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Nuclear Renaissance in France: Legal and Regulatory Challenges[2]

Abstract

"The revival of nuclear energy in France is driven by the need to meet climate objectives under the Paris Agreement and ensure energy security amidst global crises. Nuclear power offers a reliable, carbon-free baseload energy source, complementing renewables. This study examines the legal and regulatory challenges of this resurgence, focusing on authorization procedures for new nuclear facilities, nuclear fuel supply chains, and spent fuel management. Special attention is given to Small Modular Reactors (SMRs), evaluating whether current frameworks are adequate or require tailored approaches, and exploring opportunities for international regulatory harmonization".

Keywords: Nuclear energy, Energy security, Climate objectives, Small Modular Reactors Authorization procedures, Nuclear fuel supply, Comparative analysis, Carbon-free energy, Energy transition

The nuclear energy sector is experiencing a significant resurgence in France, propelled by two principal considerations. Foremost among these is the imperative to meet climate targets established under the Paris Agreement, which necessitates the expansion of carbon-neutral energy sources. While renewable energies present undeniable advantages, their intrinsic intermittency and lack of production stability currently compromise their ability to ensure a reliable baseload supply unaided. In parallel, the ongoing global energy crisis has highlighted the strategic importance of energy security as an essential facet of state sovereignty. Within this dual context, nuclear power reemerges as a viable solution for carbon-free baseload electricity production.

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This inquiry seeks to explore the legal ramifications of this nuclear revival, focusing particularly on the authorisation procedures for new nuclear facilities. Through a comparative analysis of national regulatory frameworks, this study investigates the sequential stages of authorisation—from the initial governmental determination through to final commissioning—together with the contractual aspects and ownership structures of nuclear projects, legal issues related to nuclear fuel supply, and the distinct regulatory challenges associated with Small Modular Reactors (SMRs).

Adopting a comparative methodology, this study traces the trajectory of nuclear development in France, identifying areas of convergence and divergences in national legal systems, critical points in authorisation procedures, and the emergence of novel regulatory innovations. This approach enables a systematic examination of various jurisdictions while maintaining analytical rigour. Particular attention is paid to documenting legal sources, including legislative and regulatory texts, relevant case law, public policy documents, and relevant international agreements.

One specific interest is the legal frameworks governing nuclear fuel supply chains and spent fuel management—matters which acquire heightened importance in the context of expanded nuclear deployment. The study also addresses the emerging regulatory challenges posed by SMRs, examining whether existing frameworks are adequate or whether tailored approaches are warranted. In this regard, the potential for international regulatory harmonisation in SMR licensing is explored, along with associated jurisdictional and sovereignty considerations.

By contributing to a deeper understanding of contemporary legal challenges in nuclear development while facilitating experience sharing between legal systems. The analysis of regulatory approaches to SMRs is particularly significant, especially in light of potential international harmonisation of authorisation procedures. Through this comprehensive analysis, the study aspires to furnish policymakers, legal practitioners, and industry stakeholders with critical insights as they navigate the complex landscape of nuclear energy regulation.

The findings of this analysis are especially pertinent at a time when nations increasingly turn to nuclear power as a solution to both climate change and the exigences of energy security. Understanding the legal and regulatory frameworks that govern nuclear deployment is crucial for ensuring safe, efficient, and effective implementation of nuclear energy programmes while maintaining public confidence and international cooperation in this critical sector.

This academic treatment emphasises methodological rigour and clearly structured research objectives while maintaining the substance of the original text and providing a comprehensive analysis of the contemporary legal challenges in nuclear energy development. As a point of departure, it is necessary to consider the historical evolution of nuclear energy in France (A). This trajectory is of particular significance, as it illuminates the foundations upon which the nation's regulatory bodies and legal frameworks in the nuclear domain have been constructed (B). An analysis of the various stages involved in the licensing of nuclear power plants further provides valuable insight into the distinctive characteristics of the French approach to the nuclear sector (C), while simultaneously offering a perspective on the future of the country's nuclear strategy (D)—a matter of increasing relevance in light of the development of small modular reactors (E).

A – The evolution of nuclear energy in France

1- The beginning of nuclear industry in France

The post-war period marks a decisive juncture in French industrial history with the emergence of the nuclear programme. The creation of the Atomic Energy Commission (CEA) in 1945 laid the cornerstone of what would evolve into one of the world's most ambitious nuclear programmes. Under the impetus of General de Gaulle, who saw nuclear energy as a means of ensuring France's energy independence, the programme initially developed in a difficult post-war context, marked by fiscal austerity and considerable technological challenges[3].

The early years of the programme were characterised by an intense experimentation phase. The commissioning of ZOE in 1948, France's first experimental reactor, represents a crucial step demonstrating French scientists' ability to master fundamental nuclear technologies. This reactor, albeit modest in its performance, served as an essential learning platform for an entire generation of French scientists and engineers the subsequent period, spanning from 1953 to 1965, witnessed the programme's true transition to an industrial scale. The Marcoule site emerged as the symbol of this industrialisation with the successive construction of reactors G1, G2, and G3[4]. These facilities, designed for both civilian and military purposes, allowed France to acquire a singular proficiency in the nuclear fuel cycle. The creation of COGEMA[5], a CEA subsidiary, structured fuel cycle management, thus establishing the foundations of an integrated nuclear industry.

The broader geopolitical landscape, particularly the Suez Crisis in 1956, strengthened France's determination to pursue nuclear self-sufficiency. The signing of the EURATOM treaty in 1957 opened new perspectives for European cooperation while allowing France to maintain its technological autonomy. This period also saw the emergence of structuring industrial partnerships, notably between Électricité de France (EDF) and CEA, which would durably shape the French nuclear landscape[6]. The question of technological orientation assumed a

3 | Bouttes 2023, 67.
4 | See Goldschmidt 1969, 83–96.
5 | *Compagnie générale des matières nucléaires*
6 | Rémy 1998, 17.

position of central importance in the 1960s. France experimented with several technologies, notably the French-designed UNGG reactors and American-origin pressurised water reactors (PWR). This technical debate, often called the "war of technologies," concluded in 1975 with the choice of PWRs, a decision that definitively oriented the future of the French nuclear programme.

The industrial architecture established in support of France's nuclear endeavour is remarkable for its coherence. EDF assumed the role of architect-integrator and operator, while Framatome emerged as the principal reactor constructor. This structuring was accompanied by the development of a complete industrial fabric, involving companies such as Pechiney for materials, Saint-Gobain for chemical processing, and Creusot-Loire for heavy components[7]. Crucially, regulatory and safety considerations were not overlooked. France progressively developed a strict regulatory framework and independent control bodies. This attention to safety was accompanied by exacting training policies, designed to ensure a high level of competence among personnel employed within the nuclear sector. The economic and social impact of the nuclear programme proved substantial. It created highly skilled employment opportunities, catalysed regional development around nuclear sites, and contributed to the emergence of internationally recognised French expertise. Territories hosting nuclear installations undergo profound transformations, both economically and socially.

Another cornerstone of the programme lay in the comprehensive management of the nuclear fuel cycle. France developed capabilities in all segments: uranium extraction, enrichment, fuel fabrication, and waste treatment. This complete mastery of the cycle came to be viewed as a major strategic asset[8]. Environmental and societal considerations gradually acquired increasing prominence. Issues relating to site selection, public acceptance, and environmental impact assessment become major issues in programme development. This formative period of French nuclear power laid the foundations for an industry that would become a pillar of national energy policy, exemplifying France's capacity to successfully carry out a major industrial programme, combining technological innovation, efficient industrial organisation, and long-term strategic vision[9].

2- The Decline of Nuclear Power in France

The trajectory of French nuclear power entered a new phase in the 1990s, signalling the end of two decades of sustained expansion. This turning point was driven by both domestic and European factors that reshaped the entire electricity sector. At the supranational level, the European Union instigated a liberalisation

7 | Finon 2009, 189.
8 | Bouttes 2023
9 | Jean-Marie 1990, 126.

process that sought to dismantle national monopolies in favour of competitive electricity markets. This transition, which began in the UK under the Thatcher government, progressively extended to the Continent. Over time, the EU's support for nuclear power diminished, particularly after Germany's decision to phase out nuclear energy following the 2011 Fukushima disaster. Although France initially resisted these changes but eventually had to adapt. One of the most consequential measures was the introduction of the *Accès Régulé à l'Électricité Nucléaire Historique* (ARENH) mechanism, which required EDF to sell up to 100 TWh of its nuclear-generated electricity annually to competing suppliers at a fixed tariff of €42 per MWh. This policy significantly impacted the economics of nuclear power in France[10].

Multiple factors contributed to nuclear power's declining position. Electricity demand grew more slowly than anticipated, partly due to the closure of energy-intensive sectors. Environmental concerns about nuclear waste gained more prominence, and political support for nuclear energy began to erode. As a result, France built fewer new reactors, and existing nuclear fleet began to show signs of ageing. The statistics clearly show this downturn: nuclear power's share in French electricity generation dropped from 76.2% in 1990 to 70% in 2015, and further fell to 62.6% in 2022. Notwithstanding President Sarkozy's efforts to revive the nuclear sector, exemplified by the initiation of the Flamanville EPR project, these initiatives faced numerous challenges. Under the presidency of François Hollande, the focus shifted away from nuclear power. Several older nuclear plants were closed, along with coal-fired power stations. The country began placing more emphasis on renewable energy sources, marking a significant shift in France's energy policy.

This transformation reflects broader changes in society, economics, and politics. France's once-dominant nuclear power programme was compelled to adapt to new market conditions, changing public opinion, and evolving energy policies. While nuclear power remains important in France's energy mix, its role has significantly diminished compared to its peak in the 1990s. The story of French nuclear power demonstrates how even well-established energy systems can change dramatically due to a combination of market forces, political decisions, and social preferences. It also highlights the challenges of maintaining a large nuclear fleet in an increasingly competitive and environmentally conscious energy market[11]. A particularly symbolic moment in this decline occurred in 1998, when Prime Minister Lionel Jospin made the significant decision to shut down the Superphénix reactor, an advanced fast-breeder facility developed in partnership with Germany and Italy. Although technical issues with sodium oxidation were

10 | Taccoen 2023, 12.
11 | Débrégeas & Gassin 2023, 54.

cited as the official reason, strong pressure from environmental groups heavily influenced this decision.

The closure of Superphénix marked the beginning of a series of setbacks. When the government tried to revive advanced nuclear technology with the ASTRID project in 2006, it also failed and was eventually cancelled in 2019. Environmental groups, particularly Greenpeace, vigorously opposed these projects due to safety concerns. Technical problems also plagued the industry. The construction of the new Flamanville reactor faced continuous delays and cost overruns. AREVA, whose reorganisation gave birth to Orano and allowed Framatome to regain its name, after becoming a subsidiary of EDF, struggled to manage these projects effectively and had difficult relationships with EDF, France's main electricity provider.

Government policy decisions have introduced further constraints. In 2011, authorities limited nuclear power to 50% of France's electricity production. This regulatory ceiling was reinforced by the Programmation Pluriannuelle de l'Énergie (PPE) of 2019, requiring the closure of 14 nuclear reactors and setting ambitious targets for reducing energy consumption[12]. Experts identified several critical mistakes in France's approach. Chief among these were inadequate forecasting of future energy needs, an unnecessarily adversarial dynamic between nuclear and renewable energy supporters, and inadequate preparation for maintaining ageing reactors. The country also accepted unfavourable European energy market conditions and abandoned promising nuclear technologies too quickly. The situation now requires significant changes. France needs to reorganise its entire energy system while considering both traditional nuclear power and renewable energy sources. Most experts agree that the European electricity market needs reform and that better long-term energy planning is essential.

These changes show how quickly a country can lose its leadership in an important technology. Political decisions, technical challenges, and changing public opinion all played a role in transforming France's once-dominant nuclear programme. The country now faces the dual challenge of finding the right balance between different energy sources while ensuring a reliable and sustainable power supply for the future. The French case offers a cautionary tale about how energy policy decisions can have long-lasting effects on a country's future. It also shows the importance of maintaining technical expertise and planning carefully for future energy needs.

3- The challenges of Nuclear Power in France and Europe

The European continent remains sharply divided over nuclear energy's future. France has positioned itself at the forefront of a coalition of thirteen EU nations

12 | *Ibid.*

who affirmed their commitment to nuclear power, including several Eastern European countries, Finland, the Netherlands, and Belgium. Beyond the EU, the United Kingdom maintains its firm support for nuclear energy. Germany leads the opposition to nuclear power, joined by Italy, Spain, Austria, and Luxembourg. These nations firmly believe Europe can achieve its carbon-neutral goals through renewable energy alone, without recourse to nuclear power. This schism is mirrored in the European Union's prevailing energy policy. While setting ambitious targets for renewable energy at 45% by 2030, EU policies have largely marginalised nuclear power, despite its significant contribution of 25% to Europe's current electricity supply.

France, under the leadership of President Emmanuel Macron, has chosen a markedly divergent path. In 2022, he launched what he called a "nuclear renaissance," announcing plans to build six new EPR2 reactors immediately, with a further eight envisaged thereafter. The government has removed the previous 50% cap on nuclear power's share in the energy mix and streamlined construction regulations[13]. Notwithstanding this renewed political commitment, the practical implementation of the plan is fraught with formidable challenges. France's extant fleet of reactors is ageing and requires extensive maintenance or phased replacement. There is also a pressing need to train a new generation of nuclear engineers. France must also reduce its dependence on Russian nuclear fuel supplies. Looking ahead toward 2050, France has developed comprehensive energy plans. The country expects electricity demand to reach between 555 and 900 terawatt hours (TWh), requiring a balanced approach of nuclear and renewable energy sources. This includes ambitious targets for solar and wind power alongside nuclear capacity[14].

France has undertaken decisive steps to fortify international cooperation within the nuclear energy domain. The country has formed a Nuclear Alliance with fourteen other nations, aiming to diminish Russian influence in the nuclear fuel supply chain and share technical expertise. The economic and environmental implications of this strategy are far-reaching. France aims to ensure energy independence while meeting climate change commitments and maintaining competitive energy prices. The plan also focuses on creating high-skilled jobs and supporting industrial development. This bold approach demonstrates France's commitment to maintaining its nuclear proficiency, even as it recalibrates to meet the exigencies of a rapidly evolving energy landscape. While some European counterparts have chosen to renounce nuclear energy, France continues to regard it as essential to achieving a sustainable, carbon-free energy future.

13 | Vaglietti & Creti 2023, 14.
14 | Report of french Court of Accounts 2023, 116.

The success or failure of France's nuclear renaissance could significantly influence energy policies across Europe and shape the continent's energy landscape for generations to come. Time will tell whether this ambitious plan can overcome the technical, financial, and political challenges it faces. France finds itself confronting considerable operational challenges in its nuclear power sector but has developed a clear plan for recovery. After discovering damaged welds in multiple reactors, power production dropped notably in early 2023. Despite this setback, EDF remains confident about reaching normal production levels of 300-330 TWh by 2025. Safety inspectors have taken a proactive approach to the maintenance issues. They have approved a comprehensive plan to check and repair damaged welds, prioritising the most critical repairs first. This methodical approach aims to restore full operational capacity while maintaining strict safety standards.

Engineers are actively working to improve the efficiency of existing nuclear plants. Current reactors operate at about 35% efficiency, but technical teams believe they can increase this to 38-40%. These improvements would focus on upgrading secondary systems and optimising maintenance schedules. The Flamanville reactor project represents a crucial milestone in France's nuclear programme. After lengthy delays since construction began in 2007, this new reactor is anticipated to enter into service in 2025. The successful commissioning of this facility will demonstrate France's ability to build and operate new-generation nuclear facilities[15]. France has developed ambitious plans for future reactor construction. Six new reactors will be built in pairs at three different locations, with construction starting between 2027 and 2030. This coordinated approach allows for efficient resource use and standardised construction methods.

The country is also investing in emergent smaller nuclear reactor technology. A consortium led by EDF plans to build two 170-megawatt Small Modular Reactors (SMRs) by 2035. These compact reactors could provide more flexibility and potentially lower construction costs compared to traditional large-scale reactors. Research continues into advanced nuclear technologies at various facilities across France. The Cadarache Research Centre leads work on fusion power, while several companies develop innovative reactor designs. These research efforts ensure France maintains its position at the forefront of nuclear technology. This comprehensive strategy demonstrates France's commitment to nuclear power as a key element of its energy future. By confronting present operational difficulties while planning for future developments, France seeks to secure a reliable, clean energy supply capable of meeting the demands of the coming decades.

15 | Bouttes 2023

B – Nuclear regulatory bodies and national nuclear laws

1- The role of the Nuclear Safety Authority in France

The Nuclear Safety Authority (Autorité de sûreté nucléaire, ASN) was established in 2006 through the Nuclear Transparency and Safety Law (Loi relative à la transparence et à la sécurité en matière nucléaire, TSN). This creation addressed the crucial need for independent oversight of France's nuclear sector — one of the largest and most complex in the world. The recent decision to merge ASN with Institute for Radiological Protection and Nuclear Safety (IRSN) in 2025 marks a significant evolution in the institution's history, aiming to streamline nuclear fleet supervision amid France's nuclear programme revival[16]. The control and enforcement of nuclear safety standards forms the bedrock of of ASN's missions. Its inspectors are tasked with regular visits paid to France's 56 nuclear reactors to ensure compliance with safety standards. They closely monitor nuclear research facilities, verifying that security protocols are strictly followed.

In the medical field, ASN plays a crucial role by controlling equipment using ionising radiation in hospitals and care centres. This surveillance covers everything from radiology equipment to radiotherapy devices and nuclear medicine facilities. The supervision of radioactive material transport represents another important aspect of its activities. ASN ensures that each movement of radioactive material follows strict security protocols, from dispatch to arrival at its final destination. Organisationally, ASN is characterised by a clearly delineated hierarchical structure. At the top, a board of five commissioners, led by a president, makes strategic decisions. These commissioners are appointed for non-renewable six-year terms, ensuring their independence[17].

The day-to-day administration of the Authority is entrusted to its General Management, supported by eight specialised directorates covering different aspects of nuclear safety. Eleven territorial divisions ensure an active presence throughout France, providing local control of nuclear installations. ASN works closely with numerous nuclear sector stakeholders. It maintains regular relations with EDF—the predominant operator of the nation's civil nuclear reactors—alongside Orano, which is tasked with operations pertaining to the nuclear fuel cycle and the Commissariat à l'énergie atomique et aux énergies alternatives (CEA) for nuclear research. Partnerships extend to government institutions, local authorities, and research organisations. ASN also actively participates in international exchanges, sharing expertise with other safety authorities worldwide.

16 | See Delzangles 2013, 7–30.
17 | See Frison-Roche 2006, 17.

The progressive ageing of France's nuclear fleet poses major challenges for ASN. The authority is charged with the critical task of ensuring that ageing power plants maintain optimal safety levels while evaluating life extension projects. In parallel, cybersecurity of nuclear infrastructure has emerged as an area of mounting concern. ASN continuously develops its capabilities in this area to address emerging threats. ASN's actions directly contribute to public health protection. It ensures that exposure to ionising radiation is kept as low as reasonably achievable, both for sector workers and the public. Environmental preservation is also a priority. ASN exercises stringent control over nuclear site emissions, maintaining close surveillance of their potential impact upon surrounding ecosystems[18].

On the international stage, ASN also plays a leading role. It actively participates in developing international nuclear safety standards and offers its widely acknowledged expertise to foreign counterparts. The authority also contributes to international emergency management, as demonstrated during major transnational incidents such as the Fukushima accident. Facing energy transition challenges, ASN constantly adapts its methods and continues to refine its regulatory approaches. The development of new reactors, particularly Small Modular Reactors (SMRs), requires evolving control practices. The authority invests significantly in continuous staff training and new surveillance technologies to maintain its excellence level. This complex and evolving organisation enables ASN to fulfil its fundamental mission: ensuring nuclear safety in France while maintaining the transparency necessary for public trust. Its role is increasingly crucial in the current context of energy transition and nuclear revival in France[19].

2- The fusion between ASN and IRSN

The institutional landscape of nuclear safety in France is poised for profound transformation as the government has decided to implement a reform of nuclear safety in France by effecting the merger of the Nuclear Safety Authority (ASN) with the Institute for Radiological Protection and Nuclear Safety (IRSN). These two entities, historically distinct yet complementary—one serving as the regulatory authority, the other as technical and scientific expert—are to be consolidated into a single body: the Nuclear Safety and Radiation Protection Authority (ASNR), to be formally established in January 2025. The rationale for such a reorganisation, initiated behind closed doors at the Élysée Palace in February 2023, came as a surprise to many within the sector.

18 | See Tuot 2006, 229.
19 | About the role of ASN in France see: Delzangles 2008, 545.

In the context of France's nuclear energy revival, including a programme of six to fourteen reactors, the government sought to create a more coherent, authoritative, and agile supervisory entity. As articulated by the Minister for Industry, Mr Roland Lescure, the objective was to render the new authority "more powerful, more independent, and more attractive," whilst aiming to "gain efficiency in state resources" and "accelerate and simplify procedures." According to Yves Marignac, head of the Nuclear and Fossil Energy Division at *négaWatt* Institute, the nuclear industry contends that "part of its difficulties stems from unreasonably high safety requirements, while its difficulties are organisational and deeper". Unsurprisingly, the proposed merger has provoked widespread concern. The government, however, remains resolute in its assurances: "we will not compromise on nuclear safety." The reform "does not modify any aspect of the safety framework applicable to nuclear operators," assures the Ministry of Energy Transition[20].

Yet this decision remains profoundly contentious. Currently, IRSN's scientists operate like independent detectives, investigating safety issues without pressure from decision-makers, whilst ASN fulfils the role of adjudicator, making final calls based on this unbiased expertise. This careful separation has been a cornerstone of French nuclear safety, however, it stands on the verge of dissolution. The human consequences of this institutional upheaval are already manifest. A quiet exodus is underway, as seasoned scientists at IRSN are quietly leaving for private companies like EDF and Orano, taking with them decades of irreplaceable expertise. Even with a recently implemented 15% increase in public sector salaries, these nuclear safety experts still earn significantly less than their private sector counterparts, rendering their retention increasingly tenuous. With just days until the January 2025 merger, 12 working groups are racing against time to piece together this complex organisational puzzle. It is a delicate operation where failure isn't an option, especially with France's ambitious nuclear power expansion plans on the horizon[21].

Critics have voiced grave concerns that the proposed merger could weaken France's nuclear safety architecture. They argue that combining nuclear expertise and decision-making in one organisation risks compromising the independence that is crucial for effective safety oversight. The funding of research presents another complex challenge. Indeed, how can a regulatory body maintain independence while accepting research funding from the operators? Beneath the surface of this administrative restructuring lies a distinctly human dimension: dedicated scientists and inspectors face uncertainty while trying to maintain rigorous safety standards. Some fear that years of organisational turbulence could impact safety at a critical time for France's nuclear industry.

20 | About this debate, see Lorino 2024, 21.
21 | Report of French Senate 2023

The proposed merger further gives rise to serious questions concerning research continuity. IRSN's laboratories have been crucial in advancing nuclear safety knowledge, yet, the future role and financing of these facilities within the emergent institutional framework remain imprecisely defined, leaving many specialists apprehensive about the potential erosion of this critical research capacity.

As the calendar inexorably advances towards the statutory establishment of the new authority in January 2025, France appears to be placing a strategic wager: that unified oversight will strengthen nuclear safety. However, in an industry where mistakes can have catastrophic consequences, this reorganisation represents either a visionary step forward or a perilous gamble with nuclear safety. The success of this merger will depend not just on organisational charts and procedures, but on preserving the expertise, independence, and rigorous safety culture that have, for decades, defined the French model of nuclear oversight. As France pushes forward with new nuclear reactors, the imperative to navigate this transition with precision and foresight has never been more urgent[22].

For several decades, France's nuclear safety relied on a unique dual system born from the lessons of Chernobyl. The ASN acted as the industry's regulatory enforcer, or "police force," while IRSN assumed the role of its analytical conscience and served as its "scientific brain". Together, they formed a sophisticated safety net protecting France's extensive nuclear programme. This institutional division of labour was neither incidental nor expedient. Born in 2001 under an environmentalist minister, IRSN earned a reputation for its rigorous standards. Sometimes they were seen as too demanding, but as former deputy director Thierry Charles noted, their role was to furnish the ASN with unvarnished scientific evidence upon which to base its regulatory determinations.

Looking beyond France's borders, different countries have taken various approaches. The United States operates under the Nuclear Regulatory Commission (NRC)—a structure frequently held up as a notional blueprint for France's forthcoming institutional configuration. However, the NRC still maintains constitutional safeguards as "checks and balances", including public commissioner meetings and independent advisory committees—elements which, notably, do not appear within the contours of France's envisaged reform. In the aftermath of the Fukushima catastrophe, Japan undertook a wholesale reconfiguration of its regulatory framework, creating the Nuclear Regulation Authority (NRA). Their experience showed how crucial independent oversight is for public safety and trust. Belgium provides yet another instructive contrast. They considered merging their equivalent organisations but ultimately chose to forgo it. Their former safety expert, Benoît De Boeck, warned that such transitions risk losing crucial expertise

22 | Roger 2024

– expertise that takes years to rebuild but only moments to lose[23]. This international perspective raises important questions about France's current reorganisation. The success of this French experiment could influence how other countries approach nuclear safety oversight in the future.

3- The nuclear legal framework in France

In the French legal order, nuclear activities are governed by Article L. 1333-1 of the Public Health Code. These activities are subject to specific rules aimed at protecting people and the environment. These regulatory measures apply uniformly across the spectrum of nuclear operations. France also applies the International legal Framework for Radiation Protection. For example, public authorities need to implement the recommendations published by the International Commission on Radiological Protection (ICRP) on how to protect workers, the public, and patients from ionising radiation. These recommendations are based on scientific research, including work done by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). In parallel, the International Atomic Energy Agency (IAEA) regularly publishes and updates safety standards for nuclear safety and radiation protection. At the European level, the Euratom Treaty, particularly Articles 30 to 33, sets out how the European Union develops rules for protection against ionising radiation and defines the responsibilities of the European Commission in applying these rules. The Euratom Directives must be followed by all EU member countries after they are integrated into national law. Council Directive 2013/59/Euratom, adopted on 5 December 2013, establishes basic safety standards for protection against ionising radiation. It was published in the Official Journal of the European Union on 17 January 2014, and constitutes the cornerstone of French radiation protection regulations, covering the protection of the public, workers, and those exposed in medical settings[24].

The legal framework governing nuclear activities in France underwent substantial reform with the transposition of Directive 2013/59/Euratom of 5 December 2013. In France, this directive was mainly implemented through Ordinance No. 2016-128 of 10 February 2016, as part of the Energy Transition Law (TECV). Two decrees, No. 2018-434 and No. 2018-437, issued on 4 June 2018, introduced additional rules concerning nuclear activities and worker protection against radiation. The ordinance of 10 February 2016, revised a section of the Public Health Code related to ionising radiation while maintaining the core principles. The aforementioned June 2018 decrees proceeded to amend a range of legislative instruments, including the Labor Code, the Public Health Code, and the Environmental Code.

23 | De Boeck 2010, 62.
24 | Neri 2021, 56.

At the heart of this regulatory framework lies Article L. 1333-2 of the Public Health Code, outlining three cardinal principles of radiation protection: justification (the benefits must outweigh the risks), optimisation (minimising radiation exposure), and limitation (there are exposure limits that must not be exceeded). These principles serve as the guiding compass for the Nuclear Safety Authority (ASN) in its regulatory actions. To improve risk management, a new registration system was introduced, which is a simplified procedure between declaration and authorisation. ASN, in its Decision No. 2018-DC-0649, updated the list of nuclear activities requiring a declaration. Decisions No. 2021-DC-0703 and No. 2021-DC-0704 outline which activities must be registered, including industrial, veterinary, research, and medical uses of ionising radiation. These rules have been in effect since 1 July 2021. Additionally, a new article—Article L. 1333-7—was inserted into the Public Health Code to protect public health, safety, and the environment from the risks associated with ionising radiation, including malicious acts[25].

In addition to the foundational principles set forth in the Public Health Code, the Environmental Code, at Article L. 591-1, defines key concepts related to nuclear security. Nuclear security includes nuclear safety, radiation protection, the prevention and combatting of malicious acts, and civil security actions in case of an accident. However, in some texts, "nuclear security" is still limited to the prevention and response to malicious acts. Within this framework, nuclear safety is defined as "all technical measures and organisational procedures related to the design, construction, operation, shutdown, and decommissioning of basic nuclear installations (BNIs), as well as the transport of radioactive materials, aimed at preventing accidents or limiting their effects", and Radiation protection refers to "the protection against ionising radiation, meaning the set of rules, procedures, and preventive and monitoring measures to prevent or reduce the harmful effects of ionising radiation on people, either directly or indirectly, including through environmental damage."

Further elaboration is provided by Article L. 593-42 of the Environmental Code, which specifies that "the general rules, regulations, and measures enacted under this chapter, as well as chapters V and VI, for public health protection, when concerning worker radiation protection, focus on collective protection measures that are the responsibility of the operator and ensure compliance with radiation protection principles as defined in Article L. 1333-2 of the Public Health Code. These apply to the design, operation, and decommissioning phases of the installation and do not affect the employer's obligations under Articles L. 4121-1 and following of the Labor Code." In this regard, the principle of nuclear transparency is defined as "all measures taken to guarantee the public's right to reliable and accessible information on nuclear security as defined in Article L. 591-1."

25 | Lamoureux 2022, 167.

Article L. 591-2 of the Environmental Code outlines the role of the State in nuclear security. It states that the State establishes regulations for nuclear security and implements the necessary controls to enforce them. Moreover, it is incumbent upon the State to "ensure that nuclear safety and radiation protection regulations, and their oversight, are evaluated and improved as necessary, taking into account operational experience, lessons from nuclear safety analyses conducted for operating nuclear facilities, technological advancements, and relevant research findings in nuclear safety." In keeping with Article L. 125-13 of the Environmental Code, "the State ensures that the public is informed about the risks related to nuclear activities defined in the first paragraph of Article L. 1333-1 of the Public Health Code and their impact on public health, safety, and the environment." The general principles applicable to nuclear activities are outlined in Articles L. 591-3 and L. 591-4 of the Environmental Code. Lastly, the Defence Code includes various provisions related to the protection against malicious acts in the nuclear field, as well as the oversight of nuclear activities and installations of interest to national defence[26].

In the context of ecological transition, the French Energy Transition for Green Growth Act (Loi relative à la transition énergétique pour la croissance verte – TECV), adopted in 2015, significantly impacts the nuclear energy sector. Title VI for example, "Strengthening Nuclear Safety and Public Information," focuses on transparency and public engagement. The roles of Local Information Commissions (Commissions Locales d'Information – CLIs) are expanded, requiring them to hold annual public meetings and granting them the power to address any relevant safety or environmental concern. CLIs can now request and must be granted site visits, even after incidents. They are also accorded a mandatory consultative role in the amendment to Special Intervention Plans (Plans Particuliers d'Intervention – PPIs) and public information efforts. For nuclear sites near international borders, CLIs must include members from neighbouring countries. The law also reinforces information procedures, mandating regular updates to residents within PPI perimeters and requiring public inquiries for reactor life extensions beyond 35 years[27].

Title VIII of the Energy Transition for Green Growth Act addresses the oversight of nuclear safety and radiation protection. The law strengthens the Basic Nuclear Installations (BNI) regime, particularly regarding subcontracting. Henceforth, operators are expressly prohibited from delegating the oversight of essential external contractors, a safeguard that had hitherto existed only at the level of subordinate legislation. Further regulatory measures concerning subcontracting are expected in due course. The BNI authorisation process is also streamlined, adopting terminology consistent with environmental regulations. "Substantial" modifications now trigger a full authorisation procedure with a public inquiry,

26 | Rambour & Carvalho 2021, 97.
27 | See Denolle 2016, 99.

while "significant" modifications require authorisation or declaration to the ASN, potentially accompanied by public consultation.

Finally, the law brings clarity to the process for definitive shutdown and decommissioning of BNIs. Immediate dismantling is now the legal standard. Operators are required to declare the planned shutdown date at least two years in advance. From that date, the installation is considered definitively shut down and must be dismantled according to procedures outlined in a decree. Any installation ceasing operation for two consecutive years is automatically deemed definitively shut down[28].

C – Licensing stages of a nuclear power plant in France

1- The authorisation process for creating a Basic nuclear installation

To grasp the future trajectory of nuclear energy in France, one must first understand the legal architecture underpinning the licensing of a nuclear power plant. French law governing Basic Nuclear Installations (BNIs), like nuclear power plants and fuel processing facilities, was substantially overhauled with the vote of the Act on Transparency and Security in the Nuclear Field (commonly referred to as the TSN Law) in 2006. This law, along with its implementing decrees, is codified within the French Environmental Code. The regulations take a comprehensive, or "integrated," approach to managing BNIs. This means they consider all potential hazards, not just radiological ones, throughout a facility's entire lifecycle. This includes for example the Initial Authorisation and Construction with strict guidelines dictating the safety requirements and approval processes for building new BNIs, Ongoing Operations and Inspections with very regular inspections and monitoring ensure compliance with safety standards during the operational phase and a special legal framework for the waste Management. Indeed, the law establishes a framework for the safe handling and disposal of all radioactive waste generated by BNIs. Finally, specific provisions govern the Decommissioning and Dismantling, with detailed procedures governing the eventual shutdown, dismantling, and cleanup of BNIs at the end of their operational life.

Transparency and public information constitute fundamental pillars of the French legislative framework governing nuclear activities. The law establishes Local Information Commissions (*Commissions Locales d'Information*, or CLIs) to provide local communities with information and opportunities for input regarding nearby BNIs. At the national level, the High Committee for Transparency and Information on Nuclear Safety (*Haut Comité pour la Transparence et l'Information sur la Sécurité Nucléaire*, or HCTISN) fulfils a parallel function. Both institutions

28 | See Russo 2024, 76.

serve to guarantee the public's right of access to information and foster dialogue on nuclear safety issues. The law also guarantees the public's right to information about BNIs and their potential impacts.

The authorisation procedure for the creation of a BNI is comprehensively set out in Chapter III of Title IX of Book V of the Environmental Code. This legal chapter delineates a multi-stage process encompassing the full operational lifespan of an installation—from initial design considerations to final decommissioning. It also provides a legal framework for modifications during the installation's operational life. Even before formally applying for creation authorisation, a prospective BNI operator can consult with the ASN about their chosen safety options. The ASN provides feedback and may request additional studies or justifications. These safety options are then formally presented as part of the preliminary safety report submitted with the creation authorisation application. This preliminary consultation streamlines the later regulatory review process.

For new nuclear production sites or other BNIs exceeding certain cost thresholds (€460 million or €230 million, depending on the type of installation), the involvement of the National Commission for Public Debate (*Commission nationale du débat public*, or CNDP) is mandatory[29]. The CNDP is tasked with determining whether a full public debate is necessary or if a less formal public consultation process suffices. Should a public debate be deemed appropriate, the CNDP assumes responsibility for its organisation and appoints a dedicated special commission to oversee its conduct. For consultations, the project leader organises the process, and the CNDP appoints a guarantor to ensure its fairness[30].

The entity seeking to establish the installation, upon submitting its application, acquires the legal status of "*exploitant*" (operator). The application for creation authorisation must be lodged with the Minister responsible for nuclear safety and must be accompanied by a comprehensive dossier. This includes detailed plans, an environmental impact assessment, a preliminary safety report, a risk assessment study, and a decommissioning plan. Upon receipt of the application, the ASN, at the request of the Ministry, reviews the application. Simultaneously, public and expert consultations are conducted.

The BNI creation project undergoes an environmental assessment procedure, which includes an impact study by the project leader, consultations with the environmental authority, local authorities, and other relevant groups, and a review of all gathered information by the authorising authority. The complete project dossier—including the environmental impact study and the formal application—is submitted for expert opinion to the environmental authority within the General Council for the Environment and Sustainable Development for their opinion[31].

29 | Article L 121-8 of Environmental Code
30 | About the question of democracy and nuclear energy: Pontier & Roux 2013
31 | Article 122-1 of Environmental Code

Prior to the granting of any authorisation, a public inquiry is mandatory[32]. This inquiry aims to inform the public and gather their opinions, suggestions, and counter-proposals. This information is crucial for the authorising authority's decision-making process. The inquiry follows specific legal procedures and is held in any municipality located within five kilometres of the proposed BNI. The inquiry lasts at least one month and no more than one and a half months, barring suspensions or additional inquiries. The application dossier, inclusive of the preliminary safety report—which outlines the potential risks associated with the installation, as well as the preventive and mitigating measures proposed—is made publicly available. A non-technical summary of the risk assessment is also provided for easier understanding. The entire inquiry file is published online and is also accessible physically at designated locations. Computer access is also provided at public venues. Finally, the operator must obtain a construction permit from the *préfet* (the State's local representative) according to building code regulations[33]. Importantly, construction activities may not commence until the public inquiry concerning the creation authorisation has been formally concluded[34].

Following the conclusion of the public inquiry, the Minister responsible for nuclear safety sends the operator a draft decree granting or refusing creation authorisation (décret d'autorisation de création, DAC). The operator has two months to submit their observations. The Minister then obtains the opinion of the ASN. ASN Decision No. 2010-DC-0179 of 13 April 2010, allows operators and CLIs to be heard by the ASN board before it issues its opinion. The creation authorisation for a BNI is issued by decree of the Prime Minister, countersigned by the Minister responsible for nuclear safety. The DAC determines the perimeter and characteristics of the installation. It also sets the duration of the authorisation, if any, and the commissioning deadline. Furthermore, it imposes the essential elements required for the protection of public security, health, and safety, as well as the protection of nature and the environment.

For the implementation of the DAC, the ASN defines the requirements relating to the design, construction, and operation of the BNI that it deems necessary for nuclear safety. The ASN also determines the regulatory conditions pertaining to water abstraction and effluent discharges arising from the BNI. The requirements setting the limits for discharges from the BNI under construction or in operation into the environment are subject to approval by the Minister responsible for nuclear safety. Prior to the commissioning of the installation, the operator must submit a comprehensive file to the ASN. This submission must include an updated version of the preliminary safety report for the "as-built" installation, the general

32 | About the role of transparency in nuclear acceptance: Cohen & Raineau 2020, 147.
33 | Article R 421-1 of Urbanism Code
34 | About the debate concerning the development of nuclear energy in France: Stenberg & Topçu 2019, 225.

operating rules, the internal emergency plan, and an update, if necessary, of the decommissioning plan and, if applicable, an update of the impact study.

Upon verifying that the installation conforms to the objectives and rules set forth in Chapter III of Title IX of Book V of the Environmental Code and the texts adopted for its application, the ASN authorises the commissioning of the installation. This authorisation is duly notified to the operator, and a formal communication is made to the Minister responsible for nuclear safety, the *préfet*, and the CLI. The authorisation decision is published in the Official Bulletin of the Nuclear Safety Authority.

Also, there are specific rules that govern the modifications of a BNI. Pursuant to Article L. 593-14 of the Environmental Code, minor modifications are exempt from the authorisation process. However, "substantial" modifications are subject to a more stringent regulatory regime. These modifications are subject to a procedure similar to that of an application for creation authorisation, conducted according to the procedure provided for in Articles L. 593-7 to L. 593-12 of the same Code. A modification is deemed "substantial" where it meets the criteria listed in Article R. 593-47 of the Environmental Code. This includes, inter alia: Any change in the nature of the installation or an increase in its maximum capacity; Any modification of the essential elements for the protection of the interests mentioned in the first paragraph of Article L. 593-1 of the Environmental Code, which appear in the authorisation decree; The addition, within the perimeter of the installation, of a new BNI whose operation is linked to that of the installation in question. Other modifications, depending on their significance, may either be subject to declaration to the ASN or to authorisation by this authority pursuant to Article L. 593-15 of the Environmental Code. This same article provides that these modifications may be subject to public consultation.

The BNI are also subject to two important international conventions for Environmental Protection. First, the OSPAR Convention, signed in 1992, is a comprehensive agreement for protecting the marine environment of the Northeast Atlantic. It involves the European Commission and 15 countries, including France. Of particular relevance is its objective to curb the discharge of radioactive substances into the sea. This is achieved through a strategic approach of progressively decreasing the release of radioactive substances. The ultimate aim is to reach near-zero levels for artificial radioactive substances and natural background levels for naturally occurring radioactive materials. The convention takes into account radiological impacts on both humans and marine life, legitimate uses of the sea, and technical feasibility in its decision-making process. The second instrument is the Espoo Convention, adopted in 1991 and entering into force in 1997. This Convention imposes binding obligations upon Parties to undertake environmental impact assessments (EIAs) for activities with potential transboundary effects. This is particularly relevant for nuclear facilities, including power plants, fuel production and enrichment facilities, and radioactive waste management sites. The convention requires countries to notify and consult with potentially affected neighbouring states before authorising such activities. This mechanism promotes international cooperation in mitigating environmental risks associated with large-scale projects, especially in the nuclear sector[35].

2- The management of radioactive waste

France has also established a distinct regulatory framework for the control of discharges from BNIs. As with other industries, nuclear activities (including nuclear industry, nuclear medicine, and research facilities) give rise to both radioactive and non-radioactive by-products. A source reduction approach aims to minimise their quantity. The radioactivity released in effluents represents only a marginal fraction of that confined in waste. The choice between liquid or gaseous discharge routes is part of an approach to minimise the overall impact of the installation. The French Nuclear Safety Authority (ASN) ensures that the BNI creation authorisation request explicitly details, in the impact study, the operator's choices. This includes source reduction measures and trade-offs between substance containment, treatment, or dispersion based on safety and radiation protection criteria. Optimisation efforts, prompted by authorities and implemented by operators, have led to continuous emission reductions for "equivalent operation". The ASN imposes discharge limit values to encourage operators to maintain their optimisation and discharge control efforts. It ensures that discharges are as limited as the best available techniques allow and has been revising discharge limits for several years[36].

Substances discharged from BNIs can impact the environment and population due to their chemical characteristics. The ASN considers that such discharges should be regulated in a manner identical to that applied to other industrial installations. French law and general technical regulations on discharges and the environment incorporate this objective. This integrated approach is uncommon abroad, where chemical discharges are often controlled by a different authority than the one overseeing radioactive discharge. Within France, however, the ASN bears responsibility for ensuring that chemical discharges, no less than radioactive ones, pose the lowest possible risk to human health and the environment.

A number of BNIs, particularly nuclear power plants, release cooling water into rivers or the sea, either directly or after cooling in cooling towers. These thermal discharges result in a localised increase in ambient water temperature, which generally remains moderate but can reach several degrees in certain circumstances, especially during low water periods. The limits imposed on BNI discharges aim

35 | About environmental issues and the development of nuclear energy: Kerboul 2023, 54.
36 | About the evolution in management of radioactive waste and discharges from BNIs in France: Le Dars 2004, 116.

to prevent modification of the receiving environment, particularly fish fauna, and to ensure acceptable sanitary conditions if there are downstream water intakes for human consumption. These limits may therefore differ depending on the environments and technical characteristics of each installation. The law of 7 February 2012, and the ASN decision of 16 July 2013 (as subsequently amended) on controlling nuisances and the impact on health and environment of BNIs impose requirements aimed at preventing or limiting, in case of an accident, the direct or indirect spillage of toxic, radioactive, flammable, corrosive, or explosive liquids into sewers or the natural environment. This regulatory framework demonstrates France's comprehensive approach to managing nuclear installations, prioritising environmental protection, public safety, and continuous efforts improvement in operational practices.

The management of waste, whether radioactive or otherwise, in BNIs is regulated by the ASN to prevent and reduce – particularly at the source – the production and harmfulness of waste, especially by acting on the design and operation of the installation, sorting, treatment, and packageing of waste. To exercise effective control in this domain, the ASN relies upon several documents established by BNI operators. Among these, the impact study, submitted as part of the creation authorisation dossier pursuant to Article R. 593-16 of the Environmental Code, occupies a central role. It presents the waste that will be produced by all installations and equipment located within the perimeter of the installation, whether radioactive or not, as well as their volume, nature, harmfulness, and planned disposal methods. It describes the provisions adopted by the operator to ensure that the management of this waste meets the objectives mentioned in Article L. 541-1 and II of Article L. 542-1-2 of the Environmental Code.

In addition, pursuant to Articles 6.4 and 6.6 of the law of 7 February 2012, the operator is mandated to undertake a rigorous analysis and assessment of waste produced, or projected to be produced, within the installation. This includes a detailed review of the arrangements in place for its management, together with the formulation and periodic update of a waste zoning plan. The operator must also produce an annual report assessing waste management performance[37]. This assessment aims to verify the adequacy of waste management with the provisions planned for waste management and to identify areas for improvement. By Decision No. 2015-DC-0508 of 21 April 2015, the ASN set requirements relating to the study on waste management and the assessment of waste produced in nuclear facilities and specified the operational procedures for waste management. Complementing these measures, ASN Guide No. 23, published on 30 August 2016, offers detailed recommendations regarding establishing and modifying the waste zoning plan for nuclear facilities.

37 | About the evolution of Safety measures in BNIs in France: Pontier & Roux 2012

3- The decommissioning of a Basic nuclear installation

With regard to the decommissioning of nuclear installations, Article L. 593-28 of the Environmental Code prescribes that the decommissioning of a nuclear installation is prescribed by a decree, taken after consultation with the ASN. The decommissioning file presented by the operator is subject to the same consultations and inquiries as those applicable to BNI creation authorisation requests according to the same procedures. This same article specifies that the decommissioning decree sets, in particular, the characteristics of the decommissioning, its completion deadline, and, if applicable, the operations to be carried out by the operator following the decommissioning process.

The responsibility for the final shutdown of a BNI rests squarely with the operator, who is required to notify both the Minister responsible for nuclear safety and the ASN at least two years prior to the anticipated date of definitive cessation—save where a shorter period is duly justified. From this date, the operator is no longer authorised to operate its installation, which is considered to be definitively shut down and must be decommissioned. Article L. 593-26 of the Environmental Code provides that, until the entry into force of the decommissioning decree, the installation remains subject to the provisions of its creation authorisation decree and to ASN prescriptions, which may be supplemented or modified if necessary. The ASN has elaborated, in a revised version of Guide No. 6, upon the regulatory framework for BNI decommissioning operations, following work aimed at clarifying the implementation of administrative procedures.

Upon the completion of decommissioning, a nuclear installation may be subject to declassification. Once declassified, the installation is removed from the list of BNIs and is no longer subject to their regime. The operator must provide, in support of its declassification request, a file demonstrating that the envisaged final state has indeed been achieved and including a detailed description of the site's condition after decommissioning (analysis of the condition of soils, remaining buildings or equipment, etc.). Depending on the final state achieved, public utility easements may be imposed, taking into account projected future uses of the site and any extant buildings. These may contain a number of use restriction measures (limitation to industrial use, for example) or precautionary measures (radiological measurements in case of excavation, etc.). The ASN retains the authority to render the declassification of a BNI conditional upon the establishment of such easements. ASN Guide No. 14 and ASN Guide No. 24, published on 30 August 2016, set out recommendations relating to the methods for decontaminating structures and managing soil polluted by BNI activities, respectively.

Sections 1 and 2 of Chapter IV of Title IX of Book V (legislative part) and Section 1 of Chapter IV of Title IX of Book V (regulatory part) of the Environmental Code establish a system relating to the securitisation of charges linked to the decommissioning of nuclear installations and the management of radioactive waste. These provisions are specified by the Order of 21 March 2007, relating to the securitisation of financing for nuclear charges. This legislative and regulatory framework is designed to ensure the long-term financial security of these obligations, in alignment with the "polluter pays" principle. It is therefore up to nuclear operators to ensure this financing, via the constitution of a portfolio of assets dedicated to the level of anticipated charges. This is done under the direct control of the State, which analyses the situation of operators and can prescribe necessary measures in case of insufficiency or inadequacy. In all cases, nuclear operators remain responsible for the proper financing of their long-term charges[38].

To that end, operators are required to prudently estimate the costs of decommissioning their nuclear installations, or, in the case of radioactive waste storage installations, the costs of final shutdown, maintenance, and post-operational monitoring. They also evaluate the charges for managing their spent fuel and radioactive waste in application of Article L. 594-1 of the Environmental Code. In application of Article D. 594-13 of the Environmental Code, the ASN is tasked with issuing an opinion as to the consistency of the operator's proposed decommissioning strategy and radioactive waste and spent fuel management plans, specifically with regard to nuclear safety and radiation protection.

Among the classes of assets that may be recognised as cover for provisions for the charges mentioned in Article L. 594-1 of the Environmental Code—namely, the decommissioning of installations, charges for final shutdown, maintenance and monitoring, charges for managing spent fuel and radioactive waste—a distinction is drawn between those mentioned by the provisions of the Insurance Code and those specific to nuclear installation operators. It makes certain debt securities admissible, notably certain negotiable medium-term notes and securitisation mutual funds and, under certain conditions, unlisted securities; it specifies, in particular, as a consequence of this extension, the exclusion criteria for unlisted intra-group securities. Furthermore, it prescribes the maximum allowable value of assets belonging to the same category or emanating from the same issuer and determines new quantitative ceilings applicable to categories of assets that have been rendered admissible under these provisions.

4- The challenges behind the legal regime applicable to BNIs

The legal regime applicable to BNIs in France presents several notable difficulties. Chief among these is the regulatory complexity inherent in a framework comprised of numerous overlapping and intersecting legislative and regulatory instruments. This fragmentation frequently renders the law difficult to interpret and apply, even for seasoned actors within the sector. A further complicating factor

38 | Bréchet & Dautray 2015, 27.

is the constant evolution of regulations. Nuclear law evolves rapidly, particularly in response to feedback and technological developments, which requires constant updating of knowledge for operators and authorities. Another complex aspect is the interface between different areas of law. The BNI regime also lies at the confluence of multiple legal domains—notably environmental law, energy law, public health law, and security law, which can create conflicts or inconsistencies in the application of texts.

Authorisation procedures for the creation, modification, or decommissioning of a BNI are themselves markedly complex. They involve numerous steps and consultations, which can slow down projects and create legal uncertainties. Continuous control and surveillance exercised by the ASN represent a significant operational constraint for operators. Although necessary for safety, these controls add a layer of complexity to the daily management of installations. Lastly, the long-term management of radioactive waste presents its own category of legal difficulty—particularly regarding the allocation of legal responsibility over geological time scales. This raises complex questions about the durability of current legal provisions.

Provisions relating to decommissioning financing equally present a number of interpretative and practical challenges. They can pose problems of interpretation and application, particularly regarding the evaluation of future costs and the securing of funds. While transparency obligations and public participation requirements constitute essential democratic safeguards, they also impose additional procedural burdens. They can sometimes conflict with the security and confidentiality imperatives specific to the nuclear sector. Moreover, the interaction between national law, international law, and European law can create difficulties in interpretation and application. The need to harmonise these different sources of law further complicates the legal framework applicable to BNIs. Finally, adapting the legal framework to new nuclear technologies represents a constant challenge. Periods of regulatory misalignment may arise during which the law is not fully adapted to technological realities, thus creating temporary legal uncertainties.

5- The use of AI in the nuclear industry39

Within this regulatory and operational landscape, the integration of Artificial Intelligence (AI) presents significant potential benefits for Basic Nuclear Installations (BNIs) in France. In the realm of safety and risk management, AI has the potential to markedly enhance predictive maintenance systems, enabling the early identification of anomalies and potential equipment failures. This proactive

39 | At this moment, Nîmes University (France) and Kokugakuin University (Japan) work on some AI tools that could be used in nuclear industry. The first results of this research will be published in 2026. Researchers on the project: Dhiego Teles da Silva, Charles Condevaux, Nobuyuki Takahashi.

approach could significantly improve safety measures and reduce unplanned operational downtime. Regulatory compliance, a complex aspect of BNI operations, could be streamlined with AI-powered systems. These systems could assist in monitoring and ensuring compliance with the intricate regulatory framework, tracking changes in regulations, and automatically updating compliance protocols. AI also offers considerable advantages in the field of data analysis, particularly in the processing and interpretation of large volumes of real-time data generated by sensors and monitoring systems. In terms of radiation monitoring, AI-driven algorithms could bolster detection and monitoring systems. This could lead to more accurate and real-time data on radiation levels, further improving safety measures[40].

In the sphere of radioactive waste management, a critical aspect of nuclear operations, could be optimised through AI. The technology could potentially find more efficient ways to treat, store, and dispose of radioactive waste. Furthermore, for installations approaching final shutdown, AI may support the strategic planning and execution of decommissioning operations. This could lead to more efficient and cost-effective decommissioning procedures. In emergency situations, AI systems could provide rapid analysis and decision support. This could potentially improve response times and effectiveness in critical situations. Lastly, operator training programmes stand to benefit from AI-integrated virtual and augmented reality simulation tools, enabling immersive, realistic, and adaptive training environments designed to reinforce operational competence and resilience.

Environmental impact assessments stand to benefit from the application of AI. The technology could aid in predicting and assessing the environmental impact of BNIs, helping to ensure compliance with environmental regulations. Public communication, an important aspect of BNI operations, could be improved through AI-enabled virtual assistants and automated information systems. These could provide accurate and timely information about plant operations and safety measures to the public. AI could also contribute to energy output optimisation by analysing various factors like demand, weather conditions, and plant performance. This could lead to more efficient energy production. In the increasingly critical domain of cybersecurity, AI systems could enhance the resilience of nuclear facilities by detecting, analysing, and responding to cyber threats with greater speed and precision. Notwithstanding these advantages, it is essential to underscore that the deployment of AI in such a critical and highly regulated industry would require careful consideration, extensive testing, and regulatory approval. The use of AI in nuclear installations would necessitate rigorous oversight, extensive validation protocols, and, where applicable, regulatory authorisation.

40 | Hewes 2023, 14.

D – The future of nuclear energy in France

1- The French energy strategy for 2030 and 2050

France's energy strategy for the coming decades relies on replacing fossil fuels with massive production of decarbonised, renewable, and nuclear electricity. As part of the France 2030 investment plan, the nuclear sector has been allocated €1.2 billion in public funding to develop a sovereign and sustainable nuclear industry. The nuclear revival is built around four pillars: diversification of uses, reduction of volume and radioactivity of nuclear facility waste, increased strategic autonomy through nuclear materials multi-recycling and improvement of nuclear safety and security. The State can rely on the French Alternative Energies and Atomic Energy Commission (Commissariat à l'énergie atomique et aux énergies alternatives – CEA) and 2,600 companies in the sector. The industrial sector, present across all value chain links, is responsible for innovating and developing new technologies in a context of increased international competition with accelerated research programmes on Small Modular Reactors (SMRs) in certain countries[41]. In parallel with these R&D efforts, the sector continues operating the existing nuclear fleet as long as it meets safety requirements and maintains the construction of new EPR2 reactors.

Innovation lies at the heart of France's nuclear resurgence. In this context, the French sector is tasked with leading the European SMR project, particularly by supporting the French SMR NUWARD project. This low-power reactor integrates notable safety innovations and may constitute a cost-competitive alternative for both industrial and decentralised energy users. The NUWARD concept aims to replace thermal power plants (coal and gas) of comparable power at a reasonable cost through "mass production." The sector's revival also aims to support emerging players by developing a new ecosystem of "nuclear startups" in nuclear fission and fusion[42]. France has launched a call for projects (Appel à projets – AAP) supported by approximately €500 million in public funding. This programme is intended to support new innovative reactor concepts and the nuclear sector in general by promoting innovative young companies.

Research and development into disruptive technologies for modular reactors opens new horizons for the long-term management of radioactive materials. Reducing waste volume and radioactivity must reduce the sector's environmental impacts[43]. Energy sovereignty is intrinsically linked to the strategy for nuclear fuel processing and recycling. France can rely on its pressurised water reactor

41 | Piketty 2024, 9.
42 | Collet 2024, 91.
43 | Lewandowski 2024, 78.

technology and new modular reactor technologies being deployed to achieve this energy independence goal. Indeed, developing techniques around Multi-Recycling in Pressurised Water Reactors (MRREP) and research on Fast Neutron Reactor (FNR) technologies could enable significant advances in strategic autonomy.

France is consolidating its leadership in the nuclear energy sector through an unprecedented investment plan. Beyond the initial €1.2 billion allocation, the government has committed an additional €5 billion in 2023 to accelerate energy transition. This additional funding underscores France's unwavering commitment to retaining its global leadership in nuclear technology. International cooperation now constitutes a key axis of France's nuclear policy, with the country establishing strategic collaborations worldwide, including collaboration with Japan on decommissioning technologies, a major agreement with India for the construction of six EPR reactors, and a strategic alliance with Canada for SMR development. These partnerships enhance France's global influence in the nuclear sector. The French nuclear industry is undergoing a technological revolution. Advanced artificial intelligence systems are being deployed for predictive maintenance, while digital twin technology is revolutionising plant operations. Virtual reality training programmes are preparing the next generation of nuclear operators more effectively than ever before.

Public participation and transparency have been substantially reinforced through citizen monitoring committees and enhanced scientific mediation programmes. Innovative public consultation tools are ensuring greater transparency and community involvement in nuclear projects. In line with its 2050 strategic objectives, France plans to construct 14 new EPR2 reactors and deploy 10 SMRs across its territory. The country aims to reduce nuclear waste volume by 75% and achieve complete fuel cycle autonomy. These goals support France's ambition to become the world's leading nuclear technology exporter. The establishment of an international training centre and active participation in global fusion projects demonstrate France's commitment to international leadership. The development of common EU standards and researcher exchange programmes are strengthening international cooperation in the nuclear field.

2- The revival of nuclear energy in France and abroad

Japan has undergone a notable shift in its nuclear energy policy, marking a significant departure from its earlier post-Fukushima phase-out trajectory. The government has officially recognised nuclear power as essential for achieving its energy security and climate goals. This policy reversal includes plans to extend the operational life of existing reactors and potentially construct new ones. It is interesting to note that the debate surrounding the operational life of nuclear reactors is not limited to France and Japan. In fact, a majority of nuclear reactors in the United States already possess extended operating licenses. The US nuclear fleet contains a substantial number of reactors that were commissioned in the 1970s for example. Among 94 reactors currently operating approximately twenty have either reached or surpassed the fifty-year mark. All of these units hold operating licenses that permit them to run for up to 60 years. In the United States, the Nuclear Regulatory Commission (NRC) initially grants operating licenses for a 40-year term. These licenses are subsequently eligible for renewal in 20-year increments. This regulatory framework differs from that of France, where operating authorisations are reviewed every ten years, subject to a comprehensive safety reassessment[44].

Another notable point of regulatory divergence lies in the regulatory framework. As observed by Sunil Félix, in the US, "the regulatory standards applied when granting a license extension correspond to the regulations that were in effect at the time of the plant's construction." He further clarifies that, despite this historical baseline "the operator need to demonstrate, at the time of the license renewal application, that the primary structures and critical components of the facility are in good condition. Furthermore, the operator must provide evidence of effective management of ageing processes throughout the extended operational period for non-replaceable components, such as the reactor pressure vessel"[45]. In regulatory practice, the licence renewal process in the United States is divided into two distinct phases, initiated between five and ten years prior to the expiration of the existing license. Notably, some US nuclear reactors already possess authorisations to operate for up to 80 years. In late August 2024, the Nuclear Regulatory Commission approved Virginia Electric and Power Company's (Dominion Energy) application to extend the operating licenses for the two pressurised water reactor units (944 MWe each) at the North Anna Nuclear Power Station. Across the United States, out of 94 operating units, 76 reactors currently have licenses permitting operation up to 60 years, and 8 have licenses extending to 80 years.

Across the globe, a significant proportion of operating nuclear reactors were constructed during the 1980s and are now approaching the end of their fourth decade of service. Consequently, several other nations, including Hungary, the Netherlands, and Switzerland, have similarly authorised the operation of nuclear reactors for up to 60 years, mirroring the US approach. In the Hungarian context, the expansion of the Paks Nuclear Power Plant—commonly referred to as Paks II—forms an integral element of a broader national strategy aimed at energy transition. This strategy envisages a substantial augmentation of the country's nuclear generating capacity to accommodate rising electricity consumption, while facilitating the gradual retirement of ageing coal-fired power stations. The Paks II development project entails the construction of two new VVER-1200 pressurised water reactors (PWRs), jointly offering an installed capacity of 2,400 megawatts electric (Mwe). These new reactors are conceived to surpass the existing the

44 | See Paulovics 2020, 344–359.
45 | Félix 2022

existing VVER-440/213 units in terms of operational safety and efficiency, whilst also yielding reduced volumes of radioactive waste.

In parallel with the Paks II initiative, Hungary is also investigating the potential deployment of Advanced Modular Reactors (AMRs) as a complementary means of bolstering its nuclear infrastructure. AMRs are smaller nuclear reactors that offer advantages in terms of faster construction timelines and reduced costs compared to large-scale, traditional nuclear power plants. They also provide greater flexibility in adapting to fluctuating electricity demand and replacing ageing generating facilities. Moreover, the Hungarian authorities are contemplating a further extension of the operational lifetime of the existing reactors by an additional twenty years, which, if authorised, would bring their total lifespan to seventy years, potentially allowing them to operate well into the 2050s. Feasibility studies and thorough safety evaluations are currently in progress. If this extension is approved, these reactors could remain operational into the 2050s. All operational extensions are subject to rigorous safety assessments conducted by the Hungarian Atomic Energy Authority. These assessments focus on key areas, including overall plant safety, ageing management programmes, and comprehensive safety analyses. Nuclear power plays a critical role in Hungary's energy mix, supplying approximately 48% of national electricity production. The Hungarian government views nuclear energy as a fundamental pillar of its energy strategy, ensuring security of supply, reducing reliance on imported fossil fuels, and contributing to the achievement of climate objectives.

The incorporation of nuclear power into Japan's green energy transition strategy marks a pronounced evolution in its national energy policy. Following the Fukushima accident, Japan has implemented the world's most stringent nuclear safety standards. Existing nuclear facilities are undergoing comprehensive modernisation, notably through the enhancement of seismic resilience and the reinforcement of flood mitigation systems. Advanced emergency response systems have been developed, incorporating lessons learned from past experiences. These improvements have set new global benchmarks for nuclear safety. A gradual transformation is also discernible in Japanese public sentiment towards nuclear power. The government and industry have implemented unprecedented transparency measures to rebuild public trust. Community engagement programmes have been expanded, giving local stakeholders more voice in nuclear-related decisions. Public information centres and educational initiatives are helping to address concerns and provide accurate information about nuclear technology.

France and Japan alike are confronted with comparable challenges in ensuring energy security while meeting climate commitments. Their approaches to technological innovation share common elements, particularly in areas such as digital transformation and safety enhancement. Both countries recognise the critical importance of developing a skilled nuclear workforce and are investing heavily in training programmes. But the historical context and public perception of nuclear power differ significantly between the two countries. Japan's regulatory framework underwent a radical and comprehensive restructuring in the wake of Fukushima, whereas France has pursued a more incremental, albeit no less rigorous, path of regulatory evolution. Geographic and seismic considerations create distinct technical challenges for each country. The scale and scope of their nuclear programmes reflect these different national contexts.

France and Japan have forged a strong bilateral cooperation within the nuclear sector, characterized by regular exchanges of technical expertise between their respective nuclear operators and regulatory authorities. Joint research programmes are addressing common challenges in areas such as waste management and advanced reactor design. Industry partnerships are facilitating knowledge transfer and technology development. The concurrent revitalisation of the nuclear sectors in these two leading economies is exerting a discernible influence upon the evolution of international nuclear policy. Their enduring commitment to nuclear power provides important reference points for other countries considering nuclear energy. Their combined efforts in climate change mitigation through nuclear power demonstrate the technology's potential role in addressing global environmental challenges[46].

E – The emergence of small modular reactors

1- The development of Small modular reactors in France

At present, France is firmly committed to developing small nuclear reactors (SMR/AMR) intended to be installed, in some cases, outside current nuclear sites, often near industrial hubs. In 2022, France launched an ambitious programme to develop innovative small nuclear reactors, Small/Advanced Modular Reactors (SMR/AMR), as part of the "France 2030" programme. Specifically, the government is supporting the development of the new Nuward nuclear reactor developed by EDF and launched a competitive call for projects (CFP) that selected about twelve companies working on the subject. These next-generation reactors embody novel fission and fusion technologies, new construction methods (modular factory manufacturing), new safety approaches (small size, intrinsic safety), and even, for some, new materials and waste management methods (multi-recycling). Beyond the generation of electricity, SMRs and AMRs are designed to fulfil emerging "deep decarbonisation" imperatives. These include low-carbon heat production for urban heating and industry needs, powering high-temperature electrolysers to produce

46 | On January 27, 2025, Nîmes University (France) and Kokugakuin University (Japan) organize a large Conference about *"Energy Sovereignty"*. My presentation in this conference was about the *"Revival of nuclear energy in France and Japan"*

clean hydrogen, or seawater desalination. Their size is suitable for serving industrial zones, communities (via heat networks), and non-interconnected areas[47].

Unlike electricity, heat cannot be conveyed efficiently over long distances. Therefore, serving these areas would, in many cases, require opening new nuclear sites closer to consumption zones than the current sites where large power reactors are operated. Most of the winning companies initially envision a first prototype on an existing nuclear site and have made requests to this effect to the government. The projects, at different stages of maturity, have already begun contacting potentially interested industrialists to better understand their needs. Jimmy company notably announced on April 30, 2024, the submission of a creation authorisation request (Demande d'Autorisation de Création, DAC)) for a project to install a 10 MWth reactor at the Cristanol site in Marne.

At the national level, the value proposition of SMRs/AMRs is primarily aimed at industrialists, with the promise of providing a reliable and competitive decarbonization solution, and also to the Nation, with a promise of energy sovereignty, qualified jobs, and reduction of greenhouse gas emissions. Until now, the French nuclear industry has remained mono-technological (with custom-made pressurised water reactors), cantered on a single operator (EDF) and dedicated solely to supplying electricity to the grid. However, the SMR model takes a completely different form. First, their "ready-to-deploy" manufacturing requires, as ASN points out, exportation outside France to be profitable. In fact, the infrastructure study cannot be ensured by the French authority alone. In this regard, the Nuward project, led by an EDF-led consortium, is already subject to a joint evaluation by ASN on the French side and five other similar agencies in the Netherlands, Sweden, Finland, Poland, and the Czech Republic. The Institute for Radiological Protection and Nuclear Safety (IRSN) has already spoken out against the temptation of harmonisation, possibly lighter, of safety rules accepted between all these organisations. Despite the advantages of SMRs, "there is no reason to lower safety requirements for SMRs," IRSN maintained in an October 2021 note. "While electrons have the advantage of not being contaminated, this is not the case for heat exchange systems between the reactor and the 'client' industrial process," underscoring the necessity of maintaining rigorous safety oversight

2- The new risks of small modular reactors

The operation of SMRs entails a series of notable challenges. Intended to be deployed at industrial sites to contribute to their decarbonisation, these installations must be "autonomous," implying operation without the need for specialised personnel on-site, and in certain cases, to be remotely controllable. Moreover, given the differences in fuels required for their operation, some of the targeted

47 | About the development of Small modular reactors: Chesne 2024, 75.

technologies will require the development of entirely new production capabilities, still non-existent in France, for example, to produce chloride salts (essential for molten salt fast reactors, MSR) or Triso-type fuel (tristructural-isotropic, based on two layers of pyrolytic carbon and one of silicon carbide around a uranium particle)[48].

In addition, bespoke solutions for transport packaging and interim storage, tailored to each specific fuel type, must be devised and subjected to rigorous regulation. Currently, as ASN reminds us, none "is approved for these new fuels." Last January, Bernard Doroszczuk, ASN president, specifically called for vigilance regarding "suppliers' lack of knowledge of important safety-specified requirements, lack of control over certain special processes, and lack of rigour and performance in supply chain monitoring. "Finally, these SMRs are not being designed to supply the electrical grid. Unlike conventional reactors, their primary function is to deliver heat to industrial installations or urban centres, or to generate electricity off-grid, thereby supporting industrial entities in their efforts to decarbonise energy consumption. "Site choice is no longer an option," ASN concludes. The degree of nuclear safety will be all the more demanding as SMRs will need to be installed at sites close to more or less populated areas. Moreover, the heat produced by SMRs to decarbonize industrial thermal processes is not without consequences. "While electrons have the advantage of not being contaminated, this is not the case for heat exchange systems between the reactor and the 'client' industrial process (food industry, manufactured products, medicines, district heating network, etc.)," explains ASN.

ASN is presently overseeing the progression of approximately ten distinct projects, over half of which have already secured public funding. However, not all are at the same level of technological maturity and, consequently, evaluation by ASN and IRSN. They are preparing, for example, to review the creation authorisation file (including a "detailed design," the final design stage before prototype construction) submitted by the startup Jimmy. This company is working on a helium-cooled high-temperature reactor (HTR) with a power of 10 MWth, associated with a Triso fuel assembly plant. Next will come, by the end of 2026, the review (and inspection) of the Nuward and Calogena projects (another light water reactor, fueled with standard uranium, with a capacity of 30 MWth). In parallel, ASN and IRSN are working to finalize the "preparatory review" (preliminary step before instruction) of two other projects: Naarea (an 80 MWth MSR), by September 2024, and Newcleo (a lead-cooled fast reactor, LFR, with two possible dimensions – 80 or 450 MWth – and fuelled with MOX), by the end of the year. The five other monitored projects (Hexana, Otrera, Blue Capsule, Thorizon, and Stellaria) remain too early in development.

48 | Greneche 2023, 35.

Conclusion

The future trajectory of nuclear energy in France presents a complex and challenging subject for analysis. Indeed, even though climate and energy challenges are significant, the investments required to develop the nuclear branch are substantial. France is already equipped with a comprehensive legal framework designed to safeguard the continuity of nuclear energy within its territory, but each technical or technological evolution creates new challenges in terms of safety and security Activities such as medical uses of radiation, the operation of nuclear facilities, the production, transport, and use of any radioactive materials, and the management of radioactive waste must be subject to safety standards. Regulating safety is a national responsibility. Nonetheless, the risks associated with ionising radiation possess the potential to transcend national boundaries, thereby rendering international cooperation indispensable. Such cooperation is paramount to fostering and enhancing safety globally by sharing experience and improving skills to control risks, accident prevention, emergency response, and the mitigation of adverse consequences. In this context, the International Atomic Energy Agency (IAEA), under the provisions of its Statute, is mandated to promote international collaboration and is empowered to develop and promulgate safety standards aimed at protecting health and minimising hazards to life and property. IAEA develops these standards through an open and transparent process that allows for the collection, integration, and sharing of knowledge and experience gained from the use of technologies and the implementation of safety standards. The safety standards include 3 series of publications: Safety Fundamentals, Safety Requirements, and Safety Guides. The first defines the fundamental safety objective and the principles of protection and safety, while the second sets out the requirements that must be met to ensure the protection of people and the environment, both now and in the future. The Safety Guides provide recommendations and guidance on how to apply the Safety Requirements[49]. However, even if many challenges remain, the opportunities offered by nuclear power are also interesting. It is undeniable that France's energy sovereignty is closely linked to the development of nuclear energy. This study offers a preliminary overview of the multifaceted issues and potentialities inherent in nuclear energy; however, it is manifestly clear that political decision-making, legislative reform, and technological innovation within this sector will demand vigilant observation and thoughtful scrutiny in the times to come.

49 | Kocsis 2016, pp. 41–62.

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