AEROTOXIC SYNDROME AND THE FUTURE OF TOXIC TORT LAW: PROVING CAUSATION IN EMERGING ENVIRONMENTAL ILLNESSES

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Abstract

Modern toxic tort doctrine requires plaintiffs to prove causation through reliable scientific evidence. That requirement is hardest to operationalize in litigation over emerging environmental illnesses—conditions marked by mixed or low-dose exposures, long latency periods, heterogeneous symptom profiles, contested science, and regulatory inaction. For such illnesses, the scientific record often develops slowly and through convergent reasoning across toxicology, mechanistic inference, clinical observation, and partial exposure evidence rather than early epidemiological closure. Courts, however, often treat the absence of definitive population-level proof as dispositive, filtering claims out through threshold gatekeeping and procedural mechanisms before the evidentiary record can mature.

This Article uses Aerotoxic Syndrome—an illness linked to contaminated aircraft cabin air—as a case study in that mismatch. It argues that aerotoxic litigation is best understood as a pattern of merits avoidance driven by evidentiary expectations calibrated to mature science. The Article situates Aerotoxic Syndrome within its scientific and regulatory context, examines how modern causation doctrine and Daubert *can convert epistemic lag into premature legal defeat, and proposes a doctrinally modest recalibration. Courts should permit plaintiffs in emerging-illness cases to prove causation through transparent, methodologically disciplined weight-of-the-evidence reasoning that integrates epidemiology where available with toxicology, mechanistic pathways, exposure reconstruction, and clinically grounded inference.*

Introduction

Modern toxic tort law requires plaintiffs to establish causation through reliable scientific evidence.[1] That requirement is normatively defensible: Liability should rest on reasoned attribution rather than speculation.[2] In practice, however,

1. *See* Restatement (Third) of Torts: Phys. & Emot. Harm § 28 (Am. L. Inst. 2010); *see also* Daubert v. Merrell Dow Pharms., Inc., 509 U.S. 579, 590 (1993) ("[T]he requirement that an expert's testimony pertain to 'scientific knowledge' establishes a standard of evidentiary reliability.").
2. *See Daubert*, 509 U.S. at 590; Margaret A. Berger, *Upsetting the Balance Between Adverse Interests: The Impact of the Supreme Court's Trilogy on Expert Testimony in Toxic Tort Litigation*, 64 L. & Contemp. Probs. 289, 299–300 (2001).

the requirement is most difficult to operationalize in litigation involving emerging environmental illnesses—conditions characterized by mixed or low-dose exposures, long latency periods, heterogeneous symptom profiles, contested science, and regulatory inaction.[3] In such cases, scientific knowledge tends to develop slowly and across domains, rather than through early population-level closure.[4] Still, "some courts have insisted on an epidemiological threshold in toxic tort cases."[5] The mismatch between courts' understandings and the true nature of scientific inquiry can determine outcomes before the merits of causation are meaningfully tested.[6]

This Article examines that structural tension through the lens of Aerotoxic Syndrome, an illness allegedly linked to contaminated aircraft cabin air.[7] Most commercial aircraft rely on a bleed air system in which compressed air from jet engines is routed into the cockpit and passenger cabin without filtration designed to remove certain chemical contaminants.[8] During discrete "fume events" and routine operations, engine oil or hydraulic fluid may enter the air supply, introducing a mixture of potentially neurotoxic substances into the breathing environment of passengers and crew.[9] Flight crew have reported acute symptoms—including dizziness, headaches, and respiratory distress—as well as chronic neurological, cognitive, and respiratory impairments following repeated exposure.[10] Despite sustained reporting and toxicological research, Aerotoxic Syndrome remains contested within the medical community and

3. *See* Carl F. Cranor, Toxic Torts: Science, Law, and the Possibility of Justice 11–13 (2d. ed. 2016); Carl F. Cranor & David A. Eastmond, *Scientific Ignorance and Reliable Patterns of Evidence in Toxic Tort Causation: Is There a Need for Liability Reform?*, 64 L. & Contemp. Probs. 5, 12–13 (2001).

4. *See, e.g.*, Cranor & Eastmond, *supra* note 3, at 15–16 (describing benzene and other substances where scientific consensus emerged slowly); *cf.* Berger, *supra* note 2, at 298 ("Because direct proof of causation is usually unavailable, and experimentation on humans is ethically proscribed, plaintiffs must rely on the kind of evidence that scientists gather when they investigate a causal link between a substance and disease. Scientists use a number of methods based on reasoning by analogy and statistics.").

5. Cranor & Eastmond, *supra* note 3, at 29; *see* Berger, *supra* note 2, at 301–05; Lucinda M. Finley, *Guarding the Gate to the Courthouse: How Trial Judges are Using Their Evidentiary Screening Role to Remake Tort Causation Rules*, 49 DePaul L. Rev. 335, 348 (1999).

6. *See* Berger, *supra* note 2, at 292–93 (noting an increase in *Daubert* motions to exclude critical experts, with favorable rulings followed by motions for summary judgment); *id.* at 300 (noting courts may misunderstand "the boundaries of science" when evaluating scientific evidence); *id.* at 323–24 (describing how segmented admissibility review verges on sufficiency review and can deny any opportunity to be heard by a jury).

7. Jonathan Burdon, et al., *Health Consequences of Exposure to Aircraft Contaminated Air and Fume Events: A Narrative Review and Medical Protocol for the Investigation of Exposed Aircrew and Passengers*, 22 Env't Health 1, 2 (2023).

8. *Id.*

9. *Id.* at 2–5.

10. *Id.* at 6–11.

has not yet been formally recognized by U.S. or major international regulatory authorities.[11]

Aerotoxic litigation illustrates a broader doctrinal pattern. When plaintiffs allege injury from hazardous exposure under conditions of scientific uncertainty, defendants routinely challenge whether existing evidence reliably establishes causation.[12] Courts, applying modern gatekeeping doctrine under *Daubert v. Merrell Dow Pharmaceuticals, Inc.*[13] and its progeny, are tasked with excluding unreliable expert testimony while permitting scientifically grounded claims to proceed.[14] Yet in emerging-illness cases, the forms of evidence often readily credited as sufficient—robust epidemiological studies demonstrating a stable and statistically significant association—are the forms least likely to exist.[15] Exposure may be intermittent or poorly monitored; the relevant population may be small or difficult to define; and the alleged harm may involve variable chemical mixtures rather than a single agent.[16] In that setting, scientific

11. *See* Stephen E. Mawdsley, *Burden of Proof: The Debate Surrounding Aerotoxic Syndrome*, 57 J. Contemp. Hist. 959, 960–961, 966 (2022) (explaining that Aerotoxic Syndrome has not been formally recognized by aviation, occupational health, or public health regulators and that it remains contested due to several factors including disputed causation and a lack of standardized diagnostic criteria).
12. *See* Cranor & Eastmond, *supra* note 3, at 15; *see also* Cranor, *supra* note 3, at 261–62 (noting that defendants' use of "junk science" and tactics to manufacture doubt contribute to courts' judgements excluding evidence on the basis of uncertainty).
13. 509 U.S. 579 (1993).
14. *See id.* (assigning gatekeeping role for judges to admit only scientifically valid expert testimony); Gen. Elec. Co. v. Joiner, 522 U.S. 136, 146 (1997) (affirming broad judicial discretion to exclude expert testimony where the analytical gap between data and opinion is too great); Kumho Tire Co. v. Carmichael, 526 U.S. 137, 147–49 (1999) (extending *Daubert* gatekeeping framework beyond scientific knowledge to all expert testimony).
15. Cranor, *supra* note 3, at 220 ("[S]uch ideal studies appear to be the exception rather than the rule."); *see also* Finley, *supra* note 5, at 352 (observing that district courts in the Ninth Circuit have extended the interpretation of *Daubert* requiring epidemiological evidence showing a doubling of the risk to establish causation, applying that threshold even where no epidemiological studies of the product exist or the available studies remain preliminary); Cranor & Eastmond, *supra* note 3, at 9–10 (arguing that courts may have overgeneralized from atypical cases such as the Bendectin litigation, where unusually extensive epidemiological evidence existed, by demanding comparable epidemiological proof in other toxic-exposure cases despite the fact that high-quality epidemiological studies are unavailable for many substances, requiring experts instead to draw causal inferences from the totality of available scientific evidence).
16. *See* Nat'l Rsch. Council, Environmental Epidemiology, Volume 2: Use of the Gray Literature and Other Data in Environmental Epidemiology 50, 54 (1997) (noting that chemicals to which community populations are exposed "are often poorly or inadequately identified, complex mixtures may be the rule rather than the exception, and exposure routes are not well defined," and that these problems are compounded when the mixture varies across sites or time).

understanding typically develops through evidentiary inferences arising from toxicology, mechanistic evidence, and clinical observation.[17]

The absence of population-level proof can operate as a categorical bar when courts treat the *Daubert-Joiner* admissibility inquiry as a proxy for sufficiency and equate reliability with the outputs of mature epidemiology.[18] Through threshold relevance determinations, rigid application of *Daubert*'s reliability factors, or rulings that deem expert testimony admissible only if supported by epidemiological studies demonstrating at least a doubling of risk, courts exclude causation evidence before the record can fully develop.[19] The pattern that emerges is not necessarily a merits-based rejection of causation.[20] Rather, it is a form of merits avoidance driven by evidentiary expectations calibrated to well-established hazards rather than to developing scientific knowledge. In practical effect, epistemic lag becomes legal defeat.[21]

The allocation of uncertainty that results has systemic consequences. The governing standard of persuasion in civil litigation remains preponderance of the evidence; this does not require scientific consensus, regulatory recognition, or any particular form of proof.[22] Yet in some toxic tort cases, courts have treated the absence of epidemiological evidence demonstrating the requisite increase in relative risk as independently dispositive, converting a standard of persuasion into an evidentiary prerequisite.[23] The result is to collapse preponderance into

17. Cranor, *supra* note 3, at 144–45, 321–22.

18. Finley, *supra* note 5, at 348–50; *see* Steve C. Gold, *Causation in Toxic Torts: Burdens of Proof, Standards of Persuasion, and Statistical Evidence*, 96 Yale L.J. 376, 385–92 (1986) (explaining that courts' reliance on statistical epidemiology in toxic tort cases has led to a "collapse" of the distinction between the burden of proof and the standard of persuasion which in turn distorts proof standards, encourages rigid numerical thresholds, and narrows admissible causation evidence).

19. Finley, *supra* note 5, at 348–50*; see* Berger, *supra* note 2, at 307–08 (describing how stringent causation requirements can lead federal courts to exclude all plaintiff expert proof as "unreliable").

20. *See* Cranor & Eastmond, *supra* note 3, at 7 ("[T]hose . . . who have reliable, but not ideal, evidence may be disadvantaged because of courts' admissibility decisions. As a result, some litigants with meritorious cases will not receive compensation, and the wrong signals will be sent to those who manufacture, use, and dispose of substances, thus further reducing incentives reasonably to ensure the safety of substances.").

21. *See id.* (party with burden loses when ignorance exists); Berger, *supra* note 2, at 365–66.

22. *See* Gold, *supra* note 18, at 392; *see also* Cranor & Eastmond, *supra* note 3, at 15 ("When there is evidence that a plaintiff has been exposed to a defendant's substance, plaintiff must show that defendant's substance more likely than not causes the kind of injury from which plaintiff suffered (general causation) and that it more likely than not did cause plaintiff's injuries (specific causation).").

23. *See* Finley, *supra* note 5, at 348; Cranor & Eastmond, *supra* note 3, at 29; Michael D. Green, *Expert Witnesses and Sufficiency of Evidence in Toxic Substances Litigation: The Legacy of Agent Orange and Bendectin Litigation*, 86 Nw. U. L. Rev. 643, 670 (1992); Gold, *supra* note 18, at 385–92.

a demand for scientific closure that the standard does not require and that the underlying epistemology of emerging science cannot yet supply.

That concern does not counsel abandoning reliability requirements or relaxing plaintiffs' burdens categorically. False positives are genuine institutional risks: premature legal ratification of contested science, manipulation of flexible standards by partisan experts, and the systemic effects of expanded liability on defendants, insurers, and future litigation.[24] But false negatives carry costs as well: the foreclosure of potentially legitimate claims, the continued persistence of hazardous exposure conditions, and the erosion of any deterrent that liability might otherwise provide.[25] A framework that implicitly requires the most demanding form of proof at the earliest stage of disease recognition predictably allocates uncertainty to plaintiffs, forecloses claims before the record matures, and diminishes incentives for the further research that might eventually resolve that uncertainty.[26]

Aerotoxic Syndrome brings these dynamics into focus. A plaintiff alleging injury from cabin air contamination is unlikely to present a single study establishing a stable causal relationship between a variable exposure mixture and a heterogeneous symptom profile. The more plausible evidentiary record will consist of indicators distributed across domains: documentation of fume events; toxicological evidence regarding the neurotoxic or respiratory effects of relevant compounds; mechanistic accounts of biological pathways; temporal relationships between exposure and symptom onset; and clinically grounded differential diagnoses. The legal question is whether such a convergent record, if methodologically disciplined and transparently reasoned, can satisfy the ordinary civil standard—or whether the absence of epidemiological closure will foreclose adjudication as a matter of law.

This Article argues for a doctrinally modest recalibration.[27] In emerging environmental illness litigation characterized by structural constraints on research and a fragmented regulatory landscape, courts should permit plaintiffs to establish causation through transparent, methodologically rigorous

24. *See* Green, *supra* note 23, at 669–71 (describing criticisms of expert witness testimony); *see also* Stephen G. Breyer, Title 1, 3–4 (Fed. Jud. Ctr. ed., 2000) (outlining negative social consequences of false positives).

25. *See generally* Steve C. Gold, *The "Reshapement" Of The False Negative Asymmetry In Toxic Tort Causation*, 37 Wm. Mitchell L. Rev. 1507 (arguing that toxic tort courts developed causation-proof rules that collectively create a "false negative asymmetry" and that prevailing rationales do not justify systematically erring against plaintiffs); *see also* Cranor, *supra* note 3, at 212–13 (describing that "plaintiffs are substantially disadvantaged as a result of factors beyond their control and often because of the . . . failures of others" in post market contexts).

26. *See* Finley, *supra* note 5, at 373–74 (describing how causation law leads to "premature closure on scientific and public health issues that warrant further investigation").

27. The proposal is modest because it does not alter the burden of proof, does not require overturning *Daubert* doctrine, and is consistent with how leading scientific bodies reason about causation under uncertainty.

weight-of-the-evidence reasoning that integrates epidemiology where available with toxicology, mechanistic inference, exposure reconstruction, and clinically grounded analysis, while preserving *Daubert*'s insistence on reliability and fit.[28] This Article situates that proposal within a literature that has examined *Daubert*'s gatekeeping pathologies, toxic tort causation standards, and the epistemology of emerging science, and argues that existing doctrine already contains the resources for a more calibrated approach. Properly understood, this approach does not require relaxed standards but demands more epistemically honest ones.

The Article proceeds as follows. Part I situates Aerotoxic Syndrome within its scientific and regulatory context, examining the current state of research on cabin air contamination and the sources of ongoing contestation. Part II analyzes how modern causation doctrine structures proof in ways that predictably disadvantage emerging-illness plaintiffs, and Part III examines how *Daubert* gatekeeping can compound that disadvantage. Part IV places aerotoxic litigation in comparative perspective, drawing on asbestos, Agent Orange, and per- and polyfluoroalkyl substances (PFAS) to map the range of judicial responses to uncertainty. Part V surveys aerotoxic-related claims in U.S. courts, administrative adjudication, and foreign proceedings. Parts VI develops the normative stakes, and Part VII proposes doctrinal and procedural reforms designed to preserve reliability while ensuring meaningful merits adjudication.

I. Scientific and Regulatory Background

Aerotoxic Syndrome presents a familiar posture in environmental health: a plausible exposure pathway, persistent symptom reporting, and an evidentiary record dispersed across disciplines—paired with predictable limits on definitive epidemiology and a fragmented regulatory landscape. This Part does not attempt to resolve the underlying medical controversy or to establish Aerotoxic Syndrome as a formally recognized diagnosis. It aims to explain why the evidentiary profile of aerotoxic claims is structurally incomplete in precisely the ways modern toxic tort doctrine often treats as disqualifying. The features documented here are the same features that Parts II and III will show courts converting into threshold grounds for dismissal.

A. Scientific Overview of Aerotoxic Syndrome

Most commercial aircraft rely on a bleed air system in which compressed air drawn directly from jet engines is routed into the cockpit and passenger cabin without filtration specifically designed to remove chemical contaminants.[29] During routine operations, trace quantities of engine oil constituents

28. *See infra* Part VII.A–B.
29. Burdon, *supra* note 7, at 2.

may be present in the circulated air.[30] During fume events—episodes associated with mechanical failure or seal degradation—larger quantities of engine oil or hydraulic fluid may enter the air supply.[31] Thermal degradation of these fluids can generate a mixture of neuroactive and irritant compounds, including organophosphates such as tricresyl phosphate (TCP), volatile organic compounds, and ultrafine particles.[32]

Aerotoxic Syndrome refers to a "constellation of symptoms and health disorders" associated with exposure to this contaminated air supply.[33] Reported effects span neurological and neurobehavioral symptoms, respiratory irritation, fatigue-related manifestations, and sensitivity-type responses.[34] Symptoms are reported following both acute high-intensity exposure episodes and repeated low-level exposure over time.[35] The etiology remains contested, and Aerotoxic Syndrome is not recognized as a discrete disease entity by U.S. or major international medical or regulatory authorities.[36]

Two features of aerotoxic claims are particularly salient for legal analysis. First, the exposure mechanism is relatively well-defined: a known system architecture, identified chemical constituents, and documented failure modes.[37] The evidentiary challenge is characterizing its frequency, intensity, and chemical composition across the range of ordinary operations and discrete fume events. Second, the symptom profile is variable rather than uniform.[38] Reported effects may depend on exposure intensity and frequency, individual susceptibility, and differences in cabin conditions.[39] This variability complicates both clinical attribution and population-level study. Its significance for litigation is that the evidentiary record is likely to develop through partial, convergent indicators rather than through the kind of early epidemiological closure that tort doctrine has often treated as a prerequisite for causation.[40]

B. Why the Science Remains Contested

The scientific controversy surrounding Aerotoxic Syndrome does not arise from a single empirical disagreement. It reflects a convergence of methodological constraints characteristic of emerging exposure risks—constraints that make

30. *Id.*
31. *Id.*
32. *Id.* at 3–4.
33. *Id.* at 20.
34. *Id.*
35. *Id.*
36. *See* Gerard Hageman, et al., *Aerotoxic Syndrome, Discussion of Possible Diagnostic Criteria*, 58 Clinical Toxicology 414, 414 (2020).
37. *See* Burdon, *supra* note 7, at 2.
38. *Id.* at 6–7; Hageman, *supra* note 36, at 415.
39. Burdon, *supra* note 7, at 6.
40. *See id.* at 21–22.

robust causal inference difficult even where exposure signals and symptoms reporting persist.

The primary challenge is exposure characterization. Research has tended to focus on discrete fume events while giving comparatively little attention to the low-level contamination that may occur during ordinary aircraft operation.[41] Efforts to characterize exposures across both categories are further complicated by limited crew awareness and training, incomplete incident reporting, and the absence of onboard contaminant detection systems.[42] These factors obscure the prevalence of exposure and impede reliable characterization of its intensity, duration, and chemical composition.

Those characterization difficulties translate directly into study design constraints. In occupational and environmental health, randomized controlled trials are ethically unavailable; researchers depend on observational designs.[43] The designs most capable of supporting robust causal inference—prospective cohort studies tracking exposed and unexposed populations over time—are precisely the designs most difficult to implement for aircraft crew populations, which are limited in size, experience heterogeneous exposure circumstances across flights, and may exhibit health effects with long latency periods.[44] More feasible designs, such as case-control studies, are correspondingly more vulnerable to recall bias, exposure misclassification, and other sources of inferential uncertainty.[45] The result is a structural mismatch between the methodological demands of robust causal inference and the conditions under which aerotoxic exposure occurs.

The difficulty is compounded by the nature of the exposure itself. Aerotoxic hypotheses generally posit harm from intermittent exposure to thermally degraded mixtures of engine oils and hydraulic fluids rather than a single identifiable agent.[46] This is consistent with a broader pattern in environmental health science in which real-world risk arises from cumulative and combined exposures that single-chemical risk assessment methods fail to capture.[47] Mixed

41. *Id.* at 20.
42. *Id.*
43. Michael D. Green et al., *Reference Guide on Epidemiology*, in Reference Manual on Scientific Evidence 549, 555–56 (Fed. Jud. Ctr. & Nat'l Rsch. Council eds., 3d ed. 2011).
44. *See id.* at 557–58; Burdon, *supra* note 7, at 21.
45. *See* Burdon, *supra* note 7, at 21–22; Green et al., *supra* note 43, at 559–60; Kenneth J. Rothman, Sander Greenland & Timothy L. Lash, Modern Epidemiology 120–151 (3d ed. 2008) (discussing common sources of bias in observational epidemiology, including recall bias, exposure misclassification, and confounding); Green, *supra* note 23, at 649–54 (describing sources of error or "bias" that must be considered to appropriately asses the value of causal inferences generated from epidemiological studies).
46. *See* Burdon, *supra* note 7, at 3–4, 13, 21–22.
47. *See* Nat'l Rsch. Council, Science and Decisions: Advancing Risk Assessment 213 (2009), https://perma.cc/K5PN-P4GL (concluding that risk assessments centered on individual chemicals "do[] not accurately capture the risks associated with exposure, given

exposures complicate causal inference in two related ways. First, variation in the composition and concentration of contaminants across exposure episodes makes it difficult to construct consistent exposure metrics.[48] Second, the resulting health effects may not correspond to a single well-defined disease entity: reported symptoms span neurological, respiratory, and systemic domains and may be consistent with multiple plausible etiologies, making population-level signal detection correspondingly harder.[49]

For these reasons, the aerotoxic evidence base has developed largely through case reports, case series, descriptive studies, and toxicological and mechanistic inference.[50] Such sources do not establish causation independently. They nevertheless perform an important scientific function in emerging exposure contexts: identifying recurring symptom patterns, establishing biological plausibility, and generating hypotheses for more systematic evaluation. Gaps in population-level evidence in this setting reflect methodological constraint rather than the absence of risk.[51]

C. Regulatory Inertia and Fragmentation

The scientific uncertainty surrounding Aerotoxic Syndrome is compounded by a fragmented regulatory landscape in which no single agency bears clear responsibility for systematically monitoring cabin air quality or protecting flight crew from chronic chemical exposure. That institutional landscape helps explain why regulatory standards remain limited and why defendants may invoke agency nonrecognition as a proxy for safety—even when the regulatory record reflects jurisdictional constraint, incomplete monitoring, and developing science.

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simultaneous exposure to multiple chemical and nonchemical stressors and other factors that could influence vulnerability").

48. *See* Nat'l Rsch. Council, *supra* note 16, at 50 (identifying three central problems in studying complex-mixture exposures: quantification of exposure, characterization of combined or interactive effects, and identification of susceptible subpopulations, and noting that these problems are "multiplied where the mixture may vary from one site or time to another or when the mixture is not well characterized").

49. *See* Burdon, *supra* note 7, at 6–8, 14, 20–21 (documenting symptoms reported by aircrew following cabin air exposure, noting that affected individuals are frequently misdiagnosed with unrelated conditions, and acknowledging that the breadth and non-specificity of the symptom profile has complicated both clinical recognition and population-level epidemiological investigation).

50. *See id.* at 22.

51. *See id.* (noting "prior attempts to gather epidemiological data have been neither timely, comprehensive, nor systematic" yet features associated with exposure to air fumes and the adverse health effects documented in medical and health literature are suggestive of causation and warrant further research).

1. The Federal Aviation Administration

In the United States, the Federal Aviation Administration (FAA) exercises primary authority over aircraft design, certification, and flight safety.[52] The agency has characterized cabin air quality as falling within its safety mission and enforces baseline standards addressing smoke, vapor, and noxious fumes.[53] To be sure, apart from limitations on carbon monoxide and carbon dioxide, FAA regulations neither define what constitutes "toxic air" nor establish permissible exposure thresholds for the chemical constituents central to aerotoxic claims.[54]

The FAA's approach reflects a conceptual orientation toward safety engineering and episodic incident response rather than a comprehensive occupational health regime for chronic chemical exposure. The agency relies primarily on voluntary reporting mechanisms—including Service Difficulty Reports—for incidents involving smoke, vapor, or noxious odors, and it has described investigating such reports to identify causes and require corrective action.[55] The FAA has continued to sponsor research on bleed-air contamination and health implications, including initiatives prompted by congressional directives.[56] That research posture signals ongoing attention to unresolved questions rather than regulatory closure, and it complicates any inference that FAA engagement with cabin air quality constitutes an affirmative finding of safety.

2. The Occupational Safety and Health Administration

The Occupational Safety and Health Administration (OSHA) is charged with protecting workers from hazardous workplace conditions. In the aviation context, OSHA's authority is constrained by jurisdictional overlap and statutory displacement under the Occupational Safety and Health Act, which limits OSHA enforcement where another federal agency exercises authority over the relevant working conditions.[57] The FAA's asserted authority over in-flight operations has historically displaced OSHA jurisdiction in aircraft cabins. Even where limited OSHA authority may apply, its primary exposure-control

52. *Cf. Mission*, Fed. Aviation Admin. (Jan. 22, 2025), https://perma.cc/S23R-6Q6K.

53. *Cabin Air Quality*, Fed. Aviation Admin. (Sep. 4, 2025) (citing Ventilation, 14 C.F.R. § 25.831 (2025)), https://perma.cc/924W-YMW8.

54. David J. Harrington & Robert D. Alaimo, *Toxic Cabin Air Litigation Continues to Recirculate Through the Courts*, 45 Brief (Summer 2016) at 40 ("Bleed air systems are not prohibited by federal regulations, and aside from guidance on carbon monoxide and carbon dioxide, the regulations state only generally that aircraft must not be contaminated with toxic substances.").

55. *Cabin Air Quality*, Fed. Aviation Admin., *supra* note 53.

56. *Id.* (listing historical research, initiatives, and related studies).

57. *See* Occupational Health and Safety Act, 29 U.S.C. § 653(b)(1) (2018) ("Nothing in this chapter shall apply to working conditions of employees with respect to which other Federal agencies . . . exercise statutory authority to prescribe or enforce standards or regulations affecting occupational safety or health.").

instruments are poorly matched to the low-concentration, multi-chemical mixture exposures central to aerotoxic claims.[58] For example, permissible exposure limits were developed for terrestrial industrial workplaces and are often structured around single-substance thresholds.[59]

The consequence is a regulatory gap that is structural rather than deliberate. Flight crew occupy a jurisdictional space in which the agency with safety authority lacks comprehensive occupational health instruments, but the FAA's regulatory presence introduces preemption uncertainty that may narrow that alternative without eliminating it. Arguments for field preemption of state tort claims touching on air quality and cabin safety, and for express preemption under the Airline Deregulation Act, have not been directly tested in the context of toxic fume exposure claims, leaving plaintiffs to litigate threshold jurisdictional questions on an unsettled doctrinal landscape alongside the evidentiary constraints already described.[60] The result is a compounding institutional failure: plaintiffs potentially stripped of state law remedies by the breadth of federal aviation regulation and of federal regulatory protection by its depth. The FAA's regulatory framework may thus be simultaneously broad enough to cloud state tort remedies and too limited to supply an alternative.

3. International Divergence and The Limits of Regulatory Signaling

Regulatory engagement outside the United States has been similarly inconclusive. Some authorities, including the European Aviation Safety Agency and certain national bodies, have funded or conducted research on cabin air

58. In 2013, the FAA acknowledged that it had not exercised authority over all working conditions affecting aircraft cabin crewmembers and issued a policy statement identifying a narrow set of areas—such as noise, hazard communication, and bloodborne pathogens—where OSHA standards could apply onboard aircraft in operation. *See* Occupational Safety and Health Standards for Aircraft Cabin Crewmembers, 78 Fed. Reg. 52848, 52848 (Aug. 27, 2013); *see also* Memorandum from Thomas Galassi, Dir. of Enf't Programs, OSHA, through Dorothy Dougherty, Acting Deputy Assistant Sec'y, OSHA, to Reg'l Adm'rs, OSHA, *Re: Applicability of Certain OSHA Standards to Cabin Crew Members on Aircraft in Operation* (Apr. 1, 2014), https://perma.cc/5FR9-YLUU. A subsequent FAA–OSHA memorandum of understanding formalized that limited division of responsibility. *See* Memorandum of Understanding Between the Fed. Aviation Admin. U.S. Dep't of Transp. and the Occupational Safety & Health Admin. U.S. Dep't of Lab. (Aug. 26, 2014), https://perma.cc/C4QL-RTGZ. Yet even under this more permissive framework, the OSHA standards most clearly recognized as applicable do not address the low-dose, mixed-chemical exposure theory central to aerotoxic claims. *See* Burdon, *supra* note 7, at 20 ("The use of exposure limits and individual substances fails to consider the complex mixture and other toxicity factors associated with the various compounds.").

59. *See Permissible Exposure Limits – Annotated Tables*, Occupational Safety & Health Admin., https://perma.cc/K9XP-6TEV.

60. *See* Harrington & Alaimo, *supra* note 53, at 39. Neither theory of preemption in the context of a toxic fume claim has been fully tested or addressed directly in an opinion or order of a court in the United States.

contamination.[61] None has formally recognized Aerotoxic Syndrome as an occupational disease or enacted mandates for system redesign or continuous contaminant detection.[62] The resulting pattern of investigation without recognition has preserved rather than resolved uncertainty.[63]

This divergence illustrates a broader analytical point: regulatory positions on emerging environmental risks reflect not only scientific findings, but also institutional priorities, resource constraints, jurisdictional limits, and political economy. Agencies frequently lack authority to act, operate under regulatory instruments that predate the relevant exposure hypothesis, or face a structural circularity: they cannot generate the evidence needed to support formal action without the monitoring infrastructure that formal action would itself require.[64] The absence of binding exposure limits or formal disease recognition is therefore better understood as a product of fragmented authority and informational

61. *See, e.g.*, *Cabin Air Quality Assessment of Long-term Effects of Contaminants*, Eur. Union Aviation Safety Agency, https://perma.cc/UL9B-3TQS.

62. *See*, Monica Piccinini, *A Silent Threat in the Skies: The Under-Reported Dangers of 'Aerotoxic Syndrome'*, Canary (Jan. 23, 2024), https://perma.cc/W35R-7TLL.

63. *See, e.g.*, Comm. on Toxicity of Chems. in Food Consumer Prods. & the Env't, Statement on the Review of the Cabin Air Environment, Ill-Health in Aircraft Crews and the Possible Relationship to Smoke/Fume Events in Aircraft ¶85–86 at 24–25 (2007), https://perma.cc/S5WF-XHLR. Drawing on several hundred reported fume events compiled by the British Airline Pilots Association and the U.K. Civil Aviation Authority, the Committee concluded that the available evidence was insufficient to establish a causal association between cabin air exposures and ill health among commercial aircrew, though it acknowledged that an association was "plausible" in a number of incidents based on the temporal proximity between fume events and symptom onset and recommended precautionary measures to prevent cabin air contamination. *Id.* ¶ 86, at 25. Scholars criticized the report's reliance on incident reporting systems that likely capture only a fraction of actual exposures, noting that pilots and crew may underreport fume events because symptoms can be transient, reporting procedures are burdensome, or professional incentives discourage documentation of health complaints. *See generally* Susan Michaelis et al., Critique of the UK Committee on Toxicity Report on Exposure to Oil Contaminated Air on Commercial Aircraft and Pilot Ill Health (May 2008), https://perma.cc/4SFT-KWBT; Judith Murawski & Susan Michaelis, *A Critique of Recent Air Sampling Data Collected on Aircraft: How Much Exposure to Neurotoxic Fumes is Acceptable?*. 11 J. Biological Physics & Chemistry 147 (2011).

64. *See generally* Sheldon Krimsky, *The Unsteady State and Inertia of Chemical Regulation Under the US Toxic Substances Control Act*, 15 PLOS Biology e2002404 (2017), https://perma.cc/SP8S-LN6E (documenting how TSCA's original goals were undermined by "cumbersome administrative burdens, data limitations, vulnerabilities in risk assessments, and recurring corporate lawsuits," leaving countless chemicals in commerce without toxicological information, and noting that EPA needed data to compel testing but could obtain data only through the testing it lacked authority to compel); Steve C. Gold & Wendy E. Wagner, *Filling Gaps in Science Exposes Gaps in Chemical Regulation*, 368 Science 1066 (2020) (demonstrating through the case of PFAS compounds that the regulatory system permits chemicals to enter commerce and the environment under statutory frameworks that predate any hypothesis about their toxicity).

asymmetries—not an affirmative determination that cabin air contamination poses no cognizable risk.

The portrait that emerges from this scientific and regulatory survey is one of genuine, structurally produced uncertainty: exposure that is real but difficult to characterize, symptom reporting that is persistent but heterogeneous, and an institutional landscape that has generated research without resolution. For aerotoxic plaintiffs, that uncertainty represents a legal hurdle. The following Parts show how modern causation doctrine and *Daubert* gatekeeping translate the structural features documented here into threshold grounds for dismissal, foreclosing adjudication before the evidentiary record can mature.

II. Doctrinal Pathways That Transform Structural Uncertainty Into Legal Closure

Part I shows that aerotoxic claims arise from a familiar evidentiary posture: plausible exposure pathways, persistent symptom reporting, and developing mechanistic and clinical evidence, paired with predictable limits on epidemiological study. This Part explains why that posture can become outcome-determinative under modern toxic tort doctrine. It does not argue that epidemiology is irrelevant or that plaintiffs' burdens should be relaxed.[65] Governing doctrine permits convergent, multi-disciplinary proof in principle.[66] The problem is that, in certain settings, courts operationalize sequencing, admissibility, and sufficiency in ways that make epidemiology function as a practical prerequisite, especially in emerging-illness cases where robust population studies are slow or infeasible.[67] The mechanisms analyzed here—sequencing rules, evidentiary hierarchies, latency and diagnostic complexity, and procedural design—compound, and they create the conditions under which *Daubert* gatekeeping, examined in Part III, can convert the structural disadvantages documented in Part I into dismissal.

A. The Sequencing and Structuring of Proof

Modern toxic tort doctrine divides causation into two inquiries: general causation, whether a substance can cause the alleged injury, and specific causation, whether it caused the plaintiff's harm.[68] The distinction is conceptually

65. *See* Cranor, *supra* note 3, at 9–10 (noting that epidemiology can be good evidence of harm from toxic exposure, but important limitations affect the availability and sensitivity of such studies); Green, *supra* note 23, at 646.

66. Restatement (Third) of Torts: Interference with Econ. Int. §20 A (Am. L. Inst. 2010).

67. *See* Green, *supra* note 23.

68. *See* In re Joint E. & S. Dist. Asbestos Litig., 52 F.3d 1124, 1131 (2d Cir. 1995) [hereinafter "Joint Asbestos Litig."] (quoting In re Agent Orange Prod. Liab. Litig., 611 F. Supp. 1223,

sound. In federal toxic tort litigation, however, courts treat it as a mandatory sequence, requiring that plaintiffs establish general causation—frequently through population-level evidence—before individualized proof is considered.[69] That sequence may be sensible in mature exposure contexts where epidemiological evidence is available and reliable. It is not logically compelled,[70] and it does not follow from how causal inference operates in toxicology, where causal conclusions characteristically rest on convergent evidence across multiple domains rather than on any single form of direct demonstration.[71]

Where exposure timing and intensity are documented, competing etiologies are responsibly ruled out, and mechanistic pathways align with clinical presentation, a robust inference to the best explanation may support a finding that exposure contributed to harm in an individual case.[72] Indeed, in a world of imperfect information, a sufficiently powerful showing of specific causation can illuminate general causation—revealing a previously unsuspected relationship on the basis of one event or a small number of events when background information and alternative explanations make the inference scientifically coherent.[73] General and specific causation are analytically related inquiries, not a strict evidentiary hierarchy in which the first must be independently resolved before the second is reached.

The sequencing problem is most consequential in emerging-illness cases, where individualized evidence may be comparatively developed while population-level data remains predictably incomplete.[74] A plaintiff may assemble

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1261–62 (E.D.N.Y. 1985), *aff'd*, 818 F.2d 187 (2d Cir. 1987), *cert. denied*, 487 U.S. 1234 (1988)) ("Causation in toxic torts normally comprises two separate inquiries: whether the epidemiological or other scientific evidence establishes a causal link between c (asbestos exposure) and d (colon cancer), and whether plaintiff is within the class of persons to which inferences from the general causation evidence should be applied.").

69. *See* Cranor, *supra* note 3, at 258–60; Williams v. BP Expl. & Prod., Inc., 143 F.4th 593, 598 (5th Cir. 2025) (quoting Wells v. SmithKline Beecham Corp., 601 F.3d 375, 378 (5th Cir. 2010)) ("Sequence matters: a plaintiff must establish general causation before moving to specific causation. Without the predicate proof of general causation, the tort claim fails"); Snyder v. Upjohn Co., No. 94–1826–GHK at 8 (C.D. Cal. May 20, 1997) (the only possible specific causes "are those for which general causation has already been established").

70. Cranor, *supra* note 3, at 259.

71. *See* Berger, *supra* note 2, at 298 ("Because direct proof of causation is usually unavailable, and experimentation on humans is ethically proscribed, plaintiffs must rely on the kind of evidence that scientists gather when they investigate a causal link between a substance and disease."); Cranor, *supra* note 3, at 138 ("In order to come to conclusions about a substance's toxicity, good scientific practice dictates that scientists consider human evidence, if it is available, evidence from experimental animals, structure-activity evidence, mechanistic evidence, and so on to come to a conclusion about what the overall weight of the evidence shows about a substance.").

72. Cranor, *supra* note 3, at 259–60.

73. *Id.*

74. *See* Nat'l Rsch. Council, *supra* note 16, at 13 (noting that methyl mercury, asbestos, and radon were first identified through individual clinical observations and case reports before population-level epidemiological data became available).

exposure reconstruction, differential diagnosis, toxicological and mechanistic support, and clinically grounded reasoning. Yet some courts decline to reach those showings absent epidemiological evidence deemed sufficiently robust.[75] In effect, the order of proof becomes outcome-determinative. Rather than asking whether the plaintiff established causation by a preponderance of the evidence on the record presented, courts condition adjudication on the prior availability of preferred forms of evidence.[76] Epistemic lag operates as categorical insufficiency by design.

B. Evidentiary Hierarchies and the Privileging of Epidemiology

The sequencing problem is compounded by a judicial privileging of epidemiology.[77] In several lines of toxic tort cases, courts treated statistically significant epidemiology as the benchmark for general causation while discounting animal studies, mechanistic toxicology, clinical observation, and case reports as less probative.[78]

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75. *See, e.g.,* Thomas v. Hoffman-La Roche, Inc., 731 F. Supp. 224, 227–28 (N.D. Miss. 1989), *aff'd on other grounds*, 949 F.2d 806 (5th Cir. 1992) ("[W]ithout some epidemiological study or statistical basis for the expert's opinion . . . the opinion as to causation amounts to little more than speculation."); Hall v. Baxter Healthcare Corp., 947 F. Supp. 1387, 1413 (D. Or. 1996). ("[T]estimony regarding specific causation in a given patient is irrelevant unless general causation is established." (citations omitted)).
76. *See, e.g.*, Wade-Greaux v. Whitehall Lab., Inc., 874 F. Supp. 1441, at 1450–53 (D.V.I. 1994), *aff'd*, 46 F.3d 1120 (3d Cir. 1994).
77. *See* Green, *supra* note 23, at 658 ("[T]here plainly is a hierarchy to these different indirect forms of toxic effect evidence. Epidemiology is at the top, and structural similarity, in vitro testing, and case reports are at the bottom.").
78. *See* In re Breast Implant Litig., 11 F. Supp. 2d 1217, 1224–25 (D. Colo. 1998):

> The most important evidence relied upon by scientists to determine whether an agent (such as breast implants) cause disease is controlled epidemiologic studies. Epidemiology can be viewed as the study of the causes of diseases in humans." (Ory Affidavit, Exhibit A p. 7 to Defendants' June 2, 1997 Science Brief). Therefore, epidemiological studies are necessary to determine the cause and effect between breast implants and allegedly associated diseases. A valid epidemiologic study requires that study subjects, cases, and controls are chosen by an unbiased sampling method from a definable population. Epidemiology is the best evidence of causation in the mass torts context. Linda A. Bailey, et al., *Reference Guide on Epidemiology*, REFERENCE MANUAL ON SCIENTIFIC EVIDENCE at 126 (1994) [sic] ("In the absence of an understanding of the biological and pathological mechanisms by which disease develops, epidemiological evidence is the most valid type of scientific evidence of toxic causation") (citations omitted); *see also* Raynor, 104 F.3d at 1376 (non-epidemiological studies, "singly or in combination," were "not capable of proving causation in human beings in the face of the overwhelming body of contradictory epidemiological evidence") (citations omitted); Allen v. Pennsylvania Engineering Corp., 102 F.3d 194, 197 (5th Cir. 1996) (affirming exclusion of plaintiffs' non-epidemiological causation evidence because "the most useful and conclusive type of evidence in a case such as this is

The dynamic is visible in the *Agent Orange* opt-out litigation, where Judge Weinstein characterized epidemiologic evidence as the "only useful" evidence with meaningful bearing on causation and other forms of proof were discounted as incapable of supporting a legally cognizable causal inference.[79] This framing did not merely evaluate the evidence presented but established a hierarchy that determined which evidence could count. The pattern is sharpened further in the *Bendectin* litigation, where the *Richardson* court of appeals treated the absence of statistically significant epidemiological findings as independently dispositive,

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epidemiological studies"); Elkins v. Richardson–Merrell, 8 F.3d 1068, 1073 (6th Cir. 1993) (affirming summary judgment where plaintiff failed to raise a genuine issue of fact regarding causation in light of epidemiological evidence), *cert. denied*, 510 U.S. 1193, (1994); Brock v. Merrell Dow Pharmaceuticals, Inc., 874 F.2d 307, 311 (5th Cir.) ("the most useful and conclusive type of evidence in a case such as this is epidemiological studies"), *modified*, 884 F.2d 166 (1989), *cert. denied*, 494 U.S. 1046 (1990); Lynch v. Merrell–National Laboratories, 830 F.2d 1190, 1193–97 (1st Cir. 1987) (affirming summary judgment for Bendectin manufacturer where plaintiff offered only criticism of defendant's epidemiological evidence with no epidemiological evidence of its own); Hall, 947 F.Supp. at 1403 ("[t]he existence or nonexistence of relevant epidemiology can be a significant factor in proving general causation in toxic tort cases") (citations omitted); Conde v. Velsicol Chem. Corp., 804 F.Supp. 972, 1025–26 (S.D. Ohio 1992) ("[e]pidemiologic studies are the primary generally accepted methodology for demonstrating a causal relation between a chemical compound and a set of symptoms or a disease"), *aff'd*, 24 F.3d 809 (6th Cir. 1994); In re Agent Orange Product Liability Litigation, 611 F.Supp. at 1231 ("[a] number of sound epidemiological studies have been conducted on the health effects of exposure to Agent Orange. These are the only useful studies having any bearing on causation.").

The Tenth Circuit has cited with approval several pre-*Daubert* Bendectin cases recognizing the primacy of epidemiological evidence. Wilson v. Merrell Dow Pharmaceuticals, Inc., 893 F.2d 1149, 1154 (10th Cir. 1990) ("This lack of epidemiological proof for the Wilsons' claims is particularly significant in light of recent decisions of federal courts of appeals granting judgment n.o.v. for Merrell Dow based upon the absence of epidemiological evidence showing a causal relationship between Bendectin use and birth defects") (citations omitted). Likewise, in *Renaud*, the trial court recognized that epidemiology is required in toxic tort cases "where collection of such evidence is possible." 749 F.Supp. 1545, 1554 (D.Colo. 1990) ("even if plaintiffs had been able to prove exposure by their direct evidence, they would have been required to submit epidemiological evidence in support of their causation contentions"), *aff'd*, 972 F.2d 304, 307 (10th Cir. 1992) (noting that plaintiffs' causation evidence "was not sufficiently reliable, being drawn from tests on non-human subjects without confirmatory epidemiological data.") (citations omitted).

79. In re "Agent Orange" Prod. Liab. Litig., 611 F. Supp. 1223, 1231 (E.D.N.Y. 1985); *id.* at 1241 ("The animal studies are not helpful in the instant case because they involve different biological species. They are of so little probative force and are so potentially misleading as to be inadmissible.").

rejecting plaintiffs' reliance on toxicological and mechanistic evidence as inadequate foundation for expert testimony.[80] The defect was framed as one of evidentiary insufficiency rather than methodological unreliability—a distinction that matters because it locates the problem not in how the expert reasoned but in what the expert reasoned from.

Some post-*Daubert* courts have gone further, treating the availability of epidemiological evidence as a practical prerequisite for admissibility and, in doing so, collapsing reliability into a demand for population-level confirmation.[81] Others disagree sharply.[82] Still, when epidemiological evidence exists, some courts require that such studies have a relative risk of at least 2.0.[83] *Brock v. Merrell Dow Pharmaceuticals, Inc.* crystallized this move by framing the defect as one of evidentiary insufficiency and treating statistical significance as a gatekeeping proxy for causation.[84] The 2.0 floor represents the threshold at which exposed individuals are more likely to have been harmed by the agent than by background or other causes. As a categorical admissibility rule, it conflates the standard of proof with an evidentiary prerequisite, excluding expert testimony whenever the available population-level evidence does not independently establish probable causation. As Professor Michael D. Green observes, that move rests on an unstable foundation: "[f]or most potentially toxic substances, there will not be a solid body of epidemiologic evidence on which to rely."[85] Statistical significance addresses only one dimension of uncertainty (random error) and cannot resolve systematic bias or distinguish limited statistical power from the absence of an effect.[86] Deployed as a gatekeeping proxy, it risks mistaking methodological constraint for substantive negation.

The broader consequence is a de facto epidemiology requirement that many emerging-exposure plaintiffs cannot satisfy—not because causal inference is unavailable, but because the proof courts privilege is predictably slow to develop, costly to generate, or unlikely to exist given the nature of the exposure.[87]

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80. Green, *supra* note 23, at 662–64 (quoting Richardson v. Richardson-Merrell, Inc., 857 F.2d 823 (D.C. Cir. 1988), *cert. denied*, 493 U.S. 882 (1989)).
81. *See, e.g.*, In re Breast Implant Litig., 11 F. Supp. 2d at 1224–25.
82. *See, e.g.*, In re Paoli R.R. Yard PCB Litig., 35 F.3d 717, 779–82 (3d Cir. 1994); Globetti v. Sandoz Pharm., 111 F. Supp. 2d 1174, 1179 (N.D. Ala. 2000).
83. *See, e.g.*, Allison v. McGhan Med. Corp., 184 F.3d 1300, 113-15, 1315 n. 16 (11th Cir. 1999); In re Breast Implant Litig., 11 F. Supp. 2d at 1225–26; Hall v. Baxter Healthcare Corp., 947 F. Supp. 1387, 1403–05 (D. Or. 1996). *But see* Joint Asbestos Litig, 52 F.3d 1124, 1139 (2d Cir. 1995); Grassis v. Johns-Manville Corp., 591 A.2d 671, 675 (N.J. Super. Ct. App. Div. 1991).
84. Green, *supra* note 23, at 666–68 (citing Brock v. Merrell Dow Pharms., Inc., 874 F.2d 307 (5th Cir. 1989), *cert. denied*, 110 S. Ct. 1511 (1990)).
85. *Id.* at 680.
86. *Id.* at 681–82.
87. *Id.* at 680.

C. Latency, Multifactor Causation, and Diagnostic Instability

The sequencing and evidentiary-hierarchy problems are sharpened by three features of emerging-illness litigation: latency, multifactor causation, and diagnostic instability. Each independently complicates causal proof. Together, they create conditions in which the evidentiary record is likely to be structurally incomplete at precisely the moment courts are asked to evaluate it.

Latency amplifies proof problems in at least two ways. First, it triggers threshold disputes—particularly over accrual and limitations—that can dispose of claims before the factfinder reaches causation.[88] Second, latency predictably erodes the evidentiary record. Historical exposure reconstruction becomes difficult; contemporaneous measurements are rarely preserved; and relevant documentation may be dispersed or controlled by parties other than the plaintiff.[89] Courts may treat these evidentiary gaps as failures of diligence rather than as the ordinary consequence of injuries that emerge years after the relevant exposure.[90]

Multifactor causation creates a parallel challenge. Exposure-related injuries characteristically arise through cumulative and interactive mechanisms in which chemical exposure operates alongside co-exposures, baseline vulnerability, and background risks.[91] Tort doctrine contains conceptual tools for causal complexity, but courts remain most receptive to linear narratives in which a discrete agent produces a discrete outcome.[92] Defendants can exploit that preference by reframing causal complexity as indeterminacy and arguing that the plaintiff has failed to isolate a singular cause.[93] Plaintiffs are thus placed in a familiar

88. *See* Danielle Conway-Jones, *Factual Causation in Toxic Tort Litigation: A Philosophical View of Proof and Certainty in Uncertain Disciplines*, 35 U. Richmond. L. Rev. 875, 879 n.19 (2002).

89. *Id.* at 881; Berger, *supra* note 2, at 307; Cranor, *supra* note 3, at 12.

90. *But see* Allen v. United States, 588 F. Supp. 247, 341 (D. Utah 1984), *rev'd on other grounds*, 816 F.2d 1417 (10th Cir. 1987) ("Construing the statute in this fashion avoids the impossible burden that would be placed on a plaintiff who would otherwise be expected to commence a lawsuit years before he knew he had an injury, knew the source of the injury and thus knew he had a cause of action. In such cases, the underlying policy of the statute of limitations, discouraging litigation of 'stale' claims, does not arise. The claim is not stale. It merely took time to accrue. Genuine concern about lost evidence, fading memories and the passage of time are subordinated to a greater concern that legal wrongs be remedied at the first practical opportunity.").

91. *See* Nat'l Rsch. Council, Science and Decisions: Advancing Risk Assessment 109–12 (Nat'l Acads. Press 2009) (explaining that real-world environmental health risks frequently arise from combined exposures to multiple chemical and nonchemical stressors, including background disease susceptibility and social or biological vulnerability); *see also* Ken Sexton & Stephen H. Linder, *Cumulative Risk Assessment for Combined Health Effects From Chemical and Nonchemical Stressors*, 101 Am. J. Pub. Health Supp. 1 S81, at S81 (2011).

92. *See* Troyen A. Brennan, *Causal Chains and Statistical Links: The Role of Scientific Uncertainty in Hazardous-Substance Litigation*, 73 Cornell L. Rev. 469, 490–91 (1988).

93. *See generally* David Michaels & Celeste Monforton, *Manufacturing Uncertainty: Contested Science and the Protection of the Public's Health and Environment*, 95 Am. J. Public Health Supp. 1 (2005).

bind: Presenting causation in a scientifically responsible way—acknowledging interactive mechanisms and probabilistic contribution—can be characterized as insufficiently specific, while simplifying the causal account invites attack as methodologically unsound.

Diagnostic instability compounds both. Some exposure-related conditions present as overlapping symptom clusters rather than uniform syndromes with stable diagnostic signatures. This reflects genuine biological variability across individuals with different susceptibilities, exposures, and background conditions.[94] Courts may treat that variability as a reason to discount causation, implicitly requiring that a legally cognizable condition manifest consistently across individuals.[95] Where adjudication turns on the presence of a settled diagnostic label or administrative recognition, doctrine risks elevating classification over inference.

These three features interact in aerotoxic claims with particular force. The alleged harm involves variable exposure mixtures, heterogeneous symptom profiles, long potential latency for chronic neurological effects, and no settled diagnostic classification; these are structural features of the litigation. Together, they ensure that the evidentiary record will be incomplete in precisely the ways that sequencing rules and evidentiary hierarchies may treat as disqualifying.

D. Procedural Mechanisms and Early Termination

The substantive doctrinal pressures analyzed above are reinforced by procedural design. Federal courts managing mass-exposure disputes rely primarily on multidistrict litigation under 28 U.S.C. § 1407 and consolidation under Federal Rule of Civil Procedure 42 to coordinate pretrial proceedings and reduce duplicative litigation.[96] These mechanisms allow common issues to be litigated once rather than repeatedly, and they can make individually uneconomic claims viable.[97] In emerging-exposure litigation, aggregation can shift the function of procedure from coordination to substantive gatekeeping.[98]

The mechanism is straightforward. Multidistrict litigation (MDL) centralization places scientific gatekeeping in the hands of a single transferee court, often at an early stage of the proceedings and under institutional pressure to

94. *See* Cranor, *supra* note 3, at 324–25.
95. *See id.* at 325.
96. Manual for Complex Litigation (Fourth) §§ 22.31, 22.312 (Fed. Jud. Ctr. 2004).
97. *See id.* at §§ 22.313, 22.314; *see* Amchem Prods., Inc. v. Windsor, 521 U.S. 591, 617 (1997) (citations omitted) (describing public policy aims supported by the class action mechanism).
98. Courts have cautioned that the drive toward procedural efficiency must not displace individualized adjudication. *See* In re Asbestos Litig., 173 F.R.D. 81, 83 (S.D.N.Y. 1997) (quoting In re Brooklyn Navy Yard Asbestos Litig., 971 F.2d 831, 853 (2d Cir. 1992) "systemic urge to aggregate litigation must not be allowed to trump . . . individual justice").

structure discovery and facilitate resolution.[99] In emerging-exposure disputes, where exposure pathways and biological mechanisms remain under investigation, the evidentiary record may still be developing when courts confront admissibility questions. A general-causation ruling excluding plaintiff's expert testimony at that stage can terminate large numbers of claims before individualized exposure evidence or injury histories are meaningfully developed.[100] Procedural design in that circumstance does not merely streamline adjudication; it shapes the conditions under which causation can be adjudicated at all.

Aggregation also tends to privilege generalizable forms of proof. Population-level epidemiology naturally becomes the focal point of general-causation analysis in MDL proceedings because it can be addressed through common expert testimony and applied across thousands of claims. Other forms of evidence—such as mechanistic toxicology, clinical observations, or exposure-pathway reconstruction—may receive less weight because they are harder to standardize across a large and heterogenous plaintiff population. In emerging-exposure contexts, where epidemiological evidence may be incomplete or poorly aligned with the alleged mechanism of harm, that structural preference compounds the evidentiary challenge described herein.[101]

These institutional pressures are justified as safeguards against false positives. Courts have expressed concern that aggregation may create settlement pressure untethered to the merits, particularly when large plaintiff pools and substantial potential liability are concentrated in a single proceeding.[102]

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99. *See* D. Theodore Rave, *Management and Judging in Multidistrict Litigation*, 42 Rev. Litig. 291, 291–94, 299–301 (2023) (observing that in MDL the transferee judge functions as a "judicial manager" whose pretrial rulings effectively resolve most cases).

100. *See generally* In re Mirena IUS Levonorgestrel-Related Prods. Liab. Litig. (No. II), 341 F. Supp. 3d 213 (S.D.N.Y. 2018) (excluding all seven of plaintiffs' general-causation experts in MDL alleging that the Mirena IUD's hormonal component caused idiopathic intracranial hypertension, where the proposed biological mechanism had not been tested, published, or generally accepted, and the primary supporting study was fatally confounded), *aff'd*, 982 F.3d 113 (2d Cir. 2020); In re Mirena IUS Levonorgestrel-Related Prods. Liab. Litig. (No. II), 387 F. Supp. 3d 323 (S.D.N.Y. 2019) (granting summary judgment and dismissing all approximately 800 remaining claims on general-causation grounds), *aff'd*, 982 F.3d 113 (2d Cir. 2020); *see also* In re Zoloft (Sertraline Hydrochloride) Prods. Liab. Litig., 176 F. Supp. 3d 483 (E.D. Pa. 2016) (granting summary judgment dismissing more than 300 cases alleging sertraline caused birth defects, after *Daubert* hearings excluded all general-causation experts, where the epidemiological evidence was mixed and the proposed teratogenic mechanism remained under investigation), *aff'd sub nom.*, 858 F.3d 787 (3d Cir. 2017).

101. *See* Cranor, *supra* note 3, at 138–39.

102. *See, e.g.*, Amchem Products, Inc. v. Windsor, 521 U.S. 591, 597, 617–18 (1997); In re Brooklyn Navy Yard Asbestos Litig., 971 F.2d 831, 853 (2d Cir. 1992) (cautioning that "the systemic urge to aggregate litigation must not be allowed to trump our dedication to individual justice"); Malcolm v. Nat'l Gypsum Co., 995 F.2d 346, 350–52 (2d Cir. 1993) (reversing consolidation of forty-eight asbestos cases where uniform apportionment of liability among defendants with different evidentiary records indicated that aggregation had overwhelmed individualized fact-finding).

The predominance requirement of Rule 23 reflects a related concern: when exposure, specific causation, and damages vary substantially across members of the class, aggregate treatment may compromise accuracy and fairness.[103] Those concerns are real and are addressed in Part VI. Their institutional weight, however, cannot obscure the systemic consequence: when general-causation rulings operate across an entire litigation at an early stage, claims may be foreclosed before the scientific record has matured. Procedural structure thereby influences whether emerging exposure risks are adjudicated incrementally as evidence develops or only after scientific consensus has emerged—at which point the tort system's deterrence and compensation functions are significantly compromised.

Aerotoxic litigation, if it were to achieve the scale that triggers aggregation, would face these compounding pressures at precisely the moment when its evidentiary record is underdeveloped. Claims by flight crew sharing common exposure pathways, common questions of general causation, and a common defendant class present the formal prerequisites for coordination. Whether coordinated proceedings would allow convergent evidence to be assessed on the merits or screened out at the threshold would depend on the timing of general-causation rulings and the evidentiary standard applied to them.

The mechanisms analyzed in this Part do not operate in isolation. Each independently disadvantages emerging-illness plaintiffs; together, they constitute a compounding system of evidentiary constraint. That system operates most powerfully at the point where substantive causation doctrine meets judicial gatekeeping: the *Daubert* hearing. Part III examines how *Daubert* has, in certain applications, become the mechanism through which the structural disadvantages documented in this Part are translated into dismissal.

III. *Daubert* and the Judicial Management of Scientific Uncertainty

This Part examines how *Daubert* is properly understood as an accountability mechanism for expert reasoning: a standard of methodological reliability, not a requirement that science resolve causation before adjudication may proceed. In certain applications, however, courts have operationalized *Daubert* in ways that collapse admissibility into sufficiency review.[104] At that point, gatekeeping ceases to screen for unreliable reasoning and begins to screen for scientific maturity. The admissibility ruling becomes the merits ruling, and the structural disadvantages documented in Part II become irreversible. The 2023 amendments to Federal Rule of Evidence 702 clarify that admissibility and sufficiency are distinct inquiries and that the proponent must establish admissibility by a

103. *See* Amchem, 521 U.S. at 623–24 (1997) (explaining that Rule 23(b)(3) requires sufficient class "cohesion" and noting that toxic-exposure litigation often involves individualized questions of exposure, causation, and damages).

104. Finley, *supra* note 5, at 337, 348.

preponderance of the evidence, but they do not address what courts should do when the evidentiary record is structurally incomplete because the underlying science is immature, which is precisely the condition that makes the collapse most consequential.[105]

A. Daubert*'s Commitment: Reliability, Not Scientific Closure*

Daubert v. Merrell Dow Pharmaceuticals, Inc. is now treated as the canonical basis for excluding expert testimony in toxic tort cases involving contested or developing science.[106] That treatment, however, reflects less a categorical command from the Supreme Court than the way certain lower courts have operationalized reliability in the direction of scientific closure. *Daubert* did not hold that only settled science is admissible, nor did it require scientific consensus as a condition of admissibility.[107] Rather, it reframed the admissibility inquiry around reliability and relevance, understood as features of an expert's method and reasoning.[108]

The Court began from the text of Federal Rule of Evidence 702, emphasizing that nothing in the Rule makes "'general acceptance' . . . an absolute prerequisite to admissibility."[109] It rejected *Frye*'s general-acceptance test as "absent from, and incompatible with" the Federal Rules' "liberal thrust" toward admitting opinion evidence and relying on adversarial testing to evaluate credibility

105. The 2023 amendments respond to lower court decisions that had treated disputed methodological questions as going to weight rather than admissibility. *See* Fed. R. Evid. 702 advisory committee note to 2023 amendment. Three features of the structural problem analyzed here survive the amendment: the abuse-of-discretion standard of appellate review established in *Joiner* remains unchanged, leaving district court gatekeeping decisions substantially insulated from correction regardless of the threshold applied; the practice of conditioning admissibility on epidemiological studies meeting a specified risk ratio has achieved near-precedential status in certain circuits and MDL proceedings that the amendment's clarificatory text is unlikely to dislodge; and the amendment is silent on the epistemological mismatch between evidentiary expectations calibrated to mature science and the convergent, multi-disciplinary evidence available in emerging-illness litigation that is the subject of the reform proposed in Part VII.

106. Though *Daubert* replaced the rigid *Frye* "general acceptance" test with a more flexible reliability inquiry, the Court acknowledged that "a gatekeeping role for the judge, no matter how flexible, inevitably on occasion will prevent the jury from learning of authentic insights and innovations." Daubert v. Merrell Dow Pharms., 509 U.S. 579, 597 (1993); *cf.* Lloyd Dixon & Brian Gill, Changes in the Standards for Admitting Expert Evidence in Federal Civil Cases Since the Daubert Decision xiii–xvi (RAND Inst. for Civil Justice 2001), https://perma.cc/A734-3QS2 (following *Daubert*, the rate of expert testimony exclusion rose significantly, and successful summary judgment motions roughly doubled).

107. *See Daubert*, 509 U.S. at 590 ("[I]t would be unreasonable to conclude that the subject of scientific testimony must be 'known' to a certainty; arguably, there are no certainties in science.").

108. *See id.* at 589–95.

109. *Id*. at 588.

and weight.[110] The admissibility standard the Court articulated instead required that expert testimony be both relevant and reliable—grounded in "the methods and procedures of science," rather than "subjective belief or unsupported speculation."[111] Crucially, the Court expressly recognized that certainty cannot be demanded: the question is not whether a proposition is established but whether the inference is "derived by the scientific method" and "supported by appropriate validation—*i.e.*, 'good grounds,' based on what is known."[112]

Operationally, *Daubert* instructs judges to assess "whether the reasoning or methodology underlying the testimony is scientifically valid" and whether it "properly can be applied to the facts in issue."[113] The opinion identifies familiar considerations: testability, "peer review and publication," known or potential error rates, "standards controlling the technique's operation," and "general acceptance."[114] But, the Court cautioned that these considerations do not form a "definitive checklist or test" and stressed that the Rule 702 inquiry is "a flexible one."[115] Most significantly for present purposes, the Court drew a sharp line between evaluating the integrity of an expert's approach and resolving the underlying scientific debate: "[t]he focus . . . must be solely on principles and methodology, not on the conclusions that they generate."[116]

The subsequent cases in this trilogy completed the gatekeeping framework in ways that matter for emerging-exposure litigation. *General Electric Co. v. Joiner*[117] established that appellate review of gatekeeping decisions proceeds under an abuse-of-discretion standard, a posture of significant deference that has insulated lower court exclusions from meaningful correction and contributed to the persistence of the pathological applications examined in Section B.[118] *Kumho Tire Co. v. Carmichael*[119] extended the gatekeeping obligation from scientific testimony to all expert testimony, including technical and experiential knowledge, a doctrinal

110. *Id.* (citation omitted).
111. *Id.* at 589–90.
112. *Id.* at 590 (emphasizing that "it would be unreasonable to conclude that the subject of scientific testimony must be 'known' to a certainty; arguably, there are no certainties in science.").
113. *Id.* at 592–93.
114. *Id.* at 593–94.
115. *Id.*
116. *Id.* at 595.
117. 522 U.S. 136 (1997).
118. *Id.* at 141; *see* Margaret A. Berger, *The Admissibility of Expert Testimony*, in Reference Manual on Scientific Evidence 11, 20–21 (Fed. Jud. Ctr. & Nat'l Rsch. Council eds., 3d ed. 2011) (observing that this framework "convert[s]" the de novo standard that would ordinarily apply to sufficiency determinations "into the lower abuse-of-discretion standard that governs evidentiary rulings on admissibility, and thereby undermines the jury trial mandate of the Seventh Amendment"); Finley, *supra* note 5, at 337 (documenting how the deferential standard of review has enabled trial judges to impose substantive causation requirements through evidentiary rulings without meaningful appellate oversight).
119. 526 U.S. 137 (1999).

expansion with direct consequences for the clinical and differential-diagnosis testimony on which aerotoxic plaintiffs may need to rely.[120]

Daubert also addressed the concern that abandoning *Frye* would expose courts to unreliable testimony without adequate safeguards. For "shaky but admissible evidence," the Court reaffirmed the traditional tools of adversarial testing—"[v]igorous cross-examination, presentation of contrary evidence, and careful instruction on the burden of proof"—as the "appropriate means" of addressing weaknesses.[121] Where the evidentiary basis is too thin to permit a reasonable juror to find causation "more likely than not," conventional procedural tools such as summary judgment and judgment as a matter of law remain available.[122] This framework limits admissibility to methodological soundness and reserves substantive sufficiency for post-admission procedural review.

Taken together, *Daubert* and its progeny position the gatekeeping inquiry as an accountability mechanism for expert reasoning: a standard asking whether experts have applied the available evidence transparently and reliably, with "good grounds," and whether their testimony fits the factual questions the factfinder must decide.[123] What that standard does not require—and what the Court's own framing affirmatively resists—is that the evidence base be mature, epidemiologically complete, or capable of independently resolving causation.[124] In emerging-exposure litigation, a gatekeeping inquiry faithful to that framing would ask whether the expert's convergent, multi-disciplinary reasoning is methodologically sound and appropriately fitted to the causal question at issue.

B. How Gatekeeping Becomes Substantive Screening

The pathology this Part addresses is the collapse of admissibility into sufficiency review: courts requiring, as a condition of admissibility, that individual evidentiary components independently establish causation rather than asking whether the expert's methodology is sound and the testimony fits the dispute.[125] That collapse proceeds through two analytically distinct routes—one running through *Daubert*'s reliability prong,[126] the other through its relevance prong[127]—each of which converts a methodological inquiry into a substantive causation screen.

The reliability route treats epidemiological studies demonstrating a relative risk below 2.0 as "unreliable" as a matter of law.[128] The 2.0 threshold has a

120. *Id.* at 141.
121. *Daubert*, 509 U.S. at 596.
122. *Id.*
123. *Id.* at 590–91.
124. *Id.* at 590.
125. *See* Gold, *supra* note 18, at 385–92; *see also* Finley, *supra* note 5, at 348 n.47.
126. Finley, *supra* note 5, at 349.
127. *Id.* at 349–50.
128. Finley, *supra* note 5, at 349; *see* Cranor, *supra* note 3, at 227.

probabilistic basis: a relative risk greater than 2.0 implies that more than half of observed cases in the exposed population are attributable to the exposure rather than to background causes, providing a statistical correlate for the more-probable-than-not standard.[129] But, translating that probabilistic rationale into a categorical reliability rule produces a significant doctrinal error.[130] *Daubert* defines reliability as a feature of the expert's method and reasoning, not of the strength of the statistical association the studies report.[131] Redefining reliability as requiring a particular risk ratio does not evaluate how the expert reasoned; it establishes a legal rule about what level of association is sufficient to support a causal inference and excludes testimony whenever the available evidence does not clear that threshold. In *Joiner*, the district court excluded testimony partly on the ground that the supporting studies, though showing elevated risk, did not sufficiently support the expert's causal inference, and this exclusion was affirmed on abuse-of-discretion review—a result that illustrates how the deference standard compounds the reliability-as-threshold pathology.[132]

The relevance route proceeds through a different conflation: between the plaintiff's burden of persuasion and the admissibility standard under Federal Rule of Evidence 401. Some courts reason that because plaintiffs must prove causation by a preponderance of the evidence, only epidemiological studies demonstrating a relative risk of at least 2.0 are legally relevant; evidence short of that threshold cannot, on its own, establish that exposure more probably than not caused the harm, and is therefore inadmissible.[133] On this logic, scientifically valid toxicological, mechanistic, and clinical evidence is legally irrelevant unless corroborated by epidemiology meeting the required risk ratio.[134] The error in that reasoning is fundamental. Rule 401 defines relevance incrementally: evidence is relevant if it makes a fact of consequence more or less probable than it would be without it.[135] That is a comparative standard, not an absolute one. Evidence that contributes to a convergent causal inference without independently establishing it satisfies Rule 401 on any sound reading. Conditioning admissibility on independent sufficiency does not apply the relevance standard;

129. *See* Gold, *supra* note 18, at 385–92; Finley, *supra* note 5, at 349–50.

130. *See* Sander Greenland, *Relation of Probability of Causation to Relative Risk and Doubling Dose: A Methodologic Error That Has Become a Social Problem*, 89 Am. J. Pub. Health 1166, 1166–69 (1999) (demonstrating that equating the attributable fraction derived from a relative risk greater than 2.0 with the probability of individual causation is a methodologic error that has been uncritically incorporated into law and policy).

131. Daubert v. Merrell Dow Pharms., 509 U.S. 579, 592–93 (1993).

132. Gen. Elec. Co. v. Joiner, 522 U.S. 136, 146–47 (1997).

133. *See* Finley, *supra* note 5, at 350–55.

134. *Id.*

135. *See* Fed. R. Evid. 401 ("Evidence is relevant if: (a) it has any tendency to make a fact more or less probable than it would be without the evidence; and (b) the fact is of consequence in determining the action.").

it substitutes the burden of proof for it, excluding evidence before the factfinder can evaluate what the full record establishes.[136]

Both routes require each evidentiary component to bear the entire weight of causation rather than permitting convergent proof to be assessed together. That requirement is not only inconsistent with *Daubert*'s methodology-focused inquiry, but also inconsistent with how causal inference operates in emerging-exposure science, where no single study or evidence type independently resolves causation and where the probative force of the record depends on the integration of multiple sources.[137] The result is a gatekeeping standard calibrated to scientific maturity rather than methodological reliability.

Judicial application is not uniform. Some courts have rejected the epidemiological threshold requirement, permitting plaintiffs to satisfy their burden of production through convergent evidence even where relative risk falls below 2.0, provided other reliable evidence bearing on individual causation is presented.[138] The variation confirms that restrictive applications reflect judicial posture toward scientific uncertainty, not a doctrinal command, and that the framework proposed in Part VII operates within the existing range of legitimate gatekeeping practice. Part IV examines how courts have navigated that choice across three prior exposure disputes, and what those choices reveal about the conditions under which judicial recalibration has occurred.

IV. How Courts Treat Uncertainty When Science Lags

Thus far, this Article has shown how emerging environmental illnesses often generate convergent evidence before they generate definitive epidemiology, diagnostic closure, or regulatory standards—and how modern doctrine can translate that posture into threshold defeat. The comparative record confirms that this result is not inevitable. Across prior waves of contested toxic harms, courts have responded to scientific uncertainty in at least four recognizable ways: excluding claims by treating evidentiary incompleteness as a categorical disqualifier; adapting causation standards to permit adjudication under

136. *See* Berger, *supra* note 118, at 20–21 (identifying the conflation of admissibility with sufficiency as an error, noting that conditioning admissibility on the independent sufficiency of individual studies replaces the de novo review applicable to sufficiency determinations with the more deferential abuse-of-discretion standard governing evidentiary rulings); Finley, *supra* note 5, at 336–38 (arguing that judges have used *Daubert* to impose substantive causation requirements under the guise of admissibility rulings, effectively converting evidentiary gatekeeping into a merits determination).

137. *See* Susan Haack, *Proving Causation: The Holism of Warrant and the Atomism of* Daubert, 4 J. Health & Biomedical L. 253, 266–73 (2008) (arguing that scientific causal inference is inherently holistic, depending on the convergent force of multiple types of evidence, none of which independently establishes causation, and *Daubert* as applied encourages an atomistic evaluation that is epistemologically unsound).

138. *See supra* note 43, at 616; *see, e.g., id.* at 616 n. 207.

conditions of imperfect information; retreating from tort adjudication in favor of administrative substitutes; or re-engaging with uncertainty through procedural and evidentiary calibration. The following episodes are instructive because they illuminate the range of institutional responses available when tort law confronts scientific lag, and the differences among them reveal what drives courts toward one response rather than another.

A. Asbestos

Asbestos litigation is the foundational reference point for toxic tort causation under conditions of scientific uncertainty, and it remains instructive because it demonstrates that courts possess the doctrinal tools for adjudicating probabilistic injury without demanding deterministic proof. [139] That courts developed those tools in the asbestos context, and have selectively declined to deploy them in others, locates doctrinal rigidity as a contingent choice.

Asbestos is a term for a group of naturally occurring fibrous silicate minerals valued for their heat resistance, tensile strength, and insulating properties.[140] Throughout much of the twentieth century, asbestos was widely incorporated into insulation, fireproofing, cement, brake linings, and other construction and industrial materials.[141] Workers in shipbuilding, construction, manufacturing, and maintenance settings were often exposed repeatedly and in varying concentrations, frequently alongside other airborne hazards.[142] Diseases associated with asbestos exposure—including asbestosis, lung cancer, and mesothelioma—typically manifest decades after exposure.[143] These features—diffuse occupational exposure, mixed environmental conditions, and delayed onset of disease—created predictable evidentiary challenges in reconstructing exposure histories and proving causation.[144]

From the outset, asbestos cases presented features now familiar in emerging toxic tort disputes: diseases manifesting decades after exposure, incomplete exposure histories, multiple potential sources across employers and products,

139. *See, e.g.,* Borel v. Fibreboard Paper Prods. Corp., 493 F.2d 1076, 1094 (5th Cir. 1973) (imposing strict liability on asbestos manufacturers for failure to warn where the health hazards of asbestos, though long studied, were characterized by latency, cumulative exposure effects, and dose-response uncertainty).

140. *See* Agency for Toxic Substance and Disease Registry, Toxicological Profile for Asbestos 15 (U.S. Dep't of Health & Human Servs., 2001), https://perma.cc/CE38-MVXX.

141. Britannica Editors, *asbestos*, Encyclopedia Britannica (last edited February 23, 2026), https://perma.cc/S95W-6H9R.

142. *See* William Nicholson et al., *Occupational Exposure to Asbestos: Population at Risk and Projected Mortality 1980–2030*, 3 Am. J. Indus. Med. 259, 259–311 (1982).

143. *See id*. at 17.

144. *See Borel*, 493 F.2d at 1083, 1094; Rutherford v. Owens-Illinois, Inc., 16 Cal. 4th 953, 975 (Cal. 1997).

and scientific evidence linking cumulative dose to disease risk.[145] Rather than treating these characteristics as a categorical bar to recovery, courts developed doctrinal standards that translated epidemiological and clinical uncertainty into legally cognizable probability questions.[146]

The central mechanism was the substantial factor test.[147] Under this framework, plaintiffs are not required to prove that fibers from a particular defendant's product were the sole or independently sufficient cause of disease.[148] Instead, they must show that exposure to the defendant's asbestos-containing product was, in reasonable medical probability, a substantial factor in contributing to the aggregate dose of asbestos inhaled and thereby to the risk of disease.[149] Courts made clear that "substantial" in this context requires more than a negligible or theoretical exposure, but does not require identification of the specific fibers that produced the malignancy.[150] *Rutherford v. Owens-Illinois, Inc.*[151] and *Borel v. Fibreboard Paper Products Corp.*[152] reflect this approach, recognizing that asbestos-related injury results from cumulative exposures and that each tortious exposure may count incrementally.[153] By focusing on contribution to aggregate dose, courts avoided imposing evidentiary demands structurally incompatible with the occupational realities of the exposure.[154]

Courts have also integrated epidemiological reasoning without converting statistical thresholds into dispositive rules. In *In re Joint Eastern & Southern District Asbestos Litigation*,[155] for example, the court declined to treat doubling of the risk as a categorical prerequisite.[156] Even where relative risk estimates fell below 2.0, courts may permit jurors to consider epidemiological findings alongside clinical, experimental, and exposure-specific evidence.[157] Causation assessments may incorporate proximity, frequency, duration, product type, and

145. *Borel*, 493 F.2d at 1083–84 (describing the long latency of asbestos-related disease and the difficulty of tracing responsibility across years of industrial exposure); *Rutherford*, 16 Cal. 4th at 957–62 (describing decades-latent disease, exposure across numerous products and defendants, and expert testimony that asbestos-related cancer risk increases with cumulative occupational dose rather than exposure to any single product).

146. *See, e.g., Rutherford*, 16 Cal. 4th at 976–77; Joint Asbestos Litig., 52 F.3d 1124, 1134 (2d Cir. 1995).

147. *Rutherford*, 16 Cal. 4th at 976–77.

148. *Id.* at 976.

149. *Id.* at 976–77.

150. *See id.*

151. 16 Cal. 4th 953 (1997).

152. 493 F.2d 1076 (5th Cir. 1973).

153. *See Rutherford*, 16 Cal. 4th at 958; *Borel*, 493 F.2d at 1094.

154. *See Rutherford*, 16 Cal. 4th at 976–77.

155. 52 F.3d 1124 (2d Cir. 1995).

156. *See id.* at 1134.

157. *See id.* ("We believe that it would be far preferable for the district court to instruct the jury on statistical significance and then let the jury decide whether many studies over the 1.0 mark have any significance in combination.").

expert testimony concerning cumulative effects rather than insisting on population-level certainty untethered to case-specific facts.[158]

The lesson of asbestos jurisprudence is that courts possess the tools (including substantial factor causation, flexible integration of epidemiology, and case-specific probability assessment) for adjudicating causation under conditions of imperfect information. Whether those tools are deployed in emerging-illness cases is a matter of doctrinal choice, not an institutional constraint.

B. Agent Orange

Agent Orange was the code name for a series of herbicides used by the United States military during the Vietnam War to defoliate vegetation and destroy crops.[159] The formulation most closely associated with subsequent litigation contained 2,4-D and 2,4,5-T, the latter contaminated with 2,3,7,8-TCDD (dioxin), a highly toxic compound.[160] Spraying occurred across broad geographic areas under wartime conditions, and individualized exposure levels were rarely documented.[161] Many of the diseases later attributed to exposure were alleged to manifest years after service.[162] Diffuse exposure, multiple sources, imprecise records, heterogeneous outcomes, and latency defined the evidentiary landscape.[163]

Beginning in 1978, veterans and their families filed product liability actions against the manufacturers.[164] Cases were consolidated in the Eastern District of New York and a nationwide class was certified under Federal Rule of Civil Procedure Rule 23(b)(3). The litigation settled on the eve of trial in May 1984 for $180 million, and the Second Circuit affirmed approval in 1987.[165] The case thus resolved without any merits adjudication of general or specific causation. This outcome represents, at scale, the pattern of merits avoidance this

158. *See, e.g.*, Woo v. Gen. Elec. Co., 198 Wash. App. 496, 512–14 (Wash. Ct. App. 2017).

159. Inst. of Med. (US) Comm. to Rev. the Health Effects in Viet. Veterans of Exposure to Herbicides, Veterans and Agent Orange: Health Effects of Herbicides Used in Viet. 90 (1994).

160. *Id.* at 89–92.

161. *Id.*

162. Inst. of Med. (US) Comm. to Rev. the Health Effects in Viet. Veterans of Exposure to Herbicides, Veterans and Agent Orange: Update 1998 408 (1999) (noting that diseases such as cancer may take "years or even decades" to appear after exposure).

163. *Cf.* Robert L. Rabin, *Book Review: Tort System on Trial: The Burden of Mass Toxics Litigation Agent Orange on Trial Mass Toxic Disasters in the Court (Enlarged Edition) by Peter Schuck, 1987*, 98 Yale L.J. 813, 822–23 (1989).

164. *See* Peter H. Schuck, Agent Orange On Trial: Mass Toxic Disasters in the Courts 23–57 (1986) (describing the development and initial filings of the cases against Agent Orange manufacturers).

165. *See* In re "Agent Orange" Prod. Liab. Litig., 597 F. Supp. 740 (E.D.N.Y. 1984), *aff'd*, 818 F.2d 145 (2d Cir. 1987) (approving class settlement in light of scientific uncertainty and establishing compensation program).

Article identifies: the most consequential questions about exposure and disease were absorbed into a settlement whose terms reflected administrative and institutional pressure rather than scientific determination.[166]

A subset of plaintiffs opted out and proceeded individually. In these cases, the court confronted causation directly. In *In re "Agent Orange" Product Liability Litigation*,[167] the district court granted summary judgment against opt-out plaintiffs, characterizing epidemiological studies as "the only useful studies having any bearing on causation" and treating animal studies, mechanistic evidence, and clinical observations as insufficient to establish general causation in humans.[168] As Part II established, this ruling did not merely evaluate the evidence presented; it established a hierarchy that determined which evidence could count. The combination of an epidemiological prerequisite,[169] the procedural concentration of mass litigation in a single court, and institutional pressure to resolve at scale produced the convergence of doctrinal and procedural exclusion that effectively eliminated individual merits adjudication for a generation of claimants whose scientific record was, at the time, predictably incomplete.

Congress responded to the difficulties of individualized proof by enacting a presumptive compensation regime. Under 38 U.S.C. § 1116, veterans who served in Vietnam are presumed to have been exposed to certain herbicides, and specified diseases are presumptively deemed service-connected if they manifest to a defined degree. This statutory framework represents a legislative judgment that individualized tort proof was ill-suited to the evidentiary realities of wartime herbicide exposure.[170] In *Nehmer v. United States Veterans Administration*,[171] the court invalidated portions of the Department of Veterans Affairs (VA)'s implementing regulation for requiring proof of a strict "cause and effect" relationship—holding instead that statistical association, appropriately credited,

166. *Cf.* Rabin, *supra* note 163, at 822 (noting Agent Orange was "exceptional because of its origins in the traumatic war in Vietnam. The contextual setting of the case created an emotional and ideological overlay that colored every aspect of the controversy, including the initial characterization of the case by an activist attorney, the growing sense of alienation of the claimant class, and the eventual resolution by an empathetic judge.").

167. 597 F. Supp. 740 (E.D.N.Y. 1984).

168. *Id*. at 1241–42.

169. *See* Gold, *supra* note 18, at 394.

170. *Cf.* Rabin, *supra* note 163, at 822 ("Agent Orange was distinctive because the problem of establishing dioxin exposure in individual cases would have been virtually insoluble. Although the Army did maintain records indicating where Agent Orange had been sprayed, it would have been a hopeless task to pinpoint the residue in a particular area on a specified calendar date and link that potential exposure data with the movements of a particular veteran in the jungle during the same period."); Schuck, *supra* note 164, at 296 (suggesting mass toxic torts might be better handled by "nontort techniques of deterrence, compensation, and dispute resolution"); Robert L. Rabin, *Environmental Liability and the Tort System*, 24 Hous. L. Rev. 27, 29–32 (1987) (describing evidentiary problems of "identification," "boundaries," and "source" that challenge the traditional tort system in environmental harm cases).

171. 712 F. Supp. 1404, 1418–22 (N.D. Cal. 1989).

could satisfy under the statute, and that veterans were entitled to the benefit of the doubt required by law.[172] *Nehmer*'s epistemological holding reflects the same judgment this Article makes about the preponderance standard: that demanding definitive causal proof in a setting of structural evidentiary constraint is both doctrinally unwarranted and normatively indefensible.

The Agent Orange episode thus illustrates how courts may retreat when heightened evidentiary demands converge with institutional concerns about administrability. The political availability of an administrative substitute produced departure from tort adjudication rather than doctrinal adaptation. The resulting system's scope and generosity were shaped as much by political compromise as by scientific determination—a tradeoff that the presumptive compensation framework made explicit and that individual tort adjudication, had it proceeded, would have been forced to confront directly.

C. PFAS

Per- and polyfluoroalkyl substances (PFAS) are a large class of synthetic chemicals used for decades in industrial processes and consumer products due to their resistance to heat, water, and oil.[173] Their carbon–fluorine bonds render them highly persistent in the environment and in human tissue, producing bioaccumulation and long-term exposure through drinking water, food, and occupational contact.[174] PFAS litigation accordingly offers a contemporary example of courts assessing causation amid heterogeneous exposures and a still-developing scientific record.[175]

Unlike asbestos, where doctrinal adaptation followed decades of litigation, or Agent Orange, where institutional scale contributed to retreat, PFAS litigation has required courts to evaluate causation in real time—acknowledging that the science is developing while simultaneously applying reliability standards that prevent adjudication from becoming a mechanism for ratifying unsupported claims.[176] The contrast with Agent Orange is instructive: where Agent Orange courts treated epidemiological incompleteness as a categorical

172. *Id*.

173. *See Properties: PFAS Information for Clinicians–2024*, Agency for Toxic Substances and Disease Registry (Nov. 12, 2024), https://perma.cc/7VEV-YJ5P.

174. *See id*.; Human Exposure: PFAS Information for Clinicians–2024, Agency for Toxic Substances and Disease Registry (Nov. 12, 2024), https://perma.cc/9B66-GM3K.

175. The current PFAS docket spans water-contamination, occupational-exposure, and consumer-product suits, requiring courts to assess causation theories across differing exposure pathways and a scientific literature that continues to develop. *See, e.g.*, In re: Aqueous Film-Forming Foams Prods. Liab. Litig., 357 F. Supp. 3d 1391 (U.S. Jud. Pan. Mult. Lit. 2018) (centralized pretrial proceedings for 75 actions involving allegations concerning PFAS contamination in groundwater and drinking water supplies).

176. *See* Conklin v. Corteva, Inc., 782 F. Supp. 3d 268, 277 (E.D.N.C. 2025) (quoting plaintiffs' briefing which states PFAS research is "ongoing" and "much of the science may still be developing").

disqualifier, PFAS courts have generally treated developing science as a condition of adjudication to be managed.

In *Conklin v. Corteva, Inc.*,[177] the district court acknowledged that ongoing EPA research and publication of maximum contaminant levels would "affect the viability of [plaintiffs'] claims," but held that plaintiffs could proceed without "waiting for further development of the science."[178] Scientific uncertainty at the frontiers of harm recognition was not treated as dispositive evidence that causation was inherently speculative. At the same time, the court issued a Lone Pine order requiring plaintiffs to submit expert declarations supporting causation before discovery proceeded, reasoning that such disclosures implicated "the same 'information which plaintiffs should have had before filing their claims.'"[179] The stated aim was to balance efficiency and equity while preventing meritless claims from advancing absent foundational expert support.[180] That balance is worth noting for its limits as well as its virtues. In a setting where the evidentiary record is structurally incomplete, as for aerotoxic claims, an early expert disclosure requirement may function as a threshold exclusion device rather than a filtering mechanism, for precisely the reasons Parts I and II established about the interaction between evidentiary expectations and emerging science.

The DuPont C-8 MDL provides the most developed illustration of PFAS courts' approach to general and specific causation.[181] Through a contractually-created Science Panel, independent epidemiologists issued "Probable Link Findings" on general causation; once those findings issued, defendants waived general causation challenges and litigation proceeded to specific causation in individual cases.[182] At that stage, courts required experts to reliably "rule in" PFAS exposure through disciplined differential diagnosis while permitting defendants to contest dose, exposure pathways, and alternative etiologies.[183] This sequencing channeled broad scientific uncertainty into structured inquiries rather than collapsing all causation questions into a single threshold determination—precisely the move that the admissibility-sufficiency collapse in *Daubert*-era gatekeeping resists.

At the evidentiary level, the courts maintained traditional *Daubert* requirements while adopting a generally liberal posture toward admissibility. Reliability was understood as methodological soundness, not scientific certainty.[184]

177. 782 F. Supp. 3d 268 (E.D.N.C. 2025).
178. *Id.* at 277–78 (quoting plaintiffs' briefing).
179. *Id.* at 276.
180. *Id.* at 274–75 (quoting *In re* Vioxx Prods. Liab. Litig.), 557 F. Supp. 2d 741, 743 (E.D. La. 2008), *aff'd*, 388 F. App'x 391 (5th Cir. 2010).
181. *See* In re E.I. du Pont de Nemours & Co. C-8 Pers. Injury Litig., 348 F. Supp. 3d 650 (S.D. Ohio 2016); In re E.I. du Pont de Nemours & Co. C-8 Pers. Injury Litig., 337 F. Supp. 3d 728 (S.D. Ohio 2015).
182. *In re E.I. du Pont*, 348 F. Supp. at 656.
183. *Id.* at 661; *In re E.I. du Pont*, 337 F. Supp. at 740.
184. *In re E.I. du Pont*, 337 F. Supp. at 739.

Competing interpretations of uncertain but methodologically grounded data were resolved through adversarial testing, with judicial exclusion reserved for opinions resting on conjecture.[185] Animal studies, regulatory assessments, and mechanistic data were integrated through the kind of convergent, multi-disciplinary reasoning that the reform proposed in Part VII would recognize as the appropriate standard for emerging-illness causation proof.

PFAS litigation does not represent categorical judicial liberalism in the face of uncertainty, nor does it signal a dilution of Rule 702. It illustrates a calibrated re-engagement: adherence to reliability doctrine; recognition that epidemiology, while highly probative, is not invariably indispensable; insistence that non-epidemiological evidence be integrated through disciplined reasoning; and procedural sequencing filters unsupported claims without foreclosing those grounded in convergent proof. Whether PFAS plaintiffs ultimately prevail on the merits, the litigation demonstrates that courts can engage developing toxicology without demanding premature scientific closure as the price of adjudication.

D. Exclude, Adapt, Retreat, or Re-Engage

Taken together, these episodes confirm that scientific uncertainty does not by itself determine outcomes in toxic tort litigation. What drives courts toward one institutional response rather than another appears to depend on three interacting variables: the maturity of the epidemiological record at the time of litigation; the scale and manageability of the plaintiff population and exposure circumstances; and the availability of an adequate administrative alternative.

Asbestos combined a sufficiently developed scientific record, a defined occupational population, and no adequate administrative substitute—conditions that produced adaptation. Courts had the doctrinal resources and the institutional occasion to develop probability-based causation standards, and they did. Agent Orange combined a scientifically immature record, an enormous and diffuse plaintiff population, and a politically available administrative substitute—conditions that produced retreat. The convergence of epidemiological prerequisites, mass aggregation, and institutional pressure to resolve at scale generated exit rather than adaptation, with the terms of resolution set by political compromise rather than scientific adjudication. PFAS involves a developing but legally engaged scientific record, a structured plaintiff population amenable to MDL management, and no adequate substitute—conditions that have produced calibrated re-engagement, with courts managing uncertainty through procedural design.

Aerotoxic Syndrome occupies an uncertain position across these variables. The plaintiff population, including flight crew with documented occupational exposure in an identifiable environment, is more bounded and manageable than

185. *Id.* at 738–39; *In re E.I. Du Pont*, 348 F. Supp. at 660 (citing Daubert v. Merrell Dow Pharms., 509 U.S. 579, 596 (1993)).

Agent Orange's dispersed wartime claimants, which reduces the institutional pressure toward retreat. But the scientific record exhibits the features that Agent Orange courts and certain *Daubert*-era courts have treated as disqualifying: mixed exposures, incomplete epidemiology, contested recognition, and no formal regulatory acknowledgment of the condition. Whether aerotoxic litigation follows the exclusion or the re-engagement pattern depends, in significant part, on whether courts approach the evidentiary record with the epistemological honesty that PFAS courts have shown and that the asbestos courts developed over decades. Part V surveys what has happened in aerotoxic-related proceedings to assess how existing frameworks have structured their disposition.

V. Aerotoxic Syndrome in the Courts

Aerotoxic-related claims have generated a limited but instructive body of decisions across jurisdictions. The reported record is notable less for merits-stage causation rulings than for the procedural and institutional settings in which claims have been resolved. Across U.S. litigation, administrative adjudication, and foreign proceedings, the absence of definitive merits adjudication reflects the architecture through which these claims have been routed.

A. United States

The most developed reported U.S. aerotoxic litigation to date is *Vuksanovich v. Airbus Americas, Inc.*,[186] brought by a former JetBlue flight attendant alleging neurological injury from repeated exposure to contaminated bleed air aboard Airbus A320 aircraft.[187] In 2022, the district court dismissed the claims of a co-plaintiff whose pleadings alleged progressively worsening symptoms beginning more than three years before suit.[188] It reached a different conclusion as to Vuksanovich, who alleged that her early symptoms in the summer of 2017 abated within one to two weeks and that her permanent neurological condition manifested later.[189] Accepting those allegations as true and drawing reasonable inferences in her favor, the court held that the earlier symptoms could plausibly be deemed "isolated or inconsequential" at the pleading stage and therefore insufficient to trigger accrual.[190] The court also held that Vuksanovich had adequately pleaded strict products liability and negligence claims under design-defect and failure-to-warn theories, relying on allegations of recurrent fume events, bleed-air system design features, and governmental attention to

186. 608 F. Supp. 3d 92 (S.D.N.Y. 2022).
187. *See id.* at 98–102.
188. *See id.* at 104–07 (applying New York's toxic-tort discovery rule).
189. *Id.* at 107–10.
190. *Id.* at 109.

cabin air quality.[191] The opinion did not evaluate general causation, conduct a Rule 702 analysis, or determine the scientific validity of Aerotoxic Syndrome; it addressed plausibility and timeliness only.

After discovery, the case ended differently. In 2025, the court granted summary judgment on statute-of-limitations grounds.[192] The court concluded that Massachusetts law supplied the shorter limitations period because the plaintiffs were nonresidents and the injury occurred there.[193] Under Massachusetts's discovery rule, accrual begins when a reasonable person knows or should know both that she has suffered appreciable harm and that the defendant's conduct may have caused it.[194] On a developed record—including evidence that Vuksanovich experienced immediate symptoms during a June 16, 2017 fume event, received a contemporaneous employer communication warning that cabin odors could cause illness, knew of a colleague who had become sick from similar exposure, sought medical care that month, and identified that date as the onset of her symptoms in workers' compensation documentation—the court held that a reasonable person would have been on inquiry notice by late June 2017.[195] Because the action was filed in October 2020, her claims were time-barred.[196] Having resolved the case on limitations grounds, the court did not reach Airbus's *Daubert* motions or its alternative merits arguments.[197]

The accrual analysis in *Vuksanovich* is instructive beyond its outcome. The features that made the limitations question close—gradual symptom onset, initial symptoms that abated, uncertainty about whether early exposure events had caused permanent harm—are the same features that characterize aerotoxic injury generally: heterogeneous symptom profiles, variable exposure intensity, and the absence of a discrete injury moment. The discovery rule's "knew or should have known" standard, applied to a plaintiff who experienced early symptoms and sought medical care, resolved accrual against her before causation was meaningfully tested. This is a structural feature of aerotoxic litigation, not a case-specific anomaly: the conditions that make exposure-related neurological injury difficult to prove on the merits are the same conditions that make accrual determinations adverse to plaintiffs at the threshold.

Taken together, the *Vuksanovich* decisions demonstrate how accrual doctrine and borrowing statutes can be dispositive in aerotoxic litigation, resolving claims without a developed merits-stage assessment of causation. The court

191. *See id.* at 112–16.

192. *See* Vuksanovich v. Airbus Americas, Inc., No. 21-CV-3454-LTS-VF, 2025 WL 2780817, at *13 (S.D.N.Y. Sept. 30, 2025).

193. *See id.* at *5–6 (applying New York's borrowing statute).

194. *Id.* at *8.

195. *Id.* at *3, *9–11.

196. *Id.* at *7.

197. An appeal from the 2025 summary judgment order was filed and remains pending. *See* Notice of Appeal, Vuksanovich v. Airbus Americas, Inc., No. 21-CV-3454-LTS-VF, 2025 WL 2780817 (pincite S.D.N.Y. Sept. 30, 2025), ECF No. 235.

reached the limitations question twice, at pleading and after discovery, and the case ended on that question both times. Whether the evidentiary record assembled through discovery would have supported or defeated causation under *Daubert* and applicable substantive standards remains untested.

Other U.S. aerotoxic-related suits have encountered threshold barriers of a different kind. In *Herd v. Airbus SAS*,[198] an Australian flight attendant sued Airbus and Rolls–Royce in federal court in California over alleged injury from contaminated bleed air on a Qantas long-haul flight.[199] The court dismissed on forum non conveniens grounds after finding Australia an adequate alternative forum and concluding that the relevant witnesses and proof were overwhelmingly located abroad.[200] The practical consequence extends beyond the individual case: forum non conveniens dismissal to a foreign jurisdiction means that causation will be litigated, if at all, outside the U.S. discovery apparatus and under a different evidentiary framework, which has direct implications for the development of the aerotoxic evidence base in U.S. courts. The dismissal reflected convenience and forum interests, not any assessment of whether contaminated cabin air can cause the alleged injuries.

Wragge v. Boeing Co.[201] likewise involved Australian pilots alleging illness following contaminated-air events aboard a Boeing aircraft in Australia, and the decision addressed only removal and federal jurisdiction.[202] The court held that Boeing's pre-service removal was permissible and that the amount in controversy was plausibly satisfied.[203] The case generated no causation analysis.

The domestic aerotoxic litigation record to date is a record of architectural preclusion operating before the merits are reached. Even when aerotoxic allegations are pleaded in conventional product-liability terms and reach federal courts, the disputes are resolved through forum allocation, accrual doctrine, and jurisdictional gatekeeping. Causation is left to be tested elsewhere and on a different record.

B. Administrative Adjudication: Workers' Compensation

A different institutional posture appears in administrative adjudication. In 2020, the Oregon Workers' Compensation Board held compensable a JetBlue pilot's claims for toxic encephalopathy and mild neurocognitive disorder arising from a discrete onboard fume event.[204] The Board's causation inquiry required the claimant to prove by a preponderance of the evidence that the claimed

198. No. 217CV05001SVWMRW, 2017 WL 6504162 (C.D. Cal. Dec. 11, 2017).
199. *See id.* at *1.
200. *See id.* at *2–4.
201. No. 20-CV-04457, 2022 WL 4119777 (N.D. Ill. Sept. 9, 2022).
202. *See id.* at *1–2, *5–12.
203. *See* Wragge v. Boeing Co., 532 F. Supp. 3d 616, 620–25 (N.D. Ill. 2021).
204. *See* Andrew J. Myers, Claim No. 555232469, (Or. Workers' Comp. Bd. 2020), https://perma.cc/FS4K-XYJY.

conditions existed and that the workplace exposure was a "material contributing cause" of his need for treatment or disability.[205] This standard differs from both the but-for test that dominates civil toxic tort litigation and the substantial factor test that asbestos courts developed, placing the threshold of required causal contribution meaningfully below either.

On a record the Board described as scientifically complex and marked by conflicting expert testimony,[206] it credited medical opinions linking the acute toxic inhalation to cognitive impairment based on mechanism-of-injury analysis, medical literature regarding organophosphate exposure (including TCP), and a strong temporal relationship between the fume event and symptom onset.[207] The Board concluded that the January 2017 exposure resulted in compensable toxic encephalopathy and mild neurocognitive disorder.[208]

The decision's significance for present purposes is methodological rather than precedential. The Board's approach exemplifies the convergent, multi-disciplinary evidentiary reasoning that this Article's reform proposal would recognize as appropriate for emerging-illness causation proof: it integrated mechanistic evidence, toxicological literature, clinical observation, and temporal relationship without requiring epidemiological confirmation of a population-level association. That methodology was sufficient, in a remedial adjudicative framework designed to resolve uncertainty in favor of claimants, to establish that occupational exposure materially contributed to diagnosed conditions on a developing scientific record.[209]

C. Foreign Proceedings

Foreign proceedings further complicate any account of categorical judicial rejection of aerotoxic claims. In *East West Airlines Ltd. v. Turner*,[210] the New South Wales Court of Appeal affirmed a damages award arising from a 1992 in-flight smoke event.[211] The lower court found that cabin smoke exposure caused a compensable respiratory condition, and the appellate court dismissed the airline's challenge, leaving the liability and damages findings intact.[212] The case did not resolve broader scientific debates about Aerotoxic Syndrome. Its significance is narrower but instructive: an Australian appellate court permitted recovery on a fact-specific exposure record without treating scientific uncertainty as a categorical bar to causation. That a pattern of threshold dismissal exists in U.S.

205. *See id.* at 42 (applying ORS 656.005(7)(a) and ORS 656.266(1)).
206. *See id.* at 43.
207. *See id.* at 44–55, 65; *see also id.* at 60–61 (emphasizing "multiple layers of objective medical evidence of injury" which defendants' experts neglected).
208. *See id.* at 65–66.
209. *See id.* at 65–67.
210. [2010] NSWCA 53 (Apr. 1, 2010) (Austl.), https://perma.cc/6VTD-B5NU.
211. *See id.*
212. *Id.*

courts alongside a willingness in analogous common-law jurisdictions to permit recovery on comparable evidentiary records suggests that the outcome in U.S. litigation reflects contingent doctrinal choices rather than inherent limitations.

In the United Kingdom, coordinated personal-injury proceedings have been brought on behalf of pilots and cabin crew against multiple airlines including British Airways, EasyJet, Jet2, Thomas Cook, and Virgin Atlantic.[213] These proceedings remain ongoing and do not yet supply a final judicial determination of general causation. Their existence is nonetheless a comparative data point worth marking: the same claims that have not reached merits adjudication in U.S. courts are being actively litigated on the merits in a major common-law jurisdiction with substantially similar evidentiary standards. That gap suggests that the absence of U.S. merits adjudication likely reflects something about the U.S. doctrinal and procedural architecture.

Scottish authority has articulated the governing principle with the greatest doctrinal precision. In *Gough v. Cannons Law Practice*,[214] the Court of Session acknowledged ongoing medical controversy surrounding Aerotoxic Syndrome but held that the absence of scientific consensus was not fatal to legal viability.[215] The court's distinction between the difficulty of proof and the permissibility of adjudication is this Article's central normative claim applied as a matter of doctrine.[216] Scientific uncertainty affects the evidentiary demands placed on plaintiffs; it does not foreclose adjudication. Courts that have treated the absence of consensus as a categorical bar have conflated those two questions. *Gough* declines to make that conflation, and in doing so identifies the correct relationship between scientific uncertainty and legal standards: one calls for calibration of evidentiary demands, not their abandonment, while the other calls for adjudication to proceed on the record that is realistically available.

Aerotoxic litigation functions as a stress test for contemporary toxic-tort doctrine. Across jurisdictions, reported decisions rarely rest on an express determination that contaminated cabin air cannot cause neurological injury. More often, outcomes turn on threshold doctrines—pleading standards, accrual rules, forum non conveniens, or the distinct proof norms of administrative schemes—that determine whether causation be adjudicated on a fully developed record. The existing case law therefore reflects the procedural architecture through which emerging toxic-harm claims are permitted, redirected, or terminated. The critical inference to draw from that architecture is that U.S. tort doctrine has not yet permitted the evidentiary record to develop to the point where that question can be meaningfully tested on the merits. Whether that outcome is

213. *See Pilots and Cabin Crew Launch Court Action Against Airlines in Toxic Air Dispute*, Unite Legal Servs. (Mar. 28, 2019), https://perma.cc/Q69U-JFEP.

214. [2025] CSOH 28 (Scot.).

215. *See id*. at 136–37 (noting "the absence of a medical consensus as to any causal relationship" is not fatal, even if it makes the plaintiff's burden "more difficult.").

216. *See id.*

acceptable, and what a more calibrated doctrine would look like, are addressed in Part VI.

VI. Normative Analysis

Parts I through V establish a descriptive account of contemporary toxic tort adjudication under conditions of emerging environmental illnesses: structural uncertainty is predictable, and courts often convert that predictability into threshold defeat. The normative question is whether that outcome is justified. The institutional concerns animating modern gatekeeping doctrine are real—about speculative litigation, error at scale, and adjudicatory competence. But so are the costs of a regime that treats the absence of ideal proof as dispositive. This Part argues that courts need not choose between epistemic overreach and institutional passivity. A legitimate judicial role can preserve rigor without allowing scientific indeterminacy to function as immunity.

A. The Case Against Relaxed Standards Per Se

Any proposal to recalibrate causation in toxic tort litigation invites a familiar concern: that relaxing evidentiary discipline risks eroding meaningful limits in liability. That concern is not merely rhetorical. The *Daubert* trilogy reflects a considered institutional judgment that juries are especially vulnerable to overconfident technical testimony in complex cases, and that the gatekeeping function exists precisely to prevent credentialed experts from offering conclusion-driven syntheses untethered to disciplined inference.[217] The "too great an analytical gap" formulation of *Joiner* speaks directly to that risk.[218]

The structural features of toxic exposure disputes amplify these concerns. Such cases often involve large plaintiff pools, heterogeneous diseases, long latency periods, and incomplete exposure reconstruction.[219] Under those conditions, even weak causal signals can generate settlement pressure. As the Court acknowledged in *Amchem Products, Inc. v. Windsor*,[220] aggregation in mass exposure contexts can create leverage untethered from the underlying merits.[221]

217. *See* Daubert v. Merrell Dow Pharms., Inc., 509 U.S. 579, 597 (1993) (holding that Rule 702 imposes a "gatekeeping" obligation on trial courts to ensure that expert testimony is grounded in scientific knowledge and reliable methodology); Kumho Tire Co. v. Carmichael, 526 U.S. 137, 147–49 (1999) (extending *Daubert*'s reliability framework to all expert testimony and emphasizing the "specialized experience" that renders all expert testimony more difficult for juries to evaluate).

218. Gen. Elec. Co. v. Joiner, 522 U.S. 136, 146 (1997) ("A court may conclude that there is simply too great an analytical gap between the data and the opinion proffered.") (citation omitted).

219. *Supra* note 3.

220. 521 U.S. 591 (1997).

221. *See id.* at 621–28 (rejecting aggregate settlement structures in asbestos litigation where the class device was being used to achieve comprehensive resolution under conditions that compromised individualized representation).

Scholars have likewise documented how the combination of scientific uncertainty and aggregation can distort incentives for both litigants and courts, producing what Richard A. Nagareda describes as a "world of settlement" in which accuracy competes with closure.[222]

Concrete episodes from toxic tort history illustrate the stakes. In the Bendectin litigation of the 1980s and 1990s, thousands of claims alleging birth defects proceeded alongside a scientific record that ultimately failed to demonstrate teratogenic causation;[223] courts and commentators cite this experience as emblematic of the need for disciplined admissibility standards.[224] In silicone breast implant litigation, early waves of claims alleging systemic autoimmune disease generated extensive settlement activity before more robust epidemiological evidence failed to substantiate the asserted causal link.[225] Appellate decisions excluding expert testimony emphasized that differential diagnosis, case reports, or mechanistic speculation cannot substitute for reliable evidence of general causation where courts "would have to make several scientifically unsupported leaps of faith in the causal chain."[226] Premature endorsement of contested causal claims can impose error costs on defendants, on the judicial system, and on the integrity of science itself.

To be sure, the reforms this Article proposes do not address settings in which a mature and contrary epidemiological record exists and fails to support causation. It addresses the setting in which mature epidemiology does not yet exist in either direction—where the absence of population-level confirmation reflects structural constraint rather than scientific refutation. Those are materially different evidentiary conditions and conflating them by citing Bendectin and breast implants against any departure from epidemiological primacy proves too much.

These risks establish what any credible reform must concede and what it must deliver. Methodological transparency is non-negotiable; inference must be bounded and traceable from data to conclusion; and some evidentiary floor must distinguish genuine weight-of-the-evidence reasoning from ipse dixit. The

222. *See generally* Richard A. Nagareda, Mass Torts in a World of Settlement 1–28 (2007).

223. *Cf.* Joseph Sanders, *The Bendectin Litigation: A Case Study in the Life Cycle of Mass Torts*, 43 Hastings L.J. 301, 328–45 (1992) (detailing the scientific research and litigation dynamics surrounding Bendectin claims).

224. *See, e.g.,* David E. Bernstein, *Getting to Causation in Toxic Tort Cases*, 74 Brook. L. Rev. 51, 72–74 (2008).

225. *See* Krista R. Stine, *Silicone, Science and Settlements: Breast Implants and A Search for Truth Although Current Science Is in Their Favor, Implant Manufacturers Will Be Better Served by Sticking with the New Settlement*, 63 Def. Couns. J. 491, 491–92, 494 (1996); *see also* Finley, *supra* note 5, at 351 (explaining that courts' exclusion of plaintiffs' expert testimony in Bendectin and breast implant litigation coincided with the maturation of epidemiological research that ultimately failed to demonstrate any substantial increase in risk).

226. Rider v. Sandoz Pharms. Corp., 295 F.3d 1194, 1199–202 (11th Cir. 2002) (rejecting reliance on case reports and speculative extrapolation absent reliable evidence of general causation).

question is not whether limits should exist, but whether the specific limit of epidemiological closure is the right one when scientific knowledge is incomplete and injury claims are plausibly grounded.

B. The Case Against Status Quo Stringency

Recognizing the risks of overreach does not resolve the normative difficulty presented by the prevailing causation framework. In emerging environmental illness litigation, demanding epidemiological closure or regulatory consensus does not merely defer liability until science matures. It can function as a structural barrier to adjudication during the period when proof is predictably incomplete.[227] That posture has three interrelated costs.

First, it creates a functional safe harbor during epistemic lag. Where courts calibrate admissibility or sufficiency to statistically significant population-level evidence, liability is effectively conditioned on scientific maturity. In many environmental contexts, that maturity arrives only after protracted exposure and injury.[228] When courts treat regulatory silence or scientific contestation as dispositive, they risk delaying adjudication—sometimes decades—while exposure continues. For certain injuries—low-dose, long-latency, or ethically non-replicable exposures—large-cohort epidemiology may be infeasible as a practical or ethical matter.[229] In those settings, the absence of epidemiology is a foreseeable product of the exposure's structure, not a reflection of the claim's merit. The result is functional insulation during the interval when accountability pressures might most effectively influence conduct.

The second cost is the asymmetric allocation of uncertainty burdens. Latency, incomplete monitoring, evolving diagnostic criteria, and fragmented regulatory oversight are features of environmental exposure, not failings of individual plaintiffs. Yet when claims are terminated at the admissibility or summary judgment stage for want of epidemiological closure, plaintiffs absorb the full cost of that indeterminacy. Defendants in industrial and environmental contexts often control relevant exposure pathways, maintain internal testing data, and possess superior capacity to generate and preserve the relevant information.[230] A regime that conditions adjudication on proof that predictably matures only after prolonged exposure risks entrenching that asymmetry. The party least able to accelerate scientific development bears the consequences of its absence.

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227. Cranor, *supra* note 3, at 154–55.

228. *See* Albert C. Lin, *Beyond Tort: Compensating Victims of Environmental Toxic Injury*, 78 S. Cal. L. Rev. 1439, 1446 (2005) (describing difficulties due to latency of harm in toxic exposure cases).

229. Cranor, *supra* note 3, at 95–96; Berger, *supra* note 2, at 298.

230. Cranor, *supra* note 3, at 12–13 ("The firms creating and using such substances have many more resources and information to develop and investigate the properties of such substances.").

Third, the prevailing framework embeds an implicit normative judgment about error allocation that has never been openly made or defended. Courts operationalized, through admissibility doctrine and sufficiency standards, a structural preference for false negatives over false positives—for tolerating unredressed injury over risking erroneous liability—without acknowledging that this preference is a normative choice with distributive consequences. The choice may be defensible. Preventing erroneous liability in cases involving contested science and large plaintiff populations is a genuine institutional concern. But defending it requires confronting what false negatives cost: the premature foreclosure of meritorious claims, the muting of deterrence during periods of exposure, the disincentive to further research that legal closure produces, and the persistence of hazardous conditions while regulatory responses remain fragmented.[231] Those costs fall on identifiable people—workers, flight crew, residents of contaminated communities—whose claims are resolved not on their merits but on the basis of an evidentiary standard calibrated to scientific conditions that do not yet exist.

A causation regime calibrated to epidemiological consensus privileges the avoidance of false positives, often at the cost of tolerating false negatives during periods of scientific research and emergence. That allocation of error costs may be defensible, but it is neither inevitable nor neutral. It reflects a normative judgment about who should bear the burdens of uncertainty in the shadow of evolving science—and about the conditions under which the civil standard should require proof that the evidentiary structure of a given exposure category cannot yet supply.

C. Reframing the Judicial Role

The foregoing analysis does not require courts to resolve scientific controversy or to choose sides in contested toxicological debates. Rather, it requires that courts maintain evidentiary rigor without treating the predictable incompleteness of emerging science as a categorical bar to adjudication. The civil standard demands reasoned judgment on the best available record—a standard that tort law applies routinely under conditions of uncertainty far less tractable than those presented by emerging environmental illness.[232]

As Carl Cranor has observed, the slow accumulation of scientific knowledge about the toxicity of substances creates important impediments to identifying and documenting adverse health effects in humans.[233] In toxic tort litigation,

231. *See* Carl F. Cranor, *Discerning the Effects of Toxic Substances: Using Science Without Distorting the Law*, 38 Jurimetrics J. 545, 551–52 (1998); Cranor, *supra* note 3, at 165–67; Finley, *supra* note 5, at 373–74 (emphasizing disproportionate impact on women, minorities, and people experiencing poverty).

232. *See* Restatement (Third) of Torts: Phys. & Emot. Harm § 28 cmt. a (A.L.I. 2010).

233. *See* Cranor, *supra* note 3, at 202.

"science delayed can easily be justice denied."[234] Judges cannot accelerate scientific development, but they can respond to epistemic lag without compromising plaintiffs' access to adjudication: by taking "a more realistic view of the availability of evidence," recalibrating what they demand from proof, and modifying how they evaluate the evidence that parties can reasonably produce.[235]

This approach does not relax gatekeeping. It clarifies what gatekeeping, properly understood, should do.[236] Courts should evaluate the reliability of expert methods without converting uncertainty into disqualification. Where experts apply accepted scientific methods and draw transparent, bounded inferences from available data, disagreement about conclusions is ordinarily a matter for adversarial testing rather than categorical exclusion.[237] The choice to treat epidemiological absence as equivalent to scientific negation is not compelled by *Daubert*, not required by the preponderance standard, and not epistemically honest about what the absence of mature population-level evidence means in a setting where that evidence is structurally constrained.

The normative case, in short, is not for abandoning reliability requirements or lowering the burden of proof. It is for applying those requirements in a manner that reflects how causal knowledge develops in emerging-exposure contexts—through convergent, disciplined reasoning across multiple evidence streams rather than through a single dispositive study.[238] That standard preserves the gatekeeping function *Daubert* assigned to courts while ensuring that the absence of scientific closure does not operate as a substitute for merits adjudication. Part VII operationalizes that principle.

VII. Reform Proposals

Prior scholarship addressing causation in toxic exposure litigation has proposed a range of doctrinal and institutional reforms. This Article does not survey that literature comprehensively. Instead, it advances a set of reforms that are doctrinally realistic, administrable within existing legal structures, and directly responsive to the evidentiary challenges that arise when emerging environmental illness claims encounter a causation framework calibrated to scientific closure. The proposals preserve causation as a meaningful constraint, retain *Daubert*'s gatekeeping function, and respect courts' institutional limits, while ensuring that emerging exposure claims can be evaluated on a developed record through reasoned inference.

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234. *Id.*
235. *Id.*
236. *See supra* Part III.A.
237. *See* Cranor et al., *Judicial Boundary Drawing and the Need for Context-Sensitive Science in Toxic Torts After* Daubert v. Merrell Dow Pharmaceuticals, Inc., 16 Va. Env't L. J. 1, 17 (1996).
238. *See* Cranor, *supra* note 3, at 130–39 (outlining how scientific theories of causation are developed and the importance of relative plausibility in hypotheses); *id.* at 260.

A. A Convergent, Probabilistic Causation Framework

Courts evaluating toxic tort claims involving emerging environmental illnesses should adopt a convergent, probabilistic approach to causation. Tort law has long permitted causation to be established through circumstantial evidence and expert inference where direct proof is unavailable, and it recognizes that causal processes may be probabilistic, cumulative, and multifactorial.[239] The adjustment proposed here concerns how courts synthesize heterogeneous forms of scientific proof. Rather than evaluating each category of evidence in isolation—treating the absence of any single evidentiary modality as dispositive—courts should assess the evidentiary record as an integrated whole.[240] The central inquiry remains unchanged: whether the plaintiff's proof, considered collectively, supports a reasoned inference, consistent with the preponderance standard, that the defendant's exposure materially contributed to the injury alleged.

This mode of reasoning reflects how scientific bodies themselves evaluate toxic risk. Regulatory and scientific institutions routinely integrate multiple lines of evidence to assess whether an agent is capable of producing adverse health effects, drawing on epidemiology, toxicology, mechanistic data, and clinical observations without imposing a rigid evidentiary hierarchy.[241] Their methodology reflects the Bradford Hill criteria's established approach to causal inference under uncertainty: no single criterion is decisive, but the convergence of multiple partially informative lines of evidence can establish biological plausibility and support a causal judgment about toxicity.[242] Courts evaluating toxic tort claims therefore need not treat incomplete evidence as evidentiary failure; the relevant question is whether the combined weight of the available evidence supports the inference that the exposure at issue more likely than not contributed to the plaintiff's harm.

A convergent framework does not relax the plaintiff's burden or invite speculation. Each evidence type must be methodologically sound; the inferential chain from data to conclusion must be explicit, bounded, and traceable; competing explanations must be addressed rather than ignored; and the overall

239. *See* Restatement (Third) of Torts: Phys. & Emot. Harm § 28 cmt. c (A.L.I. 2010).

240. Cranor, *supra* note 3, at 141.

241. *See, e.g.*, Int'l Agency for Rsch. on Cancer, *Preamble to the IARC Monographs* 8–10 (amended Jan. 2019), https://perma.cc/WK85-4N72 (describing a weight-of-evidence approach integrating epidemiological, animal, and mechanistic data to classify carcinogenic hazards); U.S. EPA Guidelines for Carcinogen Risk Assessment, 70 Fed. Reg. 17766 (Apr. 7, 2005) (establishing a framework for integrating multiple evidence streams).

242. *See* Restatement (Third) of Torts: Phys. & Emot. Harm § 28 cmt. c (A.L.I. 2010); *see also* Austin Bradford Hill, *The Environment and Disease: Association or Causation?*, 58 Proc. Royal Soc'y Med. 295, 299 (1965) ("None of my nine viewpoints can bring indisputable evidence for or against the cause-and-effect hypothesis and none can be required as a *sine qua non*.").

synthesis must support a probability judgment rather than merely a causal possibility. Three principles structure that inquiry, addressing respectively the role of epidemiology, toxicological and mechanistic evidence, and clinical inference within the integrated framework.

First, epidemiology remains probative but not dispositive. Where robust, well-designed population studies exist, they carry substantial weight.[243] But their absence should not operate as a categorical barrier when structural features of the exposure make such studies infeasible, underpowered, or slow to emerge. Toxic tort disputes often arise precisely in circumstances where the epidemiologic record is incomplete or developing. In those contexts, demanding epidemiology as a practical prerequisite to causation would impose an evidentiary requirement that the scientific record cannot yet satisfy.[244] Courts should instead evaluate causation by reference to the "preponderance of the available evidence," considering all scientifically relevant sources of information.[245] Several circuits have already applied this principle, permitting causation testimony in the absence of complete epidemiological support where the expert's methodology was otherwise sound and the inferential chain was disciplined.[246]

Second, toxicological and mechanistic evidence bears on biological plausibility. Its function is not to replicate human disease outcomes but to test whether the proposed causal pathway coheres with established principles of exposure science and physiology. Laboratory studies, structure–activity relationships, and molecular or mechanistic findings may illuminate whether a substance can plausibly produce the kind of injury alleged, particularly where exposures involve complex chemical mixtures, cumulative pathways, or low-dose mechanisms that are difficult to isolate epidemiologically. Scientific institutions routinely rely on such

243. *Cf.* Green, *supra* note 23, at 680 ("Where the epidemiologic record is substantial, reliable, and consistent, the saliency of animal studies or other evidence of toxicity is quite low.").

244. *See* Cranor, *supra* note 3, at 219–20 ("*Well-designed* and *well-done* epidemiological studies (much is built into these ideas), with *sufficiently large samples* that are *sufficiently sensitive* to detect the adverse effects in question with a *sufficient duration after exposure* can greatly assist in identifying toxic effects of product. Unfortunately, such ideal studies appear to be the exception rather than the rule.") (emphasis in original).

245. *See* Green, *supra* note 23, at 681 ("[T]he reality is that stronger and better evidence is unavailable through no fault of anyone and a decision based on the preponderance of the available evidence, rather than imposing an evidentiary threshold, would seem in keeping with the role of the civil justice system.").

246. *See* Kennedy v. Collagen Corp., 161 F.3d 1226, 1229–30 (9th Cir. 1998) (reversing exclusion of causation testimony and holding that the district court placed too much emphasis on the absence of epidemiological studies where such studies "would be almost impossible to perform," and that clinical reasoning based on medical records and analogical analysis satisfied *Daubert*); Ambrosini v. Labarraque, 101 F.3d 129, 135–41 (D.C. Cir. 1996) (reversing exclusion and holding that expert testimony based on "related human, animal, and pharmacological studies" was admissible despite the absence of epidemiological studies); *see also* Heller v. Shaw Indus., 167 F.3d 146, 156 (3d Cir. 1999) (holding that the district court erred "to the extent that [it] excluded Dr. Papano's testimony on the basis that it was not grounded in scientific studies," though affirming exclusion on other grounds).

convergent reasoning in evaluating toxicity, integrating animal studies, cellular data, and mechanistic insights with whatever human evidence is available.[247] When epidemiology is limited or inconclusive, excluding these other forms of toxicological evidence is methodologically unwarranted.[248] Courts should treat toxicological and mechanistic evidence as contributing to biological plausibility within the integrated framework, with its weight proportional to the specificity of the data and the closeness of the proposed pathway to the human exposure and disease at issue.

Third, specific causation may be supported by disciplined clinical inference grounded in exposure evidence.[249] Differential diagnosis and clinical pattern analysis can be probative when conducted systematically, tethered to a credible exposure history, and transparent about competing explanations. Because many environmental exposures occur outside controlled monitoring environments, precise quantification is often unavailable. Exposure reconstruction—drawing on occupational history, environmental measurements, or other contextual evidence—therefore becomes central. The relevant question is not perfect dose reconstruction but whether the plaintiff can demonstrate exposure above background levels in a manner consistent with the proposed mechanism of injury and the temporal course of the illness. Importantly, under a convergent framework, general and specific causation inquiries need not proceed strictly sequentially: as Part II established, the mandatory general-before-specific sequence can itself become a structural barrier where population-level evidence is immature. A disciplined showing on specific causation may itself contribute to the general causation inference where no mature epidemiology exists in either direction.[250] Courts in several circuits have permitted differential diagnosis to support specific causation without population-level epidemiological confirmation where the methodology was rigorous and the exposure history was documented.[251]

The factfinder ultimately confronts the familiar tort question: which causal explanation is more probable given the totality of the evidence? Plaintiffs may contend that exposure to the defendant's substance contributed to the injury; defendants may point to alternative causes such as genetic predisposition, background disease incidence, or unrelated environmental factors. The jury's task is to compare competing causal accounts and determine whether the plaintiff's explanation is more persuasive on the available record. A convergent framework simply ensures that this determination proceeds through integrated reasoning

247. *See* Restatement, *supra* note 232, § 28 cmt. c; Cranor, *supra* note 3, at 106–15.

248. Green, *supra* note 23, at 680 ("when epidemiologic evidence is lacking, thin, of questionable validity and ultimately inconclusive, dismissing other toxicological evidence is unjustifiable.").

249. *See* Cranor, *supra* note 3, at 249–50.

250. *See* Restatement (Third) of Torts: Phys. & Emot. Harm § 28 cmt. c(4) (Am. L. Inst. 2010).

251. *See, e.g.,* Westberry v. Gislaved Gummi AB, 178 F.3d 257, 262–66 (4th Cir. 1999).

about the totality of the evidence rather than through evidentiary silos that prematurely foreclose the inquiry.

B. Aligning Daubert *Gatekeeping with the Realities of Scientific Uncertainty*

A convergent causation framework will matter only if implemented through admissibility doctrine that evaluates methodological integrity rather than scientific closure. Two adjustments can bring gatekeeping practice into alignment with *Daubert*'s mandate.

First, courts should evaluate the inferential reasoning underlying expert testimony rather than the maturity of the scientific field. The relevant inquiry is whether the expert's inferential chain is scientifically defensible: what data are relied upon, how competing explanations are addressed, and why the causal attribution follows from the available evidence. Courts should exclude testimony resting on ipse dixit, selective literatures, and unexplained extrapolation.[252] But the mere fact that experts disagree, or that the scientific literature remains unsettled, should not be treated as a proxy for unreliability. Scientific disagreement is a normal feature of developing research areas, and the presence of competing interpretations typically signals a question for adversarial testing.[253]

Second, courts should evaluate scientific evidence in ways that reflect how scientists themselves reason under conditions of partial knowledge. Large portions of the chemical environment remain poorly understood, but toxicology and environmental health research proceed despite substantial gaps.[254] Scientific investigators rely on convergent patterns of evidence to evaluate whether substances are capable of causing harm.[255] Judicial admissibility decisions should not impose evidentiary constraints more restrictive than those used in scientific practice.[256] Nor should courts import scientific standards to generate "bright-line legal rules."[257] Part VI acknowledges that epidemiology's conservative null-hypothesis orientation reflects disciplinary values that differ from law's preponderance standard. Evidence that scientists regard as probative of biological plausibility should not be categorically excluded as legally irrelevant simply because it does not independently satisfy the burden of proof. When courts exclude categories of evidence that scientists routinely consider informative, they

252. *See, e.g.,* Est. of Mitchell v. Gencorp, Inc., 968 F. Supp. 592, 596–97 (D. Kan. 1997), *aff'd sub nom*, 165 F.3d 778 (10th Cir. 1999).

253. Cranor, *supra* note 3, at 149–55.

254. *See Cranor & Eastmond*, *supra* note 3, at 6 (noting that large portions of the chemical environment lack adequate toxicity information).

255. Cranor, *supra* note 3, at 138–39.

256. *Cf.* Berger, *supra* note 2, at 299–302.

257. *See* Restatement (Third) of Torts: Phys. & Emot. Harm § 28 cmt. c(1) (A.L.I. 2010) ("Courts . . . should be cautious about adopting specific 'scientific' principles, taken out of context, to formulate bright-line legal rules or conclude that reasonable minds cannot differ about factual causation.").

risk distorting the relationship between legal proof and scientific reasoning in a manner incompatible with *Daubert*'s methodology-focused inquiry.

A further institutional adjustment concerns judicial understanding of scientific proof. Toxic tort litigation regularly requires courts to interpret unfamiliar forms of evidence, yet judges typically receive little formal training in scientific reasoning. The challenge is not that courts must become scientists; rather, they must understand the distinct questions science and law are asking. Scientific inquiry seeks to determine whether causal relationships exist in the natural world, often demanding high levels of statistical confidence.[258] Tort law asks whether a particular causal explanation is more probable than competing alternatives given the available evidence. When these inquiries are conflated, courts may inadvertently import scientific standards of certainty into a legal framework built around probabilistic proof. Continued judicial engagement with scientific methods—through reference materials, expert tutorials, and specialized training—can improve courts' ability to evaluate expert reasoning while maintaining the proper distinction between scientific validation and legal causation. The Federal Judicial Center's *Reference Manual on Scientific Evidence* represents an existing institutional model for this kind of systematic judicial education; its frameworks for evaluating epidemiological and toxicological testimony have already shaped gatekeeping practice in several complex exposure cases.[259]

Where exclusion of expert testimony will effectively terminate a case, courts should articulate the basis for their gatekeeping decisions with particular clarity. Transparent explanations distinguish methodological defects from disagreements about evidentiary sufficiency, and they reveal whether the court is implicitly requiring proof that is unobtainable at the current stage of scientific development. Because *Joiner*'s abuse-of-discretion standard provides limited appellate correction of gatekeeping errors, inadequate articulation of the exclusion rationale is one of the few grounds on which circuit courts have reversed district court gatekeeping decisions.[260] Requiring clear explanation both

258. *See* Daubert v. Merrell Dow Pharms., Inc., 509 U.S. 579, 596–97 (1993) (observing that "there are important differences between the quest for truth in the courtroom and the quest for truth in the laboratory," and that "scientific conclusions are subject to perpetual revision").

259. *See generally* Reference Manual on Scientific Evidence (Fed. Jud. Ctr. & Nat'l Research Council eds., 3d ed. 2011). The Reference Manual has been cited by federal courts in hundreds of *Daubert* rulings and provides detailed frameworks for evaluating epidemiological, toxicological, and statistical evidence. *See, e.g.*, In re Acetaminophen – ASD-ADHD Prods. Liab. Litig., 707 F. Supp. 3d 309, 321–24 (S.D.N.Y. 2023) (relying on the Reference Manual's epidemiology chapter).

260. *See* Gen. Elec. Co. v. Joiner, 522 U.S. 136, 146 (1997) (establishing abuse-of-discretion review); Kennedy v. Collagen Corp., 161 F.3d 1226, 1229–30 (9th Cir. 1998) (reversing where the district court applied an overly restrictive standard by requiring epidemiological studies as a prerequisite); Ambrosini v. Labarraque, 101 F.3d 129, 141 (D.C. Cir. 1996) (reversing where the district court "conflated the questions of the admissibility of expert testimony and the weight appropriately to be accorded such testimony").

improves appellate review and reduces the risk that admissibility doctrine will become an indirect mechanism resolving uncertainty against plaintiffs without acknowledgement.

These adjustments together constitute a recalibrated gatekeeping practice: one that filters for methodological reliability—the concern that motivated the Supreme Court's evidentiary reforms—without converting scientific uncertainty itself into a categorical admissibility bar.[261] Implemented in this way, *Daubert* can fulfill its function of screening unreliable science while preserving the Federal Rules' "liberal thrust" toward admissibility and adversarial testing.[262]

C. Procedural and Institutional Calibration

Procedural architecture can undermine even well-calibrated substantive standards. In mass toxic-exposure litigation, courts often confront pressure to resolve general causation early, particularly in multidistrict proceedings. In mature mass torts, where legal standards and evidentiary foundations have been tested through repeated adjudication and outcomes fall within a predictable range, early global causation rulings may appropriately promote efficiency.[263] But many exposure disputes do not begin in that posture.[264] In less mature litigation, foundational information about exposure pathways, biological mechanisms, and injury patterns is often incomplete, and few prior adjudications provide guidance about claim viability.[265] Under those conditions, procedural design can determine whether litigation generates the information necessary to evaluate causation or forecloses that development before it can occur.[266]

Sequencing of discovery and admissibility practice. In emerging-exposure cases, relevant evidence concerning exposure pathways, monitoring practices, and technical mechanisms is typically concentrated in defendants' control and inaccessible to plaintiffs before discovery.[267] A litigation posture that places general causation at the threshold can collapse the causation inquiry into what evidence

261. *See* Robert W. Littleton, *Supreme Court Dramatically Changes the Rules on Experts*, N.Y. St. B.J., at *10 (1999) ("In the late 1980s, business interests expressed concerns that academically qualified litigation experts were propounding–and often convincing lay juries of–the authenticity of 'scientific' conclusions that would be laughed out of any respectable scientific forum. Many commentators argued that cross-examination was proving insufficient protection against 'junk science' that was demeaning the credibility of the justice system.").

262. *Daubert*, 509 U.S. at 588 (emphasizing that the Federal Rules of Evidence embody a "liberal thrust" favoring admissibility).

263. *See* Manual for Complex Litigation § 22.314 (4th ed. 2004). A mass tort is "mature" when law and proof are sufficiently settled that case outcomes fall within a predictable valuation range. *Id.*

264. Maturity exists on a continuum, not as a categorical status. *Id.*

265. *Id.*

266. *Id.* ("The need for such information may lead a judge to require a number of single-plaintiff, single-defendant trials, or other small trials.").

267. *See* Cranor, *supra* note 3, at 12.

is currently available rather than what the record ultimately shows. Targeted early discovery into exposure and mechanistic foundations—before or alongside litigation-wide *Daubert* practice—reduces the risk that admissibility determinations rest on an artificially narrow evidentiary record.[268] In the aerotoxic context, discovery into manufacturers' bleed-air system design documentation, internal fume event reporting practices, exposure monitoring data, and crew health records would constitute precisely the kind of mechanistic and exposure foundation that should be developed before causation is adjudicated on a litigation-wide basis. Sequencing does entail tradeoffs—expanded discovery increases costs and delays resolution—and a fuller record does not guarantee that expert testimony will survive *Daubert* review. Still, record development can improve the reliability of gatekeeping. Otherwise, premature causation rulings on undeveloped records produce the appearance of rigor without its substance.

Neutral methodological assistance. Federal Rule of Evidence 706 authorizes court-appointed experts, [269] yet federal judges have traditionally treated such appointments as exceptional.[270] Empirical research suggests that judges who used neutral experts found them "highly valu[able]"—particularly in cases presenting unusually "demanding evidentiary issues,"[271] Those conditions frequently arise in complex exposure litigation, where the parties' experts frame the record through sharply adversarial lenses, and neutral expertise can help courts evaluate whether competing experts employ reliable methods and apply them appropriately.[272] *Soldo v. Sandoz*[273] illustrates one dimension of this function: the court appointed Rule 706 experts to evaluate the methodological reliability

268. *See, e.g.*, In re Roundup Prods. Liab. Litig., 390 F. Supp. 3d 1102 (N.D. Cal. 2018) (denying *Daubert* motion on general causation after structuring the MDL to permit a dedicated general causation phase with extensive discovery into manufacturer's internal research and communications with regulatory agencies, which materially informed the court's evaluation of the competing expert testimony); *see also* In re Nat'l Prescription Opiate Litig., No. 1:17-md-2804 (N.D. Ohio) (structuring complex MDL with phased bellwether tracks and two-phase trial proceedings to develop the evidentiary record incrementally rather than resolving all causation questions at the outset).

269. *See* Fed. R. Evid. 706; *see also* Daubert v. Merrell Dow Pharms., Inc., 43 F.3d 1311, 1318 n.10 (9th Cir. 1995) (referencing Rule 706 when discussing procedures for resolving disputes about expert methodology admissibility).

270. Joe S. Cecil & Thomas E. Willging, Federal Judiciary Court–Appointed Experts: Defining the Role of Experts Appointed Under Federal Rule of Evidence 706 4–5 (1993).

271. *Id.* at 79, 95.

272. *See, e.g.,* Hall v. Baxter Healthcare Corp., 947 F. Supp. 1387, 1392–93 (D. Or. 1996) (appointing neutral technical advisors to assist the court in evaluating competing scientific claims about silicone breast implants, a process the court described as "unique in federal practice"); *see also* In re Breast Implant Cases, 942 F. Supp. 958, 960 (S.D.N.Y. 1996) (Weinstein, J.) (relying on the "imaginative procedures" and neutral expert evaluations developed by J. Jones in Oregon and noting the pending national Rule 706 panel appointed by C.J. Pointer).

273. 244 F. Supp. 2d 434 (W.D. Pa. 2003).

of the parties' causation evidence.[274] The appointed experts rejected the idea of epidemiology as an absolute prerequisite to causal inference but nevertheless concluded that plaintiff's remaining evidence did not support a reliable causal conclusion, and the claims were dismissed.[275] This example demonstrates the screening function of neutral expertise while illustrating the separate point that properly applied neutral review does not treat the mere absence of epidemiological studies as dispositive. Both functions are valuable, and together they can reinforce *Daubert*'s methodological focus without converting scientific uncertainty into a binary contest over whether definitive studies exist.

MDL management to accommodate heterogeneity. When courts respond to individual variation by insisting on a single global causation narrative at an early stage, the structure of a proceeding can compress scientific complexity into questions that do not correspond to the underlying facts. MDL tools allow courts to manage these cases while preserving informational development. Track-based scheduling, phased discovery, and structured bellwether pools can generate information about how claims perform across different exposure scenarios without treating early results as dispositive of the entire docket.[276] In the *Ethicon Physiomesh* litigation, the court established separate schedules for trial-pool cases and the broader MDL, allowing intensive development of selected claims while maintaining flexibility across the larger docket.[277] Courts may design bellwether pools to capture meaningful variation in exposure and injury.[278] The Sixth Circuit's discussion of bellwether practice in the *In re E.I. du Pont de Nemours (C-8)* litigation recognized bellwethers as informative signals for resolution.[279] There, the district court's prioritization of the most severely

274. *See id.* at 442.

275. *Id.* at 506–07.

276. *See* Melissa J. Whitney, Bellwether Trials in MDL Proceedings: A Guide for Transferee Judges 4–6 (Fed. Jud. Ctr. 2019), https://perma.cc/G2YW-T9DP (explaining that MDL courts often identify representative categories of claims, create discovery or bellwether pools, advance selected cases through phased discovery, and use early trial results to provide information for case management and settlement rather than to determine all remaining claims); Manual for Complex Litigation § 22.315 (4th ed. 2004) (noting that representative bellwether trials may help parties assess the nature and strength of claims and the range of potential case values if broader resolution is pursued).

277. *See* Ethicon Physiomesh Flexible Composite Hernia Mesh Prods. Liab. Litig. v. Ethicon, Inc., No. CV 1:17-MD-2782-RWS, 2020 WL 10046953, at *2 n.5 (N.D. Ga. 2020).

278. In re E.I. du Pont de Nemours & Co. C-8 Pers. Inj. Litig., 54 F.4th 912, 927 n.7 (6th Cir. 2022) (quoting Fed. Jud. Ctr., *Bellwether Trials in MDL Proceedings* 22 (2019); citing Manual for Complex Litigation (Fourth) § 22.315 (Fed. Jud. Ctr. 2004)) (noting agreement "that bellwether trials are most effective when 'representative of the range of cases included in the MDL proceeding'").

279. *Id.* at 919 n.3 (quoting Eldon E. Fallon et al., *Bellwether Trials in Multidistrict Litigation*, 82 Tul. L. Rev. 2323, 2343 (2008)) ("The court's and parties' intentions were aligned with the broader purpose of bellwether trials, which serve the 'twin goals' of being 'informative indicators of future trends and catalysts for an ultimate resolution.'").

impacted plaintiffs for early trial demonstrates how sequencing can reflect heterogeneity without sacrificing manageability.[280]

Together, these reforms address the distinct points at which the compounding system of exclusion identified in Parts II and III operates: substantive causation standards that treat evidentiary incompleteness as categorical insufficiency; admissibility gatekeeping that converts scientific uncertainty into a reliability defect; and procedural architecture that forecloses evidentiary development before causation can be meaningfully tested. Together, they constitute a recalibration of the standards applied to emerging exposure claims. Here, the objective is to ensure that emerging toxic harm claims, including aerotoxic claims, are evaluated on a record that the available science can produce, through reasoning that the available evidence can support.

Conclusion

Aerotoxic Syndrome is not simply an aviation dispute. It is a stress test of whether contemporary toxic tort doctrine can function under conditions that increasingly define environmental risk: mixed exposures, intermittent monitoring, heterogeneous symptoms, long latency, and regulatory lag. The difficulty in such cases is not that science is uncertain; indeed, uncertainty is a recurring feature of toxic tort litigation and of the scientific process. Courts too often treat uncertainty as a reason to foreclose adjudication rather than as a condition to be managed through disciplined evidentiary reasoning.

This Article argues that modern doctrine has recalibrated causation proof in toxic exposure cases toward scientific closure. Courts frequently privilege statistically significant epidemiological proof—even when it's uneconomical to undertake, unethical to produce, or slow to emerge. Aerotoxic litigation illustrates the consequence: genuine claims rarely reach merits adjudication. They are diverted or terminated through procedural doctrine and evidentiary expectations calibrated to mature science. That posture does not resolve uncertainty. It allocates uncertainty largely against plaintiffs, including in settings where defendants control exposure pathways and possess superior access to relevant information.

The doctrinal implications are modest but consequential. *Daubert* was designed to exclude unreliable methods, not to require scientific consensus as a prerequisite. Tort law does not demand certainty as a prerequisite to adjudication. Courts can preserve rigorous gatekeeping while permitting causation to be established through convergent, probabilistic proof—integrating epidemiology, toxicology, mechanistic evidence, exposure reconstruction, and disciplined clinical inference—so long as experts employ reliable methods, explain inferential steps transparently, and engage alternative causes. Properly implemented, this

280. *See* In re E. I. du Pont De Nemours, 204 F. Supp. 3d 962, 976–77 (S.D. Ohio 2016).

approach preserves evidentiary discipline without allowing scientific uncertainty to function as de facto immunity.

The implications extend beyond aerotoxic claims. As exposure profiles become more diffuse and causal inferences probabilistic, courts will increasingly confront disputes in which the best available evidence is convergent rather than definitive. If toxic tort adjudication remains effectively conditioned on maturity or epidemiology, it risks losing operational capacity at the frontiers of harm recognition. Compensation is predictably denied when plaintiffs are most vulnerable; deterrence predictably weakens when precautionary incentives are most valuable; and accountability is predictably deferred until after harm has already become widespread.

Judicial legitimacy in toxic tort litigation depends on confronting uncertainty with transparency: demanding methodological rigor, acknowledging scientific limits, and permitting reasoned risk attribution when convergent evidence supports it. In a legal system increasingly defined by emerging and cumulative environmental harm, the central question is whether courts will treat uncertainty as a condition that disciplined evidentiary reasoning can navigate, or as a categorical obstacle that forecloses adjudication before the record develops further.