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An examination of the relationship between environmental science and law due to emerging micro-scale gas chromatography technology

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AN EXAMINATION OF THE RELATIONSHIP BETWEEN ENVIRONMENTAL SCIENCE AND LAW DUE TO EMERGING MICRO-SCALE GAS CHROMATOGRAPHY TECHNOLOGY

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DEDICATION

For my Mother

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TABLE OF CONTENTS

ABSTRACT

The intersection of science and law is very complex. The two disciplines frequently interact due to environmental issues. Expert testimony is most often the method used to introduce scientific data into the legal system. Advances in technology have allowed scientists to increase the preciseness and reliability of data produced. The development of the gas chromatograph and the recent microFAST gas chromatograph has greatly increased the amounts of data available to the legal system.

The legal system has relatively recently developed a set of guidelines with which to evaluate scientific evidence and determine whether it should be admitted into trial. Previously novel scientific evidence such as the microFAST gas chromatograph would not have been admitted because it was not generally accepted. The new guidelines in admissibility, however, require that the relevance and reliability of the evidence be examined.

A comparison of the mechanics of a conventional gas chromatograph to the microFAST gas chromatograph reveals that the two machines operate on the same basic theoretical principles. Since data produced by a conventional gas chromatograph is readily accepted by the legal system, this same standard of admissibility should be applied to the microFAST gas chromatograph. The increased rate of data production by the microFAST machine will help establish causation in trial and improve the relevancy of the scientific evidence. Reliability is established by adherence to quality control procedures and repeatability. This thesis examines the relationship between law and science and projects that data produced by the microFAST gas chromatograph will ultimately be accepted into the legal system.

CHAPTER 1. INTRODUCTION

The complex relationship between the scientific and legal communities in the United States is most apparent when evaluating the admissibility of scientific evidence into trial. The foundations of both of these communities date back to the development of civilization. Both schools of thought are based on many hundreds of years of study, leading to unique traditions and methods of progression for science and law that are generally very resistant to change. The merger of these two very different communities is therefore an extremely delicate and often contentious process.

One of the primary issues over which the scientific and legal communities are most often forced into contact is the natural environment. In the United States, increased environmental awareness has resulted in rapid growth of both environmental science and regulation through laws and regulatory processes. Development of sound, effective, and enforceable environmental laws and policies requires a full understanding and utilization of environmental science. These two communities should work together very closely; regrettably, too often their interactions are plagued by misunderstandings, preconceptions, and conflict.

U.S. laws and regulatory policies are designed to protect the environment by limiting pollution. The detection and identification of contamination falls within the field of environmental science, specifically environmental toxicology. The levels, sources, chemical structures and toxic properties of contaminants are determined by specific methodologies. Resultant scientific conclusions are available for use in both the enforcement of environmental laws and the design of environmental policy.

In the environmental arena, the legal system has two primary tasks – determining violations of environmental law and quantifying the harm done by environmental contamination.

Invariably the courts require input from the scientific community to aid them in making these decisions. The actual process of introducing scientific evidence into the courts continues to evolve and is a constant source of debate between and among the scientific and legal communities.

Scientific data is usually introduced into the legal system by way of expert witnesses. The admittance of expert testimony into trial is always a matter of contention. For much of the twentieth century, the legal system relied on guidelines established in 1923 concerning the admittance of scientific testimony. The growth of environmental awareness and protection in the latter half of the twentieth century led to refinement of those guidelines in the 1970's. The exponential growth of environmental science required the legal system to further refine admittance standards in the 1990's, leading to the creation of the guidelines presently in use by the legal system.

One of the reasons legal guidelines were forced to keep evolving is because of rapid advances in environmental tools and technologies. A critical factor in the advancement of environmental technology was the development of the Gas Chromatograph. This instrument allowed scientists for the first time to efficiently and accurately identify volatile (gaseous at ambient temperature) compounds in a mixture. The impact of this instrument on the field of environmental monitoring was immense. For example, the gas chromatograph would allow scientists to evaluate the specific components in a mixture of gases emitted from the smokestack of a factory. The gas chromatograph coupled with another instrument, the Mass Spectrometer, provides reliable identification of components in a sample.

Today, advances in microtechnology have yielded the development of a much faster and more useful gas chromatograph: the microFast gas chromatograph. This machine can analyze similar ranges of compounds at a much higher rate than conventional gas chromatographs. This technology will result in much greater amounts of data generated by the environmental scientific community.

The goal of this thesis is to evaluate the implications of advanced microtechnology, specifically the microFast gas chromatograph, on the relationship between the legal system and environmental science . The first part of the thesis addresses both the current guidelines governing the admissibility of scientific evidence and the derivation and reasoning for those standards. A thorough understanding of how and why scientific evidence enters the legal system is critical to predicting the future of that relationship.

The second portion of the thesis is devoted to the history, fundamentals and operation of both the conventional gas chromatograph and the microFast gas chromatograph. Data accumulated using the conventional gas chromatograph is readily accepted into the legal system as scientific evidence under the current admissibility guidelines as long as the data is obtained properly. A comparison of the characteristics of the conventional and microFast machines is required to evaluate the future relationship between the courts and gas chromatograph data produced by microtechnology.

The thesis concludes with a discussion of the implications of the amplified relationship between environmental science and the legal system resulting from the development of the microFast gas chromatograph. The potential problems and advantages brought by advances in microtechnology will be evaluated. Projections will be made concerning the future legal admissibility of data produced by the new technology.

Both the legal and scientific communities have the common goal of finding and evaluating facts - even though they do so in very different manners. The current relationship between law and science came about due to the development of progressive societal issues such as concern for the environment. This relationship will persist and become increasingly complex so long as both schools of thought continue their search for truth.

CHAPTER 2. ENVIRONMENTAL LITIGATION

Environmental disputes are among the most rapidly expanding areas of modern litigation. (Wait) Reasons for this trend vary. One factor is heightened popular awareness of the dangers of environmental pollution. Public concern about pollution reached an unprecedented high in the latter part of the 20^{th} century due to the efforts of private activist groups, government agencies, and other organizations focused on environmental protection and public health. (Michalak, Cohen & Mindnich) Another factor is rapidly advancing technology. Increases in the magnitude and complexity of industrial technology can result in a greater release of chemicals and other pollutants into the environment, thus raising existing levels of environmental contaminants. (Michalak)

Technological developments contribute to the prevalence of environmental litigation in other ways as well. As some technological developments release new and increased amounts of pollutants into the environment, other recent advances such as micro-scale and nano-scale gas chromatography technologies enable scientists to better identify smaller amounts of environmental contaminants. Because the source of environmental contamination is at the heart of environmental litigation, an improved ability to detect such contaminants often leads to more litigation.

In trial, a critical part of establishing causation is the use of multiple samples showing the path of contamination from the source to the target area. An increased number of samples linking source to target greatly improves the admissibility and persuasion of such types of scientific evidence. The increase in and improvement of methods of identifying contamination seem to indicate that environmental litigation will continue to flourish as new technology both pollutes and facilitates detection of pollutants. (Michalak)

2.1 Science and the Law

Scientific issues appear in a wide range of legal contexts, ranging from copyright violations to criminal prosecutions. As science and technology advance, the legal system struggles to keep up – which is no easy task, given the astonishing developments that have occurred over the last few decades in areas as diverse as genetics, computers and psychology. (Poulter) The three issues that most frequently surface in debates regarding the interplay between science and the law are: (1) the capacity of judges, juries and lawyers to understand science, (2) discrepancies between scientific and legal understandings of causation, and (3) novel scientific evidence and the legal system's treatment of scientific innovation. (Case & Ritter)

Environmental protection laws further ensure that there will always be a close relationship between science and the law. The Environmental Protection Agency was created in 1970 to oversee important statutes such as the Clean Air Act, the Toxic Substances Control Act, the Clean Water Act, the Resource Conservation and Recovery Act and the Comprehensive Environmental Response, Compensation and Liability Act (Superfund). The federal government can file suit against violators of these statutes. For example, in 1997 the EPA initiated 278 criminal cases and 426 civil cases through the Department of Justice. States also can pass statutes regulating the environment. (Ferrey)

Common law tends to fill the gaps between the federal and state statutes regarding pollution. Often no specific statute has been violated, but a plaintiff can still recover for damages. In these cases, successful litigation requires proving detection, causation, and linkage to the environmental pollutant in question. Common law provides punitive awards for damages and jury trial in many cases, whereas the statute laws often do not provide for such awards and procedures. Thus, the common law can be viewed as a supplement to federal and state statutes. (Ferrey)

2.2 The Fundamental Differences between Science and Law

Scientific and legal commentators often attribute the disconnect between the scientific and legal worlds to judges' and jurors' inability to grasp the scientific complexities underlying a case. Some argue that judges should exercise a particularly heavy hand in deciding whether to admit scientific evidence, since juries are more likely than judges to be swayed by "technical jargon". As recently as the early 1990s, courts' lenience in admitting scientific evidence may have been due in part to their concern that they would exclude valid evidence simply because they were incapable of accurately estimating its validity. (Poulter)

Given the fundamental differences between the fields of science and law, it is not surprising that efforts to wed the two create conflict. The underlying predicament is that both define themselves as truth-seeking systems, but they use diametrically opposite methods to achieve this goal. On its most basic level, science attempts to explain the physical world through an ongoing cycle of hypothesis and experimentation. (Case & Ritter) As noted by the Supreme Court, even hypotheses that are proven incorrect through experimentation are valuable to scientists, for the very process of excluding them is inherently educational. (Daubert)

Conversely, the legal field requires a relatively quick evaluation of two opposing arguments, both presented as truths, regarding specific events. (Daubert) Legal judgments, like scientific hypotheses, certainly can and do face revision. The laws regarding the admissibility of scientific evidence itself serve as good illustrations of this fact. Yet a change to the law is viewed in a very different context than a change in scientific theory. Any scientist can prove a scientific truth if he or she has proper evidence. Laws, however, can only be changed by legislatures and courts. Changes in science are based on concrete facts, while changes to the law are as likely to evolve from changing sociological views, political events, and personal opinions as they are from factual errors. (Case & Ritter)

Thus, the law seeks certainty where it can, leading to its perhaps unreasonable requirements of scientific evidence in litigation. Judges, jurors and lawyers often resort to extremes in their faith in science, either placing blind confidence in scientific testimony that they don't begin to understand, or refusing to admit evidence that deviates even slightly from the techniques and theories customarily used. In both circumstances, they usually find the underlying science equally incomprehensible. Scientists, meanwhile, suffer from a lack of understanding as to the standards of legal proof, and thus run the risk of developing novel theories and techniques that end up offering little value to the "real world." (Case & Ritter)

These fundamental differences between science and the law have contributed to the development and growth of an industry aimed at tailoring scientific output and procedures specifically for legal admissibility. While the courts modify the legal system to make it more compatible with science through important cases such as *Daubert v. Merell Dow Pharmaceuticals, Inc*., third party institutions such as environmental consulting firms attempt to ensure that scientific evidence is presentable to the courts. Analysts for this growing industry determine what protocols are currently demanded by the legal system and then provide guidance to the scientists producing the evidence.

2.3 The Role of Science in Environmental Litigation

The intersection of science and the law is particularly volatile with regard to environmental litigation. This is due in great part to many courts' tendency to over-emphasize epidemiology (causal relationships between events). Science and the law have two entirely different understandings of causation, and the clash between the two fields is never more evident than in litigation involving plaintiffs seeking to present scientific evidence that some agent has caused injury, while defendants claim that no link has been established. (Case & Ritter) The legal system fails to recognize that causal (in the legal sense) relationships are not required by scientists to establish causal (in the science sense) relationships in scientific population studies – especially if the adverse effects are obvious and immediate. A scientifically established link between two events may be considered a questionable assumption by the court. (Black - ATLA) The role of science in environmental litigation is by no means limited to epidemiology – a scientific explanation of various concepts or procedures may be required, or the case may be one in which an evaluation of scientific knowledge at the time is relevant. (Cohen & Mindnich)

Some legal commentators argue that the courts are particularly lenient about admitting scientific evidence in environmental litigation, particularly toxic torts, because they are more concerned with protecting public health and compensating injured plaintiffs than they are with the rules of evidence. As the scientific community discusses topics such as the use of experimental chemicals in consumer products and the impact of environmental pollutants and radiation upon human health, the legal community sometimes seems to lose track of what is proven fact and what is mere speculation. The divergent truth-seeking methods employed by science and law become apparent once again – the courts' flexible standards of admissibility may be a function of their already-existing belief that "mainstream" scientists' definitions of proof are too strict, while "the unconventional scientists who testify that an exposure caused a plaintiff's disease may be correct." (Poulter)

Many of these trials feature testimony by one or more expert witnesses. Expert witnesses are needed when the jury cannot on its own determine the facts from a given set of conditions because of the science or specialization involved. Often during trials, however, one expert witness will offer scientific testimony that directly counters the scientific testimony given by another expert during the same trial. The issue then arises of how the trier of fact is supposed to determine which expert has actually derived the true facts applicable to the case at hand. In the past, this meant that in many cases, judges and juries were forced to delve into subject matter foreign to them in order to determine which expert's testimony should be persuasive in their decision. Clearly, this unqualified research was prone to frequent error. The United States Supreme Court in the past decade has implemented a much more structured approach for the legal system to utilize in regards to the admissibility of scientific, technical and otherwise specialized expert testimony. (Kesan)

2.4 Scientific Evidence

The current primary guidelines for the admissibility of expert witness testimony are set forth in Federal Rules of Evidence (FRE or "the Rules") 702 and 703, and a trilogy of Supreme Court decisions: *Daubert v. Merell Dow Pharmaceuticals, Inc.*, 509 U.S. 579 (1993), *General Electric Co. v. Joiner*, 522 U.S. 136 (1997), and *Kumho Tire Co. Ltd. v. Carmichael*, 526 U.S. 137, 119 S.Ct. 1167 (1999). Until the last decade, however, the common law standard used to determine the reliability of novel scientific evidence was set forth in *Frye v. United States,* 293 F. 1013 (D.C. Cir. 1923).

Frye was a murder trial in the 1920s in which the defense wanted to introduce expert scientific testimony as evidence. Specifically, the lawyers for James Frye wanted to show the results of a blood pressure test in which increased blood pressure indicated lying. This was an anxiety test based on the same principles as the present-day polygraph test. The court ruled that the evidence was not admissible because it had not gained "general acceptance" in the scientific community. The appeals court confirmed the trial court's ruling with the holding that for scientific evidence to be admissible it must be based on generally accepted principles in its relevant field of science. Difficulties in applying *Frye* soon arose, particularly in defining the relevant field of science for specific evidence and determining whether the principles for that evidence had been generally accepted in the relevant field. (Kesan)

Roundly criticized as too strict a standard, *Frye*'s already dim future further faded with the enactment of the Federal Rules of Evidence in 1975. The Federal Rules made no mention of *Frye* in their content nor was *Frye* mentioned in their derivation. Few courts expressly rejected *Frye*, but the adoption of the Federal Rules seemed to prompt many courts to move towards a broader standard of admissibility. (Riesel, Slater, Black)

2.5 Federal Rules of Evidence 702, 703

FRE 702 addresses expert witness testimony, outlining the circumstances in which such testimony is permissible and offering guidance as to the required qualifications of an expert witness.

Prior to December 1, 2000, FRE 702, "Testimony by Experts", read as follows:

> "If scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training, or education, may testify thereto in the form of an opinion or otherwise."
> Fed. R. Evid. 702

The standard articulated here is actually little more than a "common sense inquiry" - if an ordinary person couldn't understand an issue without an explanation from someone who has a particular understanding of the topic, an expert's testimony should be admissible. (Ladd) The scope of the rule is broad. While a witness must be "qualified," it is specifically noted that the areas of expertise from which witnesses can be drawn are not limited to scientific and technical venues - "other specialized knowledge" could refer to any individual whose work experience or education has given him a more advanced grasp of some subject or skill. The determination of what constitutes "qualified" depends upon the particulars of each individual case. (Slater)

In the midst of all this generalization, the only solid criteria that emerges from FRE 702 is that the proffered testimony must "assist the trier of fact". It was soon determined that this vague wording left far too much in question before and during trial. FRE 703 attempted to elaborate further on the guidance given in FRE 702 by addressing the reasoning and data employed by the expert in reaching a conclusion. (Riesel)

While FRE 702 requires the court to evaluate the helpfulness and reliability of an expert witness' testimony, FRE 703 (Bases of Opinion Testimony by Experts) looks to the facts and data that form the basis for the expert's conclusion:

> The facts or data in the particular case upon which an expert bases an opinion or inference may be those perceived by or made known to the expert at or before the hearing. If of a type reasonably relied upon by experts in the particular field in forming opinions or inferences upon the subject, the facts or data need not be admissible in evidence.
> Fed. R. Evid. 703

Because the distinction between FRE 702 and FRE 703 is often hazy, courts often appear to apply the rules in a backwards manner. That is, instead of determining admissibility of expert witness testimony by going through the criteria of each individual Rule, they make a decision and then "backtrack into a particular rule in an effort to articulate a basis for their holding." (Slater)

Courts' difficulty in applying the FRE did not go unnoticed. The Rules packed a double punch, in that they created ambiguous guidelines for the admissibility of expert testimony and at the same time seemed to encourage the use of expert witnesses. After the Rules were enacted, the prevalence of expert testimony increased, and the courts struggled to keep up as they attempted to evaluate the quality and reliability of each expert's contribution. (Slater)

In 1992, the Advisory Committee to the Judicial Conference Standing Committee on Rules of Practice and Procedure attempted to assist the courts' efforts by recommending an amendment to FRE 703, which would have provided more selective standards for defining a witness or testimony as "expert." As justification, the Advisory Committee noted that the increase in expert testimony not only clogs the courts trying to apply the Rules, but is expensive, often less helpful than parties claim, and opens the door to "junk science" - that is, unreliable scientific or technical theories proffered by "forensic experts" in search of employment. (Slater)

Yet members of both the Advisory Committee and the Standing Committee had reservations about the amendment. Some felt that it was not strict enough to fulfill its intended purposes. Others expressed concern that it was too rigid and likely to discourage testimony regarding valid new science and technology. (Slater) These paradoxical contentions were a repeat of the criticisms that led to *Frye*'s demise. (Polin) It is therefore unsurprising that the Advisory Committee's approval of the amendment was not unanimous, and ultimately the Standing Committee did not submit the proposed amendment for the Supreme Court's consideration. (Slater) Ironically, the legal community's understanding of FRE 703 was soon transformed anyway - just one year later, the Supreme Court granted *certiorari* to *Daubert v. Merell Dow Pharmaceuticals, Inc*.

2.6 The *Daubert* Trilogy

Frye was finally called to task in *Daubert v. Merell Dow Pharmaceuticals, Inc.*, which reached the Supreme Court because the parties disagreed as to whether FRE 702 supported or superseded *Frye's* "general acceptance" standard. This case formalized a debate that had been raging among courts and legal scholars since the enactment of the Federal Rules in 1975. (Slater) In its decision, the Supreme Court's interpretation of FRE 702 indicated in no uncertain terms that *Frye*'s day had passed, at least on the federal level. The standard of "general acceptance" was no longer the only condition with which expert testimony had to comply in order to be admissible.

> Nothing in the text of this Rule establishes "general acceptance" as an absolute prerequisite to admissibility. Nor does respondent present any clear indication that Rule 702 or the Rules as a whole were intended to incorporate a "general acceptance" standard. The drafting history makes no mention of Frye, and a rigid "general acceptance" requirement would be at odds with the "liberal thrust" of the Federal Rules and their "general approach of relaxing the traditional barriers to 'opinion' testimony." Given the Rules' permissive backdrop and their inclusion of a specific rule on expert testimony that does not mention "general acceptance," the assertion that the Rules somehow assimilated Frye is unconvincing. Frye made "general acceptance" the exclusive test for admitting expert scientific testimony. That austere standard, absent from and incompatible with the Federal Rules of Evidence, should not be applied in federal trials.
> *Daubert*, 509 U.S. 579 (1993) (*Daubert*)

According to *Daubert*, FRE 702 set forth two criteria – relevance and reliability – that trial courts are obliged to look for when deciding whether to admit expert scientific testimony. This became known as the infamous "gatekeeper" function of trial courts. In fact, the Supreme Court even provided trial courts with a list of four general evaluations that they could consult in making their determinations:

1) Has or can the evidence be tested by scientific methodology?
2) Has the underlying theory or technique been subjected to peer review and been published in the professional literature?
3) How reliable are the results in terms of potential error rate?
4) General acceptance can have a bearing on the inquiry.
   (Michalak)

In Justice Harry Blackmun's opinion, however, he warned against viewing this list as an all-inclusive mandatory reference. Many scholars theorized after *Daubert* that its holding would apply to all fields of expert testimony. They were later proved correct by *Kumho Tire*. (Black)

Two other cases, *General Electric Co. v. Joiner* in 1997 and *Kumho Tire Co. Ltd. v. Carmichael* in 1999, helped refine the meaning of *Daubert* – leading experts to refer to these as the *Daubert* trilogy. *Joiner* arose when an appellate court (Eleventh Circuit) reversed a trial court's decision on the basis that the trial judge had been too quick to exclude scientific testimony. *Daubert* failed to establish a specific standard of review for appeals courts regarding the admissibility of expert testimony. The Eleventh Circuit concluded that the appellate courts in general should be more concerned about evidence excluded in trial courts rather than admitted evidence when reviewing trial cases. The Supreme Court disagreed, however, stating that both admitted and excluded evidence should be reviewed equally by the appellate courts. Regarding the list of factors governing the admittance of expert testimony in *Daubert*, the Supreme Court reiterated in *Joiner* (and later once more in *Kumho Tire*) that there was no uniform standard list of factors determining how trial judges should rule. (Black)

Kumho Tire broadened the "gatekeeper" function to include all expert testimony, as opposed to just scientific expert testimony. *Daubert* addressed scientific testimony but not testimony based on technical or other specialized knowledge. *Kumho Tire* established that the *Daubert* factors were applicable to expert testimony not considered scientific such as that given by an engineer.

Kumho Tire increased the trial courts' authority in other ways as well, giving trial judges even more discretion to create their own standards by which to assess the relevance and reliability of expert witness testimony, and emphasizing that they need only take into account the

Daubert factors if they are "reasonable measures of the reliability" of the testimony in question. (Kumho Tire, 1176) The Supreme Court in *Kumho Tire* determined that trial judges could require of expert witnesses that they explain not only how they reached their conclusions but also why they chose their methodology. Trial judges had complete discretion to determine if the methodology used by the expert witness was appropriate and or relevant to the case. (Black)

On April 17, 2000, the Supreme Court issued an order approving an amendment to FRE 702, effective December 1, 2000, and authorized transmission of this amendment to Congress in accordance with 28 USCS § 2072. The amended rule reads as follows:

> "If scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training, or education, may testify thereto in the form of an opinion or otherwise, if (1) the testimony is based upon sufficient facts or data, (2) the testimony is the product of reliable principles and methods, and (3) the witness has applied the principles and methods reliably to the facts of the case."
> Fed. R. Evid. 702

FRE 702 post-*Daubert* could now be viewed as having three smaller tests to evaluate the two main tests of relevance and reliability: the knowledge test, the helpfulness test, and the qualifications test. The knowledge test ascertains that the testimony is scientific and specific in nature. The trial judge determines if the methodology used in obtaining a conclusion was sound and applicable. The helpfulness test determines if the evidence that passes the knowledge test is relevant to the case. The conclusions drawn from the evidence may be well-founded but still cannot be admitted if it determined by the trial judge that they are irrelevant. The qualifications test examines the credentials of the expert witness. The trial judge determines if the background of the expert qualifies him/her to testify. The *Daubert* trilogy clearly gives the trial judge considerable power in determining the admissibility or exclusion of evidence.

Like FRE 702, the Supreme Court amended FRE 703 by an April 17, 2000 order, effective December 1, 2000, and authorized the amendment's transmission to Congress in accordance with 28 USCS § 2072. The amended rule reads as follows:

> The facts or data in the particular case upon which an expert bases an opinion or inference may be those perceived by or made known to the expert at or before the hearing. If of a type reasonably relied upon by experts in the particular field in forming opinions or inferences upon the subject, the facts or data need not be admissible in evidence in order for the opinion or inference to be admitted. Facts or data that are otherwise inadmissible shall not be disclosed to the jury by the proponent of the opinion or inference unless the court determines that their probative value in assisting the jury to evaluate the expert's opinion substantially outweighs their prejudicial effect.
> Fed. R. Evid. 703

Daubert can be perceived as more restrictive than *Frye* in that trial judges can carefully examine scientific evidence for its reliability and relevance to the case regardless of whether or not it is “generally accepted.” Before *Daubert*, if the lawyers could prove that the evidence was generally accepted, then it was admitted. However, *Daubert* also allows much more “novel” scientific evidence to be admitted into the courts. Previously lawyers could argue that “novel” scientific evidence (such as micro- and nanotechnology) could not be admitted because since it was “novel” it by definition did not meet the standard of “general acceptance” established by *Frye*.

Trial judges can hire experts of their own to aid them in evaluating the validity of evidence. Post–*Daubert*, if a trial judge determines the evidence meets his standards for admissibility, then he can allow the evidence into trial. “General acceptance” is still an important factor in determining the reliability of evidence, but it is clearly just one of many factors taken into consideration. (Fenner)

The Supreme Court has reduced the weight of the "general acceptance" factor in admissibility but has not eliminated it. The scientific community regulates itself and essentially utilizes the same "general acceptance" standard through the process of peer review. Scientific results are "admitted" into the scientific community through publication.

The publication of scientific data only occurs once the data has been subjected to a peer review process in which fellow scientists in the relevant field examine the results and/or attempt to duplicate them. If flaws are found in the methodology or conclusions of the work or if it cannot be duplicated, it is sent back to the originator without publication. However the standard of "general acceptance" applied in the scientific community differs from the *Frye* version because usually the peer review process consults only scientists in the specific relevant discipline, such that even areas of "novel" science can achieve "general acceptance." (Poulter)

2.7 Expert Testimony in Louisiana

In Louisiana the principles established by *Daubert* and *Khumo Tire* were first implemented in *State v. Foret* and *Independent Fire Insurance Co. v. Sunbeam Corp*. Since the *Louisiana Code of Evidence* is based on the *Federal Rules of Evidence* the Louisiana State Supreme Court decided to interpret the very similar Louisiana Code in the same way that the United States Supreme Court interpreted the Federal Code in *Daubert*. Thus in Louisiana trial courts must check testimony for relevancy and reliability before it can be admitted. (Harges)

Six months after *Daubert* was concluded, the Louisiana Supreme Court incorporated the concepts of relevance and reliability of evidence and the list of factors recommended by the United States Supreme Court to establish relevance and reliability into *State v. Foret*. In *Foret* the issue revolved around whether or not the expert testimony of a psychologist regarding child abuse characteristics was admissible in the State's prosecution of a child molestation case. The trial court determined that the testimony was relevant and reliable under *Daubert* and it was therefore admitted into the case. The Louisiana Supreme Court reversed the trial and appeals courts however because the high court determined that the testimony was not admissible under *Daubert*. (Harges)

The difference in interpretation of *Daubert* was because the Louisiana Supreme Court applied the *Daubert* factors supplied by the United States Supreme Court, whereas the lower courts had not. Therefore, the Louisiana Supreme Court set a binding precedent within the state legal system for application of the *Daubert* factors to determine relevance and reliability for expert scientific testimony. This is a significant issue because Justice Blackmun in his opinion for the United States Supreme Court on *Daubert* explicitly warned against viewing the list of *Daubert* factors as mandatory or all inclusive. This issue may become important with reference to cases from Louisiana that reach the federal court system. (Harges)

The case of *Independent Fire Insurance Co. v. Sunbeam Corp*. partially incorporated the principles established in *Khumo Tire* into Louisiana law. *Khumo Tire* established that *Daubert* applied not only to expert scientific testimony but also to technical or specialized (i.e. non-scientific) expert testimony. In *Independent Fire*, a summary judgment had been granted by a trial court because the expert testimony offered to avoid the summary judgment was excluded since it was presented by a technical expert and was therefore not scientific testimony governed by *Daubert*. The Louisiana State Supreme Court reversed the lower court and admitted the expert technical testimony on the basis that technical or specialized expert testimony could not be automatically excluded. (Harges)

The Louisiana Supreme Court did not express the general holding of *Khumo Tire* concerning the general admissibility of technical or specialized expert testimony in trial, it only referred to summary judgments in its decision. However the lower courts in Louisiana have consistently applied the *Khumo Tire* holding and apply the *Daubert* principles to both technical and specialized expert testimony as well as scientific expert testimony. (Harges)

It is significant to note that the Louisiana State Supreme Court did not extend in *dicta* the admissibility of technical or specialized expert testimony in regards to general trial as established in the *Khumo Tire* holding. The rulings of the lower courts embracing the holding in *Khumo Tire* have yet to be expressly tested by the state's highest court and therefore the application of the *Daubert* principles to both technical and specialized expert testimony can still be challenged in Louisiana. (Harges)

2.8 Investigating Toxic Torts

The questions common to any toxic tort investigation include the source of the contamination, the contribution of various parties, and the time and method of the release. Historically, environmental investigators identified parties responsible for environmental contamination by distinguishing unique characteristics of either the contaminated site or the contaminant itself. Investigation of the contaminated site included consideration of its history and procedures, while investigation of contaminants often focused on specific compounds targeted for regulation due to their prevalence and potential for harm (known as "regulatory analytical chemistry methods". (Wait)

Some of these methods (target-analyte methods), while useful in some contexts, have proven inadequate for both investigative and litigation purposes. Other methods of analyzing compound mixtures, including gas chromatography/mass spectroscopy (GC/MS) analyses, have produced reliable, legally-admissible qualitative and quantitative data. The 1970s saw a number of new developments in analytical chemistry technology that permitted environmental investigators to selectively search for compounds with specific attributes. (Wait) More recent decades have seen increased environmental litigation based on cases in which multiple potential sources of pollution exist, since technological advances have rendered formerly undetectable pollutants identifiable. The integrity of both the data itself and the sampling procedures utilized are critical since the principles of reliability and relevance as set forth in *Daubert* will be applied to the entire investigative process when evaluating the admissibility of the purported conclusions. (Michalak)

2.9 Data Integrity

Over the last three decades, quality control procedures and quality assurance programs have played an increasingly important role in environmental investigations. Data collection resulting from investigations has been held to the standards and guidelines set forth by organizations such as the Association of Official Analytical Chemists. In 1978, the American Chemical Society created guidelines for the acquisition and quality evaluation of environmental chemistry data. In 1979, the Environmental Protection Agency published its *Handbook for Analytical Quality Control in Water and Wastewater Laboratories*, followed in 1980 by the *Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans*. As recently as 1996, Congress directed federal agencies to seek the assistance of groups such as the American Society of Testing and Materials (a professional, private-sector consensus standard group) before generating technical standards. (Wait)

Guidelines and legislation dictating the criteria for data integrity are equally, if not more, essential to environmental investigations than are quality control and assurance. Data integrity is determined by factors such as accuracy, precision and representativeness. Both the EPA and the ASTM have set an acceptable level of uncertainty regarding environmental measurements, known as “data quality objectives”. Data quality objectives include, but are not limited to, consideration of analytic accuracy and precision. Acceptable levels of uncertainty account for factors such as “probable measurement error” in regulatory quantitative standards as put forth by organizations such as the EPA. (Wait)

In order to ensure the integrity of environmental data, environmental investigators and litigators must authenticate the procedures used for data generation, sample collection and sample analysis. Quality assurance and quality control procedures must be followed, and procedures to control documents and the chain-of-custody of evidence must be implemented. Finally, inept or fraudulent laboratory practices must not be tolerated.(Wait)

Instances of fraud involving scientific evidence have significantly risen in recent years resulting in even further scrutiny of proposed evidence by opposing parties. Fraud frequently occurs due to financial pressure when a time contract is involved. The most common forms of fraud are alterations of instrument response to substances, violation of sample analysis hold time requirements, selective exclusion of data, and of course, fabrication of data. In order to reduce fraud, environmental consultant agencies now often require laboratories producing data to gain specific accreditations and certifications. Third party independent checks are done on the data produced and the labs are subjected to audits and unannounced inspections. Documentation of fraud prevention and control procedures greatly enhance the probability of scientific evidence being admitted. (Wait)

The integrity of data also depends on the proper use of software and statistics in obtaining and processing data. Statistics are infamous for their ability to support two opposing conclusions. Often dramatically different results from a universal statistical formula are obtained because of variance in the value of an assumed constant. Since the assigned values of constants are usually dependent on peripheral conditions, the subjective reasoning involved in choosing both the particular values for constants in a statistical formula and also the formula itself must be justified. The choice of software utilized in processing the data must also be analyzed for its relevancy to the task at hand. For example, many computers use a default program which may be very similar to the appropriate software but contains critical differences that can lead to faulty conclusions that appear valid at first glance. (Moenssens)

2.10 Sampling Evidence

A plaintiff in a toxic tort case who claims injury due to exposure to hazardous substances released into the environment by the defendant must establish liability in one of two ways: (1) defendant must admit fault, or (2) plaintiff must introduce as evidence the results of a lab analysis of oil, water, or air samples from the geographic area in which plaintiffs were allegedly exposed. (Vinal)

A plaintiff in a "citizen suit" (a civil action brought under the citizen suit provisions of federal or state environmental statutes) must show that the hazardous substance is statutorily regulated. This is done by showing its chemical composition and identifying it as a substance that environmental laws and regulations classify as hazardous or toxic.

The admissibility of the results of a technician's analysis of environmental samples is a frequent evidentiary issue in environmental litigation. To be admissible, a sample must represent the entire body of material from which it was extracted. The court considers various factors when making a determination as to the representativeness of a sample, including the distance between the location of the sample and the source of the discharge, and the time that passed between the discharge and the sample being taken. Location of the sample is also relevant in determining the degree of inhomogeneity - that is, inequities in contaminant distribution within the substance being sampled. (Vinal)

Sampling protocols are written plans that identify the substance to be sampled, the location of the sampling, the proposed number of samples, the method to be employed, the equipment to be used, the procedure for labeling, storing, and transporting the samples to the lab, and any other necessary documentation. The legal admissibility of sampling results depends on the integrity and comprehensiveness of the sampling protocol. A key component of any sampling protocol is the degree to which quality control measures are implemented. (Vinal)

The results of the samples and their implications are presented by an expert whose testimony is scrutinized by the principles established in *Daubert*. Specifically the methodology chosen, the relevancy of that methodology to the case, the execution of chosen methodology and the manner in which he derived his conclusions are critical to the admissibility of expert testimony. In general, the chosen methodology and the derivation of conclusions are not as subject to scrutiny as long as the expert is credible in the specific field of expertise. However, both the proper execution of methodology and the relevance of the specific methodology to the case are subject to increased scrutiny because they are often more susceptible to error. (Kesan, Moenssens)

The introduction of sampling evidence usually primarily depends on the integrity of the actual sampling procedure (i.e. the execution of the methodology). Any errors or inconsistencies that are in the procedure that was applied as apparent in records, logs, or accounts by eyewitnesses can greatly diminish the admissibility of sampling evidence. Since many other parties may be involved in the sampling procedure other than the expert witness himself (such as contracted laboratories, students and staff), the possibility for mistakes along the sampling chain is substantial. (Kesan, Moenssens)

The relevance of the chosen methodology to the trial is also a critical proving ground in gaining admissibility for expert testimony. A sampling procedure may have been perfectly executed but if the samples are not representative of the issue at hand then the results will probably be inadmissible. Quite often this occurs because too few samples have been taken to establish causation, and thus the testimony is deemed irrelevant and inadmissible. (Kesan, Moenssens)

2.11 Admissibility of Sampling Results Generated by GC/MS Analysis

Each stage of the testing process requires proof that certain steps were properly executed in order for testing results to be legally admissible. In procuring the sample, the party proffering the results must be prepared to show: the sampler's qualifications, the sampling plan, the equipment and techniques used, the quality control methods implemented, the proper labeling of sample containers (if appropriate), the proper storing and preservation of the samples, the safe transport of the samples to the lab, and a documented chain of custody from the site to the lab. (Vinal)

Once the sample reaches the lab, the transfer of the samples to the lab must be documented, as well as the chain of custody procedures within the lab, the proper preservation of the samples prior to analysis, and the subsequent distribution of the samples for analysis. The training and qualifications of the lab technician must be proven, along with the conditioning, tuning and calibration of all analytical instruments. The admissibility of sampling results also hinges on the condition of the instruments being used to conduct the analysis. GC/MS analytical equipment must be tuned using precise concentrations of Decafluorotriphenylphosphine

(DFTPP) and p-Bromofluorobenzene (BFP). Furthermore, frequent tests of the packed or fused silica capillary chromatography columns must be conducted to ensure that EPA standards are upheld and that the sampling results are thus reliable. (Vinal)

The technician has to have followed an approved testing procedure, complete with quality control measures, careful recording of the test results, and proper disposition of the samples. Any suspicions of lab fraud must be dispelled, and a suitable method of destroying the samples following analysis must be utilized. (Vinal)

Typically, sampling results are introduced into evidence through the testimony of two witnesses - the individual who took the sample, and the lab technician who analyzed it. This is known as "laying the foundation" for the sample's admission into evidence.

GC/MS analysis is treated differently, however, because it generates computer printouts. A lab technician who is trained to run the tests that generate results from the sample may not necessarily be capable of interpreting those results. In that case, a qualified expert's interpretation of the resulting computer printout is admissible, regardless of whether the testifying expert is the same person who conducted the actual test. The "qualified expert" is typically a chemist who serves as the lab manager.

In such a case, laying the foundation of the admissibility of sampling evidence would begin with the testimony of the sampler, possibly followed by the lab's sample intake coordinator (depending upon the method by which samples are stored in the lab). The lab technician would testify next, and, assuming he or she was not qualified to interpret the test results, the testimony of the lab manager or other qualified chemist would conclude the process. (Vinal)

In interpreting the lab report, the expert witness must present a lab document package, show that the contaminant tested for is indeed present, prove that quality control/data validation steps were taken, and verify that the data is complete. The test results will only be admitted into evidence if it is established that the sample is a regulated substance and the defendant is the source of the pollution. The witness must also indicate how the substance moved within the environment (migration), the contaminant's concentration, and the admissibility of both the sample test results and the lab report. (Vinal)

CHAPTER 3. GAS CHROMATOGRAPHY

3.1 Chromatography

The Russian botanist Mikhail Tswett first developed the process of chromatography in 1903. He extracted a mixture of pigments from plant leaves and pushed a small sample of the mixture dissolved in petroleum ether (mobile phase) through a thin column coated in calcium carbonate [chalk] (stationary phase). The various plant pigments separated from each other while being pushed through the column based on their attraction for the calcium carbonate, resulting in a trail of colored bands. These colored bands signified the components of the mixture of plant pigments. The word chromatography is a combination of the two Greek words “khroma” (color) and “grafein” (written). (McMurry, Denney)

Chromatography is essentially a process of separation utilizing the interaction between two phases of matter: a mobile phase and a stationary phase. The mobile phase is either a gas or a liquid and the stationary phase is a solid or liquid. The components of a sample mixture which is to be separated have varying affinities for the mobile and stationary phases. Those components which have a higher affinity for the mobile phase substance will move through the system much faster than those which have less affinity for the mobile phase and more affinity for the stationary phase. The components which have the most affinity for the stationary phase substance will move through the system at the slowest rate. As the various components move across the stationary phase they emerge at the output of the chromatographic system in a process called elution. The various components of the sample mixture elute at differing times, called retention times, which result in separation and identification. (McMurry)

3.2 Fundamentals of Gas Chromatography

Gas chromatography identifies the individual substances that make up an unknown sample by separating those substances utilizing the basic chromatographic principles of mobile and stationary phases. The distinguishing feature of gas chromatography is that the mobile phase is a gas. The stationary phase can be a solid or liquid. Gas-solid chromatography is the term used when the stationary phase is a solid adsorbent material. Gas-liquid chromatography refers to a liquid stationary phase. The liquid is maintained on either the walls of the column or the surfaces of small particles. The separated substances are identified by their features or identified by comparing their features to those of known substances, and finding a match. (Polin, Denney)

Specifically, gas chromatography analysis works by pushing the sample through a column using a comparatively inert carrier gas as the mobile phase, usually helium or hydrogen. As the sample moves through the column, the molecules that resemble the adsorbent packing material (stationary phase) found inside the column take longer to pass through than those that have no such affinity and keep moving. Thus, the molecules separate and are released from the column at different times (retention times). The retention time can be influenced by many factors such as the flow rate of the carrier gas, the temperature of the column, and the composition of the stationary phase. (Willett)

The composition of the stationary phase generally has the greatest affect on separation because the mobile gaseous phase serves mainly as a vehicle to carry the mixture through the column. The stationary phase can be either liquid, which is most common, or a solid material. Liquid stationary phases are very reliable and their performance is a function of their degree of polarity. Solid stationary phases are usually not as reliable due to poor reproducibility and separation but they give superior selectivity for components of a mixture especially when dealing with gasses. The composition of the stationary phase for packed columns is chosen if possible with the general type of compounds which will be analyzed for in mind because there are hundreds of types of stationary phases each with distinct properties which are best at separating out certain classes of compounds. Today’s popular capillary columns have a smaller variety of stationary phases because of their high efficiency at separation due to their open tubular design. Commonly stationary phases are often made out of highly heat resistant silicone rubbers and silicone oils which separate out components of a mixture based on their boiling points. (Williamson)

A detection device at the end of the column records each substance as it is emitted, noting the length of time it spent in the column. The length of time identifies the substance, and the intensity of the detector's response reveals the amount of that substance in the unknown sample. The elution time [retention time] and amount of each unidentifiable substance in the sample are then graphed. The resulting graph of data which is essentially a plot of current or voltage (from the detection device) versus time is called a gas chromatogram. These graphs are compared to graphs of the elution times and quantities of known substances run through the same process under the same conditions. In this manner the components of the mixture in the sample can be accurately identified. (Polin, Willett)

3.3 History of Gas Chromatography

Gas chromatography was first visualized in 1941, when A.J.P. Martin and R.L.M. Synge suggested that gas could substitute for liquid in the liquid mobile phase of liquid chromatography, resulting in a more efficient chromatographic process with shorter separation times. They theorized that solute would transfer at a faster rate between the mobile and stationary phases due to the higher solute diffusivity properties associated with gasses. Gas chromatography was not actually realized for another decade, however, when Martin and A.T. James published a paper describing the first gas chromatograph.

Gas chromatography technology developed quickly, and within four years, Martin and James assembled a more complex version of the original instrument. The new gas chromatograph was only able to sense ionic material, so Martin created a detector with greater versatility – the Gas Density Balance – that quickly led to a series of increasingly sensitive and selective detectors over the subsequent decade. The first commercial gas chromatograph was produced in the mid 1950's. As one might imagine, the gas chromatograph was also a huge financial success, commanding a multi-million dollar market just four years after its inception. Major companies such as Perkin Elmer and Hewlett Packard quickly began building and marketing the machines. (Scott, Willett)

Today, gas chromatography is the prevalent procedure relied upon for contemporary chemical analysis. The modern gas chromatograph is a sophisticated, computerized analytical instrument – in fact, the gas chromatograph was among the first instruments whose analysis was controlled by a computer that also processed its data and reported results. After the samples are mechanically inserted, the computer automatically calculates and prints out results, along with relevant operating conditions. The gas chromatograph was also the first instrument to be developed as a composite unit and commercially released. Yet despite its rapid evolution, the bulk of its creation occurred, or was at least envisioned, in its earliest years. (Scott)

The gas chromatograph's initial burst of development was due to the contributions of people from a variety of fields such as math, physics, engineering and chemistry. 1956, 1958, and 1960 saw the first three of what would become recurring international symposia devoted to the refinement and expansion of gas chromatography technology and development. The significance of these initial three symposia is apparent given that the modern gas chromatograph contains little that was not in some way predicted at those meetings. (Scott)

Today gas chromatography continues to be one of the most important tools utilized in identifying the components of mixture samples. The results produced are accurate, reliable and relatively inexpensive to obtain. Gas chromatography yields higher resolution and sensitivity than other chromatography techniques. The previous drawback to portable gas chromatographs is that they could only be used for volatile mixtures. The development of the microFAST GC, however, has removed this obstacle and facilitated the use of a portable gas chromatograph and its accompanying advantages for a much greater range of compounds. (Willett, Scott, ASI)

3.4 Components of the Modern Gas Chromatograph

The majority of gas chromatographs are composed of four chromatography units, which are supported by three temperature controllers and two microprocessor systems. First is the gas supply unit, which provides all required gas supplies. The type of detector selected for use dictates the requisite number of gases. For each different gas, a separate flow controller, flow monitor and potentially flow programmer is needed, along with a microprocessor to serve the gas supply unit by monitoring flow rates, adjusting individual gas flows. The pressure of the carrier gas is usually maintained at approximately 40 pounds per square inch (psi). A flow programmer may also be necessary – if so, the microprocessor must also program the mobile phase flow rate. (Scott)

Next is the sampling unit, containing an automatic injector inside of a thermostatically controlled enclosure. Samples are usually very small amounts such as one milligram or less. Typically, the injector has its own oven for temperature control, which is serviced by a temperature controller that monitors and controls the temperature. Occasionally, however, the injector relies upon the column oven. The injector might be a simple sample valve, a mechanically actuated syringe, or a microprocessor controlled automatic multi sampler. It can have a complex transport system to take samples, wash containers, prepare derivatives and potentially enact complicated sample preparation procedures prior to injecting the sample onto the column. If a lab robot is used for sample preparation, the robot becomes part of the sampling unit and can be programmed to prepare numerous different samples, in which case software has to be written for each type of sample. After the sample is injected into the system it is usually immediately vaporized (if it was a liquid at ambient temperature) and mixed with the carrier gas. A portion of this mixture then heads for the column while the remainder is released to the atmosphere. The goal is to have a very small concise unit of sample directed to the column so as to improve the overall precision of the output. If the sample is too large it will take too long to vaporize and a fairly large plug of sample will enter the column resulting in much broader peaks in the output. (Scott, Willett)

The third unit is the column unit, containing the most significant part of the entire chromatograph – the column. This is where the separation actually occurs. The column must be constructed of a material that is both non-adsorbent and chemically inert. There are two general types of columns: packed and capillary columns. Packed columns, which contain a granular powder are relatively inexpensive and easy to use. Capillary columns have no packing but instead have the stationary phase attached to the inner wall of the capillary. Capillary columns are more expensive than packed columns but give much greater resolution. (Willett, Scott)

The third unit also houses the oven, which controls the column's temperature and includes a temperature sensor and possibly a temperature programmer. Temperature programming is the gas chromatograph's answer to techniques such as gradient elution or solvent programming, which control elution time in other forms of chromatography. Those techniques are not possible in gas chromatography, since the mobile phase is a gas and thus interactions between the sample components and the mobile phase rarely occur. (Scott)

The detector, located in its own oven, is the fourth and final unit of the gas chromatograph. Numerous types of detectors exist, each with their own operational features and functional limits. Common detectors used are the Katharometer (Thermal Conductivity Detector [TCD]), the Flame Ionization Detector (FID) and the Electron Capture Detector (ECD). (Willett)

The first detector utilized was the Katharometer. This device produces an output based on a combination of the thermal conductivity properties of the components in the sample mixture and known electrical properties within the device. This device is very reliable for basic samples but cannot detect trace amounts or decipher complex mixtures as well as the Flame Ionization Detector or Electron Capture Detector. (Willett)

The Flame Ionization Detector is in general the best detector for analyzing organic compounds. The detector mixes hydrogen gas with the effluent gas containing the separated components exiting the column and then burns the mixture in the presence of electrodes with a steady potential difference provided by Direct Current (DC). Each component in the mixture when burned then acts as a current carrier between the electrical potentials momentarily completing the circuit and providing an electrical output. The Flame Ionization Detector is the most commonly used detector in modern gas chromatography because of its simplicity and reliability. (Willett)

The Electron Capture Detector can only detect certain substances such as halogenated compounds but is very good at their detection. The device exposes the effluent of the column to ionizing radiation which alters the electrical conductivity of the effluent gas which is passed between electrodes with a potential difference between them. Current flow between the electrodes is constant due to the steady ionization of the effluent gas by the ionizing radiation source. When a separated component of the sample mixture passes through it changes the current flow between the electrodes and this alteration is recorded as output. (Willett)

The detector, along with the conduit that connects it to the column, must stay at a temperature of at least 15˚C above the oven's maximum analysis temperature, otherwise molecules from the sample might condense within the conduit or detector. Any such condensation detracts from the detector's sensitivity, and thus the accuracy of its results. The detector oven, set at a user-defined temperature, is operated isothermally and controlled by its own detector-oven temperature controller. The conduit, meanwhile, has a separate heater. The gas chromatography procedure concludes with an associated data processing computer, which acquires the detector's output, processes it, and prints a report. The chromatogram obtained from this procedure is then compared to the chromatogram of a standard run through the same machine for identification of components of the mixture. A diagram of the four chromatographic units along with their associated controllers and processors is depicted in figure 1. (Scott, Willett)

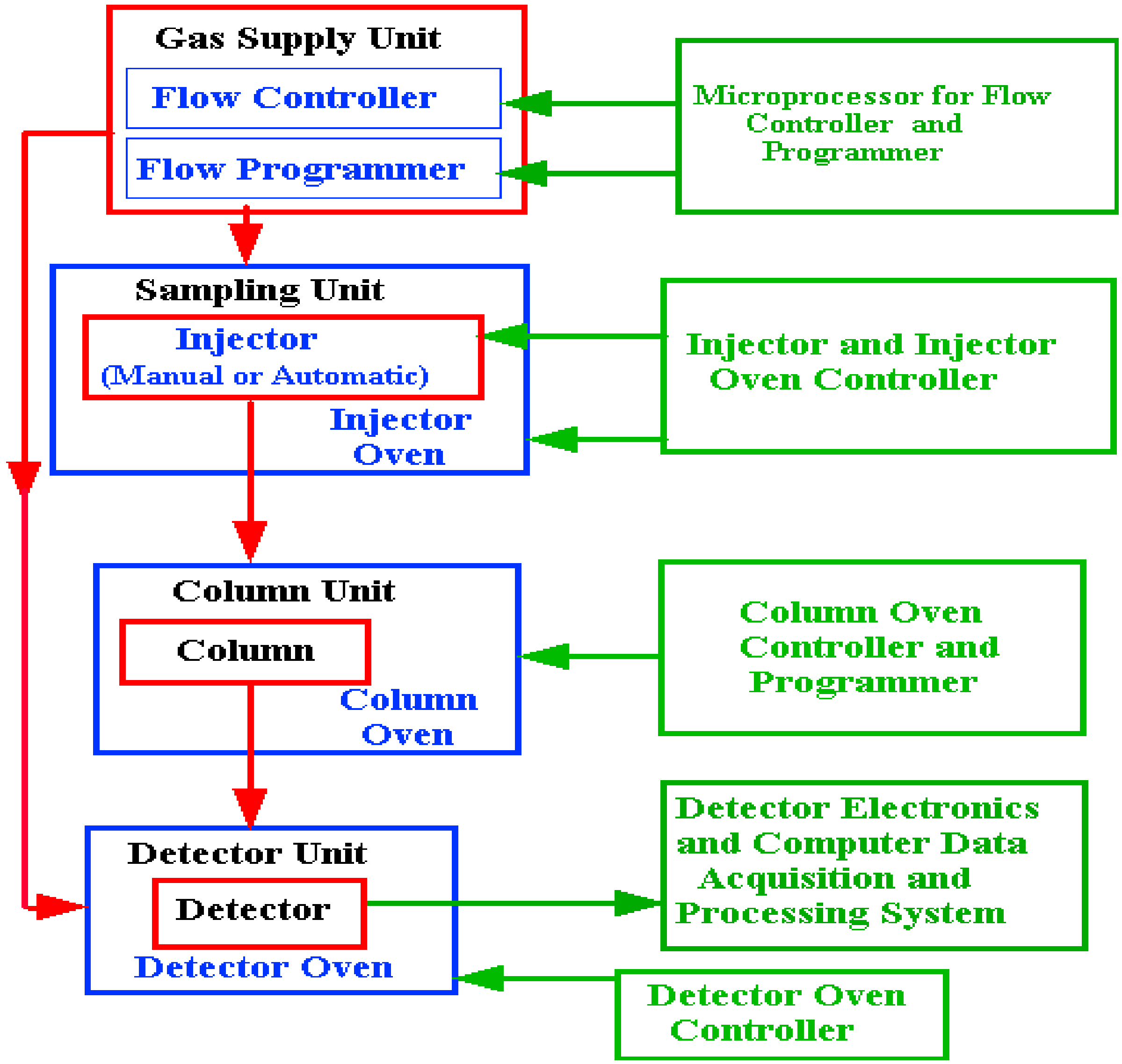

Figure 1. Gas Chromatograph Functional Diagram (Scott)

3.5 Development of the microFAST Gas Chromatograph

The conventional size gas chromatograph (GC) machine is very large and heavy. Due to its physical dimensions the machine is essentially immobile and therefore permanently located in the laboratory. The conventional GC also requires large amounts of power to operate further ensuring its immobility. Samples which are to be tested must therefore be brought from their source to the lab. This transfer of sample from the field to the laboratory results in complicated procedures to ensure the integrity of the sample during transportation. The actual time required for obtaining identification of a sample using a conventional GC depends partly on the length of time required to transport the sample from origin to lab which can take from days to weeks depending on the location of origin and the procedures required to handle specific samples. (ASI)

Scientists have realized the inherent problems associated with the conventional GC and have been developing in recent years several smaller portable gas chromatographs using microtechnology. Companies such as Varian, Agilent and PerkinElmer currently have several portable, battery operated gas chromatographs on the market. These portable machines provide quick analysis and accurate results as compared to the conventional gas chromatograph. (ASI)

The major drawback however is that all the current machines on the market can only analyze volatile compounds (gasses), whereas the conventional laboratory machine can analyze many more compounds which are classified as semivolatile. This is due to the fact that the conventional gas chromatograph can heat semivolatile compounds at relatively high temperatures which makes them volatile and therefore subject to analysis. The portable machines currently on the market cannot achieve the temperatures necessary to make semivolatile compounds volatile because of thermodynamic and power consumption limitations so the substances which they can analyze are limited to compounds which are already volatile. This severely limits the number of compounds which the portable machines on the market right now can analyze as compared to the conventional gas chromatograph. (ASI)

The microFAST GC is an instrument incorporating instrumentation and structural design features to facilitate the range of temperatures that can be achieved in a conventional laboratory based gas chromatograph. This allows the microFAST GC to analyze the same number of compounds as a conventional GC. The microFAST GC therefore combines the attributes of a portable GC with the applicability of the conventional GC. (ASI)

The microFAST GC analyzes samples approximately 10 times quicker than the time required per analysis by a conventional GC. Specifically the microFAST GC can separate volatile organic compounds (VOC) in less than 10 seconds and semivolatile organic compounds (SVOC) in less than 50 seconds. The typical time required for a complete analytical cycle to take place is 3 to 5 minutes. The machine can independently perform 100 consecutive cycles with the use of an auto sampler. Therefore a large amount of data can be generated without supervision by personnel saving immense manpower time and money. Since the microFAST GC can analyze samples at their point of origin the concept of real time analysis is achieved. One major benefit of real time analysis is the isolation of the source of an environmental contaminant. Instead of going out into the field and gathering random samples which must be then sent to the lab for conventional GC analysis, samples can immediately be determined as positive or negative for a particular substance. Since the time required for sample processing is so short, many samples can quickly be analyzed from over a wide area therefore the potential source of a contaminant can be isolated quickly and precisely. (ASI)

Several engineering aspects of the microFAST GC are critical for its many advantages. The column design, trap configuration, and thermodynamics all contribute to the machine's versatility. (ASI)

The machine utilizes dual separation columns. Each sample is analyzed simultaneously and independently by each column. This allows for much greater accuracy in interpreting results. Dr. Ed Overton developed and patented the design of the column which is protected under patent number 5,611,846 held by Louisiana State University. Each column can range from one to three meters long and has an inside diameter of 100 - 320 micrometers. The carrier gas consumption is less than 5mL per minute and total hydrogen gas consumption averages less than 50mL per minute. These low flow rates translate to decreased gas supply requirements hence greater system portability due to smaller and lighter supply gas containers. Column diameter and length contribute to the high resolutions and speeds achieved. High resolution is essential in precisely identifying specific compounds. (ASI)

The trap design incorporated into the microFAST GC allows for the detection of very low levels of compounds. For a gas injection, organic compounds are adsorbed onto the trap material (typically TENAX) which is a granular substance. The physical dimensions of the trap material can be manipulated (mesh size) to be more efficient for specific compounds. The trap is then heated, the compounds are released from the trap material, the flow through the trap is reversed, and the organic compounds form a highly concentrated "plug" which facilitates much lower detection levels for the microFAST GC. For liquids the procedure is similar to gasses. The liquid is heated in the oven vaporizing the solvent and the solvent and analytes enter the trap where they are adsorbed. The solvent then passes through via a process called "breakthrough" leaving the concentration of analytes in the trap material. The trap is then heated, flow is reversed, and the highly concentrated plug of analytes enters the column. (ASI)

The unique thermodynamic design distinguishes the microFAST GC from the other current portable GCs and hence allowing it the much greater range of analysis. In the current portable GC's the column is heated by conduction. The microFAST GC employs a patented column design in which the heater is embedded in the column assembly where it both heats the columns by conduction and simultaneously employs temperature programming. (figure 1). Conduction heating coupled with temperature programming allows for much more precise and efficient heating which translates to much lower power consumption. The column heater uses less than 100W of power at 24 VDC. The temperature can be adjusted at a rate of 25 C/sec for a maximum of 350 C/sec. (ASI)

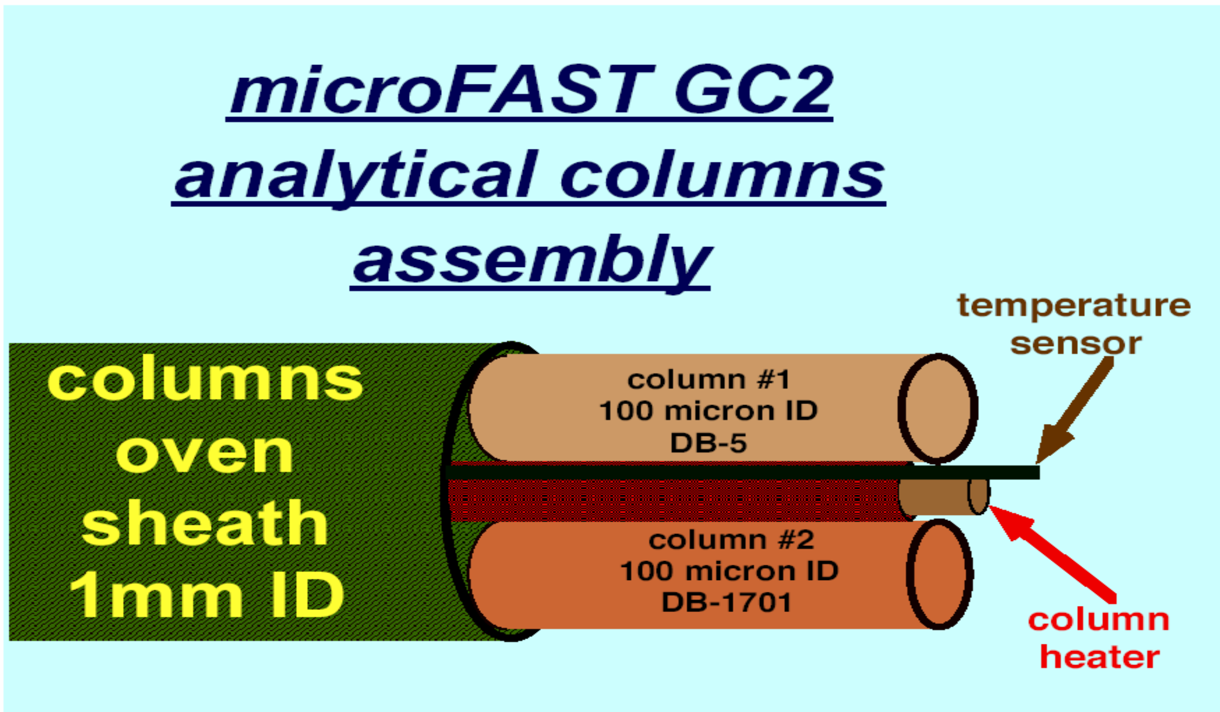

Figure 2: Heating element incorporation into column assembly. (ASI)

CHAPTER 4. CONCLUSION

Recent advances in microtechnology, resulting in the development of the microFAST gas chromatograph, demand a close look at the existing relationship between environmental science and the legal system because this relationship will soon be greatly amplified. Both the scientific and legal communities will have to adapt to remain compatible with one another. This author hypothesizes that within a few years scientific evidence properly prepared as a result of the microFAST gas chromatograph will be both admissible into the court of law and also serve as a mechanism for improving the relationship between the two disciplines.

As a result of the *Daubert* trilogy, the legal system now has a fairly specific methodology to address the introduction of scientific evidence into the courts. It is significant to note the increasing frequency with which the legal guidance governing scientific evidence has been modified. The initial vague guidelines were established in 1923 and remained unchanged for fifty years. In the mid 1970's, legislation attempted to clarify those guidelines and then less than twenty years later the courts further refined the means by which science enters the courtroom.

The increased frequency of legal action on the issue of scientific evidence mirrors the exponential curve depicting the explosion of environmental technology in the last three decades. The legal system has long recognized the value of scientific evidence in aiding the courts with their task of rendering verdicts regarding environmental pollution and other scientific issues. Since the rapidly growing field of environmental science has an especially close relationship with the legal system, new avenues of expansion are often directed with the courts in mind. Streamlining methodologies concerning data collection, processing and result derivations not only aid the scientific process, they also help translate that process into a format the courts can both recognize and evaluate on their own.

The preciseness of both science and the law is a major reason for their possible compatibility. Science is based on principles such as mathematical formulas, constants and unchanging physical properties of matter. The results obtained by manipulating those principles must be repeatable and identical. Law in the United States is centered on precise definitions of the English language. The principles of the legal system are determined by social conditions, but the interpretation of those principles always comes down to the strict definitions of words. In cases of ambiguity, the legal system seeks to explicitly define those words.

The *Daubert* trilogy is a perfect example of the law and its dependence on exact language. The holding from *Daubert* did away with the vague general acceptance test established in *Frye*, instead replacing it with the more specific relevance and reliability requirements for scientific evidence. However, since the term "scientific" in that case only referred to the classical sciences such as chemistry and physics, evidence from fields such as engineering was not relevant under *Daubert*. Another case, *Khumo Tire,* had to transpire for the new relevancy and reliability guidelines to be applicable to technical or specialized knowledge which is not classically defined as "scientific".

Another good example of the precision of the legal system is the central statement of the National Environmental Policy Act, which requires that an Environmental Impact Statement must be prepared if an event is "a major federal action significantly affecting the human environment". The definitions of every word in this statement are scrutinized when determining compliance with the law. If any one word can be determined to be not applicable to an event, then the party responsible for that event is not required to file an Environmental Impact Statement (which of course often involves large amounts of time and money).

The current general guidelines used by the courts in determining the admissibility of scientific evidence center around the terms “relevance” and “reliability”. The courts are given factors which they can use at their own discretion to assist them in determining if the evidence is relevant and reliable such as peer review, error rate and general acceptance. Determination of the admissibility of evidence produced using the microFAST gas chromatograph therefore requires evaluating the relevance and reliability of that evidence.

The easier term to evaluate in this case is relevance. The evidence must be applicable to the specific trial for which it is intended. If it is determined that a chromatogram is applicable to a case, then it makes no difference whether that chromatogram was generated by a conventional gas chromatograph or the microFAST gas chromatograph. Once the court has decided that a chromatogram depicting the separation of elements within a mixture is relevant to the trial, the issue of how that chromatogram was created falls under the reliability test, not the relevance test.

In general, environmental litigation centers on contamination. The legal system relies heavily on causation in making its decisions and the easiest method of proving causation when dealing with contamination is by introducing evidence establishing a trail of contaminants from the source element to the response element. Evidence which consists of a low number of samples does not readily establish a trail and is often inadmissible because it is irrelevant to the case; it does not clearly establish causation and is therefore merely speculative. Evidence containing a high number of samples, however, can depict a trail of contamination between source and target, thereby proving causation and establishing the evidence’s relevancy.

The use of a conventional gas chromatograph to produce evidence often yields a low number of samples due to the constraints of that technology. The use of the microFAST gas chromatograph, however, yields a much higher number of samples for the same evidence. It follows that the use of the microFAST gas chromatograph may actually increase the rate of relevancy for environmental scientific evidence because it would help develop evidence tailored to the establishment of causation.

When considering the reliability of evidence developed using the microFAST gas chromatograph, the trier of fact will look at factors such as the procedure used in operating the machine, the repeatability of results produced, the interpretation of those results and the machine's general acceptance in the scientific community. Since the microFAST gas chromatograph is just now entering mass production, the factors determining reliability are difficult to evaluate. Standard operating procedures need to be written, for example, so that the scientific and legal communities can verify the integrity of data processed by the machine. However, the preliminary trials of the machine have yielded positive results regarding many of the general factors determining reliability.

A key factor in evaluating the reliability of evidence produced by the microFAST machine is that the fundamentals upon which the machine is based are the same as for a conventional gas chromatograph. The chromatographic processes are essentially the same – just on a much smaller scale. Techniques in microtechnology have drastically reduced the size of all of the components and rearranged their classical locations within the system as compared to a conventional gas chromatograph, but the principles of separation upon which the microFAST machine is based are the same as for the conventional gas chromatograph. Since reliability is well established for the principles governing operation of a conventional gas chromatograph, then it is not a major leap in logic to transfer that reliability (at least in terms of approval of theory of operation) to the microFAST machine.

The microFAST technology is well established in the scientific communities dealing with micro-scale gas chromatography. The results of data processed by the machine have been subjected to the peer review process and published. Independent testing of the microFAST has yielded accurate and repeatable results. These initial observations are probably not sufficient for establishing reliability in the legal system at the present time, but if they continue in the current trend, they will establish reliability for evidence properly produced by the machine.

Evidence produced using the microFAST gas chromatograph will clearly be viewed as novel scientific evidence. Prior to 1993 (*Daubert*) this evidence could have been ruled inadmissible since by virtue of its novel status the claim could have been made that the microFAST has not been "generally accepted". When microFAST-produced evidence comes to the legal system now, however, the court will have to carefully examine both the relevance and reliability of that evidence when determining its admissibility. This signifies another major advance in the relationship between the scientific and legal communities. A relatively specific method is in place now that limits the input of "junk science" into the courts while at the same time allowing credible science to be evaluated.

As long as it was accumulated in the proper manner, evidence produced by the MicroFAST gas chromatograph will thus satisfy both the relevance and reliability tests. The proper manner includes training and qualification of the operators, chain of custody for samples and appropriate derivation of conclusions, among other factors.

The environmental sciences are continuing to develop more advanced methods to detect and identify contaminants in the environment. Technology is entering the ever-smaller scale of nanotechnology, in which the diameter of columns for gas chromatographs will be less than the diameter of a human hair. Further work in microtechnology and nanotechnology will facilitate the detection of previously undetectable amounts of matter at incredible speeds. The amount of data being submitted to the legal system as evidence will continue to increase at perhaps an even faster rate due to these and many other scientific advances.

Careful interpretation and fairness in enforcement of environmental legislation by the legal system is the mechanism that maintains the integrity of our nation's environmental agenda. Environmental scientific evidence is invaluable in aiding the trier of fact in the U.S. legal system. The foundation laid by the *Daubert* trilogy established a promising future for the relationship between the courts and environmental science, and there will almost definitely be more pivotal legal decisions in the years to come that further refine the guidelines regarding admissibility of scientific evidence.

As was stated at the beginning of this thesis – the relationship between the legal system and environmental science will persist and grow more complex so long as each community continues its search for truth. Mutual respect and care for the environment by members of both disciplines promise to make that relationship fruitful.

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