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VOLUNTARY INDUSTRY INITIATIVES IN FRONTIER AI GOVERNANCE: LESSONS FROM AVIATION AND NUCLEAR POWER

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Voluntary Industry Initiatives in Frontier AI Governance: Lessons from Aviation and Nuclear Power

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Abstract

This paper examines the growing role of voluntary, industry-led safety initiatives in AI governance, focusing on their potential to mitigate risks in frontier AI systems. To explore this, the paper includes case studies from the aviation and nuclear power industries, where human safety is paramount and industry consortia have been instrumental in improving safety outcomes. The paper offers five key recommendations for AI industry consortia, including the Frontier Model Forum (FMF) and the U.S. AI Safety Institute Consortium (AISIC): facilitate anonymised incident monitoring systems, establish consensus-based minimum safety standards with regulator involvement, develop the capacity to investigate major AI incidents, encourage cross-industry cooperation beyond safety, and use peer-shaming to promote safety compliance. For national regulators, the paper recommends prioritising oversight of frontier AI and high-stakes applications while delegating lower-risk safety oversight functions to firms, and introducing stricter reporting requirements to curb the early mover advantage of frontier AI companies.

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Executive Summary

As voluntary, industry-led safety initiatives take on an increasingly central role in strategies to reduce risks from frontier AI systems, they deserve greater scrutiny. This paper addresses this need for scrutiny by examining two industries—aviation and nuclear power—where human safety is paramount and industry consortia have been key to improving safety outcomes. By examining these sectors, we demonstrate how voluntary safety initiatives can serve an important function in the governance of frontier AI systems, leveraging the expertise and resources of frontier AI firms to address emerging risks. With the recent formation of two AI industry consortia—the Frontier Model Forum (FMF) and the US AI Safety Institute Consortium (AISIC)—it is increasingly important to understand how voluntary safety initiatives can mitigate AI risks without imposing excessive burdens on firms.

This paper offers five recommendations for industry consortia, including FMF and AISIC, and two for national regulators, all aimed at enhancing frontier AI safety. These recommendations are based on eight lessons from voluntary safety measures in aviation (lessons 1–4) and nuclear power (lessons 5–8). Our analysis draws on regulatory documents, expert assessments of voluntary initiatives, industry reports, incident statistics, and case histories, allowing us to qualify and contextualise our findings for frontier AI governance.

	Recommendations for Industry Consortia	Supporting Lesson(s)
I	**Facilitate anonymised incident monitoring systems** Industry consortia should implement such a system to bring incident reporting practices in line with the standard in aviation and nuclear power. Frontier AI firms are most likely to participate in incident monitoring systems when these systems are anonymised and administered by a trusted third party.	1,8
II	**Establish consensus-based minimum safety standards, with the participation of AISIs and national regulators in working groups** AI industry consortia are well-placed to establish consensus-based minimum safety standards. By involving regulators and AI safety institutes (AISIs) in working groups and aligning these standards with national and international regulations, industry consortia can promote broad cross-industry adoption.	4,7
III	**Develop the capacity to investigate major AI incidents and recommend mitigations in response** AI industry consortia should develop incident investigation capacity in order to bring the sector in line with the safety standard in nuclear power and aviation.	8
IV	**Encourage cross-industry cooperation beyond safety** AI industry consortia should promote cooperation on topics beyond safety, such as cybersecurity, operational excellence, and novel model evaluations, in order to build the foundation for future safety initiatives that afford cross-industry benefits.	2
V	**Use peer-shaming to encourage safety compliance among AI firms** AI industry consortia should leverage peer-shaming—by ranking each firm's safety performance—to encourage firms to meet their consensus-based minimum safety commitments.	5

	Recommendations for National Regulators	Supporting Lesson(s)
VI	**Prioritise frontier AI and high-stakes oversight and delegate lower-risk safety functions to firms** Regulators should focus on direct oversight of frontier AI models and high-stakes applications, while delegating lower-risk safety functions to firms where incentives align with safety, ensuring sufficient capacity to monitor the most critical areas.	3
VII	**Introduce stricter reporting requirements in order to mitigate the early mover advantage of frontier AI firms** National regulators should introduce stricter reporting requirements for frontier AI firms in order to improve oversight and reduce reliance on voluntary industry initiatives in critical areas. This could include information around cybersecurity practices, organisational processes, and model design decisions.	6

Lessons from the Aviation Industry	
1	**Anonymised incident monitoring systems provided essential data to regulators and were acceptable to firms.** Incident monitoring systems like the IATA Safety Trend Evaluation and Data Exchange System (STEADES) provide critical safety data to regulators while minimising reputational and regulatory risks for airlines by anonymising reports, thereby encouraging voluntary participation.
2	**Two factors made the participation of airlines in voluntary safety initiatives more likely: (i) commercial incentives to cooperate on non-safety issues and (ii) opportunities to reduce regulatory burden.** Airlines were motivated to participate in the IATA Operational Safety Audit (IOSA) due to the commercial and reputational benefits of International Air Transport Association (IATA, an industry body) membership and because it provided an alternative to completing multiple overlapping audits across different jurisdictions.
3	**Outsourcing of safety oversight to firms allowed for striking improvements in aviation safety, despite a relative decline in regulatory funding.** A 96% decrease in the rate of fatalities was supported by outsourcing safety oversight to industry experts through systems like the Federal Aviation Administration's (FAA) designee program and the Continuing Analysis and Surveillance System (CASS), without an expansion of regulatory funding.
4	**Voluntary safety initiatives and national standards enforcement increased compliance with international standards.** The IATA's IOSA and FAA's International Aviation Safety Assessment (IASA) increased global compliance with the International Civil Aviation Organization's (ICAO, an international standards organisation) Standards and Recommended Practices (SARPs), filling the enforcement gap left by the ICAO's limited regulatory authority.

Lessons from the Nuclear Power Industry	
5	**Peer comparisons led to nuclear safety improvements.** The Institute of Nuclear Power Operations (INPO, an industry body) motivates firms to implement safety measures by assigning safety scores to each utility and presenting these rankings at exclusive executive conferences. This motivation is reinforced through an escalation process for noncompliance, including INPO leadership and other utilities' CEOs applying personal pressure on utilities to implement recommendations.
6	**Proactive voluntary safety initiatives from industry bodies went on to shape nuclear power regulation.** The INPO's close relationship with nuclear utilities enabled it to proactively implement credible safety measures, leading the Nuclear Regulatory Commission (NRC, a regulator) to endorse its training accreditation, incident data-sharing systems, and performance metrics.
7	**Nuclear industry safety groups created safety standards for management and operational processes.** The INPO addressed regulatory gaps in management and operational safety by developing and auditing standards around management structure and culture, and creating a system for monitoring incidents (Significant Event Evaluation and Information Network).
8	**Major nuclear power accidents caused significant increases in voluntary safety initiatives, coordinated by industry bodies.** The Three Mile Island accident led to the creation of the INPO and the adoption of industry-wide safety initiatives like the Significant Event Evaluation and Information Network (SEE-IN); the Chernobyl disaster spurred international collaboration, resulting in the formation of the World Association of Nuclear Operators (WANO), which implemented international peer evaluations and safety workshops.

Contents

List of Abbreviations

- AEC: Atomic Energy Commission
- AEA: Atomic Energy Act
- ACA: Aero Club of America
- AISIC: US AI Safety Institute Consortium
- ATOS: Air Transportation Oversight System
- ASAP: Aviation Safety Action Program
- ASRS: Aviation Safety Reporting System
- CAA: Civil Aeronautics Authority
- CASS: Continuing Analysis and Surveillance System
- FAA: Federal Aviation Administration
- FMF: Frontier Model Forum
- ICAO: International Civil Aviation Organization
- IATA: International Air Transport Association
- INPO: Institute of Nuclear Power Operations
- IOSA: IATA Operational Safety Audit
- IPP: International Participant Program
- ISARPs: IOSA Standards and Recommended Practices
- NIST: National Institute of Standards and Technology
- NEI: Nuclear Energy Institute
- NPRDS: Nuclear Plant Reliability Data System
- NRC: Nuclear Regulatory Commission
- OSHA: Occupational Safety and Health Administration
- SALP: Systematic Assessment of Licensee Performance
- SEE-IN: Significant Event Evaluation and Information Network
- STEADES: Safety Trend Evaluation and Data Exchange System
- TMI: Three Mile Island
- UN: United Nations
- WANO: World Association of Nuclear Operators

I Introduction

Frontier AI systems[1] are increasingly capable of solving complex problems across a wide range of domains, from resolving intricate software engineering issues in GitHub codebases[2] to scoring in the 62nd percentile on the US bar exam[3] and tackling high school competition-level maths problems.[4] As the compute required to train these models has grown 4–5x annually since 2012,[5] so have the concerns about their potential misuse,[6] failure in high-stakes applications,[7] and loss of control over autonomous agents.[8] This paper explores how voluntary, industry-led safety initiatives—similar to those in safety-critical industries like aviation and nuclear power—can mitigate emerging risks from frontier AI. As these systems are increasingly used in critical sectors,[9] the consequences of failure could be severe, leading us to classify frontier AI as a safety-critical technology—technologies with the potential to cause hundreds of deaths if they fail.

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[1] '[Highly] capable general-purpose AI models that can perform a wide variety of tasks and match or exceed the capabilities present in today's most advanced models.' See: U.K. DSIT, 'Capabilities and Risks from Frontier AI' (UK Department for Science, Innovation & Technology, October 2023), https://assets.publishing.service.gov.uk/media/65395abae6c968000daa9b25/frontier-ai-capabilities-risks-report.pdf.

[2] Carlos E. Jimenez et al., 'SWE-Bench: Can Language Models Resolve Real-World GitHub Issues?' (arXiv, 5 April 2024), https://doi.org/10.48550/arXiv.2310.06770; Carlos E. Jimenez et al., 'SWE-Bench', n.d., https://www.swebench.com/.

[3] Eric Martínez, 'Re-Evaluating GPT-4's Bar Exam Performance', *Artificial Intelligence and Law*, 2024, https://doi.org/10.1007/s10506-024-09396-9.

[4] OpenAI, 'Simple Evals Benchmark Results', OpenAI GitHub, 11 April 2024, https://github.com/openai/simple-evals#benchmark-results.

[5] Epoch AI, 'Machine Learning Trends', 11 April 2023, https://epochai.org/trends.

[6] Yoshua Bengio, et al., 'International Scientific Report on the Safety of Advanced AI - Interim Report' (UK Department for Science, Innovation & Technology, May 2024), https://assets.publishing.service.gov.uk/media/6716673b96def6d27a4c9b24/international_scientific_report_on_the_safety_of_advanced_ai_interim_report.pdf; Christopher A. Mouton, Caleb Lucas, and Ella Guest, 'The Operational Risks of AI in Large-Scale Biological Attacks: Results of a Red-Team Study' (RAND Corporation, January 2024), https://www.rand.org/pubs/research_reports/RRA2977-2.html.

[7] Bengio, et al., 'International Scientific Report on the Safety of Advanced AI - Interim Report'.

[8] Richard Ngo, Lawrence Chan, and Sören Mindermann, 'The Alignment Problem from a Deep Learning Perspective' (arXiv, 19 March 2024), https://doi.org/10.48550/arXiv.2209.00626.

[9] Including healthcare, transportation, and military operations. See: Thomas Davenport and Ravi Kalakota, 'The Potential for Artificial Intelligence in Healthcare', *Future Healthcare Journal* 6, no. 2 (2019): 94, https://doi.org/10.7861/futurehosp.6-2-94; Sikandar Khan, Adnan Adnan, and Naveed Iqbal, 'Applications of Artificial Intelligence in Transportation', in *2022 International Conference on Electrical, Computer and Energy Technologies (ICECET)*, 2022, 1–6, https://doi.org/10.1109/ICECET55527.2022.9872928; Adib Bin Rashid et al., 'Artificial Intelligence in the Military: An Overview of the Capabilities, Applications, and Challenges', *International Journal of Intelligent Systems* 2023, no. 1 (2023): 8676366, https://doi.org/10.1155/2023/8676366.

Since mid-2023, two major AI industry consortia have emerged to address these risks: the Frontier Model Forum (FMF) and the US AI Safety Institute Consortium (AISIC). FMF includes six leading AI firms—OpenAI, Meta, Microsoft, Amazon, Anthropic, and Google—focused on advancing frontier AI safety through collaborative research and responsible development practices.[10] AISIC, formed under the National Institute of Standards and Technology (NIST), is a voluntary group of over 280 organisations, including companies, academic institutions, and civil society groups, dedicated to developing science-based safety guidelines and fostering interdisciplinary collaboration to address AI's societal impacts.[11] These consortia represent a growing demand for voluntary, industry-led approaches to AI safety, leveraging the expertise and substantial resources of frontier AI firms.

This paper examines the potential for voluntary safety initiatives to enhance frontier AI governance. Drawing lessons from two safety-critical industries—aviation and nuclear power—where industry-led efforts have been pivotal in improving safety outcomes, we offer insights and recommendations for both AI industry consortia and national regulators. Our analysis draws on regulatory documents, expert assessments of voluntary initiatives, industry reports, incident statistics, and case histories, allowing us to qualify and contextualise our findings for frontier AI.

This paper is divided into two substantive case studies: the first tracks the evolution of airline cooperation in the US aviation industry since 1903, and the second illustrates the development of cooperation between US nuclear power firms since 1946. Each case study begins with a short history of the industry and provides explanatory figures related to important industry groups, national regulators, and international organisations. Each history section is followed by key lessons from the case studies, which include analysis of their relevance to frontier AI safety and propose actionable recommendations for both industry consortia and national regulators. These lessons and recommendations from both case studies are summarised in subsequent sections. The paper then offers a conclusion and two appendices which help to contextualise voluntary safety initiatives in the aviation industry.

[10] Frontier Model Forum, 'Frontier Model Forum: Advancing Frontier AI Safety', 2024, https://www.frontiermodelforum.org/.

[11] NIST, 'Artificial Intelligence Safety Institute Consortium (AISIC)', 2024, https://www.nist.gov/aisi/artificial-intelligence-safety-institute-consortium-aisic.

II History: Aviation Safety in the US over the 20th Century

II.A Overview

This case study traces the evolution of aviation safety in the US, from the perilous experimental flights of the early 1900s through the formation of federal regulators, industry groups, and international organisations and a series of striking improvements in aviation safety over the course of the 20th century.[12] The four organisations which made the most significant contributions to aviation safety in the US were the Civil Aeronautics Authority (CAA), the Federal Aviation Administration (FAA), the International Civil Aviation Authority (ICAO), and the International Air Transport Association (IATA). The next three sections contextualise the formation and operation of these organisations.

Prominent organisations in aviation safety

The FAA (Federal Aviation Administration) is an agency within the US Department of Transportation, which regulates and oversees all aspects of civil aviation in the US. Among its responsibilities are the certification of aircraft and personnel, the implementation and enforcement of safety standards, and air traffic control. The FAA administrator is a presidential appointee who must be confirmed by the Senate.

The IATA (International Air Transport Association) is an international trade association whose membership consists solely of commercial airlines. The IATA publishes and maintains a set of standards and recommended practices (ISARPs) covering eight safety-relevant functional areas, ranging from Aircraft Engineering and Maintenance to Security Management. IATA member airlines are required to undergo an IATA Operational Safety Audit (IOSA) every two years to test compliance with the ISARPs. Noncompliance can lead to the loss of IATA membership, which carries significant reputational and commercial consequences. Without membership, companies are typically excluded from attending the IATA's Annual General Meeting, a key event for forming commercial agreements and alliances. The IATA also administers the aviation industry's

[12] Between the 1920s and 2000, the number of fatal accidents per million miles flown fell from around 1 to around 0.0001. See: R. G. Grant, 'Flight – 100 Years of Aviation', *Aircraft Engineering and Aerospace Technology* 75, no. 2 (2003), https://doi.org/10.1108/aeat.2003.12775bae.002.

largest de-identified incident monitoring system—the Safety Trend and Data Exchange System (STEADES).

The ICAO (International Civil Aviation Organization) is the specialised UN agency responsible for coordinating the principles, rules, and practice of civil aviation between UN member states. A core function of the ICAO is the development and maintenance of international standards and recommended practices (SARPs) on topics including aviation safety, security, and environmental protection. While the ICAO periodically evaluates the rules of national regulators to assess their uniformity with the SARPs, it is not a global regulator of international aviation law—no such body exists.

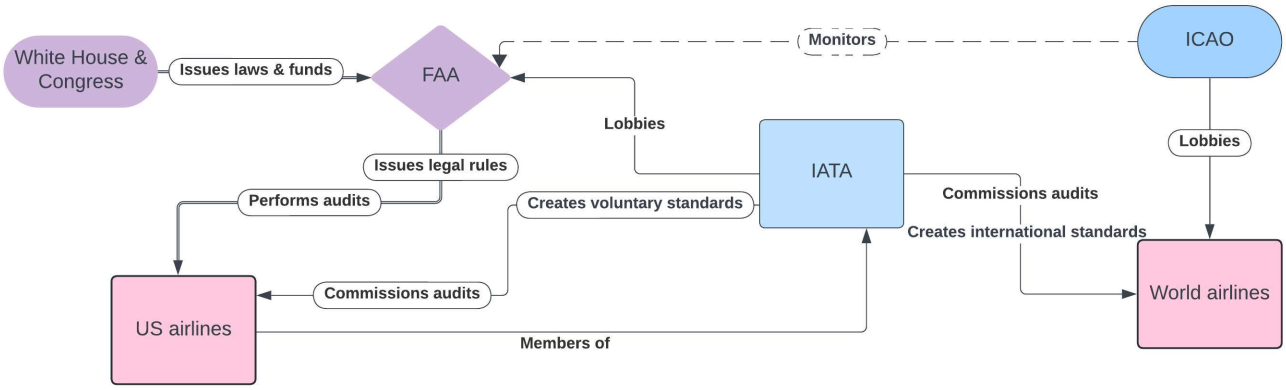
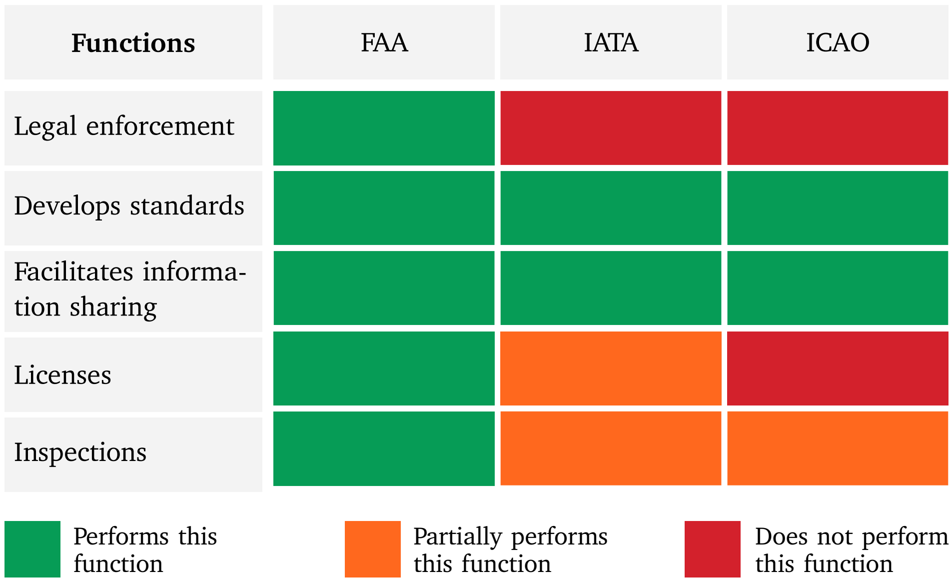


Figure 1: *Diagram of relationships between prominent organisations in aviation safety.*

II.B The Functions of Aviation Organisations



II.C 1903 to 1938 The Early Years of Aviation Safety

The period between the first successful aeroplane flight by the Wright brothers in 1903 and the end of WWI in 1918 was marked by dangerous private aviation experiments and the use of aircraft for reconnaissance by the US military. Whilst safety was limited, this period saw the introduction of the first certification process for pilots in the US by the Aero Club of America (ACA)[13] and the formation of the first federal agency with responsibility for aviation, the Aeronautics Division of the US Army Signals Corps.

[13]The Aero Club of America was established in 1905 by aviation enthusiasts in order to promote aviation and facilitate sporting events. The club established its pilot certification process in 1911; notably, the US Army set ACA certification as a requirement for its pilots until 1914. See: ACA, *Aero Club of America 1919* (New York, 1919), https://babel.hathitrust.org/cgi/pt?id=mdp.39015020227933&view=1up&seq=1.

Following the First World War, over 30 states met at the Paris Convention of 1919 to establish international regulations for aviation. The most significant outcome of the convention was the establishment of the International Commission for Air Navigation (ICAN), a precursor to the ICAO. The ICAN was responsible for facilitating information sharing and settling technical disagreements between contracting states.[14] Because of the convention's association with the League of Nations, the US did not ratify the Paris Convention of 1919, limiting the success of the process and the utility of the ICAN.[15] 1919 also saw the establishment in the Hague of the International Air Traffic Association, a private institution, formed by six European airlines, that was a precursor to the IATA. The airlines met semi-annually to share commercial and technical information and coordinate on air routes and scheduling.[16]

The period between 1918 and 1938 saw the emergence of the commercial passenger industry in the US. An early proof of the usefulness of aviation came with the formation of the Federal Air Mail Service in 1918, an agency dedicated to the delivery of mail between US cities.[17] Outside of air mail delivery and aircraft production, commercial applications of aviation remained limited. The high rate of aircraft accidents resulted in few willing passengers, limited capital investment, and high insurance premiums. These barriers led some industry leaders to call for federal regulation to promote aviation safety.[18] The Air Commerce Act of 1926 established the Aeronautics Branch of the Department of Commerce,[19] leading to the standardisation of inspection, licensing, and enforcement practices. This organisation established certification requirements for airlines and, in 1930, a permanent inspection force.

[14]Albert Roper, 'The Organization and Program of the International Commission for Air Navigation (C.I.N.A.)', *Journal of Air Law and Commerce* 3, no. 2 (1932): 167–78, https://scholar.smu.edu/cgi/viewcontent.cgi?article=3684&context=jalc.

[15]John C Cooper, 'United States Participation in Drafting Paris Convention 1919', *Journal of Air Law and Commerce* 18, no. 3 (1951): 266–80, https://scholar.smu.edu/cgi/viewcontent.cgi?article=3519&context=jalc.

[16]Peter H Sand, Jorǵe de Sousa Freitas, and Geoffrey N. Pratt, 'An Historical Survey of International Air Law Before the Second World War', *McGill Law Journal* 7, no. 1 (1960): 24–42.

[17]As the Air Mail Service expanded, it began to offer contracts to private companies to take some flight routes. Following the Air Mail Act of 1925, virtually all air mail delivery was conducted by private companies.

[18]Nick A. Komons, *Bonfires to Beacons: Federal Civil Aviation Policy Under the Air Commerce Act 1926-1938* (Washington, D.C.: Department of Transportation, Federal Aviation Administration, 1978), 75.

[19]Later renamed to the Bureau of Air Commerce.

II.D 1938 to 1978 Federal Reform and the Internationalisation of Aviation Safety

The most important domestic development between 1938 and 1953 in the US for aviation safety was the establishment of the Civil Aeronautics Authority (CAA, a new federal agency for aviation). Unlike its predecessor, this agency was explicitly responsible for aviation safety and free to pursue this objective independently from the goal of promoting the aviation industry. The growth of the aviation industry during this period led to increased workloads for government inspectors. To address this challenge, the CAA instated a 'designee', where industry personnel were permitted to conduct primary safety inspections of aircraft and award certification.[20]

Concurrently, the period between 1944 and 1947 was marked by the most significant developments for international aviation safety over the 20th century. The end of WWII led to the Chicago Convention and the internationalisation of aviation safety. The most significant outcome of the Chicago Convention was the establishment of the ICAO, a UN agency responsible for producing and implementing technical standards, formalising practices, and coordinating between contracting states. Another important outcome of the Chicago Convention was the formation of the IATA in 1945, the primary international trade association for airlines.[21] The IATA has facilitated commercial agreements between airlines and has developed a number of important initiatives to promote aviation safety.

A key development within the period of 1953 to 1978 in the US was the replacement of the CAA with a new agency, the FAA, under the Eisenhower administration. This change came after two highly salient aircraft accidents[22] and criticism of the CAA which highlighted issues with the agency's designee[23] and the fragmentation of military and civil air traffic control.[24] Like its predecessor, the FAA faced criticism for its slow response to a series of hazardous materials violations by airlines, its increased

[20]Mark Hansen, Carolyn McAndrews, and Emily Berkeley, 'History of Aviation Safety Oversight in the United States' (The National Center of Excellence for Aviation Operations Research, March 2005), https://www.researchgate.net/profile/Mark-Hansen-7/publication/237545650_History_of_Aviation_Safety_Oversight_in_the_United_States/links/57a1c32e08aeb16048334384/History-of-Aviation-Safety-Oversight-in-the-United-States.pdf, 13.

[21]John C. Leslie, 'International Air Transport Association: Some Historical Notes', *Journal of Inter-american Studies and World Affairs* 13, no. 3–4 (1971): 319–41, https://doi.org/10.2307/174926.

[22]Stuart I. Rochester, *Takeoff at Mid-Century: Federal Civil Aviation Policy in the Eisenhower Years, 1953-1961* (Washington D.C.: U.S. Department of Transportation, Federal Aviation Administration, 1976).

[23]Rochester, *Takeoff at Mid-Century*, 145-146.

[24]Edward P. Curtis, 'Interim Report of the President's Special Assistant for Aviation Facilities Planning' (Eno Center for Transportation, 1957), https://www.enotrans.org/eno-resources/1

delegation of safety oversight to industry, and its lack of in-house manufacturing and engineering expertise.[25] By the middle of the 1970s, the FAA had gained a reputation for sluggish rule-making and implementation.[26]

II.E 1978 to 2000+ Deregulation and the System Safety Regime

Congress passed the Airline Deregulation Act in 1978, resulting in a significant economic liberalisation of aviation.[27] This development led to a doubling of the number of US airlines between 1979 and 1983, introducing a new set of challenges for the FAA.[28] In response, the FAA introduced measures to make inspection activities more targeted and began to develop a number of new information-gathering and data-management initiatives.[29] These initiatives paved the way for the system safety era of aviation safety, in which data related to aircraft safety was integrated with data from other sources, allowing the FAA to more readily identify and control risks. One such initiative, the Aviation Safety Analysis System (ASAS) of 1982, digitised some data-collection and decision-making tasks, allowing inspectors to spend more time conducting inspections.[30]

Despite marked improvements in aviation safety, aircraft crashes in the last two decades of the 20th century led to renewed criticism of the FAA's safety oversight regime. The ValuJet Flight 592 crash in 1996 is particularly notable, as it led to an intense 90-day safety review, a substantial tightening of the regulations on the handling of hazardous materials, and enhanced oversight of airline maintenance and operational practices.[31]

957-interim-report-of-the-presidents-special-assistant-for-aviation-facilities-planning/.

[25]Hansen, McAndrews, and Berkeley, 'History of Aviation Safety Oversight in the United States', 28–31.

[26]Edmund Preston, *Troubled Passage: The Federal Aviation Administration During the Nixon-Ford Term, 1973-1977* (Washington, D.C.: U.S. Department of Transportation, Federal Aviation Administration, 1987), 181.

[27]This development was mirrored by plans for the deregulation of federal safety, but this change proved unpopular, and was scrapped before implementation. See: J.R. Breihan et al., *FAA Historical Chronology: Civil Aviation and the Federal Government, 1926–1996* (Washington, D.C.: U.S. Department of Transportation, Federal Aviation Administration, 1998), 192–193.

[28]Some of the new airlines outsourced aircraft maintenance to third parties. Airlines also faced new incentives to rush or defer maintenance activities, e.g. to meet stricter flight schedules. This complicated the process of inspection and added to inspectors' case load. See: Hansen, McAndrews, and Berkeley, 'History of Aviation Safety Oversight in the United States', 34–35.

[29]National Research Council and Committee on FAA Airworthiness Certification Procedures, *Improving Aircraft Safety: FAA Certification of Commercial Passenger Aircraft* (Washington, D.C.: National Academy of Sciences, 1980).

[30]Breihan et al., *FAA Historical Chronology*, 227.

[31]FAA, 'McDonnell Douglas DC-9-32', U.S. Department of Transportation, Federal Aviation Administration, 19 December 2022, https://www.faa.gov/lessons_learned/transport_airplane/accidents/N904VJ.

A key contributing factor of the crash was identified as the FAA's inability to adequately monitor the third-party maintenance operations that were seeing increasingly wide adoption among airlines.[32]

The FAA responded both with a deepening of government-initiated industry self-surveillance initiatives: initiatives where the aviation industry is empowered to participate in monitoring and reporting its own safety compliance, with government oversight ensuring accountability. Further information on these initiatives is provided in Appendix B. Additionally, the FAA took steps to mitigate similar accidents by establishing the Certification Standardization and Evaluation Team, which conducted more intense surveillance on the operations of new airlines.[33]

[32] FAA, '90-Day Safety Review' (U.S. Department of Transportation, Federal Aviation Authority, 16 September 1996).

[33] Mark Hansen et al., 'Understanding and Evaluating the Federal Aviation Administration Safety Oversight System' (National Center of Excellence for Aviation Operations Research, July 2006), https://www.researchgate.net/profile/Shahab-Hasan/publication/266372988_Understanding_and_Evaluating_the_Federal_Aviation_Administration_Safety_Oversight_System/links/56585f3508ae4988a7b73fbe/Understanding-and-Evaluating-the-Federal-Aviation-Administration-Safety-Oversight-System.pdf, 17.

History of commercial aircraft manufacturing

Since the emergence of commercial aircraft manufacturing, the industry has transitioned from a state of substantial competition between several firms to a near duopoly dominated by Boeing and Airbus. In the early 20th century, Boeing, Douglas (later McDonnell Douglas), and Lockheed emerged as leading manufacturers in the US, producing commercially successful aircraft including the Boeing 247 and Douglas DC-3.[34] Following World War II, Boeing's specialisation in jet engine technology, utilised in the influential Boeing 707 aircraft, led to Boeing gaining a significant advantage over its US and international rivals.[35]

In the 1970s, several European aircraft manufacturing companies merged to form Airbus, a development explicitly aimed at challenging US dominance in commercial aviation manufacturing.[36] Airbus succeeded in gaining market share, finding striking commercial success with its innovative twin-engine A300 aircraft. Boeing continued to consolidate its leadership among US aircraft manufacturers over the next two decades, which were marked by the exit of Lockheed as a commercial manufacturer in the 1980s and Boeing's acquisition of McDonnell Douglas in 1997.[37] This left Boeing and Airbus as the two leading global manufacturers.

Since the 2000s, the manufacturing duopoly has deepened, with Boeing and Airbus producing the bulk of the world's commercial airliners. A series of accidents linked to Boeing's 737 MAX have highlighted the safety and commercial risks posed by the high degree of market concentration in the aircraft manufacturing sector.[38] The dangers of relying on a single manufacturer are clear, as demonstrated by Ryanair, which faced significant disruptions after Boeing was forced to delay the shipment of airliners due to safety concerns.[39] In contrast,

[34] Ayoung Woo et al., 'An Analysis of the Competitive Actions of Boeing and Airbus in the Aerospace Industry Based on the Competitive Dynamics Model', *Journal of Open Innovation: Technology, Market, and Complexity* 7, no. 3 (2021): 192, https://doi.org/10.3390/joitmc7030192.

[35] Woo et al., 'An Analysis of the Competitive Actions of Boeing and Airbus in the Aerospace Industry Based on the Competitive Dynamics Model'.

[36] Woo et al., 'An Analysis of the Competitive Actions of Boeing and Airbus in the Aerospace Industry Based on the Competitive Dynamics Model'; Government Accountability Office, 'Commercial Aviation Manufacturing: Supply Chain Challenges and Actions to Address Them' (United States Government Accountability Office, March 2024), https://www.gao.gov/products/gao-24-106493.

[37] Woo et al., 'An Analysis of the Competitive Actions of Boeing and Airbus in the Aerospace Industry Based on the Competitive Dynamics Model'.

[38] Government Accountability Office, 'Commercial Aviation Manufacturing'.

[39] Anna Cooban, '"Inexcusable." Ryanair Says It May Have to Raise Fares This Summer Because of Boeing', CNN, 26 February 2024, https://www.cnn.com/2024/02/26/business/ryanair-boeing-delays-increase-air-fares/index.html.

airlines with diversified fleets, employing both Boeing and Airbus airliners were better positioned to manage these risks and avoid widespread operational delays.

While Boeing and Airbus both participate in safety initiatives hosted by the ICAO, IATA, FAA, and EASA, there is a notable absence of direct safety cooperation between the aircraft manufacturing firms. Unlike airlines, which benefit from increased safety sector-wide, manufacturers may gain from a competitor's safety issues, which can shift demand for airliners in their favour. This competitive relationship reduces incentives for collaboration, because safety problems for one company often translate to commercial opportunities for the other; this is evidenced by the commercial success of Airbus in the wake of the Boeing 737 MAX crisis.[40]

III Lessons from the Evolution of Aviation Safety in the US over the 20th Century

Lesson 1: Anonymised incident monitoring systems provided essential data to regulators and were acceptable to firms

It is striking that many of the private safety initiatives of the aviation industry complement and support the activities of national regulators. In 2001, the IATA formed the Safety Trend Evaluation and Data Exchange System (STEADES) programme: the world's largest collection of de-identified aviation incident reports. Participating airlines periodically submit air safety reports featuring risk assessments, narrative incident descriptions, and event classifications to the STEADES system.[41] While airline employees are responsible for filing reports, it is important to note that reports are submitted with permission from airlines. Airlines are willing to grant this permission

[40] Kasper Oestergaard, 'Airbus and Boeing Report December and Full Year 2023 Commercial Aircraft Orders and Deliveries', Flight Plan, 15 January 2024, https://flightplan.forecastinternational.com/2024/01/15/airbus-and-boeing-report-december-and-full-year-2023-commercial-aircraft-orders-and-deliveries/.

[41] While participation in STEADES is restricted to airlines, the system is part of a broader ecosystem of responses to aviation incidents. National governments and the ICAO also investigate and respond to such incidents, often involving aircraft manufacturers in the process. See: ICAO, 'Accident Investigation and Prevention (AIG)', n.d., https://www.icao.int/safety/Pages/Accident_Investigation.aspx.

because the IATA commits to de-identifying each incident report,[42] reducing the reputational and regulatory risk of reporting. Once the reports are filed, IATA staff conduct analysis on incident trends, produce documents highlighting hazards, and transfer safety-relevant data to STEADES members, the ICAO, and national regulators.[43]

One major motivation for airline participation in STEADES is that it allows them to benchmark their incident rates against aggregate industry-wide safety data[44]. Equally important is the high degree of trust between airlines, the IATA, and national regulators. Trust between firms and regulators can be developed through prolonged 'adherence to non-punitive corrective action.'[45] Notably, the high degree of congruence between airlines and national regulators on the goal of promoting aviation safety makes high degrees of trust and complementary public and private safety initiatives more likely in the aviation industry.

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Recommendation I: Facilitate anonymised incident monitoring systems. (Industry Consortia)

As the capabilities of AI systems continue to advance, the need for effective incident monitoring systems becomes increasingly clear. This is especially true for frontier AI models, because these models sometimes display emergent capabilities, which can lead to unexpected or harmful impacts once deployed. The monitoring of AI incidents can support efforts by firms, regulators, and third parties to design and implement responses to prevent harms from released models and future unreleased models. In aviation, targeting airlines for incident monitoring was effective, but AI's complex development and deployment context—where general-purpose AI models are often modified by downstream developers—means that effective incident monitoring will likely need input from a wider range of actors and effective monitoring of model access by frontier AI developers.[46]

[42] In addition to removing identifying information, the IATA does not publish any incident analysis until there are at least three participant airlines in a new incident category. IATA, 'STEADES FAQ' (International Air Transport Association, n.d.), https://www.iata.org/contentassets/7686e6e630ca406f9c7dab74361f8854/steades-faq.pdf.

[43] Mills, 'The Interaction of Private and Public Regulatory Governance', pg.51.

[44] IATA, 'STEADES FAQ'.

[45] Mills, 'The Interaction of Private and Public Regulatory Governance', pg.52.

[46] Joe O'Brien, Shaun Ee, and Zoe Williams, 'Deployment Corrections: An Incident Response Framework for Frontier AI Models' (arXiv, 30 September 2023), https://doi.org/10.48550/arXiv.2310.00328.

Presently, leading third-party and industry-led incident monitoring systems, including the Partnership on AI-supported AI Incident Database[47] and the OECD's AI Incident Monitor[48], do not facilitate or encourage the participation of frontier AI firms in their incident monitoring activities. Instead, these initiatives generally rely on individuals to report incidents, where the source of incidents are typically articles from news organisations. While incident monitoring systems of this kind can play an important external oversight function against the activities of frontier AI firms, external organisations are necessarily limited in their access to pre-deployment or proprietary information, both of which are important for incident monitoring.

In contrast to leading AI incident monitoring systems, the IATA's STEADES aviation incident monitoring system is designed to encourage the active participation of firms as it is administered by a trusted third party, firms choose what to include in incident reports, and, crucially, identifying information is removed from incident reports. Firms are well-placed to participate in incident monitoring activities due to their extensive access to technical and organisational knowledge and records related to their own corporate operations. This is certainly true in the AI industry, because frontier AI firms are often the only entities who have access to sensitive product information, such as model weights, and a detailed understanding of their model development process.[49] As such, there is a growing need for an incident monitoring system which is led by, or highly trusted by, frontier AI firms and encourages their participation.

Two factors complicate the implementation of such a system. Firstly, aviation accidents are extremely salient and attributable, whereas it can be especially challenging to attribute harms stemming from AI models.[50] For this reason, the pressure on AI firms to monitor their own processes to ensure that their products are safe is, all else equal, less intense. Secondly, AI firm employees may be less willing to participate in an incident monitoring system that they suspect could impact the share price of their firm because employees typically hold a relatively high proportion of shares of their employer companies compared to employees in other industries.[51]

[47]'Artificial Intelligence Incident Database', n.d., https://incidentdatabase.ai/.

[48]OECD.AI Policy Observatory, 'AIM: The OECD AI Incidents Monitor', n.d., https://oecd.ai/en/incidents.

[49]Benjamin S Bucknall and Robert F. Trager, 'Structured Access for Third-Party Research on Frontier AI Models: Investigating Researchers' Model Access Requirements' (AI Governance Initiative, 2023), https://www.oxfordmartin.ox.ac.uk/publications/structured-access-for-third-party-research-on-frontier-ai-models-investigating-researchers-model-access-requirements.

[50]Harms can result from the insufficiently responsible development practices of model developers or intermediary developers, or from terms-of-conditions violations committed by end users.

[51]Software engineers in American Airlines, a leading airline, are offered 0% equity; in contrast, equity accounts for between 40% to 70% of a typical OpenAI compensation package. See: 'American Airlines Software Engineer Salary', Levels.fyi, n.d., https://www.levels.fyi/companies/american-airlines/salaries/software-engineer; 'OpenAI Software Engineer Salary',

Lesson 2: Two factors made the participation of airlines in voluntary safety initiatives more likely: (i) commercial incentives to cooperate on non-safety issues, and (ii) opportunities to reduce regulatory burden

Airlines contributed to private safety by participating in voluntary safety initiatives and forming industry groups: most importantly, the International Air Transport Association (IATA) and its predecessor, the International Air Traffic Association.[52] While both organisations made significant contributions to aviation safety, their safety initiatives initially emerged as by-products of broader industry agreements centred on matters other than safety.[53] The International Air Traffic Association was primarily formed to address logistical, navigational, and legal challenges faced by the fledgling European airline industry as it began to engage in international air travel after the First World War.[54] Similarly, although the promotion of aviation safety is an explicit priority of the IATA, it attracts members by offering a forum in which airlines can coordinate traffic routes and, historically, negotiate international fares.[55] The IATA now represents close to 300 airlines from 120 countries, comprising over 80% of global air traffic.[56]

The IATA Operational Safety Audit (IOSA) programme is the IATA's most substantial contribution to aviation safety.[57] To maintain membership in the IATA, airlines must undergo this audit every two years to ensure that their operations and procedures are in compliance with the IOSA Standards and Recommended Practices (ISARPS), a comprehensive set of safety requirements determined by airlines (representing each global alliance group), national and regional airline associations, international and national regulatory authorities (including the ICAO, FAA, and US Department of Defense), and additional technical and auditing experts.[58]

Levels.fyi, n.d., https://www.levels.fyi/companies/openai/salaries/software-engineer.

[52] IATA membership is only available for airlines, though major manufacturers like Boeing are involved as strategic partners; partners are permitted to attend the IATA's Annual General Meeting. See: IATA, 'Directory of Strategic Partners', n.d., https://www.iata.org/en/about/sp/partners-directory/.

[53] Leslie, 'International Air Transport Association'.

[54] Leslie, 'International Air Transport Association', 322–325.

[55] The IATA has been described as a private cartel and criticised for facilitating price fixing. See: John A. Hannigan, 'Unfriendly Skies: The Decline of the World Aviation Cartel', *Pacific Sociological Review* 25, no. 1 (1982): 107–36, https://doi.org/10.2307/1388890.

[56] IATA, 'IATA Members', n.d., https://www.iata.org/en/about/members/.

[57] A more thorough description of the IOSA program is included in Appendix A.

[58] David Hodgkinson, 'Standardization and Business Development: The Global Impact of the IOSA Standards and the Value of Anticipation' (The Hodgkinson Group, 2005), https://web.archive.org/web/20230524153949/https://www.hodgkinsongroup.com/documents/IEC_IOSA_IATA.pdf.

A core motivation for the establishment of the IOSA by the IATA was to reduce the number of redundant audits that airlines were required to undergo in order to operate internationally; the IATA estimated that overlapping and redundant auditing requirements cost airlines over $3 billion during the 1990s.[59] The success of this effort was first marked by the FAA's 2004 announcement that the IOSA would be recognised as an acceptable audit for foreign airlines entering into code-sharing agreements with US airlines.[60] The simplification of auditing requirements, in addition to reputational benefits associated with IOSA certification, remains an important motivating factor in the continued participation of airlines in the IOSA programme.

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Recommendation IV: Encourage cross-industry cooperation beyond safety. (Industry Consortia)

The IATA was able to raise the standard of safety in the aviation industry by making participation in its safety audit mandatory for members and encouraging participation by providing, de facto, commercial opportunities linked to membership. We should expect an analogous program to be difficult to implement in the AI industry, for two reasons.

Firstly, market segmentation allows for a high degree of international cooperation between airlines: a Chinese airline has little need to compete with a domestic US airline for customers but still reaps the benefits of entering into code-sharing agreements or coordinating on routes with other airlines. The commercial aircraft manufacturing industry is far less regionally segmented than the airline industry, as Boeing and Airbus compete globally for contracts with airlines. As a result, direct collaboration between the two manufacturers on safety matters is rare. Frontier AI models face few barriers to deployment across national borders and, increasingly, across different industry sectors.[61] In effect, this means that most frontier model firms compete for a similar set of customers; this, as in the aircraft manufacturing sector, makes commercial cooperation more challenging.

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[59] Russell W Mills, 'The Interaction of Private and Public Regulatory Governance: The Case of Association-Led Voluntary Aviation Safety Programs', *Policy and Society* 35, no. 1 (2016): 43–55, https://doi.org/10.1016/j.polsoc.2015.12.002, referring to: Philipp Binder, *The IOSA Story: Effects of the IATA Operational Safety Audit* (VDM Verlag, 2008).

[60] Lindsey Sabec, 'FAA Approves IATA's Operational Safety Audit (IOSA) Program: A Historical Review and Future Implications for the Airline Industry', *Transportation Law Journal* 32, no. 1 (2004): 1–20, https://digitalcommons.du.edu/tlj/vol32/iss1/2/.

[61] OpenAI, 'Stories', n.d., https://openai.com/news/stories/.

Secondly, while participation in the IATA's safety audit was mandatory for IATA members, current AI consortia, including the Frontier Model Forum, rely on voluntary commitments from members. Attempts to implement safety requirements for membership may face antitrust scrutiny, especially because stringent safety measures can be costly for small firms to implement. Indeed, the IATA's safety audit may have only escaped antitrust scrutiny due to the active role regulators and international organisations played in the design of the IOSA.[62]

While commercial cooperation may present challenges due to competition, there are other areas where collaboration between AI firms could be mutually beneficial. Industry consortia like the Frontier Model Forum should explore opportunities for cooperation on issues where consensus is more likely. For example, working groups focused on responsible scaling, model-access governance, and cybersecurity could provide common ground, similar to the working groups formed by AISIC.[63] By targeting these areas, firms can develop mutual trust, making further collaboration on AI safety issues more likely.

Lesson 3: Outsourcing of safety oversight to firms allowed for striking improvements in aviation safety, despite a relative decline in regulatory funding

The history of commercial aviation is defined by striking improvements in safety. In the 50 years between 1970 and 2020 the rate of fatalities per million passengers fell from 4.77 to 0.18 globally, representing a 96% incident reduction.[64] The US saw similarly impressive reductions in fatal accidents across the 20th century, from a peak in 1929.[65] Previous research papers have focused on several drivers of improvements

[62]Hodgkinson, 'Standardization and Business Development: The Global Impact of the IOSA Standards and the Value of Anticipation'.

[63]NIST, 'AISIC Working Groups', 7 February 2024, https://www.nist.gov/aisi/aisic-working-groups.

[64]'Global Aviation Fatalities Per Million Passengers', Our World in Data, n.d., https://ourworldindata.org/grapher/aviation-fatalities-per-million-passengers?tab=table&time=earliest..2020.

[65]NTSB, 'Accident Data', National Transportation Safety Board, n.d., https://www.ntsb.gov/safety/data/Pages/Data_Stats.aspx; Ian Savage, 'Aviation Deregulation and Safety in the United States: The Evidence After Twenty Years', in *Taking Stock of Air Liberalization*, ed. Marc Gaudry and Robert R. Mayes (Boston, MA: Kluwer Academic Publishers, 1999), 93–114.

in aviation safety, including personnel training,[66] safety management systems,[67] global competition,[68] technological progress,[69] and regulatory regimes.[70] Here, we highlight the outsourcing of safety oversight to airlines and aircraft manufacturers as a factor which supported safety improvements, despite a relative decline in regulatory funding over the past 90 years of commercial aviation.

In 1934, the US air transportation industry was valued at around $550 million (2018 dollars),[71] six times[72] as much as the annual budget of the main federal regulatory body for aviation safety in the same year. By 2018, the value of the US air transportation industry had increased to around $135 billion,[73] around eight times larger than the FAA's 2018 annual budget.[74] The numbers of commercial air passengers in the US has also dramatically increased since 1970.[75] US aviation regulators responded to the parallel challenges—the growth of the aviation industry and the relative decline

[66]Robert L Helmreich and H Clayton Foushee, 'Why CRM? Empirical and Theoretical Bases of Human Factors Training', in *Crew Resource Management*, ed. Barbara G. Kanki, Robert L Helmreich, and José Anca (Academic Press, 2010), 3–57, https://booksite.elsevier.com/samplechapters/9780123749468/9780123749468.pdf; Nick Mcdonald, Sam Cromie, and Marie Ward, 'The Impact of Safety Training on Safety Climate and Attitudes', in *Aviation Safety, Human Factors - System Engineering - Flight Operations - Economics - Strategies - Management*, ed. Hans M. Soekkha (London: CRC Press, 1997).

[67]Charley Besselink, 'ISMS - Integrated Safety Management System', in *Aviation Safety, Human Factors - System Engineering - Flight Operations - Economics - Strategies - Management*, ed. Hans M. Soekkha (CRC Press, 1997).

[68]Kenneth Button, 'Interactions of Global Competition, Airlines Strategic Alliances and Air Traffic Safety', in *Aviation Safety, Human Factors - System Engineering - Flight Operations - Economics - Strategies - Management*, ed. Hans M. Soekkha (CRC Press, 1997).

[69]Clinton V. Oster, John S. Strong, and C. Kurt Zorn, 'Analyzing Aviation Safety: Problems, Challenges, Opportunities', *Research in Transportation Economics*, The Economics of Transportation Safety, 43, no. 1 (2013): 148–64, https://doi.org/10.1016/j.retrec.2012.12.001.

[70]Devinder K. Yadav and Hamid Nikraz, 'Implications of Evolving Civil Aviation Safety Regulations on the Safety Outcomes of Air Transport Industry and Airports', *Aviation* 18, no. 2 (2014): 94–103, https://doi.org/10.3846/16487788.2014.926641.

[71]Roughly $30 million 1934 dollars. See: ACCA, 'The Aircraft Year Book for 1934'. *The Aircraft Year Book for 1934*, vol. 16 (New York, NY: Aeronautical Chamber of Commerce of America, 1934), 33.

[72]The annual budget of the Bureau of Air Commerce in 1934 was around $5,000,000 in 1934 dollars. See: Department of Commerce, 'Twenty-Second Annual Report of the Secretary of Commerce' (Washington, D.C.: Government Printing Office, 1934), https://www.fmc.gov/wp-content/uploads/2019/04/ANNUAL_REPORT_1934.pdf, 9

[73]Statista Research Department, 'Air Transportation: U.S. Value Added 2021', Statista, 2024, https://www.statista.com/statistics/255548/value-added-of-the-us-air-transportation-industry/.

[74]FAA, 'Budget Estimates: Fiscal Year 2018' (U.S. Department of Transportation, Federal Aviation Authority, 2018), https://www.transportation.gov/sites/dot.gov/files/docs/mission/budget/281191/faa-fy-2018-cj-final.pdf.

[75]World Bank, 'Air Transport, Passengers Carried - United States', World Bank Open Data, n.d., https://data.worldbank.org/indicator/IS.AIR.PSGR?locations=US&view=chart.

of regulatory funding—by outsourcing safety oversight duties to individuals and companies working in the airline and aircraft manufacturing industries.

In the 1940s, the CAA implemented a 'designee' programme through which factory workers, operations staff, and airlines became licensed to conduct inspections and certify both equipment and pilots. This development allowed the CAA to expand its safety oversight capacity and transition from conducting primary inspections to 'inspecting the inspectors'.[76] The designee programme remains a cornerstone of the FAA's approach to safety.

In 1964, the FAA implemented the Continuing Analysis and Surveillance System (CASS), another example of safety outsourcing to firms. As part of this program, airlines are required to carry out audits of the in-house or third-party maintenance programs they employ and 'correct deficiencies in the performance and effectiveness' of these programs.[77] Centrally, CASS serves to reduce the likelihood of a non-airworthy aircraft being approved for service.[78] Both programmes have the benefit of leveraging industry resources and expertise to contribute to safety oversight. However, the success of these programmes relies on a high degree of trust between the aviation industry and aviation regulators. Without this trust, and the high degree of goal congruence between airlines and national regulators, the reliance on firms for oversight might have led to worse safety outcomes.

[76]John R. M. Wilson, *Turbulence Aloft: The Civil Aeronautics Administration Amid Wars and Rumors of Wars, 1938-1953* (Washington, D.C.: U.S. Department of Transportation, Federal Aviation Administration, 1979), 150.

[77]Fred J. Leonelli, 'Continuing Analysis and Surveillance System (CASS) Description and Models' (U.S. Department of Transportation, Federal Aviation Authority, October 2003).

[78]FAA, 'AC 120-79A - Developing and Implementing an Air Carrier Continuing Analysis and Surveillance System' (U.S. Department of Transportation, Federal Aviation Administration, 7 September 2010), https://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentid/328356.

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Recommendation VI: Prioritise frontier AI and high-stakes oversight, delegate lower-risk safety functions to firms. (National Regulators)

The release of ChatGPT in November 2022 broke the record for the fastest growth in the user-base of a consumer application in history.[79] Several features of AI systems indicate that we may see similarly rapid growth in the size of the industry in coming years: the low marginal cost of deploying AI systems make these models highly scalable, algorithmic and compute progress may lead to large improvements in AI performance, and highly general systems may contribute to value production in a large number of industry sectors. In contrast, the growth of regulatory capacity, most importantly in the US, can be heavily constrained by domestic politics, leading to relatively slow growth to the budget and personnel count of some regulatory bodies.[80] In the aviation industry, similar dynamics led to a substantial reliance by US aviation regulators on aviation firms for safety oversights, exemplified by the designee and CASS programs. Despite substantial investments in activities to support safe AI development by some national governments,[81] there are early indications that a similar reliance may emerge in the AI industry.[82]

The reliance of aviation regulators on firms for safety oversight does not seem to have negatively impacted aviation safety outcomes; indeed, throughout the 1970s and 1980s, airline fatalities decreased despite a reduction in the FAA's budget relative to

[79] Krystal Hu, 'ChatGPT Sets Record for Fastest-Growing User Base - Analyst Note', *Reuters*, 2 February 2023, https://www.reuters.com/technology/chatgpt-sets-record-fastest-growing-user-base-analyst-note-2023-02-01/.

[80] Some federal agencies, including the Food and Drug Administration, have the authority to collect user fees, service charges, or other types of revenue to partially fund their operations. See: FDA, 'FDA: User Fees Explained', U.S. Food & Drug Administration, 2024, https://www.fda.gov/industry/fda-user-fee-programs/fda-user-fees-explained.

[81] U.K. DSIT, 'Introducing the AI Safety Institute' (UK Department for Science, Innovation & Technology, 2023), https://www.gov.uk/government/publications/ai-safety-institute-overview/introducing-the-ai-safety-institute; The White House, 'FACT SHEET: The President's Budget Advances President Biden's Unity Agenda', 11 March 2024, https://www.whitehouse.gov/briefing-room/statements-releases/2024/03/11/fact-sheet-the-presidents-budget-advances-president-bidens-unity-agenda/; Chrystia Freeland, 'Remarks by the Deputy Prime Minister on Securing Canada's AI Advantage', Government of Canada, 7 April 2024, https://www.canada.ca/en/department-finance/news/2024/04/remarks-by-the-deputy-prime-minister-on-securing-canadas-ai-advantage.html.

[82] Will Knight, 'America's Big AI Safety Plan Faces a Budget Crunch', *Wired*, 21 December 2023, https://www.wired.com/story/americas-ai-safety-plan-budget-crunch/.

the size of the aviation industry.[83] This can be attributed to the high degree of trust and congruence on the goal of aviation safety between aviation regulator, airlines, and aircraft manufacturers: preventing accidents was a top priority for all three. Instead of relying on these factors, AI regulators should aim to adopt a coordination and enforcement role, potentially by outsourcing to firms when certain conditions are met. For instance, outsourcing may be reasonable in areas where the incentives of firms are closely aligned with safety, such as evaluating the robustness of models. In parallel, regulators should allocate more resources to monitoring high-risk or highly uncertain AI developments, especially related to frontier AI models.[84] Further, national regulators should prioritise areas in which the costs of a harmful incident substantially outweigh the costs to private developers, such as threats to national security.

Lesson 4: Voluntary safety initiatives and national standards enforcement increased compliance with international standards

In the aviation industry, enforcement of international standards is supported by voluntary safety initiatives, administered by the IATA, and national standards enforcement, principally from the FAA. The ICAO's SARPs, a series of international aviation standards, are developed by the Air Navigation Commission[85] and approved by the ICAO Council, which is composed of representatives from ICAO member states. Although the SARPs are adopted to promote uniformity and a high standard of aviation safety across contracting states, these states bear little legal responsibility for implementing SARPs.[86] Relatedly, the ICAO's enforcement mechanism for ensuring state compliance with SARPs is weak:[87] the ICAO audits state aviation-oversight systems and publishes each state's level of compliance in Its Universal Safety Oversight Audit Programme

[83] Savage, 'Aviation Deregulation and Safety in the United States: The Evidence After Twenty Years'.

[84] Merlin Stein et al., 'Public vs Private Bodies: Who Should Run Advanced AI Evaluations and Audits? A Three Step Logic Based on Case Studies of High Risk Industries' (Oxford Martin AI Governance Initiative, 2024), https://www.oxfordmartin.ox.ac.uk/publications/public-vs-private-bodies-who-should-run-advanced-ai-evaluations-and-audits-a-three-step-logic-based-on-case-studies-of-high-risk-industries.

[85] Ludwig Weber, *International Civil Aviation Organization (ICAO)* (The Netherlands: Kluwer Law International B.V., 2021).

[86] Under Article 37 of the Chicago Convention, states commit to collaborate on safety uniformity but do not explicitly commit to comply with SARPs. See: Michael Milde, *International Air Law and ICAO* (Eleven International Publishing, 2008), 159.

[87] Michael Milde, 'Problems of Safety Oversight: Enforcement of ICAO Standards', in *The Use of Air and Outer Space Cooperation and Competition*, ed. Chia-Jui Cheng (Brill, 1998), 251–71, https://doi.org/10.1163/9789004642010_022.

report.[88] The ICAO's weak enforcement of the SARPs is strengthened by initiatives of national regulators and industry trade associations.

In 1992, the FAA introduced the International Aviation Safety Assessment (IASA) programme, with the aim of increasing the level of international compliance with the ICAO SARPs. Under this programme, the FAA investigates the safety oversight systems within each country whose airlines operate in the US or code-share with US airlines.[89] If the FAA determines that a country's oversight system is not in compliance with ICAO standards, then the FAA can prohibit that country's airlines from operating in the US.[90] As a result of this programme, any country whose airlines seek to operate in the US, the world's second-largest aviation market, must meet ICAO safety oversight standards.

The IATA has also implemented programmes which increase compliance with the ICAO SARPs. In support of its IOSA auditing programme, the IATA developed a series of IOSA Standards and Recommended Practices (ISARPs), modelled on the technical specifications of the ICAO SARPs. There are now over 1000 ISARPs, covering issues such as flight operations, maintenance activities, and operational security.[91] When an IOSA audit reveals that an airline fails to comply with an IOSA Standard, the association issues the airline a Corrective Action Report; continued noncompliance can result in the removal of IOSA certification and all associated benefits.[92] Notably, unlike the FAA's IASA programme, the IATA's ISARPs directly target the conduct of airlines rather than the safety oversight systems of national regulators.

[88] ICAO, 'Universal Safety Oversight Audit Programme: Continuous Monitoring Approach Results 1 January 2016 to 31 December 2018' (Montréal, Canada: International Civil Aviation Organization, 2019), https://www.icao.int/safety/CMAForum/Documents/USOAP_REPORT_2016-2018.pdf.

[89] FAA, 'International Aviation Safety Assessment (IASA) Program', U.S. Department of Transportation, Federal Aviation Administration, 2024, https://www.faa.gov/about/initiatives/iasa.

[90] Article 6 of the Chicago Convention states that 'no scheduled international air service may be operated over international or into the territory of a contracting State, except with the special permission or other authorization of that State, and in accordance with the terms of such permission or authorization.' See: ICAO, 'Convention on International Civil Aviation' (International Civil Aviation Organization, 7 December 1944), https://www.icao.int/publications/pages/doc7300.aspx, Article 6.

[91] IATA, *IOSA Standards Manual (ISM)*, 15th ed. (International Air Transport Association, 2022).

[92] Alongside reputational benefits, IOSA certification simplifies access requirements to some markets and reduces the audits required for cross-airline code-sharing agreements. See: Mills, 'The Interaction of Private and Public Regulatory Governance'.

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Recommendation II: Establish consensus-based minimum safety standards, with the participation of AISIs and national regulators in working groups. (Industry Consortia)

AI industry consortia are well-positioned to establish consensus-based minimum safety standards because they can leverage the resources and expertise of frontier AI firms. However, broad cross-industry adherence is unlikely unless standards are established through a consensus-seeking process that is perceived as legitimate by national regulators. Involving both national regulators and AI safety institutes (AISIs) in working groups adds legitimacy and increases the likelihood that these processes will serve the public interest and support national and international regulations.

Similar to the challenges in aviation, where international enforcement of safety standards is limited, international organisations may be unable, and in some cases poorly suited,[93] to promoting compliance with standards among AI firms, not least because there is a lack of global consensus in many areas of AI governance.[94] Yet, as seen with voluntary industry safety standards in aviation, AI industry consortia could offer a valuable alternative to encourage safe development and deployment practices across the sector. By establishing consensus-based standards[95] and creating mechanisms to ensure firm compliance—such as auditing, corrective action reports, or even suspending membership for noncompliance—industry consortia can play a crucial role in driving the adoption of safety standards across the industry.

[93]Claire Dennis et al., 'What Should Be Internationalised in AI Governance?' ('What Should Be Internationalised in AI Governance?' Oxford Martin AI Governance Initiative, 2024). https://www.oxfordmartin.ox.ac.uk/publications/what-should-be-internationalised-in-ai-governance

[94]Cameron F. Kerry, 'Small Yards, Big Tents: How to Build Cooperation on Critical International Standards', Brookings, 11 March 2024, https://www.brookings.edu/articles/small-yards-big-tents-how-to-build-cooperation-on-critical-international-standards/.

[95]The ongoing NIST US AI Safety Institute's AI-800-1 process is an especially promising effort to define best practices for AI developers. See: NIST, 'Managing Misuse Risk for Dual-Use Foundation Models' (Gaithersburg, MD: National Institute of Standards and Technology, 2024), https://doi.org/10.6028/NIST.AI.800-1.ipd.

IV History: Nuclear Safety in the US over the 20th Century

IV.A Overview

This case study traces the evolution of nuclear safety in the US, beginning with the Atomic Energy Act of 1946 and ending with the nuclear revival at the end of the 20th century. This helps to contextualise the formation and operation of the national regulators, industry groups, and international organisations which made the most significant contributions to nuclear safety in the US. Six organisations are especially notable: the Atomic Energy Commission (AEC), the International Atomic Energy Agency (IAEA), the Nuclear Regulatory Commission (NRC), the Institute of Nuclear Power Operations (INPO), the Nuclear Energy Institute (NEI), and the World Association of Nuclear Operators (WANO). In this case, it is striking that US national regulators placed intense restrictions on the first applications of nuclear power and maintained tight restrictions throughout the 20th century. These restrictions prevented serious accidents in the US but constrained the growth of the nuclear power industry.

One key **disanalogy** between the AI industry and the nuclear power industry is that AI innovation is moving much more quickly than that of nuclear power. There's been very little innovation in nuclear reactor design since the late 1960s, when utilities converged on the light water reactor. The fact there are few trade secrets means that utilities are happy to share information about plant operations and allow workers from other plants extensive access for INPO evaluations.

Prominent organisations in nuclear power safety

The **NRC** (Nuclear Regulatory Commission) is an independent US federal agency, which makes legal rules and issues guidance for US nuclear power plants. It regulates the design, construction, day-to-day operation, nuclear materials tracking, decommissioning, and waste disposal of commercial plants. The NRC administers a licensing regime, whereby in order to build a power plant utilities must submit thousands of pages of detailed plans for the plant, and then audits utilities through in-person inspections. The NRC is run by five commissioners, who are appointed by the president and approved by the Senate. It is funded through Congress and licence fees paid by utilities.

The **INPO** (Institute of Nuclear Power Operations) is a safety group for US commercial nuclear plant operators. The NRC coordinates with the INPO to, for example, share information about operational experience or incidents at plants. The NRC has delegated to the INPO the responsibility to accredit the safety training programs that utilities run for their workers. The INPO also develops safety standards on power plant operation and audits those standards through in-person inspections. In addition, the INPO lobbies Congress, the White House, and the NRC in accordance with its safety-focussed mission. All US utilities are INPO members, but membership is voluntary, so there is no legal obligation for plants to adhere to these standards. The INPO's board of directors is made up mostly of nuclear plant utilities, and the board of directors appoints a CEO. The INPO is registered as a 501(c)(3) corporation and is nearly entirely funded by membership fees from utilities.

The **NEI** (Nuclear Energy Institute) is a lobby group for the US nuclear power industry and represents, among others, reactor designers, fuel suppliers, and architect firms. It is registered as a 501(c)(6), which allows it more freedom than the INPO has to lobby the NRC and Congress.

The **WANO** (World Association of Nuclear Operators) is a safety group for commercial nuclear power operators around the world, including operators in Russia, China, France, and Mexico. Like the INPO, the WANO develops safety standards around the operation of nuclear power plants, audits these standards through in-person inspections, and facilitates information sharing between plants about adverse events. The WANO and the INPO share information with each other about adverse events. Like the INPO, membership is voluntary, and nuclear power operators do not have a legal obligation to follow its standards.

The **IAEA** (International Atomic Energy Agency), a UN agency, oversees global nuclear compliance by verifying that signatory nation-states adhere to the Treaty on the Non-Proliferation of Nuclear Weapons (NPT). It establishes international safety standards, evaluates national regulatory frameworks like NRC rules, and promotes the peaceful use of nuclear power. In addition to its verification role, the IAEA assists countries in developing civilian nuclear energy programs, ensuring that they meet global safety and security standards.

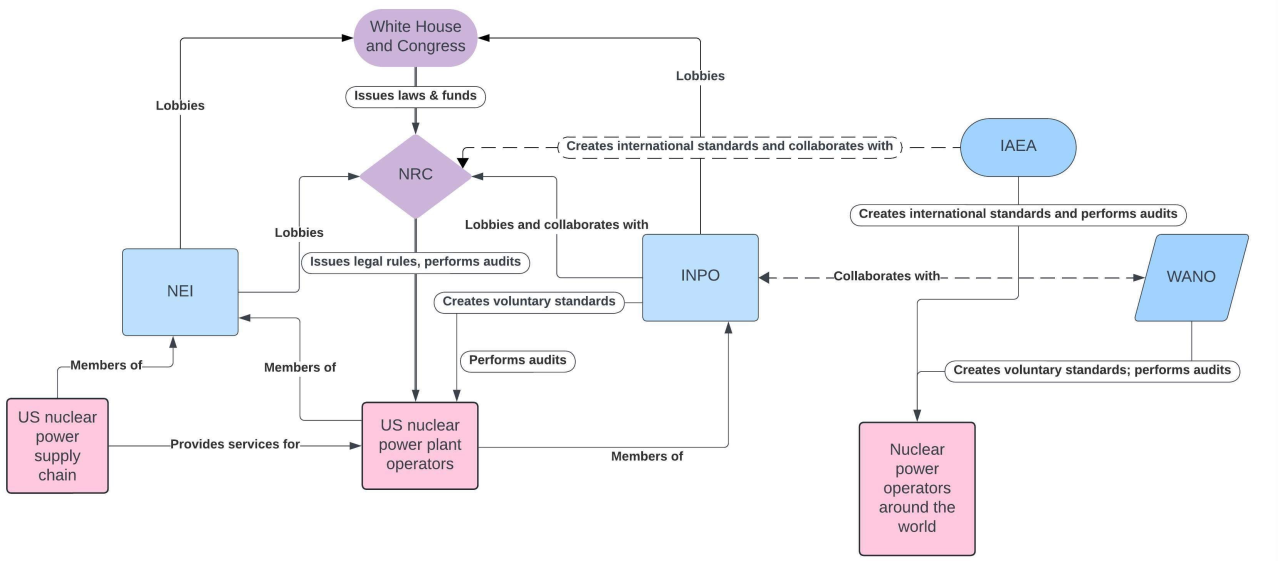

Figure 2: *Diagram of relationships between prominent organisations in nuclear power safety.*

IV.B The Functions of Nuclear Power Organisations

Functions	INPO	NEI	NRC	WANO	IAEA
Performs legal enforcement	Does not perform	Does not perform	Performs	Does not perform	Partially performs
Develops standards	Performs	Does not perform	Performs	Performs	Performs
Facilitates information sharing	Performs	Does not perform	Performs	Performs	Does not perform
Issues licences	Performs	Does not perform	Performs	Does not perform	Does not perform
Conducts inspections	Performs	Does not perform	Performs	Performs	Performs
Certifies or performs safety training	Performs	Does not perform	Does not perform	Does not perform	Does not perform

Performs this function — Partially performs this function — Does not perform this function

IV.C 1946 to 1974 The Early Years of the Nuclear Power Industry

In August of 1946, President Truman signed the first Atomic Energy Act (AEA/1946), which transferred responsibility for nuclear power from the US military to a civilian federal independent agency, the Atomic Energy Commission (AEC).[96] In April 1953, a private trade association called the Atomic Industrial Forum (AIF) was formed to promote civilian applications of nuclear energy and lobby for the private sector to be allowed to operate nuclear power plants.[97] In December of 1953, President Eisenhower's Atoms for Peace address to the UN General Assembly paved the way for a change in US nuclear power posture, leading to the Atomic Energy Act of 1954 (AEA/1954) and the start of a commercial nuclear power industry.

[96] 'The Atomic Energy Act of 1946', Pub. L. No. 79–585 (1946), https://web.archive.org/web/20230610155218/https://www.atomicarchive.com/resources/documents/deterrence/atomic-energy-act.html.

[97] 'All-Congress Banquet Highlights 1958 Nuclear Congress in Chicago', *Electrical Engineering* 77, no. 6 (June 1958): 524–26, https://doi.org/10.1109/EE.1958.6445143.

In his Atoms for Peace address, Eisenhower called for the creation of an international organisation to promote the peaceful use of nuclear energy. Despite initial hesitancy from the USSR, both leading nuclear powers joined a negotiation process, culminating in the formation of the IAEA on the 29th of July, 1957.[98] The IAEA is a UN agency, reporting to both the UN General Assembly and the UN Security Council. The organisation is tasked with facilitating scientific exchange, providing nuclear materials and assistance to developing nations, establishing and applying safeguards to ensure materials and assistance are not used for military purposes, and establishing nuclear safety standards.

Despite the commercial opportunities on offer after AEA/1954, financial and technological barriers slowed the uptake of nuclear power plant contracts by energy utilities. For example, commercial plants initially found it difficult to obtain adequate insurance coverage. In response, the US government passed the Price-Anderson Act whereby it underwrote an extra $500 million in damages following any accident.[99] These efforts were followed by a rapid period of growth in the commercial nuclear sector, starting in the mid 1960s. Between 1965 and 1970 the AEC caseload increased by 600%, whereas the size of the regulatory staff grew by only around 50%[100]—causing significant licensing delays.

In 1974, the Energy Reorganization Act was passed, resulting in a major restructuring of the US nuclear regulatory regime. The AEC was disbanded, and the NRC became responsible for regulating commercial nuclear power plants. While the AEC had a dual mandate to both promote and regulate nuclear power, the NRC was responsible only for regulating the industry.[101] This restructure followed criticism of the AEC's handling of investigations into a new reactor component, and a plan by the AEC to store radioactive waste produced by the industry.[102]

[98]David Fischer, *History of the International Atomic Energy Agency: The First Forty Years* (Vienna, Austria: International Atomic Energy Agency, 1997), 29–40.

[99]George Mazuzan and J. Samuel Walker, *Controlling the Atom: The Beginnings of Nuclear Regulation 1946-1962*, 1997th ed. (Washington, D.C.: U.S. Nuclear Regulatory Commission, n.d.), https://web.archive.org/web/20211030123026/https://www.nrc.gov/docs/ML2014/ML20149F702.pdf.

[100]Mazuzan and Walker, *Controlling the Atom: The Beginnings of Nuclear Regulation 1946-1962*, 28.

[101]Chet Holifield, 'Energy Reorganization Act', H.R. 11732 (1973), https://www.congress.gov/bill/93rd-congress/house-bill/11732.

[102]J. Samuel Walker and Thomas R. Wellock, 'A Short History of Nuclear Regulation, 1946–2024 (NUREG/BR-0175, Revision 2)' (U.S. Nuclear Regulatory Commission, October 2010), https://www.nrc.gov/docs/ml1029/ml102980443.pdf, 2–4.

IV.D 1974 to 2000+ Three Mile Island, Industry Self-Governance, and Nuclear Revival

A major accident at the Three Mile Island (TMI) power plant in 1979 led to a considerable transformation of nuclear power safety in the US. The accident began with a minor fault—a pressure relief valve malfunctioned—but compounding equipment and managerial failures, in addition to inadequate operator training, led to severe damage to the reactor core.[103] A series of protective measures, indicative of the defence-in-depth approach of the NRC, prevented harmful levels of radiation from escaping the plant.[104] Despite this, the credibility of the NRC and the nuclear industry was harmed, and a commission was formed to investigate the accident.

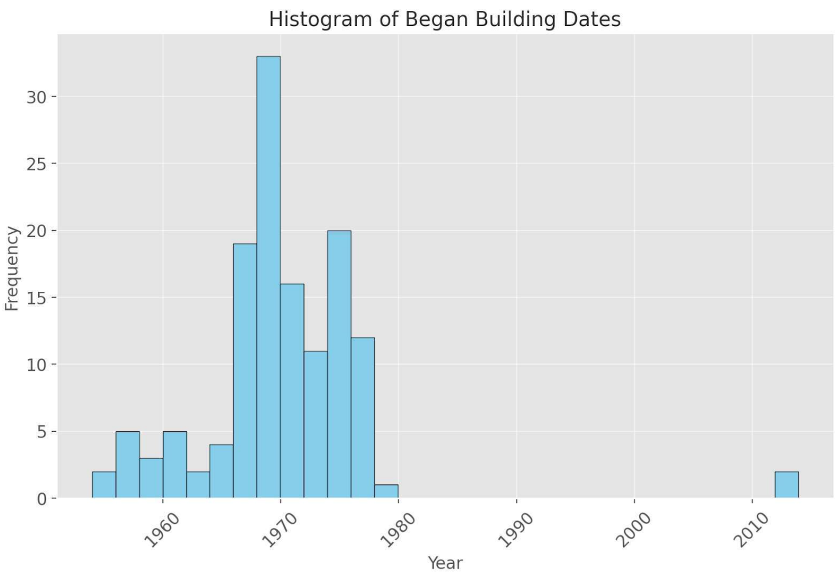

Figure 3: *Histogram of the number of nuclear power plants that started construction in a given year.*[105]

In response to the commission's findings, the NRC introduced new regulation, including stricter requirements for worker training and testing, and expanded its resident

[103]The President's Commission on the Accident at TMI, 'Report of the President's Commission on the Accident at Three Mile Island: The Need for Change: The Legacy of TMI', October 1979, http://large.stanford.edu/courses/2012/ph241/tran1/docs/188.pdf.

[104]Arthur C. Upton, 'Health Impact of the Three Mile Island Accident', *Annals of the New York Academy of Sciences* 365, no. 1 (1981): 63–75, https://doi.org/10.1111/j.1749-6632.1981.tb18117.x.

[105]Wikipedia contributors, 'List of Commercial Nuclear Reactors', in *Wikipedia*, 2024, https://en.wikipedia.org/w/index.php?title=List_of_commercial_nuclear_reactors&oldid=1254877926#United_States.

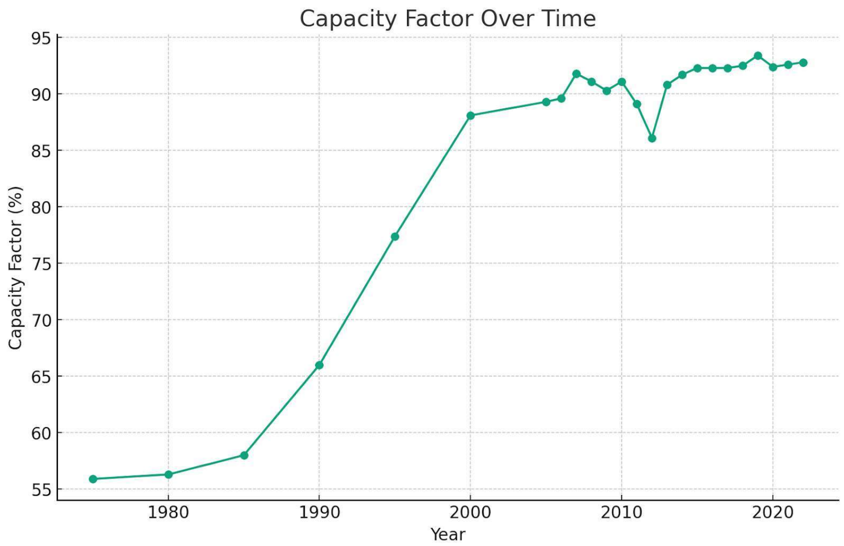

Figure 4: *Capacity factor is 'actual energy output over a certain period' divided by 'maximum possible energy output over that period'. Therefore, it measures how often plants need to be taken offline for maintenance, which is a good proxy for number and severity of minor faults.*[110]

inspector program.[106] The NRC adopted a new form of risk assessment (probabilistic risk assessment) and increased its scrutiny on plant culture and management as drivers of accident risk. The median cost of constructing a nuclear power plant increased by nearly 2.8x following TMI,[107] and since 1980, only two new power plants have begun construction in the US.[108] On the other hand, nuclear safety, as measured by how often plants have to shut down for maintenance, increased substantially in the years after TMI.[109]

The industry also committed to establishing and funding the Institute of Nuclear Power Operations (INPO), a nonprofit organisation dedicated to improving nuclear safety in the US. the INPO develops standards on plant operation, performs in-person plant

[106] Robert J. Budnitz, 'The Response of the Nuclear Regulatory Commission to the Accident at Three Mile Island', *Annals of the New York Academy of Sciences* 365, no. 1 (1981): 203–9, https://doi.org/10.1111/j.1749-6632.1981.tb18133.x.

[107] Jessica R. Lovering, Arthur Yip, and Ted Nordhaus, 'Historical Construction Costs of Global Nuclear Power Reactors', *Energy Policy* 91 (1 April 2016): 371–82, https://doi.org/10.1016/j.enpol.2016.01.011, Figure 3.

[108] Wikipedia contributors, 'List of Commercial Nuclear Reactors'.

[109] U.S. Energy Information Administration, 'Monthly Energy Review, Table 8.1 Nuclear Energy Overview'.

[110] U.S. Energy Information Administration, 'Monthly Energy Review, Table 8.1 Nuclear Energy Overview'.

evaluations, makes safety recommendations, lobbies the NRC, and accredits the safety training programs that individual power plants run for their workers.

The accident at the Chernobyl nuclear plant in 1986 led to the formation of another industry-led nonprofit, the World Association of Nuclear Operators (WANO). Unlike the INPO, the WANO is dedicated to improving nuclear safety at power plants across the world. The WANO took direct inspiration from the success of the INPO and performs peer evaluations of plant operations, collects and analyses performance data, sets standards, and organises conferences.[111]

1994 saw the formation of another industry group, the Nuclear Energy Institute (NEI), a trade association that now represents the whole US nuclear power industry. It includes, for example, suppliers and contractors as well as power plant operators. The NEI hosts conferences to facilitate collaboration between power companies,[112] lobbies Congress on behalf of the nuclear industry,[113] and produces and commissions reports on developments related to nuclear power.[114]

The NRC is involved at nearly every stage of building and operating a nuclear power plant. Utilities must first apply for a licence, submitting comprehensive safety plans covering all aspects of the plant's design and construction. The NRC monitors the plant's construction to ensure it aligns with the approved plans. Once a plant is operational, the NRC assigns resident inspectors to work onsite daily,[115] collects safety-relevant plant data,[116] and conducts external inspections to ensure ongoing compliance.[117]

Increased demand for energy and worsening attitudes to fossil fuels in the US led to a modest nuclear revival in the early 2000s. The nuclear safety regime awaiting these new plants, with its industry groups and dedicated national regulator, was fundamentally changed from that faced by the industry half a century earlier.

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[111]Philip Louis Cantelon, *Nuclear Safety Has No Borders: A History of the World Association of Nuclear Operators* (World Association of Nuclear Operators, 2016).

[112]Nuclear Energy Institute, 'Conferences', n.d., https://www.nei.org/conferences.

[113]Nuclear Energy Institute, 'Advocacy', n.d., https://www.nei.org/advocacy.

[114]Walker and Wellock, 'A Short History of Nuclear Regulation, 1946–2024 (NUREG/BR-0175, Revision 2)', 70–71;Nuclear Energy Institute, 'Resources Archive', n.d., https://www.nei.org/resources/resources-archive.

[115]U.S. NRC, 'Backgrounder on NRC Resident Inspectors Program', December 2022, https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/resident-inspectors-bg.html.

[116]U.S. NRC, 'Inspection Manual by Cornerstone: Initiating Events', 2024, https://www.nrc.gov/reactors/operating/oversight/rop-description/cornerstone.html.

[117]U.S. NRC, 'ROP Framework: Inspection Programs', 2024, https://www.nrc.gov/reactors/operating/oversight/rop-description.html.

V Lessons from the Evolution of Nuclear Safety in the US over the 20th Century

Lesson 5: Peer comparisons led to nuclear safety improvements

It is striking that the nuclear utilities voluntarily collaborate with the INPO, given that INPO membership has significant cost: up-front membership fees, disruption from in-person inspections on plant operation, and diverted money to comply with inspection safety recommendations. But the INPO takes several steps to make it more likely that utilities voluntarily comply with their safety recommendations.

They work closely with nuclear utility executives, including with CEOs and boards of directors. The INPO uses regular peer comparison to incentivise executives to improve safety, which one INPO official described as preying on the fact that 'executives tend to want to compare their plant to other plants and want to be better than the next guy.'[118] Each year, the INPO gives every utility a safety score, based on the number and importance of unimplemented INPO recommendations.[119] At an annual private 'Executives Conference', the INPO president announces to all attendees the relative ranking of each utility.[120] CEOs are handed a summary report and list of safety recommendations. Further, the INPO asks that each CEO deals with the INPO's inspection response and the utility's response and 'strongly urges' that the CEO pass both documents onto their board of directors.[121] [122]

The INPO cannot force utilities to comply with its recommendations, but the organisation follows an escalation process for noncompliance with critical recommendations. First, the INPO president makes a personal call to the CEO of the utility in noncompliance. Then, if insufficient progress is made, members on the INPO board—often *other* utilities' CEOs—contact the CEO of the noncompliant utility. If necessary, these board members may escalate the issue to the utility's full board of directors. As a last resort, the utility faces expulsion from the INPO.[123]

The INPO's actions do not have much of an effect on the finances of utilities—the INPO shares inspection reports and other data with the utility's insurer, but this has

[118] Joseph V. Rees, *Hostages of Each Other: The Transformation of Nuclear Safety since Three Mile Island* (Chicago: University of Chicago Press, 1996), 147.
[119] Rees, *Hostages of Each Other*, 147.
[120] Rees, *Hostages of Each Other*, 108.
[121] Rees, *Hostages of Each Other*, 209.
[122] Rees, *Hostages of Each Other*, 98.
[123] Rees, *Hostages of Each Other*, 109.

a negligible effect on their insurance rates.[124] However, after Three Mile Island, US nuclear power utility companies set up the joint insurance company Nuclear Electric Insurers Ltd. (NEIL) to prevent an individual utility from bankruptcy in the event of another accident. This means that leaving or being ejected from the INPO would also have an adverse effect on insurance rates.[125] Notably, at one point it looked like the INPO might be even more closely tied to insurance: under initial plans, any plant that failed an INPO inspection would be removed from NEIL, with large financial consequences. This measure, however, was not implemented.[126]

Insights for AI

Recommendation V: Use peer-shaming to encourage safety compliance among AI firms. (Industry Consortia)

The INPO had success in encouraging power plants to adhere to its safety standards. In order to achieve similar levels of compliance with voluntary safety recommendations, safety-focussed AI industry groups like the Frontier Model Forum should use similar tactics.

Such a safety-focussed industry group should encourage compliance with its safety recommendations by inviting the CEOs of major AI firms and announcing each company's safety ranking to the room, and, through the group director, personally contacting CEOs to encourage them to prioritise safety recommendations. For the latter to work well, it would be important for the group director to have a close working relationship, and effective lines of communication, with each CEO. This industry group may also ask that its recommendations and reports about a company get sent to that company's board. OpenAI[127] and Anthropic[128] have the stated missions to 'build artificial general intelligence that is safe and benefits all of humanity' and 'ensure transformative AI helps people and society flourish', respectively. Given these missions, and that the board members have no financial stake in the companies, we might expect these boards to take such safety reports unusually seriously.

[124] Rees, *Hostages of Each Other*, 209 footnote 11.

[125] Robert F. Willard, 'The Role of the Institute of Nuclear Power Operations in Supporting the United States Commercial Nuclear Power Industry's Focus on Nuclear Safety' (Institute of Nuclear Power Operations, 13 November 2019), https://www.epw.senate.gov/public/_cache/files/7/3/736241ed-3922-4144-a905-b965bb1cbe88/A7587FA91CC97E396A67DF16C8D4665A.willard-testimony-11.13.2019.pdf.

[126] Rees, *Hostages of Each Other*, 94.

[127] OpenAI, 'Our Structure', n.d., https://openai.com/our-structure/.

[128] Anthropic, 'The Long-Term Benefit Trust', 19 September 2023, https://www.anthropic.com/news/the-long-term-benefit-trust.

Lesson 6: Proactive voluntary safety initiatives from industry bodies went on to shape nuclear power regulation

There are multiple occasions where INPO activities have influenced later NRC rules or guidance. After Three Mile Island, workforce training became a core safety priority in the US, with Congress directing the NRC to work out a system for accrediting training programs for a variety of plant workers. While the NRC and the newly formed the INPO each started developing their own programs, the NRC ended up simply endorsing the INPO's plans; this decision was partly motivated by a desire to protect nascent industry accreditation efforts.[129] By 1985, the INPO had accredited 131 training programs at nuclear plants.[130]

The story of operational experience sharing is similar: in 1980, the NRC started developing a system for collecting detailed descriptions of hardware reliability data and significant events (e.g., cyber-attacks, operator failures). But ultimately the NRC ended up endorsing the INPO's SEE-IN and NPRDS systems instead.[131]

A series of performance indicators—objective safety metrics like 'collective radiation exposure at a plant in man-rem per unit'—were developed by the INPO in the mid 1980s to inform their utility rankings.[132] From 1997, these became an important part of how the NRC audits the day-to-day operation of nuclear plants with the launch of the Reactor Oversight Process. Separately, one nuclear engineer recounts that 'the Department of Energy is implementing the INPO standards [on safety and pollution at nuclear weapons plants] just about verbatim'.[133]

Insights for AI

Recommendation VII: Introduce stricter reporting requirements in order to mitigate the early mover advantage of frontier AI firms. (National Regulators)

In nuclear power, the INPO influenced NRC regulations and guidance by moving early and creating its own safety standards. With AI, voluntary safety initiatives like

[129]NRC, 'Training and Qualification: January 1983 to Present' (Nuclear Regulatory Commission, n.d.), https://www.nrc.gov/docs/ML1625/ML16257A453.pdf.
[130]NRC, 'Training and Qualification: January 1983 to Present'.
[131]Rees, *Hostages of Each Other*, 198.
[132]Rees, *Hostages of Each Other*, 98.
[133]Rees, *Hostages of Each Other*, 4.

Anthropic's Responsible Scaling Policy and OpenAI's Preparedness Framework[134] may play a role in shaping US domestic regulation. For example, California's state bill SB-1047 would have required AI firms to write and implement 'Safety and Security Protocols' which specify procedures for testing model safety in a similar manner to these voluntary frameworks.[135] This suggests that working on voluntary safety measures could be an important route towards influencing regulation.

Industry bodies are particularly well suited to put in place first-of-their-kind safety measures, like responsible scaling policies, because they represent the firms that will implement the controls. This gives the groups easier, voluntary access to the relevant companies and their current processes, allowing them to craft concrete standards that achieve the goals they care about.

However, AI companies are less likely than other firms to internalise all the harms they cause to others. One cause is that it may be harder to attribute harms caused by AI systems compared to those caused by nuclear plant accidents. With nuclear power, any accident is localised in space around the nuclear plant, whereas harms from AI systems may come from data centres anywhere in the world. Another cause is due to tort law: some damages caused by AI systems may not be compensable for practical reasons if they are particularly catastrophic, or they may not be covered under current US tort law (e.g., political misinformation may not be compensable).[136]

Conversely, government regulators are likely to have a lot less detailed knowledge about the processes of individual companies, making it harder for them to craft precise safety standards.[137] Governments could ameliorate this by requiring companies to report information around, for example, security practices, organisational processes, and design decisions at each stage of model development.[138]

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[134] Anthropic, 'Anthropic's Responsible Scaling Policy.' 15 October 2024, https://assets.anthropic.com/m/24a47b00f10301cd/original/Anthropic-Responsible-Scaling-Policy-2024-10-15.pdf and OpenAI, 'Preparedness Framework (Beta)', 18 December 2023, https://cdn.openai.com/openai-preparedness-framework-beta.pdf.

[135] Scott Wiener et al., 'Safe and Secure Innovation for Frontier Artificial Intelligence Models Act', Cal. SB-1047 (2024), https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202320240SB1047.

[136] Gabriel Weil, 'Tort Law as a Tool for Mitigating Catastrophic Risk from Artificial Intelligence' (SSRN, 13 January 2024), https://doi.org/10.2139/ssrn.4694006.

[137] Edward J. Kane, 'Accelerating Inflation, Technological Innovation, and the Decreasing Effectiveness of Banking Regulation', NBER Working Paper (SSRN, 1 March 1981), https://papers.ssrn.com/abstract=227138.

[138] Noam Kolt et al., 'Responsible Reporting for Frontier AI Development' (arXiv, 3 April 2024), https://doi.org/10.48550/arXiv.2404.02675.

Lesson 7: Nuclear industry safety groups created safety standards for management and operational processes

The INPO has been particularly influential in shaping safety practices related to operational experience, management, and culture. Its safety recommendations focus on core management and operational issues such as 'training,... procedures,... supervision.' the INPO places significant emphasis on ensuring licensee CEOs take its recommendations seriously. Each year, the INPO president publicly announces the relative safety ranking of each utility at the annual Executives Conference. After Three Mile Island, the INPO set up the Significant Event Evaluation and Information Network (SEE-IN), which allowed utilities to exchange data on hardware component reliability. These efforts are correlated with the reduction in risk post-1979, as seen by the increase in capacity factor since then.[139] Although some actors believe that these efforts caused a reduction in risk,[140] it is out of scope for this paper to evaluate these arguments.

Prior to the Three Mile Island incident, the NRC did not place much focus on issues related to culture or plant management.[141] After the incident, the NRC was directed[142] to pay closer attention to these areas, but its efforts often faltered. While the NRC initially attempted to create its own standards for management and organisational structure, it ultimately abandoned these efforts, choosing to accept the INPO's corporate evaluations instead.[143] The NRC introduced the Systematic Assessment of Licensee Performance (SALP) program to evaluate utilities' management practices, but this faced resistance. One utility noted that 'NRC inspectors should not be evaluating licensee management and management systems.'[144] Even within the NRC, there were mixed feelings about how deeply the agency should get involved in management, with one official explaining that the NRC 'is a heavy technical agency' and its staff are relatively uncomfortable with management issues.[145] The SALP program was discontinued in 2000.

[139] U.S. Energy Information Administration, 'Monthly Energy Review, Table 8.1 Nuclear Energy Overview'.

[140] Zack T Pate, 'Born of TMI, the Institute of Nuclear Power Operations Promotes Excellence', *IAEA Bulletin* 28, no. 3 (1986): 60–62, https://www.iaea.org/sites/default/files/publications/magazines/bulletin/bull28-3/28304796062.pdf.

[141] Rees, *Hostages of Each Other*, 31, 32.

[142] Jon F. Elliott, 'The Kemeny Report on the Accident at Three Mile Island', *Ecology Law Quarterly* 8, no. 4 (1980): 810–17, https://doi.org/10.15779/Z38KZ5K.

[143] Rees, *Hostages of Each Other*, 38.

[144] Rees, *Hostages of Each Other*.

[145] Rees, *Hostages of Each Other*.

Insights for AI

Recommendation II: Establish consensus-based minimum safety standards, with the participation of AISIs and national regulators in working groups. (Industry Consortia)

AI industry bodies like the Frontier Model Forum and NIST Consortium are particularly well-placed to establish voluntary minimum standards around safe management and operational processes, and to ensure these standards are broadly adopted by frontier AI firms.

An example of management and operational process is given by the OpenAI Preparedness Framework, which describes the procedures by which safety decisions are made (the Preparedness team is responsible for creating criteria for designating model risk levels and then evaluating models, the Safety Advisory Group makes mitigation recommendations if those risks are deemed *high,* and these measures are then approved by the Leadership).

As noted in Lesson 6, the industry bodies are better suited than governments are to craft concrete standards because, as representatives of firms, they have voluntary access to the relevant companies and their current processes; for example, the Frontier Model Forum and NIST Consortium are made up of frontier AI firms like OpenAI, Anthropic, and Google DeepMind.[146]

Lesson 8: Major nuclear power accidents caused significant increases in voluntary safety initiatives, coordinated by industry bodies

The degree of safety cooperation between nuclear power firms is strikingly high—one surprising function involves loaned employees performing a two-week in-person safety inspection at *another* companies' plant and writing a safety recommendation report.[147] But this level of cooperation only emerged after two highly salient incidents.

The Three Mile Island incident led to more cooperation between utilities within the US. One regulatory official described the industry prior to this as 'fragmented', with

[146] Kane, 'Accelerating Inflation, Technological Innovation, and the Decreasing Effectiveness of Banking Regulation'.

[147] Rees, *Hostages of Each Other*, 54, 55.

each utility acting as if it were a 'fiefdom'. Nuclear utilities rarely interacted with each other.[148] In the face of a large regulatory backlash after Three Mile Island, it became salient to the utilities that they were interdependent. One executive described the shift in attitude from 'not my brother's keeper' to one of 'everything my brother does is going to affect me'.[149] The INPO was set up to head off this threatened increase in regulation and also to stop similar accidents happening in the future.

The Chernobyl incident led to deeper international cooperation, coordinated by the WANO. Prior to Chernobyl there had been some international cooperation, with about half of nuclear power operators outside of the Soviet Union taking part in the INPO International Participant Program (IPP).[150] Notably, the WANO has in its membership all major civil nuclear states (US, Russia, France, Japan, China, etc.) and many other countries. The WANO performs many similar functions to the INPO, including conducting peer evaluations, facilitating information sharing and hosting workshops.[151]

We speculate that the following mechanism explains why an accident increases industry cooperation: 1) public opinion or attention puts pressure on the regulator as a result of the accident, 2) a regulatory backlash follows or is feared to follow, and 3) firms recognise that they are interdependent and start to cooperate more.

The public had some negative associations with nuclear power even prior to Three Mile Island due to concern over fallout from atmospheric testing of nuclear weapons and the dumping of nuclear radiation waste in oceans. In the 1960s, protests against proposed power plants in New York City and Bodega Bay, California, led to the plants being cancelled.[152]

Notably, even after the period of intense public and congressional scrutiny on nuclear power utilities in the wake of these accidents had subsided, INPO activities helped maintain a high level of cooperation between firms. The INPO runs workshops on all manner of topics related to safety such as 'emergency preparedness, maintenance, [. . .] and radiological protection'.[153]

After Three Mile Island, the INPO established the Significant Event Evaluation and Information Network (SEE-IN) to enhance safety reporting. Under this program, utilities

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[148] Rees, *Hostages of Each Other*, 43.

[149] Rees, *Hostages of Each Other*, 45.

[150] Cantelon, *Nuclear Safety Has No Borders: A History of the World Association of Nuclear Operators*, 5.

[151] WANO, 'Services and Support', n.d., https://www.wano.info/services-and-support/.

[152] Walker and Wellock, 'A Short History of Nuclear Regulation, 1946–2024 (NUREG/BR-0175, Revision 2)', 22–24.

[153] Rees, *Hostages of Each Other*, 59.

notify the INPO of any safety-related incidents, such as equipment failures or near-miss accidents. The INPO reviews these reports and issues concrete recommendations to the utilities.[154] Additionally, up to half of an INPO inspection team consists of 'peer evaluators'—employees from other plants are loaned to the INPO for a three-week period: one week to prepare and 2 weeks to conduct the evaluation.

Insights for AI

Recommendation III: Develop the capacity to investigate and recommend mitigations in response to major AI incidents. (Industry Consortia)

Any major accidents caused by AI systems are likely to lead to changes to safety standards and regulation. This happened in the nuclear power industry in the US after the Three Mile Island accident, when the INPO was set up and created voluntary safety standards, and the NRC put in place extra regulation.

If an AI accident does occur, an industry body should have the capacity to investigate the causes of the accident and to recommend mitigations so that accidents are less likely in the future. As detailed in Lesson 7, industry groups may be particularly well suited to investigating how a company's operations, management, and training may have contributed to an accident, and also to developing and auditing safety standards on these three areas in order to reduce the chance of future accidents.

[154] Rees, *Hostages of Each Other*, 126, 127.

VI Summary of Lessons from Aviation and Nuclear Power

	Lessons from the Aviation Industry
1	**Anonymised incident monitoring systems provided essential data to regulators and were acceptable to firms.** Anonymised incident monitoring systems, such as the IATA's Safety Trend Evaluation and Data Exchange System (STEADES), play a critical role in supporting safety oversight of aircraft manufacturing and operations while promoting trust between aviation firms and regulators. By ensuring reports are de-identified, STEADES reduces the reputational and regulatory risks for participating airlines, which encourages voluntary reporting. This system enables firms to benchmark their performance against industry-wide data and helps regulators track safety trends without punitive measures, thereby fostering a collaborative safety culture across the aviation industry.
2	**Two factors made the participation of airlines in voluntary safety initiatives more likely: (i) commercial incentives to cooperate on non-safety issues and (ii) opportunities to reduce regulatory burden.** Airlines were incentivised to participate in safety initiatives like the IATA's Operational Safety Audit (IOSA) because IATA membership—offering reputational benefits and commercial opportunities, such as route coordination and fare negotiations—required firms to comply with IOSA standards. The IOSA itself was developed to lower compliance costs by minimising redundant audits across multiple regulatory jurisdictions, thus streamlining the process for airlines to meet safety requirements while still enjoying the commercial advantages of IATA membership.
3	**Outsourcing of safety oversight to firms allowed for striking improvements in aviation safety, despite a relative decline in regulatory funding.** A 96% reduction in global aviation fatalities over 50 years was achieved despite declining regulatory budgets, partly due to the outsourcing of safety oversight to industry experts. Programs like the FAA's designee system licensed factory workers and airline staff to conduct inspections and certify pilots and equipment, while the Continuing Analysis and Surveillance System (CASS) tasked airlines with auditing their maintenance programs. These measures enabled regulators to focus on high-risk areas by leveraging industry expertise, reducing direct regulatory burdens, and maintaining safety improvements through strong trust and shared safety goals.
4	**Voluntary safety initiatives and national standards enforcement increased compliance with international standards.** Voluntary industry-led safety initiatives, like the IATA's IOSA programme, and national regulatory enforcement, such as the FAA's International Aviation Safety Assessment (IASA), have been crucial in increasing global compliance with the ICAO's Standards and Recommended Practices (SARPs). The FAA's IASA targets national oversight systems by limiting the operations of noncompliant airlines, while the IOSA focuses on airlines directly, mandating compliance with rigorous safety standards to maintain operational benefits like strategic partnerships. Together, these initiatives have filled the enforcement gap left by the ICAO's limited enforcement capacity, improving international aviation safety compliance.

	Lessons from the Nuclear Power Industry
5	**Peer comparisons led to nuclear safety improvements.** The INPO encourages nuclear utilities to follow its safety recommendations through regular peer comparisons and INPO leadership having close personal relationships with utility executives and boards. Each year, the INPO assigns safety scores to utilities and presents the rankings at an exclusive executives' conference. This process, combined with a structured escalation process for noncompliance, applies pressure to encourage utilities to take corrective actions.
6	**Proactive voluntary safety initiatives from industry bodies went on to shape nuclear power regulation.** The INPO's close ties with nuclear utilities gave it an early mover advantage, allowing it to implement voluntary safety initiatives quickly and effectively. The NRC endorsed the INPO's workforce training accreditation programs instead of developing its own, and went on to adopt the INPO's SEE-IN and NPRDS data-sharing systems. The NRC's decision to incorporate the INPO's performance indicators into its Reactor Oversight Process further highlights how the INPO's industry-driven initiatives shaped US nuclear safety standards and regulatory practices.
7	**Nuclear industry safety groups created safety standards for management and operational processes.** The INPO focused its resources on improving management and operational safety, while the NRC struggled to implement rules in these areas. For instance, the INPO created standards around utility corporate office structure and promoted operational safety by establishing the Significant Event Evaluation and Information Network (SEE-IN), which facilitated information sharing on equipment failures. The NRC attempted to issue rules around management through its Systematic Assessment of Licensee Performance (SALP) program, but this was heavily criticised both inside and outside the NRC and was eventually discontinued.
8	**Major nuclear power accidents caused significant increases in voluntary safety initiatives, coordinated by industry bodies.** Major accidents revealed that an incident at one plant could lead to widespread regulatory scrutiny and negative impact for the entire industry. Following the Three Mile Island accident, utilities recognised voluntary safety efforts could help prevent future incidents and reduce the chance of a regulatory backlash. This led to the establishment of the INPO, which fostered safety cooperation through initiatives like the Significant Event Evaluation and Information Network (SEE-IN), which facilitated information sharing on equipment failures and safety risks. The Chernobyl disaster similarly spurred international collaboration through the WANO, leading to an expansion of peer evaluations and safety workshops across major nuclear power nations.

VII Our Recommendations

	Recommendations for Industry Consortia	Supporting Lesson(s)
I	**Facilitate anonymised incident monitoring systems** In order to bring incident reporting practices in line with the standard in aviation and nuclear power, AI industry consortia should establish anonymised incident monitoring systems to support voluntary sharing of operational experience and safety data. The aviation industry's Safety Trend Evaluation and Data Exchange System (STEADES) and the nuclear industry's Significant Event Evaluation and Information Network (SEE-IN) demonstrate that firms are more likely to participate in voluntary incident reporting when data is anonymised and managed by a trusted third party. This reduces reputational risks while promoting transparency and improving industry-wide safety standards. Such systems can enhance cooperation among frontier AI firms and support the early detection and mitigation of risks posed by AI models.	1,8
II	**Establish consensus-based minimum safety standards, with the participation of AISIs and national regulators in working groups** AI industry consortia, such as the Frontier Model Forum and NIST Consortium, are well-positioned to establish consensus-based minimum safety standards by leveraging the expertise and operational insights of frontier AI firms. Involving both national regulators and AI safety institutes in working groups adds legitimacy and increases the likelihood that these processes will serve the public interest and support national and international regulations. Such legitimacy was essential in promoting broad cross-industry adoption of voluntary safety standards in the aviation industry, as it had an important coordinating effect on airlines.	4,7
III	**Develop the capacity to investigate major AI incidents and recommend mitigations in response** AI industry consortia should develop the capacity to investigate incidents and make mitigation recommendations in order to bring the sector in line with the safety standard in nuclear power and aviation. In the nuclear industry, major incidents like Three Mile Island led to new voluntary and regulatory safety initiatives. Given their close ties to frontier AI firms, AI consortia are well-placed to perform investigations into incidents and then make concrete recommendations to firms to avoid such incidents in the future. They are especially well-placed to make recommendations on AI firms' operations, management, and training.	8
IV	**Encourage cross-industry cooperation beyond safety** AI industry consortia should promote cooperation on topics beyond safety, such as cybersecurity, operational excellence, and novel model evaluations, to build the foundation for future safety initiatives. In aviation, the IATA initially focused on issues like logistics and reducing redundant audits, which paved the way for key safety programs such as the IATA Operational Safety Audit (IOSA). Similarly, fostering collaboration in the AI industry on non-safety topics can strengthen trust and communication, creating the necessary groundwork for more effective safety cooperation in the future.	2

V	**Use peer-shaming to encourage safety compliance among AI firms** AI industry consortia can leverage peer-shaming—by benchmarking safety performance against industry standards—to pressure safety laggards into compliance. In the nuclear industry, the INPO uses peer comparisons, safety rankings, and direct communication with CEOs to incentivise utilities to improve their safety practices. Similarly, AI consortia like the Frontier Model Forum can employ peer-shaming by publicly or privately ranking member firms based on safety performance and directly engaging with CEOs to prioritise safety improvements. This can be further reinforced by involving firms' boards of directors, ensuring that safety concerns are taken seriously at the highest levels of leadership.	5
	Recommendations for National Regulators	**Supporting Lesson(s)**
VI	**Prioritise frontier AI and high-stakes oversight and delegate lower-risk safety functions to firms** Regulators should focus on direct oversight of frontier AI models and high-stakes applications, while delegating lower-risk safety functions to firms where incentives align with safety, ensuring sufficient capacity to monitor the most critical areas.	3
VII	**Introduce stricter reporting requirements in order to mitigate the early mover advantage of frontier AI firms** National regulators should introduce stricter reporting requirements for frontier AI firms in order to improve oversight and reduce reliance on voluntary industry initiatives in critical areas. This could include information around cybersecurity practices, organisational processes, and model design decisions.	6

Conclusion

This paper has examined the history of voluntary safety initiatives in the aviation and nuclear power industries to produce findings for frontier AI safety. Through two historical case studies, we have highlighted eight lessons related to the role of voluntary safety initiatives in aviation (Lessons 1–4) and nuclear power (Lessons 5–8), with an emphasis on the US throughout the 20th century. We have identified parallels with frontier AI, offering five recommendations for industry consortia and two for national regulators, which we argue will help to mitigate harms associated with frontier AI technologies and promote AI safety.

In the aviation industry case study, industry groups promoted cross-industry safety collaboration by linking safety compliance to commercial incentives and fostering anonymised incident reporting (Lessons 1 and 2). Outsourcing safety oversight allowed regulators to allocate limited resources more efficiently (Lesson 3), while voluntary certifications filled compliance gaps in international standards enforcement (Lesson 4). In the nuclear power case study, industry groups leveraged their early mover advantage and cross-industry peer comparisons to shape regulatory practices and drive safety improvements (Lessons 5 and 6). Industry groups also played a key role in advancing safety in areas like management and operational practices, addressing gaps in government oversight (Lesson 7). Accidents catalysed greater collaboration, with subsequent initiatives consolidating safety practices and expanding cooperation internationally (Lesson 8).

We argue that industry consortia should create anonymised incident monitoring systems (Recommendation I); establish consensus-based minimum safety standards, with regulator and AISI participation in working groups (Recommendation II); and develop capacity to investigate and respond to any major AI accidents (Recommendation III). They should also encourage cooperation in areas beyond safety (Recommendation IV) and use peer-shaming to promote safety compliance across AI firms (Recommendation V). National regulators should prioritise frontier AI and high-stakes AI deployment oversight and delegate lower-risk safety functions to firms (Recommendation VI). Regulators should also introduce stricter reporting requirements to mitigate the early mover advantage of frontier AI firms (Recommendation VII).

Further valuable research could be performed to examine voluntary safety initiatives in other safety-critical industries, such as biotechnology, pharmaceuticals, automobiles, commercial shipping, civil engineering, and process engineering. Investigating how consumer power and market structure influence participation in these initiatives would also be valuable, particularly through cross-industry comparisons. Additionally, econometric analysis could disentangle the relative impact of different factors on safety improvements in aviation, nuclear power, and other industries. Tools such as difference-in-differences, instrumental variable (IV) regression, and propensity score matching could help to identify causal relationships between regulatory changes, industry cooperation, and safety outcomes.

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A History of the IOSA and ISARPs

In February 2001, the IATA director general created the IOSA Advisory Group (IAG) to establish the IOSA as an 'internationally recognised evaluation system by which the level of competence and reliability of an airline to deliver a safe operation and manage attendant risks may be assessed'[155]. The IOSA was initially conceived as a voluntary audit program, aimed at complementing the existing audit programs of national regulators and the ICAO.

In line with the IAG terms of reference,[156] membership of the IAG consisted of airlines (representing each global alliance group), national and regional airline associations, international and national regulatory authorities (including the ICAO, FAA, and US Department of Defense), and additional technical and auditing experts.[157] Eight IAG meetings were held between 2001 and the implementation of the IOSA in 2003.

Under the supervision of the IAG, twelve IOSA task forces consisting of aviation experts were created. These task forces held the responsibility for developing a series of aviation safety standards to act as the foundation of the IOSA initiative.[158] The task forces had to ensure that the standards were rigorous enough so that regulators would consider the IOSA to be a suitable replacement to existing audits, whilst minimising the cost of compliance with the standards for the airlines and the IATA itself.

In creating the IOSA Standards and Recommended Practices (ISARPs), the task forces drew heavily on the ICAO's Standards and Recommended Practices (SARPs) and the Air Transport Association's (ATA) standards for code-share operational reviews. There are now over 1000 ISARPs, divided into 8 functional areas.[159] The ISARPs in each functional area are at least as rigorous as the corresponding ICAO SARPs.

In addition to producing the ISARPs, the task forces established a process by which IOSA audits would be conducted every two years by independent audit organisations,

[155]Mills, 'The Interaction of Private and Public Regulatory Governance', referring to: Paul Woodburn, 'Safety Management Systems: Challenges and Benefits' (Slides, 19th Annual FAA/JAA International Conference, Phoenix, AZ, 4 June 2002).

[156]International Air Transport Association, Terms of Reference: IATA Operational Safety Audit (IOSA) Advisory Group (IAG) (International Air Transport Association, Montreal, 2001).

[157]Hodgkinson, 'Standardization and Business Development: The Global Impact of the IOSA Standards and the Value of Anticipation'.

[158]Hodgkinson, 'Standardization and Business Development: The Global Impact of the IOSA Standards and the Value of Anticipation'..

[159]Functional areas are Organisation and Management System, Flight Operations, Operational Control and Flight Dispatch, Aircraft Engineering and Maintenance, Cabin Operations, Ground Handling Operations, Cargo Operations, and Security Management. See: IATA, *IOSA Standards Manual (ISM)*.

which in turn would be accredited by the IATA.[160] Further, to encourage information exchange between airlines and regulators, the IATA implemented an audit findings sharing system, which permitted interested parties to view an airline's audit results, provided that this airline approved the request.[161]

Upon implementation of the IOSA, the IATA needed to overcome two core challenges to ensure the success of the program. Firstly, the IATA needed to convince regulators to recognise the IOSA as an acceptable alternative to existing audits. Secondly, the IATA needed to convince airlines to voluntarily participate in the program. While initial participation in the program was low—there were 39 IOSA audits completed in 2004[162] whereas there were over 200 IATA members[163]—a series of factors led to broad adoption of the program.

Firstly, in 2004 the FAA announced that the IOSA would be recognised as an acceptable audit for foreign airlines entering into code-sharing agreements with US airlines.[164] It is important to note that the FAA held membership in the IAG and that the IOSA explicitly drew on ATA code-sharing standards; both of these factors supported the FAA's 2004 decision. In turn, the FAA's decision helped demonstrate the value of the IOSA to airlines, leading to an increase in participation in the program.

In 2005, the IATA waived all IOSA program management fees and made IOSA standards freely available to members and non-members.[165] In the same year, the IATA launched its Partnership for Safety, which provided funding for African and Latin American airlines to conduct IOSA audits and meet technical standards.[166] Both measures expanded access to the IOSA program to smaller and less well-funded airlines.

In 2006, the ICAO published its Safety Management Manual, which directed all airlines to adopt some form of safety management system (SMS), with an audit component. This development increased demand for participation in the IOSA program because it offered airlines an easier pathway to satisfying the ICAO's requirement than establishing a new self-audit system would.[167]

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[160] Mills, 'The Interaction of Private and Public Regulatory Governance'.
[161] Mills, 'The Interaction of Private and Public Regulatory Governance', 48.
[162] Mills, 'The Interaction of Private and Public Regulatory Governance', 48.
[163] IATA, 'Annual Report 2005' (International Air Transport Association, 2005), https://www.iata.org/contentassets/c81222d96c9a4e0bb4ff6ced0126f0bb/annual-report-2005.pdf.
[164] Sabec, 'FAA Approves IATA's Operational Safety Audit (IOSA) Program: A Historical Review and Future Implications for the Airline Industry'.
[165] Mills, 'The Interaction of Private and Public Regulatory Governance', 48.
[166] Mills, 'The Interaction of Private and Public Regulatory Governance', 48.
[167] Mills, 'The Interaction of Private and Public Regulatory Governance', 48.

Ultimately, the ICAO's SMS guidance led the IATA to mandate participation in the IOSA for all IATA members in 2009; it has remained mandatory since. Following this development, 23 airlines lost membership to the IATA as a result of failing an IOSA audit.[168] IATA membership confers substantial benefits to airlines, such as providing opportunities to negotiate route-sharing agreements and strategic partnerships;[169] controversially, IATA events have historically been used by airlines to set passenger prices.[170] For this reason, the prospect of IATA membership represents a substantial incentive for IATA participation. As of September 2023, there are 418 airlines (accounting for roughly 90% of global air traffic[171]) listed on the IOSA registry,[172] out of an estimated ∼1100 active commercial airlines[173].

B Government-Initiated Aviation Industry Self-Surveillance Initiatives

The FAA employs a number of voluntary safety reporting programs, which allow it to leverage industry resources and information to boost safety oversight. The FAA uses this information to improve the targeting of its inspection and oversight programs.

In 1964, the FAA implemented the Continuing Analysis and Surveillance System (CASS). As part of this program, air carriers are required to carry out audits of the in-house or third-party maintenance programs they employ and 'correct deficiencies in the performance and effectiveness' of these programs.[174] A range of internal, external, scheduled, and unscheduled audits are required.[175] Centrally, CASS serves to reduce the likelihood of a non-airworthy aircraft being approved for service.[176]

[168] Mills, 'The Interaction of Private and Public Regulatory Governance', 48.

[169] Bedan Thendu et al., 'Influence of Strategic Alliances on the Performance of Airline Carriers Registered Under IATA: A Literature Based Review', *African Journal of Emerging Issues* 2, no. 2 (2020): 48–69, https://www.ajoeijournals.org/sys/index.php/ajoei/article/view/91.

[170] Hannigan, 'Unfriendly Skies'.

[171] European Aviation Systems Planning Group, 'EUR 2019 Annual Safety Report' (International Civil Aviation Organization, 2020), https://www.icao.int/EURNAT/EUR%20and%20NAT%20Documents/EUR%20Documents/EUR%20Annual%20Safety%20Reports/EUR%20ASR%202019.pdf, 14.

[172] 'IOSA, 'IOSA Registry', n.d., https://ic.iata.org/registry/iosa.

[173] Allan Jay, 'Number of Flights Worldwide in 2024: Passenger Traffic, Behaviors, and Revenue', FinancesOnline, 23 October 2024, https://financesonline.com/number-of-flights-worldwide/.

[174] Leonelli, 'Continuing Analysis and Surveillance System (CASS) Description and Models'.

[175] Leonelli, 'Continuing Analysis and Surveillance System (CASS) Description and Models', 7.

[176] FAA, 'AC 120-79A - Developing and Implementing an Air Carrier Continuing Analysis and Surveillance System'.

The FAA developed the Air Transportation Oversight System (ATOS) in 1998, which tailors oversight activities to the risk profile of each airline.[177] In order to target ATOS inspections, the FAA draws on a number of industry voluntary reporting programs, three of which are discussed below.

The Aviation Safety Reporting System (ASRS) was instituted in 1976 and provides industry personnel with a confidential reporting system to describe hazardous practices. Individuals who file reports are offered limited immunity from regulatory enforcement, which incentivises cooperation.[178] Similarly, the Aviation Safety Action Program (ASAP), which was instituted in 2002–2003, allows airline employees to report safety-relevant events in exchange for immunity for events detailed in the report.[179] The Voluntary Disclosure Reporting Program (VDRP), instituted in 2006, differs from ASRS and ASAP in that it permits airlines to report systemic safety-relevant issues, in exchange for reduced regulatory action.[180]

The FAA conducts analysis on the data collected through the ASRS, ASAP, and VDRP initiatives, and uses this analysis to target ATOS inspections and other oversight activities. Additionally, the FAA collaborates with industry to resolve issues raised through these initiatives. The FAA's voluntary safety reporting programs have proven especially successful because of a high level of trust within industry that the FAA will provide reportees with reduced regulatory enforcement.[181] Ultimately these programs have supported safety efforts and provided regulators with a deeper and more thorough organisational understanding of the aviation industry[182].

[177] FAA, 'Air Transportation Oversight System Version 1.2' (U.S. Department of Transportation, Federal Aviation Administration, 27 July 2007), https://www.faa.gov/documentLibrary/media/Notice/ND/N8900_11.pdf.

[178] Stephan J. Corrie, 'The US Aviation Safety Reporting System', SAE Technical Paper (Warrendale, PA: SAE International, 13 October 1997), https://doi.org/10.4271/975562.

[179] FAA, 'Aviation Safety Action Program', U.S. Department of Transportation, Federal Aviation Administration, 15 August 2024, https://www.faa.gov/about/initiatives/asap.

[180] FAA, 'Voluntary Disclosure', U.S. Department of Transportation, Federal Aviation Administration, 21 February 2024, https://www.faa.gov/hazmat/air_carriers/report_incident/voluntary_disclosure.

[181] Russell W. Mills and Dorit Rubinstein Reiss, 'The Role of Trust in the Regulation of Complex and High-Risk Industries: The Case of the U.S. Federal Aviation Administration's Voluntary Disclosure Programs', in *Trust in Regulatory Regimes*, ed. Frédérique Six and Koen Verhoest (Cheltenham, UK: Edward Elgar Publishing, 2017), 37–59, https://doi.org/10.4337/9781785365577.00006.

[182] Russell W. Mills and Dorit Rubinstein Reiss, 'Secondary Learning and the Unintended Benefits of Collaborative Mechanisms: The Federal Aviation Administration's Voluntary Disclosure Programs', *Regulation & Governance* 8, no. 4 (2014): 437–54, https://doi.org/10.1111/rego.12046.