The Manipulation and Control of Nicotine and Tar in the Design and Manufacture of Cigarettes: A Scientific Perspective

by William A. Farone, Ph. D.

It is well recognized within the cigarette industry that there is one principal reason why people smoke -- to experience the effects of nicotine, a known pharmacologically active constituent in tobacco. The recent discussion concerning the regulatory status of nicotine has led to some confusion over the role of nicotine and tar in the design and construction of cigarettes. As a scientist who devoted seven years to the industry as the Director of Applied Research, in the Research & Development department of Philip Morris U. S. A., part of Philip Morris, Inc., I would like to put forth a scientific, hopefully objective, assessment of strides made by fellow scientists within the industry.

Research into the importance of nicotine to the tobacco industry can be traced to the 1960's when the British American Tobacco Company initiated research to understand some of the activities of nicotine. [1] Clearly by the 1970's and early 1980's the tobacco industry established that smokers required a minimal level of nicotine within a cigarette.[2]

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[1] Haselbach CH., et al., "Final Report on Project HIPPO II." for the British American Tobacco Co Ltd., Battelle Memorial Institute, Geneva, March. 1963.

[2] Dunn WL, "Motives and Incentives in Cigarette Smoking," Philip Morris, 1972.

Teague, CE, "Research Planning Memorandum on the Nature of the Tobacco Business and the Crucial Role of Nicotine Therein," R. J. Reynolds Tobacco Co., April 14, 1972.

The industry's understanding of the need for a minimum level of nicotine is further reflected in patents held by cigarette manufacturers. See U. S. Patent No. 3,584,630, Inskeep GE., "Tobacco Product Having Low Nicotine Content Associated with a Release Agent having Nicotine Weakly Absorbed Thereon," Philip Morris Inc., June 15, 1971, C1:18-20, 39-43.

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Knowledgeable industry personnel, primarily scientists and blend and development personnel, understood that a level of nicotine had to be present to result in a commercially successful cigarette. As publicly available documents reveal, the tobacco industry began to study how to design and construct cigarettes to ensure acceptable nicotine levels.[3] It was common knowledge within the industry that cigarettes without nicotine would not sell. Nicotine free cigarettes in the 1950's and 1980's were failures.[4]

While the negative health consequences of smoking, particularly emphysema and the increased rate of lung cancer among smokers, are well known, it should also be noted that smoking, like the use of fermented beverages and bean and leaf extracts, is a centuries old phenomenon. The fact that a wide variety of plants contain chemicals with pharmacological activity can either be regarded as positive or negative depending on whether one is looking for a cure for disease or believes that behavior modification is a negative result.

Research by the industry has shown that the pharmacological effects of nicotine have been a two edged sword. The industry understood that consumers smoke cigarettes

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U. S. Patent No. 3,109,436, Bavley A., et al., "Tobacco Products." Philip Morris Inc., November 5, 1963, Cl:11-15, 34-39.

[3] Eichorn PA and Dunn WL, "Quarterly Report of Projects 1600 and 2302." Philip Morris, December 31, 1970, in 141 Cong. Rec. H8127 et seq.

Philip Morris USA, "Research and Development Five Year Plan, 1974-1978," May 1973, in 141 Cong. Rec. H8130 et seq.

[4] Freedman AM., "Past is Ominous for Substitute Smokes," The Wall Street Journal, June 15, 1989.

because of the pharmacological properties of nicotine.[5] Industry researchers were also aware that the nicotine found within cigarette smoke may have negative peripheral nervous system (cardiovascular) effects .[6] However, it should also be pointed out that industry research on nicotine's pharmacological effects has shown some potential benefits. For example, research completed by R. J. Reynolds Tobacco Company maintains that cigarettes provide smokers with psychological benefits, such as increased mental alertness and anxiety reduction.[7] In addition, research at Philip Morris analyzed the possible benefit of nicotine related to hyperkinetic children as well as nicotine's beneficial effects on reducing stress experienced by smokers and improving the performance of tasks.[8]

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[5] Ryan/Dunn Alternate, "Third Version of Board Presentation," Philip Morris, Fall 1969, in 141 Cong. Rec. H7646 et seq.

Memo from JL Charles to RB Seligman, "Nicotine Receptor Program - University of Rochester," March 18, 1980, in 141 Cong. Rec. H7680 et seq.

Teague, supra n. 2.

[6] Charles, supra n. 5.

Hearings on Regulation of Tobacco Products, before the Subcommittee on Health and the Environment of the Committee on Energy and Commerce, 103d Cong. 2d Sess., pt. 2 at 33 (April 28, 1994) (testimony of former Philip Morris scientist Victor John DeNoble, Ph.D.).

[7] Robinson JH, et al., "The Role of Nicotine in Tobacco Use," Psychopharmacology, 108:397, 1992.

[8] Phillip Morris Research Center, "Behavioral Research Annual Report," July 18, 1975, in 141 Cong. Rec. H7652 et seq.

Memo from FJ Ryan to WL Dunn, "Proposed Research Project: Smoking and Anxiety," Philip Morris, December 23, 1969, in 141 Cong. Rec. H7648 et seq.

Eichorn PA, et al., "Quarterly Report -- Projects 1600 and 2302," Philip Morris, October 5, 1972, in 141 Cong. Rec. H7649 et seq.

If we accept the premise -- as the cigarette industry surely does -- that cigarettes are a nicotine delivery system, and that current laws do not forbid the self administration of nicotine via smoking by adults, then it becomes a desirable technical challenge to decrease the "tar" in a cigarette while maintaining the delivery of nicotine. This has been a key objective of the cigarette industry over the last 20-30 years, as some industry documents now publicly reveal.[9] Minimizing the exposure to the potential negative health effects of the undesirable chemical components in tar while maintaining an acceptable and pharmacologically active nicotine level is thus a valid and useful technical challenge that I and many of my former colleagues in the cigarette industry considered a top priority.

Achieving this acceptable and pharmacologically active nicotine level was an enormous challenge. It required cigarette manufacturers to deliberately control the levels of nicotine in their products in order to overcome the naturally-occurring variability of nicotine in tobacco plants. Since tobacco is a natural product and the content of nicotine varies from year to year, by type of tobacco, by varieties within types, and from farm to farm, it is also necessary to be able to control nicotine levels and the ratio of nicotine to

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[9] Memo from TS Osdene to WL Dunn, "5-Year Plan," Philip Morris, October 29, 1973, in 141 Cong. Rec. H 8149 et seq.

Teague, supra n. 2.

Mörini HA. "Cigarettes with Health Assurance," BATCO, 1976.

U. S. Patent 4,676,259, Ellis MP., et al., "Nicotine Enhanced Smoking Device," Advanced Tobacco Products Inc., June 30, 1987, C1:21-22, 52-58.

tar to be able to make a consistent product and to accurately label the product for nicotine and tar as required by law.

Cigarette manufacturers have invested enormous financial resources to achieve the desired level of control over nicotine and tar in their products. The industry employs two principal means of controlling the nicotine levels:

1. By modification and control of the tobacco blend , i.e., the ratio of Burley (air cured), Bright (flue cured), Oriental, stems, expanded tobacco products, and reprocessed tobacco products such as tobacco sheet made from stems and waste leaf.

2. By modification of the construction of the cigarette such as filter type, the type of filter material used, the number and placement of ventilation holes, the density, composition and porosity of the cigarette paper, the length and diameter of the paper, and the types and amounts of flavor additives.

Over the years, these techniques have been described or discussed in the public domain at various meetings and by publications in books, patents, scientific papers, and newspapers.[10]

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[10] The following references cover a wide variety of the published methods for modifying the nicotine to tar ratio:

Spears AW., "Factors Affecting Smoke Delivery of Nicotine and Carbon Monoxide," presented at the "1975 Symposium - Nicotine and Carbon Monoxide," presented by the Tobacco and Health Research Institute and The Kentucky Tobacco Research Board, November 17-18, 1975.

The strongly held conviction of most industry scientists and product developers was that nicotine was the primary reason why people smoked. This was sometimes openly expressed.[11] In fact, it was commonly understood within the industry that the smoker's

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Spears AW and Jones ST, "Chemical and Physical Criteria for Tobacco Leaf of Modern Day Cigarettes," Recent Advances in Tobacco Science, 1981, 7:19-39.

Halter HM., et al., "Effect of Tobacco Reconstitution and Expansion Processes on Smoke Composition," in Recent Advances in Tobacco Science, 32nd Tobacco Chemists' Research Conference, October 30 - November 1, 1978, vol. 4, pages 113, 126.

Freedman AM., et al., "Why Don't Low-Tar Cigarettes Have Lower Nicotine?" The Wall Street Journal, July 14, 1995.

Freedman AM, "'Impact Booster' Tobacco Firm Shows How Ammonia Spurs Delivery of Nicotine," The Wall Street Journal, October 18, 1995.

"Filter Material Reduces CO/Tar Ratio Without Pressure Drop," *Tobacco Reporter*, April 1985;112(4):30-34.

Kiefer JE., "Ventilated Filters and their Effect on Smoke Composition," Research Laboratories, Tennessee Eastman Company, pages 69-83.

McMurtie A., et al., "Cigarette Paper Effects on Tar/Nicotine and CO/Tar Ratios," Abstract from the 35th Tobacco Chemists' Research Conference, Winston-Salem, NC, Paper No. 17, 1981.

Selke WA, "Making the Cigarette Do Just What You Want It To Do," *Journal Tobacco International*, September 16, 1983.

Norman V., "The Effect of Tip Dilution on the Filtration Efficiency of Upstream and Downstream Segments of Cigarette Filters," *Beitrage zur Tabakforshung International*, Vol. 12, No. 4, July 1984.

Browne CL., The Design of Cigarettes, Third edition, Hoechst Celanese Corporation, 1990, page 73.

Browne CL, et al., "The Effect of Filter Ventilation on the Yield and Composition of Mainstream and Sidestream Smoke," Abstract from the 32nd Tobacco Chemists' Research Conference, Montreal, Canada, Paper No. 16, 1978.

Owens WF, "Effect of Cigarette Paper on Smoke Yield and Composition," Abstract from the 32nd Tobacco Chemists' Research Conference, Montreal, Canada, Paper No. 1, 1978.

Lee BM, "Modification of Nicotine to Tar Ratio in Cigarette Smoke," Abstract from the 42nd Tobacco Chemists' Research Conference, Lexington, KY, Paper No. 34, 1988.

Philips JA, "Filters for Cigarettes: An Integral Part of the Cigarette," Tobacco Reporter, October 1981.

acceptance of a cigarette was related to the amount of nicotine it contained. Extensive, in some instances ground breaking, research by the tobacco industry was necessary to construct a cigarette that ensured an adequate delivery of nicotine as the cigarette market evolved from the traditional full flavored, unfiltered product of the 1950's to the filtered, low tar cigarette demanded by many smokers for the last 30-40 years. The objective of industry scientists and product developers, simply stated, was to provide the consumer with the same pharmacological satisfaction derived from nicotine in the natural blends and flavor of the full strength cigarettes of the 1950's as the marketplace shifted to the naturally less flavorful and satisfying low tar and nicotine cigarette demanded by the more health conscious consumer.

A major contributor to this process was Dr. William Dunn, Principal Scientist and manager of the Behavioral Research group of Philip Morris. Dunn believed that nicotine was a beneficial component of cigarette smoke.[12] Tar was considered to be the "biologically active," i.e. harmful, component of cigarette smoke. Therefore, the development of low tar cigarettes that gave the smokers the nicotine they wanted but exposed them to less tar were considered good research and product development objectives. Industry scientists were proud to be working on the development of these products. Discussions at industry or company sponsored meetings such as the Tobacco

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[11] Dunn, supra n. 2.

Charles, supra n. 5.

Teague, supra n. 2.

[12] Dunn, supra n. 2.

Chemists Research Conferences often occurred among blend specialists, market researchers, and research & development scientists on how to attain that level of acceptability while reducing the tar. An attempt by R. J. Reynolds to produce the ultimate low tar cigarette was the PREMIER nicotine delivery device. PREMIER, which was test marketed by RJR, delivered virtually no tar at nicotine levels slightly lower than currently marketed fuller flavor low tar cigarettes.[13] According to news reports, Philip Morris was also working on their own version of PREMIER, code named TABLE.[14]

While working at Philip Morris, Dunn and his behavioral science group promoted the need to provide adequate levels of nicotine in the product, and to maintain adequate levels of nicotine in order to keep smokers satisfied. This concept of nicotine delivery being essential to consumer satisfaction was common knowledge within Philip Morris and the rest of the industry.[15] When consumer testing indicated that a product was lacking in "impact" or some similar descriptor that could be associated with nicotine, experienced market researchers and product developers would compensate by increasing nicotine levels to provide the necessary impact in future versions of that product.

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[13] "New Cigarette Prototypes that Heat Instead of Burn Tobacco," R. J. Reynolds Tobacco Company, Winston-Salem, NC, 1988, page 3.

[14] Freedman AM., "Philip Morris Memo Likens Nicotine to Cocaine," The Wall Street Journal, December 8, 1995, B1.

[15] Dunn, supra n. 2.

Charles, supra n. 5.

Teague, supra n. 2.

As in any discipline, basic pharmacological research was necessary to properly understand a phenomenon. The industry applied considerable effort and manpower to the study of nicotine in order to understand this relationship between nicotine and the smoker's needs. Many internal industry documents that have recently become publicly available reflect, in part, the novel and extensive research conducted. Philip Morris undertook research into nicotine's effect on brain waves, brain receptors, the cardiovascular system, physiological impact, juvenile hyperkinesis, alleviating anxiety, stress, and aggression, the smoker's motivation to continue smoking, as well as on the smoker's cognitive abilities.[16] R. J. Reynolds (RJR) research involved human experimentation including analyzing nicotine blood levels and nicotine urine levels as well as the identification of specific brain receptor locations involving the binding sites for nicotine.[17] British American Tobacco Company (BATCO), the parent company of U. S.-based Brown & Williamson Tobacco Co., sponsored pioneering work into the addictive nature of nicotine more than 30 years ago and Philip Morris later conducted state-of the-art animal studies demonstrating that nicotine is a "positive reinforcer," and

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[16] 141 Cong. Rec. 7646 (reprinting Philip Morris research documents), July 25, 1995.

[17] R. J. Reynolds Tobacco Company, New Cigarette Prototypes that Heat Instead of Burn Tobacco, supra n. 13, at pp. 457-557.

Fluhler, et. al, "A Hybrid PBPK/PD Model for Nicotinic Receptor Dynamics in the Rat Brain," Duke University Medical Center and R. J. Reynolds Tobacco Co., Abstract, Society for Neuroscience, 22nd Annual Meeting, Anaheim, CA, Vol. 18, Part 1, October 25 - 30, 1992.

that this effect is centrally mediated, one of the defining characteristics of addictive drugs.[18]

This basic research provided product developers with the scientific foundation that was necessary to help construct a low tar cigarette that maintained an adequate level of pharmacological activity from nicotine in reduced tar products. Product developers and blend and leaf specialists were responsible for manipulating and controlling the design and production of cigarettes in order to satisfy the consumer's need for nicotine in lower yield products.

Blend changes were an especially important tool used to ensure desired nicotine levels. Tar is a function of tobacco weight. However, an all-burley cigarette will produce a higher nicotine level than an all-bright tobacco cigarette of the same weight. The industry knew that by using a higher percentage of higher nicotine tobacco in their low tar cigarettes they could achieve an increase of their nicotine levels. Therefore a blend change incorporating the greater use of higher nicotine tobacco while reducing the overall tobacco weight, such as through the use of expanded tobacco, could produce a low tar cigarette with the desired pharmacologically active level of nicotine associated with a conventional full flavor cigarette. An example is the Merit Ultra Light, which was

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[18] Haselbach C., et al., "A Tentative Hypothesis on Nicotine Addiction." Southampton, England, May 30, 1963, pages 1-3.

Hearings on Regulation of Tobacco Products, April 28, 1994, supra n. 6, at 5, 6, 20.

introduced in 1981 with an elevated nicotine to tar ratio of 0.11.[19] In fact, Philip Morris utilized much of the technology and expertise of leaf and flavor chemistry and behavioral research to mask the harsher taste associated with the presence of higher nicotine burley tobacco in the blend of Merit.[20]

The cigarette industry also altered the cigarette filter in order to increase nicotine delivery. As the public literature describes, the industry knew that "selective filtration" was possible.[21] Filter design and ventilation allowed the design and manufacture of cigarettes that removed a higher percentage of tar than nicotine. Selective filtration was accomplished by altering the technical specifications for a filter, e.g. by selecting different filter tow combinations, varying the denier per filament, and deciding whether or not to use additives in the filter. After the blend was selected, appropriate filters were identified to attain a predetermined nicotine/tar ratio. Manufacturers of cigarette filter materials produced detailed technical presentations promoting filters that provided higher nicotine to tar ratios by selectively filtering out more tar. As noted above, the public literature describes these techniques.[22]

Another component of cigarettes that is used to control nicotine delivery is reconstituted tobacco. The tobacco industry originally developed reconstituted tobacco as a cost-

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[19] Remarks of Rep. Henry A. Waxman. July 31, 1995, 141 Cong. Rec. H 8007.

[20] "Second Speaker, Merit Team," Remarks, Philip Morris, January 14, 1976.

[21] Browne CL., The Design of Cigarettes. Third Edition, Hoechst Celanese Corporation, 1990, page 72.

[22] Supra n. 10.

saving measure. Over the last several decades the industry has used reconstituted tobacco products to assist in controlling the nicotine delivery in cigarettes. Reconstituted tobacco is composed of returned cigarettes, tobacco stems, scraps, and dust. By use of either a wet paper making process or a bandcast process these scraps are made into tobacco sheet or reconstituted tobacco.[23] By controlling the ingredients that go into making reconstituted tobacco, the industry controls the chemical and physical properties of the finished sheet, including its nicotine content. For example, reconstituted tobacco used in a low tar cigarette blend can be made differently from the reconstituted tobacco used in a full flavor cigarette. The reconstituted tobacco blend destined for a low tar cigarette can be made with a higher concentration of burley tobacco scraps than the blend of reconstituted tobacco designated for a full flavor brand. Reconstituted tobacco is closely controlled for its chemical properties and burn rate and flavor controlling additives. The alkaloid (mostly nicotine) and sugar content of all the scrap used can be measured and precisely blended into reconstituted tobacco. The levels of nicotine and other key compounds can also be measured to insure control in reconstituted tobacco. Quality control checks involving the use of a gas or liquid chromatography to ascertain the exact nicotine amounts are routinely employed during the process. Final product that fails to meet the design specifications for nicotine can be returned to the start of the process or re-blended.

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[23] Browne CL., supra n. 21, pages 44-47.

The delivery of tar and nicotine is a complicated scientific problem and recent reports are now shedding more light on how the problem was solved. The use of ammonia chemistry was important to the industry in maintaining adequate nicotine delivery to satisfy smokers.[24] The industry was able to deliver more of the available nicotine in the blend to the smoker by using ammonia compounds. This apparently works by increasing the pH of the tobacco smoke. Commonly, the pH (or level of basicity) is increased by the addition of ammonia compounds either as additives or in the manufacture of reconstituted tobacco. Ammonia is sometimes introduced by casings such as urea that are applied to tobacco and then decompose into ammonia at which point they can increase the pH of the smoke. These casings include ingredients like amino acids, proteins, and other products that decompose or by pyrolysis are changed into pH increasing agents, such as ammonia. In the complex world of tobacco smoke chemistry, by increasing the pH of the aerosol in the mainstream smoke, more of the aerosol would be in the vapor phase and less in the liquid (or condensed) phase. By increasing the ratio of vapor phase to liquid phase, one increases the total nicotine delivery since the condensed phase is less likely to survive the filter and the trip to the lungs.

All of the cigarette components described above were incorporated into complex computer models to help determine nicotine and tar deliveries while cigarettes were in the product development stage. These models allowed blend ingredients, filter and paper components, and numerous other variables to be considered simultaneously. The models

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[24] Freedman AM., "'Impact Booster' Tobacco Firm Shows How Ammonia Spurs Delivery of Nicotine," The Wall Street Journal, October 18, 1995, A1.

enabled nicotine and tar deliveries to be successfully predicted and enabled product developers to identify which components were required to produce specific nicotine and tar deliveries. Models of this type are well suited to the use of computers and are discussed in the published literature.[25]

The tobacco industry found that in the manipulation of the nicotine/tar ratio, the methods used to increase the nicotine to tar ratio sometimes resulted in a cigarette that was too harsh. With a standard nicotine/tar ratio in a traditional cigarette no flavor smoothing compounds are generally needed to produce a palatable cigarette. The higher tar levels in traditional cigarettes mask the harshness of nicotine and the associated compounds produced in higher nicotine to tar ratios. A low tar cigarette with a higher nicotine/tar ratio than a traditional cigarette could be very harsh due to the lack of sufficient specific tar components to mask the nicotine and related basic compounds. To overcome the

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[25] Schneider M., et al., "Computer Aided Cigarette Design," Abstract from the 36th Tobacco Chemists' Research Conference, Raleigh, NC, Paper No. 34, 1982.

DeBardeleben HZ., "Role of Cigarette Physical Characteristics on Smoke Composition," Abstract from the 32nd Tobacco Chemists' Research Conference, Montreal, Quebec, Paper No. 5, 1978.

DeLucia ML., et al., "Principles for the Design of Low Delivery Cigarettes," Abstract from the 34th Tobacco Chemists' Research Conference, Richmond, Virginia, Paper No. 34, 1980.

Ohlemiller, et al., "A Mathematical Model of Cigarette Smoking and Predictions of Cigarette Performance," Abstract from 27th Tobacco Chemists' Research Conference, Winston-Salem, NC, Paper No. 34, 1973.

Curran JG, et al., "Perforated Tipping and Porous Plugwrap Effects on Performance of Vented-Filter Cigarettes: Mathematical Models," Abstract from 34th Tobacco Chemists' Research Conference, Richmond, VA, Paper No. 34, 1980.

harshness due to the increased burley in the blend, the industry used flavor "smoothers."[26]

While some of the research into the construction and design of the low tar cigarette is now becoming publicly available, much of the novel and groundbreaking scientific research of the tobacco industry has not come to the public's attention. The sequestering of much good science within the industry can be traced to fears within the industry that this research might be used in litigation against the industry. Recent documents and stories have come to light that illustrate the quandry faced by tobacco industry management. The argument is that any company should not create or be exposed to information that may come back to haunt them in civil litigation. The closing down of Dr. Victor DeNoble's nicotine studies at Philip Morris and the screening of British American Tobacco (BATCO) scientific reports by Brown & Williamson attorneys as described by Dr. Jeffery Wigand are two well known examples.[27] The point, however, is that much of this research is beneficial to the smoker if we concede the premise that smoking is lawful and enjoyable to many people.

In other countries smoking research is treated in a much more open manner and this has led to a great deal of smoking research being performed outside the U. S. Some countries

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[26] Leffingwell JC., "Nitrogen Components of Leaf and Their Relationship to Smoking Quality and Aroma," The 30th Tobacco Chemists' Research Conference, Nashville, TN, Paper No. 1, 1976.

[27] Freedman AM., "Cigarette Defector Says CEO Lied to Congress About View of Nicotine," The Wall Street Journal, January 26, 1996.

require testing of flavor additives, including tests on animals. In Japan, where the government controls the tobacco monopoly, the research on lowering carcinogenicity is discussed openly.

Tobacco industry scientists conducted research utilizing electroencephalograms (EEG's) in the 1970's.[28] The initial theory behind EEG research was to expand upon published research that nicotine had a beneficial effect on brain wave patterns. The work was demonstrating that positive brain wave patterns could be achieved with persons who smoked a cigarette and were then required to undertake difficult tasks. The workers tested three cigarettes with the same tar level but varying levels of nicotine. Subjects who smoked the cigarettes were monitored by EEG. This research is valuable because as the EEG testing became more sophisticated, the EEG might be used to determine whether cigarettes had adequate levels of nicotine, and whether a particular ingredient was a nicotine enhancer or nicotine substitute.

Research of this type can be carried out in foreign countries, or in an environment where fear of lawsuits do not override the need to improve products. In an "open" environment, with cooperation on the nature of cigarette products between the industry and government regulators, research of this type could be used to "optimize" the cigarette for those who continue to desire to smoke. Rather than restrict the options of what companies could do,

[28] Memo from WL Dunn to TS Osdene, "Plans and Objectives – 1979," Philip Morris, December 6, 1978, in 141 Cong. Rec. 7668 et seq.

agreement between regulators and industry would open up entirely new options for cigarette construction and progress in the industry.

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MAR 8 1996

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