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DOI: https://doi.org/10.64388/IREV10I1-1719714

Pulsed Neutron Logging Frameworks for CO_2 Plume and Well Integrity Surveillance in Mature Asset Conversion

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***Abstract-** The world is moving towards CCS and considerable interest has been created in the re-use of old oil and gas wells for CO_2 injection and storage. This has many economic and logistics benefits, but also creates a dual monitoring need: not only tracking the migration of the subsurface CO_2 plume but also ensuring the long-term mechanical integrity of the converted well systems. Permanently cased wellbores are an area of great monitoring need that conventional open-hole wireline techniques are unable to meet. This paper offers a proposed concept of a synthesized framework for the deployment of PNL as a dual-purpose surveillance tool in a converted hydrocarbon producing well for CO_2 injection/CO_2 storage. The framework has been developed based on the field deployments and analyses of the various international CCS projects, such as Ketzin (Germany), the Otway project (Australia), the Illinois Basin-Decatur Project (USA) and simulation work in China and Romania, and combines the two main measurement modalities of PNL, the macroscopic thermal neutron capture cross-section (Sigma, Σ) and the carbon/oxygen (C/O) ratio log. These measurements can be combined to provide quantitative estimation of CO_2 saturation, identification of plume boundaries and detection of fluid migration behind casing in a single cased hole tool deployment. The paper also makes a synthesis of multi-detector acquisition configurations, forward modeling using Monte Carlo methods and the new emerging machine learning interpretation schemes that can improve the diagnostic accuracy of PNL. Importantly, the multi-purpose nature of PNL—the geochemical plume tracking and structural integrity survey—makes it an essential part of a comprehensive CCS portfolio. The framework takes the research forward in the systematic nature of closing the gap in the monitoring for mature asset conversion scenarios.*

***Keywords:** Carbon Capture and Storage (CCS), Pulsed Neutron Logging (PNL), CO_2 Plume Monitoring, Well Integrity, Mature Asset Conversion, Sigma Logging, Carbon/Oxygen (C/O) Ratio Logging.*

I. INTRODUCTION

Storage of CO_2 in mature oil and gas assets is one of the most realistic opportunities for scaling up carbon capture and storage (CCS) deployment in the near-term. The cost of CCS projects is reduced compared to purpose-drilled greenfield sites, as is the time needed to develop projects, due to existing wellbore infrastructure, the loss of reservoir pore volume, and decades of reservoir characterisation data (Ringrose, 2020). But converting production wells to injection or monitoring wells creates a surveillance challenge, which is complex and partially unsolved. After wells are permanently completed in steel casing and cement, conventional formation evaluation methods (open-hole wireline logging, core analysis, and pressure transient testing) are not available. However, regulatory requirements for CO_2 storage, such as the European Union's CCS Directive (2009/31/EC) and similar national regulations, have strict monitoring requirements after CO_2 is injected, including the ability to prove that injected CO_2 is contained within the authorised storage complex and that well integrity is maintained during the operational and post-closure phases.

The main issue that this paper addresses is this monitoring gap within cased wellbores between what regulators need and what conventional monitoring techniques are able to provide. Pulsed neutron logging (PNL) tools, which were first developed for cased-hole formation evaluation in hydrocarbon reservoirs, have the ability to interrogate the subsurface fluid composition and saturation state without any physical contact with the wellbore completion and through steel casing and cement. The operation mode makes them very sensitive to variations and fluid change, such as replacing brine or residual HC with CO_2 and recording the gamma-ray/neutron response as a function of time. There are documented prior applications in hydrocarbon

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settings (Pemper et al., 2006; Radtke et al., 2012) but the systematic use of these applications in a dedicated CCS monitoring framework is still an emerging, and unsynthesised area of practice.

This paper has three aims. It first examines the physical basis of PNL responses to CO_2 saturation, and the measurement modalities pertinent to the CCS surveillance. Secondly, it compiles research gained from work completed in selected field deployments and analytical studies to create a repeatable methodology to support dual purpose PNL surveillance (CO_2 plume tracking and well integrity assessment), in the context of mature asset conversion. Third, it will help define the key integration needs, constraints, and future development needs that will define the usefulness of PNL as a foundational CCS monitoring technology. The paper fits into the larger literature on subsurface surveillance by specifically placing PNL in the regulatory and operational requirements of the conversion of a mature asset.

II. BACKGROUND AND LITERATURE REVIEW

2.1 Physical Principles of Pulsed Neutron Logging

Pulsed neutron logging (PNL) is based on the principle of high energy (14MeV) neutron pulses from a downhole electronic neutron source (typically a deuterium–tritium (D–T) or deuterium–deuterium (D–D) generator) being fired into the surrounding formation (Ellis & Singer, 2007). After every pulse, the tool collects the responses of the neutrons and gamma rays with the near and far detectors. The macroscopic thermal neutron capture cross section (Sigma, Σ) is the principle parameter used for CO_2 storage that represents the rate of absorption of thermal neutrons by the formation. When saline formation water is replaced by CO_2, the measure change in Sigma is significant due to the high value of the saline formation water compared to CO_2. These changes can be translated into quantitative estimates of CO_2 saturation under the right conditions of calibration and understanding of the formation matrix and fluid properties (Anghel Sorin, 2025; Li & Zhang, 2024).

The second important measurement, which is derived from an inelastic gamma-ray spectrum, is the carbon/oxygen (C/O) ratio log. Carbon to oxygen ratios are useful for distinguishing the carbon from the oxygen in the formation, and are generally not influenced by the salinity of formation water, so they are especially useful where formation-water salinity is uncertain or patchy in space (Pemper et al., 2006; Watson et al., 2018). While C/O logging may be more useful in these conditions to get more reliable saturation estimates, it tends to take longer acquisition times due to lower count rates (Radtke et al., 2012). Modern multi-detector PNL tools are used to enhance depth of investigation and reduce borehole effects, and Monte Carlo neutron transport simulations, such as using MCNP, are used to generate calibration models for different reservoir conditions and how they affect field measurements (Jia et al., 2026; Li & Zhang, 2024).

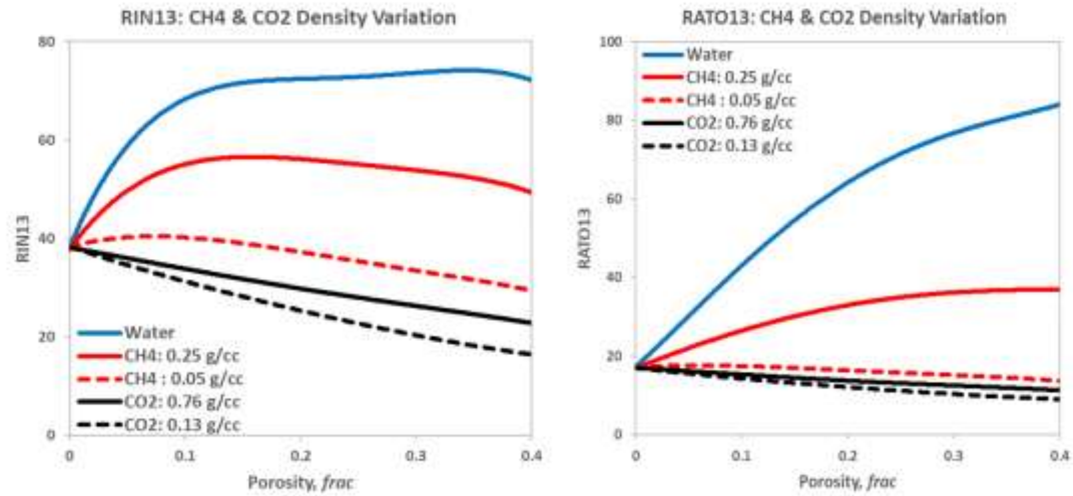

Fig 1: Monti Carlo models, showing Pressure & Temperature changes, RIN13 & RATO13 for CO2 has less variation than CH4 , PN data are less sensitive to CO2 density variation than CH4 . (Kin et al 2016)

2.2 Prior Field Deployments in CCS Contexts

PNL has been used with success in a number of large-scale CO_2 storage demonstration projects. The Frio Brine Pilot in Texas, USA, showed successful identification of CO_2 breakthrough in saline sandstone in the reservoir, which was a first proof of the potential of time-lapse Sigma logging to monitor CO_2 movement into a geological storage formation (Hovorka et al., 2006). The Midwest Regional Carbon Sequestration Partnership (MRCSP) project also showed the potential of PNL to carbonate reservoir applications; however, quantitative estimates of reservoir saturations were less accurate due to reservoir heterogeneity (Clulow et al., 2010). In Germany, the borehole logging was combined with the seismic survey, and with electrical resistivity tomography and laboratory petrophysical analyses to monitor CO_2 migration into the Stuttgart Formation for the Ketzin pilot project (Martens et al., 2012). The project used geoelectrical methods as the main monitoring technology, but showed the benefit of combining the various monitoring technologies to aid the interpretation. The Illinois Basin–Decatur Project in the USA used the Schlumberger Reservoir Saturation Tool (RST) during the pre-injection, injection and post-injection stages with successful monitoring of the CO_2 plume migration and redistribution, consistent with seismic monitoring and vertical seismic profiling (VSP) (Greenberg et al, 2017). Likewise, the CO_2 saturation estimates were produced using the Baker Hughes PNL tools and Monte Carlo modelling for the Otway Stage 2C Project in Australia, where salinity was not a concern. The gas accumulation above perforations and CO_2 breakthrough were observed using time-lapse logging, establishing PNL's potential to monitor plumes and assess well integrity (Watson et al., 2018). These studies, taken together, validate the use of PNL as a tool for CCS monitoring, and identify some reservoir heterogeneity issues, formation-water salinity, and the need to use PNL in combination with other monitoring technologies.

2.3 Well Integrity Failure Modes in Converted Assets

Well integrity is a critical aspect of a safe conversion of mature oil and gas wells for CO_2 storage and is defined as the integrity of the casing as well as the hydraulic performance of the cemented annuli (Carey et al., 2007). The principal failure mechanisms are the formation of corrosion on the casing due to the generation of carbonic acid as a result of the reactions between CO_2 and the brines, cement carbonation forming micro-annuli or fractures and the mechanical stresses due to the variations in pressure and temperature during the transition from hydrocarbon production to CO_2 injection (Duguid et al., 2011). Older wells are especially susceptible owing to the fact that the majority of the wells were drilled using

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DOI: https://doi.org/10.64388/IREV10I1-1719714

conventional Portland cement that is not suitable for long-term CO_2 exposure (Zhang & Bachu, 2011).

Relying on the CO_2 or any formation fluid change in the cement defects and annular areas that changes the neutron and gamma-ray response in the cement, PNL plays a role in well integrity monitoring. PNL is not a direct cement evaluation tool, but when combined with other integrity monitoring methods (such as ultrasonic cement evaluation logs) it can give valuable evidence of fluid migration and it is more effective in this regard.

III. METHODOLOGY / FRAMEWORK

3.1 Framework Overview

The framework created in this study brings together the monitoring protocols, interpretation methods and integration strategies found in the six selected studies. It offers a framework to be followed for the use of pulsed neutron logging (PNL) throughout the life of CO_2 storage in mature assets. There are four successive phases to the framework: pre-injection baseline acquisition, active injection monitoring, post-injection surveillance, and well integrity assessment. The objectives of each phase as well as the complementary monitoring technologies for CO_2 plume tracking and well integrity evaluation are detailed.

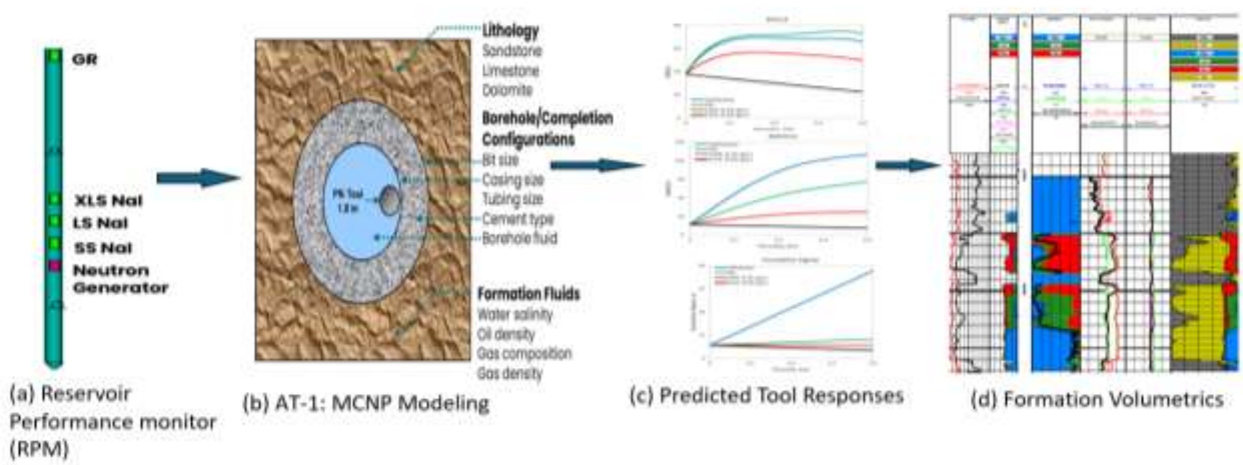

Fig 2: Pulsed Neutron Based Framework for Saturation Evaluation (Akagbosu et al. 2023)

3.2 Phase 1: Pre-Injection Baseline Acquisition

There is a need for baseline PNL logging for accurate time-lapse interpretation. Pre-injection logging was completed for both the Decatur and Otway projects to create reference Sigma and Carbon/Oxygen (C/O) ratio profiles for injection prior to the start of CO_2 injection (Greenberg et al., 2017; Watson et al., 2018). Likewise, Anghel Sorin (2025) suggests baseline surveys and using fluid substitution modelling to consider the salinity variability of the formation water. In this stage, Monte Carlo simulations are performed to construct calibration models of the neutron responses, which are calibration models relating neutron responses with porosity, lithology and fluid saturation (Jia et al., 2026; Li & Zhang, 2024). These calibrated responses are used as a reference to all subsequent passes of logging, thus enhancing the accuracy of the estimation of CO_2 saturation.

3.3 Phase 2: Active Injection Monitoring

Repeated PNL surveys are performed during active injection, observing the migration and the saturation changes of CO_2 plume. The Decatur project illustrated the benefits of ongoing monitoring during injection and the Geticas framework suggests monitoring should be carried out periodically depending on the reservoir conditions and operational needs (Greenberg et al., 2017; Anghel Sorin, 2025). The emphasis on interpretation is with sigma log

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differences from the baseline; in cases of low or variable formation-water salinity, logging using the C/O ratio can also be helpful. Integrated Sigma/Salinity independent interpretation helped at the Otway project improve saturation estimates and discovered gas saturation above perforations, suggesting vertical plume migration by Watson et al. (2018). Jia et al. (2026) also showed that machine learning models can significantly enhance the accuracy of saturation prediction when combined with data from neutrons across the entire spectrum, but there is a need for further field validation.

3.4 Phase 3: Post-Injection Surveillance

Post-injection monitoring can be used to ensure long-term security of storage and to monitor CO_2 redistribution following cessation of injection. The reduced-frequency PNL surveys were used to successfully track the evolution of the plumes at the Decatur project and have been found to be well correlated with seismic observations and reservoir simulations (Greenberg et al., 2017). In the Ketzin project it was demonstrated that PNL offers higher sensitivity than seismic surveys for the detection of the thin and heterogeneous CO_2 accumulations close to the well bore (Martens et al., 2012). Post-injection PNL can be combined with pressure monitoring and distributed temperature sensing for enhanced plume interpretation, separating plume redistribution, dissolution and trapping processes (Li & Zhang, 2024). Monitoring wells that are near injection wells also provide increased monitoring during the early post-injection period (Anghel Sorin, 2025).

3.5 Phase 4: Well Integrity Supplemental Assessment

PNL is also used to assess well integrity due to its ability to detect movement of fluids behind casing. The multiple loggings at the Decatur project showed good containment of CO_2 within the storage interval (Greenberg et al., 2017). Camera inspections at Ketzin did not find corrosion of the casing after it had been exposed to CO_2 for a long period of time (Martens et al., 2012). According to the Geticas framework the application of PNL in combination with sonic and ultrasonic logging can be used for assessing casing and cement integrity, especially in converted mature wells where defects may be present in the casing and cement that were used in the original construction (Anghel Sorin, 2025). The framework suggests, therefore, a combination of PNL and complementary integrity monitoring technologies to enable complete monitoring of leakage pathways and long-term performance of a well.

Summary of selected studies

Title, Author, Year, Country, Study Type	Site and Reservoir Details	Tool and Acquisition Setup	Key Log Results and Saturation Method	Well Integrity Findings	Validation, Comparison, and Limitations
Europe's Longest-Operating Onshore CO_2 Storage Site at Ketzin, Germany, Martens et al. (2012), Germany, Field-Scale Pilot Project.	Formation: Upper Triassic Stuttgart Formation (fluvial sandstones). Depth: 630–650 m. Reservoir: Heterogeneous sandstone units. Injection: Approximately 53,000 tonnes of CO_2 over 39 months (≈45 t/day).	Baseline reservoir characterization (2005–2007), followed by repeated monitoring during injection (2008–2011). Borehole logging integrated with seismic surveys, electrical resistivity tomography (ERT), laboratory petrophysics and reservoir simulation.	Time-lapse monitoring showed increasing CO_2 saturation. ERT recorded increasing resistivity as CO_2 displaced brine. AVO analysis estimated CO_2 saturation of >68% at Ktzi201, >60% at Ktzi200 and <60% at Ktzi202.	Pressure remained below the approved operational limit. Camera inspections confirmed no casing corrosion or leakage. Two-phase CO_2 conditions (vapour and liquid) were observed in monitoring wells without compromising integrity.	Reservoir simulations reproduced plume arrival times within approximately 10%. Seismic monitoring was less sensitive to plume thicknesses below 7 m. Geoelectrical monitoring was affected by anthropogenic noise, while dynamic modelling remained limited by reservoir

					heterogeneity.
Risk-Based Framework for Compliance Assessment and CO_2 Geological Storage Monitoring: Application in the Geticas CCS Study, Anghel Sorin (2025), Romania, Feasibility Study.	Formation: Saline aquifers within the Moesian Platform and Getic Depression. Depth: 800–3000 m. Reservoir Capacity: Approximately 860 × 10^9 m^3 (Zone 5) and 72.55 × 10^9 m^3 (Zone 1). Injection: Five planned injection wells.	Pulsed neutron logging proposed before injection, during plume migration and every 4–5 years after injection. Single- and multi-detector Sigma tools evaluated alongside complementary monitoring technologies.	Sigma logging proposed for quantitative CO_2 saturation estimation. Neutron porosity expected to decrease with increasing CO_2 saturation. Fluid substitution modelling recommended before field implementation because formation-water salinity strongly influences interpretation.	Monitoring programme includes pressure monitoring, soil gas surveys, InSAR, microseismic monitoring and sonic/ultrasonic logging for casing and cement integrity. Faults identified as the principal leakage pathways requiring continuous surveillance.	Monitoring effectiveness depends on formation-water salinity, porosity and well spacing. Gravity methods become effective only after prolonged injection periods. Monitoring wells should ideally remain within 500 m of injection wells during early plume migration.
The Otway Stage 2C Project – End-to-End CO_2 Storage in a Saline Formation, Watson et al. (2018), Australia, Field Demonstration Project.	Formation: Paaratte Formation (1453.1–1464 m). Porosity: Approximately 25%. Permeability: 1–2 Darcy. Injection: 15,006 tonnes of CO_2 over 125 days (≈120 t/day).	Baker Hughes pulsed neutron logging performed before injection and after injection completion. Monte Carlo modelling used for interpretation.	Time-lapse neutron logging detected CO_2 breakthrough. Salinity-independent interpretation converted neutron responses into quantitative CO_2 saturation estimates.	Gas accumulation identified above perforations in CRC-2, indicating plume redistribution.	Good agreement observed between neutron logging, pressure monitoring and reservoir simulation. Absolute saturation values were influenced by reservoir simulation grid resolution.
Geologic Carbon Storage at a One Million Tonne Demonstration Project: Illinois Basin–Decatur Project, Greenberg et al. (2017), USA, Near-Commercial Scale Demonstration Project.	Formation: Mt. Simon Sandstone. Depth: Approximately 2,100 m. Injection: 999,215 tonnes of CO_2 over three years (≈1,000 t/day).	Schlumberger Reservoir Saturation Tool (RST) pulsed neutron logging conducted eight times from pre-injection through post-injection monitoring.	Time-lapse neutron logging successfully tracked CO_2 plume migration and post-injection redistribution.	No CO_2 detected outside casing. Well integrity remained intact throughout injection and post-injection monitoring.	Excellent agreement between neutron logging, 3D seismic surveys, vertical seismic profiling (VSP) and reservoir simulation. Monitoring frequency reduced after injection ceased.
Hybrid Machine Learning Model for CO_2 Monitoring, Jia et al. (2026), China, Simulation-Based Machine Learning Study.	Formation: Enping and Wenchang Formations. Porosity: Simulated values of 5%, 10%, 20% and 30%. Brine Salinity: 3.5–15%	Single-detector pulsed neutron logging simulated using MCNP with a D–D neutron source. Machine learning applied to full-spectrum	Hybrid NMF–SVR model predicted CO_2 saturation with RMSE as low as 4.2%, outperforming conventional interpretation methods.	Not applicable because the study used synthetic simulation datasets.	Results demonstrate strong predictive capability; however, field validation is required because synthetic datasets

	NaCl.	neutron and gamma responses.			may not fully represent reservoir conditions.
Geophysical Monitoring Technologies for CO_2 Geological Sequestration, Li and Zhang (2024), China, Comprehensive Review Paper.	Reviews Ketzin, Otway, Decatur and Nagaoka storage projects. Typical Depth: 1,500–2,100 m. Injection Volumes: Approximately 150 tonnes to 1 million tonnes of CO_2.	Reviews the application of Pulsed Neutron Logging (PNL), Pulsed Neutron-Gamma (PNG), Sigma logging and Carbon/Oxygen logging across multiple storage projects.	Demonstrates that integrated Sigma logging and Carbon/Oxygen logging effectively quantify CO_2 saturation and monitor plume migration when combined with pressure monitoring and distributed temperature sensing (DTS).	Migration pathways and reservoir behaviour were successfully identified by integrating neutron logging with fibre-optic sensing and pressure monitoring.	Concludes that pulsed neutron logging is indispensable for cased-hole CO_2 monitoring but should always be integrated with seismic, fibre-optic and reservoir saimulation techniques because reservoir heterogeneity limits standalone interpretation.

IV. DISCUSSION

Results from all the selected studies come together to support the pulsed neutron logging as the most practically viable and technically sound cased-hole technology for both CO_2 plume monitoring and well integrity monitoring in converted mature wells. But the potential can only be realised if attention is given to a series of constraints which are consistently raised in the field record: operational constraints, interpretative constraints and integrative constraints. The most common limitation found in all the studies is the dependence of the sigma interpretation on water-salinity of the formation. According to Anghel Sorin (2025) the salinity of the brine is a key parameter that strongly influences the Sigma contrast between CO_2 saturated and brine saturated intervals—particularly, that poor constraints on salinity result in unreliable quantitative estimates of CO_2 saturation. This restriction is directly applicable to mature asset conversion situations where salinity readings may be limited and/or apply to logging vintages prior to the use of modern cased-hole tools. Watson et al. (2018) tackle this by showing that an interpretation using salinity-independence for neutron ratio data is not only accurate in terms of the amount of saturation being captured, but it also is effective in low salinity and salinity variable environments at the Otway project. The Decatur RST deployments also support this result: The high degree of agreement between PNL and seismic constraints reported by Greenberg et al. (2017) was facilitated by the favorable Sigma contrast that was provided by the well characterized saline brines in the Mt. Simon Sandstone. Combined, these results suggest the choice of primary interpretation modality (Sigma vs C/O ratio) should be based on the salinity conditions of the formation before injection, emphasizing the importance of the pre-injection baseline phase in the proposed framework.

The second main limitation obtained in the studies explored is the reservoir heterogeneity. In the case of Ketzin, Martens et al. (2012) state that the plume arrival times could be better simulated in the reservoir and that the uncertainties caused by the heterogeneities of the fluvial Stuttgart sandstones reduced the accuracy of saturation estimates from all monitoring techniques, including borehole geophysics. In several of the projects reviewed, Li and Zhang (2024) found that PNL needs to be used in combination with other technologies such as seismic monitoring, fibre-optic distributed sensing, and pressure monitoring, as the use of PNL alone is not enough to provide good interpretation of the system in a heterogeneous system. The multi-pass RST programme has been highly successful in the Decatur project, where the independent constraints on various aspects of the plume geometry from the 3D seismic and VSP data are in excellent agreement at the same resolution (Greenberg et al., 2017). The multi-method integration is not just a best practice but a technical imperative in the mature asset domain where there may be greater reservoir heterogeneities than in purpose selected CCS sites.

Machine learning interpretation is an emerging technology that could be a game-changer for PNL in low porosity or low salinity formations where traditional method of using ratios is not as effective. Using the full spectral response of PNL, the NMF–SVR hybrid model is shown by Jia et al. (2026) to have a CO_2 saturation RMSE of about 4.2% for the simulated porosity range from 5% to 30% by MCNP simulation – much better than the traditional approaches for low porosity situations. The results of this study are especially relevant to the types of tight and moderately porous reservoirs that are found in many mature oil and gas fields that are likely to be targeted for CO_2 storage. But, as Jia et al. (2026) admit, the approach needs to be validated in the field before it can be used in practice. The approach taken in the present paper with respect to machine learning—augmented interpretation is one way of thinking about the problem; it is not an operational instrument at this time, but rather a possible future instrument, consistent with the "precautionary" approach to regulatory CCS monitoring contexts.

In the field of well integrity a field record shows that PNL plays an important role in integrity surveillance, however, it is not a complete field record. The lack of CO_2 signal outside the Mt Simon interval over eight logging passes at Decatur is compelling evidence of containment integrity (Greenberg et al., 2017) and the direct camera inspection of the borehole combined with the borehole logging results from Ketzin confirmed that there was no evidence of corrosion of the casing under two-phase CO_2 conditions (Martens et al., 2012). In the context of the Geticas project, for an asset undergoing its transition from field gas to production of geothermal fluids, the framework presented here recommends the coverage of the sonic and ultrasonic casing monitoring and pressure monitoring included in the suite of well integrity monitoring tools, as the standard for this type of asset transition.The sonic and ultrasonic casing monitoring and the pressure monitoring included in the suite of well integrity monitoring tools are recommended by the framework here presented as the standard for the monitoring system to be used for mature asset conversion cases. One of the challenges of converted wells with legacy cement formulations is the reduced effectivity of the existing ultrasonic cement evaluation tools, to which PNL adds.

V. IMPLICATIONS OF THE STUDY

These are key issues that have implications for the planning, operation and regulation of CO_2 storage in mature assets converted during their operation. It points out that pulsed neutron logging (PNL) should be included in a multi-phase monitoring program of the well as a planned operation, starting with a baseline survey prior to the injection that is accompanied by modelling for calibration and fluid substitution analysis. The results highlight for regulators the need for minimum requirements for PNL monitoring, logging frequency and the need to incorporate other monitoring technologies in monitoring, reporting, and verification (MRV) plans and storage permits. The study also suggests that machine learning techniques for interpreting PNL could be one of the areas that needs further development by researchers as it has the potential to enhance the CO_2 saturation estimation. The application of these techniques in existing CCS projects would help validate and improve the usefulness of PNL to track plumes and monitor for well integrity under a wide range of geologies.

VI. RECOMMENDATIONS

Evidence reviewed and several recommendations are made. PNL baseline data should be obtained in injection and observation wells prior to injection, with the support of Monte Carlo modelling and formation water salinity characterisation, by the operators. Second, the difference between the two types of logging, Sigma and Carbon/Oxygen (C/O), should be determined by site specific reservoir conditions, and where appropriate, the application of sites independent of salinity should be considered. Third, it is necessary that PNL should be united with complementary monitoring techniques such as pressure monitoring, temperature monitoring, seismic survey, distributed temperature sensing (DTS), ultrasonic cement evaluation. Fourth, if wells are to be used to monitor movement of the plume, they should be placed near the injection wells during early plume migration to enhance detection. Lastly, completed wells should be evaluated for cement integrity prior to injection and future work should focus on machine learning-based PNL interpretation for demonstration projects in active CCS operations in the field.

VII. CONCLUSIONS

In this research an evidence-based methodology has been created for the application of pulsed neutron logging (PNL) for the monitoring of CO 2 plume migration and well integrity in converted mature oil and gas wells for geological storage. The framework is built on six selected studies, including field applications at Ketzin, Otway and Decatur, feasibility and simulation studies in Romania and China. The research indicates PNL is the best commercial cased-hole method for measuring CO 2 saturation and identifying behind-casing fluid flow. However, its success requires on robust baseline data, proper interpretation methods, and consideration of formation-water salinity. The study further reveals that PNL should be combined with seismic, pressure, fibre-optic and cement integrity monitoring to boost monitoring confidence. In summary, the suggested approach provides a realistic roadmap for implementation of phased PNL monitoring in the life cycle of CO2 storage projects incorporating converted mature assets.

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