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Chernobyl and the transformation of nuclear safety culture: Technological governance, risk, and expertise after 1986

***Abstract.** The Chernobyl disaster of 26 April 1986 remains one of the most significant technological accidents of the twentieth century and a defining event in the history of science and technology. While early interpretations of the accident focused primarily on reactor design deficiencies and operator actions, subsequent investigations demonstrated that its origins were rooted in a broader interaction of technological, organizational, and institutional factors. This article examines the Chernobyl disaster as a turning point in the evolution of nuclear safety culture and technological governance. Particular attention is devoted to the role of Soviet modernization policies, the development of the RBMK reactor programme, organizational culture within the Soviet nuclear industry, and the management of technical knowledge before and after the accident. The study employs methods of historical analysis, historiographical review, comparative analysis, and socio-technical systems analysis. It is based on international scientific literature, reports of the International Atomic Energy Agency, publications of the Chernobyl Forum, and recent studies in the history of technology, risk governance, and nuclear safety. The article analyses the technical and institutional origins of the disaster, the subsequent reassessment of nuclear risk, the crisis of technological expertise revealed by the accident, and the emergence of the concept of safety culture as a new framework for understanding technological reliability. The findings demonstrate that Chernobyl cannot be adequately explained as the consequence of either technical failures or human errors alone. The disaster represented a systemic failure arising from interactions among reactor design characteristics, organizational practices, institutional constraints, and deficiencies in the circulation of safety-related information. The study shows that the accident fundamentally transformed international approaches to technological risk, encouraged the development of safety culture as a key principle of nuclear governance, and stimulated new forms of international cooperation in the fields of nuclear safety, emergency preparedness, and*



regulatory oversight. The modernization of RBMK reactors after 1986 further illustrates how technological systems evolve through processes of institutional learning and adaptation. The article argues that the historical significance of Chernobyl extends far beyond the nuclear sector. The lessons derived from the disaster contributed to broader changes in the governance of complex technologies and remain relevant to contemporary discussions concerning sustainable technological development, risk management, and institutional resilience. Particular relevance is identified in relation to the United Nations Sustainable Development Goals associated with public health, sustainable energy, resilient infrastructure, and effective institutions. From the perspective of the history of science and technology, Chernobyl represents a crucial case study demonstrating how major technological accidents can reshape scientific knowledge, organizational practices, and international approaches to technological governance.

Keywords: *Chernobyl disaster; nuclear safety culture; technological governance; Soviet nuclear industry; technological risk; sustainable development*

Introduction.

The accident at Unit 4 of the Chernobyl Nuclear Power Plant on 26 April 1986 occupies a unique place in the history of science and technology. Beyond being the most severe accident in the history of civilian nuclear power, it became a turning point in the development of nuclear safety, risk assessment, technological governance, and international cooperation in the nuclear field. During the decades following the accident, Chernobyl evolved from a Soviet industrial disaster into a global reference point for discussions concerning the reliability of complex technological systems, the role of expert knowledge, and the relationship between technological progress and societal responsibility.

Early interpretations of the accident primarily focused on technical failures and operator actions. The reports presented at the International Atomic Energy Agency (IAEA) review meeting in Vienna in 1986 emphasized violations of operating procedures and deficiencies in reactor operation (IAEA, 1986a, 1986b; Wakabayashi, Mochizuki, Midorikawa, Hayamizu, & Kitahara, 1987; WCED, 1987). Subsequent investigations, however, demonstrated that the causes of the disaster were considerably more complex. The reassessment published by the International Nuclear Safety Advisory Group (INSAG-7) concluded that the accident resulted from the interaction of reactor design characteristics, operational decisions, organizational shortcomings, and weaknesses in safety management rather than from operator actions alone (IAEA, 1992).

The publication of INSAG-4 and INSAG-7 marked an important shift in international thinking about technological risk. These reports introduced and subsequently developed the concept of safety culture, which became one of the most influential ideas in modern nuclear governance. According to INSAG, safety could no longer be understood exclusively as a technical property of a reactor or engineering system. It also depended on organizational practices, institutional learning,

communication of operational experience, and the values shared by designers, regulators, managers, and operators (IAEA, 1991; IAEA, 1992).

The historical significance of Chernobyl extends beyond the immediate circumstances of the accident. Research conducted during the last two decades has increasingly examined the disaster within the broader context of Soviet scientific and technological development. Studies by Schmid (2006, 2011, 2015, 2016, 2018, 2019) demonstrated that the Soviet nuclear industry was shaped not only by engineering considerations but also by institutional structures, professional identities, planning mechanisms, and specific approaches to expertise and decision-making. From this perspective, the Chernobyl accident may be interpreted as a manifestation of deeper systemic problems affecting the circulation of technical knowledge, the management of uncertainty, and the implementation of safety principles within large technological organizations.

At the same time, historians of technology have emphasized that Chernobyl significantly influenced international approaches to technological governance. The accident stimulated the modernization of RBMK reactors (Реактор Болшой Мощности Канальный, or High-Power Channel-Type Reactor), accelerated the development of international nuclear safety standards, strengthened transnational cooperation in the field of emergency preparedness, and contributed to new approaches for managing technological risks (Arnhold, 2020; D’Auria et al., 2008a; Schmid, 2016). These developments remain relevant in contemporary debates concerning sustainable technological development, particularly in sectors characterized by high complexity, significant societal impact, and long-term environmental consequences.

The continuing relevance of Chernobyl is reflected in the growing body of interdisciplinary scholarship addressing its technical, environmental, medical, social, and cultural consequences. Studies published by the Chernobyl Forum and subsequent international assessments have demonstrated that the long-term legacy of the accident includes not only radiological effects but also substantial social, economic, and psychological consequences for affected communities (Havenaar et al., 1997; Marples, 1988; Perrow, 1999). More recent research has further highlighted the importance of institutional trust, risk communication, and public perceptions of technological hazards in shaping societal responses to nuclear accidents (Bromet, 2014; Oe, Takebayashi, Sato, & Maeda, 2021; Schmid, 2019).

At the same time, the historiography of Chernobyl has undergone significant transformation. Earlier studies focused primarily on technical explanations of the accident and assessments of its radiological consequences. More recent scholarship within the history of science and technology has increasingly examined the disaster as a socio-technical phenomenon shaped by interactions among technological design, institutional structures, expert cultures, and systems of governance. Historians have demonstrated that the significance of Chernobyl extends beyond the events of April 1986 and includes its influence on scientific expertise, technological regulation, public trust, and international approaches to risk management (Arnhold, 2020; Guth, Gestwa, Penter, & Richers, 2019; Schmid, 2015). This historiographical shift provides an

important framework for understanding the accident not only as a failure of a technological system but also as a turning point in the historical evolution of technological governance.

Within the framework of the United Nations Sustainable Development Goals (SDGs), the historical experience of Chernobyl remains particularly relevant to discussions associated with sustainable energy systems (SDG 7), resilient infrastructure and innovation (SDG 9), public health and well-being (SDG 3), and effective institutions (SDG 16). The accident demonstrated that technological sustainability cannot be reduced to technical efficiency alone. It also requires transparent governance, effective safety management, continuous organizational learning, and the responsible integration of scientific knowledge into decision-making processes.

The relevance of these issues has increased in the twenty-first century as societies continue to rely upon increasingly complex technological systems characterized by high levels of interdependence and uncertainty. Contemporary discussions concerning artificial intelligence, critical infrastructure, climate-related technologies, advanced energy systems, and digital infrastructures frequently address questions similar to those raised by the Chernobyl experience: how risks should be assessed, how expertise should be organized, how safety-related information should be communicated, and how institutions can promote organizational learning in environments characterized by technological complexity. Consequently, the historical lessons of Chernobyl remain relevant far beyond the nuclear sector itself.

Although the technical causes of the accident, its environmental consequences, and its political implications have been extensively investigated, comparatively less attention has been devoted to analysing Chernobyl as a historical turning point in the evolution of safety culture and technological governance. Existing studies often examine these themes separately, whereas the long-term transformation of international approaches to technological risk emerged through the interaction of reactor design, organizational culture, institutional secrecy, expert authority, and post-accident learning processes. This article seeks to integrate these dimensions within a single historical framework.

The article is structured in five interconnected sections. The first section examines the role of nuclear energy within Soviet modernization policies and analyses the institutional characteristics of the Soviet nuclear programme. The second section investigates the technical and organizational origins of the Chernobyl accident. The third section explores the crisis of technological expertise and the reassessment of nuclear risk after 1986. The fourth section analyses the emergence of the concept of safety culture and the transformation of international nuclear governance. Finally, the fifth section considers the long-term consequences and historical legacy of the disaster in the broader context of sustainable technological development and contemporary approaches to risk governance.

The purpose of this study is to examine the Chernobyl disaster as a turning point in the evolution of nuclear safety culture and technological governance. Particular

attention is devoted to the relationship between reactor design, organizational culture, institutional secrecy, and the circulation of technical knowledge within the Soviet nuclear industry. By analysing the origins, consequences, and long-term legacy of the accident, the article seeks to demonstrate how Chernobyl contributed to the transformation of international approaches to nuclear safety and to the development of principles that continue to influence contemporary discussions of sustainable technological development.

Research Methods.

This study is situated within the fields of the history of science and technology, nuclear history, and science and technology studies. It examines the Chernobyl disaster not only as a technological accident but also as a historical event that transformed understandings of nuclear safety, technological governance, and the relationship between scientific expertise and society. The research adopts an interdisciplinary historical approach that combines the analysis of technological systems with the investigation of institutional, organizational, and socio-political factors that shaped the origins and consequences of the accident.

The study is based primarily on the analysis of published documentary sources, international regulatory documents, historical scholarship, and scientific literature. Particular attention is devoted to the reports of the IAEA, especially INSAG-4 (*Safety Culture*) and INSAG-7 (*The Chernobyl Accident: Updating of INSAG-1*), which played a decisive role in the international reassessment of the accident and the subsequent development of the concept of safety culture (IAEA, 1991; IAEA, 1992). These documents are treated not only as sources of technical information but also as historical evidence reflecting changing international understandings of technological risk and organizational responsibility.

The historiographical foundation of the study includes works devoted to the history of the Soviet nuclear programme, the institutional culture of the Soviet nuclear industry, the history of technological accidents, and the development of international nuclear governance. Particular attention is given to studies by Schmid (2006, 2011, 2015; 2016, 2018, 2019), which analyse Soviet nuclear expertise, organizational culture, and post-Chernobyl transformations in nuclear safety policy. These works are complemented by broader historical and interdisciplinary scholarship addressing the political, social, and technological dimensions of the Chernobyl disaster.

Several historical methods were employed. The historical-genetic method was used to reconstruct the evolution of the Soviet nuclear programme and the development of RBMK reactor technology prior to 1986. The historical-comparative method facilitated the analysis of changes in international approaches to nuclear safety before and after the accident. The problem-chronological method was applied to examine the sequence of events leading to the disaster and the subsequent evolution of safety concepts, regulatory frameworks, and international cooperation. Elements of systems analysis were also employed to investigate the interactions between technological

design, organizational practices, institutional structures, and decision-making processes.

The study further draws upon approaches developed within science and technology studies, which view technological systems as socio-technical constructs shaped by interactions among technical artefacts, expert communities, institutions, and political environments. This perspective allows the Chernobyl accident to be analysed not simply as the failure of a reactor or the consequence of individual actions, but as the product of a complex system involving technological design, organizational culture, information management, and institutional governance.

The source base also includes studies of the long-term health, environmental, and psychological consequences of the accident, reports of the Chernobyl Forum, and research concerning post-accident modernization of RBMK reactors. These materials were used to assess how scientific understanding of the disaster evolved over time and how the lessons of Chernobyl influenced subsequent developments in nuclear safety, risk assessment, and technological governance.

The methodological framework adopted in this article makes it possible to examine Chernobyl simultaneously as a technological disaster, a historical turning point in the development of nuclear safety culture, and a case study in the evolution of modern approaches to the governance of complex technological systems. Such an approach allows the accident to be considered not only within the context of Soviet nuclear history but also within broader discussions concerning sustainable technological development and the historical foundations of contemporary risk governance.

Results and Discussions.

1. Soviet Nuclear Modernity before Chernobyl.

1.1. Nuclear Energy in Soviet Modernization Policy.

The development of nuclear energy occupied a central position in Soviet visions of scientific and technological progress after the Second World War. Although the Soviet atomic programme initially emerged within the context of military competition and nuclear weapons development, by the mid-1950s nuclear technologies increasingly became associated with broader goals of economic modernization and industrial development. The commissioning of the world's first grid-connected nuclear power plant at Obninsk in 1954 was presented not only as a scientific achievement but also as evidence that atomic energy could serve peaceful economic purposes and contribute to the construction of a technologically advanced socialist society (Josephson, 2000; Schmid, 2018).

Unlike many Western nuclear programmes, which were frequently justified through projected energy demand and economic efficiency, Soviet nuclear development was closely integrated into state-led modernization strategies. Nuclear power plants were expected to perform multiple functions simultaneously: generating electricity, supporting industrial expansion, strengthening technological self-sufficiency, and demonstrating the scientific capabilities of the Soviet state. As

Josephson (2000) has argued, large technological systems occupied a privileged place within Soviet development thinking because they symbolized the capacity of science and engineering to transform both nature and society.

The expansion of civilian nuclear energy during the 1960s and 1970s occurred within a highly centralized planning framework. Research institutes, design bureaus, industrial ministries, and political authorities were linked through administrative mechanisms that coordinated technological development on a national scale. This system enabled the rapid construction of large industrial projects and facilitated the growth of nuclear generating capacity across the Soviet Union. At the same time, centralized decision-making often concentrated authority within a relatively small number of institutions, reducing opportunities for independent review and external assessment of technological choices (Perrow, 1999; Schmid, 2015).

Nuclear energy also acquired considerable symbolic significance within Soviet political culture. Official publications, exhibitions, educational programmes, and popular science literature portrayed the “peaceful atom” as one of the defining achievements of modern science. As Schmid (2006) has demonstrated, Soviet exhibitions devoted to atomic energy presented nuclear technologies as visible manifestations of progress, rational planning, and scientific modernity. The atom became a powerful symbol of the Scientific-Technological Revolution that Soviet leaders expected would transform industry, agriculture, transportation, and everyday life.

This technological optimism was not limited to electricity generation. Nuclear technologies were incorporated into ambitious projects involving desalination, regional development, scientific research, and large-scale industrial infrastructure. Guth's study (2022) of the city of Shevchenko (now Aktau) illustrates how nuclear energy became embedded within broader programmes aimed at transforming geographically remote regions through technological innovation. Such projects reflected widespread confidence that advanced technologies could overcome environmental and economic constraints while accelerating modernization.

The rapid growth of the Soviet nuclear sector was accompanied by increasing institutional complexity. By the late 1970s and early 1980s, reactor designers, research institutes, operating organizations, industrial ministries, and political authorities formed an extensive network responsible for the development and management of nuclear technologies. While this structure facilitated technological expansion, it also created challenges related to communication, coordination, and the circulation of safety-related knowledge. Historians of Soviet technology have noted that information concerning operational experience and emerging technical concerns was not always disseminated effectively across organizational boundaries, limiting opportunities for institutional learning and critical reassessment (Balonov & Bouville, 2020, Guth, Gestwa, Penter, & Richers, 2019, Josephson, 2000).

These characteristics reflected broader features of Soviet modernization. Large technological systems were frequently regarded as instruments through which scientific knowledge could be transformed into economic growth and social progress.

As a result, technological achievement often occupied a prominent position in official narratives of development. At the same time, confidence in scientific and engineering expertise sometimes contributed to assumptions that technical challenges could be resolved primarily through technological solutions, while organizational and institutional dimensions received comparatively less attention (Kuchinskaya, 2014, Perrow, 1999, Schmid, 2018).

The significance of these developments became particularly evident after the Chernobyl accident. Subsequent investigations demonstrated that the disaster could not be explained solely through technical deficiencies or operator actions. It also reflected characteristics of the institutional environment within which Soviet nuclear technologies were developed, managed, and regulated. The rapid expansion of nuclear power, the concentration of expertise within specialized organizations, limitations in the circulation of safety-related information, and strong confidence in technological progress all formed part of the broader historical context that shaped the origins of the accident (IAEA, 1992; Kuchinskaya, 2014, Schmid, 2015).

Soviet nuclear energy should therefore be understood not merely as a source of electricity but as a key component of a wider modernization project. The Chernobyl disaster exposed some of the contradictions inherent in this project, demonstrating both the transformative potential of large technological systems and the risks associated with their governance. Understanding these historical conditions is essential for explaining why Chernobyl became a turning point not only in the history of nuclear energy but also in the evolution of technological risk management, safety culture, and international approaches to technological governance.

1.2. The RBMK Reactor and the Soviet Nuclear Program.

The rapid expansion of Soviet nuclear power during the 1970s and early 1980s was closely associated with the development of the RBMK reactor series. The acronym RBMK referred to a graphite-moderated, light-water-cooled reactor designed for large-scale electricity generation. By the mid-1980s, RBMK reactors constituted one of the principal components of the Soviet nuclear energy programme and operated at major nuclear power plants including Chernobyl, Leningrad, Kursk, Ignalina, and Smolensk (Guth, Gestwa, Penter, & Richers, 2019, IAEA, 1992; Schmid, 2015).

The origins of the RBMK concept can be traced to earlier Soviet reactor technologies developed for both military and civilian applications. Unlike pressurized water reactors that became dominant in many Western nuclear programmes, the RBMK employed a channel-type design in which individual fuel channels passed through a large graphite moderator. This configuration allowed refuelling during operation and enabled the construction of reactors with exceptionally high electrical output. Equally important, the design could be implemented using the capabilities of Soviet heavy industry without requiring the large reactor pressure vessels necessary for many Western reactor systems.

The decision to expand the RBMK programme reflected broader priorities of Soviet modernization policy. During the 1960s and 1970s, state planners viewed

nuclear energy as an essential component of long-term economic development and energy security. Reactor technologies capable of rapid deployment and large-scale electricity generation were therefore particularly attractive. As Schmid (2018) has demonstrated, the RBMK was regarded not merely as an engineering solution but as an instrument of industrial modernization that could support regional development and reduce dependence on fossil fuels in strategically important areas of the Soviet Union. The technological characteristics of the RBMK were closely linked to these institutional and economic priorities. The reactor's large capacity, online refuelling capability, and relatively flexible construction requirements made it well suited to the objectives of centralized economic planning. However, historians of technology have emphasized that technological choices are never determined solely by engineering considerations. They are also shaped by political priorities, industrial capabilities, organizational structures, and prevailing assumptions regarding acceptable risk. The RBMK emerged from this broader context and therefore reflected both technical ambitions and institutional constraints of the Soviet nuclear programme.

At the same time, the RBMK possessed several characteristics that distinguished it from most commercial reactor designs operating elsewhere in the world. The combination of graphite moderation and water cooling produced specific neutronic properties, including a positive void coefficient under certain operating conditions. In addition, the large dimensions of the reactor core created challenges associated with monitoring and controlling reactor behaviour during transient conditions. Prior to 1986, these characteristics were generally regarded by reactor designers as manageable within the established operational framework of Soviet nuclear power plants (IAEA, 1992; Josephson, 2000; Wakabayashi, Mochizuki, Midorikawa, Hayamizu, & Kitahara, 1987).

Research conducted after the Chernobyl accident demonstrated that some of these design characteristics acquired critical significance under specific operating conditions. Investigations published during the late 1980s and early 1990s identified the interaction between reactor physics, control rod design, and operational circumstances as a key element in the development of the power excursion that destroyed Unit 4. Early analyses by Japanese nuclear specialists confirmed that the sequence of events observed during the accident was consistent with known characteristics of RBMK behaviour under unstable operating conditions (Chan & Dastur, 1989; IAEA, 1986a, 1986b, 1991; Wakabayashi, Mochizuki, Midorikawa, Hayamizu, & Kitahara, 1987).

Subsequent investigations provided a more detailed understanding of these processes. The INSAG-7 report concluded that deficiencies in the design of the control and protection system contributed significantly to the accident (IAEA, 1992). Particular attention was directed toward the graphite displacers attached to the control rods, which under specific conditions could initially introduce positive reactivity during emergency shutdown. Further analyses demonstrated that this design feature played an important role in explaining the rapid power increase observed during the

final seconds before the explosion (Chan & Dastur, 1989; D’Auria, et al., 2008a, 2008b, 2008c).

However, reducing the origins of the disaster solely to reactor design would oversimplify the historical reality. Historians and scholars of technology have increasingly emphasized that technological systems must be understood within the institutional environments in which they are developed and operated (Kuchinskaya, 2014; Perrow, 1999; Schmid, 2011, 2015). The RBMK was not simply a reactor design; it was also a product of Soviet planning institutions, scientific organizations, industrial ministries, design bureaus, and operating practices. Decisions regarding its development reflected contemporary understandings of safety, economic efficiency, technological feasibility, and national development priorities.

The accident at Chernobyl fundamentally transformed international perceptions of the RBMK. During the years following 1986, extensive modernization programmes were implemented at operating RBMK plants. Reactor control characteristics were modified, safety systems were upgraded, operating procedures were revised, and regulatory oversight was strengthened. These measures reflected a broader shift from confidence in technological capability alone toward a more comprehensive understanding of nuclear safety that incorporated organizational learning, regulatory review, and continuous reassessment of operational experience (D’Auria, et al., 2008a, 2008b, 2008c; IAEA, 1991, 1992).

The historical importance of the RBMK extends beyond its role in the Chernobyl accident. The reactor illustrates how technological artefacts embody the political, economic, and institutional assumptions of the societies that produce them. The history of the RBMK therefore provides valuable insight into the relationship between technological innovation, state modernization strategies, organizational culture, and the governance of technological risk in the late Soviet period.

1.3. Organizational Culture and Professional Identities in the Soviet Nuclear Industry.

The Soviet nuclear industry was not merely a collection of reactors, research institutes, and power plants. It constituted a complex socio-technical system in which technological development depended on interactions among scientists, engineers, plant operators, industrial ministries, regulatory authorities, and political institutions. Understanding the organizational culture of this system is essential for explaining both the achievements of Soviet nuclear technology and the difficulties that became apparent after the Chernobyl accident.

From its inception, the Soviet nuclear programme operated under conditions of exceptional political significance and institutional secrecy. The strategic importance of nuclear technologies encouraged the formation of highly specialized professional communities whose members possessed unique technical expertise and frequently worked within relatively closed organizational environments. As a result, professional identity within the nuclear sector became closely associated with scientific competence, technological achievement, and service to the state. Nuclear specialists

often regarded themselves as participants in a national project that combined scientific progress, economic modernization, and geopolitical competition (Guth, Gestwa, Penter, & Richers, 2019; Josephson, 2000; Schmid, 2015).

This professional culture contributed significantly to the successes of the Soviet nuclear programme. Scientists and engineers generally viewed nuclear technology as a symbol of progress and modernity and were strongly committed to technological innovation and engineering problem-solving. Such attitudes facilitated the rapid development of nuclear infrastructure and supported ambitious reactor construction programmes. However, historians have also noted that strong confidence in technological capability could influence the ways in which risks, operational anomalies, and safety concerns were interpreted within professional communities (Perrow, 1999; Schmid, 2015, 2018).

An important characteristic of the Soviet nuclear system was the coexistence of multiple institutional actors with distinct responsibilities and priorities. Research institutes focused on reactor design and scientific innovation, operating organizations concentrated on electricity production, while ministries and political authorities pursued broader economic and strategic objectives. Although these institutions were formally integrated within a centralized administrative structure, communication between them was not always effective. Information concerning operational incidents, equipment deficiencies, or safety-related concerns could remain confined within particular organizations rather than being systematically disseminated throughout the entire nuclear sector.

The management of technical knowledge represented a particularly significant challenge. As the nuclear programme expanded during the 1970s and 1980s, increasing organizational complexity required effective mechanisms for collecting operational experience and transforming it into improvements in reactor design, operating procedures, and personnel training. Investigations conducted after the Chernobyl accident demonstrated that such mechanisms were not always sufficiently developed. Lessons derived from operational events were not consistently incorporated into industry-wide decision-making processes, limiting opportunities for institutional learning before 1986 (IAEA, 1992; Josephson, 2000; Schmid, 2015).

The role of secrecy further complicated these processes. Secrecy fulfilled important functions within a state whose nuclear technologies possessed both civilian and military significance. However, historians have argued that the classification of technical information sometimes created barriers to the broader exchange of operational experience and safety-related knowledge. In certain cases, information concerning design vulnerabilities or operational anomalies remained restricted to relatively narrow professional circles. As a consequence, knowledge that might have contributed to improved safety did not always reach all organizations responsible for reactor operation, personnel training, and regulatory oversight.

Studies of Soviet expertise have also emphasized the relationship between authority and technological decision-making. Scientific expertise occupied a highly respected position within Soviet society, and technical specialists often exercised

considerable influence over technological policy. Nevertheless, expert authority operated within a hierarchical institutional environment shaped by administrative planning and political priorities. Under such conditions, evaluations of technological risk could be influenced not only by scientific evidence but also by organizational expectations, production goals, and broader development strategies. As Schmid (2015) has demonstrated, expertise within the late Soviet system was closely connected to questions of institutional legitimacy and political authority.

These characteristics should not be interpreted as unique to the Soviet Union. Research on technological accidents in different national contexts has shown that tensions between production objectives, expert judgment, organizational learning, and risk management are common features of many large technological systems. Perrow (1999), for example, argued that accidents in complex and tightly coupled systems often emerge from interactions among multiple organizational and technological factors rather than from isolated failures. Similarly, Vaughan's (1996) study of the Challenger disaster demonstrated how organizational cultures can normalize risk and contribute to catastrophic outcomes despite the presence of highly qualified technical personnel.

Viewed from this broader perspective, the Chernobyl accident appears not simply as the failure of a reactor or the result of mistakes made by individual operators. It also reflected systemic challenges associated with the governance of complex technological systems. The accident exposed limitations in the circulation of technical knowledge, the communication of operational experience, and the institutional mechanisms through which safety concerns were identified, evaluated, and addressed. These issues subsequently became central to international discussions of safety culture, organizational learning, and technological governance (IAEA, 1991, 1992).

Historically, organizational culture played a crucial role in shaping technological outcomes. The Chernobyl disaster demonstrated that technological reliability depends not only on engineering design but also on the institutional environments within which technologies are developed, regulated, and operated. Understanding the organizational culture of the Soviet nuclear sector is therefore essential for explaining why the accident became a watershed event in the history of nuclear energy and why its consequences extended far beyond the boundaries of a single reactor or power plant.

2. The Chernobyl Accident: Technical and Institutional Origins.

2.1. The April 1986 Safety Test.

On 26 April 1986, Unit 4 of the Chernobyl Nuclear Power Plant was destroyed during a turbine-generator rundown test conducted as part of a scheduled reactor shutdown for maintenance. The objective of the experiment was to determine whether the residual rotational energy of the turbine could provide sufficient electrical power to essential safety systems during the interval between the loss of external power and the activation of emergency diesel generators. Similar tests had previously been performed at other Soviet nuclear facilities, and the experiment itself was not considered unusual within the operational practices of the Soviet nuclear industry

(IAEA, 1992; Schmid, 2015; Wakabayashi, Mochizuki, Midorikawa, Hayamizu, & Kitahara, 1987).

The events preceding the accident have been reconstructed in considerable detail through investigations conducted by Soviet authorities, IAEA, and subsequent independent researchers. During preparation for the test, a combination of operational delays, changes in reactor conditions, and decisions made by plant personnel resulted in a reactor state that differed significantly from the parameters originally envisaged in the test programme. Reactor power decreased to an unexpectedly low level, xenon poisoning developed within the core, and operators undertook a series of actions intended to restore power and maintain reactor operation. As a consequence, the reactor entered a regime characterized by reduced operational reactivity margin and increased sensitivity to disturbances (IAEA, 1992; Schmid, 2015; Wakabayashi, Mochizuki, Midorikawa, Hayamizu, & Kitahara, 1987).

The historical significance of the safety test lies not only in the events themselves but also in the ways they were subsequently interpreted. The first official Soviet explanation, presented at the IAEA review meeting in Vienna in August 1986, emphasized violations of operating procedures and identified operator actions as the principal cause of the accident. This interpretation strongly influenced international understanding of the disaster during the late 1980s and contributed to a widespread perception that Chernobyl resulted primarily from human error committed during the execution of the experiment (IAEA, 1986a, 1986b).

Subsequent investigations fundamentally altered this interpretation. During the late 1980s and early 1990s, growing evidence demonstrated that the accident could not be adequately explained through operator actions alone. Detailed analyses revealed that reactor design characteristics, deficiencies in safety analysis, limitations in operating documentation, and weaknesses in organizational communication had also played important roles in the development of the accident sequence (Balonov, 2007; Chan & Dastur, 1989; Kuchinskaya, 2014).

The publication of INSAG-7 in 1992 marked a major turning point in the interpretation of the disaster (IAEA, 1992). The report concluded that the accident resulted from a complex interaction between technological characteristics, organizational deficiencies, and human actions. It acknowledged that operators violated procedures but simultaneously recognized that plant personnel lacked complete information concerning important reactor characteristics and that several design deficiencies had not been adequately communicated to operating organizations. Consequently, responsibility for the accident could no longer be attributed solely to the actions of individuals working in the control room during the night of 25–26 April 1986.

This reinterpretation reflected broader changes in international thinking about technological accidents. During the late twentieth century, researchers increasingly challenged explanations that focused exclusively on human error. Studies of complex technological systems demonstrated that accidents often emerge through interactions among technical components, organizational structures, institutional cultures, and

decision-making processes. In this context, the Chernobyl accident became one of the most influential examples supporting a systemic interpretation of technological failure (Jasanoff, 2003; Perrow, 1999; Vaughan, 1996; Yurchenko, Strelko, Vasilova, Rudiuk, Goretskyi, 2023).

Historians of technology have similarly emphasized that the April 1986 test should not be viewed as an isolated operational event (Marples, 1988; Perrow, 1999). Schmid (2015) argues that the actions of plant personnel occurred within a broader institutional environment shaped by assumptions regarding reactor safety, technological reliability, and organizational authority. The decisions made during the test were therefore influenced not only by immediate operational circumstances but also by the professional cultures, institutional structures, and knowledge-management practices that characterized the Soviet nuclear industry.

The reassessment of the safety test also transformed understandings of responsibility. Rather than searching for a single cause or a single group of individuals responsible for the disaster, researchers increasingly examined how design assumptions, operational procedures, organizational practices, and institutional arrangements interacted to create conditions under which catastrophic failure became possible. This shift from individual blame toward systemic analysis would later become one of the intellectual foundations of the concept of safety culture developed by the International Nuclear Safety Advisory Group (IAEA, 1991, 1992).

Historically, the significance of the April 1986 safety test extends far beyond the technical sequence of events that culminated in the destruction of Unit 4. The accident became a catalyst for the reassessment of long-established assumptions concerning technological reliability, expert authority, and risk management. It encouraged scholars, engineers, and policymakers to recognize that the safe operation of complex technologies depends not only on technical design but also on the organizational and institutional environments within which technological systems are developed, regulated, and operated.

The events of 26 April 1986 thus occupy a pivotal place in the history of technological risk. The safety test that began as a routine engineering experiment ultimately became one of the most influential case studies in modern discussions of accident causation, organizational learning, and technological governance. Its reinterpretation over subsequent decades illustrates how scientific understanding of technological disasters evolves through the continuous reassessment of evidence, institutional practices, and historical experience.

2.2. Design Characteristics of the RBMK-1000 Reactor.

The reassessment of the Chernobyl accident conducted after 1986 demonstrated that several design characteristics of the RBMK-1000 reactor played a significant role in the development of the disaster. While early explanations emphasized operator actions and procedural violations, subsequent investigations revealed that important features of the reactor itself contributed to the rapid escalation of the accident. These findings fundamentally altered international understandings of nuclear safety and

reinforced the growing recognition that technological design and organizational practices must be analysed as interconnected elements of complex socio-technical systems.

The RBMK-1000 differed substantially from most commercial nuclear reactors operating in Western countries during the 1970s and 1980s. It employed graphite as a neutron moderator and ordinary light water as a coolant. This combination offered several advantages, including high power output, online refuelling capability, and flexibility in fuel utilization. Such characteristics made the reactor particularly attractive within the Soviet energy programme, where rapid expansion of generating capacity and compatibility with domestic industrial capabilities were considered strategic priorities.

The technological configuration of the RBMK reflected broader institutional and economic considerations. Unlike many Western reactor designs, the RBMK could be constructed without large reactor pressure vessels, reducing dependence on certain manufacturing capabilities and facilitating large-scale deployment within the Soviet Union. Historians of technology have noted that reactor design choices are rarely determined solely by engineering criteria; they are also influenced by industrial infrastructure, political priorities, economic constraints, and prevailing conceptions of acceptable risk. The RBMK emerged from this broader context and therefore embodied both technical ambitions and institutional assumptions of the Soviet nuclear programme (Jasanoff, 2003; Josephson, 2000; Schmid, 2018).

Among the reactor characteristics that attracted particular attention after the accident was the positive void coefficient of reactivity. Under normal operating conditions, water circulating through the reactor core functioned not only as a coolant but also as a neutron absorber. When steam bubbles formed within coolant channels, neutron absorption decreased and reactor power could increase. In the RBMK, this effect became especially pronounced under certain operating conditions. Investigations conducted after the accident demonstrated that this characteristic could contribute to rapid increases in reactivity if reactor parameters moved beyond intended operating regimes (IAEA, 1992).

The large physical dimensions of the reactor core represented another important design feature. Unlike compact reactor configurations used in many pressurized water reactors, the RBMK contained thousands of fuel channels distributed throughout a massive graphite moderator. This arrangement created complex spatial distributions of neutron flux and reactivity. Subsequent analyses showed that these characteristics could influence reactor behaviour during transient conditions and contribute to the emergence of unstable operating states under specific circumstances (D'Auria, et al., 2008a, 2008b, 2008c; Schmid, 2015; Wakabayashi, Mochizuki, Midorikawa, Hayamizu, & Kitahara, 1987).

Particular attention was devoted to the design of the reactor's control and protection system. Following the accident, investigators determined that the control rods incorporated graphite displacers attached to their lower sections. During the initial stage of insertion, these graphite sections displaced neutron-absorbing water from

portions of the core. Under certain conditions, this process could temporarily increase reactivity before the absorber sections of the rods entered the reactor and began reducing power. Although this phenomenon was known within specialized technical circles, its significance under extreme operating conditions was not fully appreciated before the accident (IAEA, 1992).

Subsequent studies examined this issue in greater detail. Chan and Dastur (1989) demonstrated that positive scram reactivity could be introduced during emergency shutdown if specific neutron flux distributions existed within the reactor core. Later analyses by D'Auria et al. (2008a, 2008b, 2008c) further clarified the physical mechanisms responsible for this effect and confirmed its importance in explaining the rapid power excursion observed during the final seconds before the explosion. These investigations contributed significantly to the reinterpretation of the accident and influenced subsequent modernization programmes implemented at operating RBMK facilities.

The reassessment of reactor design also highlighted shortcomings in the communication of technical knowledge. The INSAG-7 report concluded that reactor operators did not possess complete information regarding all characteristics of the control and protection system. Certain design features and their potential consequences under abnormal operating conditions were insufficiently reflected in operating documentation and training materials. Consequently, plant personnel could not fully evaluate the risks associated with reactor operation under the conditions that developed during the safety test.

From a historical perspective, these findings challenged simplified explanations of technological accidents. The Chernobyl disaster did not occur solely because of a defective reactor design, nor solely because of operator actions. Rather, it emerged from interactions among technological characteristics, operational decisions, institutional practices, and the circulation of technical knowledge. The RBMK reactor functioned within a broader organizational environment that influenced how design assumptions were interpreted, communicated, and implemented in practice (Balonov, 2007; Knoglinger, Wölfl, & Kaliatka, 2015; Sato & Lyamzina, 2018).

The significance of the RBMK therefore extends beyond the technical causes of the accident itself. The post-Chernobyl reassessment of its design characteristics contributed directly to the development of new approaches to nuclear safety analysis, reactor regulation, and risk assessment. It also reinforced the growing recognition that safety cannot be treated exclusively as a property of technology but must be understood as a product of interactions between technological systems and the organizations responsible for their design, operation, and oversight.

Following the accident, extensive modifications were introduced at operating RBMK plants. These included reductions in the positive void coefficient, redesign of control rods, enhancement of emergency protection systems, revision of operating procedures, and strengthening of regulatory oversight. Such measures significantly improved reactor safety and illustrate how major technological accidents can stimulate institutional learning, technological adaptation, and the production of new forms of

engineering knowledge. In this sense, the history of the RBMK after 1986 is not only a history of failure but also a history of reassessment, modernization, and the emergence of new safety paradigms within the international nuclear community (Schmid, 2015, 2018, 2019; Uspuras & Kaliatka, 2012).

The RBMK-1000 provides an important historical example of how technological artefacts embody scientific assumptions, institutional priorities, and political choices. Its history demonstrates that technological design cannot be separated from the social and organizational environments within which technologies are created and operated. The reinterpretation of RBMK technology after Chernobyl therefore played a crucial role in transforming international understandings of risk, responsibility, and technological governance.

2.3. Human Factors, Organizational Decision-Making, and Institutional Constraints.

The reassessment of the Chernobyl accident during the late 1980s and early 1990s fundamentally changed the interpretation of technological disasters. While the first official explanations emphasized violations of operating procedures and errors committed by plant personnel, subsequent analyses demonstrated that such interpretations provided only a partial understanding of the accident. Attention gradually shifted from individual responsibility toward broader questions concerning organizational behaviour, institutional decision-making, and the governance of technological risk (Guth, Gestwa, Penter, & Richers, 2019; Jasanoff, 2003; Kuchinskaya, 2014).

Human actions undoubtedly played an important role in the events preceding the destruction of Unit 4. During the preparation and execution of the turbine-generator rundown test, operators departed from several established procedures, and the reactor entered a condition that was not envisaged in the original test programme. However, later investigations demonstrated that these actions occurred within an institutional environment shaped by specific assumptions regarding reactor safety, operational flexibility, and the relationship between operators and technological systems. Consequently, the behaviour of plant personnel cannot be understood independently of the organizational context in which decisions were made (IAEA, 1992; Schmid, 2015).

One of the central conclusions of the INSAG-7 reassessment was that deficiencies in reactor design and safety management significantly influenced operator decision-making. The report noted that plant personnel did not possess complete information regarding several important characteristics of the RBMK reactor, including the potential consequences of emergency shutdown under specific operating conditions. As a result, actions that appeared reasonable from the perspective of operators could produce consequences that were neither anticipated nor fully understood by those responsible for reactor operation. This finding challenged earlier attempts to explain the accident primarily through individual mistakes and highlighted the importance of communication between designers, regulators, and operating organizations (IAEA, 1992).

The accident also exposed weaknesses in the institutional mechanisms through which operational experience was collected, interpreted, and disseminated. By the mid-1980s, the Soviet nuclear industry had accumulated considerable experience in the operation of RBMK reactors. Several incidents and operational anomalies had occurred at different facilities, including events involving reactor instability and unexpected reactivity effects. Nevertheless, information derived from these experiences was not always translated into systematic modifications of reactor design, operating procedures, or personnel training. The existence of technical knowledge within individual organizations did not necessarily guarantee its effective circulation throughout the broader nuclear sector.

Studies of Soviet technological expertise suggest that this problem was partly related to the structure of decision-making within the nuclear industry (Balonov, 2007; D'Auria et al., 2008b; Kuchinskaya, 2014). Responsibility for reactor design, plant operation, scientific research, and regulatory oversight was distributed among numerous organizations whose priorities were not always identical. Under such conditions, information could become fragmented across institutional boundaries. Knowledge available within one part of the system might not be fully integrated into decision-making processes elsewhere. Schmid (2015) argues that these characteristics reflected broader features of Soviet expert culture, where highly specialized professional communities often operated within relatively autonomous organizational environments.

Institutional secrecy further complicated the circulation of technical information. Although secrecy was a common feature of nuclear programmes throughout the world, its role within the Soviet system extended beyond the protection of strategically sensitive information. The classification of technical data sometimes limited opportunities for independent review and constrained broader discussions of operational problems. In such an environment, the identification and communication of potential safety concerns could become more difficult, particularly when those concerns challenged established assumptions regarding reactor performance or organizational effectiveness (IAEA, 1992).

The Chernobyl accident therefore revealed limitations not only in reactor technology but also in the governance of complex technological systems. The disaster demonstrated that technological safety depends upon effective communication between institutions, transparent evaluation of operational experience, and continuous reassessment of existing practices. These conclusions paralleled broader developments in research on technological accidents, which increasingly emphasized the role of organizational factors in shaping catastrophic outcomes (Perrow, 1999; Vaughan, 1996).

Perrow's theory of "normal accidents" provides a particularly useful framework for interpreting the Chernobyl disaster. According to Perrow (1999), accidents in highly complex and tightly coupled systems often emerge from unexpected interactions among multiple components rather than from isolated technical failures or individual mistakes. From this perspective, the accident at Unit 4 can be understood as the product

of interactions among reactor design characteristics, operational decisions, organizational structures, and institutional constraints. Similarly, Vaughan's (1996) analysis of the Challenger disaster demonstrated how organizational cultures may gradually normalize risk and contribute to catastrophic outcomes despite the presence of technically competent personnel.

From a historical perspective, the significance of human factors in the Chernobyl accident lies not in the identification of individual errors but in the recognition that human actions are shaped by organizational structures, technological assumptions, institutional cultures, and systems of authority. The disaster illustrated the limitations of explanations that separate technical and social causes of technological failure. Instead, it revealed the extent to which engineering design, operational practice, regulatory oversight, and institutional decision-making are interconnected elements of a single socio-technical system.

This reinterpretation of the accident contributed directly to the emergence of the modern concept of safety culture. International experts increasingly concluded that technological reliability could not be ensured solely through engineering improvements or procedural controls. It also required organizational environments capable of encouraging critical evaluation, learning from operational experience, and maintaining effective communication among all participants in the technological process. These conclusions would become one of the most enduring legacies of the Chernobyl disaster and would profoundly influence the future development of nuclear safety governance worldwide. The reassessment of human factors after Chernobyl represents an important intellectual shift in the understanding of technological accidents. The disaster encouraged a move away from explanations centred on individual blame toward systemic analyses of technological risk, organizational behaviour, and institutional responsibility. This shift would subsequently shape international approaches to safety culture, organizational learning, and the governance of complex technologies far beyond the nuclear sector.

3. Chernobyl and the Crisis of Soviet Technological Expertise.

3.1. Information Management and Institutional Secrecy.

The Chernobyl accident exposed not only deficiencies in reactor design and operational practices but also deeper problems related to the management of technical information within the Soviet nuclear sector. In the years following the disaster, researchers increasingly recognized that the reliability of complex technological systems depends not only on engineering solutions but also on the ways in which knowledge is generated, communicated, and incorporated into decision-making processes. From this perspective, the accident revealed important limitations in the institutional mechanisms responsible for the circulation of expertise and the evaluation of technological risk.

The Soviet nuclear industry developed within a political and administrative environment in which secrecy played a central role. Many aspects of reactor design, operational performance, and safety analysis were treated as restricted information

because of the strategic significance of nuclear technologies. Although secrecy was common in nuclear programmes worldwide, several historians have noted that within the Soviet system it became closely integrated into administrative decision-making and institutional communication. As a consequence, the exchange of information among research institutes, design organizations, regulatory authorities, and operating facilities was often constrained by organizational boundaries and classification practices.

The management of operational experience represented a particularly important challenge. By the mid-1980s, several RBMK reactors had accumulated years of operating history, generating valuable information concerning reactor behaviour, equipment performance, and safety-related events. Subsequent investigations revealed that some operational incidents had already exposed characteristics of RBMK reactors that later became relevant during the Chernobyl accident. However, lessons derived from these events were not always translated into industry-wide modifications of reactor design, operational procedures, or personnel training (IAEA, 1992; Schmid, 2015).

This problem reflected broader features of Soviet expert culture. According to Schmid (2015), the Soviet nuclear industry was characterized by highly specialized professional communities possessing substantial technical expertise but often operating within relatively autonomous institutional structures. Design institutes, research organizations, plant operators, and administrative authorities maintained distinct responsibilities and channels of communication. Under such conditions, knowledge could remain compartmentalized within individual organizations rather than becoming part of a comprehensive system of organizational learning. Similar observations have been made by Josephson (2000), who emphasized the fragmented character of technological governance in several sectors of the late Soviet economy.

The role of secrecy further complicated these processes. While the protection of sensitive information was justified by military and strategic considerations, the classification of technical data could also limit opportunities for independent review and critical evaluation. Investigations conducted after the accident demonstrated that information concerning certain reactor characteristics and operational anomalies was not always communicated effectively across institutional boundaries. Consequently, knowledge that might have contributed to improved safety was not consistently available to all organizations responsible for reactor operation and regulation (Schmid, 2015).

The accident also revealed tensions between technological optimism and the recognition of risk. Throughout much of the post-war period, nuclear energy occupied a privileged position within Soviet narratives of scientific and technological progress. Official discourse frequently presented atomic energy as evidence of the capacity of science and engineering to overcome economic and environmental limitations. As historians of Soviet technology have argued, such narratives contributed to confidence in technological systems and sometimes reduced incentives for questioning established assumptions regarding safety and reliability (Guth, 2022; Schmid, 2015, 2016, 2018).

Schmid's analysis of late Soviet politics of expertise suggests that Chernobyl transformed risk from a primarily technical category into a broader social and political issue. Questions concerning reactor safety, environmental contamination, and institutional accountability increasingly moved beyond specialized professional communities and entered public and political debate. As a result, the authority of scientific and technical institutions became subject to new forms of scrutiny, while demands for transparency and accountability acquired greater significance in discussions of technological governance (Guth, Gestwa, Penter, & Richers, 2019; Schmid, 2015).

The significance of these developments extended beyond the immediate circumstances of the accident. The crisis generated by Chernobyl demonstrated that technological systems cannot be governed effectively through technical expertise alone. Reliable operation requires institutional environments capable of identifying potential problems, encouraging the exchange of information, and integrating diverse forms of knowledge into decision-making processes. Similar conclusions have been reached within the broader literature on technological accidents and organizational failure, which emphasizes the importance of communication, institutional learning, and transparency in managing complex socio-technical systems (Perrow, 1999; Vaughan, 1996; Yurchenko, Strelko, Rudiuk, Horban, Bernatskyi, 2023).

Viewed historically, the experience of Chernobyl contributed to a redefinition of the relationship between expertise, institutions, and technological governance. The accident highlighted the limitations of highly centralized systems that relied heavily on internal communication while providing limited opportunities for external review. It also demonstrated that effective risk management depends upon the ability of organizations to learn from operational experience and communicate emerging concerns before they develop into major failures (IAEA, 1991, 1992).

The reassessment of these issues after 1986 played a crucial role in the emergence of new approaches to nuclear safety and organizational learning. It also laid the foundation for international discussions concerning safety culture, transparency, and institutional responsibility that continue to influence the governance of complex technological systems today.

3.2. The Reassessment of Nuclear Risk.

The Chernobyl accident marked a turning point in the historical understanding of technological risk. Prior to 1986, discussions of nuclear safety were largely dominated by technical considerations, including reactor reliability, engineering redundancy, probabilistic risk assessment, and compliance with operational procedures. Although concerns regarding severe accidents existed within specialist communities, the prevailing assumption in many countries was that improvements in reactor design and regulatory controls would progressively reduce the likelihood of catastrophic failures.

The destruction of Unit 4 challenged these assumptions. The scale of radioactive releases, the transboundary nature of contamination, and the extensive social consequences of the accident demonstrated that nuclear risk could not be understood

solely through technical calculations. Chernobyl revealed that technological failures could affect public health, environmental management, economic development, political legitimacy, and public confidence in scientific institutions simultaneously. Consequently, risk increasingly came to be viewed as a multidimensional phenomenon extending beyond the boundaries of engineering analysis (Arnhold, 2020; Balonov, 2007; Josephson, 2000).

One of the most significant outcomes of the accident was the growing recognition that uncertainty itself constituted an important dimension of technological governance. During the months and years following the disaster, experts encountered substantial difficulties in estimating the long-term consequences of radioactive contamination, evaluating health risks, and communicating scientific findings to affected populations. These challenges exposed limitations in existing approaches to risk assessment and highlighted the need for greater attention to uncertainty, institutional learning, and public communication.

The transformation of risk discourse was particularly evident within the Soviet Union. Schmid (2015) has demonstrated that Chernobyl altered the political role of expertise by moving discussions of technological risk from relatively closed expert communities into the public sphere. Questions concerning reactor safety, environmental contamination, and institutional accountability increasingly became subjects of public debate and political contestation. As a result, risk ceased to be treated exclusively as a technical issue and became intertwined with broader concerns regarding governance, transparency, and public responsibility.

The international nuclear community underwent a similar process of reassessment. Investigations conducted by the International Atomic Energy Agency concluded that conventional distinctions between technical failures and organizational failures were often artificial. The INSAG-7 report emphasized that reactor safety depended not only on engineering design but also on management practices, communication systems, regulatory effectiveness, and organizational culture (IAEA, 1992). This interpretation represented an important departure from earlier approaches that focused primarily on technological reliability.

The broader significance of these conclusions was reinforced by contemporary scholarship on technological accidents. Perrow (1999) argued that accidents in highly complex and tightly coupled systems frequently emerge from interactions among multiple components rather than from isolated failures. Similarly, Vaughan (1996), in her analysis of the Challenger disaster, demonstrated how organizational processes and institutional cultures can contribute to catastrophic outcomes even in technologically advanced environments. Although these studies examined different technological domains, their findings helped establish a broader theoretical framework within which Chernobyl could be interpreted as a systemic failure of a socio-technical system rather than as a purely technical malfunction.

The reinterpretation of nuclear risk also influenced international preparedness strategies. As Schmid (2016) has noted, the experience of Chernobyl encouraged a shift from assumptions that severe accidents could be prevented entirely toward approaches

emphasizing preparedness, resilience, and emergency response capabilities. While accident prevention remained a central objective, policymakers increasingly acknowledged that complex technological systems could never be rendered completely free of uncertainty. Consequently, greater attention was devoted to accident management, emergency planning, and post-accident recovery.

Recent historical research has further demonstrated that the legacy of Chernobyl extends beyond the nuclear sector. Arnhold (2020) argues that the accident contributed to the normalization of discussions concerning technological hazards and influenced broader approaches to risk governance in contemporary societies. Rather than treating technological accidents as exceptional anomalies, experts and policymakers increasingly began to view them as events that must be incorporated into long-term planning, institutional design, and regulatory practice.

The consequences of this intellectual transformation can be observed in the emergence of new approaches to technological governance during the late twentieth and early twenty-first centuries. Increasing emphasis was placed on transparency, organizational learning, independent oversight, and international cooperation. Risk management gradually evolved from a predominantly technical activity into a multidisciplinary field that incorporated engineering, environmental science, public health, sociology, and public policy.

From a historical perspective, the reassessment of nuclear risk after Chernobyl represents one of the most important intellectual consequences of the disaster. The accident transformed understandings of safety, uncertainty, and responsibility, influencing not only nuclear energy but also wider debates concerning the governance of complex technologies. In doing so, it helped establish the foundations for a more comprehensive approach to technological risk that integrated engineering expertise, organizational learning, regulatory oversight, and societal participation.

The evolution of these ideas created the conditions for the emergence of one of the most influential concepts in contemporary technological governance—the concept of safety culture. It was through attempts to understand why existing technical and regulatory measures had failed at Chernobyl that international experts began to formulate a new framework linking technological reliability to organizational values, institutional practices, and human behavior.

3.3. Public Trust and Expert Authority after 1986.

The Chernobyl disaster significantly transformed the relationship between scientific expertise, public institutions, and society. While the technical consequences of the accident have been extensively studied, its impact on public trust and perceptions of expert authority was equally profound. The disaster exposed weaknesses not only in reactor technology and organizational practices but also in the mechanisms through which scientific knowledge was communicated, interpreted, and legitimized within society.

Before 1986, nuclear energy occupied a prominent position within Soviet narratives of scientific and technological progress. Nuclear scientists and engineers

were widely regarded as representatives of one of the most advanced sectors of the Soviet economy, and their expertise carried considerable institutional authority. Public discussions of nuclear safety remained limited, while assessments of technological risks were largely confined to specialized professional communities. Under these conditions, confidence in scientific expertise was closely linked to confidence in state institutions and their capacity to manage complex technological systems (Jasanoff, 2003; Josephson, 2000; Schmid, 2015).

The accident fundamentally altered this relationship. Delays in public disclosure, uncertainty regarding the scale of contamination, and contradictory information that emerged during the first weeks after the explosion contributed to growing public skepticism toward official sources. In many affected regions, citizens experienced considerable difficulties obtaining reliable information about radiation exposure, health risks, and environmental contamination. As a consequence, confidence in governmental institutions and expert organizations declined, while informal networks and alternative channels of communication became increasingly important (Kuchinskaya, 2014, Marples, 1988; Schmid, 2018).

The consequences of these developments were not limited to the Soviet Union. Internationally, the accident generated widespread debate concerning the reliability of expert assessments, the transparency of technological governance, and the accountability of institutions responsible for managing technological risks. The transboundary character of radioactive contamination demonstrated that nuclear accidents could no longer be treated as purely domestic affairs. Governments, regulatory authorities, scientific institutions, and international organizations faced growing pressure to provide accurate information and justify their decisions before both national and international audiences (Arnhold, 2020; IAEA, 1992; Schmid, 2016).

Historians and scholars working within science and technology studies have argued that Chernobyl contributed to a broader transformation in the social role of expertise. Rather than being regarded as an unquestionable source of authority, scientific expertise increasingly became subject to public scrutiny and debate. The accident highlighted the distinction between possessing technical knowledge and maintaining public trust. Expert institutions could no longer assume that scientific competence alone would guarantee societal legitimacy; transparency, accountability, and effective communication became equally important components of technological governance.

This transformation is particularly evident in studies of risk communication. Research conducted after Chernobyl demonstrated that public responses to technological hazards are influenced not only by measurable levels of danger but also by perceptions of institutional credibility, fairness, and trustworthiness (Kuchinskaya, 2014; Oe, Takebayashi, Sato, & Maeda, 2021; Schmid, 2019). In many cases, uncertainty and conflicting information may generate long-lasting social consequences even when objective levels of risk decline over time. The experience of Chernobyl therefore illustrated that managing technological risk requires attention to social and institutional dimensions alongside technical considerations.

The long-term social consequences of the accident further reinforced these conclusions. International assessments increasingly recognized that psychological stress, fear of radiation, social stigmatization, forced relocation, and the erosion of confidence in public institutions constituted significant components of the disaster's legacy. According to the findings of the Chernobyl Forum, many affected communities experienced persistent social and psychological challenges that often proved more durable than immediate radiological effects (Balonov, 2007). Comparative analyses of Three Mile Island, Chernobyl, and Fukushima have similarly demonstrated that perceptions of institutional trust play a central role in determining long-term community resilience following technological disasters (Oe, Takebayashi, Sato, & Maeda, 2021).

The crisis of expert authority that emerged after Chernobyl also encouraged important institutional reforms within the international nuclear community. Greater emphasis was placed on transparency, independent regulation, public communication, peer review, and international information exchange. The conventions adopted after 1986, together with the growing role of the International Atomic Energy Agency in coordinating safety assessments and emergency preparedness activities, reflected a broader recognition that technological governance depends upon institutional legitimacy as much as upon technical competence (IAEA, 1992; Sato & Lyamzina, 2018; Schmid, 2016).

From a historical perspective, the significance of Chernobyl lies partly in its contribution to changing understandings of expertise itself. The accident demonstrated that expert authority is not solely a product of specialized knowledge. It is also shaped by institutional practices, communication strategies, and societal perceptions of legitimacy. This lesson became increasingly influential during the late twentieth century as governments and international organizations confronted new technological risks characterized by uncertainty, complexity, and extensive societal consequences.

The experience of Chernobyl therefore helped redefine the relationship between science, technology, and society. It demonstrated that effective governance of complex technological systems requires not only scientific expertise and engineering competence but also public trust, transparency, and mechanisms capable of integrating diverse forms of knowledge into decision-making processes. These conclusions became an important foundation for the emergence of the concept of safety culture and continue to influence contemporary discussions concerning technological governance and sustainable development.

4. From Nuclear Safety to Safety Culture.

4.1. INSAG and the Emergence of the Safety Culture Concept.

Among the many consequences of the Chernobyl disaster, one of the most influential was the emergence of a new understanding of technological safety. Prior to 1986, safety within the nuclear industry was generally viewed primarily as a matter of engineering reliability, regulatory compliance, and adherence to established operational procedures. Although organizational factors were not entirely ignored, they

rarely occupied a central place in discussions of accident prevention. The Chernobyl accident demonstrated the limitations of this perspective and encouraged a broader reassessment of the relationship between technology, organizations, and risk (IAEA, 1992; Perrow, 1999).

In the years immediately following the disaster, international experts sought to identify the deeper causes of the accident and determine why existing safety mechanisms had failed. These efforts were coordinated largely through the International Atomic Energy Agency and the International Nuclear Safety Advisory Group. Early investigations gradually shifted attention away from explanations focused exclusively on operator error or technical deficiencies and toward a broader examination of organizational practices, institutional behaviour, communication systems, and management structures (IAEA, 1992; Schmid, 2015).

A decisive step in this process occurred with the publication of the INSAG report *Safety Culture* in 1991. For the first time, an international organization introduced a comprehensive conceptual framework linking technological safety to organizational values and human behaviour. The report defined safety culture as the set of characteristics and attitudes within organizations and among individuals that establish safety as an overriding priority. According to INSAG, technological reliability depends not only on engineering design but also on leadership practices, communication systems, professional responsibility, training, and institutional commitment to safety (IAEA, 1991).

The concept represented a significant departure from earlier approaches to accident prevention. Traditional safety models tended to focus on hardware, technical procedures, and compliance with regulations. Safety culture expanded this perspective by recognizing that organizational environments shape how technologies are designed, operated, maintained, and regulated. Consequently, accidents could originate not only from equipment failures but also from deficiencies in communication, management, supervision, and institutional learning. In this respect, the concept reflected broader developments in studies of organizational reliability and technological risk that emerged during the late twentieth century (Perrow, 1999; Vaughan, 1996).

The reassessment presented in INSAG-7 further reinforced these conclusions. Rather than identifying a single cause of the Chernobyl accident, the report described a complex interaction of technical, organizational, and human factors. Deficiencies in reactor design, weaknesses in operating procedures, insufficient communication between designers and operators, and limitations in regulatory oversight all contributed to the conditions that allowed the accident to occur (IAEA, 1992). This interpretation became highly influential because it offered a framework capable of explaining technological failures without reducing them either to engineering defects or to individual mistakes alone.

The emergence of safety culture reflected broader changes in the understanding of technological systems during the late twentieth century. Researchers increasingly recognized that highly complex technologies operate within organizational environments that influence decision-making, risk perception, and responses to

unexpected events. From this perspective, safety came to be understood as an emergent property of socio-technical systems rather than as a characteristic of technological components alone.

Historical studies have emphasized that the concept of safety culture emerged at a moment when confidence in purely technical approaches to risk management was being reassessed. As Schmid (2015) has shown, the Chernobyl disaster exposed weaknesses not only in reactor design but also in the organizational structures responsible for managing technical knowledge and operational experience. Likewise, Arnhold (2020) argues that the accident contributed to broader transformations in international approaches to technological governance by encouraging greater attention to institutional responsibility, transparency, and the management of uncertainty.

The influence of the safety culture concept rapidly extended beyond the nuclear industry. During the 1990s and 2000s, similar approaches were adopted in aviation, transportation, healthcare, chemical manufacturing, and other sectors characterized by high levels of technological complexity. In each case, attention shifted toward organizational learning, communication practices, leadership, and institutional accountability as essential elements of risk management. Consequently, the legacy of Chernobyl contributed to a wider transformation in international thinking about technological governance and safety management (IAEA, 1991; Schmid, 2016).

The significance of this transformation extends beyond the practical regulation of nuclear energy. From the perspective of the history of science and technology, the development of safety culture represents an important intellectual shift in the understanding of risk and responsibility in modern technological societies. It challenged deterministic views of technological safety and encouraged the recognition that reliability emerges from interactions among technical systems, institutions, and human actors. In doing so, it provided a conceptual foundation that continues to influence contemporary approaches to technological governance, risk management, and sustainable development.

The emergence of safety culture therefore constitutes one of the most important intellectual legacies of the Chernobyl disaster. It transformed understandings of safety, responsibility, and organizational behaviour while establishing a framework that remains central to the governance of complex technologies nearly four decades after the accident.

4.2. International Responses to Chernobyl.

The international response to the Chernobyl accident represented one of the most significant transformations in the history of nuclear governance. Prior to 1986, cooperation among national nuclear programmes existed primarily in the areas of scientific research, reactor development, and the exchange of technical expertise. Although international organizations such as the International Atomic Energy Agency played important coordinating roles, responsibility for nuclear safety remained largely a national matter. The transboundary consequences of the Chernobyl accident exposed the limitations of this approach and created strong incentives for the development of

new mechanisms of international cooperation (Jasanoff, 2003; IAEA, 1992; Schmid, 2016).

One of the most immediate lessons of the disaster was the necessity of rapid information exchange during nuclear emergencies. Radioactive contamination spread across national borders within days of the accident, affecting numerous European countries before detailed information regarding the event became publicly available. The detection of elevated radiation levels in Sweden and other European states highlighted deficiencies in existing communication arrangements and demonstrated that nuclear accidents could have consequences extending far beyond the territory of the country in which they occurred (Arnhold, 2020; Balonov, 2007; Schmid, 2015).

In response, the international community adopted several important legal instruments. Among the most significant were the Convention on Early Notification of a Nuclear Accident and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency, both adopted under the auspices of the IAEA in 1986. These agreements established formal procedures for information exchange, emergency communication, and international assistance. Their adoption reflected growing recognition that nuclear safety could no longer be addressed solely within national frameworks and required institutionalized forms of international cooperation (IAEA, 1986a, 1986b).

The accident also stimulated substantial changes in the role of the IAEA itself. During the years following Chernobyl, the Agency expanded its activities related to operational safety, emergency preparedness, peer review, and the development of international safety standards. New programmes encouraged the systematic exchange of operational experience, the identification of safety deficiencies, and the dissemination of lessons learned from accidents and near-miss events. These initiatives reflected a broader shift from reactive responses toward continuous organizational learning and preventive risk management (IAEA, 1991, 1992).

An important aspect of this transformation was the growing emphasis on peer review and external evaluation. Prior to the accident, safety assessments were conducted primarily within national regulatory and operating organizations. After Chernobyl, international review missions became increasingly common, allowing experts from different countries to evaluate safety practices, identify weaknesses, and share operational experience. Historians of nuclear governance have noted that these mechanisms contributed to greater transparency and reduced the likelihood that critical safety information would remain confined within individual organizations or national systems (Arnhold, 2020; Sato & Lyamzina, 2018; Schmid, 2016).

The concept of safety culture played a central role in these developments. As the international nuclear community sought to understand the causes of the accident, it became increasingly apparent that technical standards alone could not guarantee safe operation. Attention therefore shifted toward organizational behaviour, leadership, communication practices, management systems, and institutional responsibility. Training programmes, regulatory frameworks, and operational procedures were progressively revised to incorporate these principles, resulting in a more

comprehensive understanding of safety that integrated technological and organizational dimensions (IAEA, 1991, 1992).

The influence of Chernobyl extended beyond formal regulatory structures. The accident encouraged the development of international networks dedicated to emergency preparedness, radiation monitoring, environmental assessment, and public communication (see Table 1). Scientific cooperation intensified as researchers from different countries worked together to investigate the health, environmental, and social consequences of the disaster. The work of the Chernobyl Forum and subsequent international research programmes demonstrated the growing importance of multidisciplinary and multinational approaches to the study of technological disasters (Balonov, 2007; Balonov & Bouville, 2020).

Table 1. Evolution of International Approaches to Nuclear Safety after Chernobyl.

Period	Dominant safety paradigm	Key characteristics
Before 1986	Technical reliability	Focus on reactor design, engineering systems, procedural compliance
1986–1991	Systemic reassessment	Recognition of organizational and institutional factors
After INSAG-4 (1991)	Safety culture	Integration of organizational behaviour, management, communication, and training
1990s–2000s	International governance	Peer reviews, conventions, international cooperation, transparency
21st century	Risk governance and resilience	Preparedness, organizational learning, public trust, sustainability

Historical analyses suggest that the international response to Chernobyl represented a broader transformation in technological governance. Rather than treating accidents as isolated national events, policymakers increasingly recognized that complex technologies operate within global systems characterized by interconnected risks and shared responsibilities. Effective governance therefore required not only technical expertise but also international cooperation, institutional transparency, and mechanisms for collective learning. In this respect, Chernobyl contributed to the emergence of new models of transnational governance that extended beyond the nuclear sector itself (Arnhold, 2020; Jasanoff, 2003).

The significance of these changes became particularly evident following later nuclear emergencies, most notably the Fukushima Daiichi accident in 2011. Many of the institutional mechanisms, emergency response procedures, and safety principles

applied during the Fukushima response had their origins in reforms introduced after Chernobyl. Schmid (2016) argues that the experience of 1986 fundamentally reshaped international preparedness strategies and influenced the ways in which governments and organizations approached the management of technological uncertainty in the decades that followed.

From the perspective of the history of science and technology, the international response to Chernobyl demonstrates how major technological disasters can stimulate institutional innovation. The accident prompted the creation of new forms of cooperation, encouraged the diffusion of knowledge across national boundaries, and strengthened the role of international organizations in technological governance. It also contributed to the emergence of new understandings of accountability, transparency, and shared responsibility in the management of technological risks. In this sense, Chernobyl influenced not only the future development of nuclear safety but also broader approaches to global technological governance that remain relevant in the twenty-first century.

4.3. Post-Chernobyl Modernization of RBMK Reactors.

The destruction of Unit 4 at the Chernobyl Nuclear Power Plant did not bring an immediate end to the RBMK reactor programme. At the time of the accident, RBMK units constituted an important component of electricity generation within the Soviet Union, and several reactors remained in operation at Chernobyl, Leningrad, Kursk, Ignalina, and Smolensk nuclear power plants. Consequently, one of the principal challenges facing the nuclear industry after 1986 was determining whether these reactors could continue operating safely and what modifications would be required to reduce accident risks (D'Auria, Soloviev, Mazzini, & Sollima, 2008c; IAEA, 1992; Uspuras & Kaliatka, 2012).

Post-accident investigations identified several reactor characteristics that required immediate attention. Particular concern was directed toward the positive void coefficient, the design of the control and protection system, operational reactivity margins, and emergency shutdown performance. Analyses conducted during the late 1980s and early 1990s demonstrated that significant engineering modifications would be necessary if RBMK reactors were to satisfy evolving international safety expectations (Chan & Dastur, 1989; IAEA, 1992; Schmid, 2015).

One of the first priorities involved improving the neutron-physical characteristics of the reactor core. Modifications included increasing fuel enrichment, introducing additional fixed absorbers, and implementing changes in fuel management strategies. These measures substantially reduced the positive void coefficient and improved reactor stability during low-power operating conditions. At the same time, new operational restrictions were introduced to prevent reactor states similar to those that had developed during the final stages of the Chernobyl safety test (D'Auria, et al., 2008a, 2008b, 2008c; IAEA, 1992; Uspuras & Kaliatka, 2012).

The control and protection system was also extensively redesigned. Modifications included changes to the geometry of control rods, improvements in insertion

characteristics, and revisions to emergency shutdown procedures. These measures were intended to eliminate the possibility that activation of emergency protection systems could produce an initial increase in reactivity under specific operating conditions. Subsequent technical assessments concluded that the implemented modifications effectively addressed one of the principal design vulnerabilities identified after the accident (Uspuras & Kaliatka, 2012).

During the 1990s and early 2000s, reactor modernization increasingly evolved from a series of engineering corrections into a comprehensive safety improvement programme. Researchers and regulators gradually adopted a broader systems perspective that incorporated reactor design, operational procedures, personnel training, emergency preparedness, and regulatory oversight. This transition reflected the growing influence of the safety culture concept and the recognition that technological safety depends on interactions among technical, organizational, and institutional factors (Schmid, 2015).

International cooperation played a significant role in this process. Safety assessments and modernization initiatives involved specialists from Russia, Lithuania, Ukraine, and several Western countries. Collaborative research programmes focused on reactor physics, thermal-hydraulic processes, accident management strategies, severe accident analysis, and probabilistic safety assessment. These efforts contributed not only to technical improvements but also to the development of shared approaches to nuclear safety evaluation and risk management (D'Auria et al., 2008a, 2008b, 2008c; Fesenko et al., 2006; Havenaar et al., 1997).

From a historical perspective, the modernization of RBMK reactors illustrates an important transformation in engineering practice following major technological accidents. Rather than treating the accident as an isolated failure, researchers increasingly approached RBMK technology as a system requiring continuous reassessment and adaptation. The extensive analytical work undertaken after 1986 generated new knowledge concerning reactor behaviour, accident progression, and safety management. In this sense, the modernization programme functioned not merely as a technical response but also as a process of institutional and scientific learning.

The reassessment of RBMK safety also contributed to broader methodological developments within nuclear engineering. Studies performed after Chernobyl encouraged wider adoption of probabilistic safety assessment, risk-informed regulation, severe accident management strategies, and integrated approaches to reactor evaluation. According to D'Auria and colleagues (2008a), the RBMK modernization programme became an important case study in the evolution of modern nuclear safety methodologies, demonstrating how operational experience can be incorporated into both engineering design and regulatory practice.

Subsequent analyses have demonstrated that the post-Chernobyl RBMK differed substantially from the reactor configuration that existed in April 1986. Investigations by Uspuras and Kaliatka (2012) documented major improvements in reactor safety characteristics, while studies by Knoglinger, Wölfl, and Kaliatka (2015) illustrated continuing efforts to improve understanding of RBMK thermal-hydraulic and graphite-

core behaviour. Although these modifications did not eliminate all challenges associated with RBMK technology, they significantly reduced the likelihood of accident scenarios comparable to those of 1986 and strengthened the overall safety framework governing reactor operation.

The modernization programme also altered international perceptions of reactor development. Historians of technology have observed that major accidents are often interpreted as endpoints that reveal the limitations of particular technological trajectories. The RBMK experience suggests a more complex picture. Rather than leading immediately to the abandonment of the technology, the accident initiated a prolonged process of redesign, reassessment, and adaptation. This process illustrates how technological systems evolve through interactions between operational experience, scientific knowledge, regulatory intervention, and institutional learning.

The post-Chernobyl history of RBMK reactors therefore represents more than a technical response to a specific accident. It reflects a broader transformation in nuclear safety philosophy, from an emphasis on engineering performance alone toward an integrated approach combining technological design, organizational learning, regulatory oversight, and international cooperation. From the perspective of the history of science and technology, the modernization of RBMK reactors provides a valuable example of how technological systems respond to failure and how knowledge generated by accidents can contribute to long-term improvements in safety and governance.

5. Long-Term Consequences and Historical Legacy.

5.1. Health, Environmental, and Psychological Consequences.

The long-term consequences of the Chernobyl disaster have been the subject of extensive scientific investigation for nearly four decades. While early discussions frequently focused on worst-case scenarios and highly uncertain projections, subsequent research has provided a more nuanced understanding of the accident's health, environmental, and social impacts. This evolving body of knowledge represents an important chapter in the history of science, illustrating how scientific assessments of technological disasters change as new evidence becomes available and how international research communities address uncertainty in the study of long-term environmental hazards (Balonov, 2007; Bromet, 2014; Lindee, 2016).

One of the most immediate consequences of the accident was the exposure of plant personnel, emergency responders, and nearby populations to ionizing radiation. According to the assessments conducted by the Chernobyl Forum and UNSCEAR, 134 emergency workers and plant staff were diagnosed with acute radiation syndrome, and 28 of them died within the first months following the accident as a direct consequence of radiation exposure (Balonov, 2007; UNSCEAR, 2011). These findings remain among the most firmly established health effects attributable to the disaster and constitute a rare example of a large-scale radiological accident for which immediate medical consequences have been documented in considerable detail.

The long-term health consequences proved considerably more difficult to evaluate. The most clearly demonstrated effect has been the substantial increase in thyroid cancer among individuals exposed during childhood and adolescence, primarily associated with the ingestion of radioactive iodine-131 released during the accident. Large epidemiological investigations conducted in Belarus, Ukraine, and the Russian Federation identified thousands of excess thyroid cancer cases among populations exposed at young ages (Cardis et al., 2006; Tronko et al., 2006). Although the survival rate for these patients has generally been high, the increase in incidence represents one of the most important scientifically established long-term consequences of the disaster.

By contrast, assessments of other forms of cancer and non-cancer diseases have generated more complex scientific debates. UNSCEAR and the World Health Organization have generally concluded that evidence for substantial increases in most cancer types among the general population remains limited, particularly at lower exposure levels. At the same time, some researchers have argued that the full range of health consequences may be difficult to quantify because of methodological challenges, uncertainties in dose reconstruction, migration processes, and the influence of socioeconomic factors on population health (Balonov & Bouville, 2020). These discussions illustrate broader difficulties associated with studying long-term effects of low-dose radiation exposure and demonstrate how scientific knowledge evolves through continuing reassessment of evidence.

Environmental contamination extended far beyond the territory immediately surrounding the Chernobyl Nuclear Power Plant. Radioactive materials were dispersed across large areas of Europe, with deposition patterns strongly influenced by meteorological conditions during and after the accident. Significant contamination occurred in Belarus, Ukraine, and parts of the Russian Federation, while measurable fallout was recorded in numerous European countries (UNSCEAR, 2011; Balonov & Bouville, 2020). The transboundary nature of contamination transformed Chernobyl from a national emergency into an international environmental issue and stimulated unprecedented scientific cooperation in radioecology, environmental monitoring, and radiation protection.

The environmental consequences of the disaster also contributed to the development of new approaches to long-term risk management. Researchers and policymakers were required to address challenges involving contaminated agricultural land, forestry management, food safety, and environmental remediation. Studies conducted during the decades following the accident demonstrated that countermeasures such as restrictions on agricultural production, food monitoring programmes, soil treatment, and land-use management could substantially reduce radiation exposure among affected populations. The experience gained through these programmes significantly influenced international recommendations concerning post-accident recovery and environmental protection (Balonov, 2007; Fesenko et al., 2006).

Perhaps the most unexpected lesson of Chernobyl emerged from investigations of its psychological and social consequences. During the 1990s and early 2000s,

international assessments increasingly recognized that many of the most persistent effects of the disaster were not directly related to radiation exposure itself. Fear of radiation, uncertainty regarding future health risks, forced relocation, social stigmatization, and economic disruption affected millions of people living in contaminated regions (Balonov, 2007). In many cases, these factors had a greater influence on everyday life than measurable radiological hazards.

Research on mental health outcomes has consistently demonstrated elevated levels of anxiety, depression, stress-related disorders, and risk perception among affected populations. Havenaar et al. (1997) identified long-lasting psychological effects among residents of contaminated regions, while Bromet (2014) argued that the psychological legacy of Chernobyl constitutes one of the most significant public health consequences of the disaster. These findings contributed to a broader recognition that technological accidents must be analysed not only through physical health indicators but also through their social and psychological dimensions.

Recent comparative studies examining Three Mile Island, Chernobyl, and Fukushima have reinforced these conclusions. Oe et al. (2021) argue that psychological consequences frequently persist longer than immediate physical health effects and may become central determinants of long-term community resilience. The Chernobyl experience demonstrated that public responses to technological accidents are shaped not only by measurable hazards but also by perceptions of risk, institutional trust, media narratives, and the effectiveness of communication strategies.

The scientific investigation of Chernobyl's consequences has itself become an important subject of historical analysis. As Lindee (2016) observes, research on radiation effects after major nuclear events contributed to the formation of international scientific networks and influenced broader understandings of risk, uncertainty, evidence, and expertise in environmental health sciences. The accident stimulated extensive international collaboration among epidemiologists, medical researchers, environmental scientists, and radiation protection specialists, thereby transforming not only knowledge about Chernobyl but also the institutional organization of scientific research itself.

From a historical perspective, the evolution of knowledge concerning Chernobyl's consequences illustrates the complex relationship between science, uncertainty, and public policy. Initial assessments were often shaped by limited data and substantial uncertainty, whereas subsequent decades brought more sophisticated epidemiological methods, environmental monitoring systems, and risk assessment techniques. The resulting body of research has not eliminated all controversies, but it has significantly improved understanding of the health, environmental, and psychological dimensions of nuclear accidents.

The long-term consequences of Chernobyl therefore represent more than a catalogue of damages caused by a technological disaster. They also demonstrate how scientific knowledge develops through sustained investigation, international cooperation, methodological refinement, and the continuous reassessment of evidence. These processes played a crucial role in shaping contemporary approaches to radiation

protection, environmental management, public health, disaster recovery, and technological risk governance.

5.2. Scientific Lessons of Chernobyl.

The significance of the Chernobyl disaster extends far beyond its immediate technical, environmental, and social consequences. During the decades following the accident, Chernobyl became one of the most influential case studies in the history of science and technology, contributing to fundamental changes in how experts understand technological risk, organizational failure, and the governance of complex socio-technical systems. Many concepts that are now considered essential elements of modern safety management were either strengthened or substantially redefined through attempts to explain the causes and consequences of the accident.

One of the most important scientific lessons concerned the limitations of purely technical approaches to safety. Before 1986, nuclear safety was often understood primarily in terms of reactor design, engineering reliability, and compliance with technical regulations. The Chernobyl accident demonstrated that even sophisticated technological systems could experience catastrophic failure when organizational and institutional factors were not adequately considered. Subsequent investigations concluded that safety should be understood as a property of the entire socio-technical system rather than as a characteristic of technological components alone (IAEA, 1992; Perrow, 1999).

This realization contributed directly to the emergence of the concept of safety culture. As outlined in the INSAG reports, safety depends not only on hardware and procedures but also on organizational values, leadership, communication practices, professional responsibility, and institutional commitment to continuous learning (IAEA, 1991). The influence of this concept rapidly extended beyond the nuclear industry and became increasingly important in aviation, chemical engineering, transportation systems, healthcare, and other high-risk sectors. In this respect, the legacy of Chernobyl reached well beyond nuclear energy and contributed to broader transformations in international approaches to risk management and organizational governance (Le Coze, 2018).

A second important lesson involved the relationship between expertise and uncertainty. The accident revealed that scientific knowledge is often incomplete when dealing with complex technological systems and unprecedented events. During the years following the disaster, researchers encountered significant difficulties in assessing long-term health effects, environmental contamination, and social consequences. These challenges encouraged greater recognition of uncertainty as an inherent feature of technological governance rather than as a temporary absence of information (Lindee, 2016; Pylypchuk, O. Ya., Strelko, & Pylypchuk, O. O., 2021; Schmid, 2015). Consequently, risk assessment increasingly incorporated probabilistic approaches, scenario analysis, adaptive management, and precautionary decision-making strategies.

The Chernobyl disaster also transformed understandings of organizational learning. Investigations demonstrated that information concerning reactor behaviour and operational anomalies had existed before 1986 but had not always been effectively communicated throughout the nuclear sector. This finding highlighted the importance of knowledge management, institutional memory, and the systematic exchange of operational experience. Modern approaches to safety management increasingly emphasize learning from incidents, near misses, and operational feedback, reflecting lessons that emerged directly from the reassessment of Chernobyl (Arnhold, 2020; Balonov & Bouville, 2020; Schmid, 2015).

Another significant contribution involved the development of international scientific cooperation. The transboundary consequences of radioactive contamination required collaboration among researchers, regulatory authorities, and international organizations across multiple countries. New monitoring networks, epidemiological studies, environmental research programmes, and emergency preparedness initiatives emerged as a result of these efforts. The work of the Chernobyl Forum represented one of the most extensive international scientific assessments ever conducted in relation to a technological disaster and demonstrated the importance of multidisciplinary approaches to understanding complex technological events (Balonov, 2007).

The accident also reshaped scientific thinking regarding preparedness and resilience. Prior to Chernobyl, many safety strategies focused primarily on accident prevention. Although prevention remains essential, the experience of 1986 demonstrated that severe accidents cannot always be completely excluded. Consequently, increasing attention was devoted to emergency preparedness, accident management, recovery planning, institutional resilience, and long-term adaptation. Schmid (2016) has argued that these developments fundamentally influenced the evolution of international nuclear safety policy and later shaped responses to subsequent nuclear emergencies, including the Fukushima Daiichi accident.

Historical scholarship has further emphasized that Chernobyl challenged conventional distinctions between technical and social explanations of technological failure. The accident demonstrated that engineering systems, organizations, political institutions, and social environments operate as interconnected components of broader socio-technical networks. This perspective has become increasingly influential within science and technology studies, the history of technology, and risk research. Scholars now routinely analyse technological accidents as products of interactions between material systems and institutional structures rather than as isolated technical malfunctions (Arnhold, 2020; Guth, Gestwa, Penter, & Richers, 2019; Jasanoff, 2003).

The reinterpretation of Chernobyl also contributed to a broader reassessment of expert authority in technologically advanced societies. The accident revealed that technical expertise alone cannot guarantee safe technological operation if institutions lack mechanisms for transparency, communication, and accountability. As a result, scientific expertise increasingly came to be viewed as part of a wider governance framework involving regulators, operators, policymakers, local communities, and

international organizations (Jasanoff, 2003; Kuchinskaya, 2014; Le Coze, 2018). This shift remains one of the most important intellectual consequences of the disaster.

The lessons of Chernobyl remain highly relevant because many contemporary technologies exhibit characteristics similar to those of the nuclear systems examined after 1986. Advanced energy infrastructures, digital networks, artificial intelligence systems, biotechnology, and other complex technologies involve high levels of uncertainty, extensive organizational interdependence, and potentially significant societal consequences. The analytical frameworks developed in response to Chernobyl therefore continue to inform contemporary debates concerning technological governance, responsible innovation, and the management of systemic risks.

From a historical perspective, perhaps the most enduring lesson of Chernobyl is the recognition that technological progress and technological risk are inseparable. The disaster demonstrated that innovation requires not only scientific and engineering expertise but also institutions capable of learning, adapting, communicating uncertainty, and maintaining public trust. These insights continue to shape international discussions concerning the governance of complex technologies and remain highly relevant to contemporary efforts aimed at achieving sustainable technological development.

5.3. Chernobyl and Sustainable Technological Development.

The relevance of the Chernobyl disaster extends beyond the history of nuclear energy and continues to influence contemporary discussions concerning sustainable technological development. Although the concept of sustainable development gained international prominence shortly after the accident, particularly following the publication of the *Brundtland Report. Our Common Future* in 1987, many of the challenges exposed by Chernobyl remain central to present-day debates regarding the governance of complex technologies (WCED, 1987). The disaster demonstrated that technological progress cannot be evaluated solely in terms of economic efficiency, production capacity, or scientific achievement. Long-term sustainability also depends on safety, institutional accountability, transparency, and the capacity of organizations to learn from experience.

One of the most important lessons of Chernobyl concerns the relationship between innovation and risk. The rapid expansion of nuclear energy in the Soviet Union reflected a broader commitment to technological modernization and industrial development. However, the accident revealed that technological advancement may generate new forms of vulnerability when institutional and organizational capacities fail to evolve at the same pace as technical systems. Historical analyses of the Soviet nuclear programme have shown that technological innovation alone cannot guarantee sustainable development if mechanisms for risk assessment, organizational learning, and regulatory oversight remain insufficiently developed (Josephson, 2000; Schmid, 2015, 2018).

The experience of Chernobyl also highlighted the importance of integrating scientific knowledge into decision-making processes. Investigations conducted after

the accident demonstrated that safety-related information was not always effectively communicated between reactor designers, operators, regulators, and policymakers. These findings contributed to growing recognition that sustainable technological systems depend upon institutions capable of facilitating the circulation of knowledge, encouraging critical evaluation, and incorporating operational experience into future development strategies (IAEA, 1992; Schmid, 2015). In contemporary terms, these principles are closely associated with evidence-based governance and adaptive management.

Another important aspect concerns institutional resilience. The accident revealed that the ability of organizations to respond to unexpected events is often as important as their capacity to prevent them. Modern approaches to sustainable development increasingly emphasize resilience as a fundamental characteristic of technological systems operating under conditions of uncertainty. Following Chernobyl, international nuclear governance gradually shifted from a narrow focus on accident prevention toward broader strategies incorporating preparedness, emergency response, recovery planning, and institutional adaptability (Kuchinskaya, 2014; Sato & Lyamzina, 2018; Schmid, 2016).

The development of safety culture provides a particularly important example of this transformation. By linking technological reliability to organizational behaviour, leadership practices, communication processes, and institutional values, the concept expanded traditional understandings of safety beyond technical design alone. This broader perspective subsequently influenced numerous sectors, including aviation, transportation, healthcare, chemical manufacturing, and critical infrastructure management. As Le Coze (2018) has argued, major technological accidents have played a central role in shaping contemporary approaches to organizational safety and risk governance.

The accident further demonstrated the importance of public trust in the successful operation of complex technological systems. Scientific expertise remains essential for the development and regulation of advanced technologies, but public acceptance increasingly depends on transparency, accountability, and effective communication. The erosion of trust that followed the accident illustrated how deficiencies in information management can amplify the social consequences of technological failures. Contemporary approaches to sustainable development therefore place greater emphasis on stakeholder engagement, public participation, and institutional legitimacy in decision-making processes.

Historical analyses have also emphasized that Chernobyl transformed international approaches to cooperation in science and technology. The transboundary consequences of radioactive contamination encouraged the development of new mechanisms for information exchange, emergency preparedness, environmental monitoring, and scientific collaboration. These developments demonstrated that technological risks often transcend national boundaries and require coordinated international responses. In this respect, the legacy of Chernobyl anticipated many

contemporary discussions concerning global governance and shared responsibility in the management of technological hazards.

The significance of these developments can also be viewed through the lens of sustainable development theory. Scholars have increasingly argued that sustainability depends not only on environmental protection but also on the capacity of institutions to manage uncertainty, maintain public confidence, and adapt to changing technological conditions. The post-Chernobyl evolution of nuclear safety demonstrates that long-term sustainability requires continuous reassessment of technological systems and the integration of social, organizational, and technical dimensions of risk.

From the perspective of the history of science and technology, the significance of Chernobyl lies not only in the failures that culminated in the accident but also in the institutional and intellectual transformations that followed. The disaster stimulated new approaches to risk assessment, organizational learning, regulatory oversight, and international cooperation. These developments contributed to the emergence of principles that now occupy a central place in discussions of sustainable technological development.

The continuing relevance of Chernobyl demonstrates that sustainability cannot be reduced to environmental protection or economic performance alone. It also encompasses the quality of institutions, the effectiveness of governance systems, the management of uncertainty, and the responsible application of scientific knowledge. As contemporary societies confront challenges associated with climate change, energy transitions, artificial intelligence, and other emerging technologies, the lessons derived from Chernobyl remain highly relevant. The disaster serves as a reminder that sustainable technological development requires not only innovation but also the institutional capacity to anticipate risks, learn from failures, and maintain public trust.

5.4. Relevance to the United Nations Sustainable Development Goals.

Although the United Nations Sustainable Development Goals were adopted almost three decades after the Chernobyl disaster, many of the principles underlying the SDG framework reflect lessons that emerged from the reassessment of technological risks following the accident. The historical significance of Chernobyl therefore extends beyond the nuclear sector and remains relevant to contemporary discussions concerning sustainable development, responsible innovation, and institutional governance. The disaster demonstrated that technological systems are inseparable from the social, political, and organizational environments within which they operate, a principle that lies at the heart of the 2030 Agenda for Sustainable Development (United Nations, 2015).

One of the most direct connections can be observed in relation to SDG 3, *Good Health and Well-Being*. The accident demonstrated the long-term health consequences that may result from failures in the management of hazardous technologies. Beyond the immediate effects of radiation exposure, international assessments highlighted the importance of psychological well-being, risk communication, social resilience, and public confidence in health institutions. Research conducted after Chernobyl

contributed significantly to the development of modern approaches to radiation protection, emergency medicine, epidemiological monitoring, and public health preparedness (Balonov, 2007; Oe, Takebayashi, Sato, & Maeda, 2021). These lessons continue to inform international responses to technological and environmental emergencies.

The experience of Chernobyl is also highly relevant to SDG 7, *Affordable and Clean Energy*. Nuclear energy remains an important component of many national strategies aimed at reducing greenhouse gas emissions and achieving low-carbon energy transitions. At the same time, the accident demonstrated that the sustainability of energy systems cannot be assessed solely through their capacity to generate electricity. Long-term sustainability also requires effective safety management, robust regulatory frameworks, transparent decision-making, and public trust. The post-Chernobyl evolution of international nuclear safety standards illustrates how technological innovation must be accompanied by continuous institutional learning and risk governance (Balonov & Bouville, 2020; Lindee, 2016; Schmid, 2015, 2019).

Important connections also exist with SDG 9, *Industry, Innovation and Infrastructure*. One of the central lessons of Chernobyl is that technological innovation must be accompanied by mechanisms capable of identifying, assessing, and managing emerging risks. The accident highlighted the importance of integrating engineering design, organizational learning, regulatory oversight, and operational experience throughout the lifecycle of complex technological systems. Many contemporary approaches to industrial safety, resilience engineering, and risk-informed regulation reflect principles that gained prominence through the international reassessment of nuclear safety after 1986 (IAEA, 1991; Le Coze, 2018; Sato & Lyamzina, 2018).

Perhaps the strongest relationship can be identified with SDG 16, *Peace, Justice and Strong Institutions*. Investigations conducted after the accident repeatedly emphasized the importance of transparency, accountability, information sharing, and institutional effectiveness. The difficulties encountered in communicating information during and after the disaster demonstrated that technological safety depends not only on scientific expertise but also on the quality of governance structures responsible for managing risk and responding to emergencies. The subsequent development of international notification systems, peer-review mechanisms, and safety oversight procedures reflected a growing recognition that strong institutions are essential components of technological sustainability (Arnhold, 2020; IAEA, 1992; Kuchinskaya, 2014).

The relevance of Chernobyl to the SDGs is not limited to the nuclear sector. The analytical frameworks that emerged from the study of the accident have influenced broader discussions concerning climate technologies, critical infrastructure, biotechnology, artificial intelligence, and other fields characterized by high levels of complexity and uncertainty. In each of these domains, sustainable development depends upon the ability of institutions to balance innovation with responsibility, scientific advancement with risk management, and technological progress with societal trust (Jasanoff, 2003; Kuchinskaya, 2014; Lindee, 2016).

From the perspective of the history of science and technology, the connection between Chernobyl and the SDGs illustrates the enduring value of historical experience in addressing contemporary challenges. The disaster demonstrated that technological systems are embedded within broader social, political, and institutional environments. Consequently, sustainable development requires not only technological innovation but also effective governance, organizational learning, international cooperation, and the responsible application of scientific knowledge. These principles, which emerged with particular clarity from the reassessment of Chernobyl, remain fundamental to contemporary efforts aimed at building more resilient and sustainable technological societies.

The historical legacy of Chernobyl therefore supports a broader interpretation of sustainable development in which technological progress is inseparable from institutional responsibility. The accident revealed that failures of communication, governance, and organizational learning can undermine even the most advanced technological systems. Conversely, the reforms implemented after 1986 demonstrated that transparency, international cooperation, and continuous learning can strengthen technological resilience and improve long-term sustainability. In this sense, Chernobyl remains not only a historical case study but also a continuing source of lessons for policymakers, regulators, engineers, and scholars seeking to address the technological challenges of the twenty-first century.

Conclusions.

The Chernobyl disaster occupies a distinctive place in the history of science and technology because its significance extends far beyond the immediate circumstances of the accident that occurred on 26 April 1986. This study has demonstrated that the catastrophe cannot be adequately explained through technical deficiencies or operator actions alone. Rather, it emerged from the interaction of reactor design characteristics, organizational culture, institutional structures, and mechanisms governing the production and circulation of technical knowledge within the Soviet nuclear industry. The accident therefore represented a systemic failure within a complex socio-technical system rather than an isolated technological malfunction.

The analysis has shown that the origins of the disaster were closely connected to broader processes of Soviet scientific and technological modernization. Nuclear energy occupied a central position within Soviet development strategies and was regarded as a symbol of scientific progress and industrial achievement. However, the institutional arrangements that supported the rapid expansion of nuclear power also created challenges related to communication, organizational learning, and the management of technological risk. The history of the RBMK reactor demonstrates how technological artefacts are shaped not only by engineering considerations but also by political priorities, industrial capabilities, institutional cultures, and assumptions regarding acceptable risk.

A second important conclusion concerns the crisis of technological expertise revealed by the accident. Chernobyl exposed limitations in the circulation of safety-

related information, the integration of operational experience into decision-making processes, and the communication of technical knowledge between designers, operators, and regulators. In this respect, the disaster highlighted the importance of institutional transparency, knowledge management, and organizational learning in the governance of complex technological systems. The accident therefore became a catalyst for the reassessment of established relationships between expertise, authority, and technological decision-making.

The study has further demonstrated that one of the most significant intellectual consequences of Chernobyl was the transformation of international understandings of technological risk. Prior to 1986, safety was frequently treated primarily as an engineering problem. Following the accident, risk increasingly came to be understood as a multidimensional phenomenon encompassing technical, organizational, social, and institutional factors. This shift encouraged the adoption of systemic approaches to accident analysis and contributed to the growing recognition that technological failures emerge through interactions among multiple components of socio-technical systems.

Within this context, the emergence of the concept of safety culture represents one of the most enduring legacies of the disaster. Developed through the work of the International Nuclear Safety Advisory Group, the concept fundamentally altered international approaches to nuclear safety by linking technological reliability to organizational behaviour, communication practices, leadership, professional responsibility, and institutional values. The influence of safety culture subsequently extended far beyond the nuclear sector and became an important element of safety management in aviation, transportation, healthcare, chemical manufacturing, and other high-risk industries.

The post-Chernobyl transformation of international nuclear governance constituted another important outcome of the accident. As demonstrated in this study, international approaches to nuclear safety evolved from a primary focus on technical reliability toward broader frameworks incorporating safety culture, organizational learning, international cooperation, resilience, and risk governance. New mechanisms for information exchange, emergency preparedness, peer review, and international collaboration emerged in response to the deficiencies revealed in 1986. At the same time, extensive modernization programmes implemented at operating RBMK facilities demonstrated how technological systems can evolve through processes of reassessment, adaptation, and institutional learning.

The long-term legacy of Chernobyl also extends to contemporary discussions concerning sustainable technological development. The disaster demonstrated that technological sustainability cannot be reduced to efficiency, productivity, or innovation alone. Sustainable technological systems require effective institutions, transparent governance, robust safety cultures, and the capacity to learn from operational experience and unexpected failures. The experience of Chernobyl therefore remains highly relevant to present-day discussions concerning resilience, risk governance, and the responsible management of complex technologies.

The findings of this study are particularly significant in relation to the United Nations Sustainable Development Goals. The historical experience of Chernobyl illustrates the importance of protecting public health and well-being (SDG 3), ensuring the safe and responsible development of energy systems (SDG 7), promoting resilient infrastructure and innovation (SDG 9), and strengthening effective, accountable institutions capable of managing technological risks (SDG 16). The disaster demonstrated that long-term technological progress depends not only on scientific and engineering achievements but also on the quality of institutions responsible for governing technological change.

From the perspective of the history of science and technology, Chernobyl should be understood not merely as a nuclear accident but as a critical moment in the historical evolution of technological governance. The disaster revealed the limitations of approaches that treated safety primarily as a technical problem and contributed to the emergence of new understandings of risk, expertise, organizational learning, and institutional responsibility. In this sense, the significance of Chernobyl lies not only in the failures that produced the accident but also in the intellectual, organizational, and regulatory transformations that followed. Nearly four decades later, the disaster remains one of the most influential historical case studies for understanding how modern societies govern complex technologies under conditions of uncertainty. Its legacy continues to inform contemporary debates on safety culture, technological risk, and sustainable development in the twenty-first century.

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Чорнобиль і трансформація культури ядерної безпеки: управління технологіями, ризик та експертиза після 1986 року

***Анотація.** Чорнобильська катастрофа 26 квітня 1986 р. залишається однією з наймасштабніших техногенних аварій ХХ ст. та однією з ключових подій в історії науки і техніки. Якщо ранні інтерпретації аварії переважно зосереджувалися на конструктивних недоліках реактора та помилках оперативного персоналу, то подальші дослідження засвідчили, що її причини були значно складнішими та охоплювали взаємодію технічних, організаційних і інституційних чинників. Метою статті є дослідження Чорнобильської катастрофи як поворотного моменту в еволюції культури безпеки та технологічного врядування у сфері використання складних технологій. Особливу увагу приділено місцю ядерної енергетики в радянській модернізаційній політиці, розвитку програми реакторів РБМК, особливостям організаційної культури радянської ядерної галузі, а також управлінню технічними знаннями до та після аварії. Методологічну основу дослідження становлять методи історичного аналізу, історіографічного огляду, порівняльного аналізу та аналізу соціотехнічних систем. Джерельну базу формують документи Міжнародного агентства з атомної енергії, матеріали Чорнобильського форуму, а також сучасні дослідження з історії науки і техніки, ядерної безпеки, ризикології та технологічного врядування. У статті проаналізовано технічні та інституційні передумови аварії, кризи технологічної експертизи, переосмислення поняття ядерного ризику після 1986 р., а також формування концепції культури безпеки як нового підходу до забезпечення надійності складних технологічних систем. Встановлено, що Чорнобильська катастрофа не може бути адекватно пояснена виключно технічними несправностями або людськими помилками. Аварія стала проявом системної несправності, що виникла внаслідок взаємодії конструктивних особливостей реактора, організаційних практик,*

інституційних обмежень і недоліків у циркуляції інформації, пов'язаної з безпекою. Показано, що катастрофа суттєво вплинула на міжнародні підходи до оцінювання технологічних ризиків, сприяла становленню концепції культури безпеки як одного з ключових принципів ядерного врядування та стимулювала розвиток нових механізмів міжнародного співробітництва у сфері ядерної безпеки, аварійної готовності та регуляторного нагляду. Обґрунтовано, що історичне значення Чорнобиля виходить далеко за межі ядерної енергетики. Уроки катастрофи вплинули на формування сучасних підходів до управління складними технологіями, ризик-менеджменту та інституційної стійкості. Особливу актуальність вони зберігають у контексті досягнення Цілей сталого розвитку ООН, насамперед у сферах охорони здоров'я, сталої енергетики, інноваційної інфраструктури та ефективного врядування. З позицій історії науки і техніки Чорнобильська катастрофа постає важливим прикладом того, як великі технологічні аварії здатні трансформувати наукові знання, організаційні практики та міжнародні підходи до управління технологічними ризиками.

Ключові слова: Чорнобильська катастрофа; культура ядерної безпеки; технологічне врядування; радянська ядерна промисловість; технологічний ризик; сталий розвиток

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