2026 International Nuclear Atlantic Conference - INAC 2026
Escola de Guerra Naval, Rio de Janeiro, RJ, August 24 - 28, 2026



Field Implementation of Environmental Constraints During Initial Civil Infrastructure Works of the Brazilian Multipurpose Reactor

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1. Introduction

The Brazilian Multipurpose Reactor (RMB) is a strategic nuclear research infrastructure project led by the Brazilian National Nuclear Energy Commission (CNEN), designed to expand national capacity in radioisotope production, neutron-based research, materials testing, and technological development [1, 2, 3]. During the current implementation stage, CNEN acts as project owner and environmental license holder, Amazul provides field supervision, Walm executes environmental programs, and Schunck performs initial civil works. This arrangement links licensing commitments, contractor controls, and field evidence to the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA), preserving traceability across site preparation and construction. Previous studies have described the RMB licensing trajectory and the interaction between environmental and nuclear licensing [4, 5]. This paper advances that discussion by examining initial civil works and the conversion of environmental constraints into field routines. However, environmental performance during implementation remains less systematically addressed in research-reactor literature than safety, utilization, and operational planning [6, 7].

The current implementation stage comprises construction of a bridge over Ribeirão do Ferro, localized earthworks, drainage, paving, and associated site-preparation activities. These works are conducted under the environmental Installation License issued by IBAMA and precede construction of the reactor and associated nuclear buildings, which depends on a separate nuclear Construction License. Environmental implementation, however, began before the current works. Riparian restoration, surface- and groundwater baseline monitoring, fauna surveys, and archaeological investigations were conducted during the pre-construction period. The identification of the Jiboia 1 archaeological site also led to changes in the planned location of project structures. This sequence provides a suitable case for examining how environmental licensing commitments are translated into field controls before nuclear-facility construction begins [5].

This study examines how selected environmental licensing requirements were implemented during the initial civil works of the RMB. It compares pre-construction baselines, construction-period monitoring results, regulatory reference values, field deviations, and corrective responses. The detailed analysis covers the monitoring cycle from late 2024 to early 2026 and uses the 2020–2022 pre-construction period as a historical environmental reference.

2. Methodology

The RMB site is located in a predominantly rural area adjacent to the Ipanema National Forest and crossed by Ribeirão do Ferro, a tributary connected to the Sorocaba River basin. Environmental programs were selected through purposive sampling based on five criteria: direct interaction with the initial civil works; availability of baseline and construction-period data; existence of regulatory or technical reference values; occurrence of field situations requiring corrective or regulatory response; and availability of consolidated quantitative indicators. Programs restricted to future operation, components without a direct construction interface, and components lacking comparable evidence during the study period were excluded from the detailed analysis.

The analysis integrated the CNEN annual compliance report, final environmental-program reports, field supervision records, laboratory datasets, photographic documentation, and corrective-action records.

Results were organized into three reference periods: historical pre-construction surveys conducted from 2020 to 2022; the pre-mobilization background campaigns conducted in late 2024; and the construction-period campaigns conducted during 2025 and early 2026. The Environmental Construction Program provided the cross-cutting interface with construction activities, while component-specific programs generated the monitoring and corrective-action evidence [8].

Surface-water results were compared with the 2021 historical dataset, the December 2024 pre-mobilization campaign, and the Class 2 freshwater standards established by CONAMA Resolution No. 357/2005. Groundwater results were assessed against the 2021 dataset and the reference values adopted under CONAMA Resolution No. 396/2008 and Ordinance GM/MS No. 888/2021 [10].

In this study, compliance denotes documented fulfillment of a licensing requirement; non-conformity denotes a formally recorded deviation from an approved procedure or condition; environmental performance denotes a measured outcome compared with a baseline, threshold, or reference value; and improvement is used only when a favorable temporal change was documented after an intervention. Avoided impacts were not quantified because no counterfactual scenario was established.

3. Results and Discussion

Table I summarizes the selected indicators, baseline or regulatory references, construction-period evidence, and corresponding interpretation.

Table I: Selected environmental indicators, reference conditions, and construction-period outcomes.

Component	Baseline or reference	Construction-period evidence	Interpretation
Noise	40 dB daytime reference; background L_{Aeq} of 39.9–60.3 dB; 4/5 receptors above the reference.	L_{Aeq} of 34.3–66.4 dB; 15/20 construction-period measurements above 40 dB.	Exceedances persisted, but predominant sources were traffic and biotic activity rather than construction.
Dust and black smoke	Qualitative assessment based on soil moisture, vegetation cover, and wind; Ringelmann N1 criterion.	Six campaigns; 38 equipment or vehicle observations, all classified as N1 (20% opacity); ambient PM_{10} and $PM_{2.5}$ were not measured.	Dust potential varied with field controls and meteorological conditions.
Surface water	Five points; 2021 dataset; December 2024 background; Class 2 reference under CONAMA No. 357/2005.	Thirteen campaigns; initial WQI of 24.26–34.19; mean pH of 6.0–7.15; punctual nutrient and metal exceedances.	No persistent downstream increase or progressive deterioration was identified.
Groundwater	Twelve monitoring wells; 2021 dataset; CONAMA No. 396/2008 and Ordinance GM/MS No. 888/2021.	Thirteen campaigns; exceedances mainly involving Al, Fe, and Mn, with isolated organic and microbiological detections.	Frequency declined after campaign 8; no progressive plume or hydrodynamic alteration was identified.
Riparian restoration	Twenty planting areas established in permanent preservation areas between 2020 and 2022.	2,255 pits sampled (28%); survival predominantly 90–98%; 2,107 replacement or enrichment seedlings.	High seedling survival was documented, but avoided impacts were not quantified.
Formal non-conformities	Formally registered deviations.	Two cases: inadequate waste segregation and earthmoving beyond the approved archaeological layout.	The archaeological case was closed; waste corrective-action effectiveness remained under verification.

Daytime noise was assessed at five receptors against the 40 dB reference applicable to rural residential areas. Campaign-specific L_{Aeq} values at P1–P5 were, respectively: 60.3, 40.7, 39.9, 58.9, and 40.5 dB during the background campaign; 65.9, 38.2, 35.9, 39.5, and 34.3 dB in May; 63.5, 39.5, 41.0, 42.1, and 43.4 dB in August; 66.4, 60.4, 56.3, 45.6, and 46.5 dB in October; and 60.5, 55.5, 42.0, 48.9, and 41.8 dB in January. Overall, 19 of the 25 measurements exceeded the reference, including four of five background measurements and 15 of 20 construction-period measurements. Predominant sources were road traffic and local biotic activity, with no construction-related source identified as predominant. The monitoring requirement was therefore fulfilled, but the results do not demonstrate general acoustic compliance [9].

Under the Particulate Matter Monitoring and Control Program (PMCMP, retaining its official Portuguese acronym), ambient PM_{10} and $PM_{2.5}$ concentrations were not quantified. Dust-resuspension potential was classified using tactile-visual soil-moisture assessment, vegetation cover categorized as low below 30%, medium from 30% to 70%, or high above 70%, and wind intensity qualitatively rated as low, medium, or high. Across six campaigns, 38 equipment or vehicle observations were performed using the reduced Ringelmann scale, and all were classified as N1, corresponding to 20% opacity. Dry exposed surfaces initially presented medium potential under weak winds and high potential under stronger winds. Later conditions were predominantly classified as low to medium following intensified wetting, gravel placement, paving, and slope revegetation, although rainfall and soil moisture also influenced the temporal pattern [8].

The erosion program provided a documented sequence of baseline condition, field occurrence, corrective response, and subsequent verification. Sixteen initial morphodynamic features were identified during the background survey, approximately half of which showed natural stabilization by the second campaign. During concentrated rainfall in November 2025, three new rills and two sediment-deposition sites were identified, while existing detention and geotextile controls were temporarily exceeded. Corrective measures included sediment removal, enlargement of detention basins, reinforcement of geotextile barriers, drainage improvements, slope stabilization, and revegetation. The January 2026 inspection recorded lower visual turbidity and sediment accumulation, although localized risks remained near the bridge and drainage fronts [8].

Surface-water monitoring comprised 13 campaigns conducted between December 2024 and December 2025 at five points. The December 2024 pre-mobilization campaign produced Water Quality Index values (WQI; IQA in the original Portuguese reports) from 24.26 to 34.19. During subsequent campaigns, the Sorocaba River points were predominantly classified from Poor to Regular, whereas the Ribeirão do Ferro points more frequently reached Good conditions. Mean pH remained close to neutrality, ranging from 6.0 to 7.15. Turbidity was higher during the initial campaigns, declined during most of the monitoring cycle, and showed isolated increases associated with hydrological events. Punctual exceedances of nutrients and metals occurred, but no persistent upstream-to-downstream increase or progressive deterioration was identified.

The groundwater network comprised 12 wells positioned predominantly upstream and downstream of facilities with potential future interaction with the aquifer. Across 13 campaigns, the principal exceedances involved aluminum, iron, and manganese, with isolated organic and microbiological detections. The predominance of metals and their occurrence during baseline and early campaigns were considered compatible with local geochemical controls, while isolated organic and microbiological detections may reflect pre-existing rural land use. These interpretations remain hypotheses because specific source attribution was not performed. The frequency of exceedances declined after campaign 8, and no progressive dissolved plume, flow reversal, permanent drawdown, or systematic degradation was identified [10].

Vegetation restoration comprised two distinct spatial and regulatory components. The first consisted of 20 planting areas established between 2020 and 2022 within permanent preservation areas along both banks of Ribeirão do Ferro. Survival was assessed in January and February 2026 through random transects comprising 2,255 planting pits (28% of the monitored population). This index was calculated as the proportion of sampled planting pits without recorded seedling mortality. Mean seedling survival reached approximately 93% on the left bank and 90% on the right bank, ranging predominantly between 90% and 98% across individual plots. Maintenance during this assessment cycle included weed control, fertilization, irrigation, seedling replacement, and enrichment planting, totaling 2,107 additional seedlings. The planting mix comprised native pioneer and secondary species selected for the Atlantic Forest–Cerrado transition, including taxa relevant to fauna support, soil stabilization, and ecological succession [5]. The second component comprised four compensatory areas established outside the permanent preservation areas following authorized vegetation removal for bridge construction. These contiguous areas received 6,780 seedlings over 4.06 ha to strengthen the broader ecological corridor.

Two formal non-conformities were recorded during the reporting cycle. The first concerned inadequate segregation and storage of construction waste, plastic bottles, and plastic bags. Corrective actions

included additional worker training and reorganization of collection points, with effectiveness verification still in progress at the reporting cut-off [8]. The second concerned earthmoving beyond the approved archaeological work layout. The activity was immediately halted, the responsible archaeologist was mobilized, and IPHAN was notified. Work resumed only after formal consent, and the archaeological non-conformity was subsequently closed. Dust and erosion occurrences were managed through field observations and corrective requests and were not classified as formal non-conformities in the reviewed records. At a documentary level, the RMB arrangement is comparable to the construction-related environmental programs of Angra 3 and to the Environmental Management and Monitoring Plan adopted for Hinkley Point C, which similarly link mitigation measures, monitoring, assigned responsibilities, and regulatory reporting. However, differences in project scale, reactor type, regulatory context, and indicator availability prevent direct performance benchmarking [11, 12].

4. Conclusions

The RMB case provides potentially transferable lessons on converting environmental licensing requirements into defined responsibilities, monitoring routines, evidence requirements, and escalation procedures. Daily field supervision enabled rapid responses to operational deviations, whereas periodic specialist campaigns supported comparisons with baselines and regulatory reference values.

This study is limited to a single project and an early civil-construction stage preceding nuclear-facility construction. Later phases are expected to involve larger earthmoving volumes, an expanded workforce, increased vehicle traffic, higher water demand, greater waste and effluent generation, and more complex interfaces among environmental licensing, nuclear licensing, emergency preparedness, and radiological protection.

Future work should develop an integrated environmental-performance system with explicit baselines, targets, alert thresholds, temporal trends, and response mechanisms. Comparative indicator-based studies will be required before the broader applicability of the RMB approach can be evaluated.

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