APPENDIX A

**ADVANCED MR MOISTURE SENSOR
MARKET FEASIBILITY ANALYSIS (Condensed)**

MASTER

LM

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

**Portions of this document may be illegible
electronic image products. Images are
produced from the best available original
document.**

**EXECUTIVE SUMMARY OF
ADVANCED MR MOISTURE SENSOR
MARKET FEASIBILITY ANALYSIS**

Report Originally Prepared By:

**PAI PARTNERS
135 Fort Lee Road
Leonora, NJ 07605-2217**

**Originally prepared on
FEBRUARY 1995**

**Condensed by
Southwest Research Institute
June 1997**

EXECUTIVE SUMMARY OF ADVANCED MR MOISTURE SENSOR MARKET FEASIBILITY ANALYSIS

This investigation was defined at a meeting held at the Quantum Magnetics, Inc. (QM) San Diego office in September 1994. In addition to QM personnel, representatives of the Department of Energy (Golden, CO Field Office), Southwest Research Institute (SwRI), The Townsend Agency and PAI Partners attended this meeting.

The actual market investigation was launched at a subsequent meeting at SwRI's facilities in San Antonio (October 1994) attended by representatives of SwRI, The Townsend Agency and PAI Partners. The purpose of this meeting was to understand the background of the Magnetic Resonance Advanced Moisture Sensor (AMS) development effort, to become familiar with the industrial and magnetic resonance research capabilities/resources at SwRI and to develop a summary data sheet describing the AMS product for use with a broad mail survey of potential users. In addition to the mail survey, a broad range of personnel interviews were undertaken in conjunction with attendance at conferences and other meeting and a broad review of the professional and trade press.

Modern industrial process analytical instrumentation was conceived in the research laboratory of I.G. Farbenindustrie at Ludwigshafen by Dr. K.F. Luft (infrared absorption recorder) and Dr. E. Lehrer (magnetic oxygen recorder) in the late 1930's. These instruments were born in the instrumentation workshop at the I.G. Plant in Oppau. More than 50 years later, these fundamental principles: non-dispersive infrared absorption using the Luft acoustic detector and oxygen measurement by paramagnetic susceptibility were still being widely used in industrial applications.

As digital process control systems proliferated in the 1970's, the need for fast multi-component on-stream analyzers became apparent. Dow Chemical pioneered the use of on-stream mass spectrometers in an ethylene oxide process at Freeport, TX in 1975. This technology spread to other applications with relatively simple chemistries that allowed molecular-ion collection to be used (ammonia synthesis and fermentation off-gas analysis). In the last five years, on-stream FTIR has become established as an important process tool within DuPont, Exxon and other leading petro-chemical producers. Dow Chemical and Perkin-Elmer formed an alliance to bring together Dow's process application technology and PKN's instrument development and manufacturing expertise in 1992. This alliance is focusing on NIR, Raman and other optical spectroscopies as process measurement tools. The range of analytical techniques used in on-stream applications continues to expand. Ion chromatography has proven effective in high-purity water monitoring in electronics manufacturing and nuclear power generation. Supercritical fluid chromatography has been used with high-boiling streams in petroleum refining applications. Microwave spectroscopy is being used to control power plant stack-gas stripping processes (ppb-level monitoring of ammonia used in NO_x extraction). In 1994, Eli Lilly partnered with PerSeptive Biosystems (Cambridge, MA) to commercialize Lilly's extensive experience with on-stream HPLC in synthetic insulin production.

After over 50 years, this technical specialty shows no sign of slowing down and, in fact, appears to be accelerating. A substantial industrial and academic infra-structure is in-place to support the development of new analytical technologies for on-stream usage.

Capital spending by the chemical process industries (CPI- the prime process analyzer market) moved upward in 1994, and a further rise is projected for 1995, after three years (1991-93) of relative stagnation following the steep decline in 1990-91. This outlook promises to benefit the process controls business generally. Process analytical instrumentation (PAI) is generally an important beneficiary from rising CPI investments.

The US domestic market for PAI products (analyzers) was an estimated \$375 Million in 1993 and is believed to have exceeded \$400 Million in 1994. Our forecast for 1998 is \$525 Million. Worldwide, the PAI market should grow from just over \$1 Billion in 1993 to \$1.6 Billion in 1998.

The US process moisture market in 1994 was an estimated \$30-40 Million. Gas phase moisture is believed to account for 60-70% of this total with moisture in liquid streams representing another 10%. Moisture in solids (bulk moisture, surface moisture etc.) may be 20-25% of the total moisture market. In 1994, it was under \$10 Million in the US and perhaps \$25 Million worldwide.

Worldwide the laboratory NMR market may have reached \$250-300 Million in 1994. Leading producers include Bruker Instruments (Germany), Varian Associates (US), JEOL (Japan), Oxford Instruments (UK) and others. The analytical NMR market is now dwarfed by the magnetic resonance imaging (MRI) market which was recently estimated at \$1.6 Billion worldwide in 1993.

The two products that are considered "true" process NMR instruments are based on quite different designs embodying distinct strategies. The Auburn design is similar to that employed in SWRI's development work.

- Auburn International, Inc. (Danvers, MA) Magneflow-Industrial Magnetic Resonance Analyzer
- Elbit/ATI Instruments (Billerica, MA) Series 2000 Pulse FT-NMR

Auburn International originally announced their process NMR instrument in 1986. It is believed to embody in part R&D acquired from Kaiser Permanente. Auburn's original target market was moisture/fat/oil assays in the food processing industry. Market response was evidently unsatisfactory, so by the early 1990's, their strategy had shifted to polymer assays (density/melt index/molecular weight distribution) in the petrochemical industry. As of late 1993, Auburn had sold 15 units to these applications. User companies included: Union Carbide (2 units: So. Charleston, WV & Taft, LA), DuPont, BP, Phillips and Himont.

Elbit/ATI Instruments (Billerica, MA) are readying their first process NMR products which are bound for Texaco and Amoco. The Texaco system is scheduled to be installed this fall in Texaco's Los Angeles refinery on a HyTEX hydrogen generation process. The sample is a gaseous mixture of hydrogen and various hydrocarbons. Hydrocarbon component identification will not be attempted but H_2 to total H-C ratios are sufficient to control the process. The critical parameters are H_2 content and BTU-content of the stream. Elbit claims to be able to handle liquid or solid (polymer pellets) samples with its magnet design.

At the annual Texas A&M Process Instrumentation Symposium (January 1995 was the 50th meeting), a user panel on process analyzers (Chevron, Dow, Monsanto and Star Enterprises) estimated that maintenance and utilities represent about 65% of the life-service cost of a complex process analyzer. With life-cycle costs running \$300-600,000 for many analysis systems, the price of the analyzer itself, minus customized sample-systems, is usually no more than 10-20% of the user's life-cycle costs. If the analyzer manufacturer can demonstrate lower life-cycle costs, a higher first-cost could be justified.

PAI Partners interviewed a wide variety of analyzer specialists and operating personnel (40-50 individuals) primarily in the petroleum, chemicals, pharmaceuticals and food industries. Chemicals represented about 40% with the other 3 industries totaling about 50% and other affiliations making up the balance (10%).

We believe that three (3) application areas are the most promising in terms of the unique capabilities of MR to provide a reliable measurement and the number of potential uses given a successful demonstration of the method's feasibility:

- (1) Polymer production, typically polyolefins (polyethylene, polypropylene) are the most common processes
- (2) Pharmaceuticals preparation/compounding including production of dosage-form product
- (3) Prepared food processing & packaging typically involving moisture/fat/oil assays

The process MR sensor concept has generated widespread interest among potential industrial users based on its ability to perform complex assays of difficult-to-measure parameters in real-time. Important characteristics which could differentiate MR from competing, established process analyzer techniques include:

- In Situ non-contact analysis - avoiding expensive, maintenance-plagued sampling systems and sensor-fouling. No potential for product contamination by sensor.
- No reagents or complex calibration systems need to be maintained. Used reagent disposal is a major environmental concern (NPDES Permit).
- Fast multi-parameter analyses - information availability for control usage.
- Sensor can be tailored to the application requirements by unique software (data reduction) obviating the requirement for specialized technical labor.

These are all important differentiators with major economic consequences for the user's life service costs.

Based on comparative rates of development with process mass spectrometry and process FTIR, the process MR market could reach \$5 - 10 Million annually by the end of this decade.