seismicity, and analysis of some case studies in the world;
- definition of fluid characteristics and tectonic stress potentially responsible to trigger an earthquakes and their possible relations;
- structural setting and seismological analysis, supported by the elaboration of a 3D velocity model of the studied area, relocations of the seismic sequence;
- analysis of the Coulomb stress changes in the area.

A correlation analysis was conducted among the main results of this first part of the study and the principal parameters potentially able to affect the seismicity (production and reinjection water volumes and pressure); the physical characteristics of the reservoir were also considered, and a statistical analysis of seismicity and production data was carried out.

In conclusion, the Commission reported that “it is highly unlikely that the activities of hydrocarbon exploitation at Mirandola and the geothermal activity at Casaglia have produced sufficient stress change to generate an ‘induced’ seismic event. While it cannot constitute proof, the current state of knowledge and all the processed and interpreted information does not allow the ruling out of the possibility that the actions involved in hydrocarbon exploitation in the Mirandola field may have contributed to ‘trigger’ the Emilia seismic activity.

Therefore in order to build a physical model that supports the statistical analysis it would be necessary to have an image as complete as possible of the dynamics of fluids in the reservoir and in the surrounding rocks”.

This means that, while the Commission excluded any kind of link between the occurred seismicity and operations in Spilamberto, Recovato, Minerbio and Casaglia fields, it was not able to rule out that activities carried out in the Mirandola license area may have induced a triggering effect. However, considering that Apennines thrust belt buried under the Po Plain sediments is seismically active, the ICHESE experts recommended to accompany the production activity with appropriate actions (like monitoring), which can help to manage the seismic risk associated with these activities.

The Commission suggested, in its own Report, a series of recommendations -mainly for the Ministry of Economic Development- to undertake different actions, both with Operators and research Institutes.

Although any doubt about a possible correlation between the Cavone oil field production operations and seismic sequence of 2012 was later removed [4] [5], a first lesson learned based on this experience concerns the need to introduce proper changes in the Italian regulatory framework (to solve any possible lack in the law) on E&P sites monitoring, and to consequently adequate the existing monitoring systems case by case. This is crucial, given the complex tectonic setting and high seismicity of our country and considering the difficulties in distinguish natural earthquakes form induced or triggered ones. The discrimination of signals, based on a sophisticated monitoring system, is a challenge in science; in fact, it could improve knowledge and consequently provide support to the prescriptions for risk assessment of oil and gas plants and the prevention of microseismic hazard.

For this reason, the ICHESE Commission also highlighted the need for an integrated monitoring system including seismicity, ground deformation and pore pressure in hydrocarbon E&P and storage site, and suggested that all the data should be continuously statistically analyzed.

This requirement could be seen as well as a tool to encourage the dialog between institutions and territories, and as a further effort aimed at making available to the public all the main information on ongoing E&P activities and initiatives.

³ Directorate General for Safety, also environmental, in energy and mining activities of the Ministry of Economic Development (previously Directorate General for mineral and energy resources DGRME)

2. Lessons learned: actions and initiatives

The improvement of the technical procedures and the implementation of a specific regulatory framework represented an important task to develop for Ministry of Economic Development after the Emilia experience, which emphasized the lack of a standardized approach - shared among Competent Authorities, Research Institutes and Operators - in managing the monitoring activities on sites involved in industrial activities (E&P included).

In order to satisfy the ICHESE recommendations, several initiatives have been undertaken by the Competent Authorities, in particular by the Ministry of Economic Development.

In the following section all the initiatives promoted after the Emilia earthquake and listed below are described in detail (Fig. 2.1):

- The “Laboratorio Cavone” project, by Ministry of Economic Development in agreement with Emilia Romagna Region, Padana Energia S.p.A. and Assomineraria;
- The “Guidelines for monitoring seismicity, ground deformation and pore pressure in subsurface industrial activities” (hereinafter ILG, acronym for the Italian title “Indirizzi e Linee Guida”), released by a Working Group including scientists and institutional representatives [6];
- The preliminary experimental application of the ILG to three case studies (Cavone, Casaglia and Minerbio fields);
- The signature of agreements between Ministry of Economic Development and scientific institutes aimed at E&P Offshore Operations Safety.

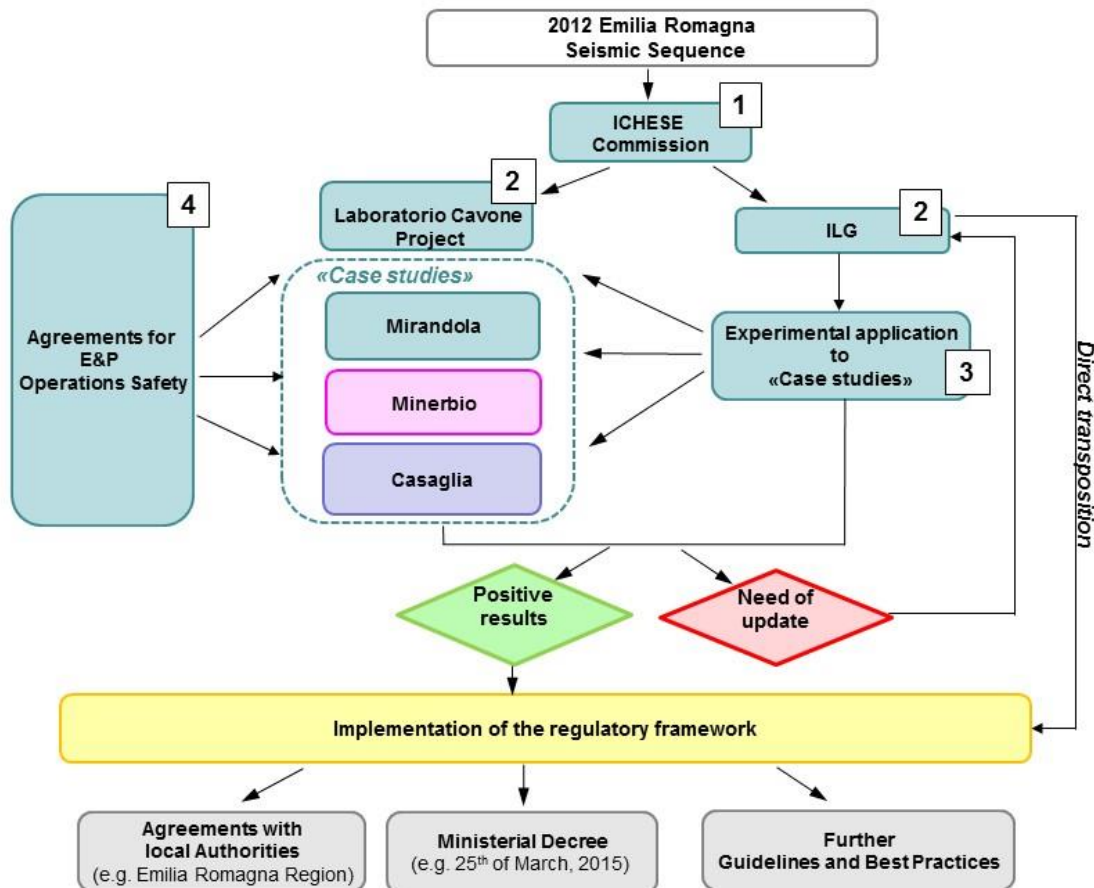


Figure 2.1 Diagram showing the four initiatives engaged by the Italian Ministry of Economic Development after the Emilia-Romagna seismic sequence (2012): 1) ICHESE Recommendations; 2) ILG; 3) Experimental



application to three Case studies; 4) Agreements for safety. Arrows define the workflow (1-4) and the interactions among these initiatives. In yellow, the first important result coming from the activities conducted in the past 3 years: the implementation of the regulatory framework.

3. The “Laboratorio Cavone” project

The “Laboratorio Cavone” project was immediately implemented, under the boost of the ICHESE Commission recommendations, with the principal aim to provide a complete geological dataset need to satisfy the last open questions in the ICHESE Report (the fluido-dynamic model of reservoir and of the surrounding rocks through an updated physical model and proper field test). This project was realized through an agreement among the Emilia-Romagna Region, the Ministry of Economic Development and Padana Energia S.p.A.⁴ under the patronage of Assomineraria.

A group of experts of the MIT University carried out the interpretation of the injection tests and built up a dynamic reservoir model, correlated with the analysis of the tectonic setting and seismicity, and integrated with the study on the possible mechanisms of induced seismicity, applied to the Cavone field (Fig. 3.1.1). The activities, which ended on July 2014, suggested that there was no physical reason to suspect a possible correlation of the production operations with seismic events of 20th and 29th May 2012[4], [5]. The National Institute of Geophysics and Volcanology (INGV) validated the modeling methodology.

All the documents about the project and the subsequently continuous collection of information and data are available on the project web site. Padana Energia S.p.A. provided INGV⁵ with data collected during the 2015. After the conclusion of the “Laboratorio Cavone” project, in fact, the experimental application of the ILG to the “Mirandola” licence started as one of three case studies.

The ongoing work in this phase consists of the detection of seismic data, referred to a wide area (extended area of 8000 km²), acquired both by the local⁶ (installed by the Companies around the reservoir) and national seismic network (managed by the INGV). Within 24 hours from an event, data are published on the web site (<http://labcavone.it>) in a table displaying all the parameters, and projected on a map that shows its location. The collected seismic data are also correlated with production data (oil and water production volumes, water injection and pressure). These data are elaborated and included in a detailed report on seismic event detected.

The reports list all information about the events detected from the local networks: localization and, comparison with the detection acquired by INGV monitoring network, depth, production and water reinjection data.

During 2015, 64 events with a Magnitude in a range of 1.1–4.0 were detected in the survey domain and analysed (following the general ILG criteria also described in part in the following section 4), 28 of which located in the so-called “inner survey domain”⁷ and the remaining ones in the “extended survey domain”⁸.

The events within the inner survey domain were examined in single preliminary reports; they are also described in an in-depth study, which covers the entire period of observation, with the aim to highlight information about the trend of the monitored seismic activity.

⁴ Data, activities and information about this project are available at link <http://labcavone.it/>.

⁵ INGV, <http://cnt.rm.ingv.it/>

⁶ The Cavone Field has a seismic monitoring network characterized by 4 permanent station around the field.

⁷ The Inner survey Domain (DI), according to ILG, defines the volume within which induced seismicity and ground deformation could be potentially caused by industrial activities. It represents the volume within which seismicity and ground deformation will be monitored, analysed and, when possible, identified with maximum sensitivity.

⁸ The Extended survey domain (DE), according to ILG, is a wider volume surrounding the DI, which is used to better constrain monitoring and to help the interpretation of the measured quantities (i.e.: seismicity, deformation, and pore pressure) within the existing structural and geological background. For all the activities, it is suggested that it stretches beyond the DI to a neighborhood of 5-10 km, taking into account both oilfield dimensions and type of activities.

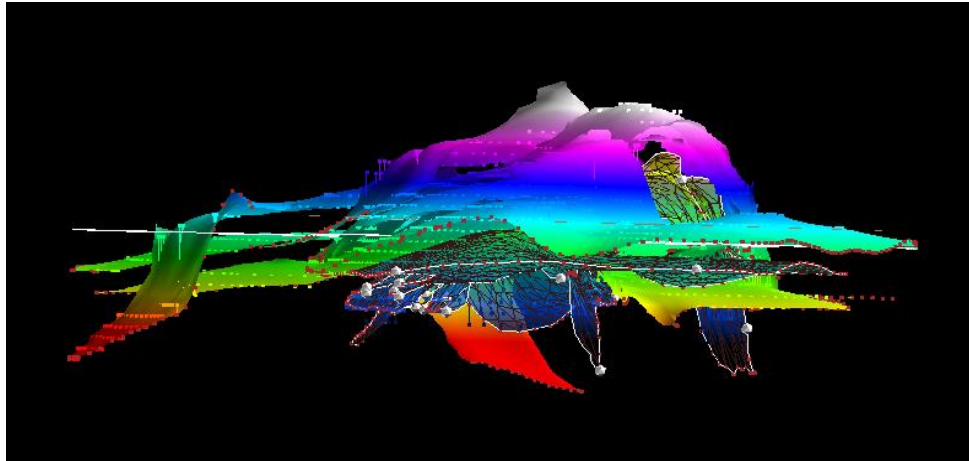


Fig. 3.1.1 Dynamic reservoir model of the Cavone field [2].

4. Guidelines for monitoring seismicity, ground deformation and pore pressure in subsurface industrial activities (IGL)

Although in Italy, in the E&P sector, several areas of license are equipped with an own seismic monitoring network⁹ following the ICHESE recommendations the Ministry of Economic Development had the opportunity to consider a new approach to the problem of natural and induced seismicity. This approach mainly consisted in the attempt to understand the link that could exist among different phenomena like microseismic events, ground deformation and pore pressure behaviour in the reservoir.

This approach brought to the ILG writing, whose pillar is represented by an integrated monitoring system of the three mentioned phenomena. It represents a new scientific challenge that, through a high level of technology, aims at reaching high standards of safety and, most of all, an immediate and efficient response in case of emergency.

At the current stage, the ILG provide indications and general criteria for technical prescriptions and best practices that the competent Administrations, involved in the licensing procedure, can set up and suggest to the Companies, with particular reference to reinjection activities carried out onshore.

The ILG are currently focused on the onshore industrial activities, to which they will be firstly applied; but they can also be applied with proper technical adjustments to the offshore activities. They are an appropriate reference for natural gas storage and hydrocarbon operations, and could be extended to other type of human activities like dams, conventional geothermal systems, closed loop geothermal binary cycles, mining activities (mines and quarries) or tunnels digging.

First of all, a geological, structural and seismotectonic characterization of the area is required, as a preparatory phase to plan the monitoring network or to upgrade the existing one if it does not fit the requirements detailed in the ILG themselves. In fact, all the prescriptions of the ILG are also finalized to optimize the existing infrastructures and increase the quality of the acquisition with respect to the crustal volume to monitor and the technical performance of the monitoring network (as defined in the ILG). Then, specific details on the monitoring activities and results are provided [6], as summarized hereinafter.

4.1 Seismic, ground deformation and pore pressure monitoring features

Monitoring activities, carried out before the industrial activities start, allow to quantify the background values of monitored parameters. This is relevant to compare the background values, previously acquired, with the possible seismicity and the variations of the parameters themselves measured in continuous during the operating period.

⁹ ISPRA Report -August 7th, 2014 reports all the licences with a seismic monitoring network



In this specific frame, *seismic monitoring* is aimed to identify and localize the seismicity in a volume surrounding the area where hydrocarbons exploitation activities take place, also with the purpose to distinguish natural seismicity from the one possibly due to such activities. The monitoring must allow the space-time-magnitude evolution of the seismicity to be followed, with the aim, if needed, to re-modulate or interrupt (in the foreseen cases) such activities. In particular, seismic monitoring before and during the operations should be carried out with a dedicated local network capable of detecting, locating and characterizing all earthquakes with magnitudes of at least 0.5 ML. The ILG indicate some information about the threshold of attention given to different ranges of magnitude, also identifying a preliminary *traffic light system* (Tab. 4.1.1 and 4.1.2). The ILG suggest to experimentally adopt a *traffic light decisional system* (specifically for underground fluids reinjection activities), defined through 4 activation levels (from 0: ordinary conditions, to 3: stop of activities), established on the evaluation of the variation in number and frequency of seismic events, related magnitudes and spatial distribution, peak ground acceleration and velocity values, change of ground deformation rates and variation of pore pressures, with threshold values. Based on the monitoring results, three different management phases are identified: Phase 1 - Ordinary management of monitoring, Phase 2 - Ordinary management of variations in the monitored parameters, Phase 3 - Extraordinary Management of variations in the monitored parameters. Each phase requires different measures to be undertaken in order to keep the activities safe during time.

As a first application, it is suggested to test the adoption of a traffic light system in the inner survey domain, related to reinjection wells. The variability of the geological settings, of the depths and ways the activities are carried out, of the natural background seismicity and its depth, does not allow to univocally set the threshold values for all the parameters, but only for some of them. In particular, the variations of ground deformations and of their velocity rates have to be evaluated case by case, depending on their spatial distribution and taking into account the background deformation frame.

Activation Level	Corresponding Status
0	Ordinary conditions
1	Attention
2	Reduction of activities
3	Stop of activities

Table 4.1.1 Activation Levels, established through the evaluation of the overall frame of the monitored parameters.

Activation Level	Traffic light	M _{max}	PGA (% g)	PGV (cm/s ²)
0	Green	M _{max} ≤ 1.5	-	-
1	Yellow	M _{green} ≤ M _{max} ≤ 2.2	0.5	0.4
2	Orange	M _{yellow} ≤ M _{max} ≤ 3.0	2.4	1.9
3	Red	M _{orange} < M _{max}	6.7	5.8

Table 4.1.2 Ranges or indicative values for the parameters monitored in the inner survey domain, to be used as a reference for the thresholds definition. The following parameters are defined: maximum magnitude (M_{max}), peak ground acceleration (PGA) and peak ground velocity (PVG).

The traffic light decisional system considers some procedures aimed at undertaking actions related to different activation levels, defined on the basis of threshold values of the monitored parameters. Taking into account the current scientific knowledge, the experts who authored the ILG did not consider appropriate to adopt a decisional model, which encompasses traffic light automatism linked to precise threshold values, for all the activities treated in the IGL. In particular, the variations of the deformations and of their velocity rates have been evaluated case by case, depending on their spatial distribution and with reference to the background deformation. Moreover, the group of experts who authored the ILG also clarified that the ILG do not foresee the application of the traffic light system to the natural gas storage activities. In fact the group explained that for reinjection is intended only the incompressible fluids.



Ground deformation monitoring is intended as the identification of possible surface deformation phenomena linked to the considered activities, and it aims to measure and analyze their space-time variations compared to the background conditions. The recommended instruments to measure the ground deformation are mostly based on Earth observation satellites: ILG defines that an interferometric (INSAR) and GPS technology should be carried out by the Companies, allowing a resolution of some mm/year with the aim of identifying subsidence trends.

The *pore (or reservoir) pressure* monitoring measures the bottom hole pressure aimed at verifying the fluid-dynamic model and at evaluating the space-time evolution of the pressures. For these reasons, it must be measured directly at the bottom of the wells and in the surrounding rocks on a daily basis.

4.2 Structure in charge for Monitoring - SPM

ILG suggest that the design, realization and maintenance of the monitoring networks be made by an independent body defined as Structure in charge for monitoring (hereinafter SPM, from Italian acronym for *Struttura Preposta al Monitoraggio*). At present, the Italian national regulation does not encompass an institutional body with specific competences, suitable for the control of the monitoring activities. For this reason, in the current transient phase, a highly skilled, technical/scientific subject has been defined to support the Authority in the management and analysis of the monitoring data. Therefore, waiting for the institution of a fund that would allow the Ministry of Economic Development to issue such a competent institutional body, the SPM is intended as technical body supporting the Ministry, and it is composed by one or more Universities or Research Institutions with proved skills in the considered fields, if needed joined in a consortium, also with private Companies. For each license, one SPM will be identified. The principal tasks of the SPM are:

- to acquire and analyse current and previous data (production/reinjection/storage, geological, monitoring data, etc.)
- to evaluate the monitoring project (or to implement it, if engaged by the Owner of the license)
- to produce elaborations, studies and interpretations of the collected data.

4.3 Recommendations

In order to minimize the potential impact of production activities implying fluids reinjection, ILG recommends to preserve the natural original load, preserving the balance between produced and reinjected fluids as near as possible to zero; to keep the reinjection pressure as near as possible to the original natural one and to evaluate the reinjection pressure by means of injectivity tests.

More in general, it is suggested that Ministers (e.g., Research, Environment, Economic Development) promote some specific research items, as recognition and characterization of induced, triggered and natural seismicity, development of quick and reliable methodologies to establish the correlation among the different monitored parameters and the exploitation activities, analysis of the meaning of the observed values in comparison with production/reinjection/storage parameters, and procedures for integrating induced seismicity in time-dependent seismic hazard evaluations.

4.4 Application

ILG define a period of evaluation of the technical prescriptions in which the indications given must be experimentally applied to some case studies, identified by the Ministry of Economic Development.



5. “Case Studies”

The case studies identified by the Ministry of Economic Development for the experimental application of the ILG are three and refer to three different kind of industrial activities:

- Cavone field (Mirandola license) – hydrocarbon exploitation with water reinjection operations
- Minerbio field – natural gas storage
- Casaglia field (Ferrara license) – traditional geothermal resources exploitation

As said before (section 3), the first agreement for the application of the ILG was related to the Cavone field, being already signed by the Parties an operational protocol for the Laboratorio Cavone project. More recent was the agreement related to the Minerbio field, signed on 5th May, 2015. The experimental phase will start when all the three protocols will be signed. In the meanwhile, the Ministry of Economic Development charged the National Institute of Geophysics and Volcanology with SPM task for the three case studies, according to the ILG. Other subjects involved in this phase of experimental application of the ILG are (apart from Ministry of Economic Development) the group of experts who wrote the guidelines, the Companies managing each case study and Assomineraria, the national association of hydrocarbon companies.

6. Agreements for Offshore E&P Operations Safety

According to the recommendations of the ILG, Ministry of Economic Development is establishing several collaboration agreements with research institutes to investigate some specific aspects of the seismic hazard (natural and induced) in the monitored zones and of the monitoring systems (in terms of technological innovation), and to study how to apply the ILG to the other kinds of activities suggested.

This method, clearly innovative and proactive, is set up by the Ministry of Economic Development, who invests in research for safety and risk prevention¹⁰. Some initiatives have been set up, in particular, to guarantee defined actions for the application of the monitoring approach proposed by the ILG:

- development of feasibility studies for seismic and ground deformation monitoring (also to identify appropriate procedures to monitor offshore platforms);
- development of methods to conduct a real-time correlation analysis between seismicity and production parameters;
- economic evaluation of the costs of monitoring as defined by the ILG;
- offshore operations monitoring – by drilling and recording systems for drilling parameters;
- seismic hazard and NATECH risk assessment for existing platforms;
- discrimination between natural and induced seismicity through specific markers in the seismic signal.

8. Conclusion

The first important result of the new approach derived from the lessons learned described in this paper is the concrete adoption of new rules in the E&P regulatory framework. In particular, with the Ministerial Decree 25th of March 2015 (art. 13 par. 1, 2; update of "Disciplinary code" for hydrocarbons exploration and production), the obligation for the Companies to implement a monitoring system following the best practices for all the new applications was introduced. The new regulation establishes that:

¹⁰ D.Lgs 18th august, 2015 n.145 (transportation of Directive 2013/30/UE) and D.Lgs 26th June, 2012 n.83



- “The Ministry Provides the application of seismic, ground deformation and pore pressure monitoring and linked operations applying advanced techniques These measures will be progressively applied also to the existing activities after an appropriate period of experimentation and verification on the case studies” (com. 1, Art. 13).
- “The ILG published by the group of experts with provision of 27th of February, 2014 is considered as representing advanced techniques” (com. 2, Art. 1).

Furthermore, Ministry also started a fruitful collaboration with the Emilia-Romagna Region through an agreement that issued a working group formed by Ministry of Economic Development and Emilia-Romagna Region to conduct and share:

- the experimentation of the ILG on the three case studies;
- the definition of a shared transitory procedure for application of monitoring measures at hydrocarbon / storage /geothermal licenses until the conclusion of experimentation of the ILG and of their official adoption;
- the evaluation of the opportunity and the modality of their application to the current procedures;
- the diffusion of information on the activities of the group;
- the definition of the way of application of the decisional model based on threshold values (“traffic light system”).

In conclusion, this new approach, and the consequent initiatives launched by Ministry of Economic Development, establishes a flexible system that allows the continuous enhancement of the regulatory framework on monitoring, taking into account the scientific progresses (in particular the innovation in technologies), the Operators’ needs of assuring the best safety measures, and the operational feedback of the application in the field of new provisions.

This virtuous cycle guarantees also the transparency and the collaboration of all involved institutions and stakeholders and, at the same time, promotes the research and development of high technologies for industries.

8. Acknowledgements

Thanks are due to all the experts from Research Institutes and Companies, who are sharing their own knowledge, data and reasoning to improve consequently the E&P activities' safety.

9. References

- [1] Dolce M. & Di Bucci D. (2015) - Comparing recent Italian earthquakes. Bulletin of Earthquake Engineering. Special Issue: Post-earthquake assessment. doi: 10.1007/s10518-015-9773-7. Pubblicato online: 23.05.2015.
- [2] International Commission on Hydrocarbon Exploration and Seismicity in the Emilia region (ICHESE), 2014. Report on the Hydrocarbon Exploration and Seismicity in Emilia Region. 213 pp. http://mappegis.regione.emilia-romagna.it/gstatico/documenti/ICHESE/ICHESE_Report.pdf
- [3] Astiz L, Dieterich JH, Frohlich C, Hager BH, Juanes R, Shaw JH (2014): On the potential for induced seismicity at the cavone oilfield: analysis of geological and geophysical data, and geomechanical modeling. Technical Report 2014/07, Massachusetts Institute of Technology, USA.



- [4] Mucciarelli M., Donda F., Valensise G., (2015): Earthquakes and depleted gas reservoirs: which comes first? *Natural Hazards Earth System Science*, 15, 2201–2208, (2015). doi:10.5194/nhess-15-2201-2015
- [5] Dialuce G., Chiarabba C., **Di Bucci D.**, Doglioni C., Gasparini P., Lanari R., Priolo E., Zollo A. (2014) - Indirizzi e linee guida per il monitoraggio della sismicità, delle deformazioni del suolo e delle pressioni di poro nell'ambito delle attività antropiche. 38 pp. Published on line on 24th november 2014 at the link: <http://unmig.sviluppoeconomico.gov.it/unmig/agenda/dettaglionotizia.asp?id=238>
- [6] Macini P., Mesini E., Panei L., Terlizzese F. (2015) - Land subsidence, seismicity and pore pressure monitoring: the new requirements for the future development of oil and gas fields in Italy. *Proc. IAHS*, 372, 533–538, 2015. Published on Prevention and mitigation of natural and anthropogenic hazards due to land subsidence. doi:10.5194/piahs-372-533-2015

1. ⁱ Italian E&P Companies' Association