

Nuclear Environmental Damage Crimes in Reggane: A Multidisciplinary Study of Law, Sharia, and Physics

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Abstract

This article examines nuclear environmental damage crimes through a multidisciplinary lens, integrating Islamic Sharia, Algerian positive law, and nuclear physics. Using the French nuclear tests in Reggane (1960–1966) as a case study, it argues that the unique nature of nuclear harm demands a legal framework informed by physical evidence. The study finds that while Sharia provides a comprehensive moral foundation categorizing such acts as "Fasad" (corruption), Algerian legislation suffers from duplication and technical complexity that hinders effective application. Physical evidence—including isotopic fingerprinting, contamination mapping, and cytogenetic biodosimetry—emerges as indispensable for establishing the material act, proving causation, and demonstrating transgenerational harm. The article concludes with recommendations for unified environmental legislation, specialized environmental courts, and a national scientific commission to document the Reggane legacy.

Keywords: nuclear environmental crime, Islamic Sharia, Algerian law, nuclear forensics, Reggane, criminal responsibility, environmental justice

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1. Introduction

The French nuclear tests conducted in Reggane, Algeria between 1960 and 1966 represent one of the most severe and underexamined cases of nuclear environmental crime in the postwar era. This research posits that Islamic Sharia is the original divine source for environmental law and sustainable development, and that its principles must form the benchmark against which modern legislation, including Algerian law, is measured.

The environment has become a victim of criminal behaviors, leading to its continuous deterioration due to human corruption and aggression. While nations have responded to environmental threats through legislation and international treaties—such as the 1972 Stockholm Conference—this study argues that a purely legal approach is insufficient. For a crime as complex as nuclear environmental damage, the law must be informed and empowered by science.

The central research question is: What is the adequacy of the legal treatment of nuclear environmental damage crimes from the penal perspective in both Islamic Sharia and Algerian law, and how can physical evidence bridge the gap between legal theory and criminal reality?

2. Methodology and Scope

This study employs a comparative and inductive analytical methodology. It collects scientific material, explains detailed facts, and compares legal provisions from Algerian

law and Islamic Sharia, based on supporting jurisprudential and legal opinions. The scope is defined by three dimensions:

- The place of protection: the environment and its elements
- The subject of protection: how law, Sharia, and physics establish the right to a healthy environment
- The means of protection: focusing on penal protection due to its importance and effectiveness

The temporal scope centers on the period of the French nuclear tests (1960–1966) and their ongoing consequences, while the spatial scope focuses on the Reggane region in the Algerian Sahara, particularly the Hamoudia site.

3. The Physical Dimension of Nuclear Environmental Crimes

Before examining the legal framework, it is essential to establish the physical reality of nuclear contamination—what it is, how it can be measured, and how it serves as evidence. Nuclear forensics and radiation biology provide the scientific foundation upon which legal arguments must be built.

3.1 Nuclear Forensics and Isotopic Fingerprinting

Nuclear forensics is a comprehensive discipline that provides historical evidence for nuclear materials, enabling verification of nuclear activities and tracing the origin and intended use of materials (IAEA, 2002). The fundamental premise is that nuclear materials carry unique "fingerprints"—elemental and isotopic signatures that reveal their origin, age, and intended use (Li et al., 2025).

The isotopic composition of nuclear materials is determined by their production method, source material, and history. Plutonium isotopic signatures, for example, serve as a unique nuclear bomb fingerprint. The French tests are characterized by a $^{240}\text{Pu}/^{239}\text{Pu}$ ratio of less than 0.07, compared to the global fallout ratio of approximately 0.18 (Xu-Yang et al., 2025). A landmark 2025 study published in *Science Advances* confirmed the persistence of these signatures across decades.

Table 1: Key Physical Indicators of the Reggane Nuclear Tests (1960–1966)

Indicator	Data / Value
Power of Gerboise Bleue	$5 \times$ Hiroshima bomb yield
Total number of tests	17 explosions (1960–1966)
Contamination range (to Ghana)	1,600 – 2,250 km
Persistence period	~65 years (1960–2025)
$^{240}\text{Pu}/^{239}\text{Pu}$ ratio – French tests	< 0.07
$^{240}\text{Pu}/^{239}\text{Pu}$ ratio – Global fallout	~ 0.18
Estimated Algerian deaths	~42,000

3.2 Environmental Pathways and Transport Mechanisms

The Reggane region is located in one of the most active dust source regions on Earth, responsible for recurrent massive Saharan dust events that reach Western Europe (Xu-Yang et al., 2025). These storms act as natural transport mechanisms, lifting contaminated soil particles and carrying them across continents.

Radionuclides do not simply disappear after release. Plutonium and other long-lived isotopes persist in soils, sediments, and vegetation for decades or centuries. The 2022 Saharan dust event demonstrated that nuclear fallout from the 1960s remains detectable in surface environments today, providing direct evidence of contamination originating from historical nuclear tests.

The RADPATH project and similar scientific initiatives have developed models for understanding how radionuclides move through atmospheric, terrestrial, and aquatic systems. These models can reconstruct the historical dispersion of fallout from the Reggane tests, demonstrating the geographical extent of contamination and exposure mechanisms.

3.3 Biological Effects and Retrospective Dosimetry

Perhaps the most compelling physical evidence for nuclear environmental crimes comes not from environmental samples but from the bodies of exposed individuals and their descendants. Biodosimetry is the science of estimating radiation dose absorbed by individuals through analysis of biological materials. Key cytogenetic techniques include:

- **Dicentric Chromosome Assay:** Dicentric chromosomes are formed when chromosomes are broken and incorrectly rejoined following radiation exposure. These aberrations are highly specific to radiation and provide a reliable indicator of exposure (Chaurasia et al., 2025a).
- **Fluorescence In Situ Hybridization (FISH):** This technique uses fluorescent probes to bind specific chromosome regions, enabling visualization of translocations and structural abnormalities. Recent advances have enabled multi-marker dose estimation from single samples (Chaurasia et al., 2025b).
- **Cytokinesis Block Micronucleus Assay:** This method detects small nuclei formed from chromosome fragments not incorporated into main nuclei during cell division (Smith et al., 2024).

A crucial capability of modern biodosimetry is retrospective dose estimation—determining exposures that occurred years or decades in the past. Chromosomal translocations persist in stable cells over time, providing a biological record of historical exposure. Moreover, radiation-induced genetic damage can be transmitted to subsequent generations, with profound implications for legal arguments about the scope of harm from nuclear testing.

3.4 The "Shot Noise" Phenomenon and Dosimetry Limitations

Recent research has revealed a critical limitation in traditional radiation dosimetry. Studies of the Three Mile Island accident demonstrated that conventional gamma dosimetry indicated minimal exposure (<2 mSv), while cytogenetic analysis showed exposures between 600–900 mSv in affected individuals (Mangano et al., 2020). This paradox is explained by "shot noise" in radiobiology—the failure of traditional models to account for the temporal distribution of ionization products from internally incorporated

beta-emitting radionuclides. This finding has profound implications for Reggane: populations exposed to fallout may have suffered significantly greater harm than previously recognized.

4. The Human Toll: Mortality Data

The human consequences of the French nuclear tests are staggering and extensively documented. Multiple independent sources converge on a death toll of approximately 42,000 Algerians attributable to nuclear test pollution.

Table 2: Documented Mortality Data for the Reggane Nuclear Tests

Deaths	Source
42,000	Algerian Radio, February 2026
42,000	Anadolu Agency, February 2021
42,000	Xinhua News / Algerian Health Ministry, January 2018
42,000	TRT World, February 2021

5. The Legal Framework: Sharia, Algerian Law, and Nuclear Crime

5.1 Islamic Sharia as Moral Foundation

Islamic Sharia provides the absolute moral and legal foundation for environmental protection, categorizing nuclear environmental damage as a severe form of "Fasad" (corruption) on earth. Its principles, derived from the Qur'an, Sunnah, and the objectives of Islamic law (Maqasid al-Shariah)—which include the preservation of life, intellect, progeny, and wealth—offer a holistic framework that predates and encompasses modern environmental concepts. The Islamic legal maxim, "Harm must be eliminated" (إِزال الضرر), reinforces the absolute duty to prevent and redress damage. Unlike positive law, Sharia's treatment of crime is comprehensive, addressing not only the act but also its spiritual and moral sources.

5.2 Algerian Positive Law: Abundance and Deficiency

The right to a healthy environment is a fundamental constitutional right in Algeria, enshrined in Article 68 of the 2016 Constitution. This mandate is operationalized in Law No. 03/10 on the protection of the environment within the framework of sustainable development. Algeria has produced an extensive legislative arsenal, including:

- Law No. 03/10 on environmental protection within sustainable development
- Law No. 01/19 on waste management, control, and disposal
- Law No. 05/12 on water resources
- Law No. 66/155 – Code of Criminal Procedure
- Various executive decrees on environmental impact studies and inspectorates

However, the duplication and technical nature of these laws make them difficult to apply by both the administration and the judiciary. The proliferation of laws has led to overlapping jurisdictions and confusion, ultimately leaving the environment to pay the price. Furthermore, none of these laws adequately addresses the unique requirements of nuclear forensic evidence.

5.3 The Three Pillars of the Nuclear Environmental Crime

5.3.1 The Legal/Sharia Pillar

The prohibition is found both in positive law (Law 03/10) and in the absolute Sharia prohibition of "Fasad." This provides an unconditional moral imperative against nuclear contamination that predates and transcends national legislation.

5.3.2 The Material Pillar and Physical Evidence

The material act is the release of radionuclides. Physical criminal evidence includes: (1) Source attribution through isotopic fingerprinting; (2) Contamination mapping demonstrating extent and persistence; and (3) Biological evidence through cytogenetic biodosimetry documenting actual harm to individuals. The French tests produced a distinct $^{240}\text{Pu}/^{239}\text{Pu}$ ratio below 0.07, distinguishable from global fallout signatures.

5.3.3 The Moral Element and Scientific Foreseeability

Physics informs the moral element by establishing what was knowable at the time of the act. Scientific knowledge from the 1950s and 1960s already demonstrated a clear understanding of the long-range transport of fallout and its biological effects. The fact that French authorities conducted tests in a remote desert location demonstrates awareness of the danger, yet they failed to protect local populations or monitor long-term consequences.

6. Criminal Responsibility and Pursuit of Justice

6.1 Establishing Causal Responsibility

Responsibility for the Reggane crimes can be attributed to both natural persons (the officials who ordered the tests) and legal persons (the French state). To establish this responsibility, the causal link between the explosions and the damage must be proven. Three categories of evidence are essential:

- **Exposure Assessment:** Modern cytogenetic biodosimetry can provide retrospective exposure data, revealing actual absorbed doses that may far exceed traditional gamma dosimetry estimates.
- **Pathways of Harm:** Scientific atmospheric transport models demonstrate how radionuclides from Reggane continue to be mobilized by Saharan dust events and transported across continents.
- **Persistence of Contamination:** Environmental samples collected decades after the explosions demonstrate the long-term and intergenerational nature of the harm.

6.2 Quality Assurance Imperatives for Legal Proceedings

A critical finding from the nuclear forensics literature is that evidence intended for legal proceedings must meet stringent quality assurance standards (IAEA, 2002). Forensic analysis results that cannot be independently verified against certified reference materials may not be accepted in a court of law. For the Reggane case, any scientific investigation must adhere to chain-of-custody protocols, use certified reference materials, and maintain documentation that would withstand judicial scrutiny.

6.3 The Role of Civil Society

Under Article 36 of Law 03/10, environmental associations gain legal personality and have the right to litigate and act as a civil party in criminal matters affecting the

environment. However, their role remains limited due to lack of material resources and a judiciary still hesitant to engage with these legal persons.

7. Discussion

7.1 Physical Evidence as the Indispensable Link

Physics and nuclear forensics are not ancillary to the legal case for Reggane; they are its core. The physical evidence—persistent radionuclides with unique isotopic fingerprints, measurable contamination transport pathways, and detectable biological damage in affected populations—provides objective, irrefutable proof of the crime, its source, and its long-term consequences. Without this evidence, claims of harm remain speculative; with it, they become scientifically demonstrable facts.

7.2 Biological Evidence and Transgenerational Harm

The FISH technique's ability to detect chromosomal translocations in stable cells means that exposed individuals carry biological witnesses to the crime within their own bodies. The scientific evidence for transgenerational effects supports legal arguments for continuing responsibility and the need for compensation mechanisms that address intergenerational justice.

7.3 The Paradox of Algerian Legislation

Algeria possesses a vast legislative arsenal for environmental protection. However, the duplication and technical nature of these laws create a "legal vacuum" where theoretical protection fails to translate into effective deterrence or remediation. The current legal framework lacks the specialized procedures and expertise required to handle nuclear crime cases, particularly regarding the admissibility and interpretation of complex scientific evidence.

8. Recommendations

Through this multidisciplinary analysis, the following recommendations emerge for achieving justice for nuclear environmental damage crimes:

- **Unify and Simplify Environmental Legislation:** Consolidate the numerous environmental texts into a single, coherent, and easily applicable code with clearly distributed competencies.
- **Establish Specialized Environmental Courts:** Create courts staffed by judges trained in environmental law and basic scientific principles, including nuclear forensics, capable of interpreting complex physical evidence.
- **Create a National Scientific Commission for Reggane:** Establish an independent commission to conduct isotopic analysis, cytogenetic biodosimetry, and contamination mapping following IAEA quality assurance protocols.
- **Strengthen Civil Society:** Increase the capacity of environmental associations through state support and clearer legal pathways for initiating public prosecutions.
- **Pursue All Legal Avenues:** Using scientific forensic evidence, pursue all available national and international legal avenues, including CIVEN engagement and the Treaty on the Prohibition of Nuclear Weapons (TPNW).

- **Develop Training Programs:** Establish specialized training in nuclear forensic science for legal professionals, including prosecutors, judges, and ministry officials.

9. Conclusion

This study demonstrates that achieving justice for nuclear environmental damage crimes requires a system that seamlessly integrates legal principles with physical evidence. Islamic Sharia provides the absolute moral and legal foundation, categorizing nuclear environmental damage as a severe form of "Fasad." Algerian positive law, despite its legislative abundance, suffers from a paradox of proliferation and effective deficiency. Physical evidence—through nuclear forensics, isotopic fingerprinting, and cytogenetic biodosimetry—constitutes the indispensable evidentiary core for any viable prosecution. The ultimate equation for environmental justice, as this study demonstrates, must be:

Coherent Legislation + Rigorous Administration + Scientifically-Literate Judiciary + Empowered Civil Society + Conclusive Physical Evidence = A Truly Deterrent Environmental Justice System

Only through such an integrated approach can the legacy of crimes like those in Reggane be addressed, and future environmental catastrophes prevented.

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