Interior view of the control room of Chornobyl Nuclear Power Plant unit 3 in December 2010. Over 3,000 people then worked at Chornobyl Nuclear Plant to monitor nuclear fuel and carry out the decommissioning of the facility. PHOTO: DANA SACCHETTI/IAEA

What we wouldn't know without Chornobyl

The important work of scientists in the Exclusion Zone

by **Olena Pareniuk** and **Kateryna Shavanova**

abstract

From the moment of its establishment, the Chornobyl Exclusion Zone (CEZ) became a territory separated from the rest of the country: governed by different rules and a distinct internal logic. The isolation of the CEZ and the urgency of its tasks have shaped – and continue to shape – specific demands on the scientists who work there. Chornobyl science is also influenced by crises that have repeatedly redefined its priorities.

KEYWORDS: The Exclusion Zone, radioactive waste, nuclear power plants, Russo-Ukrainian war.

Science is an integrated field of knowledge. Yet the accumulation of knowledge never proceeds evenly: it accelerates most intensely at moments of "extremes." The Chornobyl disaster of April 26, 1986, at the Chornobyl Nuclear Power Plant (then located in the Ukrainian SSR within the USSR), was undoubtedly such an extreme. But did it become a driver of scientific progress – and if so, at what cost, and for whom?

From the moment of its establishment, the Chornobyl Exclusion Zone (CEZ) became a territory separated from the rest of the country: governed by different rules and a distinct internal logic. The right to enter requires not only formal authorization but also

PHOTO: USFCRFC

Modern equipment was used for decontamination after the accident. An operator is seen steering a bulldozer by radio.

PHOTO: USFCRFC

A helicopter moves in to help experts check the damage to the Chornobyl reactor in 1986.

knowledge of safety procedures and acceptance of responsibility for one's actions. The Zone compels adaptation from everyone who enters, regardless of status or profession.

In 1986, immediately after the catastrophe, the primary "population" of the CEZ consisted of military units and other emergency response formations, while scientists and plant personnel were a minority. This appeared natural in a mobilization regime responding to what was often described as a "battle against an invisible threat." Nearly forty years later, the circle has closed: today, the principal permanent contingent in the Zone is once again the military.

THE SIMILARITIES BETWEEN 1986 and 2025 are immediately apparent: heightened control within the Zone, restrictions for personnel and visitors, and a high cost of error. Yet over these decades, the Zone has undergone profound transformation. Construction of Units 5 and 6 was halted; Units 1–3 were decommissioned; Unit 4 was enclosed within the New Safe Confinement; the cooling pond was drained, and trees now grow where water once stood. The nature of Polissia has been recovering: Przewalski's horses have appeared, and rare bird species have returned. A territory long labeled by the world as a "deadland" has gradually reconstituted itself as a complex ecosystem.

> **"THERE WAS A PREVAILING HOPE THAT THIS EXPERIENCE WOULD ADVANCE RADIATION SCIENCE — AND NEVER AGAIN BE NEEDED IN PRACTICE."**

The isolation of the CEZ and the urgency of its tasks have shaped – and continue to shape – specific demands on the scientists who work there. These include readiness for field conditions, practical dosimetry, the ability to adapt instrumental approaches under time and resource constraints, deep knowledge of nuclear and radiation safety, and the capacity to respond to emergencies and manage contaminated territories and high-risk infrastructure. Such infrastructure includes NPP sites, spent fuel storage facilities, radioactive waste repositories, dosimetric checkpoints, access routes, technical work zones, and protocols for handling materials that remain hazardous for decades.

For this reason, when in February 2022 the CEZ once again transformed from a "site of memory" into a territory of potential radiological and very real military danger, the competencies developed by its scientists became even more relevant – both within and beyond the Zone.

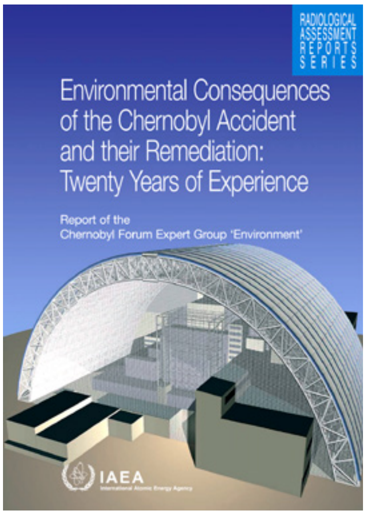
History:

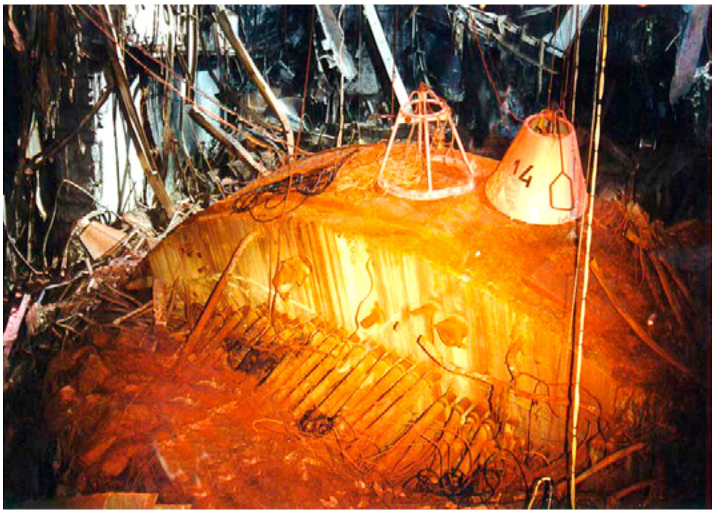
Chornobyl science as a dynamic construction

Nuclear and radiation safety is a field that learns best from its mistakes and immediately puts the newly gained knowledge into practice. What, then, did Chornobyl scientists learn – and did those lessons prove useful beyond the Exclusion Zone?

Science in the CEZ was never a structured monolith created through long-term planning and stable budgeting. Rather, it resembled a dynamic structure constantly rebuilt in response to emerging needs – by people, research groups, topics, and even planning approaches. Yet this fluidity did not imply chaos. On the contrary, science in the Zone was almost always applied in nature: its value was measured not by the number of theories produced but by its ability to answer questions arising "here and now," in a specific territory defined by specific constraints and risks.

In the 1990s, the Chornobyl accident was regarded as an exception. It was difficult to imagine that Chornobyl approaches would later be applied elsewhere (as occurred after the Fukushima Daiichi accident). There was a prevailing hope that this





Left: The 2006 IAEA report represented collaboration among hundreds of scientists worldwide.

Right: A diagnostic buoy, a device used to measure radiation, is seen on top of the reactor lid installed after the explosion in 1986.

PHOTO: US EPA

experience would advance radiation science – and never again be needed in practice.

The First Decade after the accident (1986–1996): **Operational science and managing uncertainty**

The first decade after the accident was characterized by research aimed at containment and mitigation. This was a period of rapid, highly practical investigation focused on limiting the spread of radionuclide contamination.

The logic of that time is reflected in early decisions that shaped subsequent decades: the rapid construction of the "Shelter" over the destroyed reactor; urgent mapping of radionuclide contamination (including helicopter-based surveys); the establishment of systematic monitoring; and simplification of procedures for people to access the exclusion zone. Data quickly became methodology; methodology became operational practice.

Chornobyl science during this period was relatively closed – not because of secrecy, but because of limited time and resources. International consultation was constrained by limited internet access and language barriers. Nevertheless, it became evident that decades of radiobiological theory could be implemented in practice. The principal limitation often lay not in material resources, but in persuading populations and decision-makers to follow scientific recommendations.

Despite economic crisis in newly independent Ukraine, funding for Chornobyl research remained substantial. Nearly every research institution had thematic projects related to the accident. Scientists worked – and in some cases lived – in Prypiat, and research results were implemented rapidly. Groups with access to both Chornobyl data and international platforms laid a foundation that sustained Chornobyl science until the early 2020s.

In 1992, the IAEA published INSAG-7, providing a detailed technical analysis of the accident and recommendations to prevent similar events.

During this decade, the world came to understand that severe core-damage accidents were not theoretical anomalies, but scenarios requiring containment tools and long-term management strategies. Scientists played central roles in planning mitigation, providing the knowledge necessary to understand processes inside the destroyed reactor. Mass evacuation – affecting hundreds of thousands – left long-term health consequences, lessons later considered during Fukushima (2011). It also underscored the necessity of transparent public communication regarding causes, protective measures, and emergency planning.

Regrettably, the early days of Russia's full-scale invasion of Ukraine demonstrated that society had not fully learned these lessons.

The Second Decade (1997–2006): **Systematization, openness, and emerging fatigue**

The second decade focused on environmental consequences. Amid speculation about catastrophic impacts, major work culminated in the 2006 IAEA report *Environmental Consequences of the Chernobyl Accident and Their Remediation: Twenty Years of Experience*. This nearly 200-page synthesis represented collaboration among hundreds of scientists worldwide.

Chornobyl science became internationally integrated. Ukrainian scientists joined IAEA advisory bodies, and most major projects received international funding – while domestic science funding declined. Research groups formed in the 1990s struggled to survive, but demand for Chornobyl expertise remained strong.

In 2000, the final operating unit of the Chornobyl NPP was shut down. Ukraine gained real-time experience in decommissioning and transition to long-term conservation – experience later applied to other Ukrainian nuclear facilities.

By the late 2000s, interest began to wane. Funding declined; access remained bureaucratically complex. It appeared that the accident's lessons had been absorbed globally, and Chornobyl


PHOTO: WIKIMEDIA COMMONS

Przewalski's horses in the Chornobyl Exclusion Zone, 2006.


PHOTO: WIKIMEDIA COMMONS

The New Safe Confinement in final position over reactor 4 at the Chornobyl Nuclear Power Plant, 2017.

would remain primarily a guardian of radiation knowledge.

This period reinforced the role of research groups as custodians of thematic continuity. Scientists often carried their research agendas across institutions. At times, institutional restructuring in the CEZ was so fluid that a researcher might change institutions without changing offices.

The need to popularize radiobiological and radioecological knowledge became apparent. Integration into European research networks was essential – its importance fully realized after 2022, when international colleagues supported Chornobyl scientists. Chronic underfunding forced teams to operate with minimal staff: for example, the Institute of Agricultural Radiology declined from over 3,000 employees in the early 1990s to around one hundred in the 2000s (and later, only dozens).

Knowledge was gradually lost. Methods such as the "radioactive buoy" – a device capable of measuring high-dose environments – disappeared. Techniques for constructing robots capable of navigating within the Shelter were lost. Yet, we gained practical experience in managing vast contaminated territories, – something that, unfortunately, will be needed in postwar Ukraine, which will face land rehabilitation challenges along front-line regions.

The Third Decade (2007–2016): **Infrastructure, new data, and renewed relevance**

At the start of the third decade, it seemed that Chornobyl science would slowly fade. The world had fixed Chornobyl in collective memory as a completed event. The Zone remained an open-air laboratory, but research did not appeared urgent anymore.

The Fukushima accident altered this perception. Chornobyl science became fully internationalized. Ukrainian scientists contributed expertise in Japan, adapting lessons to local conditions. Demand returned for competencies that had become routine in Chornobyl: practical dosimetry, field radioecology, risk communication, and work in territories where standard administrative rules fail. Chornobyl shifted from a "territory of consequences" to a "territory of solutions."

A major milestone was the New Safe Confinement (NSC), completed and operational by 2016–2017. While externally perceived as a final containment solution, for practitioners it established a century-scale engineering framework and intensified questions about long-term risk knowledge. The objective became transforming the NSC-Shelter complex into an environmentally safe system through removal and secure storage of fuel-containing materials (corium).

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These materials remain insufficiently understood: their long-term structural evolution and environmental interactions over decades remain uncertain. In this sense, Chornobyl is not merely a post-disaster site – it is a site where the disaster persists as a physical and scientific reality.

On February 14, 2025, a Russian drone struck the NSC, causing a fire between protective shells and compromising structural elements of robotic systems intended for corium dismantlement beginning in 2030. This created new scientific and engineering challenges under wartime conditions.

In 2016, the Chornobyl Radiation and Ecological Biosphere Reserve was established, formalizing governance of a territory that long existed in administrative ambiguity. Chronic underfunding limited its full development. Simultaneously, the immediate 10-kilometer zone surrounding the decommissioned plant remained in economic use, creating a unique configuration of

On February 14, 2025, a drone hit the Chornobyl New Safe Confinement, damaging the sarcophagus. The repair operation required workers to ascend 100 metres in extremely difficult weather conditions. PHOTO: STATE EMERGENCY SERVICE OF UKRAINE

a waste management infrastructure surrounded by a "buffer" zone of the nature reserve.

The gradual drainage of the cooling pond generated unprecedented empirical data on ecological succession and radionuclide localization – knowledge that gained practical relevance after destruction of the Kakhovka Dam in 2023.

Collectively, these processes reinforced understanding of Chornobyl not as a concluded catastrophe, but as an ongoing physical reality where science functions as a risk-management tool under constrained resources and generational knowledge loss.

The Fourth Decade (2017–2027): War, disruption, and reconfiguration

If the third decade suggested gradual stabilization, the fourth shattered that illusion. On February 24, 2022, Russian forces entered the Chornobyl Exclusion Zone from the territory of Belarus. For several weeks, the Zone became an occupied territory, and nuclear infrastructure was effectively held hostage.

This period fundamentally altered the trajectory of Chornobyl science. Research was suspended. Monitoring systems operated under extreme constraints. Personnel was isolated, and rotation was impossible for weeks. The risks were no longer theoretical: heavy military equipment disturbed contaminated soils, fortifications were dug in the Red Forest – one of the most radioactively contaminated areas – and fires became a renewed threat.

The occupation demonstrated that nuclear and radiological risk cannot be separated from geopolitical risk. Decades of work devoted to the containment and stabilization efforts proved vulnerable to conventional military action. It also revealed the fragility of institutional memory: documentation, equipment, and ongoing experiments were placed at risk of destruction or theft.

After de-occupation, scientists returned not only to research but to assessment of military impact: disturbed soils, damaged infrastructure, mine contamination, and new uncertainties in environmental monitoring. The CEZ became both a field laboratory and a case study in the intersection of environmental contamination and armed conflict.

International collaboration, built over decades, became a stabilizing force. European and global partners provided technical support, equipment, and platforms for continuity. At the same time, Ukrainian institutions faced staff shortages, mobiliza-

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tion, and resource constraints. Some scientists joined the Armed Forces or National Guard; others adapted research agendas to wartime realities.

Thus, the fourth decade reframed Chornobyl once again – not merely as a post-accident landscape, but as a territory where nuclear legacy and active war coexist. This coexistence generates new research questions: How do contaminated ecosystems respond to military disturbance? How should nuclear sites be protected in armed conflict? What monitoring systems are resilient under occupation?

The Future: Planning under uncertainty

What, then, does Chornobyl teach us about the future?

First, it teaches that knowledge must be institutionalized, not personalized. Generational turnover, chronic underfunding, and administrative instability risk eroding competencies that are difficult – sometimes impossible – to reconstruct. The loss of specialized methods and devices over past decades illustrates this vulnerability.

Second, it demonstrates that nuclear risk management must integrate environmental science, engineering, public communication, and geopolitical awareness. Severe accidents and military aggression alike expose the limits of purely technical solutions.

Third, it underscores the importance of long-term monitoring. Radionuclide behavior in soils, forests, and hydrological systems unfolds over decades. Without continuity of data series, scientific interpretation becomes speculative. Chornobyl’s value lies not only in its singularity, but in the accumulation of longitudinal datasets that allow pattern recognition across time.

Fourth, it reveals that contaminated territories are not static wastelands. Ecological succession, species adaptation, and landscape transformation continue under chronic radiation exposure. The Zone provides insight into ecosystem resilience, limits of adaptation, and trade-offs between human absence and radiological presence.

Finally, it compels reconsideration of how societies remember and learn. Memory alone does not guarantee preparedness. The occupation of 2022 demonstrated that lessons from 1986 had not been fully integrated into international security architecture.

Short conclusions

Without Chornobyl, the world would know far less about:

- The long-term environmental behavior of radionuclides in complex ecosystems
- Practical large-scale evacuation and resettlement consequences
- Engineering containment of destroyed nuclear reactors
- Decommissioning strategies under constrained political and economic conditions
- Communication challenges surrounding invisible risk
- The interaction between nuclear infrastructure and military conflict

CHORNOBYL SCIENCE emerged not as an abstract intellectual project, but as a necessity. It developed under pressure, with limited resources, shaped by crises that repeatedly redefined its priorities.

Its trajectory has been discontinuous: periods of urgency followed by fatigue, internationalization followed by isolation, stabilization followed by renewed disruption. Yet across these shifts, one feature has remained constant: adaptability.

Final: New protocols for a changed world

Chornobyl is no longer only a symbol of technological catastrophe. It is also a testing ground for resilience – scientific, institutional, and societal.

The scientists of Chornobyl have learned to work in uncertainty: with incomplete data, unstable funding, changing regulations, and now under conditions of war. Their experience suggests that nuclear safety cannot be reduced to engineering alone. It requires sustained ecological research, transparent governance, international cooperation, and protection of scientific infrastructure even in armed conflict.

As the fourth decade unfolds, Chornobyl continues to function as a paradoxical space: a territory of loss that generates knowledge; a contaminated landscape that informs environmental restoration; a restricted zone that shapes international collaboration.

If there is a central lesson, it may be this: disasters do not end when headlines fade. They persist physically, institutionally, and intellectually. Whether societies choose to transform that persistence into learning – or allow it to erode into forgetfulness – remains an open question.

Chornobyl has already provided answers to many questions humanity did not know how to ask. The responsibility now lies in preserving that knowledge, integrating it into global practice, and ensuring that future crises – whether technological or military – find us better prepared.

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