From Power Source to Waste Burden: Legal Implications of Using SMRs for AI Infrastructure

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Abstract:

As artificial intelligence (AI) compute scales, energy security has emerged as a key constraint. The UK's AI Growth Zones aim to address this by integrating Small Modular Reactors (SMRs) as a primary power source. However, this strategy faces a structural paradox: while SMRs are being fast-tracked through streamlined licensing, planning, and environmental law, the UK lacks a long-term solution for nuclear waste disposal. This paper examines the regulatory barriers to SMR deployment, the unresolved risks of AI-powered nuclear infrastructure, and the governance challenges posed by nuclear waste and AI energy demand. It argues that unless nuclear policy, AI expansion, and waste governance are treated as interdependent, the UK risks undermining its AI supercomputing strategy. By analysing UK energy law, SMR licensing, and AI compute governance, the paper contributes to current debates on the trade-offs between AI energy security, nuclear governance, and long-term waste sustainability.

Keywords: Artificial Intelligence; SMRs for AI Infrastructure; High-Intensity Compute Energy; Nuclear Waste Challenges; Licensing and Permitting; Geological Disposal Facility; Interim Storage Systems; Sustainable AI.

1. INTRODUCTION

In this article, I argue that the United Kingdom's attempt to integrate Small Modular Reactors (SMRs)—compact nuclear reactors intended for modular, distributed deployment—into its AI Growth Zones[1] strategy creates a structural paradox between two inconsistent temporalities: the rapid front-end acceleration of SMR regulatory streamlining to support AI infrastructure, and the slow, unresolved trajectory of nuclear waste management. Although no SMR has yet been licensed or constructed in the UK, several designs are progressing through early-stage regulatory processes as part of a government-backed ambition to enable deployment by the early 2030s.[2] This ambition is unfolding in the absence of a functioning Geological Disposal Facility (GDF),[3] a deep underground site designed to permanently isolate high-level radioactive waste from the environment, and amid growing evidence that SMRs may produce more chemically complex, thermally demanding, and spatially burdensome waste than existing nuclear technologies.[4] Drawing on legal, regulatory, and policy documents, I examine how the AI Growth Zone initiative has prioritised energy acceleration while deferring backend disposal planning. I argue that without first resolving the infrastructural and regulatory challenges of long-term nuclear waste containment, the UK risks constructing an energy-industrial model in which unresolved backend liabilities become a limiting condition on the very AI expansion the policy is designed to support.

In terms of structure, the paper begins with a background discussion of global AI energy demand and the resurgence of nuclear power, situating the UK's AI Growth Zones initiative within this emerging international context. It then reviews existing academic literature on AI energy infrastructure and nuclear governance and identifies a key gap concerning the long-term implications of SMR deployment for waste disposal. The next section sets out the UK's regulatory architecture for SMR deployment, covering licensing, environmental permitting, and planning law. This is followed by a detailed analysis of the risks associated with SMR waste, including volume, thermal load, material complexity, and the limitations of existing infrastructure such as Sellafield. The paper then presents a set of future scenarios—optimistic,

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[1] 'AI Opportunities Action Plan: Government Response' (*GOV.UK*) <https://www.gov.uk/government/publications/ai-opportunities-action-plan-government-response/ai-opportunities-action-plan-government-response> accessed 6 March 2025.

[2] 'Prime Minister Sets out Blueprint to Turbocharge AI' (*GOV.UK*, 13 January 2025) <https://www.gov.uk/government/news/prime-minister-sets-out-blueprint-to-turbocharge-ai> accessed 6 March 2025.

[3] National Audit Office, Department for Energy Security & Net Zero, and Nuclear Decommissioning Authority, 'Decommissioning Sellafield: Managing Risks from the Nuclear Legacy' (National Audit Office 2024) HC 233.

[4] ibid.

pessimistic, and moderate/realistic—that map how backend constraints could shape or derail the UK's AI–SMR strategy. The conclusion draws together these trajectories to argue that backend waste governance will define the strategic viability of nuclear-powered AI expansion.

2. BACKGROUND CONTEXT: AI's ENERGY PROBLEM AND THE STRATEGIC RESURGENCE OF NUCLEAR POWER

The global race to develop and deploy artificial intelligence (AI) is reshaping national strategies for energy, infrastructure, and economic growth. Governments and private actors alike increasingly view AI as a critical enabler of scientific discovery, industrial competitiveness, and geopolitical influence. [5] In this context, the United States, China, and the European Union have all launched large-scale initiatives aimed at consolidating their positions as global AI leaders—mobilising billions in public investment, adjusting regulatory frameworks, and supporting the construction of high-performance computing (HPC) facilities, supercomputing clusters, and hyperscale data centres. [6]

However, as AI deployment accelerates, a major infrastructural constraint has emerged: electricity supply. AI infrastructure is among the most power-intensive digital technologies in operation today.[7] Unlike other computing functions, AI workloads—particularly those involving large-scale training, inference, and simulation—require high-density, uninterrupted energy at scale. [8] Hyperscale data centres and AI supercomputing clusters demand a stable baseload power supply capable of supporting continuous operation with low tolerance for disruption or fluctuation. [9] This has placed energy resilience, increasingly, at the centre of AI industrial policy.

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[5] Ryan Sullivan, *The US, China, and Artificial Intelligence Competition Factors* (China Aerospace Studies Institute 2021); Edward Hunter Christie, Caroline Buts and Cindy Du Bois, 'America, China, and the Struggle for AI Supremacy', *24th Annual International Conference on Economics and Security, Volos, Greece* (2021); Huw Roberts, Emmie Hine and Luciano Floridi, 'Digital Sovereignty, Digital Expansionism, and the Prospects for Global AI Governance', *Quo Vadis, Sovereignty? New Conceptual and Regulatory Boundaries in the Age of Digital China* (Springer 2023).
[6] Sullivan (n 5); Ludovic Dibiaggio, Lionel Nesta and Simone Vannuccini, 'European Sovereignty in Artificial Intelligence: A Competence-Based Perspective' (PhD Thesis, SKEMA Business School; Université Côte D'Azur; GREDEG CNRS 2024).
[7] Radosvet Desislavov, Fernando Martínez-Plumed and José Hernández-Orallo, 'Trends in AI Inference Energy Consumption: Beyond the Performance-vs-Parameter Laws of Deep Learning' (2023) 38 Sustainable Computing: Informatics and Systems 100857.
[8] ibid.
[9] ibid; Seokki Cha, 'The Potential Role of Small Modular Reactors (SMRs) in Addressing the Increasing Power Demand of the Artificial Intelligence Industry: A Scenario-Based Analysis' [2024] Nuclear Engineering and Technology 103314; Alexandra Sasha Luccioni, Yacine Jernite and Emma Strubell, 'Power Hungry Processing:

Against this backdrop, nuclear energy has re-entered policy debates as a candidate solution. Specifically, Small Modular Reactors (SMRs)—compact nuclear reactors with outputs up to 300 megawatts electric (MWe)—are now being considered by both governments and private sector actors as a means of co-locating clean, reliable power directly alongside energy-intensive AI infrastructure.[10] SMRs offer modular construction, flexible siting, and low-carbon baseload electricity, making them especially attractive in contexts where grid reinforcement is costly or where new compute clusters are being developed in non-traditional energy corridors.[11]

Several states have already moved to explore the AI-nuclear convergence. France has pledged to allocate 1 GW of nuclear power for AI supercomputing and is advancing the NUWARD SMR design for potential data centre applications.[12] Poland's Secretary of State for Industry has publicly identified SMRs as essential to powering high-demand digital infrastructure, including AI.[13] In Bulgaria, officials have proposed SMRs to supply national high-performance computing assets,[14] while in Sweden, a domestic, commercial firm is developing an SMR-powered data centre campus.[15] In the United States, the Department of Energy and Department of Defense are supporting projects that pair SMRs with compute infrastructure,[16] while companies such as Microsoft, Amazon,[17] and Google are actively

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Watts Driving the Cost of AI Deployment?', *The 2024 ACM Conference on Fairness, Accountability, and Transparency* (2024) <http://arxiv.org/abs/2311.16863> accessed 19 February 2025; Thomas A Hemphill, 'US AI Data Centers and Deployment Challenges for Small Modular Reactors: Proposed Regulatory Policy Recommendations' (2024) 51 Science and Public Policy 999.

[10] Hemphill (n 9); Cha (n 9).

[11] 'National Policy Statement for Nuclear Energy Generation (EN-7): New Consultation, and Response to Earlier Consultation (HTML)' (*GOV.UK*) <https://www.gov.uk/government/consultations/draft-national-policy-statement-for-nuclear-energy-generation-en-7/national-policy-statement-for-nuclear-energy-generation-en-7-new-consultation-and-response-to-earlier-consultation-html> accessed 6 March 2025.

[12] 'France Tempts AI Firms with Its Nuclear Electricity' (*World Nuclear News*) <https://world-nuclear-news.org/articles/france-tempts-ai-firms-with-its-nuclear-electricity> accessed 11 March 2025.

[13] 'PRESS RELEASE: SMRs as a Key Contributor to the EU's Energy Security: A Successful Event at the European Parliament' (*ZPP*, 17 April 2025) <https://zpp.net.pl/en/32640/> accessed 18 April 2025.

[14] 'Bulgaria's Nuclear Energy Potential for AI and Data Centers' (*Novinite.com*, 18 April 2025) <https://www.novinite.com/articles/231772/Bulgaria%27s+Nuclear+Energy+Potential+for+AI+and+Data+Centers>.

[15] 'Kärnfull Next Progresses with Swedish SMR Project' (*World Nuclear News*) <https://world-nuclear-news.org/articles/karnfull-next-progresses-with-swedish-smr-project> accessed 18 April 2025.

[16] The White House, 'Executive Order on Advancing United States Leadership in Artificial Intelligence Infrastructure' (*The White House*, 14 January 2025) <https://bidenwhitehouse.archives.gov/briefing-room/presidential-actions/2025/01/14/executive-order-on-advancing-united-states-leadership-in-artificial-intelligence-infrastructure/> accessed 11 March 2025.

[17] Robert G Eccles, 'Microsoft Can Take The Lead In Small Modular Reactors For Powering AI' (*Forbes*) <https://www.forbes.com/sites/bobeccles/2024/08/31/microsoft-can-take-the-lead-in-small-modular-reactors-for-powering-ai/> accessed 20 April 2025.

investing in nuclear energy options for powering AI operations. [18] Amazon, for instance, recently acquired a 960 MW nuclear-powered data centre,[19] and Google has partnered with Kairos Power to integrate SMRs by 2030.[20]

It is within this global context that the United Kingdom has launched its AI Growth Zones initiative—a flagship industrial policy aimed at consolidating domestic compute infrastructure for AI development.[21] The objective is twofold: to enable the rapid scale-up of UK-based AI capacity and to reduce dependence on foreign cloud providers such as Microsoft Azure, Amazon Web Services, and Google Cloud.[22] The UK government has framed this as a matter of digital sovereignty, national security, and economic competitiveness.[23] By concentrating AI development in designated "Growth Zones"—geographic areas with enhanced regulatory support and infrastructure funding—the government seeks to attract major AI labs, foster public–private partnerships, and build an exportable model of AI-led industrial revitalisation.[24]

To support these ambitions, energy supply is being treated as a first-order design question. The AI Opportunities Action Plan (2025)[25] established an AI Energy Council tasked with securing clean, stable power for AI clusters. Within this framework, SMRs have been explicitly identified as candidate technologies. [26] Their modular form and high-power density make them theoretically well-suited to co-location with AI compute infrastructure—especially in inland or industrial zones not served by large nuclear plants or grid-scale renewables. The first Growth Zone, at Culham in Oxfordshire, is targeting a 100 MW deployment, with plans to expand to 500 MW. [27] Additional zones are expected to follow. [28]

[18] ibid.
[19] ibid.
[20] 'Bill Gates' Nuclear Energy Startup Inks New Data Center Deal | The Verge' <https://www.theverge.com/2025/1/23/24350335/bill-gates-terrapower-data-center-sabey-nuclear-energy-ai> accessed 20 April 2025.
[21] 'Government Fires Starting Gun on AI Growth Zones to Turbocharge Plan for Change' (*GOV.UK*) <https://www.gov.uk/government/news/government-fires-starting-gun-on-ai-growth-zones-to-turbocharge-plan-for-change> accessed 11 March 2025.
[22] 'AI Opportunities Action Plan: Government Response' (n 1).
[23] 'Government Fires Starting Gun on AI Growth Zones to Turbocharge Plan for Change' (n 21); 'AI Opportunities Action Plan: Government Response' (n 1).
[24] 'AI Opportunities Action Plan: Government Response' (n 1).
[25] ibid.
[26] ibid.
[27] 'Generating Status - EDF Nuclear Power Stations' (7 March 2025) <https://www.edfenergy.com/energy/power-station/daily-statuses> accessed 8 March 2025.
[28] 'Prime Minister Sets out Blueprint to Turbocharge AI' (n 2).

To streamline deployment, the UK government has stated that it aims to use existing planning and licensing mechanisms.[29] These include classifying SMRs as Nationally Significant Infrastructure Projects under the Planning Act 2008—enabling a fast-track Development Consent Order process—and updating the National Policy Statement for Nuclear Power Generation (EN-7) to support inland nuclear development.[30] Simultaneously, SMR designs are advancing through the Generic Design Assessment (GDA), a pre-licensing safety and environmental review.[31] These reforms signal a clear regulatory commitment to integrating SMRs into the UK's AI infrastructure plans by the early 2030s.[32]

What is striking, however, is that this strategic vision for AI–nuclear integration is advancing at a time when the UK's nuclear waste disposal system remains fundamentally unresolved.[33] As this paper argues, this mismatch of timelines—between the acceleration of front-end deployment and the inertia of backend waste management—risks generating structural vulnerabilities in the AI Growth Zone model. While the regulatory framework for SMR deployment is relatively well-developed, the UK lacks a Geological Disposal Facility and has yet to establish a coherent strategy for managing the novel and potentially more complex waste streams associated with advanced SMR technologies. These unresolved liabilities raise serious questions about the long-term viability of SMR-powered AI zones and demand closer scrutiny than they have so far received.

3. LITERATURE REVIEW AND CONTRIBUTION TO EXISTING LITERATURE

While policy momentum is clearly building across multiple jurisdictions, especially in the UK, the academic literature remains comparatively underdeveloped on one key front: the long-term consequences of powering AI with nuclear energy. That is, current scholarship on AI and its associated risks has primarily focused on ethical, legal, and governance issues, including AI

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29 ibid.

30 Amber Jackson, 'AI Growth Zones: How the UK Will Turbocharge Digital Change' (18 February 2025) <https://datacentremagazine.com/technology-and-ai/ai-growth-zones-how-the-uk-will-turbocharge-digital-change> accessed 22 February 2025; 'Prime Minister Sets out Blueprint to Turbocharge AI' (*GOV.UK*, 13 January 2025) <https://www.gov.uk/government/news/prime-minister-sets-out-blueprint-to-turbocharge-ai> accessed 19 April 2025; Oliver Wright Editor Policy, 'Ministers Will Relax Rules to Build Small Nuclear Reactors' (5 February 2025) <https://www.thetimes.com/uk/politics/article/labour-ministers-rachel-reeves-relax-nuclear-reactor-rules-92cpcc6wj> accessed 18 April 2025.

31 Brightwire.net, 'Generic Design Assessment (GDA) of New Nuclear Power Stations' (*Office for Nuclear Regulation*) <https://www.onr.org.uk/generic-design-assessment/> accessed 20 April 2025.

32 Editor (n 30).

33 National Audit Office, Department for Energy Security & Net Zero, and Nuclear Decommissioning Authority (n 3).

bias, explainability, data privacy, copyright, and the implications of AI for democracy and human rights.[34] As such, extensive debates exist around AI ethics, particularly in relation to regulatory structures, responsible AI development, and the impact of AI on employment, surveillance, and decision-making autonomy.[35] At the same time, AI's energy consumption has emerged as a growing topic of discussion, particularly in relation to sustainability and carbon neutrality. Studies have examined AI's energy demands in the context of smart grids, renewables, and energy efficiency optimisation.[36] However, most analyses of AI and energy focus on how to secure clean energy for AI expansion, rather than examining the long-term infrastructural and waste implications of specific energy sources. That is, when nuclear energy is discussed as an AI power source, the literature largely frames it as a low-carbon alternative to fossil fuels, with relatively little attention to the nuclear waste challenges that could arise from integrating SMRs into AI infrastructure.[37]

This paper contributes to existing AI-energy scholarship by shifting the focus from the question of how to power AI expansion to the unresolved issue of nuclear waste as a structural constraint on AI-driven industrial policy. While some studies have identified potential waste management concerns associated with SMRs—particularly in the context of Canada and Finland—[38] there has been little systematic examination of how these challenges intersect with AI-related energy policies. The UK's AI Growth Zones represent one of the most ambitious efforts to integrate nuclear power directly into AI expansion, yet this initiative is unfolding in

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[34] James Curzon and others, 'Privacy and Artificial Intelligence' (2021) 2 IEEE Transactions on Artificial Intelligence 96; Pamela Samuelson, 'Generative AI Meets Copyright' (2023) 381 Science 158; David Leslie and others, 'Artificial Intelligence, Human Rights, Democracy, and the Rule of Law: A Primer' [2021] arXiv preprint arXiv:2104.04147.

[35] Keng Siau and Weiyu Wang, 'Artificial Intelligence (AI) Ethics: Ethics of AI and Ethical AI' (2020) 31 Journal of Database Management (JDM) 74; Emre Kazim and Adriano Soares Koshiyama, 'A High-Level Overview of AI Ethics' (2021) 2 Patterns.

[36] Lefeng Cheng and Tao Yu, 'A New Generation of AI: A Review and Perspective on Machine Learning Technologies Applied to Smart Energy and Electric Power Systems' (2019) 43 International Journal of Energy Research 1928; Zhengxuan Liu and others, 'Artificial Intelligence Powered Large-Scale Renewable Integrations in Multi-Energy Systems for Carbon Neutrality Transition: Challenges and Future Perspectives' (2022) 10 Energy and AI 100195.

[37] Desislavov, Martínez-Plumed and Hernández-Orallo (n 7).

[38] Paula Keto and others, 'Waste Management of Small Modular Nuclear Reactors in Finland'; Sikun George Xu and others, 'Characteristic Waste Streams from Small Modular Reactors Considered for Deployment in Canada' (2020) 9 CNL Nuclear Review (Online) 83.

the context of a nuclear waste crisis that remains politically, economically, and technically unresolved.[39]

By examining the structural paradox between fast-tracked AI-nuclear acceleration and the slow, uncertain trajectory of nuclear waste disposal, this paper provides a new perspective on AI infrastructure policy—one that highlights waste as a potential long-term bottleneck for AI expansion. It argues that any country seeking to power AI through SMRs must address nuclear waste disposal as a first-order strategic priority, rather than an afterthought. In doing so, this paper advances the debate on AI sustainability by introducing an important but often overlooked dimension: the risk that nuclear waste, rather than energy scarcity, could become the limiting factor in AI's long-term scalability. However, before developing that point further, I would like to begin by setting out the legal and regulatory architecture around small modular reactors in the UK.

4. LICENSING, ENVIRONMENTAL PERMITTING, AND PLANNING APPROVALS FOR SMRs IN THE UK

To integrate SMRs into AI Growth Zones by the early 2030s,[40] the UK government aims to rely on a suite of existing legal instruments to streamline what has historically been a protracted and fragmented process.[41] While no SMR has yet been deployed for AI infrastructure, the regulatory architecture now in place provides a legally defined route from design assessment to full-scale operation, and a number of commercial reactor designs are progressing steadily through this pathway.

The first and most important gateway is the Generic Design Assessment (GDA), a voluntary but strategically important pre-licensing review jointly conducted by the Office for Nuclear Regulation (ONR) and the Environment Agency (EA) (or Natural Resources Wales, if applicable).[42] The GDA does not grant permission to build or operate a reactor. Rather, it

[39] National Audit Office, Department for Energy Security & Net Zero, and Nuclear Decommissioning Authority (n 3).
[40] 'Prime Minister Sets out Blueprint to Turbocharge AI' (n 2).
[41] Jackson (n 30); 'Prime Minister Sets out Blueprint to Turbocharge AI' (n 30); Editor (n 30).
[42] 'New Nuclear Power Plants: Generic Design Assessment Guidance for Requesting Parties' (*GOV.UK*, 19 October 2023) <https://www.gov.uk/government/publications/new-nuclear-power-plants-generic-design-assessment-guidance-for-requesting-parties> accessed 9 March 2025.

evaluates whether a proposed reactor design is likely to meet the UK's regulatory standards for nuclear safety, environmental protection, security, radioactive waste management, and safeguards, independently of any specific site proposal. [43] The GDA proceeds in structured stages: Step 1 (Initiation), Step 2 (Fundamental Assessment), and Step 3 (Detailed Assessment), which may culminate in a Design Acceptance Confirmation (DAC) from ONR and a Statement of Design Acceptability (SoDA) from the EA—together providing strong regulatory assurance that a design is potentially licensable.[44] And, as of April 2025, three reactor designs are advancing through this process. Rolls-Royce SMR Ltd's 470 MWe pressurised water reactor design is currently in Step 3, the most advanced stage of GDA. GE Hitachi's BWRX-300 and Holtec International's SMR-300—both 300 MWe designs—have recently completed Step 1 and are now in Step 2 (ONR and EA, 'GDA News Updates', 2024). While none has reached final regulatory sign-off, these developments indicate regulatory momentum, and the Rolls-Royce design is widely viewed as the UK's leading domestic candidate for near-term deployment.[45]

Following successful GDA approval, a developer seeking to construct an SMR must obtain three additional authorisations. First, a Nuclear Site Licence under Section 1 of the Nuclear Installations Act 1965 (c 57) must be secured from the ONR. This licence imposes detailed operational and safety obligations under sections 4–6 of the Act, including emergency planning, record-keeping, and regulatory compliance. Second, an environmental permit must be granted under the Environmental Permitting (England and Wales) Regulations 2016 (SI 2016/1154), Schedule 23, for any activity involving radioactive substances, including waste accumulation, treatment, and discharge. Applications must demonstrate compliance with the Best Available Techniques (BAT) standard, supported by a Waste Management Plan and a Site-Wide Environmental Safety Case (Environment Agency, GRR Guidance, 2018). Third, and importantly for SMRs intended for AI Growth Zones, the developer must obtain a Development Consent Order (DCO) under the Planning Act 2008.

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[43] ibid.
[44] ibid.
[45] 'New Nuclear Power Plants: Generic Design Assessment Guidance for Requesting Parties - GOV.UK' <https://www.gov.uk/government/publications/new-nuclear-power-plants-generic-design-assessment-guidance-for-requesting-parties/new-nuclear-power-plants-generic-design-assessment-guidance-for-requesting-parties> accessed 9 March 2025.

The DCO mechanism is central to the government's fast-track strategy. SMRs with an electrical generating capacity above 50 MWe qualify as Nationally Significant Infrastructure Projects (NSIPs) under section 15(2) of the Planning Act 2008 (c 29). This designation allows developers to bypass local authority planning processes and instead submit a unified application to the Planning Inspectorate that culminates in a single consent decision by the Secretary of State for Energy Security and Net Zero (ss 31–37, 114–121). A DCO can bundle multiple approvals—land acquisition, environmental assessments, transport links—into a single instrument that reduces procedural duplication and compresses timelines.

To facilitate this process, the government has updated its National Policy Statement for Nuclear Power Generation (EN-7), which replaces the older site-specific EN-6 regime and enables SMRs to be sited on inland or industrial land rather than being limited to coastal locations (Department for Energy Security and Net Zero, 2023). This shift is significant: it allows SMRs to be co-located with high-performance compute infrastructure in AI Growth Zones, which are often situated away from the legacy nuclear estate. The result is a legal regime in which planning, permitting, and siting constraints have been loosened in favour of geographic and procedural flexibility—provided core safety and environmental requirements are met.

Thus, while the UK has yet to approve or construct an SMR for AI purposes, the legal and regulatory conditions for such deployment are now firmly in place. The GDA provides early technical validation, while the DCO process under the Planning Act 2008 offers an integrated route through which SMR projects can obtain full authorisation. This architecture is being actively used: several SMR designs are advancing through regulatory assessment, and AI Growth Zones are being positioned as eligible sites for early deployment. The legal pathway is clear—but whether it can deliver on schedule depends not only on front-end acceleration but also on how backend constraints, particularly nuclear waste, are addressed. The following section turns to this unresolved issue, examining how the UK's nuclear waste governance system—currently facing severe infrastructural and policy delays—may limit or even derail the SMR-AI integration strategy.

5. SMRs AND NUCLEAR WASTE: RISING VOLUMES, CHEMICAL COMPLEXITY, AND DISPOSAL UNCERTAINTY

One prominent concern with this push towards SMR adoption is the significant increase in the volume and complexity of nuclear waste compared to conventional large-scale reactors. While

SMRs are often marketed as more efficient and flexible, research—specifically, a study published in *PNAS*[46] (the Proceedings of the National Academy of Sciences—hereafter 'the PNAS study') suggests that their waste streams will be more chemically reactive, physically voluminous, and more challenging to manage than those of traditional gigawatt-scale light water reactors (LWRs). The primary reason for this, according to the PNAS study, lies in the higher neutron leakage inherent to smaller reactor cores (i.e., because SMRs have smaller cores, more neutrons escape rather than contributing to the fission reaction, which in turn affects how the fuel is used and what by-products are created).[47]

This not only increases the fuel required to produce the same energy output but also generates more neutron-activated reactor components, causing the very structure of the plant to become radioactive over time. Consequently, the PNAS study concludes that SMRs produce substantially greater volumes of spent nuclear fuel, intermediate-level waste and low-level waste. Each class demands its own containment regime: low-level waste can be managed in near-surface facilities, intermediate-level waste requires robust engineered storage, and spent fuel—by far the most radioactive—must be secured in deep, long-term repositories.[48] For instance, the PNAS study shows that, once normalised for energy output, certain SMR designs can generate two to thirty times the nuclear waste volume of a conventional reactor, producing significantly more material per megawatt-hour than traditional plants. Additionally, the PNAS study also finds that SMR fuel achieves a lower burnup, leaving higher concentrations of fissile uranium and plutonium in spent assemblies. That residual material prolongs decay heat and elevates the chance of unintended chain reactions (or *recriticality*) in storage. To manage these risks, waste must be housed in larger, more sophisticated facilities equipped with enhanced heat removal systems, shielding and continuous monitoring—driving up both capital and operational costs and extending environmental liabilities.[49]

Further complicating the issue, the PNAS study indicates that many advanced SMR concepts—such as sodium-cooled fast reactors and molten-salt reactors—employ unconventional coolants and fuels that complicate waste management.[50] Instead of uranium

[46] Lindsay M Krall, Allison M Macfarlane and Rodney C Ewing, 'Nuclear Waste from Small Modular Reactors' (2022) 119 Proceedings of the National Academy of Sciences e2111833119.
[47] ibid.
[48] ibid.
[49] ibid.
[50] ibid.

dioxide fuel clad in corrosion-resistant zirconium, these designs use molten salts (stable at high temperatures but highly corrosive), liquid sodium (an efficient but pyrophoric coolant that reacts violently with air or water) or graphite moderators (pure carbon that becomes radioactive carbon-14 over thousands of years). Each material stream demands bespoke treatment, conditioning and disposal solutions.[51] Not surprisingly, these materials, according to the PNAS study, introduce entirely new categories of nuclear waste, requiring specialised processing and disposal facilities that do not currently exist on a commercial scale in the UK.[52]

The concerns raised in the PNAS study regarding SMRs and nuclear waste are largely echoed in other studies specific to the context of Canada[53] and Finland,[54] in a report by the International Energy Forum,[55] and by the UK's Committee on Radioactive Waste Management (CoRWM). [56] For that matter, the CoRWM goes further than the PNAS study and warns in its 2024 report that[57] certain SMR waste streams may not be suitable for disposal in a Geological Disposal Facility (GDF) without further, significant treatment or processing; a GDF, which the UK does not yet possess, is a deep underground repository specifically designed to contain and isolate high-level radioactive waste for thousands of years to prevent it from posing a risk to human health and the environment.[58] As it notes:

> It is not necessarily the case that all types of spent fuel and radioactive waste will be suitable for disposal in a geological disposal facility (GDF), at least without potentially difficult prior treatment processes. *Some may simply not be able to achieve the necessary state of passive safety required in a GDF* as currently planned, in which case other new options will have to be identified, which may involve treatment or conditioning and which could be expensive, complex and uncertain. (My emphasis)

[51] ibid.

[52] Stephen KC Tromans, Claire Corkhill and Malcolm Joyce, 'Development of Small Modular Reactors and Advanced Modular Reactors – Implications for the Management of Higher Activity Wastes and Spent Fuel' (Committee on Radioactive Waste Management (CoRWM) 2024).

[53] Xu and others (n 38); C Badke and P McClelland, 'Small Modular Reactors in Canada: Planning for Waste from the Outset-19254' (WM Symposia, Inc, PO Box 27646, 85285-7646 Tempe, AZ (United States) 2019).

[54] Keto and others (n 38).

[55] Boyuan Gao and others, 'Nuclear Small Modular Reactors: Key Considerations for Deployment' (International Energy Forum 2024) <[Include URL if available]>.

[56] Tromans, Corkhill and Joyce (n 52).

[57] ibid.

[58] ibid.

CoRWM is, therefore, raising three major concerns. Firstly, some of this new waste might not achieve the "passive safety" conditions required for geological disposal. In other words, it might be too chemically reactive, unstable, or prone to unwanted physical or radiological behaviour even in deep underground storage. Secondly, if this waste is to be made suitable for geological disposal, it could require extensive pre-treatment, processing, or conditioning (the process of stabilising radioactive waste by converting it into a chemically and physically stable form, often through vitrification, encapsulation in cement or synthetic materials, or chemical transformation to reduce reactivity so that it remains safe for long-term storage and disposal)—potentially involving costly and *technically uncertain* processes that do not currently exist or at scale. Thirdly, if no viable way is found to condition some of this waste for geological disposal, then the UK may need to develop an entirely new disposal method, separate from the planned GDF, to deal with these new waste streams. In other words, what the CoRWM is saying is that some of the waste from SMRs might be too dangerous, unstable, or reactive to bury underground as planned. If this is true, the UK would need to either find expensive and complex ways to make it suitable for disposal—or invent an entirely new way to get rid of it.

Even where the current, candidate UK SMR designs—Rolls-Royce, GE Hitachi BWRX-300, and Holtec—are based on light water reactor (LWR) technology, CoRWM's report makes clear that substantial regulatory, technical, and financial uncertainties persist. That is to say, these are not resolved merely by technological similarity to existing PWRs, nor by progress through early GDA steps. In that, CoRWM acknowledges that such designs fall nearer to the higher end of the technology readiness level (TRL) scale for disposability—especially compared to AMRs—but emphasises that several unresolved variables remain key even for these "less exotic" reactors. These variables include reactor operation, refuelling strategy, materials selection, burnup variability, and post-discharge storage requirements.[59]

In that, even for reactors that closely resemble existing light water reactor (LWR) designs, such as the Rolls-Royce SMR, the CoRWM report cautions that key uncertainties remain regarding the waste these systems will produce. While their similarity to conventional pressurised water reactors (PWRs) gives them a relatively higher level of readiness for geological disposal, CoRWM stresses that waste disposability cannot be assumed solely on this

[59] Committee on Radioactive Waste Management (CoRWM), 'Development of Small Modular Reactors and Advanced Modular Reactors – Implications for the Management of Higher Activity Wastes and Spent Fuel' (2024) 25–27.

basis. [60] What matters is not just the fuel type but how the reactor is actually designed, operated, and refuelled in practice. Factors such as the frequency of refuelling, the level of uranium enrichment, and the amount of energy extracted from the fuel (known as burnup) directly affect how much radioactive heat (decay heat) the spent fuel produces, how long it must cool before disposal, and how densely it can be packaged. These in turn determine how much space is needed in a Geological Disposal Facility and how much it will cost. CoRWM notes that while the Rolls-Royce design is similar to LWR designs, the lack of publicly available data on fuel cycle characteristics—such as burnup profiles, enrichment levels, and the types of materials used inside the reactor—makes it difficult to assess whether the waste it generates will fit within the UK's planned GDF design.[61] Without this information, regulators cannot determine how much space each waste package will require, how long interim storage will be necessary, or what additional safeguards might be needed. In simple terms, even familiar reactor designs can produce unfamiliar waste risks if operational details are not disclosed and optimised early. CoRWM's core point is that assessing the safety, cost, and feasibility of long-term waste disposal for SMRs requires detailed technical data that many developers have not yet provided—and until this is addressed, the long-term viability of these technologies remains an open question. [62]

In addition, the report identifies three core technical concerns related to how spent nuclear fuel from SMRs is stored in the years or decades before permanent disposal—concerns that are not limited to advanced or chemically complex AMRs, but also apply to small modular reactors (SMRs) based on conventional light water reactor (LWR) technology, such as those proposed in the UK. First, a key issue is decay heat—the residual heat that continues to be generated by spent fuel even after the reactor has been shut down. When this decay heat is elevated—whether because the fuel has been used for longer periods (higher burnup), contains more fissile material (higher enrichment), or is replaced in large batches rather than incrementally (batch-refuelling strategies)—the fuel must be kept in wet storage pools (water-cooled holding tanks) for longer periods before it can safely be moved to dry cask storage (sealed, shielded containers). This prolonged cooling requirement increases risks of water leakage or mechanical failure, and it also requires more space and ongoing operational oversight at reactor sites.[63]

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[60] ibid 32–33.
[61] ibid 33.
[62] ibid 20–21, 31.
[63] ibid 33.

Second, these higher heat levels, along with changes in the physical structure of the fuel (geometry) and its radioactive makeup (isotopic composition), affect how much fuel can be safely stored in each dry cask. [64] Fewer fuel assemblies can be loaded per container to stay within safety limits for temperature and radiation. As a result, more casks are needed, which increases the physical size and complexity of the on-site storage areas. These casks must also be spaced further apart to avoid hotspots—areas of excessive heat or radiation—which further increases land use and design complexity.

Third, the report raises concerns about material-specific corrosion and degradation. For example, graphite, used in some high-temperature reactors as a moderator to slow neutrons, and certain metallic alloys used in SMRs, can deteriorate over time when exposed to moisture or residual heat.[65] This degradation could compromise the integrity of the containers and complicate inspections and maintenance. CoRWM also emphasises the problem of fuel heterogeneity—meaning that even among so-called conventional SMRs, different designs can produce different types of waste, with varying cooling needs and packaging formats. This diversity requires ongoing tracking, monitoring, and sometimes repackaging of spent fuel, adding logistical burdens and increasing long-term storage complexity—potentially for several decades.[66]

6. THE PERPETUAL INTERIM: DELAYS, DETERIORATION, AND THE UK'S NUCLEAR STALEMATE

All of this is particularly concerning given that many of the UK's nuclear waste storage facilities, including those at Sellafield, were constructed between the 1950s and 1970s and were not designed for indefinite containment.[67] These legacy storage facilities were initially conceived as interim or medium-term repositories intended to hold radioactive waste only until a national Geological Disposal Facility was commissioned. However, decades later, no such facility exists, necessitating prolonged reliance on aging infrastructure that was not engineered to meet modern containment, shielding, and safety standards over extended timescales.[68] The

[64] ibid 35.
[65] ibid 27–28, 33.
[66] ibid 36–37.
[67] Lorraine Chiwenga, 'Nuclear New Build Renaissance, Decommissioning and Radiological Protection in the UK: Legal and Regulatory Framework'.
[68] National Audit Office, Department for Energy Security & Net Zero, and Nuclear Decommissioning Authority (n 3).

sustained use of these aging structures presents increasing radiological, environmental, and structural integrity risks, with multiple regulatory bodies and investigative reports highlighting significant degradation, containment challenges, and escalating hazards associated with long-term interim storage.

For example, in 2023, a year-long *Guardian* investigation (dubbed "Nuclear Leaks")[69] obtained internal documents warning of "cumulative risk" from worsening safety conditions at Sellafield, the UK's largest nuclear waste site. The investigation revealed that one of the most hazardous structures at Sellafield, the Magnox Swarf Storage Silo (MSSS), a legacy waste storage facility containing highly radioactive intermediate-level waste (ILW) primarily in the form of Magnox fuel cladding debris (the metallic casings that once encased uranium fuel rods in Magnox reactors, which became highly radioactive through prolonged exposure to the reactor's neutron flux and were removed and stored as waste after the fuel was used), has been experiencing sustained leakage of radioactive effluent at a rate of up to 2.5 cubic metres per day since at least 2020. This leak, according to official documents allegedly seen by the *Guardian*, could have "potentially significant consequences" for groundwater contamination if it worsens, and the full extent of the risk is unclear.

Furthermore, the *Guardian* investigation disclosed that structural degradation has been identified in the B30 pond, a legacy open-air spent fuel storage facility containing highly radioactive sludge, corroded nuclear fuel debris, and miscellaneous reactor waste materials. These findings have exacerbated concerns over escalating contamination risks. Sellafield's management has, apparently, faced persistent challenges in fully characterising the extent of structural degradation within its legacy waste storage facilities. Regulatory authorities have, according to the *Guardian*, also acknowledged that assessments of facility integrity and containment stability rely predominantly on computational modelling and extrapolated risk projections rather than direct empirical measurements, due to the high radiation fields that prevent close inspection and in situ monitoring. This reliance on indirect methodologies introduces significant uncertainty in evaluating the long-term structural resilience of key waste storage units. These unresolved containment risks have raised international alarm, prompting diplomatic concerns among officials from the United States, Norway, and Ireland, who have

[69] Anna Isaac and Alex Lawson, 'Revealed: Sellafield Nuclear Site Has Leak That Could Pose Risk to Public' *The Guardian* (5 December 2023) <https://www.theguardian.com/business/2023/dec/05/sellafield-nuclear-site-leak-could-pose-risk-to-public> accessed 7 March 2025.

privately warned that the deteriorating condition of Sellafield's nuclear waste infrastructure, compounded by insufficient transparency in risk assessment and mitigation efforts, pose an international safety concern. Norwegian officials, in particular, have, according to the *Guardian*, expressed fears that an accident at Sellafield could release a radioactive plume that would drift over Scandinavia, with significant risks to agriculture, food production, and the environment. The *Guardian* also found that internal risk reports identify more than 100 serious safety concerns at the site, including deficiencies in fire protection systems, a lack of trained nuclear safety personnel, and an increasing number of radiation exposure incidents.

The UK's National Audit Office (NAO) report (2024)[70] corroborates many of the concerns raised in *The Guardian's* "Nuclear Leaks" investigation, particularly regarding aging infrastructure, escalating risks, and delays in decommissioning at Sellafield.[71] For example, the NAO confirms that many of Sellafield's legacy waste storage facilities exhibit significant structural degradation and ongoing containment vulnerabilities due to prolonged exposure to radiological, chemical, and environmental stressors beyond their originally intended operational lifespan. The Magnox Swarf Storage Silo (MSSS), identified by *The Guardian* as a leaking structure, is still releasing 2,100 litres of contaminated water per day (this is slightly less than the 2.5 cubic metres per day the Guardian reported but confirms an ongoing leak).[72] This leak, according to the NAO, is expected to continue until at least the late 2040s or early 2050s. In addition, the First-Generation Magnox Storage Pond (FGMSP) and Pile Fuel Cladding Silo (PFCS) are still classified as "intolerable risks," with retrieval milestones slipping by 6 to 13 years compared to 2018 estimates.

Moreover, the total cost of decommissioning Sellafield has risen to £136 billion, an 18.8% increase since 2019. And, because of this, the NAO now expects the full decommissioning of Sellafield to last until 2125—*meaning that nuclear waste will remain stored at the site for another 100 years*—at an annual cost of *£2.7 billion (in total spending)* with an estimated total cost of decommissioning Sellafield at £136 billion (undiscounted, 2023-24 prices).[73] This means that the ongoing costs of operating the Sellafield site are significant, with much of the funding going toward maintaining deteriorating infrastructure, waste storage, and security.

[70] National Audit Office, Department for Energy Security & Net Zero, and Nuclear Decommissioning Authority (n 3).
[71] ibid.
[72] ibid.
[73] ibid.

Furthermore, much like the *Guardian* report, the NAO report identifies Sellafield's persistent issues with managing conventional safety hazards and suggests that there are systemic failures in learning from past mistakes. [74] It notes that the site has faced repeated problems with asbestos exposure, inadequate fire protection, and Legionella contamination, which have recurred across multiple areas of the facility.[75]

However, what is especially concerning is the point the NAO makes about the long-term sustainability of Sellafield's waste processing infrastructure, particularly in relation to its Waste Vitrification Plant (WVP) and its ability to process Highly Active Liquor (HAL) beyond 2039.[76] A WVP is a specialised facility at Sellafield designed to immobilise highly radioactive liquid waste by converting it into a stable, solid glass form through a process known as vitrification.[77] This is achieved by mixing the waste with glass-forming materials at high temperatures, which produces a durable, glass-like substance that can be safely stored over long periods. The vitrification process is essential for reducing the long-term risks posed by liquid high-level waste, as it ensures that the waste is contained in a form that is resistant to leaching, dispersal, and environmental contamination. In this context, Highly Active Liquor (HAL), on the other hand, refers to a concentrated, highly radioactive liquid waste produced from the reprocessing of spent nuclear fuel.[78] It contains a complex mix of fission products and actinides—one of the most hazardous forms of nuclear waste. HAL requires continuous cooling and robust containment, as any failure to process or store it safely could lead to severe environmental and radiological hazards.[79] The vitrification of HAL into solid glass reduces its mobility and mitigates the risk of leaks or spills that could otherwise result in long-term contamination. Thus, put plainly, the WVP is a facility that takes highly radioactive liquid waste and turns it into a solid, glass-like material so that it can be safely stored for the long term. HAL is a dangerous, radioactive liquid left over from recycling used nuclear fuel, and if not properly contained or processed, it could leak or cause serious contamination.

The strategic tolerance—i.e., the maximum acceptable time frame and operational capacity within which the facility must complete its waste processing before infrastructure limitations, safety risks, or regulatory constraints become critical— set for the WVP requires it to process

[74] ibid.
[75] ibid.
[76] ibid 30.
[77] ibid.
[78] ibid.
[79] ibid.

130 cubic metres (m³) of HAL per year to complete its mission by 2039.[80] However, in recent years, the plant has struggled to maintain this processing rate: In 2023-24, it processed only 100m³—falling short of the target and between 2020-2023, the average annual throughput was just 39m³ per year, which is less than one-third of the required rate. Meaning that, according to NAO, "it will be increasingly hard for Sellafield to maintain the necessary infrastructure beyond this point."[81] That is to say, the plant may not be operationally viable beyond 2039, meaning Sellafield could lose its ability to process highly active liquid waste if the facility deteriorates or if technical failures occur. Relatedly, if HAL processing is not completed by 2039, Sellafield may face serious challenges in safely managing this high-level waste, potentially requiring costly new infrastructure to replace or supplement the WVP.

In addition, what the NAO is also suggesting is that these risks increase over time ("it will be *increasingly hard* for Sellafield to maintain the necessary infrastructure beyond this point" [my emphasis])[82]: Even if the plant continues operating beyond 2039, maintenance will become increasingly difficult, and the likelihood of failures, inefficiencies, or expensive repairs will grow. All of which is significant because failure to complete HAL vitrification in time could result in the need for a new, high-cost processing facility, potentially costing hundreds of millions of pounds. And, interruption or inefficiency in waste vitrification could increase the risk of long-term environmental contamination or safety hazards if liquid waste storage becomes unstable.[83] And, in a worst case scenario ("beyond this point")[84], regulatory and safety constraints may force a shutdown of key facilities if they degrade beyond acceptable safety limits.

All of this is compounded by another significant conclusion of NAO, namely: the high uncertainty surrounding Sellafield's long-term waste storage and disposal plans, including the significant delays in the Geological Disposal Facility. That is, the GDF—which is supposed to be the long-term solution for storing the UK's most hazardous nuclear waste—will not be operational until the 2050s "at the earliest";[85] meaning that even this timeline is uncertain and could be subject to further delays, as the NAO does not rule out the possibility that the facility may take even longer to become operational, given the historical setbacks, planning

[80] ibid.
[81] ibid.
[82] ibid.
[83] ibid.
[84] ibid.
[85] ibid 41.

complexities, and community opposition that have plagued the project.[86] This has significant implications. In that, high-level nuclear waste was supposed to be transferred to the GDF so as to reduce the risks of long-term storage at Sellafield. Because the GDF is not ready, Sellafield may find itself in the position where it has no choice but to continue housing nuclear waste well beyond its originally planned timeframe. This increases the risks of leaks, structural failures, and other safety hazards as buildings deteriorate further and potential issues with the Waste Vitrification Plant materialises.

In addition, the UK has been debating where to build the GDF for decades—since the 1970s.[87] No final site has been confirmed, and opposition from local communities has slowed progress. A notable failure occurred in 2013 when Cumbria County Council vetoed preliminary work on an underground waste repository, citing concerns about geological suitability and community opposition.[88] This left the UK "back to square one"[89] in finding a willing host community.[90] A new consent-based siting process began in 2017, yet as of 2025 no site has been selected. The NDA's Nuclear Waste Services is in talks with three local areas, but even after a location is selected, construction could take another 20–30 years.[91] Meaning that, by the time the GDF is ready, Sellafield will have been storing nuclear waste for more than a century beyond its intended lifespan.

And, without the GDF, the UK must continue investing in temporary waste storage solutions at Sellafield, which are both expensive and increasingly difficult to maintain. By which I mean, interim storage is riskier because many of the temporary containment structures were not built for multi-decade storage. If the GDF is delayed even further, Sellafield may be forced to expand storage capacity, adding billions to long-term waste management costs. For

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[86] Chiwenga (n 67); National Audit Office, Department for Energy Security & Net Zero, and Nuclear Decommissioning Authority (n 3).

[87] WF Lawless and others, 'Public Consent for the Geologic Disposal of Highly Radioactive Wastes and Spent Nuclear Fuel' (2014) 71 International Journal of Environmental Studies 41; Catharina Landstrom and Stewart Kemp, 'The Power of Place: How Local Engagement with Geological Disposal of Radioactive Waste Re-Situated Technoscience and Re-Assembled the Public' (2020) 33 Science & Technology Studies 36; Ray Kemp, 'Why Not in My Backyard? A Radical Interpretation of Public Opposition to the Deep Disposal of Radioactive Waste in the United Kingdom' (1990) 22 Environment and Planning A 1239.

[88] Landstrom and Kemp (n 87).

[89] Martin Wainwright and Terry Macalister, 'Nuclear Expansion Plan Thwarted after Cumbria No Vote to Underground Store' *The Guardian* (30 January 2013) <https://www.theguardian.com/environment/2013/jan/30/nuclear-expansion-thwarted-cumbria-no> accessed 7 March 2025.

[90] ibid.

[91] National Audit Office, Department for Energy Security & Net Zero, and Nuclear Decommissioning Authority (n 3) 41.

example, the NAO report notes that building, maintaining, and securing these temporary waste storage facilities comes at a massive cost, estimated to be between £500 million and £760 million every 10 years.[92] This cost does not, of course, include the long-term operational expenses of keeping Sellafield running, which already exceeds £2.7 billion per year.[93]

7. OPTIMISTIC, PESSIMISTIC, OR MODERATE? MAPPING THE FUTURE OF AI GROWTH ZONES AND SMR DEPLOYMENT

Given the UK's push to integrate SMRs into AI Growth Zones while concurrently facing unresolved nuclear waste management challenges, several possible futures emerge. In this first, optimistic scenario, the UK government succeeds in aligning front-end deployment with back-end disposal, enabling SMRs to reliably power AI infrastructure without triggering long-term policy or environmental liabilities. Here, regulatory sequencing proceeds without major disruption. The Generic Design Assessment (GDA) process advances on schedule for the leading SMR candidates—Rolls-Royce, GE Hitachi, and Holtec—with Rolls-Royce's 470 MWe pressurised water reactor completing Step 3 and receiving a Design Acceptance Confirmation (DAC) and Statement of Design Acceptability (SoDA) by the late 2020s. The Justification process under the Justification of Practices Involving Ionising Radiation Regulations 2004 (SI 2004/1769) concludes that LWR-based SMRs provide a net societal benefit, including emissions reduction and energy stability for AI clusters. In parallel, environmental permits under the Environmental Permitting (England and Wales) Regulations 2016 (SI 2016/1154) are granted without significant delay, as developers integrate Best Available Techniques (BAT) at the design stage—including conditioning strategies and site-wide safety cases—into their regulatory submissions. The result is a compressed, legally robust pathway from design to operation.

Waste conditioning and compatibility are proactively addressed. Developers provide early fuel cycle data, material inventories, and burnup modelling to the Environment Agency and the Committee on Radioactive Waste Management (CoRWM), allowing pre-approval of conditioning strategies tailored to Geological Disposal Facility parameters. Only LWR-type SMRs are pursued for near-term deployment, thereby excluding chemically exotic designs

[92] ibid 40.
[93] ibid 5.

(e.g., molten salt or sodium fast reactors) that would require new waste processing methodologies. At select Growth Zones, Rolls-Royce integrates modular encapsulation units or vitrification support infrastructure to condition spent fuel at or near reactor sites, reducing dependence on Sellafield and minimising transport-based risk.

Interim storage capacity is expanded and stabilised. Sellafield's legacy infrastructure is de-risked through targeted reinforcement and monitoring upgrades, and the Waste Vitrification Plant (WVP) restores and maintains throughput at 130 m^3 of Highly Active Liquor (HAL) per year by 2027 and avoids the accumulation of untreated liquid waste. In parallel, a dedicated interim storage facility is commissioned specifically for SMR waste streams. These facilities use GDF-compatible casks and modular dry storage systems designed to accommodate the higher decay heat and neutron activation characteristics of LWR-derived fuel. Conditioning, storage, and canister materials are harmonised to meet the passive safety requirements of a future GDF and, as such, eliminates the need for repackaging and reducing long-term cost exposure.

Political consent and siting challenges are overcome. By 2032, the government secures both geological validation and community agreement for a GDF site under the revised consent-based siting framework. The process succeeds through a combination of transparency, economic incentive schemes, and early community engagement. Simultaneously, inland siting of SMRs in AI Growth Zones faces minimal opposition due to clear criteria in the updated National Policy Statement for Nuclear Power Generation (EN-7) and effective local consultation. The pilot project at Culham demonstrates the viability of co-locating SMRs with high-performance compute infrastructure, with no major environmental or planning challenges arising during the DCO process.

AI deployment proceeds at a realistic, scalable pace. Rather than relying solely on nuclear, AI Growth Zones adopt mixed energy provisioning strategies. SMRs provide stable baseload power at priority sites, but AI developers incorporate grid redundancy and renewable integration into their system designs. Deployment scales incrementally: Culham achieves 100–500 MWe capacity, followed by phased expansion in other zones, proportionate to licensing timelines and backend infrastructure maturity. This approach avoids overcommitment to any single energy modality and preserves flexibility in the face of shifting waste governance or geopolitical constraints.

In this best-case outcome, the integration of SMRs into AI Growth Zones becomes a signature success of UK industrial and energy policy. Nuclear waste risks are not eliminated, but they are rendered institutionally and technically manageable through early-stage coordination, modular infrastructure investments, and selective technology constraints. AI infrastructure is expanded without compromising long-term safety or economic sustainability, and the UK establishes a credible model of low-carbon compute provisioning consistent with secure waste governance.

7.1 Pessimistic Scenario: Waste Crisis Triggers Strategic Reversal

In this extreme trajectory, the UK's SMR–AI integration strategy unravels as long-deferred backend liabilities escalate into a structural crisis. Failures in waste conditioning, interim containment, and vitrification throughput trigger systemic breakdowns that halt further SMR deployment and undermine the credibility of the AI Growth Zone policy model.

The regulatory system seizes under backend failure. By the mid-2030s, the Waste Vitrification Plant (WVP) at Sellafield becomes non-functional. Despite its strategic tolerance target of 130 m^3/year, throughput from 2020–2024 averages just 39 m^3/year. Efforts to restore performance fail, and HAL accumulation accelerates beyond manageable levels. Without scalable vitrification or alternative containment, Highly Active Liquor reaches critical thresholds, forcing emergency suspension of WVP operations. No replacement facility is in place, and emergency contingencies require rapid reallocation of funds, disrupting other nuclear infrastructure programmes.

Interim storage infrastructure destabilises. Dry cask arrays—both at Sellafield and across early SMR sites—experience thermal runaway risks and unanticipated material degradation. Waste streams containing high-burnup fuel, graphite moderators, and exotic alloys begin to exhibit corrosion, gas generation, and structural instability under storage conditions. In the absence of conditioning protocols, regulators issue moratoria on new site authorisations and suspend active SMR licensing applications. The *Office for Nuclear Regulation* (ONR) and *Environment Agency* (EA) publicly confirm that no SMR design under assessment has demonstrated compliance with BAT or GDF compatibility under the current regulatory framework.

Legacy infrastructure fails. Structural degradation at Sellafield accelerates. The Magnox Swarf Storage Silo (MSSS), the Pile Fuel Cladding Silo (PFCS), and the First-Generation Magnox Storage Pond (FGMSP) each exhibit containment breaches or structural collapse, releasing radioactive materials into the environment. The B30 pond suffers wall degradation resulting in effluent discharge into surrounding groundwater. These failures trigger international safety alarms and diplomatic escalations, with Norwegian and Irish officials raising formal objections regarding cross-border contamination risks.

GDA and planning approvals stop. No SMR design completes GDA due to unresolved reactor operation uncertainties and unprocessable waste profiles. The Planning Inspectorate declines to recommend inland DCOs under the *Planning Act 2008*, citing cumulative radiological risk, GDF failure, and inadequate storage capacity. CoRWM concludes that waste from certain SMRs—particularly those using molten salts, graphite, or sodium coolant—cannot be integrated into the UK's planned GDF and would require bespoke disposal systems. This conclusion triggers regulatory deadlock and investor flight from the UK nuclear market.

Political and public opposition intensifies. The failure of vitrification, the indefinite delay of the GDF, and visible degradation at Sellafield provoke intense media scrutiny and political backlash. Civil society organisations call for a moratorium on all nuclear licensing, and public inquiries report years of institutional deferral and underinvestment in backend infrastructure. Parliament initiates emergency reviews of SMR authorisation powers, and the government officially suspends the SMR–AI coupling strategy by the late 2030s.

AI deployment re-orients towards conventional power. With nuclear co-location no longer viable, AI Growth Zones are reconfigured to operate on mixed renewable inputs, gas backup, and imported baseload capacity. SMRs are excluded from the revised energy strategy. Compute capacity expands more slowly, and capital costs rise due to unstable power availability. The UK loses competitiveness to jurisdictions with stable SMR-backed AI expansion strategies—such as France and the United States. The AI Growth Zone model, once framed as a flagship industrial policy, is abandoned in favour of piecemeal grid expansion. Meanwhile, Sellafield becomes a permanent site of national liability—requiring decades of emergency investment, international oversight, and reputational repair.

7.2 Realistic Scenario: Constrained Success with Structural Residues

The most plausible trajectory for the UK's SMR–AI integration strategy by 2030, I contend, reflects constrained success: a partial realisation of front-end deployment objectives accompanied by the entrenchment of unresolved backend liabilities. This scenario neither collapses under infrastructural failure nor achieves seamless regulatory coordination. Instead, it results in a legally functional but materially and temporally stretched model, characterised by selective progress, regulatory improvisation, and deferred resolution of critical waste challenges.

On the front end, the regulatory framework continues to function within its current legal and institutional parameters. The Rolls-Royce SMR design progresses through Step 3 of the Generic Design Assessment (GDA), ultimately securing a Design Acceptance Confirmation (DAC) and Statement of Design Acceptability (SoDA) by 2028. This enables it to move toward site-specific licensing, subject to a Nuclear Site Licence under the Nuclear Installations Act 1965 and environmental permitting under the Environmental Permitting (England and Wales) Regulations 2016. Although environmental approvals are eventually granted, they are delayed by protracted queries from the Environment Agency regarding decay heat thresholds, corrosion behaviour, and waste packaging compatibility with a future Geological Disposal Facility. These approvals are secured in part due to intensive back-and-forth between developers and regulators, during which interim conditioning proposals are accepted as provisional compliance.

Development Consent Orders (DCOs) under the Planning Act 2008 are granted for pilot SMR–AI co-location projects, notably in Culham and one other Growth Zone with permissive local conditions. However, these applications face objections concerning interim waste storage, particularly around site layout, land use, and futureproofing. To resolve these objections, the government obligates the inclusion of spatial buffers and minimum storage capacity guarantees within the DCO framework. These adaptations extend construction timelines and add cost, but do not derail the pilot projects.

Meanwhile, the backend infrastructure remains strained. Sellafield's Waste Vitrification Plant (WVP) continues to operate below its required throughput. By 2030, it averages approximately 70–90 m^3/year of Highly Active Liquor (HAL) processing, falling short of the strategic 130 m^3/year target. This results in a growing inventory of untreated HAL and increasing pressure to retrofit the plant's ageing systems. A replacement vitrification facility has been proposed but not yet funded or designed. As a result, Sellafield's interim containment burden deepens, and regulatory supervision intensifies, with the Office for Nuclear Regulation (ONR) requiring enhanced inspection protocols and issuing routine improvement notices. These interventions stabilise but do not resolve the site's long-term vulnerabilities.

Efforts to advance GDF development proceed, but no site is confirmed by 2030. The siting process, led by Nuclear Waste Services under a consent-based framework, continues negotiations with shortlisted communities, but geological investigations and stakeholder consultations remain incomplete. As a result, no GDF-related construction begins during this period, and disposal timelines are deferred into the 2050s or later. Regulators, therefore, adopt an adaptive licensing posture, acknowledging the absence of a final repository by issuing conditional permits for interim storage—provided that canisters, materials, and handling protocols remain compatible with evolving GDF design envelopes.

SMR developers respond by investing in modular interim storage facilities with dry cask systems capable of accommodating higher decay heat and variable isotopic compositions. However, spatial constraints and shielding requirements result in relatively inefficient land use. These interim sites are licensed as part of the DCO package but lack long-term conditioning strategies. While corrosion-resistant alloys and passive cooling systems are introduced, there is no industry-wide solution for managing heterogeneous waste profiles, particularly if repackaging is required. The resulting waste governance structure is thus fragmented: functionally regulated but materially unstable.

By 2030, the UK has achieved limited SMR deployment aligned to the AI Growth Zone model. The Culham site reaches approximately 100 MWe installed capacity, and site preparation is underway at a second Growth Zone. However, scale-up beyond these pilots is constrained by three converging factors: (1) conditional regulatory approvals based on temporary backend arrangements; (2) incomplete waste conditioning strategies; and (3) rising cost projections tied to interim storage expansion and Sellafield maintenance. These constraints lead policymakers to pursue a diversified energy provisioning model in subsequent Growth Zones, combining SMRs with grid reinforcement and renewables to hedge against backend delays.

Public and investor confidence remains cautious. While political commitment to nuclear–AI integration is not withdrawn, it is tempered by growing awareness of the unresolved waste issue and increasing scrutiny of Sellafield's long-term viability. Civil society pressure intensifies following media coverage of Sellafield degradation and delays in vitrification. In response, government repositions SMRs as one of several power options for AI Growth Zones, rather than the exclusive solution initially envisioned.

In this scenario, the UK's strategy achieves qualified progress but leaves critical waste management issues structurally unaddressed. Interim storage becomes institutionalised, the GDF remains deferred, and backend liabilities accumulate in legal and material form. The model functions, but its long-term sustainability remains conditional upon future breakthroughs in waste conditioning, site licensing, and public consent. The UK avoids crisis—but does so by embedding a new status quo of provisional containment.

8. CONCLUSION: AI, NUCLEAR ENERGY, AND WASTE – WHY INFRASTRUCTURE AND DISPOSAL MUST COME FIRST

Thus, these scenarios make one thing clear: any effort to integrate nuclear energy into AI infrastructure—whether in the UK or elsewhere—must grapple not only with questions of licensing and deployment, but with the juridical, temporal, and material instabilities of nuclear waste governance. What we are seeing in the UK is not *yet* a failure, nor a success, but the early crystallisation of a structural mismatch: between a political and regulatory system that is accelerating front-end approvals to deliver AI capacity, and a backend infrastructure of waste management that remains deferred, degraded, and in key respects technically unresolved. If SMRs are to power the AI economy of the future, their waste must become part of the governance conversation now—not after reactors are built, but before their viability is presumed. As legal scholars, we should resist the tendency to treat nuclear waste as a purely technical or post-hoc issue. It is, in every sense, constitutive of the energy regimes we are building—and its legal treatment will shape whether those regimes are stable, scalable, or ethically tenable.

This presents both a challenge and an opportunity for our field. The current literature on AI regulation has concentrated on rights, risk, and algorithmic accountability. Yet we are arguably missing a deeper inquiry into the infrastructural and legal-material architectures that make AI possible in the first place. What the SMR–AI convergence demands is a shift in our gaze—from front-end governance to backend liabilities, from algorithmic ethics to the slow time of decay heat and deferral. It asks us to think not only about regulation in the abstract, but about the physical sites, policy assumptions, and juridical temporalities through which AI is being materially sustained. In doing so, we open a critical space for socio-legal scholarship to intervene in shaping future energy infrastructures—not as neutral supports for innovation, but as contingent, contested, and profoundly consequential legal artefacts. If we fail to ask these questions now, we may inherit systems whose liabilities exceed their benefits and whose governance is reactive rather than anticipatory.