ThermoPower
CORPORATION

Tecogen Division
A Thermo Electron Company

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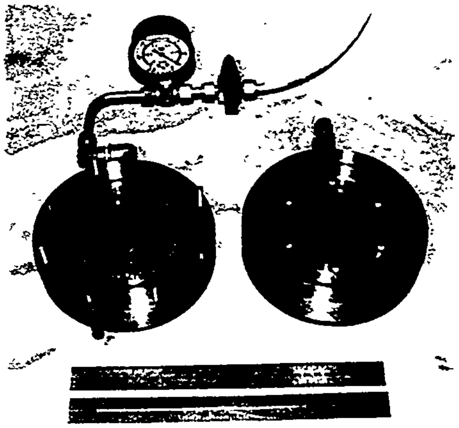
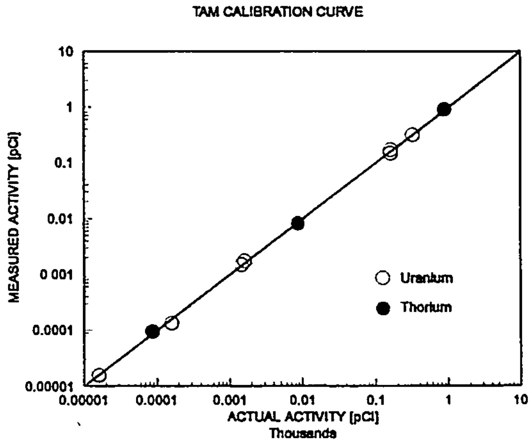
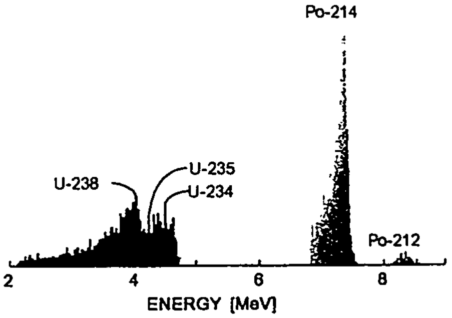
TOPICAL REPORT

DEVELOPMENT OF AN ON-LINE, REAL-TIME ALPHA RADIATION MEASURING INSTRUMENT FOR LIQUID STREAMS







MASSACHUSETTS GROUNDWATER, 2 PPB URANIUM

In Fulfillment Of:

DE-AR21-95MC32088- - 5

Prepared For:

United States Department of Energy
Morgantown Energy Technology Center
Morgantown, WV 26507-0880

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IN FULFILLMENT OF
DE-AR21-95MC32088

TOPICAL REPORT
NOVEMBER 22, 1996

PREPARED FOR

U.S. DEPARTMENT OF ENERGY
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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

1. INTRODUCTION

The Department of Energy (DOE) has expressed a need for an on-line, real-time instrument for assaying alpha-emitting radionuclides (uranium and the transuranics) in effluent waters leaving DOE sites to ensure compliance with regulatory limits. Due to the short range of alpha particles in water (~40 Tm), it is necessary now to intermittently collect samples of water and send them to a central laboratory for analysis. A lengthy and costly procedure is used to separate and measure the radionuclides from each sample. Large variations in radionuclide concentrations in the water may go undetected due to the sporadic sampling. Even when detected, the reading may not be representative of the actual stream concentration. To address these issues, Tecogen, a division of Thermo Power Corporation, a Thermo Electron company, is developing a real-time, field-deployable, alpha monitor based on a solid-state silicon wafer semiconductor (patent pending, to be assigned to the Department of Energy). The Thermo Alpha Monitor (TAM) (Figure 1) will serve to monitor effluent water streams (Subsurface Contaminants Focus Area) and will be suitable for process control of remediation as well as decontamination and decommissioning operations, such as monitoring scrubber or rinse water radioactivity levels (Mixed Waste Focus Area and D&D Focus Area). It would be applicable for assaying other liquids, such as oil, or solids after proper preconditioning. Rapid isotopic alpha air monitoring is also possible using this technology.

This instrument for direct counting of alpha-emitters in aqueous streams is presently being developed by Thermo Power under a development program funded by the DOE Environmental Management program (DOE-EM), administered by the Morgantown Energy Technology Center (METC). Under this contract, Thermo Power has demonstrated a solid-state, silicon-based semiconductor instrument, which uses a proprietary film-based collection system to quantitatively extract the radionuclides of interest from the water sample. The new instrument permits extremely sensitive counting of alpha-emitters in water, and it also provides high-resolution alpha spectrometry so that individual radionuclides can be identified and assayed simultaneously, based on their different alpha energies. The specialized film captures a broad (or narrow by choice of film) range of alpha-emitting radionuclide ions dissolved in the liquid. The radionuclides are captured on or near the film's surface, forming a very thin source for high resolution spectrometry.

Based on results to date, readily observable peaks are evident at very low levels, to 10 parts per trillion (15 femto Curies per liter) natural uranium. With an analysis time of under 30 minutes, depending on the concentration and statistical accuracy, this new technology represents a significant (by more than a factor of 1,000) advance toward rapid identification and quantitative assay of alpha-emitters in aqueous streams, both on-line and in real time. When commercialized, the new system will be more cost-effective than present methods of analysis with a simple payback period of less than five months, and often as short as several weeks.

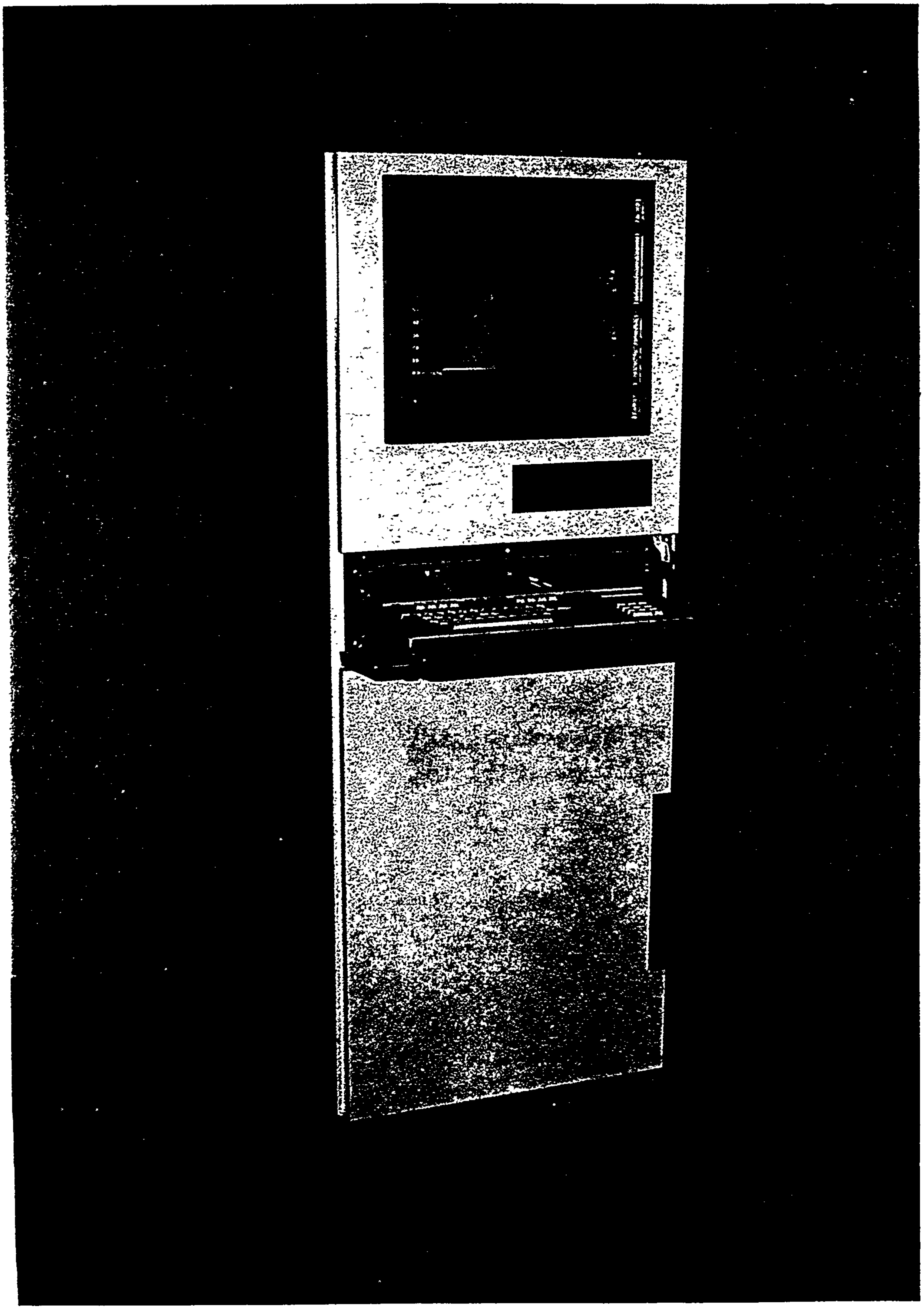

Figure 1 . Thermo Alpha Monitor (TAM)

This report details the current program's Phase I accomplishments. Most significantly, the isotopic detection limit of TAM was extended to 10 parts per trillion natural uranium (15 fCi/l), or 1/2,000th the Environmental Protection Agency's (EPA) drinking water limit of 20 ppb, which is well under the program's goal of 30 pCi/l. In addition, the TAM technology has responded to 20 ppb natural uranium (30 pCi/l) in under 30 minutes, well under the program's goal of a 1- to 12-hour instrument response time. Laboratory testing successfully quantified isotopically 1.5 pCi/l (2 ppb) total uranium in Carlisle, Massachusetts, potable groundwater, comparing quite favorably with 0.68 pCi/l levels of soluble uranium and 1.35 pCi/l total uranium that were measured by conventional analysis methods. Laboratory testing also successfully isotopically analyzed a 600 ppb uranium sample obtained from the DOE's Fernald, Ohio, site.

In addition, TAM has been used to isotopically detect thorium (^{232}Th) at 100 parts per trillion (17 femtocuries per liter), as well as lesser amounts of thorium daughters. Overall, TAM technology has demonstrated a linear dynamic range over greater than six decades of concentration, from 10 parts per trillion (15 fCi/l) to 10 parts per million (15,000 pCi/l) natural uranium, including levels of natural thorium between 100 parts per trillion (17 fCi/l) and 1 part per million (172 pCi/l).

The key recommendation of this Phase I report is to continue development of the on-line, real-time alpha monitor for liquids by authorizing the Optional Phase II of the investigation in order to conduct field tests of the instrument at the Oak Ridge Reservation.

2. TECHNICAL SUMMARY

2.1 THE NEED

The DOE must ensure that on-site process waters and effluent waters leaving contaminated DOE sites do not affect the safety or health of its employees, contractors or the public (see Table 1). Alpha-emitting radioisotopes, such as $^{238}U/^{234}U$ and ^{239}Pu, are rated by the U.S. EPA as Class A carcinogens with very low regulated limits in water. Uranium also has a high chemical toxicity. The EPA-proposed maximum concentration limit (MCL) for uranium in public drinking water supplies is 20 ppb (approximately 30 pCi/l), equivalent to an emission of 67 alphas per minute in one liter of water. For reference, the world's sea water has a uniform uranium concentration of 3.3 ppb.

Currently, process, surface and ground waters at contaminated DOE sites are monitored for alpha-emitters (and other contaminants) by intermittent sampling. These samples are chemically preserved (by the addition of acid), entered into a chain-of-custody infrastructure, packaged for shipping and then sent to a central laboratory for analysis. The analytical procedure involves separation and concentration of the alpha-emitting radionuclides from the water sample, either by precipitation or evaporation. The alpha-emitting radionuclides are plated on a planchet and counted in vacuum using a silicon wafer semiconductor detector. The results are subjected to QA/QC protocols, converted to the radionuclide concentration, pCi/l, and reported to the requestor.

Shortcomings of this current approach are summarized below:

(A) Current Approach Gathers Intermittent Information Only

Only intermittent data are available on the alpha-emitting radionuclide concentrations in the water stream. Further, only a limited number of samples are taken because of the high cost of analysis and cost-reduction desires of the DOE. High excursion of alpha-emitting radionuclides could occur between samples without anyone being aware of it.

Results of analyses at the Fernald site[1], indicate such wide variations. In 1992, 46 samples were taken from Paddys Run, sample location W-10DD, and analyzed for total uranium (and other contaminants). The minimum uranium concentration measured was 0.41 pCi/l, the maximum was 1800 pCi/l, and the average was 480 pCi/l. What was occurring in between these 46 samples (an average of one every 7.9 days) will remain unknown.

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[1] 1992 Fernald Site Environmental Report, FEMP-2290 Special UC-707, June 1993, U.S. DOE (Table 12, Page A-20).

TABLE 1

PERTINENT FEDERAL GOVERNMENT REGULATIONS

Title 10 CFR Part 20	Standards for Protection Against Radiation	NRC
Title 40 CFR Part 141, 142	National Primary Drinking Water Regulations; Radionuclides; Proposed Rule	EPA
Title 40 CFR Part 260 – 272	Resource Conservation and Recovery Act Hazardous Waste Regulations (RCRA mixed-waste regulations)	EPA
Draft Order 490	General Environmental Protection Program	DOE
Order 5400.1	General Environmental Protection Program	DOE
Order 5400.4	Comprehensive Environmental Response, Compensation and Liability Act Program (CERCLA requirements for hazardous waste clean-up and notification)	DOE
Order 5400.5	Radiation Protection of the Public and the Environment	DOE
Order 5440.1C	Implementation of the National Environmental Policy Act of 1969	DOE
Order 5480.11	Radiation Protection for Occupational Workers	DOE
Order 5480.26	Trending and Analysis of Operations/Information	DOE
Order 5480.4	Environmental Protection, Safety and Health Protection Standards	DOE
Order 5484.1	Environmental Protection, Safety and Health Protection Information Reporting Requirements	DOE
Draft Order 5820.2A	Radioactive Waste Management	DOE

When D&D or site remediation efforts are underway and the site is disturbed (by excavation, washing, etc.), continuous, rather than intermittent, monitoring is essential to ensure no public hazard. In addition, the off-gas scrubbers needed on Mixed Waste Plasma Arc Furnace and other thermal treatment systems have a DOE-identified need for controlling alpha activity levels; no commercial instrumentation exists to fill that need.

(B) High Cost of the Current Approach

The end-to-end analysis cost for isotopic uranium in drinking water is approximately $300 per sample; for total uranium, the cost is approximately $135 per sample. The majority of this cost involves taking the sample, numbering it, properly preparing it for transport to the laboratory, and logging in and evaluating the results. These sampling/processing costs average approximately 200% of the direct analysis cost for each sample. 7034 surface and ground water samples were taken and analyzed at Fernald in 1992, an average of 19.3 per day. In addition to the high cost, these samples were spread over many sampling locations, restricting the data available at each location. High cost of the current approach is a strong impediment to increasing sampling frequency for obtaining more complete data.

There is a growing emphasis on cost reduction within the federal government. One approach to reducing the cost of environmental monitoring would be to decrease the frequency of sampling while continuing to use existing analytical technology. Although this approach would certainly reduce immediate costs of analysis, much information would be lost compared to even the relatively sparse data collected today. There is clearly an opportunity now for the introduction of "better, faster and cheaper" alpha-monitoring technology. TAM would address budgetary constraints in a very different manner by both reducing costs and improving data quality while providing analyses as needed.

(C) Time Delay Between Sampling and Data Availability with the Current Approach

After submission of a sample, several days usually pass before the sample is analyzed and the results transmitted. The laboratory generally operates with a backlog of samples, which are analyzed in sequence on a production basis.

For immediate analysis, the total sample cost is much higher than $300 per sample for uranium isotopic analysis. While an immediate procedure can be used in an emergency, the number of "rush" samples must be limited because of their high cost.

This time delay can have serious consequences. Firstly, changes can be occurring to the water's composition which may not be detected for days. Secondly, in thermal treatment, D&D or site remediation operations, the time delay can result in wasted effort and slow progress since the operating personnel are ignorant of current conditions. The total operations cost remediation can thus be greatly increased due to inefficient operation, in contrast to what is possible with immediate availability of analyses of uranium (or other alpha-emitting radionuclide) concentrations.

(D) The Current Approach Is Prone to Errors

Due to the many steps involved and the production analyses, many opportunities exist for mistakes and other errors to occur in the current process. Improper sampling procedures can be used, the analysis can be faulty and the data reduction or reporting can be inaccurate. Such errors are difficult to detect and quality assurance is always an important part of environmental monitoring. Elimination of the many sequential manual steps involved in the conventional approach, by use of automatic on-line monitoring, will reduce the opportunity for errors.

(E) No Process Control Exists for Waste Processing and Decontamination Operations

In addition to improved environmental monitoring for alpha-emitting radionuclides, improved process control is required. At the Idaho National Engineering Laboratory, for instance, a Plasma Arc thermal treatment system for vitrifying mixed waste is being developed. At Fernald, an Advanced Wastewater Treatment Plant will be used to remove uranium from site waters to below proposed EPA drinking water limits. With the current analytical approach of sampling and central laboratory analyses, the same difficulties result as with environmental monitoring. Modern chemical processing plants utilize on-line, real-time analytical equipment for process control and operation. Availability of such an instrument for uranium and other alpha-emitting radionuclides will be of great benefit for process control and monitoring.

For reference purposes, Figure 2 summarizes the DOE's two trillion liters of liquid radioactivity releases of 1993, averaging 6 pCi/l, that were reported by the various DOE Operations Offices. Approximately 400,000 liquid sample alpha analyses per year are performed for both these effluent waters, as well as for on-site monitoring. The present end-to-end cost per alpha analysis is ~$300, for an annual total in excess of $100,000,000. Approximately 30% of this cost is for the actual analytical work (charged by laboratories), while the remainder is handling or overhead. (Appendix 1 contains a cost savings analysis for TAM).

2.2 PRESENT STATE-OF-THE-ART TECHNOLOGY

2.2.1 Summary

This section attempts to quantify the technology gap that exists between present state-of-the-art technology and the needs of the DOE for monitoring alpha-emitting radionuclides in

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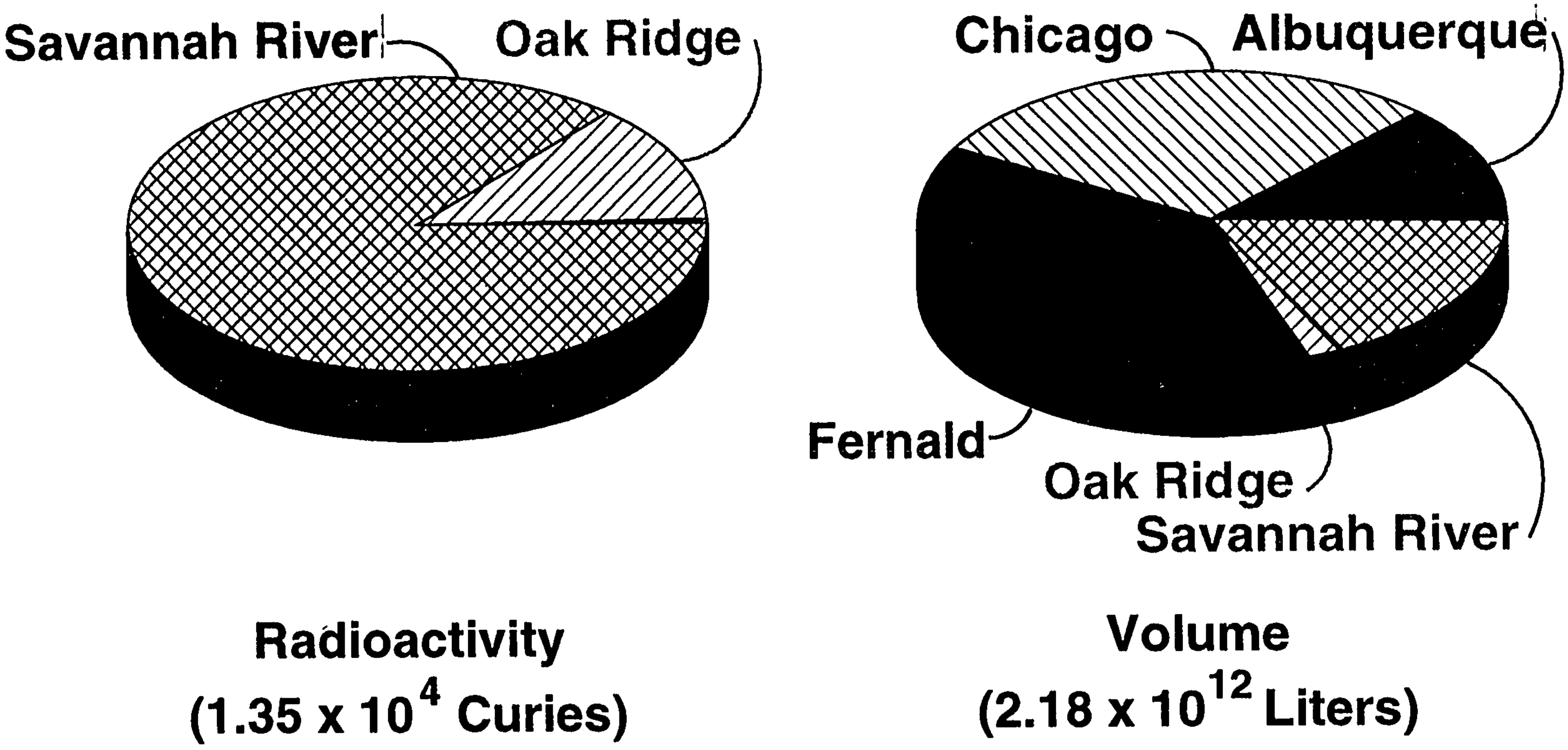

Radioactivity
(1.35×10^4 Curies)

Volume
(2.18×10^{12} Liters)

Figure 2. DOE Complex-Wide Liquid Radioactivity Releases (1993)

liquid samples. Both on-line and off-line instruments and methods are surveyed. While the major emphasis of this survey is the evaluation of instruments which are commercially available, devices and technologies under development are also surveyed. Conclusions drawn from examining these systems indicate that a factor of approximately 1,000 improvement in detection limits for on-line instrumentation is required in order to meet DOE needs.

Commercial devices and methods examined by this survey include:

1) EG&G Ortec's LB/BAI9126 Alpha/Beta/Gamma Monitoring System,
2) Eberline Instruments OLAM,
3) Canberra Industries Inc.'s In Line Real-time Water Monitoring Systems,
4) Conventional radiochemical laboratory analysis methods,
5) ORDELA, Inc.'s PERALS spectrometer,
6) Quantrad Systems' Liquid Analyzer System,
7) EG&G Ortech's LB 506 AT (Specially Modified),
8) Canberra Inc.'s Flow Cell Scintillator Analysis System, and
9) Two analytical (non alpha-detecting) analytical systems that will undergo a user-based performance evaluation at the DOE Fernald (Ohio) site.

Alpha monitoring instrumentation that is not yet commercially available includes:

1) Los Alamos' LRAD for Radioactive Liquid Waste,
2) Westinghouse Savannah River's patented fiber optic Sol-Gel Indicator (SGI) technology,
3) SCUREF'S Flow-Cell Scintillation Counting,
4) Lawrence Livermore's Fiber Optic Analytical Methods,
5) Los Alamos' Fiber Optic Analytical Methods, and
6) The University of South Carolina's research titled, "Development of a Fiber-Optic Uranium Sensor Employing Fluorescence Quenching and a Second-Order Photo-oxidation Effect."

Of the six known alternative on-line devices (both commercially available and under development), none have the capability of monitoring alpha radioactivity at drinking water levels. Of the commercial "off-line" devices and methods, six of the seven are capable of analyzing drinking water levels while the seventh is not sensitive enough. Finally, none of the three noncommercial off-line devices are sensitive enough to monitor drinking water levels of uranium. By contrast, TAM, as shown by Thermo Power Corporation, has the unique capability of performing isotopic on-line analyses of alpha-emitting radionuclides at well below drinking water levels. TAM goes beyond the DOE's required factor of 1,000 enhancement to a factor of 2,000,000, or a detection limit of 10 parts per trillion (15 fCi/l) natural uranium.

2.2.2 Commercial Devices

Commercial alpha-monitoring instrumentation has been divided into two categories: on-line devices and off-line devices.

Commercial On-line Devices

This section examines commercial on-line alpha monitoring instruments. Included are:

1) EG&G Ortec's LB/BAI9126 Alpha/Beta/Gamma Monitoring System,
2) Eberline Instruments OLAM and
3) Canberra Industries Inc.'s In Line Real-time Water Monitoring Systems.

1.) EG&G Ortec – LB/BAI9126

EG&G Ortec's LB/BAI9126 Alpha/Beta/Gamma Monitoring System is designed for effluent and drinking water applications. In the Ortec 9126, a large-area proportional counter is used to measure radioactivity leaving the surface (top 40 micrometers) of a water sample. The proportional counter used in the 9126 can discriminate between alpha and beta radioactivity. Four inches of lead shielding are used; total system weight is 3300 pounds (1500 kg). One of these units is installed at the Oak Ridge National Laboratory's Process Waste Treatment Plant, but is not used for detecting alpha-emitters (it responds only by giving false alarms during high radon level conditions on rainy days). The approximate price of the 9126 is $75,000.

EG&G Ortec's LB/BAI9126 technology will not permit detection of alpha radioactivity at drinking water levels.

2.) Eberline Instruments – OLAM

Eberline Instruments acquired the rights to OLAM from the Oak Ridge National Laboratory. OLAM pumps a thin layer of sample between two solid scintillating materials and measures the alpha radioactivity emanating from the top 40 micrometers of the sample. OLAM is no longer actively marketed by Eberline Instruments. While it was being sold, the detector cost approximately $30,000 and the required electronics cost $5,000, bringing the total system cost to $35,000.

The technology involved will not detect alpha radioactivity at drinking water levels.

3.) Canberra Industries – In Line Real-time Water Monitoring Systems

Canberra Industries Inc. has installed several custom-designed In Line Real-time Water Monitoring Systems for environmental monitoring of ^{235}U, fission products and activation products in water. Canberra's stated sensitivity of 1 ppm ^{235}U translates to a radioactivity level of 2162 pCi/l, equivalent to a naturally-occurring uranium concentration of 3.2 ppm. This system detects gamma emissions above 100 – 300 keV and is not applicable to samples containing low-gamma yielding alpha-emitters. For reference purposes, a count time of 60 minutes is used to sample the water. Costs for these systems are on the order of $80,000.

The technology involved will not detect alpha radioactivity at drinking water levels.

Commercial Off-line Devices/Methods

This section examines commercial off-line, alpha-monitoring instruments. Included are:

1) Conventional radiochemical laboratory analysis methods,
2) ORDELA, Inc.'s PERALS spectrometer,
3) Quantrad Systems' Liquid Analyzer System,
4) EG&G Ortech's LB 506 AT (Specially Modified),
5) Canberra Inc.'s Flow Cell Scintillation Analysis System, and
6) Two analytical (nonalpha-detecting) analytical systems that will undergo a user-based performance evaluation at the DOE Fernald (Ohio) site.

1.) Conventional Radiochemical Laboratory Analysis Methods

The most rapid forms of conventional radiochemical laboratory analysis involve moderate sample preparation followed by counting for » 30 minutes on a silicon-based semiconductor detector. Sample preparation takes perhaps 4 to 48 hours and usually involves either a macroprecipitation of the dissolved material using neodymium fluoride or a boiling off of the sample's water. Drinking water levels of radioactivity can be accurately measured using a one- gallon sample size. Drawbacks of the conventional method include the extensive manual processing involved and the need for qualified technical personnel to perform and oversee the analysis, leading to a high per-sample cost. The nuclear instrumentation portion of the capital cost ranges from $6,000 for a one-channel alpha spectroscopy system to $30,000 for a system capable of eight simultaneous alpha counts.

As such, conventional radiochemical laboratory analysis methods are capable of isotopic detection of alpha-emitters at drinking water levels, requiring multiple sequential handling operations and a resultant high cost. These methods are not suited for continuous or semi-continuous analysis.

2.) ORDELA – PERALS

ORDELA, Inc. manufactures the PERALS (Photon/Electron-Rejecting Alpha Liquid Scintillation) spectrometer. Analysis with the PERALS method begins with solvent extraction of the sample, using extractive liquid scintillator cocktails, followed by bubbling with argon to remove oxygen, a chemical quench agent. Finally, the prepared sample is counted on the PERALS. Sample preparation times are quoted as 30 minutes for simple (water-based sample) extraction, and four hours for soil samples. Method sensitivity (MDA) for uranium in water is quoted as approximately 1 pCi/l in four hours (equivalent to 1 ppb natural uranium). A complete PERALS system costs $21,250.

The PERALS spectrometer is capable of off-line isotopic measurements of low-level alpha-emitters at drinking water levels; the main drawback of the PERALS method is the need for disposal of secondary mixed waste (spent liquid scintillator cocktail).

3.) Quantrad – Liquid Analyzer System

Quantrad Systems manufactures a Liquid Analyzer System that performs an in situ deposition of dissolved radionuclides directly onto a silicon-based semiconductor detector. Consequently, the deposited radionuclides are analyzed as they build up on the detector's surface. After sufficient counting time has passed, the detector is cleaned with concentrated acid and a new analysis is begun. Known deficiencies of this method include: inevitable catastrophic failure of the detector due to sample or acid leaks (analyzer lifetime averaging only a few hundred hours), slow response time (days of counting for samples 1,000X stronger than drinking water limits), severe degradation in detector performance prior to catastrophic failure, production of secondary mixed waste (spent concentrated acid), and poor repeatability and stability of instrument calibration. The cost of a Quantrad system is $12,995.

The technology involved will not permit detection of alpha radioactivity at drinking water levels unless extremely long count times (in excess of weeks) are used.

4.) EG&G Ortech – LB 506 AT (Specially Modified)

EG&G Ortech is selling a flow cell scintillator analysis system that uses a liquid scintillator to analyze samples of water. It involves a technology similar to the PERALS; EG&G claims a sensitivity of at least 100 pCi/l. EG&G sells what amounts to a modified life sciences laboratory instrument that is a custom-engineered product. The 506 costs approximately $25,000; the total price to approximately $50,000.

EG&G claims the 506 to be capable of off-line isotopic measurements of low-level alpha activity at near-drinking water levels; the main drawback of this method is the need for disposal of secondary mixed waste (spent liquid scintillator cocktail).

5.) Canberra/Packard – Flow Cell Scintillation System

Canberra/Packard Inc. is selling a flow cell scintillation analysis system that uses a liquid scintillator to analyze samples of water. It involves a technology similar to the PERALS; Canberra claims a sensitivity of 30 pCi/l (uranium drinking water limit). Canberra claims that only one part of liquid scintillator is needed for each part of sample (1:2), which is much less than the 2:1 or 3:1 ratios needed by competitors' systems. The Flow Cell Scintillation System costs $20,000 to $35,000.

Canberra claims the Flow Scintillation System to be capable of off-line isotopic measurements of low-level alpha activity at drinking water levels; the main drawback of this method is the need for disposal of secondary mixed waste (spent liquid scintillator cocktail).

6.) Fernald Field Test of Two Analytical Systems

Although not capable of detecting levels of regulatory interest of short-lived radionuclides (short-lived relative to ^{238}U) such as plutonium, analytical systems are commercially available that claim three-minute response time at 5 ppb natural uranium levels. They would not be useful for sites with plutonium contamination, as the NRC water limit for ^{239}U is 3.2×10^{-4} ppb, significantly under these analytical method limits of 5 ppb. These systems include at least one based on absorptive stripping voltammetry. As site characterization has apparently revealed nonenriched (natural) uranium to be the primary contaminant of interest, it may be appropriate for Fernald to utilize such nonradiochemical instruments for off-line analyses.

Rapid off-line detection of low-level heavy metals at drinking water levels is claimed for these two analytical systems; they would not be capable of detecting short-lived alpha-emitting radionuclides such as plutonium nor would they be capable of discriminating between naturally-occurring uranium samples and those enriched in or depleted of ^{235}U.

2.2.3 Devices Under Development

Alpha-monitoring instrumentation that is not yet commercially available has been divided into two categories: on-line devices and off-line devices.

On-line Devices Under Development

This section examines on-line alpha-monitoring instruments that are not yet commercial. Included are:

1.) Los Alamos' LRAD for Radioactive Liquid Waste,
2.) Westinghouse Savannah River's patented fiber optic Sol-Gel Indicator (SGI) technology and
3.) SCUREF's Flow-Cell Scintillation Counting.

1.) Los Alamos – LRAD for Radioactive Liquid Waste

Los Alamos National Laboratory (LANL) has a project titled, "A Real Time Alpha-Monitoring System for Radioactive Liquid Waste." The technology is analogous to what is used in Eberline's commercial LRAD (Long-range Alpha Detector) Object Monitor. The unit detects the airborne ionization produced by the surface layer (40 micrometers) of liquid sample. Claimed liquid sample detection limit for the monitor is 100 pCi/l, but no response time is given. A field test was conducted in 1994 at the LANL Radioactive Liquid Waste Treatment Facility

(RLWTF). With the RLWTF's reported influent activity level of tens of nano-Curies (equivalent to 15 ppm natural Uranium), the unit produced a measurable signal. No contemporaneous sample data was reported for this field test. LANL's recent efforts have resulted in a larger, one square meter unit that may have improved detection limits.

LANL's Real Time Alpha Monitoring System for Radioactive Liquid Waste technology will not permit detection of alpha radioactivity at drinking water levels. For samples that have sufficiently high levels of gross alpha activity, no elemental or isotopic identification of individual species is possible with this technology.

2.) Savannah River – Sol-Gel Indicator Fiber Optic Analytical Method

In 1995, Westinghouse Savannah River patented a Sol-Gel Indicator (SGI) fiber optic technology that has been incorporated into an analytical measuring system. Sol-Gel indicators were reported being incorporated into flow injection analysis cells, eliminating one reagent stream from the system. Arsenazo III was used as the indicator that allowed detection of the uranyl ion. SGI uranyl sensor response time is reported as approximately five minutes; the detection limit is stated as 1 ppm. A treatment for reversal of the uranyl sensor was developed which allows it to be reused; the SGI coating is claimed to be viable for at least six months; no mention was made of performance degradation during that six-month coating lifetime. Savannah River indicates a need for additional refinement of the coating process to improve fabrication reproducibility. One CRADA has been completed, two CRADAs have been signed with industrial partners and the technology has been licensed by four companies. DOE-EM CMST-CP has funded some of this development effort.

This method has demonstrated in the laboratory the capability of detecting elemental uranium at 50X drinking water levels. This method would not be capable of detecting short-lived alpha-emitting radionuclides such as plutonium, nor would it be capable of discriminating between naturally-occurring uranium samples and those enriched in ^{235}U.

3.) SCUREF – Flow-Cell Scintillation Counting

The South Carolina University Research and Education Foundation (SCUREF) has a 1995 DOE-METC ROA contract titled, "Measurement of Radionuclides Using Ion Chromatography and Flow-Cell Scintillation Counting." The project's objective is to reach on-line counting of aqueous and nonaqueous samples at minimum detectable concentrations (MDCs) that are low enough for environmental screening; off-line counting would produce MDCs that approach typical regulatory limits. No data has been reported to date on achieving these MDCs; radiochemistry work has focused on developing hardware and evaluating scintillation detector materials.

While the objective of the technology is to permit off-line detection of alpha radioactivity at drinking water levels, no supporting data has been produced to date.

Off-line Devices Under Development

This section examines off-line alpha-monitoring instruments that are not yet commercial, including:

1.) Lawrence Livermore's Fiber Optic Analytical Methods,
2.) Los Alamos' Fiber Optic Analytical Methods, and
3) The University of South Carolina's research titled, "Development of a Fiber-Optic Uranium Sensor Employing Fluorescence Quenching and a Second-Order Photo-oxidation Effect."

1.) Lawrence Livermore – Fiber Optic Analytical Method

In 1994, Lawrence Livermore National Laboratory was developing an analytical method for analyzing heavy metals using a coated fiber optic probe. Sensitivity to 1 ppm uranium was demonstrated. Due to the limited sensitivity of the method, DOE funding was eliminated.

This method has demonstrated the capability of detecting elemental uranium at 10,000X drinking water levels; no further development is ongoing at Lawrence Livermore. This method would not be capable of detecting short-lived alpha-emitting radionuclides such as plutonium, nor would it be capable of discriminating between naturally-occurring uranium samples and those enriched in ^{235}U.

2.) Los Alamos – Fiber Optic Analytical Method

In 1994, Los Alamos National Laboratory was developing an analytical method for analyzing heavy metals using a coated fiber optic probe. Sensitivity to ppm levels of uranium was demonstrated. Status of this program is unknown.

This method has demonstrated the capability of detecting elemental uranium at 10,000X drinking water levels; its development status is uncertain. This method would not be capable of detecting short-lived alpha-emitting radionuclides such as plutonium, nor would it be capable of discriminating between naturally-occurring uranium samples and those enriched in ^{235}U.

3.) University of South Carolina – Fiber Optic Analytical Method

The University of South Carolina reported at the Environmental Technical Sessions of PITTCON '96 on research titled, "Development of a Fiber-Optic Uranium Sensor Employing Fluorescence Quenching and a Second-Order Photo-oxidation Effect." No further information is available at this time, but it is likely that this method will have a similar detection limit of approximately 1 ppm.

It is not known what the elemental uranium detection capability is for this method. This method would not be capable of detecting short-lived alpha-emitting radionuclides such as plutonium, nor would it be capable of discriminating between naturally-occurring uranium samples and those enriched in ^{235}U.

2.3 THERMO ALPHA MONITOR CONCEPT

The Thermo Alpha Monitor (TAM) is currently being developed by Thermo Power Corporation, Tecogen Division. The technology involves automated, on-line, near real-time, isotopically-resolved alpha monitoring of liquids, employing the collection of radionuclides on a film substrate followed by alpha spectroscopy using a large area solid-state diode detector. The collection film may be archived for record keeping or additional analyses. Air monitoring is also possible using this technology.

TAM has been shown to be isotopically sensitive to extremely low (ten parts per trillion, or 15 femto Curies per liter; 1/2,000th of the EPA's drinking water limit of 20 ppb total uranium) levels of a broad range of radioisotopes. Other performance data obtained during the course of this investigation have shown that on-line real-time operation is possible with a sub 15-minute response time analyzing 20 ppb (30 pCi/l) natural uranium.

TAM will provide dramatic total cost savings compared with present technology. The most dramatic savings will be through the elimination of individual sample handling and processing, the largest contributor to present monitoring costs. Additional savings will be realized through much lower cost per analysis using TAM. In a first release product, TAM is expected to reduce the cost per analysis by a factor of two to a factor of three, relative to analytical laboratory charges (see Appendix 1). The estimated annual savings to DOE by adopting TAM are at minimum (averaged over the life of the instruments, including amortization of the projected $25,000 unit capital cost):

- $36 million per year savings, 50% TAM use.
- $72 million per year savings, 100% TAM use.

Table 2 summarizes the salient features of TAM and performs a comparison with the monitors detailed in the previous section. A review of the table reveals that not only is TAM the only on-line monitor capable of analyzing drinking water levels of uranium, but its expected capital cost is less than the $39,400 average cost of all commercial monitors surveyed. In other words, not only is TAM the sole on-line instrument that meets DOE's performance requirements, but it is less expensive than the average cost for other systems.

TAM uses a semiconductor counter, which is a form of solid-state detector. Semiconductor counters are similar in concept to ionization chambers in semiconducting materials and offer advantages in detection of nuclear radiations, particularly alpha particles. A semiconductor detector is a large surface area silicon diode of the p-n or p-i-n type, operated in the reverse bias mode (see Figure 3). The energy lost by ionizing radiation, such as alpha particles, in semiconductor detectors results in the formation of ions (electron-hole pairs).

TABLE 2

CURRENT MONITOR SUMMARY

Device/Method	Commercial?	On-Line?	Drinking Water U?	Capital Cost?	Other
Thermo Alpha Monitor	N	Y	Y	$25,000	1 ppT limit, isotopic U, 10 ppb: 15' cycle time
EG&G Ortec's LB/BAI9126	Y	Y	N	$75,000	3300 # system weight
Eberline Instruments' OLAM	Y	Y	N	$35,000	Obsolete product
Canberra Industries Inc.'s Water Monitoring Systems	Y	Y	N	$80,000	Gammas, not alphas
Conventional radiochemical laboratory analysis	Y	N	Y	$6,000	Not automatic
ORDELA, Inc.'s PERALS Spectrometer	Y	N	Y	$21,250	Produces mixed waste
Quantrad Systems' Liquid Analyzer System	Y	N	N	$12,995	Not automatic
EG&G Ortech's LB 506 AT (Specially Modified)	Y	N	Y	$50,000	Produces mixed waste
Canberra/Packard Inc.'s Flow Scintillator System	Y	N	Y	$35,000	Produces mixed waste
Two analytical (nonalpha-detecting) systems to be evaluated at the DOE Fernald (Ohio) site	Y	N	Y	Unknown	Can't monitor Pu or ^{235}U
Los Alamos' LRAD for Radioactive Liquid Waste	N	Y	N	N/A	Gross alpha only
Westinghouse Savannah River's Fiber Optic Sol-Gel Indicator (SGI) Technology	N	Y	N	N/A	1 ppm detection limit
SCUREF'S Flow-Cell Scintillation Counting	N	Y	N	N/A	No data yet
Lawrence Livermore's Fiber Optic Analytical Methods	N	N	N	N/A	1 ppm detection limit
Los Alamos' Fiber Optic Analytical Methods	N	N	N	N/A	1 ppm detection limit
University of South Carolina's Fiber-Optic Uranium Sensor	N	N	N	N/A	1 ppm detection limit

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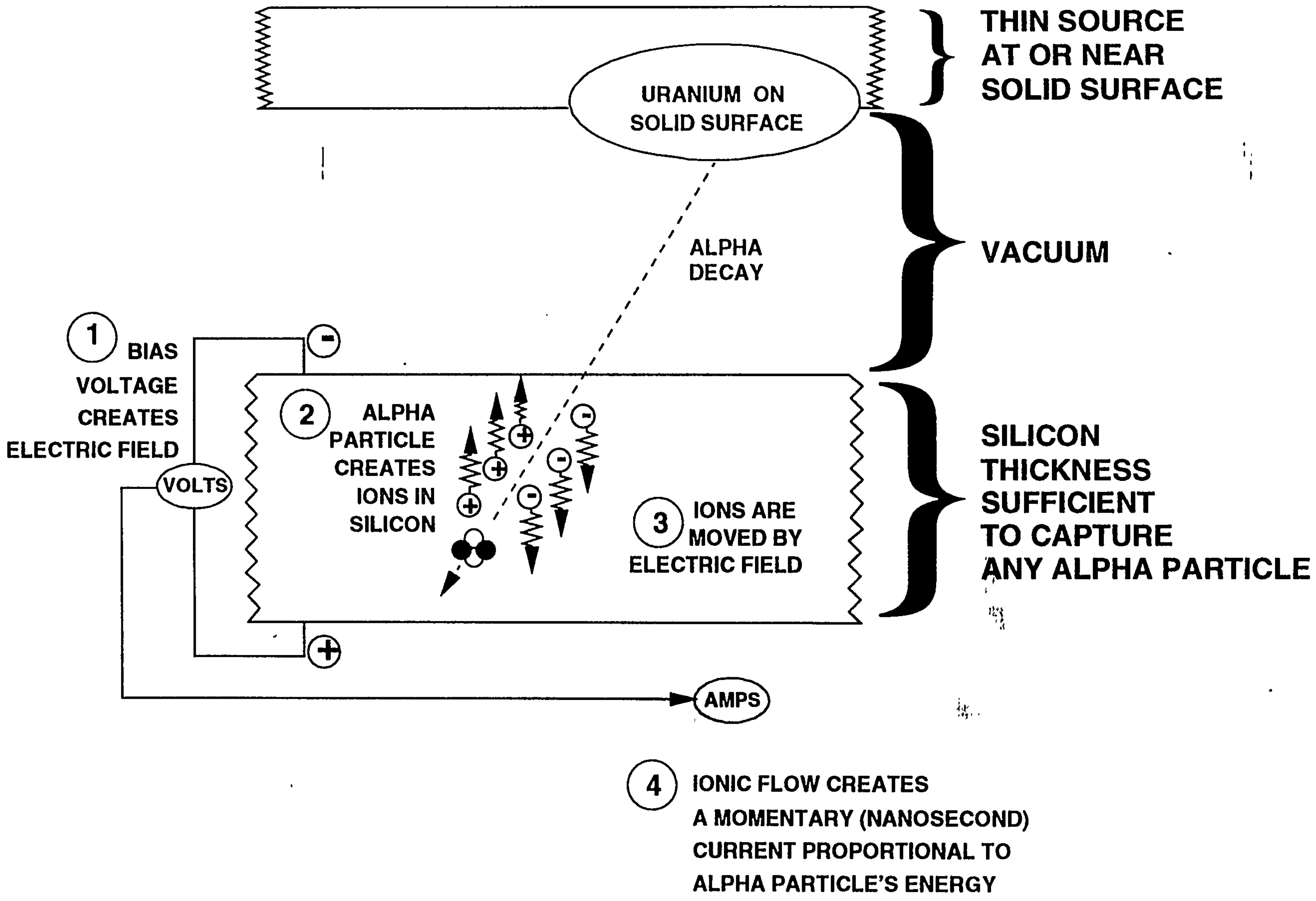

Figure 3. Silicon Diode Measurement Concept

Under the influence of the imposed electric field, these charge carriers drift to the contacts of opposite polarity, producing a short-duration (nanosecond) flow of electrical current.

The average energy loss per ion pair for alpha particles in silicon is about 3 eV, compared with about 30 eV per ion pair for gases. Hence, an alpha particle creates about 10X as many ion pairs in the semiconductor solid as in gas, and the statistics are thus about 3X better than for gas ionization detectors. In addition, the smaller distances involved in collection allow for higher electric fields and faster collection times.

Surface barrier, diffused junction and ion-implanted are the three predominant types of alpha counters, with extremely thin "windows" on the surface (typically equivalent to an 800 Å silicon thickness). The combination of a very thin window and short range in silicon (30 micrometers for 6 MeV alpha) results in 100% absorption of the alpha energy in the depletion region of the detector, with formation and collection of electron-hole pairs linearly proportional to the alpha energy, providing high energy resolution. Characteristics of the silicon detector for alpha particles are:

- High energy resolution, typically 15 keV FWHM for 5 MeV alphas.
- Fast pulse rise time of 5 to 10 nanoseconds.
- No apparent dead time.
- Linearity of charge collected with particle energy.
- detection efficiency for alphas entering surface.
- Excellent stability.
- Very low background.

For high energy resolution, it is necessary for the alpha particle emitted by a radionuclide to reach the detector surface without losing any energy by passing through other materials. This is difficult because of the short range of alphas in solid/liquid materials, typically 40 micrometers for water. In conventional counting, the radionuclide is deposited on a solid surface (planchet) as a very thin layer so that self-absorption in the source itself is negligible. The planchet is then placed in front of the silicon detector and a vacuum pulled to prevent absorption of alpha energy by the air between the source and detector. Where the source/detector spacing is small and the source smaller than the detector, 50% of the emitted alphas enter the silicon detector surface and are counted (detector efficiency). Higher energy resolution is possible using a greater source/detector spacing, although at a lower detector efficiency.[2]

Under the current DOE contract, Thermo Power has demonstrated in the laboratory a new modality which permits extremely sensitive analysis of alpha-emitters in water and provides high resolution alpha spectrometry so that individual radionuclides can be assayed

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[2] Increased source/detector spacing results in a more collimated path for alpha particles reaching the detector, and produces a reduced average transit through the inert window of the detector. This results in a lower average attenuation of the incoming alphas, thereby reducing the average peak width.

simultaneously, based on their different alpha energies. This new instrument provides the basis for an on-line, real-time monitor of alpha-emitting radionuclides in water streams for both effluent streams leaving DOE sites and process streams. It is the objective of the Optional Phase II of the current program to convert the laboratory instrument into an automated, on-line, real-time instrument for alpha-emitters in water streams and to conduct field testing and demonstrations of the prototype for monitoring of uranium and other alpha-emitters. This new on-line, real-time alpha instrument for liquids will satisfy important DOE needs, as described in a preceding section.

To analyze a sample, the proprietary TAM film is installed into the waterproof chamber (see Figure 4). The sample then passes through the film, allowing quantitative uptake of the radioactive species of interest. The alpha-emitters are captured at or near the surface of active film, forming a thin source that provides excellent alpha energy resolution during the counting step.

A small amount of de-ionized (DI) water is used for rinsing the exposed film in the waterproof chamber; subsequently, any residual liquid is withdrawn from the waterproof chamber. The captured radionuclides are adherent and are not removed from the film by a water wash. Next, the film is transferred from the waterproof chamber to a second chamber where it is prepared for the counting step. At a minimum, this preparation consists of rapid drying using one or more of the following: microwave energy, hot air, vacuum and infrared heating.

The dry film is routed to the detector chamber for counting the radioactive decay of the species on the film's surface. The counter incorporates a solid-state, silicon-based, reverse-biased, p-i-n diode. The counter is connected through a pre-amp to an 1024-channel pulse height analyzer. The multi-channel analyzer is mounted in an IBM-compatible personal computer; special software is used for data acquisition, analysis and report generation (see Chapter 2.6.2). In Figures 5 and 6, results of counts for a uranium-containing solution (20 ppb of uranium) and for a residential deep well water sample are presented, indicating the excellent alpha energy resolution and the applicability to a wide range of alpha-emitting radionuclides.

After the analysis is completed and before a new sample is counted, the film is removed from the counting chamber and archived in an appropriate plastic bag. The total sample cycle is completed in under 30 minutes, which is well under the program's stated goal of a 1- to 12-hour sample cycle time.

In Figure 7, a schematic is presented for conversion of the laboratory counter to an automated, on-line, real-time alpha monitor for water streams. Water from the sample stream is pumped continuously through the instrument's sample chamber and discharged back to the stream. To provide rapid response, a large film (53.5 cm^2) and large area detector (50 cm^2) are used. Calibration, cleaning and de-ionized rinse water are also provided and can be pumped in sequence through the instrument for calibration and cleaning between runs. Sample preparation

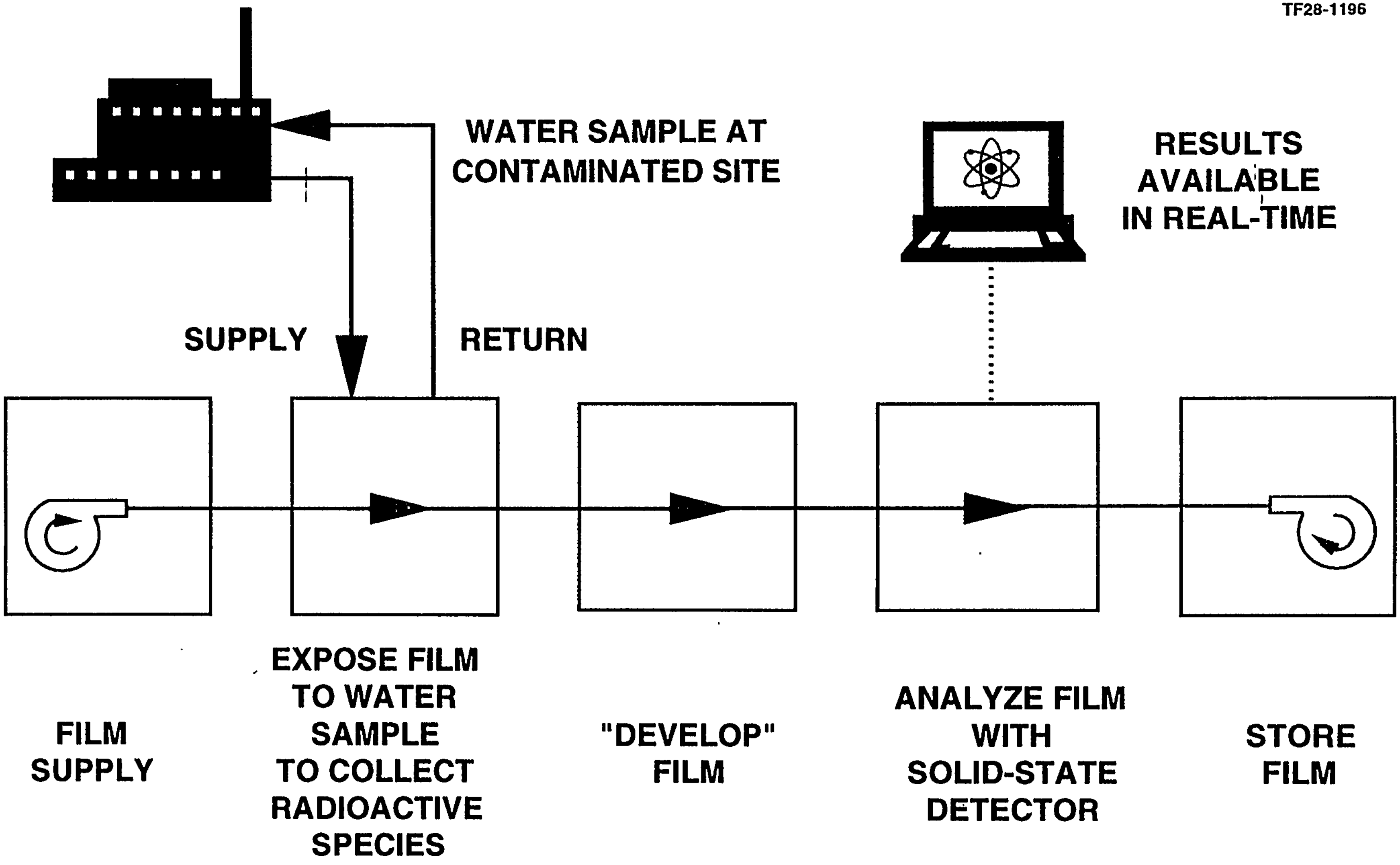

Figure 4. Thermo Alpha Monitor (TAM)

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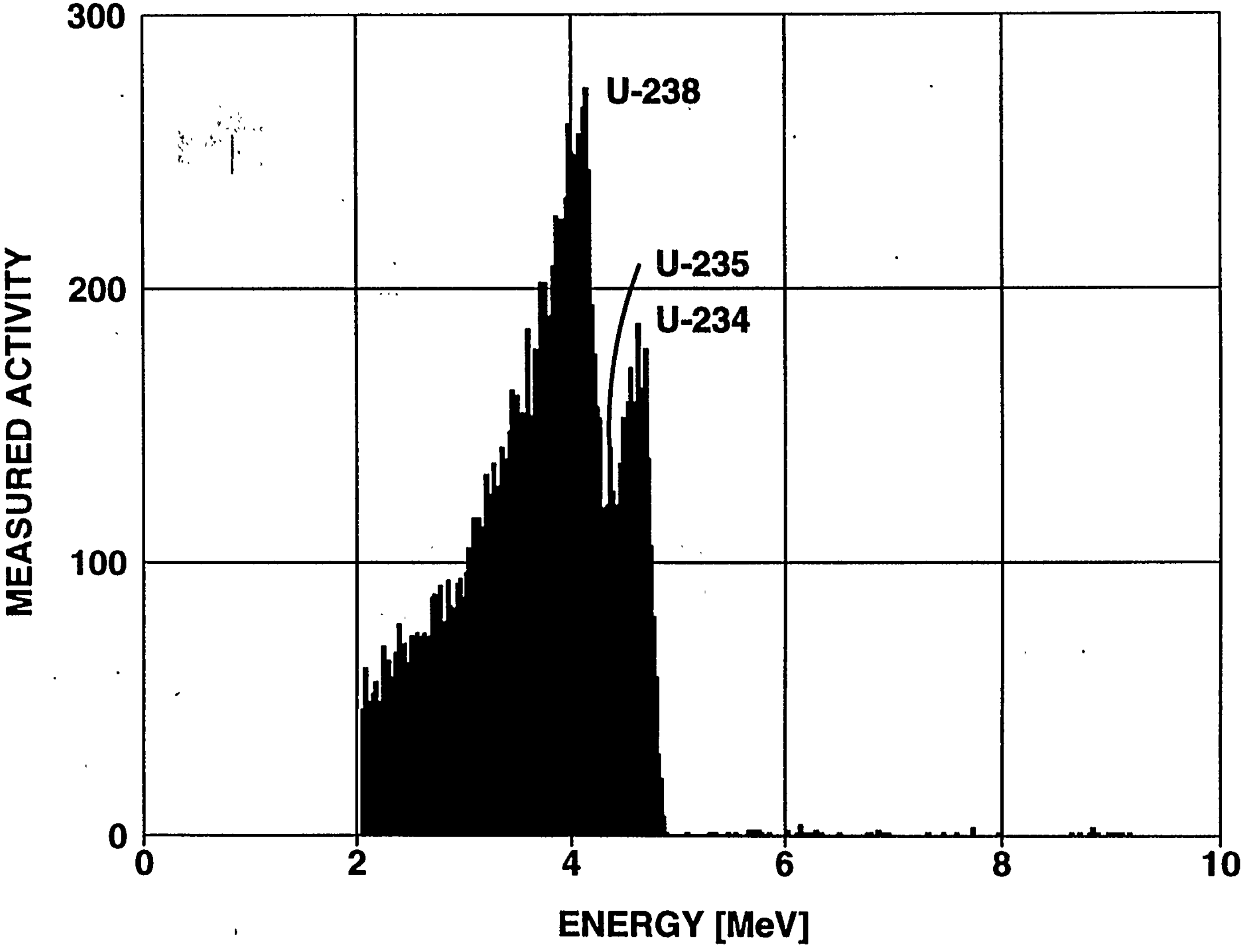

Figure 5. Laboratory Test Results - 20 Parts per Billion Natural Uranium

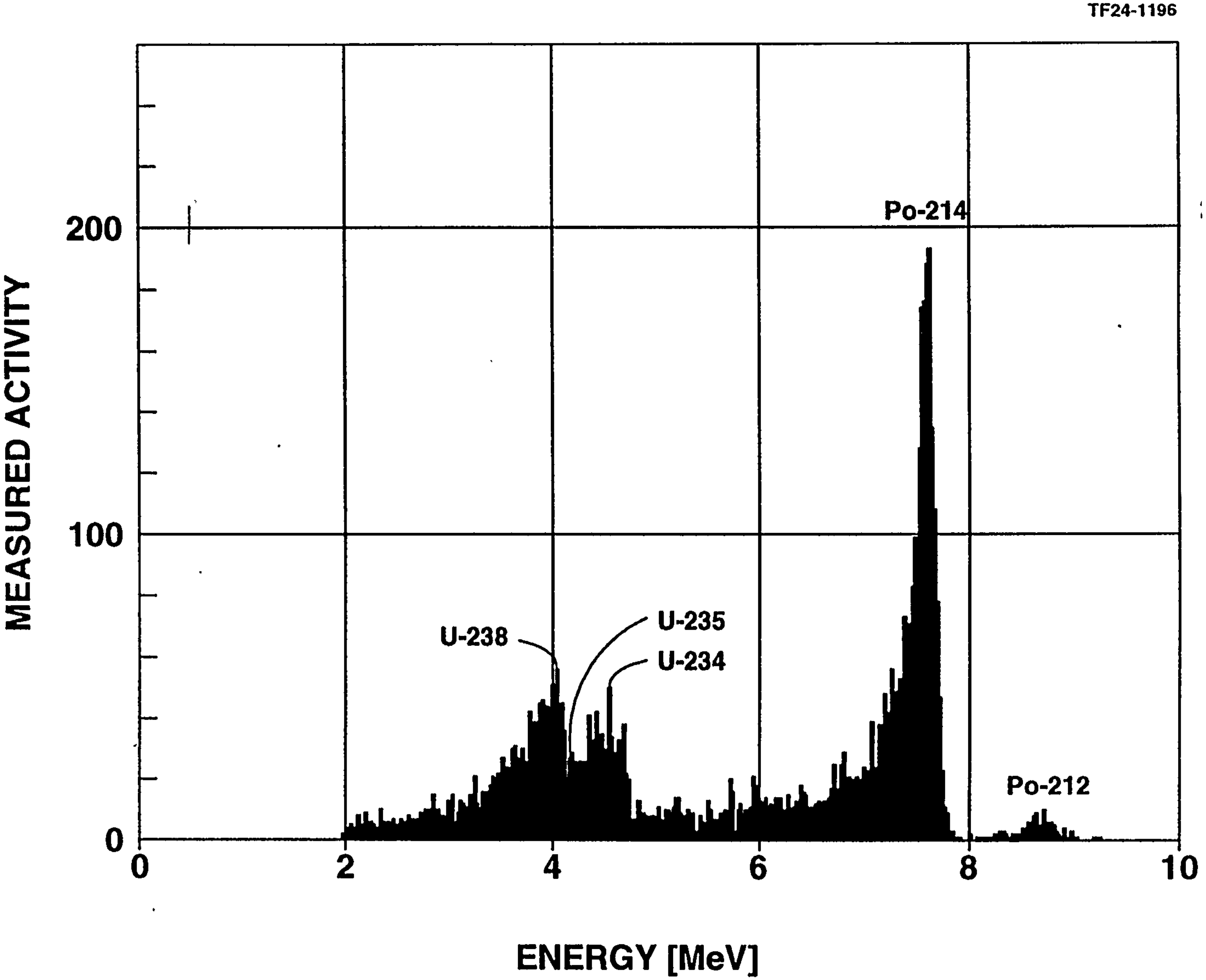

Figure 6. TAM Laboratory Test Results
Massachusetts Groundwater, 2 ppb (1.5 pCi/l) Total Uranium

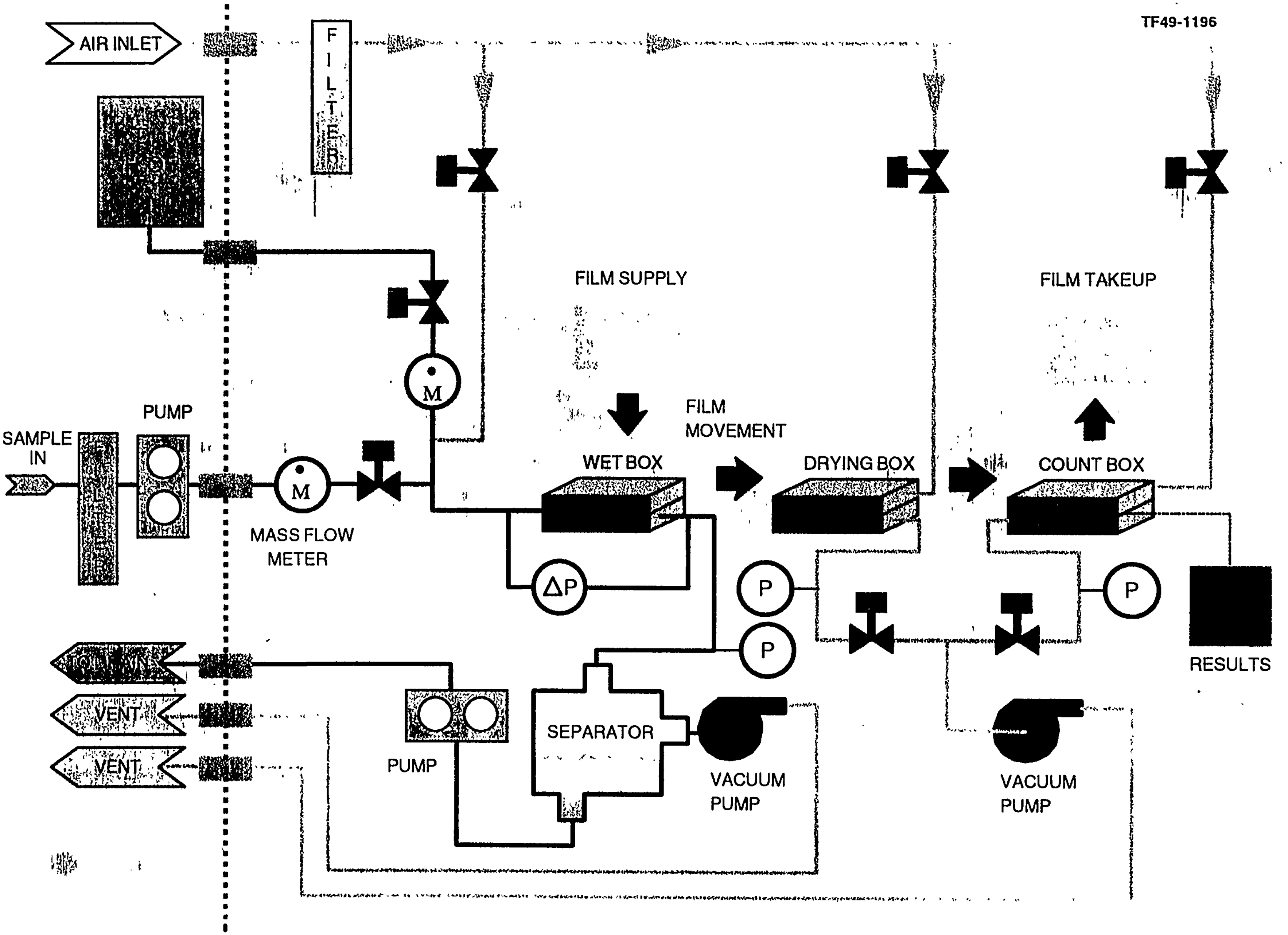

Figure 7. Thermo Alpha Monitor Schematic

is restricted to filtering of the sample stream, where necessary, and to pH control for optimum operation.

The field-deployed Thermo Alpha Monitor is envisioned to consist of the following primary components:

- Archivable film, which quantitatively recovers the nuclides of interest from the sample of interest.
- One large area silicon detector, complete with power supply and low-noise signal preamplifier.
- One multichannel analyzer card.
- One IBM-compatible personal computer.
- Control and sequencing software complete with Remote Monitoring and Control System (RMCS) software.
- Ancillary equipment (chambers for sampling and counting, sample pumps, calibration and instrument cleaning solutions, controls, valves, automatic film handling equipment, etc.).

During normal operation, a representative portion of the stream of interest will be pumped through a single film sample for on-line analysis, then returned to the main portion of the stream. After the sampling period, the film will be dried and then counted by the detector in order to complete the on-line analysis cycle. The instrument cycle will be designed so that the time to complete the drying and counting portion of the analysis is less than or equal to the required sampling time. This methodology will allow for uninterrupted on-line analysis, with a fresh film ready for sampling every 30 minutes.

Periodic automatic calibration, blank checks (to verify instrument cleanliness) and long background counts will be programmed according to the pertinent data quality objectives. This feature is included in order to verify off-line that the detector is still in calibration and that very low background levels exist. Should unacceptable background levels exist in the instrument, i.e., due to a significant change in the chemical makeup of the sample stream, 5% nitric acid will be available for removal of the offending radionuclide(s).

The laboratory measurements, discussed in upcoming Section 2.5, provide a firm base for predicting the field instrument response to varying uranium concentrations. The instrument will provide quantitative measurement over a very wide range of uranium in water concentrations, 10 ppT (15 femto Curies per liter) to over 10 ppm (15,000 pCi/l). Laboratory testing has verified the linear response of the instrument with uranium concentrations over the range of 10 ppT to

10 ppm. This linear response to concentration is expected on the basis of the physical phenomena taking place, and there is no reason to expect deviation at either lower or higher uranium concentrations.

The response time of the field instrument is directly related to the uranium concentration in the aqueous stream being monitored. The instrument typically will automatically total the ^{238}U, ^{235}U and ^{234}U peaks and measure the time required to reach 10 (for @ ± 40% statistical accuracy) to 100 net counts (for approximately ± 15% statistical accuracy). For 1 ppb uranium, the instrument cycle time will be approximately 30 minutes. For 10 ppm U, it can be as short as approximately five minutes. An unexpected excursion from ppb to ppm levels will be detected very rapidly. For each count time to reach TC net counts, the average U concentration over the count time is given by the following relation:

$$X = \frac{0.8216\,(TC)}{(V)\,(T)}$$

where:

X = average ppb uranium concentration over the sampling period.
V = total volume sampled during the sample cycle, liters.
T = count time, minutes.
TC = total cumulative net counts in time T due to $^{238}U - {}^{235}U - {}^{234}U$.

This relation is based on the following factors:

(1) Detector active area of 50 cm^2, film active area of 53.5 cm^2, detector-film spacing of 0.52 cm, giving a geometrical counting efficiency of 42.13%.

(2) Quantitative extraction of U by the film, which is based on experimental data obtained between 10 ppT and 10 ppm.

(3) The 2.7:1 activity ratio of ^{234}U:^{238}U accepted by the EPA for natural uranium in drinking water, or a specific activity of 1.3 pCi/μg natural uranium.

The factor 0.8216 is the conversion factor obtained by converting counts per minute per liter to parts per billion:

$$\frac{0.450\ \text{pCi / dpm}}{0.4213\ \frac{\text{cpm}}{\text{dpm}}\ \text{x}\ 1.3\ \text{pCi / }\mu\text{g x 1000 g / l}} = 0.8216\ \text{ppb} - \text{min} - \text{l / count}$$

Taking TC to be 100 counts, the count time corresponding to different uranium concentrations is given in Table 3. The instrument will respond to, and quantitatively monitor, a very wide range of uranium concentrations. At 1 ppb, the instrument's overall response time is 30 minutes. Should the level increase to 20 ppb U, the increased level could be identified in 10 minutes. Should an increase to 600 ppb U occur, only five minutes will be required to verify

TABLE 3

TAM INSTRUMENT CYCLE TIME VS. U CONCENTRATION

Average U Concentration Over the Sampling Time (ppb)	Volume Sampled (liters)	Required Sampling Time (Minutes)	Drying Time* (Minutes)	Count Time for TC = 100 Counts (Minutes)	Total Analysis Time (Minutes)
1	8	16	4	10.3	30.3
5	4	8	4	4.1	16.1
20	2	4	4	2.1	10.1
600	0.5	1	4	0.27	5.3
4,000	0.5	1	4	0.04	5.0

* Microwave-assisted drying has reduced this to 30-60 seconds.

the increased concentration. A very large excursion of 4,000 ppb will also be verified in five minutes. The 1 ppb overall response time is reduced by 31% to 21 minutes, by use of 10 counts instead of 100. Analyses can occur below 1 ppb by allowing larger sample volumes to pass through the film and/or allowing additional counting time to transpire. The cycle time can be reduced by over three minutes by using microwave-assisted drying.

In summary, the field instrument will operate on-line and provide a continuous measure of the uranium concentration in the effluent stream. For subdrinking water uranium levels near 1 ppb, a 20- to 30-minute instrument cycle time is required to reach 10 to 100 net counts (for statistical accuracy of approximately ± 40% or ± 15%). If an excursion to higher uranium concentrations occurs, the count time (and subsequent sampling times) will be reduced, with very short response times to 600 ppb excursions. It will not miss any such excursions. The instrument will also give the relative amount of ^{238}U, ^{235}U and ^{234}U isotopes separately, if desired. The data will be available immediately to the site workers. If desired, alarms and/or diversion of the stream to a holding area can be effected for excursions above a preset limit. The instrument is expected to readily monitor other alpha-emitting radionuclides, such as ^{239}Pu and ^{241}Am, and process streams. The instrument operation is completely automatic, with only periodic replenishment of the film, calibration, cleaning and rinsing liquids required, probably on a weekly basis. Operation will be very cost-effective.

2.4 DESCRIPTION OF INSTRUMENT

The laboratory tests provide a firm base for the field demonstration. Earlier tests used proprietary TAM film samples that were only 1 cm^2 (0.16 in^2) in area. Figure 8 compares the size of two TAM films that were used in later stages of laboratory testing. The smaller of these specimens has a usable area of 13.4 cm^2 (2.07 in^2), the larger film has a usable area of 53.5 cm^2 (8.29 in^2). This represents am increase in film area by a factor of 53.5, well in excess of the program's stated goal of a 10X increase in activation.

These films are designed to capture the alpha-emitting radionuclides of interest. They can be factory-tailored to capture either a broad or narrow range of chemical species of interest. Through modern mass-production techniques, all specialized film preparation chemistry can be performed at a central manufacturing plant prior to shipping the QA/QC-approved film to the TAM for testing.

Normally, the analysis is performed with a sample volume between 100 cm^3 and 8,000 cm^3, depending on the sample's activity and the desired counting time. (Sample volumes as great as 42 liters have been successfully used to date.) The sample is passed through the film (Figure 8) as it is held in a waterproof chamber (Figure 9). The waterproof chamber and associated plumbing apparatus (Figure 10) are designed to withstand most acidic and basic solutions, allowing for a variety of sample preparations as well as occasional acid cleaning.

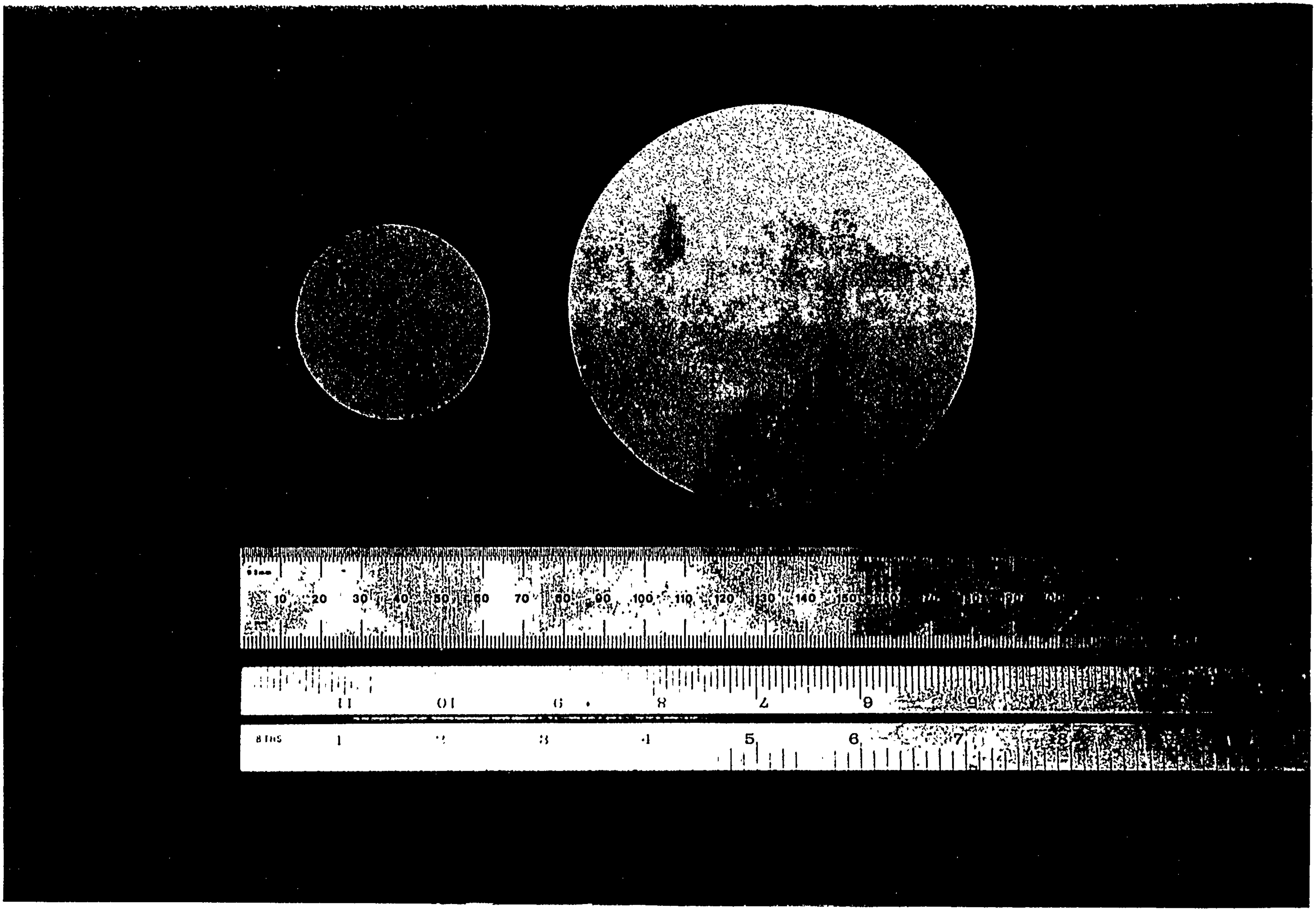

Figure 8. Sizes of Two TAM Films

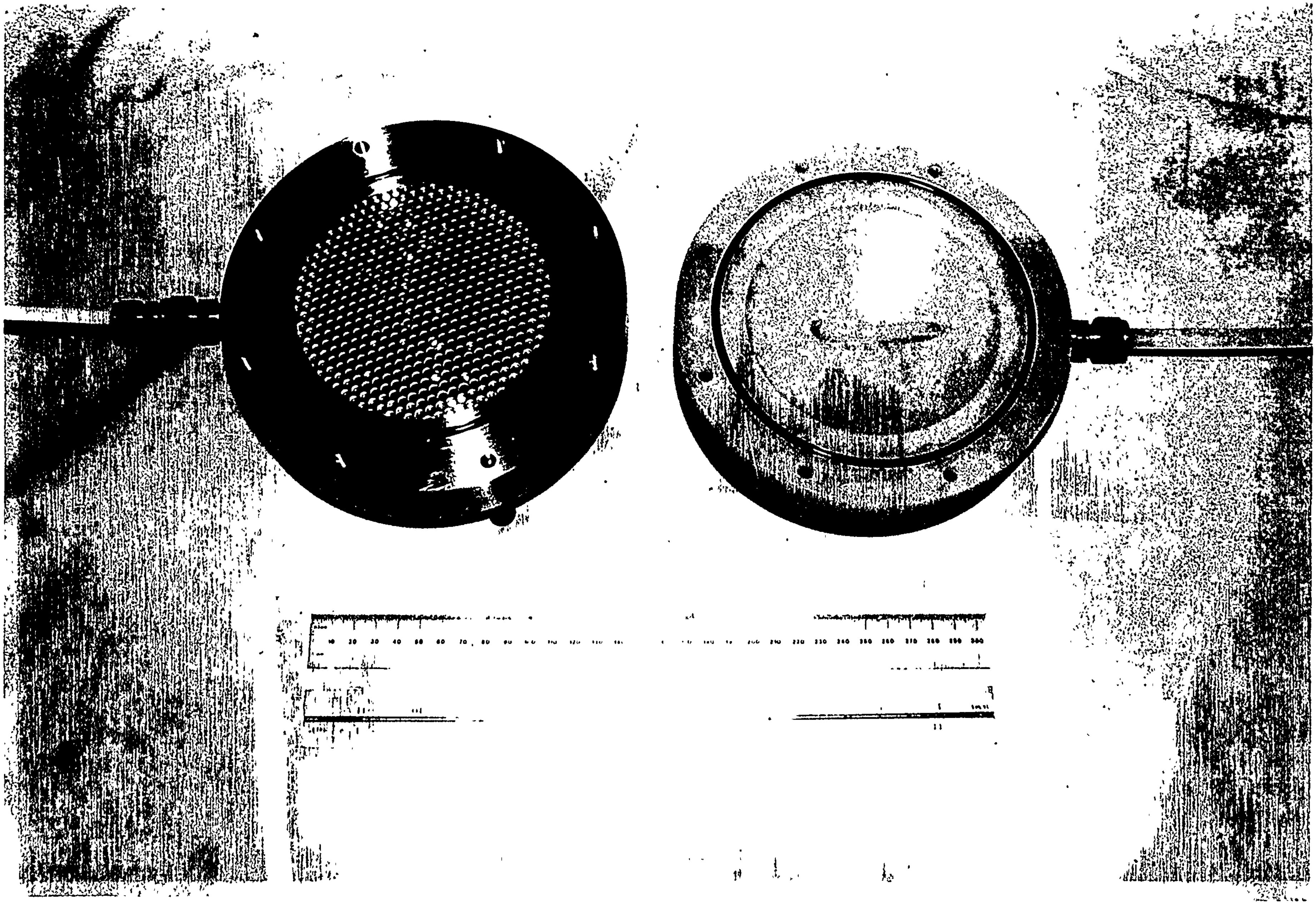

Figure 9. TAM Waterproof Chamber

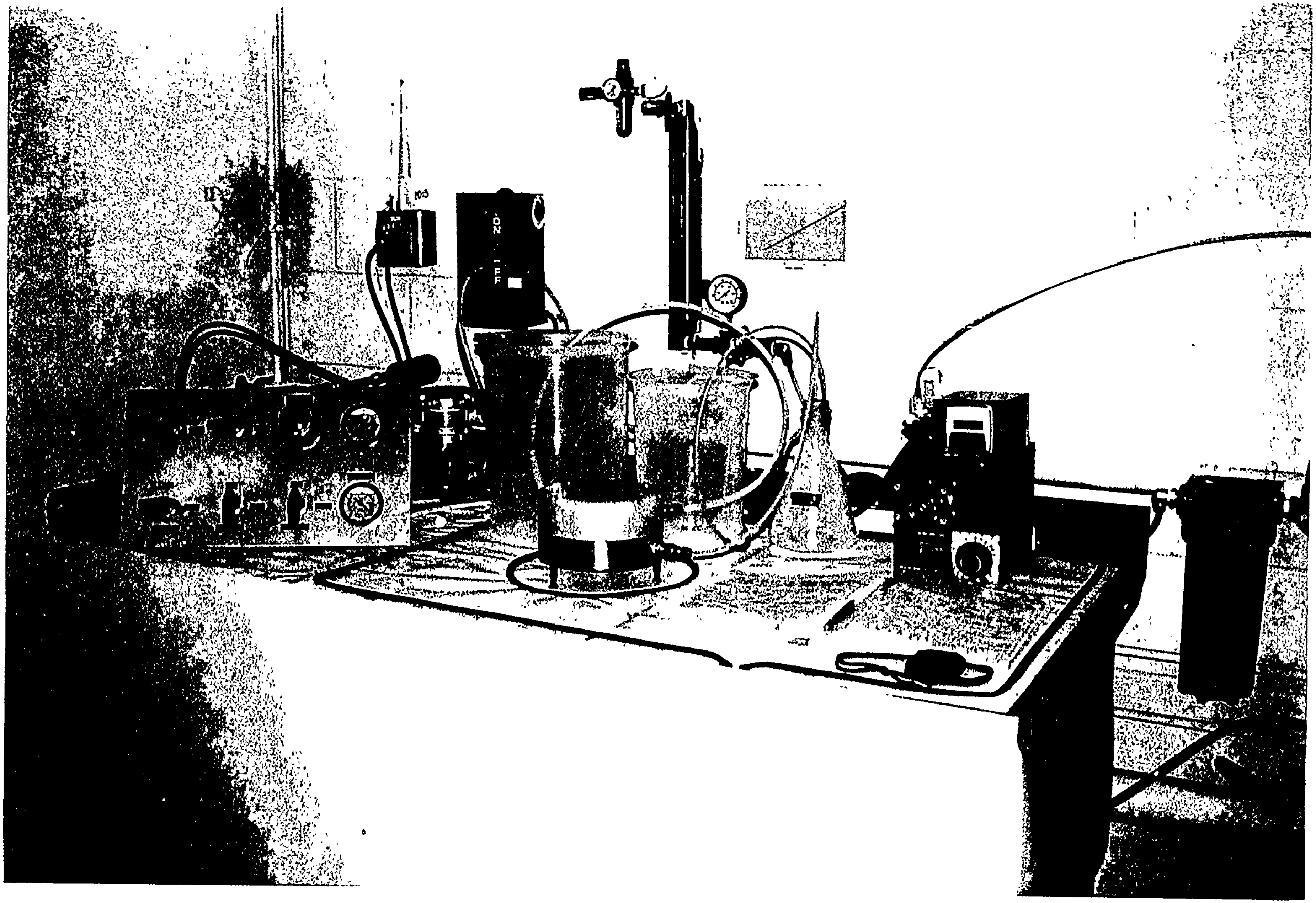

Figure 10. TAM Waterproof Chamber in Laboratory

In addition, appropriate materials of and types of construction were selected to minimize carryover of radioactive species between analyses.

To analyze a sample, the proprietary TAM film is installed into the waterproof chamber (see Figure 11). The sample is passed through the film, allowing quantitative uptake of the radioactive species of interest. Quantitative extraction is provided by the high mass transfer flux of rad to the large active surface area provided by the microporous film (average equivalent particle size is less than 10 μ). The alpha-emitters are absorbed at or near the surface of active film, forming a thin source that will provide excellent alpha energy resolution during the counting step. De-ionized (DI) water is then used for rinsing the waterproof chamber assembly and film between analyses. The DI water serves to minimize carryover of radioactive material between analyses, as well as remove all transferable surface radioactivity from the film. The absorbed radionuclides are adherent and are not removed by a water wash. Finally, any residual liquid is withdrawn from the waterproof chamber. The complete sampling cycle takes approximately 16 minutes to complete for an 8,000 cc sample.

Next, the film is transferred from the waterproof chamber to a chamber where it is prepared for the counting step. At a minimum, this preparation consists of rapid drying using one or more of the following: microwaves, hot air, vacuum and infrared heating. Appropriate instrumentation (i.e., thermocouples or thermistors) are used to monitor the film for dryness. The complete preparation cycle takes approximately four minutes to complete[3].

Subsequently, the film is routed to the detector chamber for counting the radioactive decay of the species on the film's surface. The detector subsystem used in this work is illustrated in Figure 12. The counter incorporates a solid-state, silicon-based, reverse-biased, p-i-n diode. Figure 12 shows the large surface area of the laboratory detector, as well as the enclosure that is used to produce a light-tight assembly. This detector has an active area of 50 cm^2. The counter is connected through a pre-amp to an 1024-channel pulse height analyzer. The multi-channel analyzer is mounted in an IBM-compatible personal computer (see Figure 13); special software is used for data acquisition, analysis and report generation (see Chapter 2.6.2). The complete counting cycle takes approximately six minutes for a high-accuracy film analysis of 8,000 cc of 20 ppb natural uranium.

After the analysis is completed and before a new sample is counted, the film is removed from the counting chamber and archived in an appropriate plastic bag. The total sample cycle is completed in under 30 minutes, which is well under the program's stated goal of a 1- to 12-hour sample cycle time.

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[3] Microwave-assisted drying has reduced this time to 30 to 60 seconds.

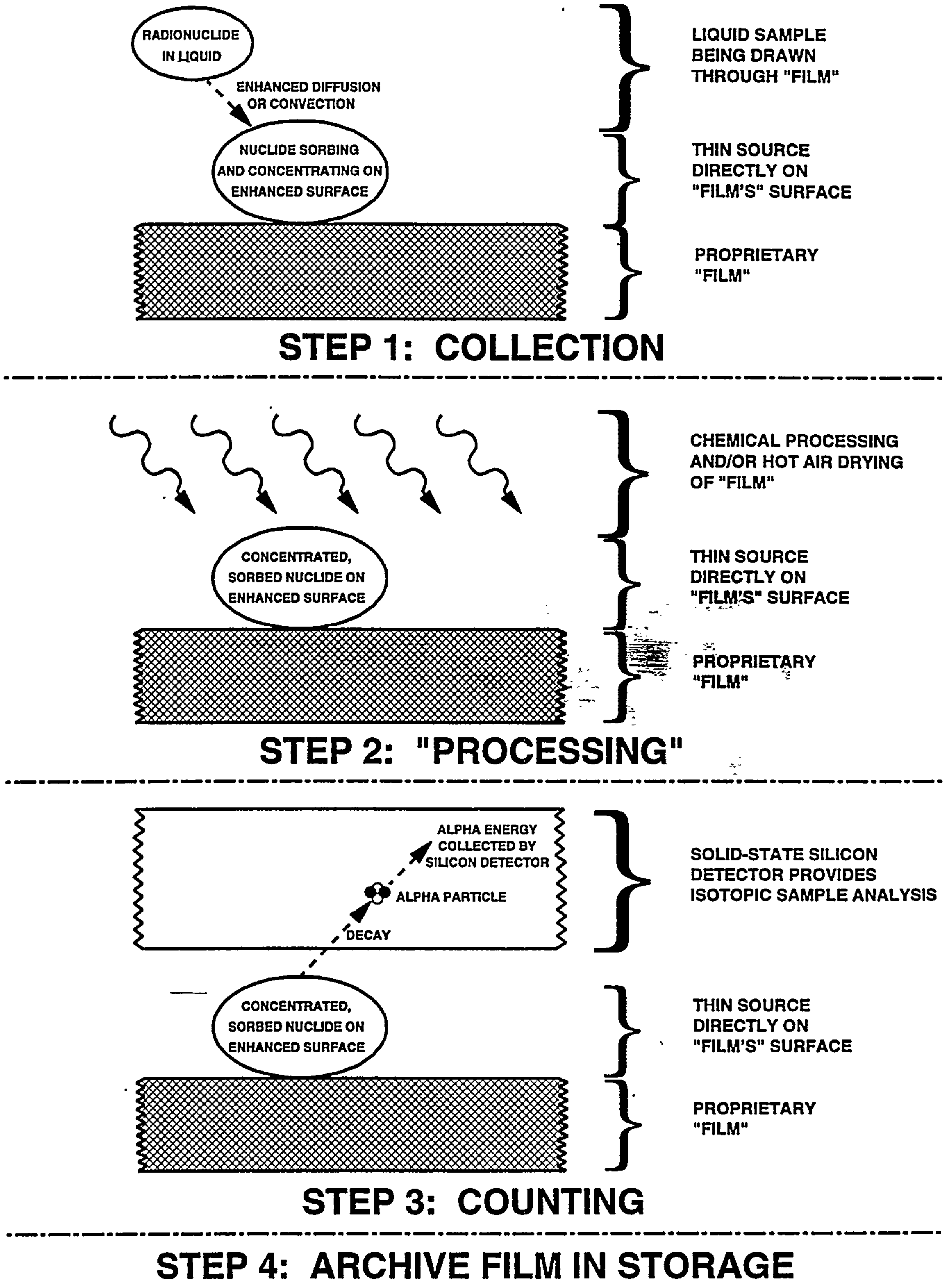

Figure 11. Basic Principle of Operation

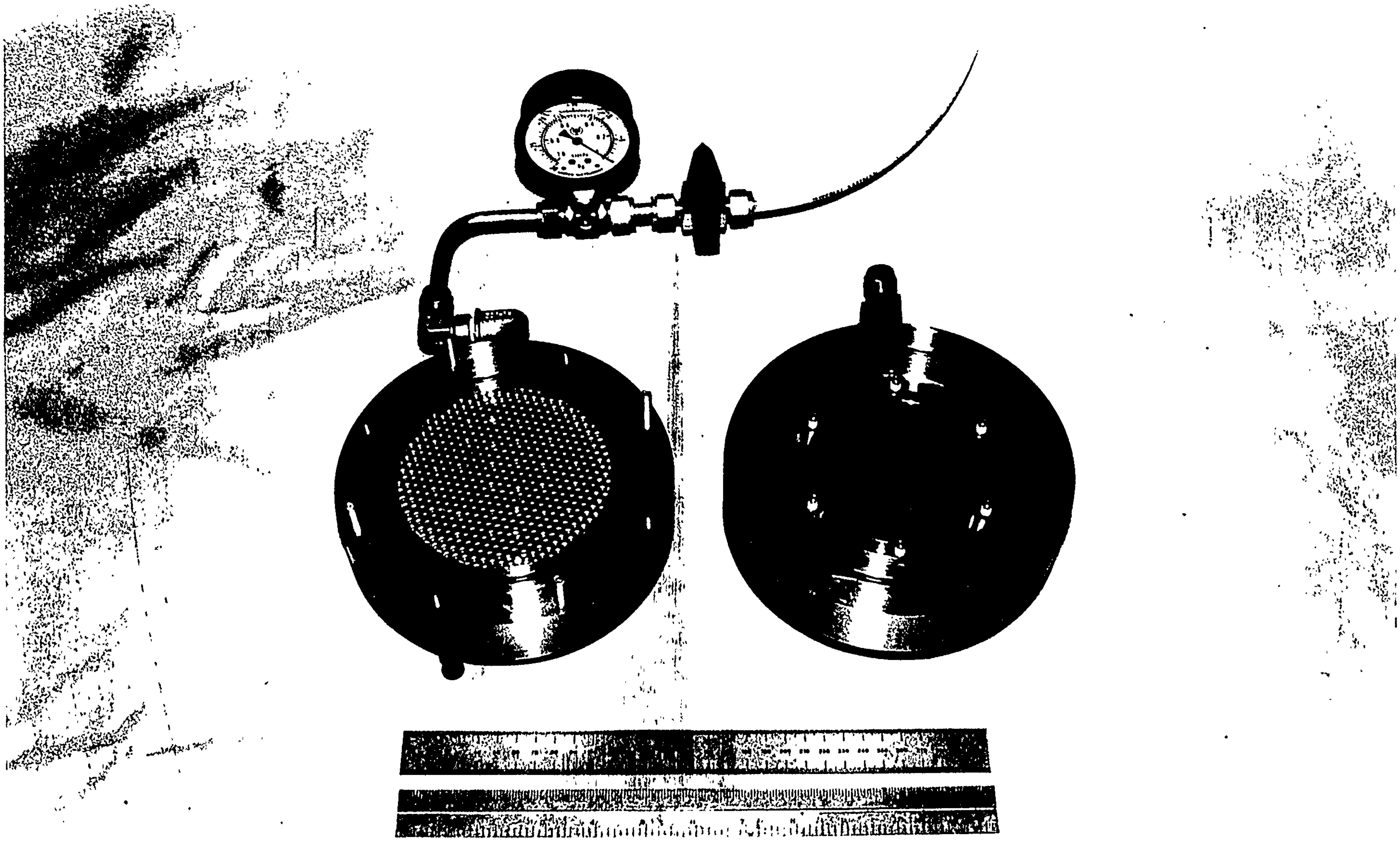

Figure 12. TAM Detector Chamber

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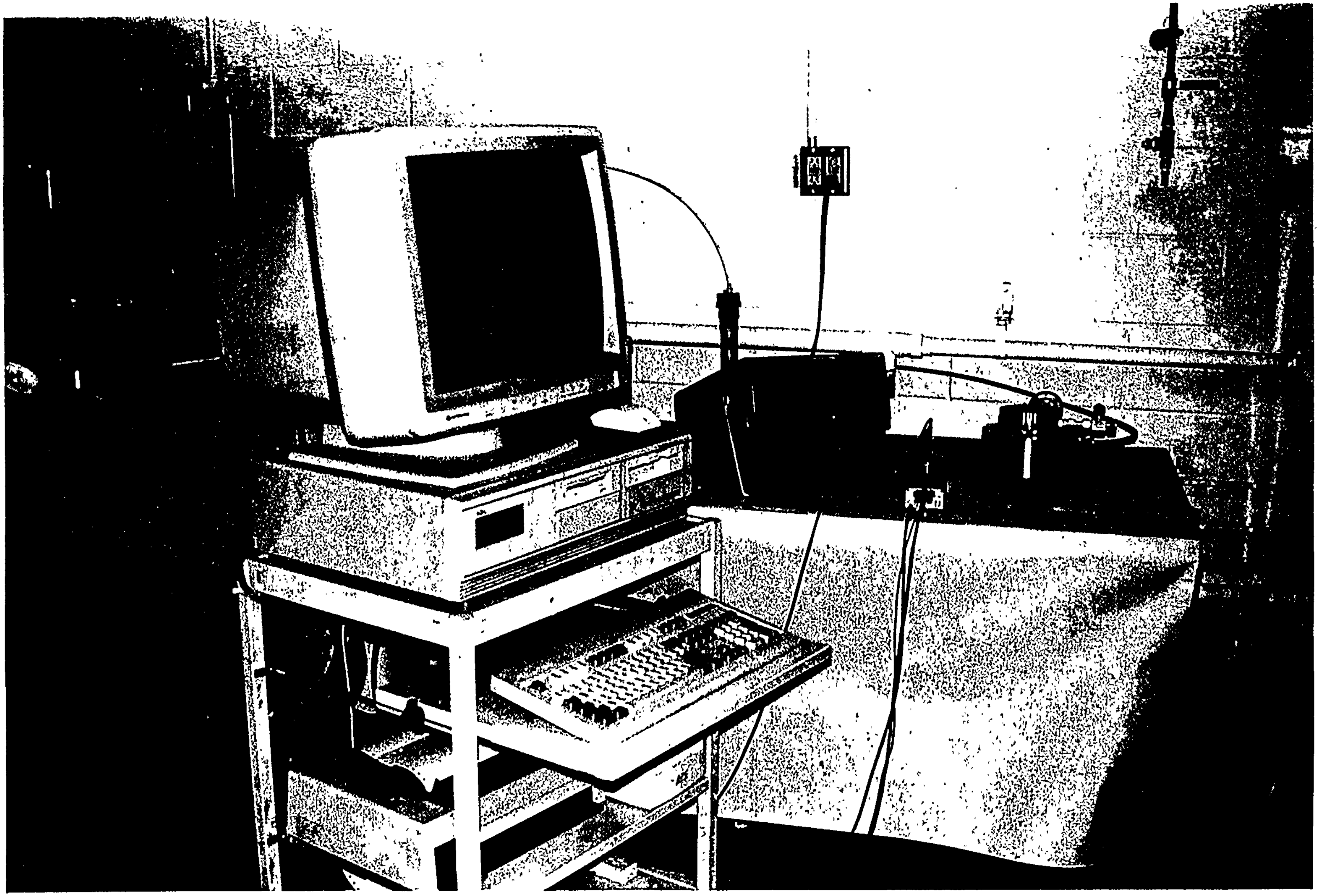

Figure 13. TAM Detector Chamber in Laboratory

2.5 RESULTS

2.5.1 Benchmark of TAM's Response Time

A benchmark was made of the current laboratory unit's response time analyzing eight liters of a calibration solution of natural uranium at the proposed EPA drinking water limit of 20 ppb (30 pCi/l) (see Table 4). As currently configured, 16 minutes were required to sample the test solution with a 53.5 cm^2 film; preparation of the film for analysis took four minutes and performing accurate[4] isotopic analysis of the resultant film took six minutes, for a total of 26 minutes. In other words, the program's major goal of a sample turnaround time of 1- to 12-hours at an alpha activity level of 30 pCi/l has been successfully demonstrated.

TABLE 4

RESPONSE TIME BENCHMARK

Analysis Step	Time
Sample test solution	16 minutes
Prepare film for analysis	4 minutes
Perform isotopic analysis	6 minutes
Total	26 minutes

2.5.2 Analysis of Uranium Nitrate Solutions

A commercially available, uranium atomic absorption (AA) standard solution was used to prepare 10 part per trillion to 10 ppm uranium solutions for testing the detector response to aqueous uranium solutions. Uranium standard solutions are prepared from purified natural uranium ore. Due to the long half-life of ^{238}U compared to ^{234}U, their relative half-lives and their natural abundance, the activity of ^{234}U in the standard solution should be equal to the ^{238}U activity, and daughter products of ^{238}U other than ^{234}U would not be expected. In addition, due to its long half-life, ^{235}U would not have had time to produce any daughter products. The natural abundance in ore and relative activities of the three isotopes are summarized below:

Isotope	Half Life (yr)	Natural Abundance (wt %)	Alpha Activity (Relative to ^{238}U)
^{238}U	4.51×10^9	99.283	1.00
^{235}U	7.10×10^8	0.711	0.0461
^{234}U	2.47×10^5	0.0054	1.00

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[4] Instead of counting to reach 100 total counts, counting until a peak height of 10 was reached.

Thus, the expected primary activities from the natural uranium standard solutions are from ^{238}U and ^{234}U, with the following alpha energies:

^{238}U	23% 77%	4.15 Mev 4.20 Mev
^{234}U	28% 72%	4.72 Mev 4.77 Mev

These tests were performed by passing a neutralized sample of the water through a 53.5 cm^2 film, drying the film and then counting the film. The results of the count are presented in Figure 14. The ^{238}U and ^{234}U peaks are clearly evident near 4.20 and 4.77 Mev, indicating that the uranium is adhering to the surface of the film. ^{235}U is apparent in this spectrum between the ^{238}U and ^{234}U peaks.

The activities are also about the same for the two main uranium isotopes. Manual subtraction of background and deconvolution of the three overlapping curves was completed in order to quantify the isotope ratio of the sample. Results of this analysis indicate that the ^{238}U peak has 58%, the ^{234}U peak had 40% and the ^{235}U peak had 2% of the net alpha activity – a ^{238}U:^{234}U:^{235}U isotope ratio of 1.0:0.69:0.034. These data either indicate that the sample is slightly depleted uranium or that the measured activity ratio is slightly in error.

These results for a sample of "natural" uranium clearly demonstrate the capability of the system to respond to low levels of uranium, to identify specific isotopes with the high energy resolution of the TAM film and silicon detector, and to provide quantification of the sample's ^{235}U enrichment level (or depletion, as in this case).

2.5.3 Analysis of Fernald Site Groundwater

An acid-preserved sample of contaminated groundwater from the DOE Fernald (Ohio) site assayed at 600 ppb total uranium (the DOE free-release limit) was obtained for testing. Again, if the contamination was caused by purified natural uranium, due to the long half-life of ^{238}U and ^{234}U, their relative half-lives and their natural abundance, the activity of ^{234}U should be equal to the ^{238}U activity and daughter products of ^{238}U other than ^{234}U would not be expected. In addition, due to its long half-life, ^{235}U would not have had time to produce any daughter products. These tests were performed by passing a neutralized sample of the water through a 13.4 cm^2 film, drying the film and then counting the film. The results of the count are presented in Figure 15. The ^{238}U and ^{234}U peaks are clearly evident near 4.20 and 4.77 Mev, indicating that the uranium is adhering to the surface of the film. Negligible ^{235}U is apparent in this spectrum.

The activities are clearly not the same for the two main uranium isotopes. Manual subtraction of background and deconvolution of the overlapping curves was completed in order to quantify the isotope ratio of the sample. Results of this analysis indicate that the ^{238}U peak has

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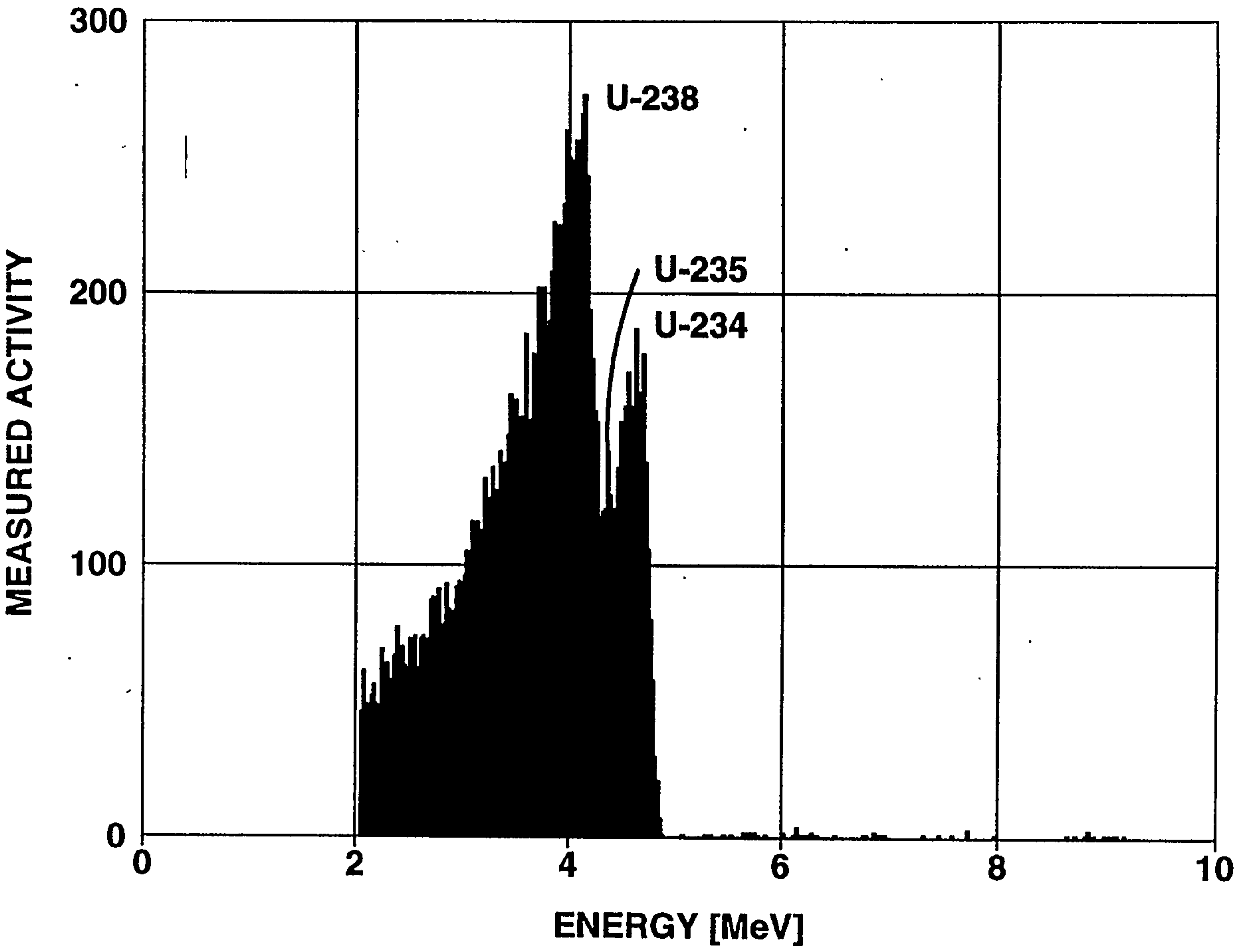

Figure 14. Laboratory Test Results - 20 Parts per Billion Natural Uranium

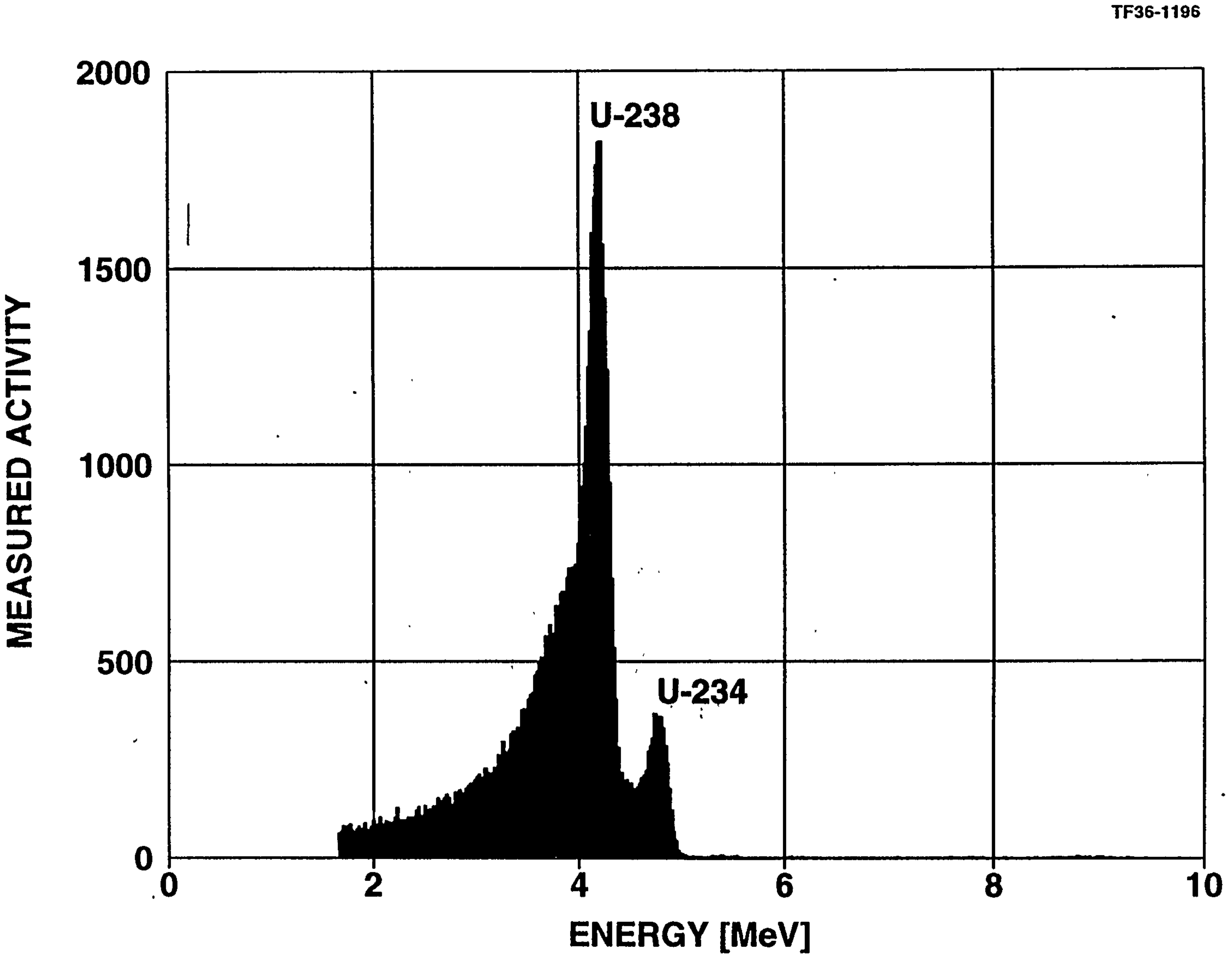

Figure 15. Laboratory Test Results, Fernald Groundwater
600 ppb Total Uranium

82% of the net alpha activity while the ^{234}U peak had 18% of the net alpha activity – a ^{238}U/^{234}U isotope ratio of 4.5.

A likely explanation for this ^{238}U/^{234}U isotope ratio of 4.5 is that this particular portion of Fernald became contaminated with depleted uranium. If it had been contaminated with natural uranium, the ^{238}U/^{234}U activity ratio would be 1; if it had been contaminated with enriched uranium, the ^{235}U and ^{234}U peaks would have been pronounced, relative to the ^{238}U peak. Consequently, the data conclusively shows that man-made (depleted) uranium contaminated this groundwater as the isotope ratio does not match natural uranium's.

These results for a sample of a DOE site's contaminated groundwater water clearly demonstrate the capability of the system to respond to low levels of uranium, to identify specific isotopes with the high energy resolution of the TAM film and silicon detector, and to provide quantification of the sample's ^{235}U enrichment level (or depletion, as in this case).

2.5.4 Analysis of Tap Water (From Well) of Carlisle, Massachusetts, Residence

Water from a deep well in granite at a Carlisle, Massachusetts, residence was analyzed in the laboratory breadboard instrument. The water sample was transported sealed in a full sample bottle and had set less than one day before starting the count. Two liters of the unfiltered water were passed through a 53.5 cm^2 film sample placed in the sample chamber. The film was dried, then counted under vacuum by a 50 cm^2 detector.

A sample TAM spectrum is provided (Figure 16) that shows the analytical results for this fresh groundwater sample. This water sample displays the isotopic presence of a high level of ^{214}Po, a uranium radon daughter that is typical of such New England groundwater samples. This isotope is part of the ^{238}U series and results directly from decay of ^{222}Rn (radon) in the well water. The alpha from ^{222}Rn is not observed, since radon is a noble gas and is not captured by the film. ^{214}Po's decay characteristics include:

^{214}Po	100%	7.69 Mev

The high level of ^{214}Po (without significant parent uranium) can be explained by the following: all radon gas that is evolved from the uranium-bearing granite's decay is dissolved in and carried along by the groundwater, as radon is soluble at such low levels in water. Negligible uranium is present, as little soluble uranium (or radon precursors) existed in the path of the groundwater. Radon, being an inert gas, is not adherent to the existing TAM film types and is not detected by the instrument. However, the decaying radon produces ^{214}Po. ^{218}Po, the other expected radon daughter, is not significantly present on the film, due to its short half-life and rapid decay after the film becomes dry (and the radon evaporates with the water).

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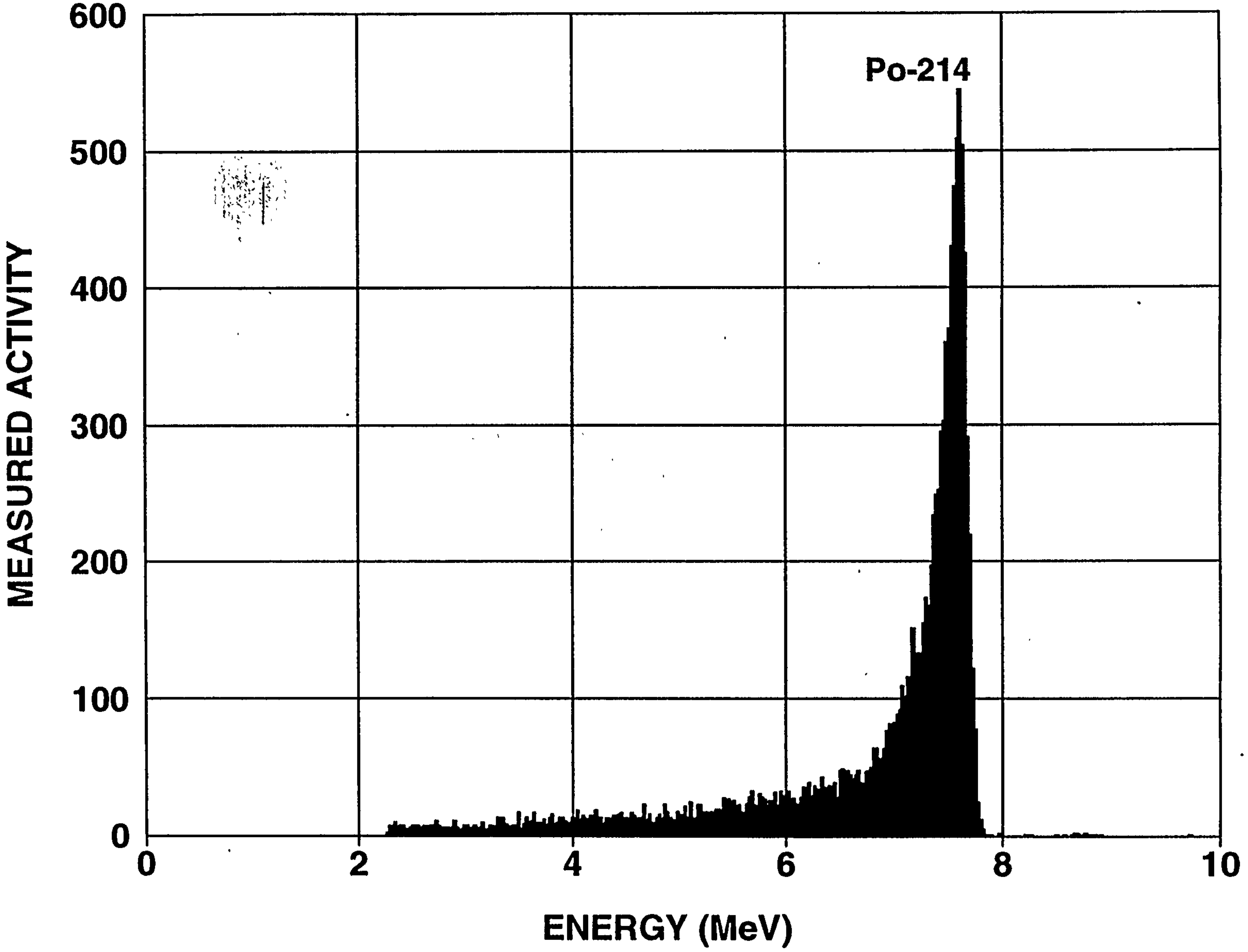

Figure 16. TAM Laboratory Test Results
Massachusetts Groundwater, 103 pCi/l Po-214

Using the existing laboratory calibration, the total ^{214}Po level is calculated as 103 pCi/l, or approximately 7X the 15 pCi/l adjusted gross alpha limit of the EPA's proposed Safe Drinking Water Act (SDWA).

Finally, a second TAM spectrum is provided (Figure 17) that shows the analytical results for the same Massachusetts groundwater sample that has been purged of radon for 10 hours (to allow the ^{214}Po radon daughter to decay). This water sample displays the isotopic presence of ^{238}U and ^{234}U that is typical of such New England groundwater samples. In addition, lesser quantities of uranium and thorium decay products are visible. In addition to the presence of previously identified ^{214}Po, ^{218}Po and ^{210}Po are present from the uranium decay series; in the thorium decay series, small amounts of ^{228}Th, ^{224}Ra, ^{216}Po, ^{212}Bi and ^{212}Po are present:

^{210}Po	100%	5.3 MeV	Uranium Series
^{228}Th	28% 71%	5.34 MeV 5.43 MeV	Thorium Series
^{224}Ra	6% 94%	5.45 MeV 5.68 MeV	Thorium Series
^{218}Po	100%	5.3 MeV	Uranium Series
^{212}Bi	25% 10%	6.05 MeV 6.09 MeV	Thorium Series
^{216}Po	100%	6.78 MeV	Thorium Series
^{212}Po	100%	8.78 Mev	Thorium Series

Using the existing TAM laboratory calibration, the total uranium level is calculated as 1.51 pCi/l (0.74 pCi/l ^{238}U and 0.77 pCi/l ^{234}U) or 2 ppb. It is interesting to note that while the dissolved uranium level of this sample is 1/10th of the EPA's SDWA's 20 ppb, the adjusted gross alpha level of the sample (Figure 17) significantly exceeds the SDWA's limit.

Conventional radiochemical analyses were performed by a commercial laboratory on a portion of the Carlisle sample. Results for these analyses include a soluble uranium analysis of 0.68 pCi/l, and a total uranium analysis of 1.35 pCi/l. TAM results compare favorably with the total uranium analysis, as they are only 12% higher than the conventional analysis results. In brief, TAM measured the total uranium of this sample, not just the soluble uranium.

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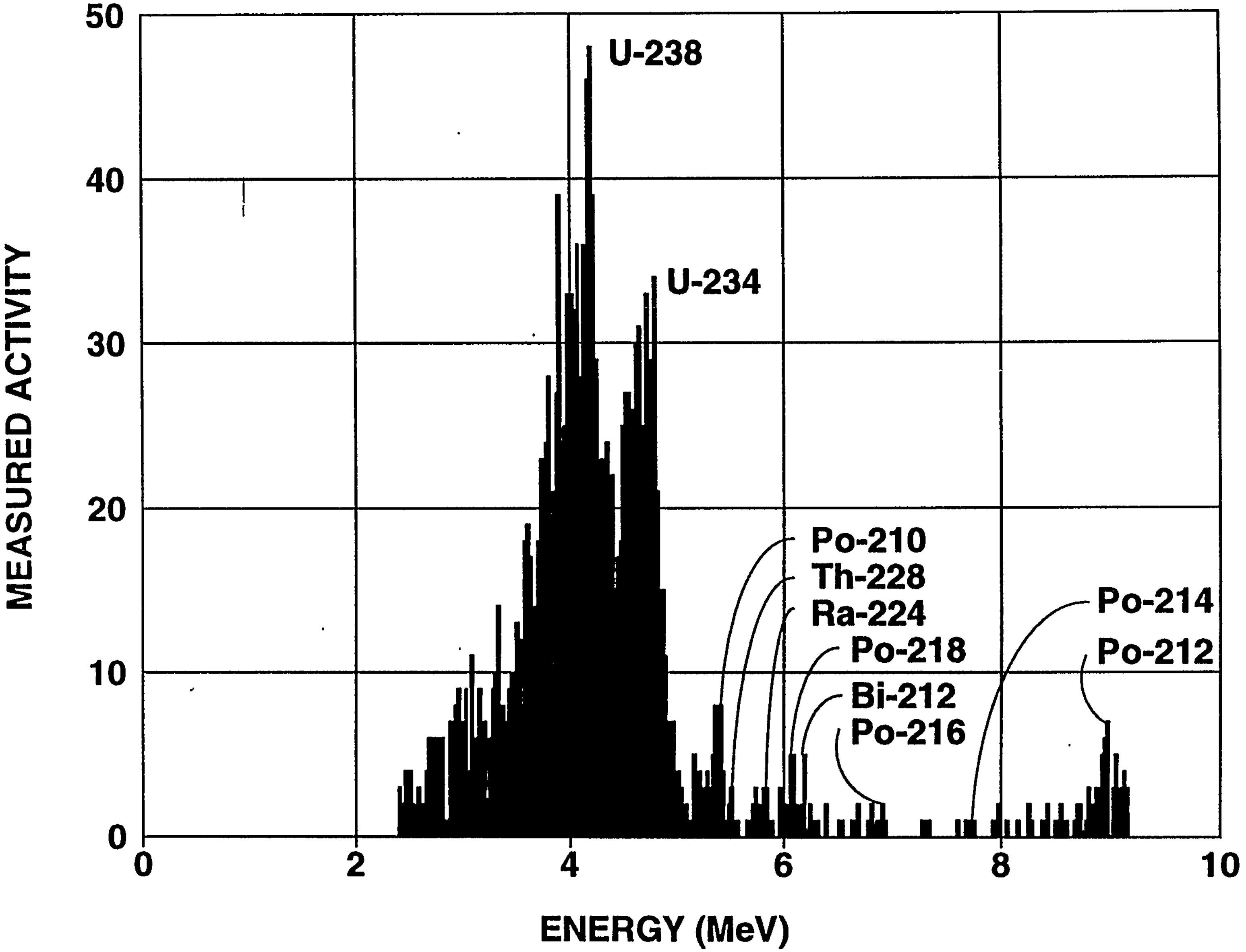

Figure 17. TAM Laboratory Test Results
Massachusetts Groundwater, 2 ppb (1.5 pCi/l) Total Uranium

These results for a potable well water sample clearly demonstrate the capability of the system to respond to very low levels of a range of alpha-emitters in a relatively short time, to identify specific isotopes with the high energy resolution of the silicon detector and to provide a total uranium analysis of a natural groundwater sample as opposed to a soluble uranium analysis.

2.5.5 Analysis of Thorium Nitrate Solutions

In Figure 18, the result of assaying a 1 ppm thorium nitrate atomic absorption (AA) standard solution is given. The two major spectral peaks in Figure 18 are analogous to the two peaks of the uranium-containing samples: ^{232}Th is the parent of the thorium decay series, with ^{228}Th being a daughter product of ^{232}Th, just as ^{234}U is a daughter product of ^{238}U in the uranium decay series. However, Figure 18 contains a third peak, which can be identified as ^{230}Th, a member of the uranium decay series.

The presence of the third ^{230}Th peak can be explained as follows: uranium is often present in thorium ore. When the uranium-containing thorium ore was purified to produce the AA standard solution, the ^{230}Th due to the uranium remained with the ^{232}Th and ^{228}Th. Hence, there are three peaks in the spectrum. The natural abundance and relative activities of the three thorium isotopes are summarized below:

Isotope	Half-Life (Years)	Yield	Energy	Decay Series	Alpha Activity (relative to ^{232}Th)
^{232}Th	1.41×10^{10}	23% 77%	3.95 MeV 4.01 MeV	Thorium	1.00
^{230}Th	80,000	24% 76%	4.62 MeV 4.68 MeV	Uranium	-N/A-
^{228}Th	1.91	28% 71%	5.34 MeV 5.43 MeV	Thorium	1.00

The preceding table indicates that for a freshly purified thorium metal sample, the relative heights of the ^{232}Th and ^{228}Th peaks would be expected to be equal. However, for approximately every two years that the purified thorium metal sample is aged, the activity of ^{228}Th will be reduced by half (due to the presence of two beta-decaying progeny between ^{232}Th and ^{228}Th) and ^{228}Th daughter products will build. Due to the long half-life of ^{232}Th and ^{230}Th, however, the activity of these two isotopes will not have changed.

As expected, Figure 18 shows the ^{228}Th peak to be visibly less significant than the ^{232}Th peak. In addition, numerous ^{228}Th daughter products appear in the spectrum. Manual deconvolution of the three overlapping thorium curves and subtraction of background was conducted in order to quantify the isotope ratio of the sample. Results of this analysis indicate

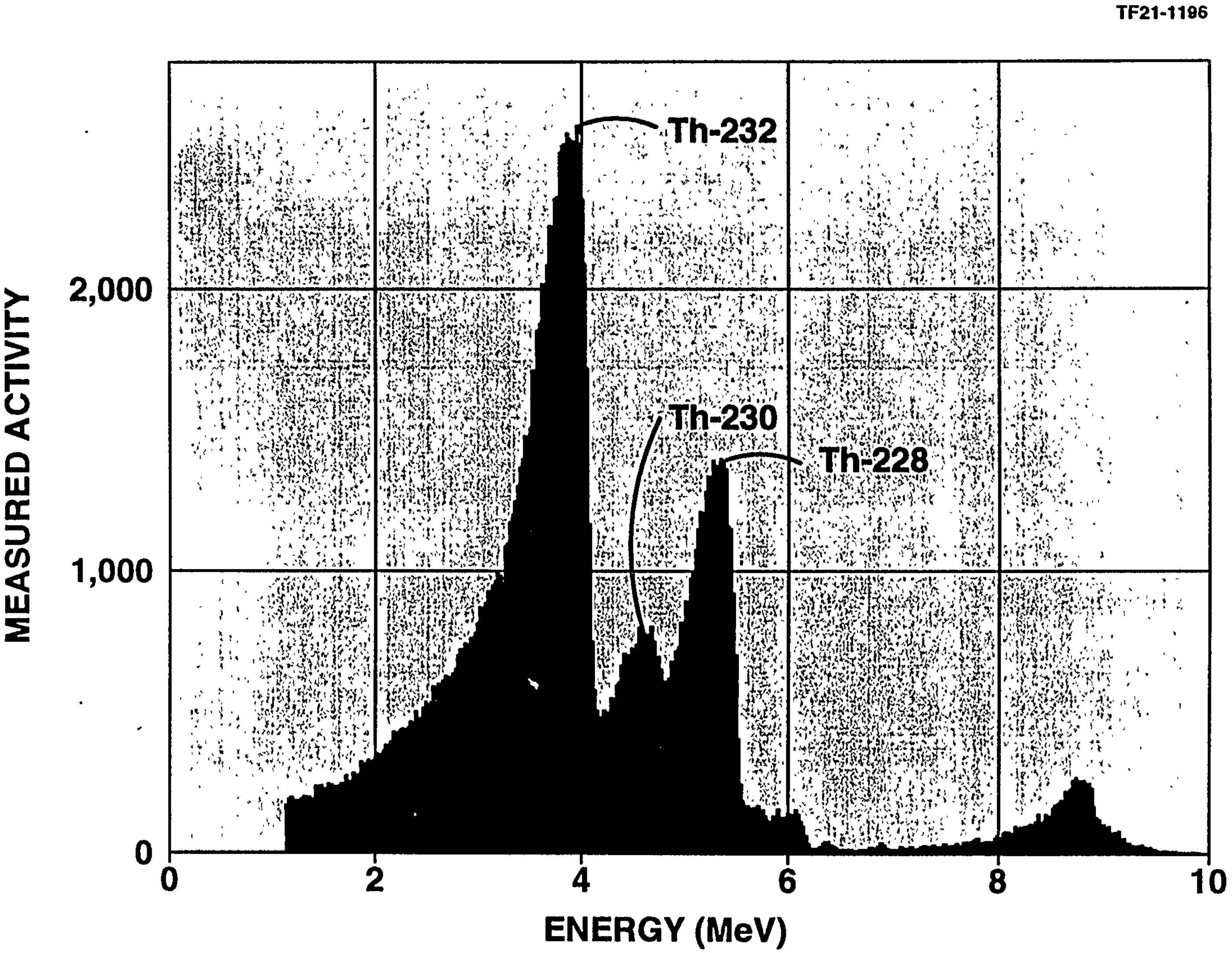

Figure 18. TAM Laboratory Test Results, 1 Part per Million Thorium

that the ^{232}Th peak has 63.8% of the net thorium alpha activity, the ^{228}Th has 28.4%, and the ^{230}Th peak has 7.8% – a ^{232}Th:^{228}Th:^{230}Th isotope ratio of 1.0:0.445:0.098. These data indicate that the sample was originally purified over two years ago and that the uranium content of the original ore was approximately 10% of the thorium.

These results for an aged sample of thorium clearly demonstrate the capability of TAM to respond to low levels of thorium, to identify specific isotopes with the high-energy resolution of the TAM system and to provide diagnostic quantification of a sample's elemental and isotopic makeup.

2.5.6 Robustness of Method

Linearity

Extensive laboratory data show that TAM has a linear dynamic range over six decades of uranium concentration. In addition, TAM has proven linearity over the four-decade range of thorium concentrations that have been analyzed. Figure 19 illustrates a logarithmic plot of the calibration curve for the TAM breadboard instrument, with data spanning a range of 10 parts per trillion (15 fCi/l) to 10 parts per million (15,000 pCi/l) natural uranium, and including levels of natural thorium between 100 parts per trillion (17 fCi/l) and 1 part per million (172 pCi/l). The correlation coefficient (R^2) for these data is 0.999, indicating the excellent linearity of the instrument.

Effect of pH

The operation of TAM has been shown to be unaffected by operation with slightly acidic or basic water chemistry (pH above 5). Figure 20, a plot of the measured total uranium activity of a variety of prepared samples relative to the known uranium activity, shows the larger effect on TAM's operation caused by analyzing very acidic solutions. For example, the relative results of analyzing a uranium solution below pH 4.5 are significantly low, as the acidic solution seriously reduces the uptake of uranium by the TAM film.

Such nonlinear response of TAM to sample pH can be accounted for in the Optional Phase II Field Test Monitor by one of three methods:

- Use an algorithm to model the nonconstant film response and correct the erroneous readings.
- Add base to the water sample prior to analysis to raise the pH above 5.
- Obtain an alternate film that has linear behavior for acidic solutions.

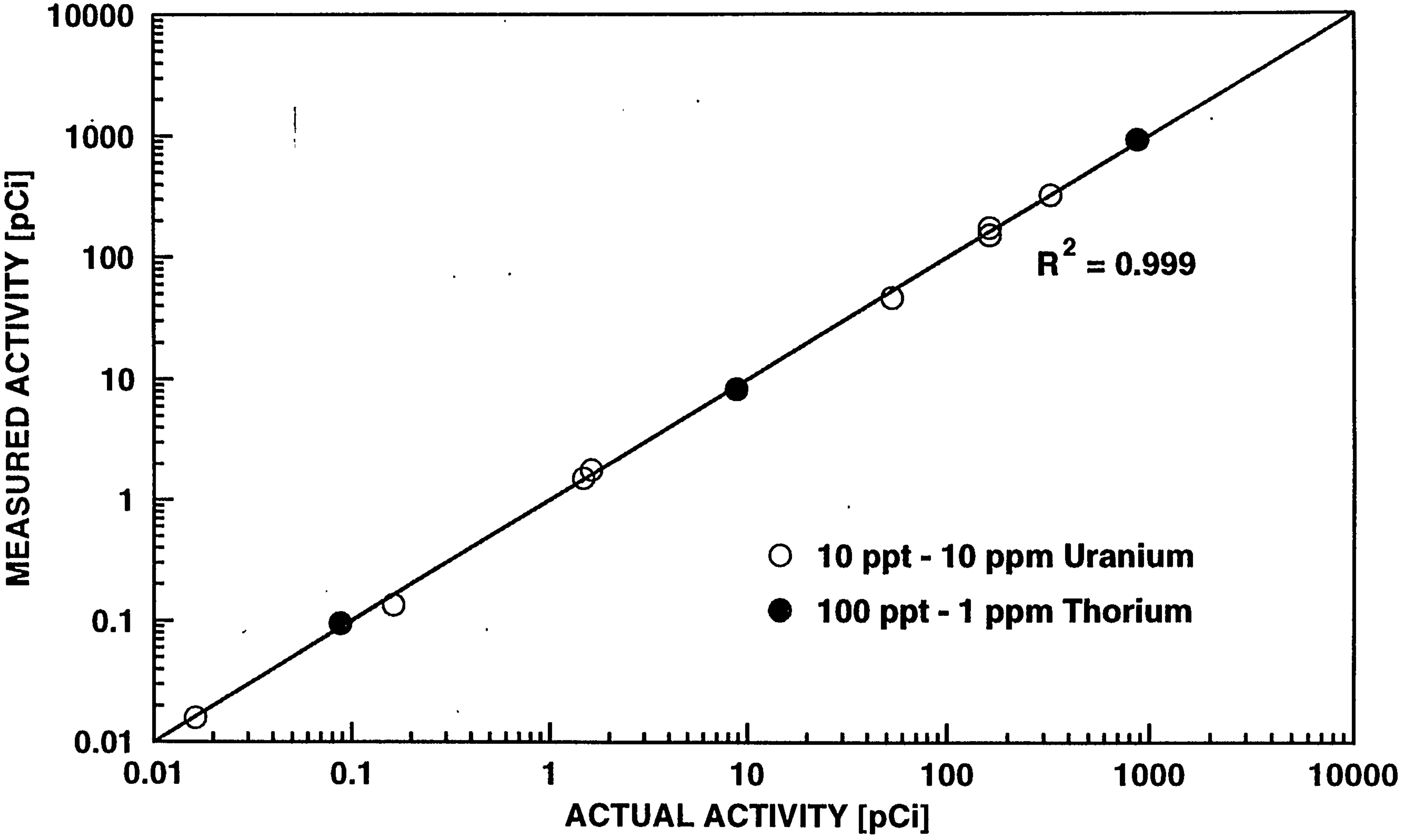

Figure 19. Broad Dynamic Range Exceeds Six Decades for Uranium and Thorium

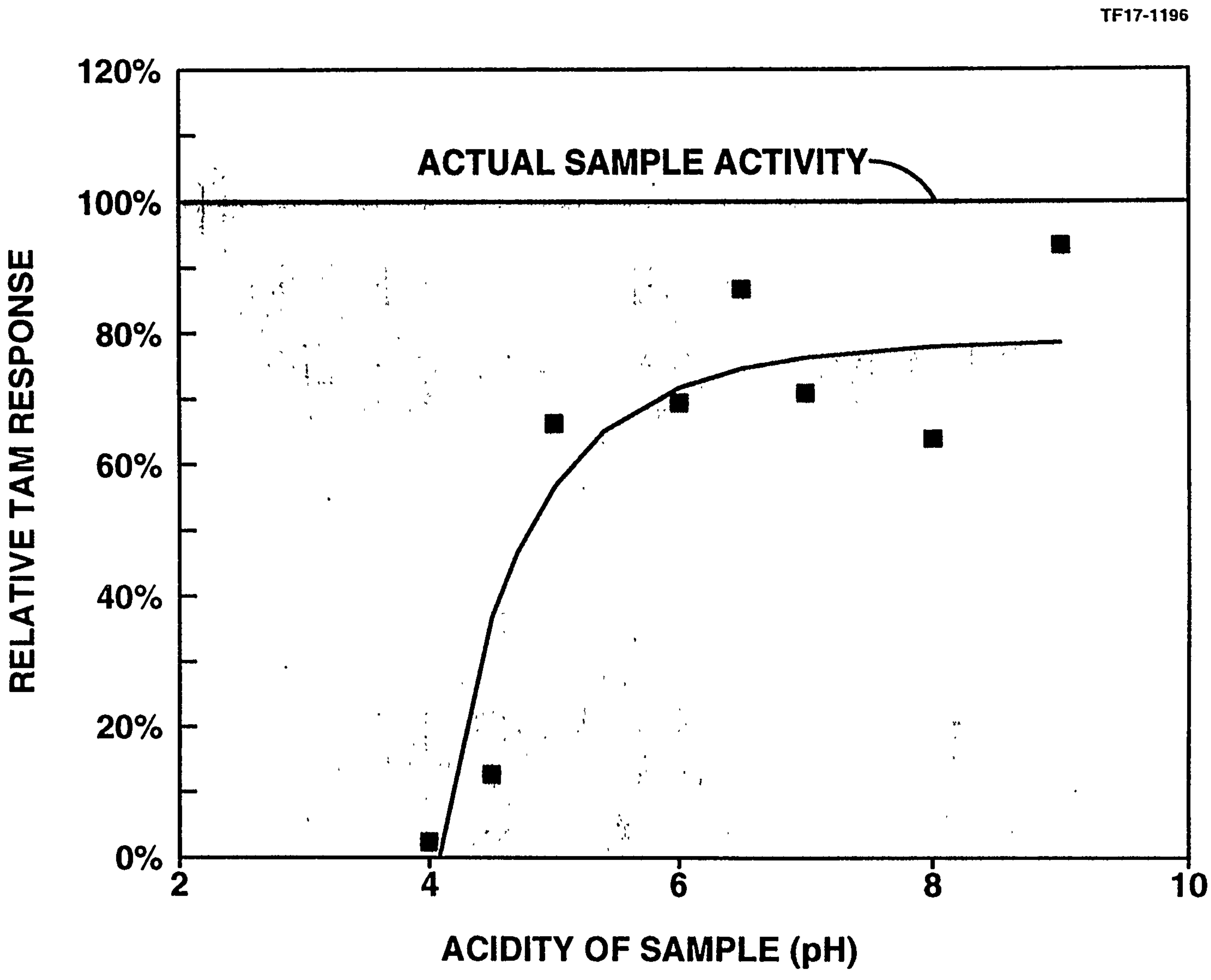

Figure 20. Illustration of TAM's Flat Response at High pH

Any of these three methods will provide acceptable TAM analysis results. For example, thermocouples and other instruments have nonlinear response characteristics, and their responses are commonly modeled and linearized. Automatic titrators exist that could add the proper amount of base to the incoming water sample prior to analysis, although at a penalty of increasing the operational complexity of TAM. Three film types have been screened in the laboratory; additional film types might prove unaffected by these low pH samples.

Effort for the Optional Phase II of the current program will focus on proving the acceptability of using an algorithm to model TAM's response to sample pH. Software correction of instrument readings is commonly performed and provides reliable results for other instrumentation. Performing additional film testing or adding an automatic titrator to TAM are viewed as beyond the existing scope of work for the program.

Effect of TDS

The operation of TAM has been shown to be unaffected by operation with total dissolved solids (TDS) levels that are between 10 and 10,000X higher than the analyses of interest. Figure 21, a plot of the measured total uranium activity of a variety of prepared samples relative to the known uranium activity, shows that for TDS levels below about 100 ppm, accurate results are obtained for uranium levels between 10 ppm and 10 ppT. TAM reports erroneous low readings when analyzing solutions with TDS levels above 1,000 ppm. For example, results of analyzing a 600 ppb uranium solution with TDS levels 2000X greater than the uranium concentration (1,300 ppm) are significantly low, as the high TDS loading seriously reduces the uptake of uranium by the TAM film.

Similar to correcting for sample pH, such nonlinear response of TAM to sample TDS can be accounted for in the Field Test Monitor by using an algorithm to model the nonconstant film response and correct the erroneous readings. The TAM to be tested in the Optional Phase II of the current program will incorporate an algorithm for correction of alpha analyses at high TDS values; the field test will validate the utility of this methodology. The algorithm is expected to involve increasing the response of TAM by dividing the unadjusted TAM response by the "Relative TAM Response" value (see Figure 21) corresponding to the sample's measured total dissolved solids. For example, if the measured TDS is 1000 ppm, the unadjusted TAM response would be divided by 0.55, resulting in an adjusted TAM response that is larger by a factor of 1.81.

2.5.7 Other Method Details

Deconvolution of Multiplets

Where necessary, source attenuation and deconvolution procedures have been incorporated in the data analysis/reduction procedures. The physics of alpha transmission and

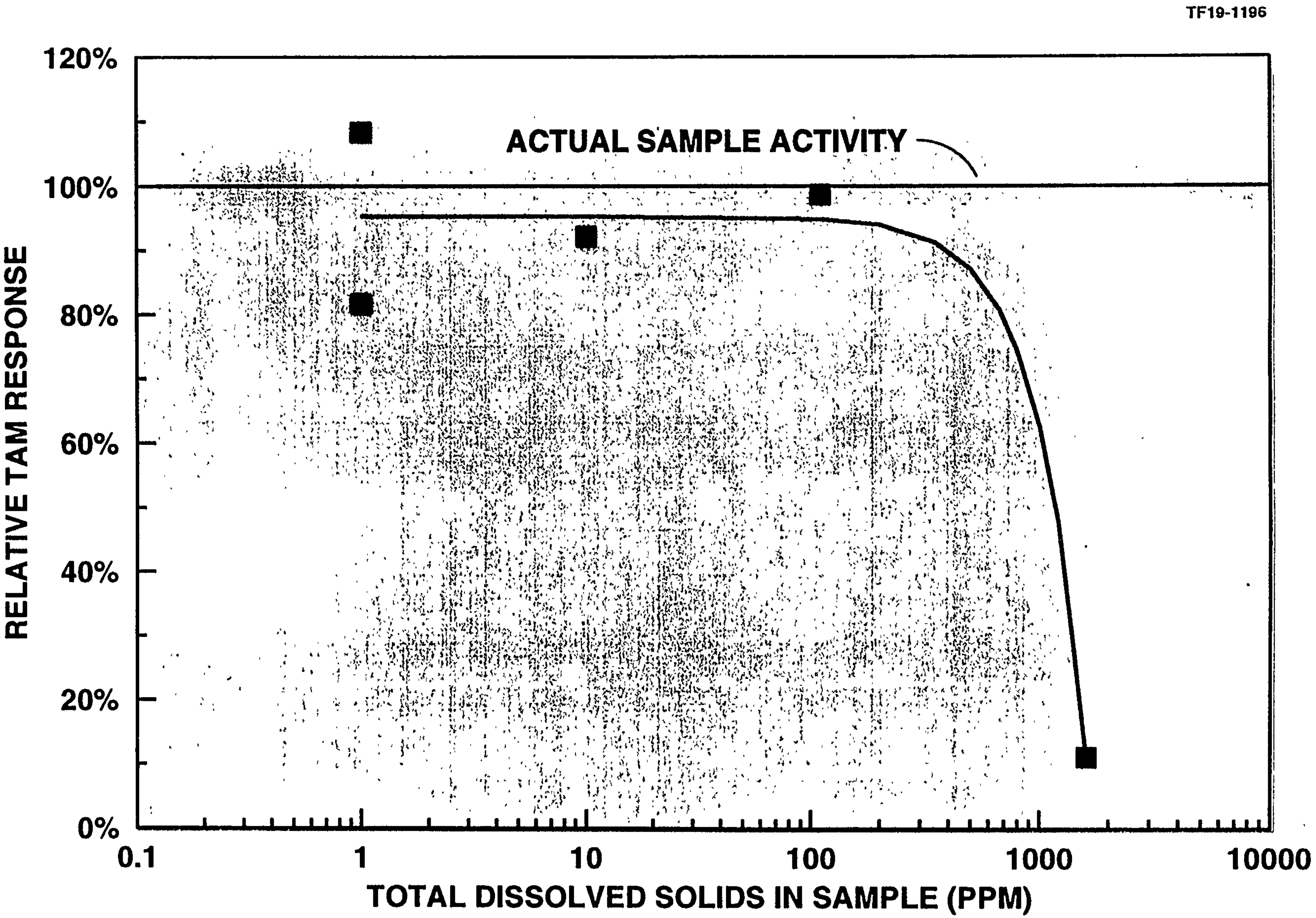

Figure 21. High Dissolved Solids' Impact on TAM Response

linear-energy-transfer (LET) of alpha particles in materials is well understood. The analysis is simplified by the fact that alpha particles travel in straight lines through materials. If required, automatic deconvolution of multiplets can be built into the TAM software.

Overall, deconvolution of laboratory data has involved joining the actual Gaussian peak shape on the high-energy side of a peak with a single exponential tailing function on the low energy side. Deconvolution of multiplets employs an iterative, logical progression from the highest-energy peak to the lowest-energy peak in the multiplet: by stripping the actual and fit values of the highest-energy peak from the multiplet, then repeating the deconvolution process on the residual lower-energy peaks of the multiplet. Triplets have been deconvoluted through this process; quadryplets (or more complicated multiplets) can be deconvoluted using the existing deconvolution procedure.

To assist in illustrating the basic steps of the deconvolution procedure, the spectrum shown in Figure 14's analysis of a 20 ppb natural uranium sample will now be analyzed. An initial iteration for the parameters of the exponential tailing function is obtained from performing a linear least-squares fit on the natural logarithm of the low-energy tail of the lowest-energy peak of the multiplet. Figure 22 illustrates the resultant least-squares fit.

These parameters are then used to determine an appropriate exponential tailing function for the highest-energy peak in the multiplet. The highest-energy peak's low-energy tailing function is smoothly joined to the higher-energy Gaussian peak by adjusting the pre-exponential factor. (Occasionally, a slight adjustment is made to the exponent to improve the tailing function's fit.) As a result, the highest-energy peak can now be defined by the actual data for the higher-energy Gaussian portion, along with the exponential low-energy tailing function (Figure 23).

Final deconvolution of the highest-energy peak occurs by subtracting both it's Gaussian and exponential portions from the multiplet. If only two peaks are present, the deconvolution is complete. If a total of three peaks are present, as in Figure 24, the deconvolution procedure is repeated to separate the higher-energy residual peak from the lower-energy residual peak (fitting a tailing function to the higher-energy peak, then stripping the residual high energy portion of the next peak and the corresponding low energy tailing function). Figure 25 contains the three resultant peaks that have been completely deconvoluted from the example spectrum. The ^{238}U:^{234}U:^{235}U isotope ratio is 1.0:0.69:0.034.

These techniques are similar to commercially available algorithms that automatically deconvolute thick source alpha spectra in commercial counting applications.

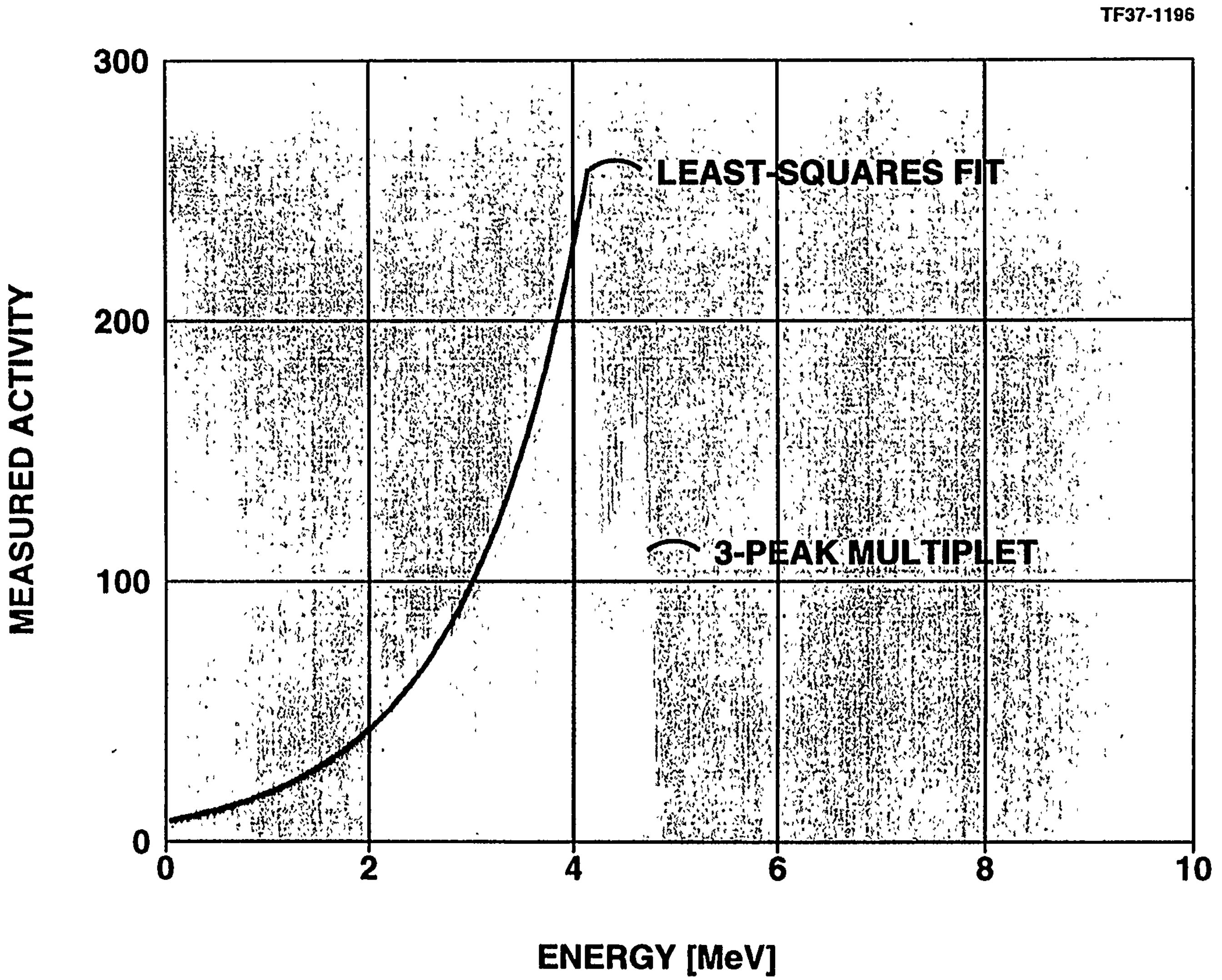

Figure 22. Multiplet Deconvolution: Logarithmic Least Squares Fit to Low-Energy Tail

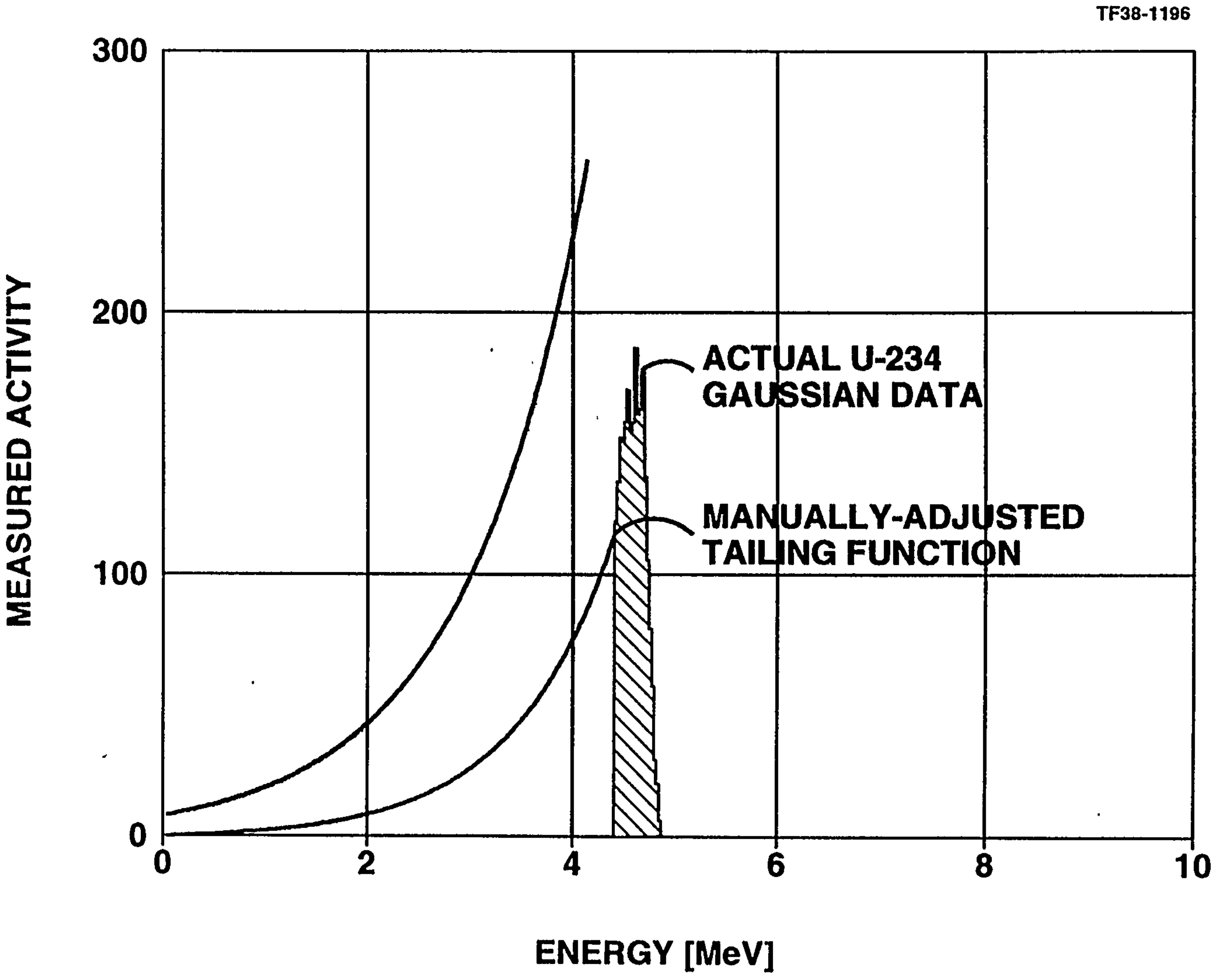

Figure 23. Multiplet Deconvolution: Manual Fit to Highest-Energy Tail

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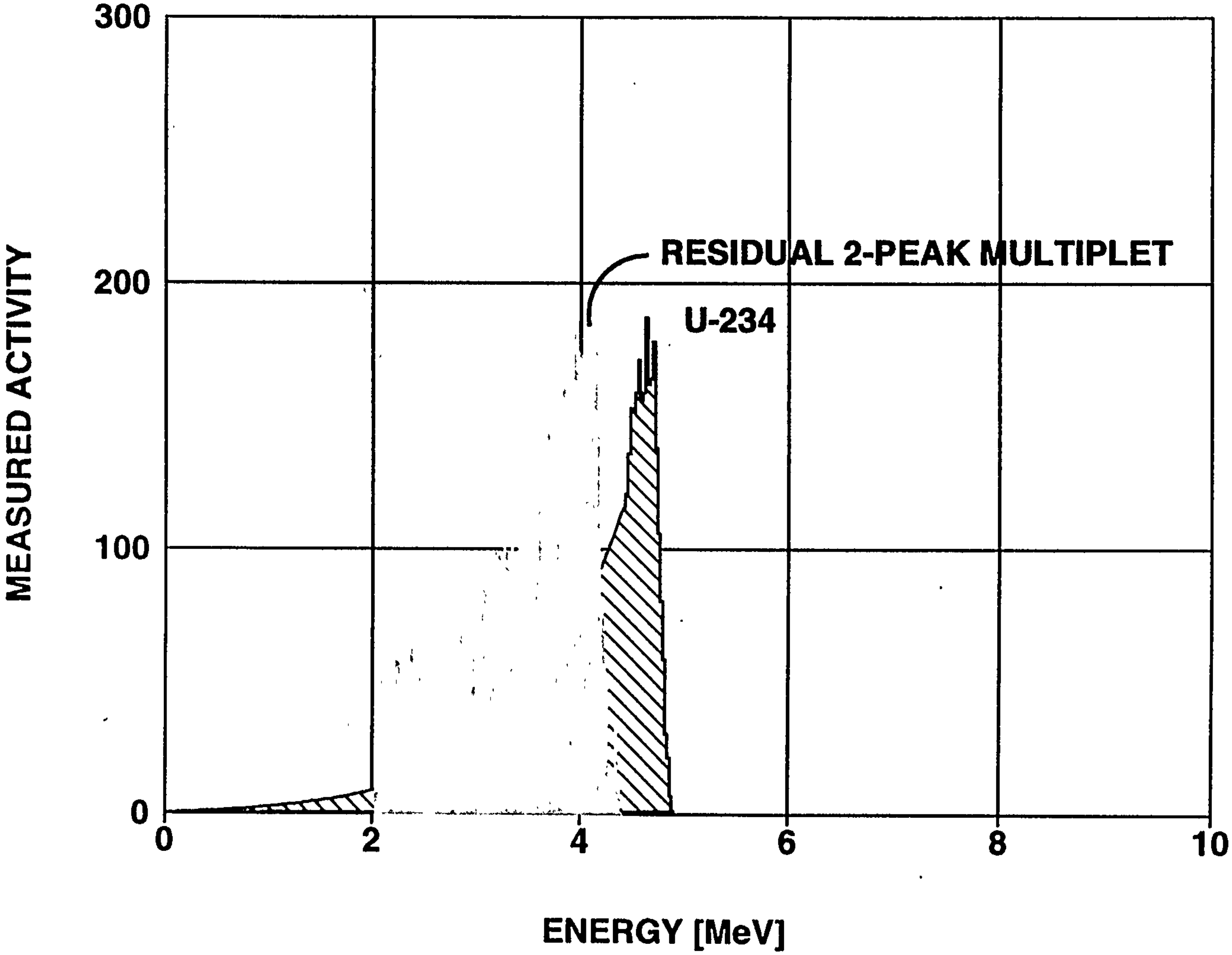


Figure 24. Multiplet Deconvolution: Resolved Peak and Residual Multiplet

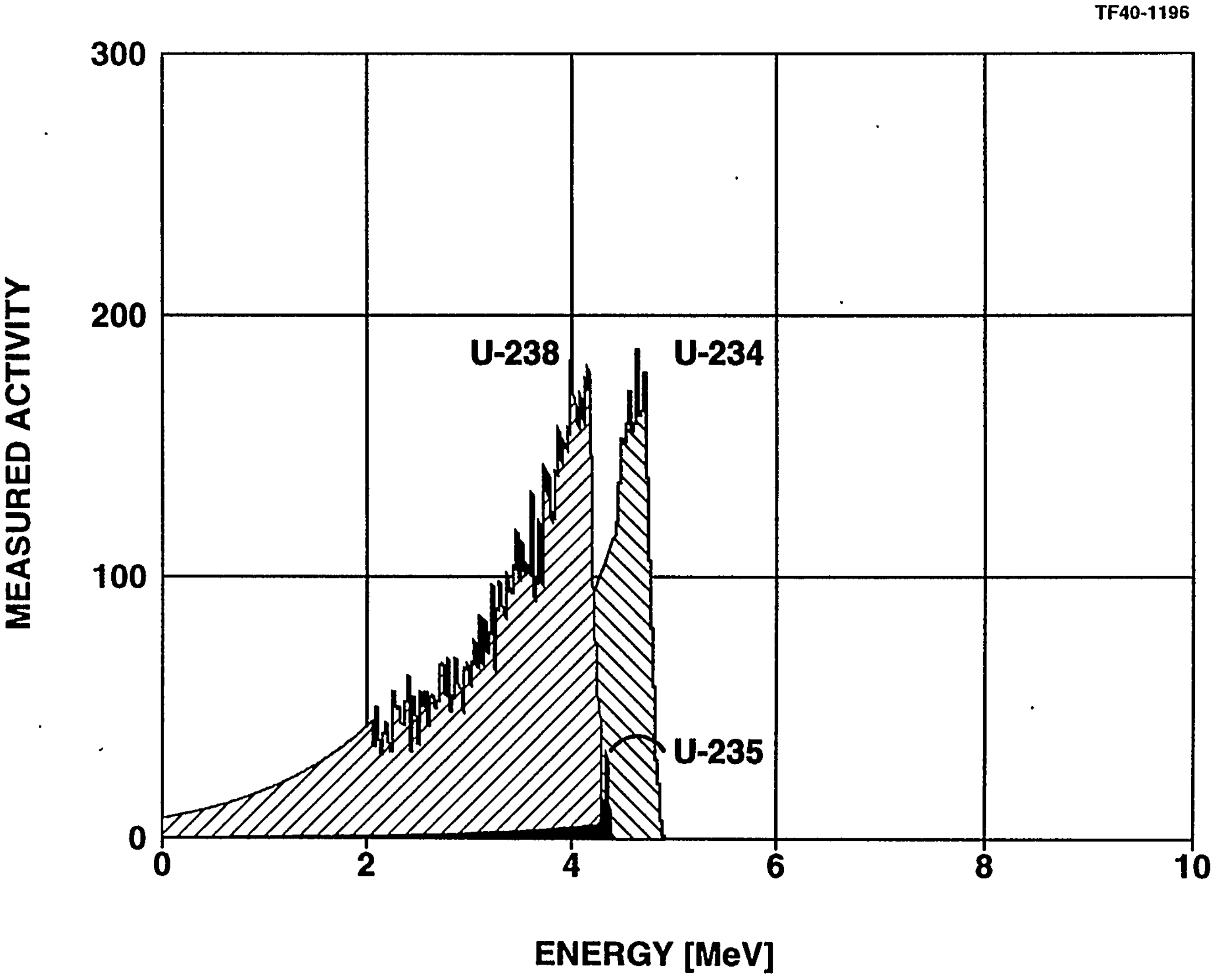


Figure 25. Multiplet Deconvolution: Three Peaks Resolved From Multiplet

Determination of Background

The best method of determining background has been to periodically perform a Blank Check, performed by analyzing a set volume of DI water with TAM. Figure 26 illustrates a typical blank check that was performed after Figure 14's analysis was completed. Generally, a Zero Count of the chamber (without any film or with an unused piece of TAM film in place) results in an extremely low count rate relative to the Blank Check (Zero well under 0.1% of Blank, as shown in Figure 27). Consequently, zero checks need to be done much less frequently than blank checks, or only as often as a site's data quality objectives (and perhaps by the site's QA/QC system).

Counts recorded during this Blank Check will then be summed in the various regions of interest (ROI) for each nuclide detected/analyzed in each analysis. These Blank Check count rates are then subtracted from the gross count rates for each isotope, resulting in the net count rates for each nuclide of interest.

Cleaning Details

The TAM field instrument will not need to be cleaned when it is analyzing multiple samples of the same stream; during these periods, a simple water rinse will be sufficient to remove transferable radioactivity from the film samples. However, when the TAM field instrument is moved between different field test sites, it will need to be cleaned. This cleaning will remove residual alpha-emitters from the first test site to very low levels and allow unbiased sampling of the potentially different second test site.

After repeated TAM laboratory analyses, simple soap and water wash/rinses have yielded Blank Check count rates that are less than 5% of normal 20 ppb natural uranium count rates. Such low Blank Check count rates will be suitable for accurate TAM instrument operation. To date, this has been the primary method of cleaning the TAM laboratory breadboard unit between analyses.

For even deeper cleaning, a 5% nitric acid rinse, followed by a DI water rinse, has been found to reduce Blank Check levels to less than 0.05% of normal 20 ppb natural uranium count rates. Such nitric acid cleaning is only expected to be required after an unexpectedly high activity sample has been analyzed by TAM, and the soap and water rinse is unable to restore the instrument to acceptable operation.

2.6 FIELD TEST INSTRUMENT DESIGN

2.6.1 Instrument Specifications

This section presents a summary of the overall requirements and needs for an On-line, Real-time Alpha Radiation Monitor for Liquid Streams. This information was obtained over the

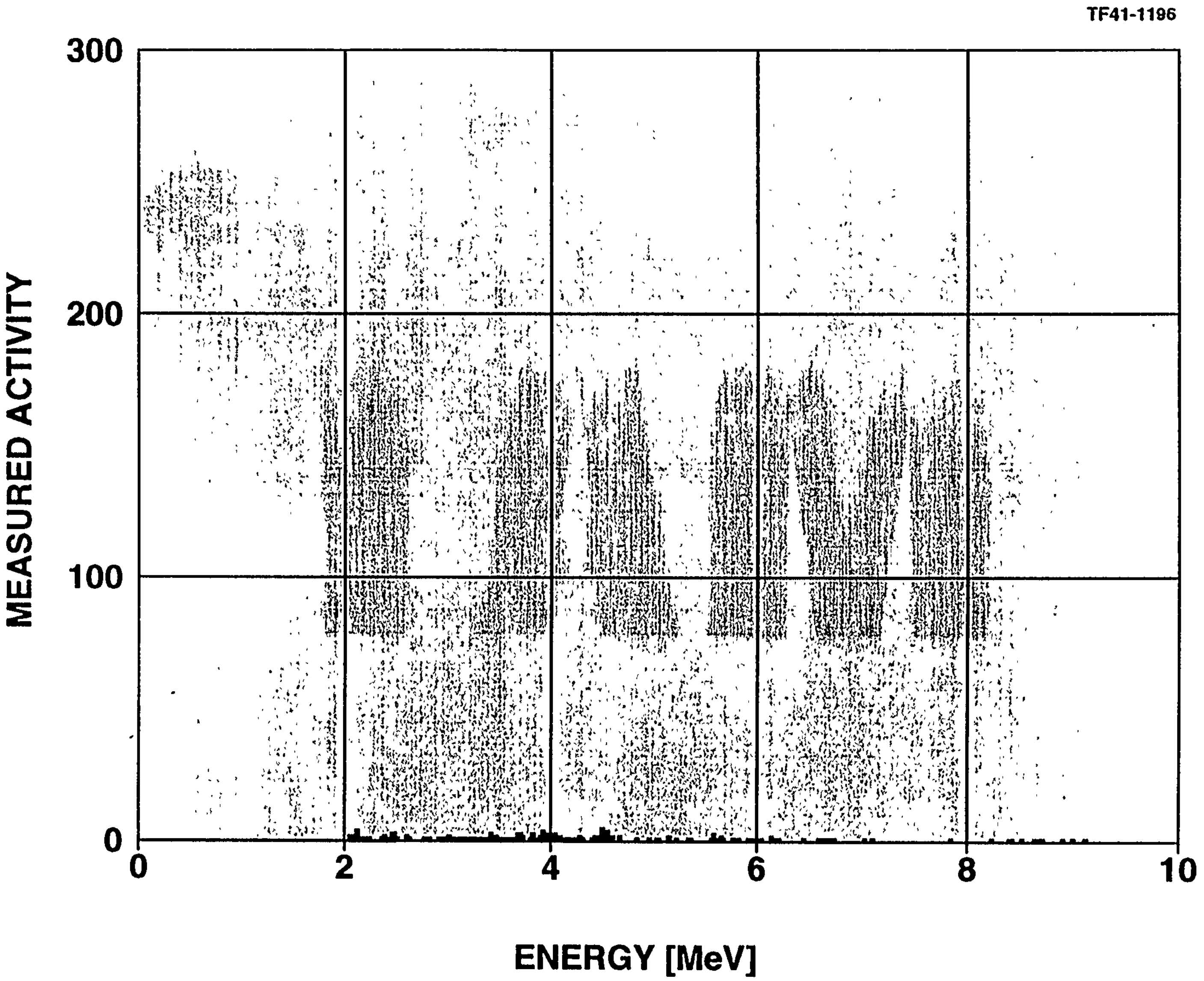


Figure 26. TAM Laboratory Test Results
Blank Check After 20 Parts per Billion Uranium and Simple Rinse

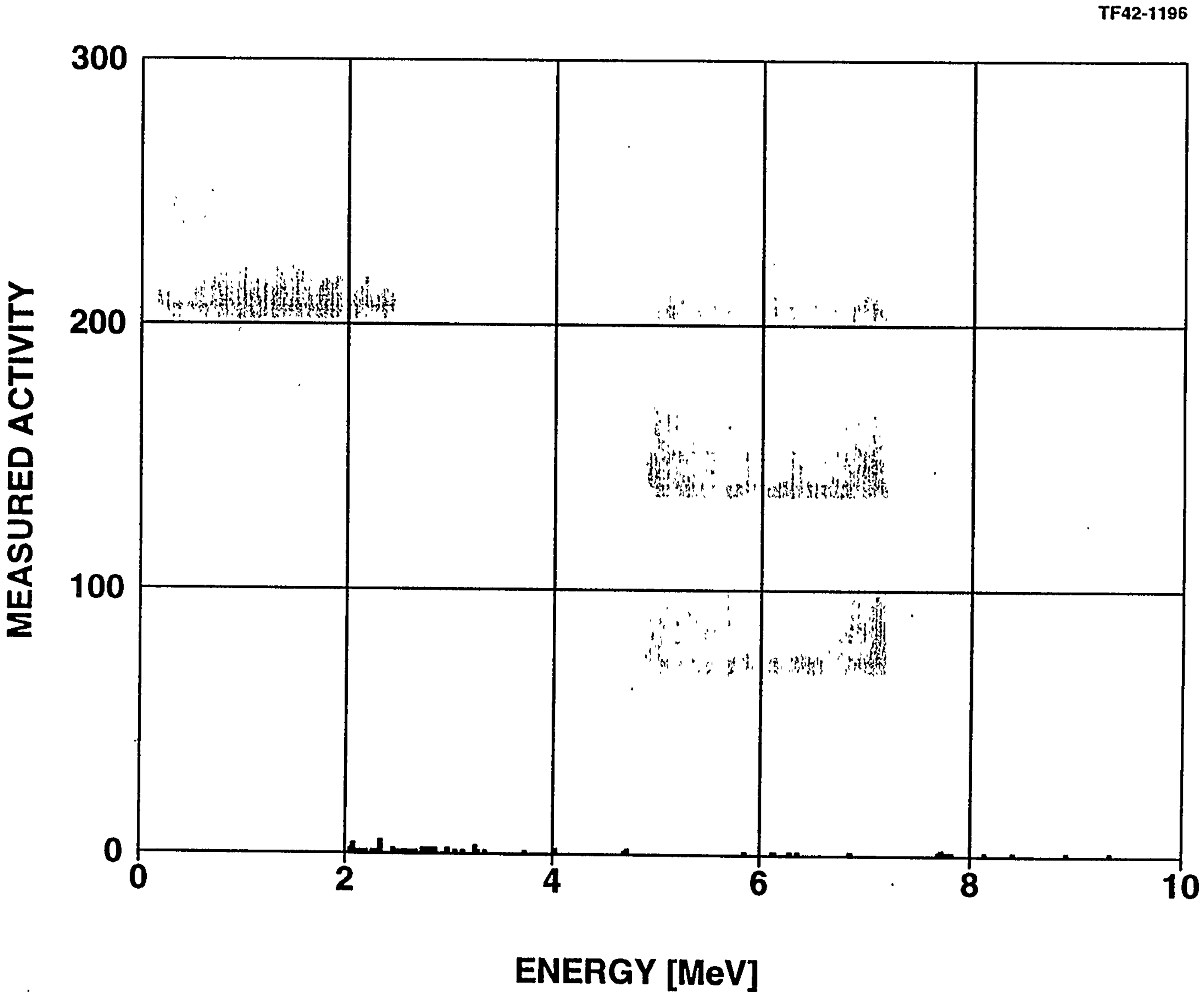


Figure 27. TAM Laboratory Test Results - Zero Check of Empty Instrument Chamber

course of the project from numerous conversations and interviews with DOE Headquarters, DOE Operations Office, M&O Contractor and commercial laboratory personnel. A consistent theme throughout these conversations was that any new, reliable alpha-measuring instrument that allows DOE to operate better, faster and cheaper will get widespread use across the DOE complex.

Federal government regulations provide a current framework for determining required minimum detection limits, data trending and analysis, and other features that would be required for any instrument measuring radionuclides in water. For instance, the maximum allowable concentration of natural uranium in any public drinking water stream is 20 ppb (30 pCi/liter), contained in 40CFR141, 142, the EPA's Proposed Rule for National Primary Drinking Water Regulations (the Safe Drinking Water Act (SDWA)). However, SDWA regulations also specify an adjusted gross alpha limit of 15 pCi/l; the proposed alpha-measuring instrument might also need to be capable of monitoring at this lower activity level.

Table 5 summarizes the product features required for an initial product.

TABLE 5

TAM REQUIRED FEATURES

Key Required Feature	Technology Status
On-line operation*	Achieved
Isotopic analysis at drinking water limits	Achieved and exceeded by 2000X
Certification	TBD
Archiving	Achieved
Two- to four-hour analysis time	Achieved (26 minutes as of 6/96)
Additional desirable features	
(Portability)	(Half height rack OK now, smaller is achievable)
(Remote data access)	(In-house network to date, no issues anticipated)

* The sampling mode may be either by batch (scheduled intervals or intermittent) or continuous for time-averaged data.

Identification of Principal Criteria for the Instrument Design

1. Operating Mode

The technology will allow for installation of the instrument so as to directly sample on-line, low-level radioisotope-containing water from water streams, as opposed to the conventional technique of collecting and bottling samples for transport to a central analytical laboratory.

2. Sensitivity

The instrument will be designed to analyze for alpha radiation to the drinking water limit of 15 pCi/l gross alpha-emitters in the water stream, including a limit of 30 pCi/l natural uranium limit.

3. Response Time

The present typical two-week total, end-to-end sample turnaround time will be reduced at least to a maximum of one day. Included will be the elimination of delays currently associated with manual sampling, logging, transport, manual chemical processing and handling, and report reconciliation.

4. Isotopic Analysis

Differentiation among radioisotopes will be provided by resolving the emitted alpha energies.

5. Certification

The design will be amenable to future certification by appropriate authorities (ASTM, EPA, etc.).

6. Archiving

A means will be provided to retain analyzed samples for future verification or additional analysis.

7. Automation

The instrument will be capable of operating unattended while making multiple sample analyses.

8. Minimize Secondary Waste

In routine operation, the instrument will not increase the contaminant levels in the water undergoing analysis.

9. Instrument Environment

The alpha instrument will be designed for indoor use.

Preliminary Specifications

Detection limit	30 pCi/l natural uranium, +/-50%
Sample turnaround time	1 to 12 hours, with a settable high-level alarm
Physical size	24" w x 24" l x 48" h
Consumables	film supply, de-ionized water
Power requirement	110 VAC, 15 A, 60 Hz, 1 phase
Operating temperature	10° Celsius to 35° Celsius
Relative humidity	20% to 90% noncondensing

2.6.2 User Interface

TAM is designed to be controlled using a standard personal computer that has been integrated into the TAM cabinet. The computer runs the Windows operating system environment. If the TAM user has any experience using Windows-based software, then the TAM control panel will afford a degree of familiarity without the need to learn a new and foreign interface.

The software has different security levels allowing varying levels of control when using TAM. The access to TAM is granted only upon successful entry of a password, which the user is prompted for when starting up the machine. On the lowest security level, the user is limited to viewing the operation and sequence of events as they occur in TAM. At the highest level, operating parameters such as alarm levels, run times, and instrument sequencing may be changed. At all levels of access, the user may stop the operation of TAM in case of an emergency.

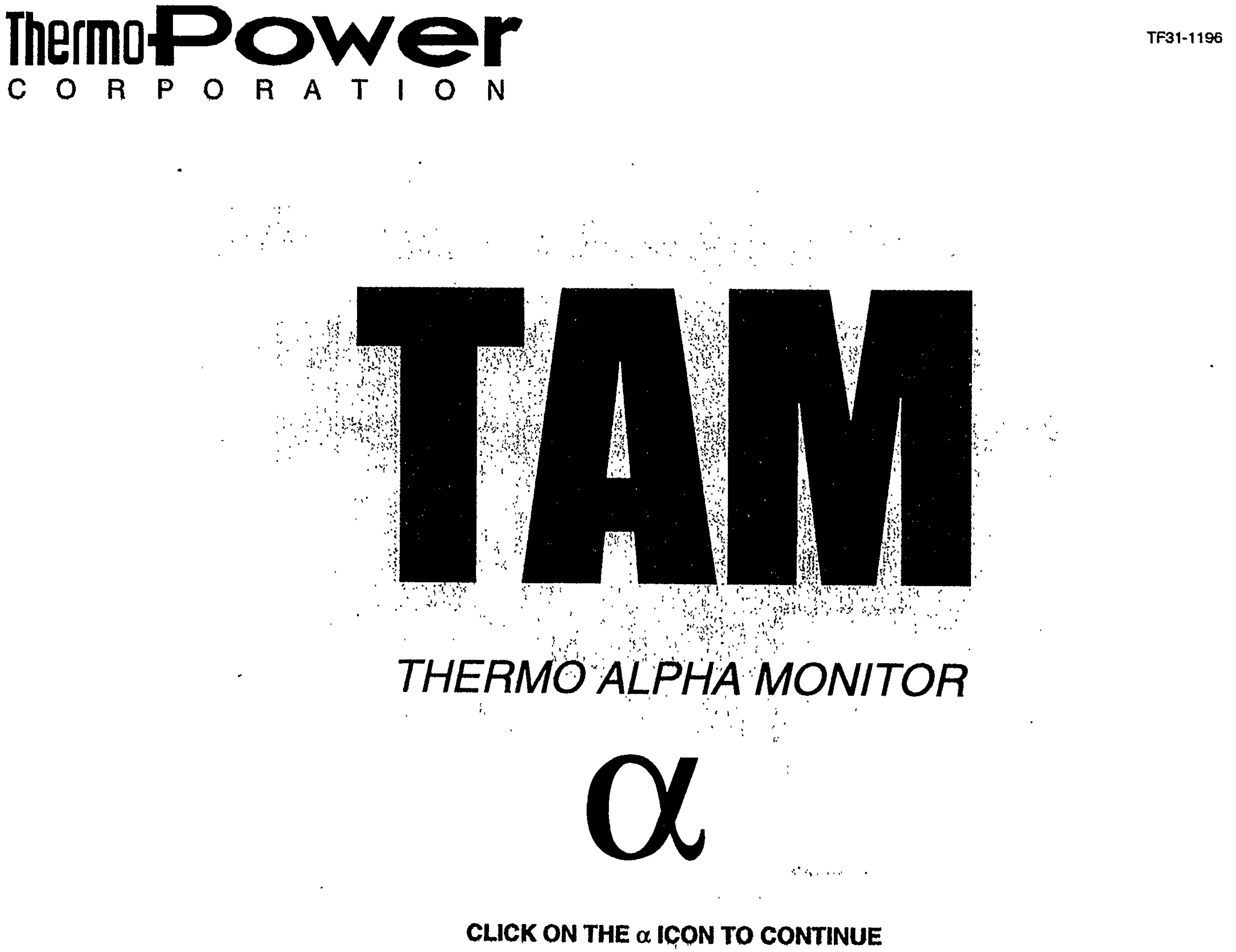
Figure 28 shows the opening screen, as it appears on the computer monitor. This screen appears under two conditions: 1) the first time power is applied to the system or 2) if a new user "logs in" to TAM. An example of a new user might be a supervisor who desires to change the operating conditions of TAM, as outlined above.

Main Menu

Once the user has successfully logged into the machine, the Main Menu appears, as shown in Figure 29. Depending on security access, the user may use a mouse to click on any of the option buttons on the screen.

The **[Run Analysis]** Button initiates the beginning of a sample sequence, based upon the parameters defined in the Set Up section of the software.

The **[Set Up Parameters]** button brings up an additional screen that controls the parameters under which TAM is to operate. Some of these parameters include Sample and Count Times, high and low alarm level triggers (temperatures, flow rates, etc.), as well as Annunciation methods (audible vs. silent alarms). Additionally, the user may choose to run a single or fixed



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TAM

THERMO ALPHA MONITOR

α

CLICK ON THE α ICON TO CONTINUE

Figure 28. TAM User Interface Opening Screen

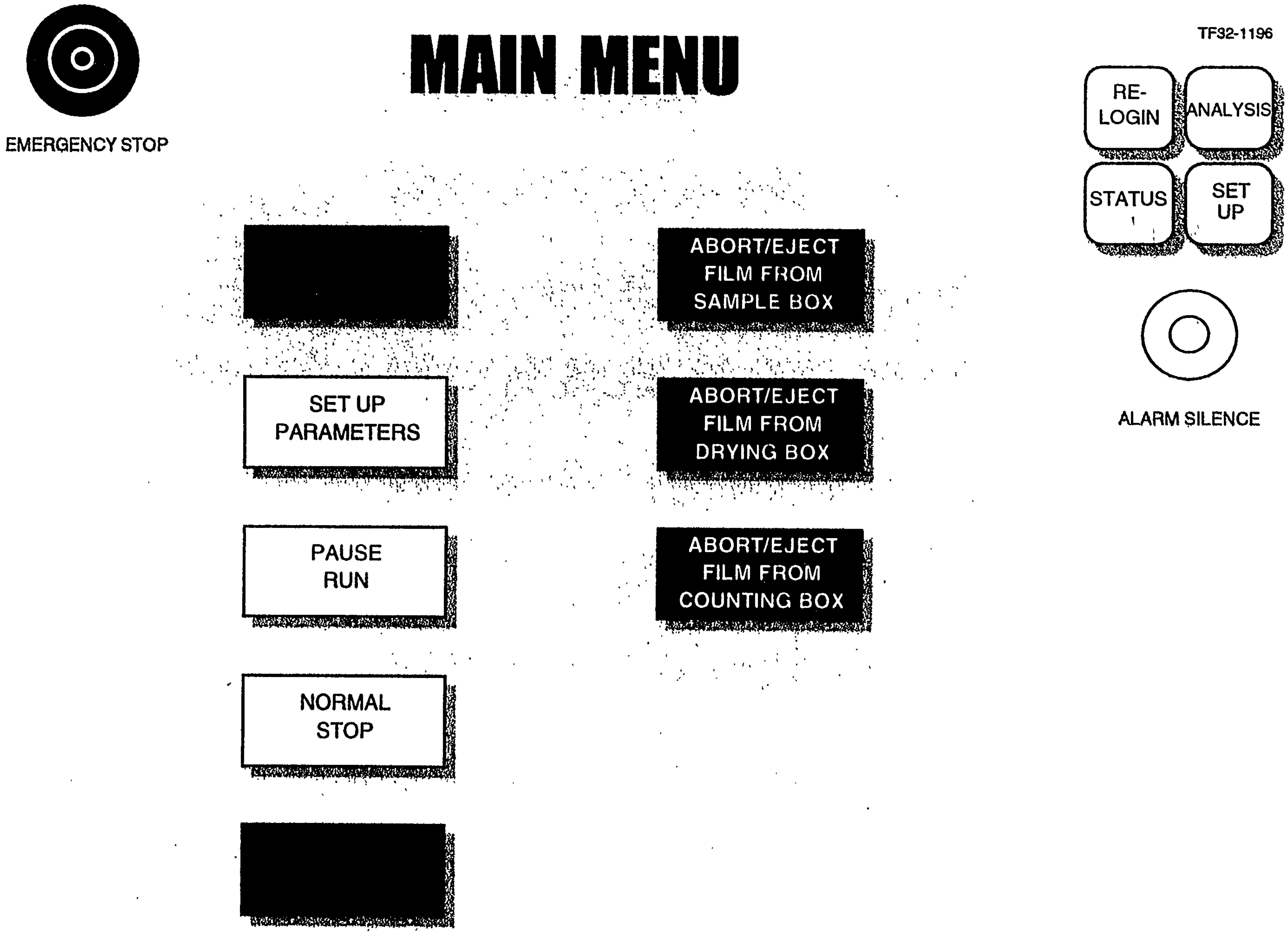

Figure 29. TAM Main Menu Screen

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number of analyses, or to operate in a continuous mode. This latter feature is useful when TAM is to be installed in remote locations where only periodic access will be available.

The **[Pause Run]** button temporarily suspends the operation of TAM without shutting down or resetting the equipment.

The **[Normal Stop]** button allows the user to stop the continuous operation of TAM at the end of the current analysis. This prevents the user from losing the most current analysis being performed.

The **[Review Data]** button allows the user to access a database of previously collected data and review it in a variety of graphical and tabular formats. This button also leads to options for printing reports for TAM as well as for storing data on floppy diskettes.

On the Main Menu screen there are also three **[Abort/Eject]** buttons. Pressing any of these buttons will immediately stop the selected process and eject any film from the affected chambers. For example, pressing "Eject Drying Chamber Film" ejects any film in the drying chamber without affecting the film in the sampling or counting chambers.

Also on the Main Menu, in the upper left-hand corner, there is an **[Emergency Stop]** button. This button will immediately stop all processes in TAM and disconnect power to the analyzer, but not the user interface screens nor the personal computer. The **[Emergency Stop]** button can be found on all of the interface screens with the exception of the Log-in screen.

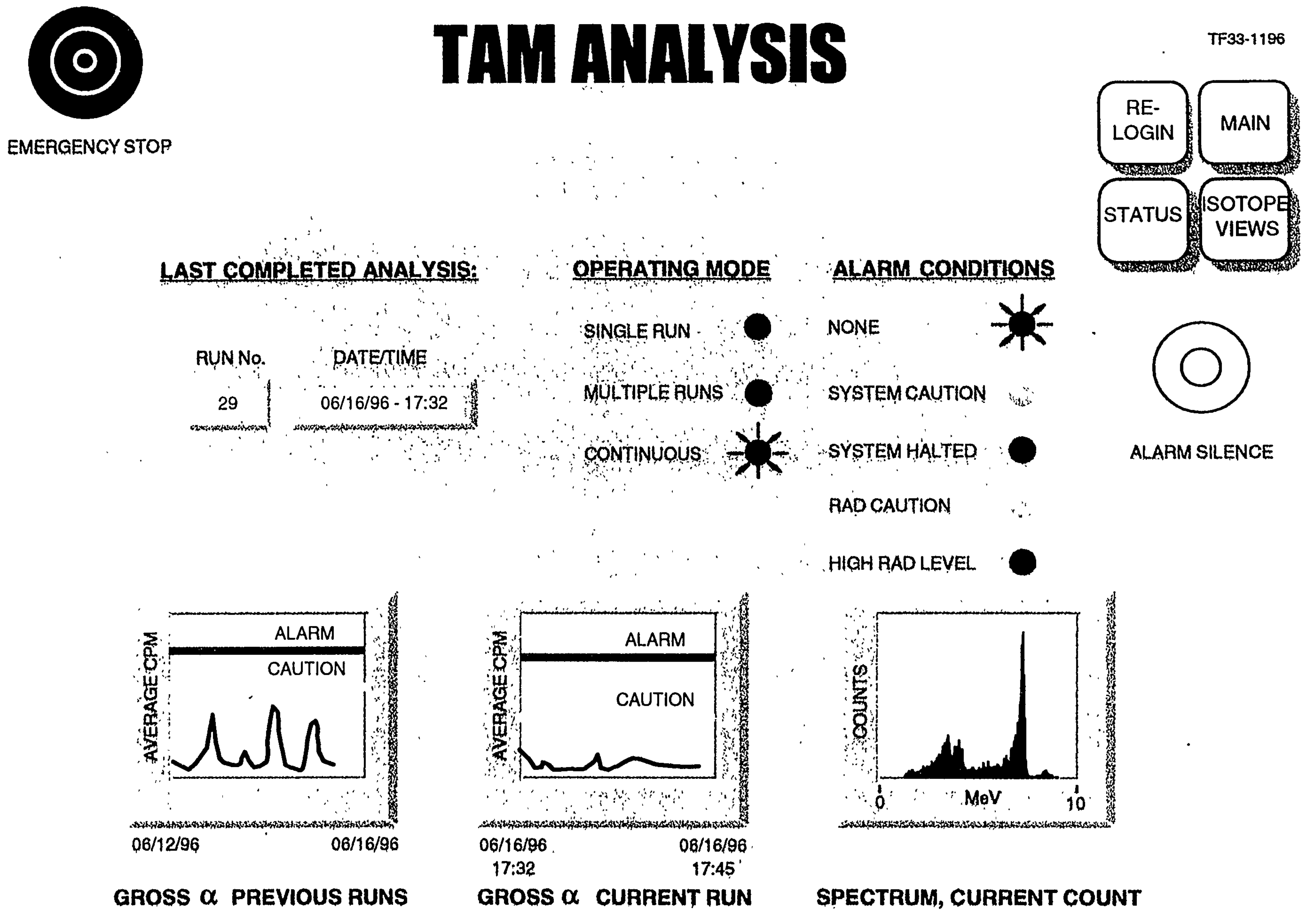
Another aspect that is common to all of the interface screens are the four buttons in the upper right-hand corner. These are quick access buttons that allow the user to directly switch to other sections/menus of the TAM operating system. These other sections/menus are described below.

Analysis Screen

The TAM Analysis screen presents a summary of information about present operating conditions as well as current and historical data. A sample TAM Analysis screen may be seen in Figure 30.

On the upper third of the screen, starting from left to right, is the Last Completed Analysis indicator. This indicator show the last successful and full analysis completed. There is also a counter that indicates the number of analyses that have been completed since the last time TAM was reset.

In the center are two sets of LEDs showing the Operating Mode and any alarms present in TAM.



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TAM ANALYSIS

LAST COMPLETED ANALYSIS:

RUN No.	DATE/TIME
29	06/16/96 - 17:32

OPERATING MODE

- SINGLE RUN ●
- MULTIPLE RUNS ●
- CONTINUOUS ✹

ALARM CONDITIONS

- NONE ✹
- SYSTEM CAUTION ○
- SYSTEM HALTED ●
- RAD CAUTION ○
- HIGH RAD LEVEL ●

Figure 30. TAM Analysis Screen

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Three trend indicators are located on the bottom third of the screen. The left indicator shows the Gross I count for all previous runs. The middle indicator shows the Gross I count for the current run. The right indicator shows the spectrum for the current run. The Gross Current and Spectrum indicators are updated every 60 seconds, as counts are read into the TAM. Alternate analysis screens can be displayed that detail isotopic data rather than gross I data.

Like all of the other screens, the upper left-hand area of the screen has an **[Emergency Stop]** button and the upper right-hand corner has four **[Quick Access]** buttons to switch to other areas of the TAM interface.

Status Screen

The TAM Status screen shows, in moderate detail, the current status of the instrumentation in a control panel format. Figure 31 shows a sample Status screen.

Under each chamber, there are indicator lights which show the status or mode of operation for each chamber. A green light indicates the current mode of operation. Next to each indicator light is a red LED used to indicate whether an alarm is present. Note also in the sample screen that the Drying Chamber is different from the Wet Chamber or Counting Chamber. The "split" chamber indicates that the drying chamber is currently in the open position and that no film is currently in the chamber. The Drying Chamber also has an analog temperature indicator. If the temperature rises above a preset level, the needle will change color from green to red to indicate that the temperature is too high in the chamber.

Each of the chambers is also equipped with a timer. The time indicated is always the amount of elapsed time since the last process was started or mode of operation was initialized.

On the left-hand side of the control panel are three level indicators and one status indicator. The three level indicators show the amount of material in each of the three containers. When a level reaches a preset low alarm level, the color of the indicator changes to red.

The Sample In Status indicator is green in color when the pump and filter are operating properly. If one or more pieces of equipment are not operating properly, the indicator will change to red.

Like all of the other screens, the upper left-hand area of the screen has an **[Emergency Stop]** button and the upper right-hand corner has four **[Quick Access]** buttons to switch to other areas of the TAM interface. On this screen, there is an additional button to shut off the power to the analyzer without shutting off the power to the interface.

TF34-1196

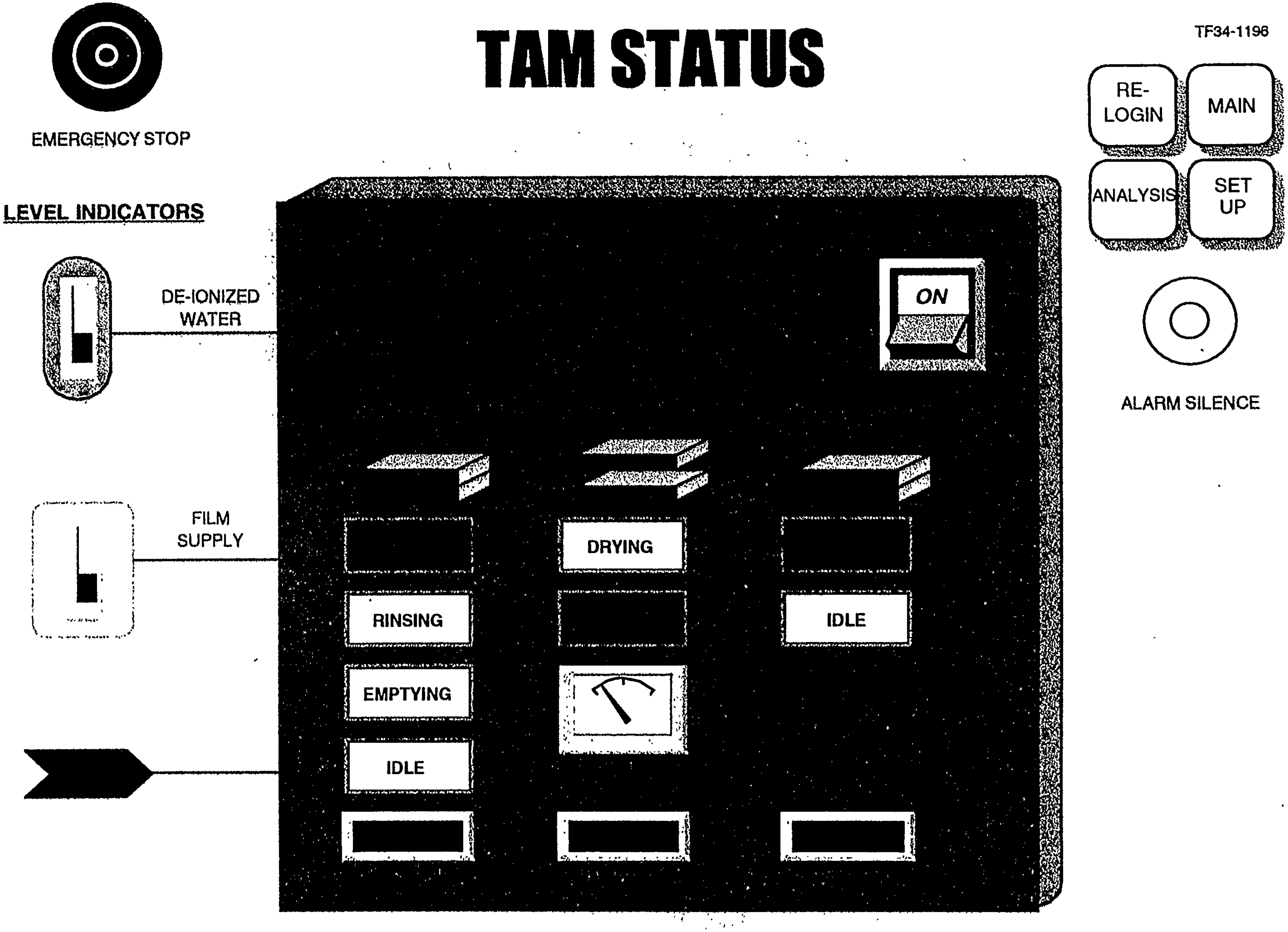

Figure 31. TAM Status Screen

Thermo Power CORPORATION

Detailed Component Status Screens

An additional feature of the TAM interface screens is the ability to look at the equipment and components connected to each of the chambers. By double clicking on any of the chambers on the Main Status screen, a detailed screen will be displayed. Figure 32 is an example of the Counting Chamber Status screen. On this screen, the user can determine which, if any, of the components need attention when an alarm is triggered; again, indicated by the specific color of a component changing from green to red. Pressure indicators also show the operating conditions of the air inlet filter as well as the vacuum in the Counting Chamber.

Like all of the other screens, the upper left-hand area of the screen has an **[Emergency Stop]** button and the upper right-hand corner has four **[Quick Access]** buttons to switch to other areas of the TAM interface.

2.7 PLANNED FIELD TEST DETAILS

2.7.1 Site Characterization

This section characterizes the Optional Phase II test sites for the project. Appendix 2 contains a summary of historical sampling data for nine locations that was supplied by site contractors at the Oak Ridge Reservation. These nine locations were chosen to be representative of those expected across the DOE Complex and were selected from three distinct Oak Ridge facilities:

- The Oak Ridge National Laboratory (ORNL)
- The Y-12 Plant
- The K-25 Plant (the old Gaseous Diffusion Plant).

The location selected from ORNL is the Influent to the Process Waste Treatment Plant (PWTP). This location is representative of those Wastewater Treatment Plants that process water known to be radionuclide-containing.

The location selected from the Y-12 Plant is the City Flow Monitoring Station. This location represents those sanitary sewer discharges from the DOE Complex that are routed off-site to a civilian wastewater treatment plant.

The seven locations selected from the K-25 Plant consist of various storm drains and surface waters that are tested during the normal course of K-25's environmental monitoring program. These locations represent the varied surface waters that are tested for radioactivity levels across the DOE Complex.

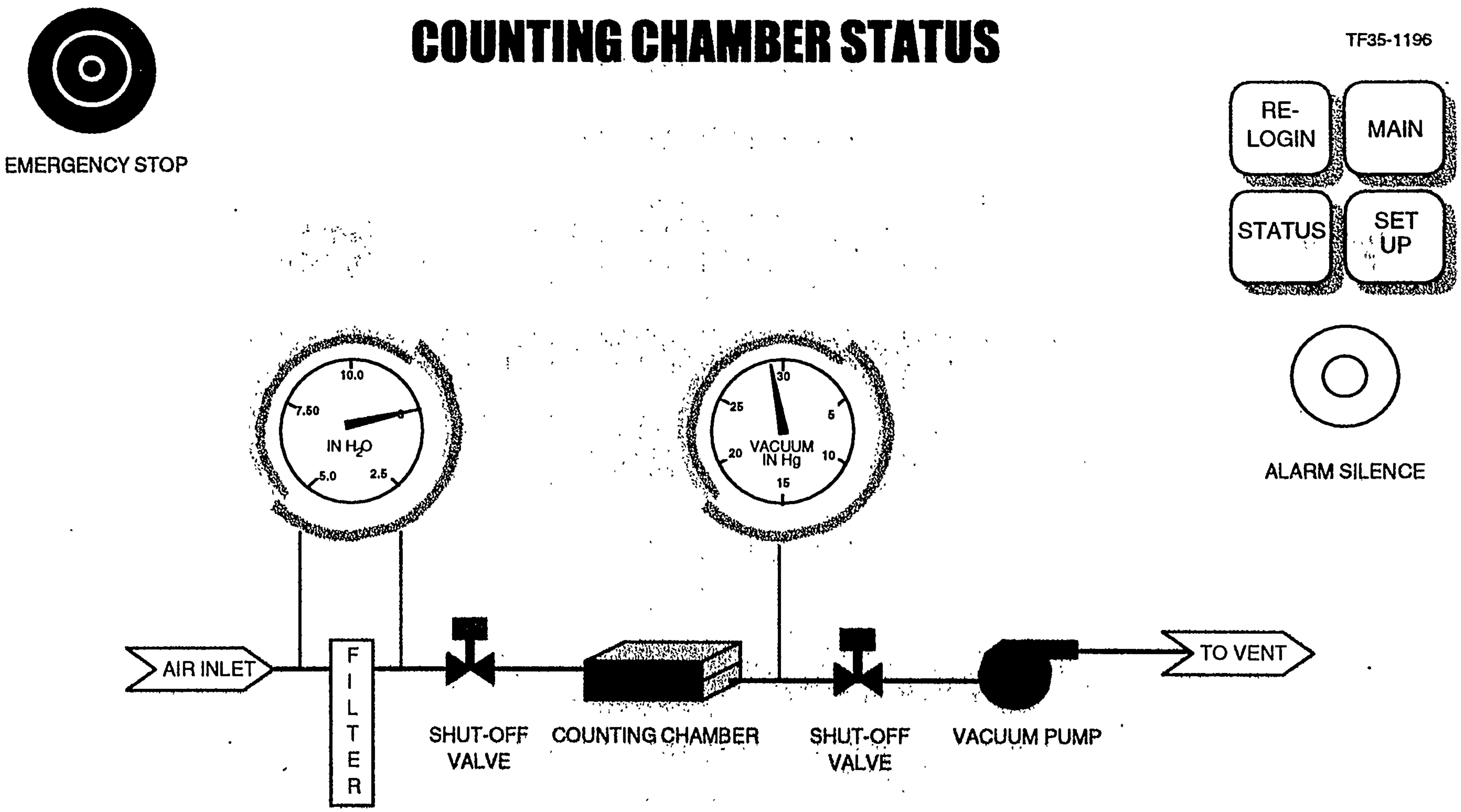

Figure 32. Representative TAM Detailed Component Status Screen

Overall, these nine sites have been selected from three of the major water types found across the DOE Complex:

- Process water
- Sanitary sewer water
- Surface waters

Final ranking and prioritization of these sites will result in a final selection of at least four sites for testing of the Thermo Alpha Monitor during Phase II (the Optional Phase) of the current program. It is anticipated that testing will include the ORNL PWTP, the Y-12 City Flow Monitoring Station, and two of the K-25 surface water sites.

2.7.2 Test Plan

The objective of the proposed Optional Phase Field Test is to confirm the instrument's proper operation and usefulness on a variety of contaminated waters at the Oak Ridge Reservation, including ground, surface and process waters.

Field testing will be conducted on several Oak Ridge test locations. Continuous monitoring with the instrument will be used to determine the uranium and other radioisotope concentration variations with time, as well as any excursions above regulatory limits. At intervals, stream samples will be taken and analyzed for uranium and other radioisotope concentrations by conventional means for direct comparison to the field test monitor results. The testing period will be six months duration.

It is expected that tests at four sites will be done. Time spent at each site will consist of two to four weeks of testing and an additional two weeks for data evaluation, test unit maintenance/modification, site results reporting, and moving to the next site.

Nine test sites have been selected, each location has been characterized. A range of water chemistries, contaminant concentrations and radioisotopes representative of expected conditions at the major areas of use across the DOE complex is desired.

The expected test sequence for each site is as follows:

1.) Laboratory check response of detector to sample of each stream (if available).

2.) Install and checkout the field test unit at first test location at Oak Ridge.

3.) Operate instrument at each site for two to four weeks and report results daily for all alpha-emitting radionuclides detected. Spot samples and proportional 24-hour average samples will be taken one time per week and analyzed by conventional methods for isotope content for direct comparison with the instrument results. Parameters to be studied in the testing may include:

a) Statistical accuracy vs. total count times.
b) Response time and statistical accuracy vs. sample flow rate to detector.
c) Reliability and life of detector and instrument.
d) Stability and reproducibility of instrument over extended test period.
e) Automated operation cycle and control of instrument.
f) Water chemistry.
g) Radioisotope type (within limits of those available at Oak Ridge).

Where shortcomings exist, the instrument will be modified to eliminate/alleviate the shortcomings and the testing continued.

4.) Prepare final report for each site.

5.) Move instrument to next site and continue testing.

3. ACHIEVEMENTS

With the successful completion of this program's Phase I, the Thermo Power on-line, real-time Alpha Monitor for liquid streams has proven to be not only a valuable laboratory tool, but also has demonstrated the ability to become the first known field-deployable instrument capable of measuring alpha-emitting radionuclides in water at parts-per-trillion (femto Curies per liter) levels. As it is an on-line real-time instrument, this accomplishment takes on even more significance. In particular, the accomplishments to date include:

- Extended the isotopic detection limit of the Alpha Monitor to 10 parts per trillion natural uranium (15 fCi/l), or 1/2000th the EPA's drinking water limit of 20 ppb, which is well under the program's goal of 30 pCi/l.

- Proven that the Thermo Alpha Monitor will respond to 20 ppb natural uranium (30 pCi/l) in under 30 minutes, well under the program's goal of a 1- to 12-hour instrument response time.

- Isotopically detected 1.5 pCi/l (2 ppb) total uranium in Carlisle, Massachusetts, groundwater, comparing quite favorably with 1 pCi/l levels of soluble uranium that were measured by conventional analysis methods.

- Isotopically detected thorium (^{232}Th) at 100 parts per trillion (17 fCi/l), as well as lesser amounts of thorium daughters and uranium.

- Demonstrated a linear dynamic range over greater than six decades of concentration, from 10 parts per trillion (15 fCi/l) to 10 parts per million (15 pCi/l) natural uranium, including levels of natural thorium between 100 parts per trillion (17 fCi/l) and 1 part per million (172 pCi/l).

- Confirmed that a simple soap and water wash is usually capable of removing residual radioisotopes to acceptably low background levels between consecutive, nonrepetitive analyses.

- Confirmed that a 5% nitric acid flush is capable of removing heavy deposits of residual radionuclides from the wetted parts of TAM, producing acceptably low background levels between consecutive, nonrepetitive analyses.

4. REMAINING ISSUES

The remaining technical and other issues in the development of the on-line, real-time Alpha Monitor for liquid streams can be summarized as follows:

- In the proposed Optional Phase II of this program, determine the robustness characteristics of the Thermo Alpha Monitor, when it is closely supervised by Thermo Power personnel in a series of field tests on waters representative of those from across the DOE complex; incorporate user feedback into an improved design.

- Determine the endurance characteristics of the Thermo Alpha Monitor, when it is used by non-Thermo Power personnel in a series of extended field tests; incorporate user feedback into an improved design.

- Improve our understanding of the underlying chemistry of the Alpha Monitor, through additional laboratory and/or field tests, in order to develop a peer-reviewed and agency-approved method for analyzing water streams.

- Continue the patenting of the Thermo Alpha Monitor technology on behalf of the DOE.

- Disseminate the technology and utility of the Alpha Monitor within the radiochemistry, DOE Environmental Management and other related fields in order to maximize knowledge of and interest in the technology.

- Pursue the commercialization of the Thermo Alpha Monitor for liquid samples while pursuing the development of related spin-offs, such as on-line, real-time alpha monitoring of air streams.

5. CONCLUSIONS

Thermo Power Corporation has proven the technical viability of an on-line, real-time alpha radionuclide instrument for aqueous sample analysis through comprehensive breadboard tests of the instrument. The instrument has been shown to be isotopically sensitive to extremely low (ten parts per trillion, or femto Curies per liter) levels of a broad range of radioisotopes. Performance enhancement and other scaling data obtained during the course of this investigation have shown that on-line, real-time operation is possible, with a sub 30-minute response time analyzing 20 ppb (30 pCi/l) natural uranium.

It is recommended that the Optional Phase II of the investigation begin without interruption in order to continue with field tests of the instrument. A primary task of the Optional Phase II effort involves assembling a prototype instrument that will be deployed at interested Oak Ridge Reservation sites for proof testing. After the successful completion of comprehensive field tests, Thermo Power plans to commercialize this instrument in order to provide the DOE with the capability of obtaining rapid feedback about the concentrations of alpha-emitting isotope contamination in effluent water streams (Subsurface Contaminants Focus Area). It will also be useful for process control of remediation and D&D operations such as monitoring scrubber/rinse water radioactivity levels (Mixed Waste Focus Area and D&D Focus Area).

APPENDIX 1

MERITS OF TAM TECHNOLOGY

TAM, the on-line, real-time monitor for direct measurement and identification of alpha-emitters in aqueous streams, meets real DOE needs at a large number of sites. The new technology on which the monitor is based has been demonstrated in the laboratory and is the only technology capable of providing an on-line, real-time monitor with the great sensitivity required for very low activity levels. The monitor will provide continuous assay and will be of use in both:

- Monitoring of effluent water streams from DOE sites to ensure compliance with regulatory limits and
- Process control in D&D and site remediation processes, such as monitoring mixed-waste thermal treatment scrubber/rinse water radioactivity levels, soil washing and wastewater treatment for off-site discharge.

Specific merits of the on-line, real-time monitor are discussed below.

A1.1 PERFORMANCE

Because of the very short range of alpha particles in liquids (40 micro meters), this new technology is the only approach that can rapidly identify and quantitatively assay alpha-emitters in aqueous streams. Further, the analysis method has great sensitivity and very low background and can be used to assay radionuclides at very low activity levels. The new instrument, with associated flow and counting equipment, permits on-line, real-time, automated monitoring of aqueous streams for alpha-emitting radionuclides over a very wide range, for natural uranium from less than 1 part per trillion (about 1 femto Curie per liter) to several hundred ppm's (100 ppm's ≅130,000 pCi/liter). The response time is, of course, faster for higher concentrations. Radionuclides can be detected at short times, with readily observable alpha peaks evident from the instrument at 10 counts per peak, corresponding to an instrument cycle time of five minutes at 600 ppb and 21 minutes at 1.0 ppb U. The statistical precision of the assay with 10 net counts in a peak is about ± 40%. The required sampling time and total count time can be varied, depending on the accuracy required in the detection and assay. For example, for 1.0 ppb U, the instrument cycle time required to achieve ± 15% accuracy (100 net counts) is 30 minutes, a factor of 1.4 higher than the above time, and ± 5% accuracy (1000 net counts) is a factor of 5.8 higher. However, 10 net counts in a peak is sufficient to clearly and positively detect and identify a radionuclide and to provide a ± 40% estimate of its concentration.

The proposed on-line, real-time instrument provides continuous information on the aqueous stream concentration at the site. With the conventional approach of collecting a sample, preserving the sample prior to shipment, shipping to a production analytical laboratory, separating the radionuclides from the water and plating them onto a planchet, counting the planchet, reducing the data, and transmitting the results to the requestor, several days up to weeks usually pass between collection and receiving the results. With the on-line, real-time monitor, results are available continuously, on-site and almost immediately. The conventional approach gives the concentration only at one specific time for each sample, with costs restricting the samples to infrequent intervals, often weekly or even quarterly. The concentration in between samples is not known. The continuous and immediately available data will be of great benefit in the efficient and effective operation and remediation of DOE sites, both for ensuring that water streams leaving DOE sites do not exceed regulatory limits for alpha-emitting radionuclides and for control of D&D and remediation processes, including mixed-waste thermal treatment scrubber/rinse water radioactivity levels monitoring.

A1.2 COST SAVINGS

The proposed on-line, real-time monitor will be cost-effective, relative to the use of conventional laboratory analyses, in addition to providing continuous rather than intermittent concentrations. The cost for conventional analyses has restricted the number of samples analyzed to date to less than a desirable level in many instances. As an example, 48 samples from Upper Bear Creek at the Y-12 plant at Oak Ridge were analyzed over 1991 with the following uranium concentrations:

Concentration, ppb for 48 Samples		
Maximum	Minimum	Average
848	98	224

A large variation is evident, leaving open the question of how the concentrations varied between the samples which were taken at an average of one sample every 7.6 days. More frequent sampling would clearly be useful.

The cost savings of the new monitor is dependent upon the sampling frequency. An initial investment for the monitor, estimated at $25,000, is required. Some labor is required for operation, maintenance and tracking/evaluation of results. With the conventional approach, each sample has a catalogue or contract cost by the laboratory, typically $125 per sample for an isotopic analysis. The overhead burden of site labor costs for collecting the sample, shipping the sample to the laboratory, and tracking/evaluation of results must be added to this conventional cost. For analysis with TAM, costs include those for operating supplies (film and de-ionized water), replacement parts (primarily detectors), and site overhead (an average of eight hours per week for replenishing supplies, calibrating and maintaining the instrument).

As illustrated in the following table, at a sampling rate as low as once per day (by conventional means), the proposed instrument would save almost $60,000 annually and pay for itself in five months.

Conventional Analysis

Sample Rate (per day)	1	6
Laboratory Cost at $100/Sample	$36,500	$219,000
Site Overhead at $200/Sample	$73,000	$438,000
Supplies	Negligible	Negligible
TOTAL ANNUAL COST	$109,500	$657,000

TAM, the On-Line, Real-Time, Automated Monitor

Sample Rate (Films per day)	1	6
Operating Supplies	$18,250	$109,500
Replacement Parts (Primarily Detectors)	$5,000	$5,000
Site Overhead at $600/Week (8 Manhours/Week)	$31,200	$31,200
TOTAL ANNUAL COST	$54,450	$145,700
SIMPLE PAYBACK PERIOD	5.4 months	0.6 months

If more frequent sampling by conventional means were desired, the cost benefits would be even more dramatic, since the cost of the on-line instrument remains constant. In addition, TAM can provide detailed information on the variation of the effluent concentration throughout the day.

Where frequent samples are not required, the instrument can be used to monitor several streams in sequence. It can also be modified to analyze batch water samples. TAM will thus be cost- effective, even where only limited samples are thought necessary and multiple streams are to be assayed.

In addition to these direct cost savings, the on-line, real-time quality of the data obtained will have important secondary cost savings. In remediation operations, immediate availability of data on process operations speeds up the remediation operations thereby reducing costs. In addition, continuous monitoring of process streams and effluent waters will eliminate/mitigate serious accidental release of radionuclides, particularly off-site, and prevent expensive clean-up resulting from such accidental releases. In effect, the on-site personnel will have much more data available almost immediately, and this increased knowledge will facilitate and reduce the costs of remediation operations.

A1.3 REDUCING PUBLIC AND OCCUPATIONAL HEALTH RISKS

The public risk will be greatly reduced by continuously monitoring all effluent streams for uranium concentration, thereby ensuring that no streams which exceed the regulatory limit leave the site. Even short excursions to high concentrations will be rapidly detected and can be used to immediately divert the stream to a holding area and/or warn of a problem. With the current approach, one sample of the total mixed effluent per day is taken and analyzed. If some problem on-site resulted in high levels in the effluent, it could be days before the high levels were detected. The on-line, real-time monitoring will also increase the public's confidence that the remediation is being performed properly and without risk, minimizing public resistance to remediation operations and the DOE.

The monitor will have a smaller effect on reducing occupational health risks than in reducing risks to the public. Handling of samples will be minimized by the automated, on-site monitor. The solutions required for the monitor are relatively nonhazardous, with the most hazardous being dilute hydrochloric acid, which is less hazardous than many cleaning materials handled in the home.

A1.4 REDUCING ENVIRONMENTAL IMPACTS

Application of the on-line, real-time monitor to effluent waters will greatly reduce the possibility of off-site contamination by unexpected excursions of high alpha-emitting radionuclide concentrations in the effluent waters leaving the site. Such continuous and real-time monitoring will be particularly beneficial during remediation actions when the site is disturbed and unexpected releases might occur. TAM will ensure that no regulatory limits are exceeded.

A1.5 IMPROVING CLEAN-UP AND WASTE MANAGEMENT PROCESSING OPERATIONS

When used for process control, as in monitoring mixed-waste scrubber effluent, soil washing or wastewater treatment, the on-line, real-time monitor will facilitate operating the process at peak effectiveness and minimize the effluent concentrations. The on-line data will also be useful in preventing unexpected releases due to process failures, such as bleed-through of over-loaded ion exchange columns.

On-line, real-time instrumentation is an essential base for modern, continuous process control. At the Fernald site, for example, use of the monitor for continuous uranium concentration measurements of aqueous process streams will be very useful in both soil washing and at the Advanced Wastewater Treatment Plant for control of the process and in identifying impending process failures before they occur, so that corrective actions can be taken. Without this U monitor, the plant operators will be operating in the dark, with only historic data rather than current data.

A1.6 REDUCING THE TIME REQUIRED FOR REMEDIATION AND/OR WASTE MANAGEMENT/PROCESSING

The continuous, on-line, real-time data will give the remediation/process operators the information needed for optimum performance. This current information will eliminate wasted time and effort due to delays from waiting for conventional analyses, or due to remediation/process actions not properly performed and which must be reworked or repeated. Operations always go smoother and faster when one has immediate feedback, rather than having to guess based on old data and analyses.

A1.7 MINIMIZING GENERATED OR SECONDARY WASTES

The primary waste from operation of the monitor is dilute acid, which can be neutralized with basic materials, such as limestone, and converted to innocuous and non-hazardous material. The quantities of materials required are small and can be recycled, i.e., used for multiple chemical treatment and cleaning cycles before disposal is required. No samples are taken which must be disposed of since a slip-stream of the stream being monitored flows continuously through the detector and back to the stream downstream of the monitor. The radionuclides absorbed on the film are adherent, allowing for safe and stable archiving of the film for QA/QC purposes.

We believe the disposal problems for the monitor will be less than those for the conventional analytical approach, where samples are taken and shipped to a central laboratory for analysis. In our laboratory development work, the only waste sent to a disposal service is the solid basic material used for neutralization of the acids, even though the waste was suitable for the local landfill based on current regulations.

A1.8 ABILITY TO MEET REGULATORY REQUIREMENTS

As described in Section 2, the environmental impact will be minimized by use of the monitor, with the primary waste being a small quantity of solid basic material used for neutralizing acids.

The monitor has great sensitivity, having the ability to perform measurements of alpha-emitting radionuclide concentrations at levels far below proposed regulatory limits.

The quality of the data will be excellent. The monitor includes a standard calibration solution which is periodically used to calibrate the monitor (on the off-line instrument) and to ensure proper operation. Periodic analyses by conventional methods will be used to ensure that the monitor is operating satisfactorily and providing accurate analyses, with the monitor providing continuous measurements between conventional samples. Field experience with the monitor on particular streams will eliminate the need for these "check" samples, as the monitor becomes an accepted and standard method.

APPENDIX 2

HISTORICAL FIELD TEST SITE CHARACTERIZATION DATA
(Supplied by Site Contractors)

FIELD TEST SITE #1
OAK RIDGE NATIONAL LABORATORY
PROCESS WASTE TREATMENT PLANT INFLUENT

JULY 1989

RADIONUCLIDE	**CONCENTRATION Bq/L**
Gross Alpha	5
Gross Beta	1,000
Sr-90	750
Cs-137	110
Co-60	25
Eu-152	30
Eu-154	8
Eu-155	5
ZrNb-95	50
Ru-106	10

PARAMETER	**CONCENTRATION MG/L**
TOC	1.9
TDS	250
TSS	3
TOTAL HARDNESS	133
ALKALINITY	125

FEBRUARY 1994	**CONCENTRATION Bq/L**
Co-60	7.4
Cs-137	230
Eu-152	23
Eu-154	8.6
Eu-155	3.6

NOVEMBER 1994	**CONCENTRATION Bq/L**
Gross Alpha	20
Gross Beta	450

FIELD TEST SITE #2
Y-12 PLANT SANITARY SEWER
CITY FLOW MONITORING STATION

	7/8/93	7/16/93	7/20/93	7/28/93	8/5/93	8/13/93	8/17/93
TOTAL U (mg/L)	0.002	0.008	0.005	0.005	0.004	0.004	0.004
TOTAL % U-235	10	0.62	0.89	0.81	0.96	0.91	0.84
SOLUBLE U	0.001	0.005	0.003	0.004	0.003	0.003	0.001
SOLUBLE % U-235	13	0.63	0.96	0.96	1.1	1.0	1.0
INSOLUBLE U	0.001	0.003	0.002	0.001	0.001	0.001	0.003
INSOLUBLE % U-235	7	0.60	0.79	0.21	0.54	0.64	0.79

FIELD TEST SITES #3 - #9
K-25 SITE
ENVIRONMENTAL MONITORING PROGRAM RADIOLOGICAL DATA

Parameter/Site K1007B	Sample	Date	Results	Error	Units
Alpha Activity	940729-050	07/29/94	1.28E0	1.1E0	pCi/L
	940831-058	09/31/94	5.03E-1	1.5E0	pCi/L
	940930-136	09/30/94	2.34E-1	8.4E-1	pCi/L
	941031-042	10/31/94	3.28E0N	1.8E0	pCi/L
	941130-084	11/30/94	3.20E0	1.7E0	pCi/L
	941229-011	12/29/94	9.64E-1	9.2E-1	pCi/L
	950131-071	01/31/95	-7.57E-2	1.3E0	pCi/L
	950228-075	02/28/95	5.74E-1	9.3E-1	pCi/L
	950330-089	03/30/95	5.00E-1	9.0E-1	pCi/L
	950428-059	04/28/95	6.10E-1	1.1E0	pCi/L
Beta Activity	940729-050	07/29/94	5.99E0	2.8E0	pCi/L
	940831-058	08/31/94	5.35E0	2.7E0	pCi/L
	940930-136	09/30/94	7.79E0	2. 1E0	pCi/L
	941031-042	10/31/94	7.00E0	2.3E0	pCi/L
	941130-084	11/30/94	7.04E0	2.2E0	pCi/L
	941229-011	12/29/94	7.63E0	2. 1E0	pCi/L
	950131-071	01/31/95	7.63E0	2.2E0	pCi/L
	950228-075	02/28/95	7.58E0	2. 1E0	pCi/L
	950330-089	03/30/95	5.64E0	2.0E0	pCi/L
	950428-059	04/28/95	8.50E0	2.2E0	pCi/L
Cesium-137	940729-050	07/29/94	-6.62E0F	1.9E1	pCi/L
	940831-058	08/31/94	1.24E1E	3.5El	pCi/L
	940930-136	09/30/94	3.71E1E	7.7EI	pCi/L
	941031-042	10/31/94	6.43E0E	5.8El	pCi/L
	941130-094	11/30/94	9.44E-lE	3.7E0	pCi/L
	941229-011	12/29/94	-6.21E0F	1.lEl	pCi/L
	950131-071	01/31/95	-2.50E0F	1 lEl	pCi/L
	950228-075	02/28/95	1.50E0E	1.lEl	pCi/L
	950330-089	03/30/95	2.43E0E	3.8E0	pCi/L
	950428-059	04/28/95	1.00E0E	1.0E1	pCi/L
Neptunium-237	940729-050	07/29/94	0.00E0	6.6E-1	pCi/L
	940831-058	08/31/94	1.64E-1	3.3E-1	pCi/L
	940930-136	09/30/94	0.00E0N	3.IE-1	pCi/L
	941031-042	10/31/94	7.90E-2	1 6E-1	pCi/L
	941130-094	11/30/94	1.90E-1	3.8E-1	pCi/L
	941229-011	12/29/94	2.40E-IN	2.8E-1	pCi/L
	950131-071	01/31/95	0.00E0N	2.4E-1	pCi/L
	950228-075	02/28/95	1.40E-1	2.8E-1	pCi/L
	950330-089	03/30/95	0.00E0	2.4E-1	pCi/L
	950428-059	04/28/95	7.17E-2	1.4E-1	pCi/L

Parameter	Sample	Date	Results	Error	Units
K1007B (continued)					
Plutonium-238	940729-050	07/29/94	0.00E0	7.2E-1	pCi/L
	940831-058	08/31/94	-1.79E-1	7.2E-1	pCi/L
	940930-136	09/30/94	-9.75E-2	3.9E-1	pCi/L
	941031-042	10/31/94	0.00E0	2..1E-1	pCi/L
	941130-094	11/30/94	8.87E-2	3.1E-1	pCi/L
	941229-011	12/29/94	7.47E-2	2.6E-1	pCi/L
	950131-071	01/31/95	-1.33E-1	3.8E-1	pCi/L
	950228-075	02/28/95	2.70E-1	3.8E-1	pCi/L
	950330-089	03/30/95	4.29E-1	3.8E-1	pCi/L
	950428-059	04/29/95	0.00E0	3.3E-1	pCi/L
Plutonium-239	940729-050	07/29/94	4.18E-1	5.9E-1	pCi/L
	940831-058	08/31/94	0.00E0	6.2E-1	pCi/L
	940930-136	09/30/94	-9.75E-2	3.9E-1	pCi/L
	941031-042	10/31/94	0.00E0	2.6E-1	pCi/L
	941130-084	11/30/94	8.87E-2	1.8E-1	pCi/L
	941229-011	12/29/94	0.00E0	2.6E-1	pCi/L
	950131-071	01/31/95	0.00E0	2.3E-1	pCi/L
	950228-075	02/28/95	6.74E-2	1.3E-1	pCi/L
	950330-089	03/30/95	-8.58E-2	3.4E-1	pCi/L
	950428-059	04/28/95	0.00E0	1.8E-1	pCi/L
Potassium-40	940729-050	07/29/94	4.39E2	2.7E2	pCi/L
Prep (PCB-)	950330-089	03/30/95			
Prep (PCB-)	940831-058	08/31/94			
	940930-136	09/30/94			
	941031-042	10/31/94			
	941130-094	11/30/94			
	941229-011	12/29/94			
Technetium-99	940729-050	07/29/94	-1.04EI	3.6E1	pCi/L
	940831-058	08/31/94	1.49E0	3.7E1	pCi/L
	940930-136	09/30/94	1.53E1	3.7E1	pCi/L
	941031-042	10/31/94	-1.74E1	2.1E1	pCi/L
	941130-084	11/30/94	9.62E0	2.1E1	pCi/L
	941229-011	12/29/94	-1.61E0	2.1E1	pCi/L
	950131-071	01/31/95	1.41E1	2.1E1	pCi/L
	950228-075	02/29/95	1..01E1	2.1E1	pCi/L
	950330-089	03/30/95	2.69E1	2.1E1	pCi/L
	950428-059	04/28/95	7.00E1	2.2E1	pCi/L
Thorium-234	940930-136	09/30/94	7.27E2H	7.0E2	pCi/L
	950428-059	04/28/95	1.00E2H	9.6E1	pCi/L

Parameter	Sample	Date	Results	Error	Units
K1007B (continued)					
Uranium-234	940729-050	07/29/94	7.67E-1	7.7E-1	pCi/L
	940831-058	08/31/94	1.48E0	1.0E0	pCi/L
	940930-136	09/30194	5.81E-1	4.7E-1	pCi/L
	941031-042	10/31/94	3.87E-1	5.8E-1	pCi/L
	941130-094	11/30/94	9.45E-1	4.5E-1	pCi/L
	941229-011	12/29/94	2.04E0	7.5E-1	pCi/L
	950131-071	01/31/95	6.67E-1	4.2E-1	pCi/L
	950229-075	02/29/95	1.95E-1	4.3E-1	pCi/L
	950330-089	03/30/95	6.31E-1	4.5E-1	pCi/L
	950428-059	04/28/95	1.91E0	7.3E-1	pCi/L
Uranium-235	940729-050	07/29/94	-8.33E0F	1.7E1	pCi/L
	940831-058	08/31/94	6.08E0E	6.7E1	pCi/L
	940930-136	09/30/94	-1.85E1F	9.3E1	pCi/L
	941031-042	10/31/94	5.18E1E	7.0E1	pCi/L
	941130-094	11/30/94	4.29E0E	6.1E0	pCi/L
	941229-011	12/29/94	-6.19E0F	1.5E1	pCi/L
	950131-071	01/31/95	-9.72E0F	1.5E1	pCi/L
	950228-075	02/28/95	-5.08E0F	1.5E1	pCi/L
	950330-089	03/30/95	-1.22E0F	6.0E0	pCi/L
	950428-059	04/28/95	-1.41E1F	1.5E1	pCi/L
Uranium-236	940729-050	07/29/94	0.00E0	6.6E-1	pCi/L
	940831-058	08/31/94	2.97E-1	4.2E-1	pCi/L
	940930-136	09/30/94	0.00E0	2.2E-1	pCi/L
	941031-042	10/31/94	6.45E-2	1.3E-1	pCi/L
	941130-084	11/30/94	5.25E-2	1.0E-1	pCi/L
	941229-011	12/29/94	-6.20E-2	2.5E-1	pCi/L
	950131-071	01/31/95	0.00E0	2.3E-1	pCi/L
	950228-075	02/28/95	6.51E-2	1.3E-1	pCi/L
	950330-089	03/30/95	0.00E0	1.8E-1	pCi/L
	950428-059	04/28/95	1.41E-1	2.0E-1	pCi/L
Uranium-238	940729-050	07/29/94	1.92E-1	3.8E-1	pCi/L
	940831-058	08/31/94	1.34E0	8.9E-1	pCi/L
	940930-136	09/30/94	1.94E-1	2.9E-1	pCi/L
	941031-042	10/31/94	3.22E-1	2.9E-1	pCi/L
	941130-094	11/30/94	1.05E-1	1.5E-1	pCi/L
	941229-011	12/29/94	5,58E-1	4.5E-1	pCi/L
	950131-071	01/31/95	4.67E-1	3.5E-1	pCi/L
	950228-075	02/28/95	2.60E-1	2.6E-1	pCi/L
	950330-089	03/30/95	2.10E-1	2.1E-1	pCi/L
	950428-059	04/29195	3.53E-1	3.2E-1	pCi/L

Parameter	Sample	Date	Results	Error	Units
K1700					
Alpha Activity	940729-052	07/29/94	1.00E1	2.9E0	pCi/L
	940831-060	08/31/94	1.54E1	4.0E0	pCi/L
	940930-138	09/30/94	1.04E1	2.4E0	pCi/L
	941031-044	10/31/94	1.01E1	2.4E0	pCi/L
	941130-096	11/30/94	1.06EI	2.3E0	pCi/L
	941229-013	12/29/94	8.24E0	2.0E0	pCi/L
	950131-073	01/31/95	7.59E0	2.1E0	pCi/L
	950228-077	02/29/95	6.37E0	1.8E0	pCi/L
	950330-091	03/30/95	9.00E0	2.2E0	pCi/L
	950429-056	04/29/95	7.72E0	1.8E0	pCi/L
Beta Activity	940729-052	07/29/94	1.52E1	3.5E0	pCi/L
	940831-060	08/31/94	2.05E1	4.0E0	pCi/L
	940930-138	09/30/94	2.36E1	3.4E0	pCi/L
	941031-W	10/31/94	1.88E1	2.7E0	pCi/L
	941130-086	11/30/94	1.79E1	2.6E0	pCi/L
	941229-013	12/29/94	1.24E1	2.4E0	pCi/L
	950131-073	01/31/95	1.25E1	2.4E0	pCi/L
	950228-077	02/29/95	1.26E1	2.5E0	pCi/L
	950330-091	03/30/95	1.31E1	2.6E0	pCi/L
	950428-056	04/28/95	1.25E1	2.3E0	pCi/L
Cesium-137	940729-052	07/29/94	8.00E0E	3.4E1	pCi/L
	940831-060	08/31/94	3.37E0E	3.5E1	pCi/L
	940930-138	09/30/94	-6.28E1F	8.6E1	pCi/L
	941031-044	10/31/94	6.93E1	5.3E1	pCi/L
	941130-086	11/30/94	-3.51E-1F	3.8E0	pCi/L
	941229-013	12/29/94	4.71E0E	1.0E1	pCi/L
	950131-073	01/31/95	-1.50E0F	1 1E1	pCi/L
	950228-077	02/28/95	-3. 10E0F	1.1E1	pCi/L
	950330-091	03/30/95	1.65E0E	3.6E0	pCi/L
	950428-056	04/28/95	1.50E0E	1.1E1	pCi/L
Neptunium-237	940729-052	07/29/94	7.62E-1	7.6E-1	pCi/l
	940831-060	08/31/94	1.66E-1	3.3E-1	pCi/L
	940930-138	09/30/94	0.00E0	3.2E-1	pCi/L
	941031-044	10/31/94	9.61E-1	5.5E-1	pCi/L
	941130-086	11/30/94	8.01E-2	2.8E-1	pCi/L
	941229-013	12/29/94	8.21E-2	1.6E-1	pCi/L
	950131-073	01/31/95	2.13E-1	2.5E-1	pCi/L
	950228-077	02/28/95	1.43E-1	2.9E-1	pCi/L
	950330-091	03/30/95	7.17E-2	1.4E-1	pCi/L
	950428-056	04/28/95	7.02E-2	1.4E-1	pCi/L
Plutonium-238	940729-052	07/29/94	8.34E-1	8.3E-1	pCi/L
	940831-060	08/31/94	-1.82E-1	7.3E-1	pCi/L
	940930-138	09/30/94	-1.00E-1	4.0E-1	pCi/L

Parameter	Sample	Date	Results	Error	Units
K1700 (continued)					
Plutonium-238	941031-044	10/31/94	2.24E-1	3.3E-1	pCi/L
	941130-096	11/30/94	-7.47E-2	3.0E-1	pCi/L
	941229-013	12/29/94	0.00E0	2.2E-1	pCi/L
	950131-073	01/31/95	6.74E-2	4.5E-1	pCi/L
	950228-077	02/28/95	0.00E0	2.8E-1	pCi/L
	950330-091	03/30/95	0.00E0	2.6E-1	pCi/L
	950428-056	04/28/95	-1.52E-1	2.7E-1	pCi/L
Plutonium-239	940729-052	07/29/94	2.09E-1	4.2E-1	pCi/L
	940831-060	08/31/94	0.00E0	6.3E-1	pCi/L
	940930-138	09/30/94	-1.00E-1	4.0E-1	pCi/L
	941031-044	10/31/94	0.00E0	2.6E-1	pCi/L
	941130-096	11/30194	0.00E0	2.6E-1	pCi/L
	941229-013	12/29/94	0.00E0	2.7E-1	pCi/L
	950131-073	01/31/95	0.00E0	2.3E-1	pCi/L
	950228-077	02/29/95	0.00E0	2.4E-1	pCi/L
	950330-091	03/30/95	-7.45E-2	3.0E-1	pCi/L
	950428-056	04/28/95	0.00E0	1.8E-1	pCi/L
Technetium-99	940729-052	07/29/94	-3.22E1	3.5E1	pCi/L
	940831-060	08/31/94	1.85E1	3.7E1	pCi/L
	940930-138	09/30/94	2.36E1	3.7E1	pCi/L
	941031-044	10/31/94	1.98E0	2.1E1	pCi/L
	941130-086	11/30/94	8.76E-2	2.1E1	pCi/L
	941229-013	12/29/94	-1.21E0	2.1E1	pCi/L
	950131-073	01/31/95	2.21E1	2.2E1	pCi/L
	950228-077	02/28/95	1.91E1	2.1E1	pCi/L
	950330-091	03/30/95	1.59E1	2.1E1	pCi/L
	950428-056	04/28/95	6.46E1	2.2E1	pCi/L
Thorium-234	940930-138	09/30/94	8.41E2H	5.1E2	pCi/L
	941031-044	10/31/94	7.77E2	4.5E2	pCi/L
Uranium-234	940729-052	07/29/94	5.00E0	1.9E0	pCi/L
	940831-060	08/31/94	9.65E0	2.3E0	pCi/L
	940930-138	09/30/94	4.05E0	1.1E0	pCi/L
	941031-044	10/31/94	5.87E0	1.8E0	pCi/L
	941130-086	11/30/94	5.32E0	1.IE0	pCi/L
	941229-013	12/29/94	8.10E0	1.3E0	pCi/L
	950131-073	01/31/95	7.57E0	1.3E0	pCi/L
	950228-077	02/28/95	5.62E0	1.3E0	pCi/L
	950330-091	03/30/95	4.74E0	1.1E0	pCi/L
	950428-056	04/28/95	6.32E0	1.2E0	pCi/L
Uranium-235	940729-052	07/29/94	-8.69E0F	6.8E1	pCi/L
	940831-060	08/31/94	6.95E0E	6.8E1	pCi/L
	940930-138	09/30/94	2.68E1E	9.1E1	pCi/L

Parameter	**Sample**	**Date**	**Results**	**Error**	**Units**
K1700 (continued)					
Uranium-235	941031-044	10/31/94	-3.24E0F	7.7EI	pCi/L
	941130-096	11/30/94	2.92E-1E	6.0E0	pCi/L
	941229-013	12/29/94	-5.38E0F	1.5E1	pCi/L
	950131-073	01/31/95	-8.52E0F	1.5E1	pCi/L
	950228-077	02/28/95	-1.23E0F	1.5E1	pCi/L
	950330-091	03/30/95	3.21E0E	5.9E0	pCi/L
	950428-056	04/28/95	-2.79E0F	1.5E1	pCi/L
Uranium-236	940729-052	07/29/94	3.57E-1	5.1E-1	pCi/L
	940831-060	08/31/94	5.36E-1	5.4E-1	pCi/L
	940930-138	09/30/94	3.92E-1	3.2E-1	pCi/L
	941031-044	10/31/94	1.05E-1	2.1E-1	pCi/L
	941130-086	11/30/94	5.66E-2	1.1E-1	pCi/L
	941229-013	12/29/94	1.03E-1	2.1E-1	pCi/L
	950131-073	01/31/95	2.23E-1	2.2E-1	pCi/L
	950228-077	02/28/95	1.29E-1	1.8E-1	pCi/L
	950330-091	03/30/95	6.40E-2	1.3E-1	pCi/L
	950428-056	04/28/95	1.18E-1	1.7E-1	pCi/L
Uranium-238	940729-052	07/29/94	3.93E0	1.7E0	pCi/L
	940831-060	08/31/94	3.62E0	1.4E0	pCi/L
	940930-138	09/30/94	4.05E0	1.0E0	pCi/L
	941031-044	10/31/94	4.51E0	1.4E0	pCi/L
	941130-096	11/30/94	3.17E0	8.5E-1	pCi/L
	941229-013	12/29/94	3.49E0	8.7E-1	pCi/L
	950131-073	01/31/95	3.73E0	9.1E-1	pCi/L
	950228-077	02/28/95	3.17E0	9.0E-1	pCi/L
	950330-091	03/30/95	2.56E0	8.1E-1	pCi/L
	950428-056	04/28/95	2.54E0	7.7E-1	pCi/L

Parameter	**Sample**	**Date**	**Results**	**Error**	**Units**
K1710					
Alpha Activity	940714-015	07/13/94	-7.46E-3+	6.6E-1	pCi/L
	940817-138	09/17/94	-3.16E-1	1.1E0	pCi/L
	940930-142	09/30/94	2.22E0	1.1E0	pCi/L
	941021-019	10/20/94	2.37E0	1.1E0	pCi/L
	941124-005	11/23/94	3.56E0	3.1E0	pCi/L
	941207-099	12/07/94	0.00E0	1.7E0	pCi/L
	950126-012	01/25/95	-2.98E-1	1.0E0	pCi/L
	950228-072	02/28/95	3.26E-1+	8.8E-1	pCi/L
	950316-007	03/15/95	1.48E0	1.2E0	pCi/L
	950426-307	04/26/95	7.37E-1	8.6E-1	pCi/L
	950511-149	05/11/95			pCi/L
Beta Activity	940714-015	07/13/94	5.48E0	2.4E0	pCi/L
	940817-138	08/17194	2.73E0	2.4E0	pCi/L
	940930-142	09/30/94	3.85E0	2.0E0	pCi/L
	941021-019	10/20/94	7.18E0	2.0E0	pCi/L
	941124-005	11/23/94	5.60E0	4.1E0	pCi/L
	941207-099	12/07/94	3.09E0	2.1E0	pCi/L
	950126-012	01/25/95	2.78E0	2.0E0	pCi/L
	950228-072	02/29/95	2.58E0	1.7E0	pCi/L
	950316-007	03/15/95	8.12E-1	2.0E0	pCi/L
	950426-307	04/26/95	3.75E0	1.8E0	pCi/L
	950511-149	05/11/95			pCi/L
Cesium-137	940714-015	07/13/94	-3.56E1F	8.4E1	pCi/L
	940817-138	08/17/94	6.06E0E	8.1E1	pCi/L
	940930-142	09/30/94	-5.23E1F	8.4E1	pCi/L
	941021-019	10/20/94	7.09E0E	2.8E1	pCi/L
	941124-005	11/23/94	-1.62E1G	1.2E1	pCi/L
	941207-099	12/07/94	-1.91E0F	3.7E0	pCi/L
	950126-012	01/25/95	-1.77E0F	2.0E1	pCi/L
	950228-072	02/28/95	3.64E0E	3.7E0	pCi/L
	950316-007	03/15/95	1.89E0E	3.8E0	pCi/L
	950426-307	04/26/95	4.05E-IE	3.7E0	pCi/L
	950511-149	05/11/95			pCi/L
Dissolved Solids	950330-102	03/30/95	140		mg/L
Neptunium-237	940714-015	07/13/94	-1.39E-1	5.5E-1	pCi/L
	940817-138	08/17/94	1.93E-1s	3.9E-1	pCi/L
	940930-142	09/30/94	0.00E0N	3.2E-1	pCi/L
	941021-019	10/20/94	-8.18E-2N	3.3E-1	pCi/L
	941124-005	11/23/94	-8.40E-2+	3.4E-1	pCi/L
	941207-099	12/07/94	2.40E-1	3.6E-1	pCi/L
	950126-012	01/25/95	-2.13E-1	3.3E-1	pCi/L
	950228-072	02/28/95	0.00E0+	2.0E-1	pCi/L
	950316-007	03/15/95	0.00E0	2.5E-1	pCi/L

Parameter	Sample	Date	Results	Error	Units
K1710 (continued)					
Neptunium-237	950426-307	04/26/95	0.00E0	1.3E-1	pCi/L
	950511-149	05/11/95			pCi/L
Plutonium-238	940714-015	07/13/94	1.39E-1	2.8E-1	pCi/L
	940817-138	08/17/94	-2.1 1E-1	8.4E-1	pCi/L
	940930-142	09/30/94	1.01E-1	2.0E-1	pCi/L
	941021-019	10/20/94	8.95E-2	3.1E-1	pCi/L
	941124-005	11/23/94	7.83E-2*	1.6E-1	pCi/L
	941207-099	12/07/94	0.00E0	2.1E-1	pCi/L
	950126-012	01/25/95	6.68E-2N	3.5E-1	pCi/L
	950228-072	02/28/95	7.77E-1	5.5E-1	pCi/L
	950316-007	03/15/95	4.18E-1C	3.2E-1	pCi/L
	950426-307	04/26/95	5.96E-2	1.2E-1	pCi/L
	950511-149	05/11/95			pCi/L
Plutonium-239	940714-015	07/13/94	4.16E-I+	4.8E-1	pCi/L
	940817-138	08/17/94	0.00E0	7.3E-1	pCi/L
	940930-142	09/30/94	0.00E0	3.5E-1	pCi/L
	941021-019	10/20/94	0.00E0	3.1E-1	pCi/L
	941124-005	11/23/94	-7.83E-2+	2.7E-1	pCi/L
	941207-099	12/07/94	7.47E-2	1.5E-1	pCi/L
	950126-012	01/25/95	0.00E0N	2.3E-1	pCi/L
	950228-072	02/28/95	0.00E0+	2.4E-1	pCi/L
	950316-007	03/15/95	5.97E-2	2.1E-1	pCi/L
	950426-307	04/26/95	2.93E-2	5.9E-2	pCi/L
	950511-149	05/11/95			pCi/L
Potassium-40	950426-307	04/26/95	7.23E1	4.6E1	pCi/L
Technetium-99	940714-015	07/13/94	5.79El	3.9E1	pCi/L
	940817-138	08/17/94	-1.39E1	3.6E1	pCi/L
	940930-142	09/30/94	-3.78E1	3.5E1	pCi/L
	941021-019	10/20/94	3.05E1	2.2E1	pCi/L
	941124-005	11/23/94	-2.50EI+	2.1E1	pCi/L
	941207-099	12/07/94	-1. 15E0	2.1E1	pCi/L
	950126-012	01/25/95	2.54EI	2.2E1	pCi/L
	950228-072	02/28/95	-1,69El+	2.1E1	pCi/L
	950316-007	03/15/95	-2.33E0	2.1E1	pCi/L
	950426-307	04/26/95	1.42E1	8.7E0	pCi/L
	950511-149	05/11/95			pCi/L
Thorium-234	950126-012	01/25/95	3.50E2H	2.9E2	pCi/L
Uranium-234	940714-015	07/13/94	2.65E-1+	3.8E-1	pCi/L
	940817-138	08/17/94	0.00E0	5.3E-1	pCi/L
	940930-142	09/30/94	1.77E0	1.0E0	pCi/L
	941021-019	10/20/94	9.20E-1	5.3E-1	pCi/L

Parameter	**Sample**	**Date**	**Results**	**Error**	**Units**
K1710 (continued)					
Uranium-234	941124-005	11/23/94	5.38E-1+	4.0E-1	pCi/L
	941207-099	12/07/94	7.17E-1	6.3E-1	pCi/L
	950126-012	01/25/95	5.73E-2	4.1E-1	pCi/L
	950229-072	02/28/95	1.79E-1+	4.0E-1	pCi/L
	950316-007	03/15/95	3.15E-1	3.0E-1	pCi/L
	950426-307	04/26/95	1.68E-1	2.0E-1	pCi/L
	950511-149	05/11/95			pCi/L
Uranium-235	940714-015	07/13/94	-2.78E1F	9.3E1	pCi/L
	940817-138	08/17/94	3.18E1E	9.2E1	pCi/L
	940930-142	09/30/94	5.09E1E	9.1E1	pCi/L
	941021-019	10/20/94	1.91E1E	4.4E1	pCi/L
	941124-005	11/23/94	5.40E0E	1.5E1	pCi/L
	941207-099	12/07/94	2.14E0E	6.0E0	pCi/L
	950126-012	01/25/95	-3.95E0F	3.9E1	pCi/L
	950228-072	02/28/95	3.04E0E	6.0E0	pCi/L
	950316-007	03/15/95	1.30E0E	6.0E0	pCi/L
	950426-307	04/26/95	-1.17E0F	6.0E0	pCi/L
	950511-149	05/11/95			pCi/L
Uranium-236	940714-015	07/13/94	-1.33E-1	5.3E-1	pCi/L
	940817-138	08/17/94	0.00E0	4.3E-1	pCi/L
	940930-142	09/30/94	9.94E-2	2.0E-1	pCi/L
	941021-019	10/20/94	-7.67E-2	3.1E-1	pCi/L
	941124-005	11/23/94	0.00E0	2.1E-1	pCi/L
	941207-099	12/07/94	0.00E0	2.1E-1	pCi/L
	950126-012	01/25/95	5.73E-2	1.1E-1	pCi/L
	950228-072	02/28/95	0.00E0	2.1E-1	pCi/L
	950316-007	03/15/95	0.00E0	1.8E-1	pCi/L
	950426-307	04/26/95	0.00E0	1.2E-1	pCi/L
	950511-149	05/11/95			pCi/L
Uranium-238	940714-015	07/13/94	-1.33E-1+	5.3E-1	pCi/L
	940817-138	08/17/94	1.52E-1	3.0E-1	pCi/L
	940930-142	09/30/94	6.89E-1	7.1E-1	pCi/L
	941021-019	10/20/94	1.53E0	7.2E-1	pCi/L
	941124-005	11/23/94	8.36E-1*	4.5E-1	pCi/L
	941207-099	12/07/94	2.99E-1	3.2E-1	pCi/L
	950126-012	01/25/95	5.73E-2	4.1E-1	pCi/L
	950228-072	02/28/95	1.79E-1+	2.1E-1	pCi/L
	0316-007	03/15/95	2.63E-1	2.4E-1	pCi/L
	950426-307	04/26/95	6.71E-2	1.3E-1	pCi/L
	950511-149	05/11/95			pCi/L

Parameter K716	**Sample**	**Date**	**Results**	**Error**	**Units**
Alpha Activity	940714-016	07/13/94	1.46E0	1.2E0	pCi/L
	940817-137	08/17/94	4.74E-1	1.3E0	pCi/L
	940930-143	09/30/94	1.10E0	8.6E-1	pCi/L
	941021-018	10/20/94	3.35E0	1.2E0	pCi/L
	941124-007	11/23/94	3.07E0	3.1E0	pCi/L
	941207-098	12/07/94	4.57E-1+	1.8E0	pCi/L
	950126-011	01/25/95	2.71E0	1.4E0	pCi/L
	950222-069	02/22/95	1. 12E0	1.3E0	pCi/L
	950315-076	03/15/95	1. 19E0+	1.2E0	pCi/L
	950426-306	04/26/95	1.69E0+	1.1E0	pCi/L
	950511-115	05/11/95			pCi/L
Beta Activity	940714-016	07/13/94	5.72E0	2.5E0	pCi/L
	940817-137	08/17/94	4.06E0+	2.5E0	pCi/L
	940930-143	09/30/94	2.49E0	1.9E0	pCi/L
	941021-018	10/20/94	7.25E0	2.0E0	pCi/L
	941124-007	11/23/94	8.22E-2	3.9E0	pCi/L
	941207-098	12/07/94	4.09E0	2.2E0	pCi/L
	950126-011	01/25/95	4.67E0	2.1E0	pCi/L
	950222-069	02/22/95	2.87E0	2.0E0	pCi/L
	950315-076	03/15/95	1.50E0+	2.0E0	pCi/L
	950426-306	04/26/95	3.38E0+	1.8E0	pCi/L
	950511-115	05/11/95			pCi/L
Cesium-137	940714-016	07/13/94	6.81E0E	7.9E1	pCi/L
	940817-137	08/17/94	-7.79E0F	3.5E1	pCi/L
	940930-143	09/30/94	3.48E1E	8.1E1	pCi/L
	941021-018	10/20/94	9.00E0E	2.8El	pCi/L
	941124-007	11/23/94	1.7E0E	3.6E0	pCi/L
	941207-098	12/07/94	1.11E0E	3.6E0	pCi/L
	950126-011	01/25/95	2.93E-1E	1.1E1	pCi/L
	950222-069	02/22/95	-7.1 1E0F	1.1E1	pCi/L
	950315-076	03/15/95	8.36E-1E	3.6E0	pCi/L
	950426-306	04/26/95	-2.71E0F	1.1E1	pCi/L
	950511-115	05/11/95			pCi/L
Neptunium-237	940714-016	07/13/94	1.37E-Is	4.7E-1	pCi/L
	940817-137	08/17/94	0.00E0+	6.4E-1	pCi/L
	940930-143	09/30/94	0.00E0	3.1E-1	pCi/L
	941021-018	10/20/94	0.00E0	2.5E-1	pCi/L
	941124-007	11/23/94	0.00E0	2.3E-1	pCi/L
	941207-098	12/07/94	8.25E-2+	2.9E-1	pCi/L
	950126-011	01/25/95	-7.08E-2	8.2E-1	pCi/L
	930222-069	02/22/95	1.45E-1+	8.6E-1	pCi/L
	950315-076	03/15/95	1.49E-1+	2.1E-1	pCi/L
	950426-306	04/26/95	0.00E0+	1.3E-1	pCi/L
	950511-115	05/11/95			pCi/L

Parameter	Sample #	Date	Results	Error	Units
K716 (continued)					
Plutonium-238	940714-016	07/13/94	0.00E0	4.7E-1	pCi/L
	940817-137	09/17/94	-2.03E-1	8.1E-1	pCi/L
	940930-143	09/30/94	0.00E0	3.4E-1	pCi/L
	941021-018	10/20/94	-9.58E-2+	3.8E-1	pCi/L
	941124-007	11/23/94	5.97E-1	4.2E-1	pCi/L
	941207-098	12/07/94	-7.69E-2+	3.1E-1	pCi/L
	950126-011	01/25/95	6.74E-2	3.6E-1	pCi/L
	950222-069	02/22/95	-1.38E-I+	3.4E-1	pCi/L
	950315-076	03/15/95	4.54E-1C	3.4E-1	pCi/L
	950426-306	04/26/95	-2.85E-2	1.1E-1	pCi/L
	950511-115	05/11/95			pCi/L
Plutonium-239	940714-016	07/13/94	1.37E-1	2.7E-1	pCi/L
	940817-137	08/17/94	0.00E0	7.0E-1	pCi/L
	940930-143	09/30/94	0.00E0	3.4E-1	pCi/L
	941021-018	10/20/94	9.58E-2	1.9E-1	pCi/L
	941124-007	11/23/94	-1.49E-1	3.3E-1	pCi/L
	941207-098	12/07/94	0.00E0	2.7E-1	pCi/L
	950126-011	01/25/95	6.74E-2	1.3E-1	pCi/L
	950222-069	02/22/95	6.91E-2+	1.4E-1	pCi/L
	950315-076	03/15/95	0.00E0+	1.8E-1	pCi/L
	950426-306	04/26/95	2.85E-2	5.7E-2	pCi/L
	950511-115	05/11/95			pCi/L
Technetium-99	940714-016	07/13/94	3.75E1	3.8E1	pCi/L
	940817-137	08/17/94	2.39E0+	3.7E1	pCi/L
	940930-143	09/30/94	-1.98E1	3.6E1	pCi/L
	941021-018	10/20/94	1.88E1+	2.2E1	pCi/L
	941124-007	11/23/94	3.03E0	2.1E1	pCi/L
	941207-098	12/07/94	2.30E0+	2.1E1	pCi/L
	950126-011	01/25/95	2.81E1	2.2E1	pCi/L
	950222-069	02/22/95	-9.44E0+	2.1E1	pCi/L
	950315-076	03/15/95	7.54E0+	2.1E1	pCi/L
	950426-306	04/26/95	2.39E1+	8.8E0	pCi/L
	950511-115	05/11/95			pCi/L
Uranium-234	940714-016	07/13/94	6.S1E-1	6.8E-1	pCi/L
	940817-137	08/17/94	7.62E-1	5.8E-1	pCi/L
	940930-143	09/30/94	-1.21E-1	6.4E-1	pCi/L
	941021-018	10/20/94	1.28E0	5.9E-1	pCi/L
	941124-007	11/23/94	0.00E0	1.7E-1	pCi/L
	941207-098	12/07/94	5.00E-1+	6.1E-1	pCi/L
	950126-011	01/25/95	4.87E-1	5.4E-1	pCi/L
	950222-069	02/22/95	8.17E-1	1.5E-1	pCi/L
	950315-076	03/15/95	1.25E0	5.3E-1	pCi/L
	950426-306	04/26/95	4.76E-1+	2.9E-1	pCi/L
	950511-115	05/11/95			pCi/L

Parameter	Sample #	Date	Results	Error	Units
K716 (continued)					
Uranium-235	940714-016	07/13/94	6.73E1E	9.0E1	pCi/L
	940817-137	08/17/94	4.13E0E	6.7E1	pCi/L
	940930-143	09/30/94	6.38E1E	9.1E1	pCi/L
	941021-018	10/20/94	1.40EIE	4.4E1	pCi/L
	941124-007	11/23/94	3.26E0E	6.0E0	pCi/L
	941207-098	12/07/94	1.90E0E	6.0E0	pCi/L
	950126-011	01/25/95	1.20E1	8.8E0	pCi/L
	950222-069	02/22/95	-6.94E0F	1.5EI	pCi/L
	950315-076	03/15/95	1.98E0E	6.0E0	pCi/L
	950426-306	04/26/95	4.18E0E	1.5E1	pCi/L
	950511-115	05/11/95			pCi/L
Uranium-236	940714-016	07/13/94	-1.70E-1	6.8E-1	pCi/L
	940817-137	08/17/94	-1.09E-1	4.4E-1	pCi/L
	940930-143	09/30/94	0.00E0	4.2E-i	pCi/L
	941021-018	10/20/94	0.00E0	1.9E-1	pCi/L
	941124-007	11/23/94	6.14E-2	1.2E-1	pCi/L
	941207-098	12/07/94	6.25E-2+	1.2E-1	pCi/L
	950126-011	01/25/95	6.09E-2	1.2E-1	pCi/L
	950222-069	02/22/95	0.00E0	1.9E-1	pCi/L
	950315-076	03/15/95	1.04E-1	1.5E-1	pCi/L
	950426-306	04/26/95	3.40E-2+	6.8E-2	pCi/L
	950511-115	05/11/95			pCi/L
Uranium-238	940714-016	07/13/94	1.02E0	9.6E-1	pCi/L
	940817-137	08/17/94	5.44E-1	4.9E-1	pCi/L
	940930-143	09/30/94	2.42E-1	6.9E-1	pCi/L
	941021-018	10/20/94	9.47E-I	5.4E-1	pCi/L
	941124-007	11/23/94	6.14E-2	1.2E-1	pCi/L
	941207-098	12/07/94	6.25E-2	2.2E-1	pCi/L
	950126-011	01/25/95	8.52E-1	6.2E-1	pCi/L
	950222-069	02/22/95	1.36E0+	5.9E-1	pCi/L
	950315-076	03/15/95	8.85E-1	4.3E-1	pCi/L
	950426-306	04/26/95	4.42E-1+	2.6E-1	pCi/L
	950511-115	05/11/95			pCi/L

Parameter K901A	Sample#	Date	Results	Error	Units
Alpha Activity	940729-049	07/29/94	1.13E0+	1 1E0	pCi/L
	940831-07	09/31/94	3.12E0+	2..0E0	pCi/L
	940930-135	09/30/94	4.73E-1+	8.8E-1	pCi/L
	941031-041	10/31/94	4.02E0	1.8E0	pCi/L
	941130-083	11/30/94	1.55E0+	1.5E0	pCi/L
	941229-010	12/29/94	2.63E0	1.2E0	pCi/L
	950131-070	01/31/95	2.25E0+	1.5E0	pCi/L
	950228-074	02/28/95	1.50E0	1.1E0	pCi/L
	950330-088	03/30/95	1.34E0+	1.1E0	pCi/L
	950428-055	04/28/95	3.1 IE0	1.4E0	pCi/L
Beta Activity	940729-049	07/29/94	NA	NA	pCi/L
	940831-057	08/31/94	9.74E0	3.1E0	pCi/L
	940930-135	09/30/94	7.6 1E0	2.1E0	pCi/L
	941031-041	10/31/94	7.25E0	2.3E0	pCi/L
	941130-083	11/30/94	5.3 5E0	2.1E0	pCi/L
	941229-010	12/29/94	7.60E0	2.1E0	pCi/L
	950131-070	01/31/95	1.14E1	2.4E0	pCi/L
	950228-074	02/28/95	2.19E1	3.3E0	pCi/L
	950330-088	03/30/95	1.59E1	2.8E0	pCi/L
	950428-055	04/28/95	1.19E1+	2.3E0	pCi/L
Cesium-137	940729-049	07/29/94	-2.25ElF	3.5E1	pCi/L
	940831-057	08/31/94	3.48E1E	7.5E1	pCi/L
	940930-135	09/30/94	1.51E1E	7.8E1	pCi/L
	941031-041	10/31/94	-1.26E1F	2.1E1	pCi/L
	941130-083	11/30/94	5.61E0E	1.0E1	pCi/L
	941229-010	12/29/94	2.54E0E	3.6E0	pCi/L
	950131-070	01/31/95	9.17E-1E	3.9E0	pCi/L
	950228-074	02/28/95	-7.01E-lF	3.7E0	pCi/L
	950330-088	03/30/95	-3.67E0F	3.8E0	pCi/L
	950428-055	04/29/95	2.05E0E	3.7E0	pCi/L
Neptunium-237	940729-049	07/29/94	1.82E-1+	3.6E-1	pCi/L
	940831-057	08/31/94	0.00E10	6.0E-1	pCi/L
	940930-135	09/30/94	1.85E-1+	2.6E-1	pCi/L
	941031-041	10/31/94	3.36E-1+	3.4E-1	pCi/L
	941130-083	11/30/94	1.58E-1+	3.2E-1	pCi/L
	941229-010	12/29/94	7.90E-2	1.6E-1	pCi/L
	950131-070	01/31/95	0.00E0	2.6E-1	pCi/L
	950228-074	02/28/95	1.42E-1	2.8E-1	pCi/L
	950330-088	03/30/95	0.00E0	2.5E-1	pCi/L
	950428-055	04/28/95	2.13E-1+	2.5E-1	pCi/L
Plutonium-238	940729-049	07/29/94	2.00E-1+	4.0E-1	pCi/L
	940831-057	08/31/94	-1.91E-1	7.6E-1	pCi/L
	940930-135	09/30/94	0.00E0+	2.9E-1	pCi/L

Parameter	Sample	Date	Results	Error	Units
K901A (continued)					
Plutonium-238	941031-041	10/31/94	2.35E-1	3.5E-1	pCi/L
	941130-083	11/30/94	7.35E-2+	2.5E-1	pCi/L
	941229-010	12129/94	7.36E-2	2.9E-1	pCi/L
	950131-070	01/31/95	-1.41E-1+	4.0E-1	pCi/L
	950228-074	02/28/95	6.74E-2	3.0E-1	pCi/L
	950330-088	03/30/95	5.72E-I+	4.0E-1	pCi/L
	950428-055	04/2gt95	0.00E0+	3.4E-1	pCi/L
Plutonium-239	940729-049	07/29/94	5.99E-1+	6.9E-1	pCi/L
	940831-057	08/31/94	0.00E0	6.6E-1	pCi/L
	940930-135	09/30/94	-1.01E-l+	4.1E-1	pCi/L
	941031-041	10/31/94	0.00E0	2.7E-1	pCi/L
	941130-083	11/30/94	7.35E-2	1.5E-1	pCi/L
	941229-010	12/29/94	1.47E-1	2.1E-1	pCi/L
	950131-070	01/31/95	0.00E0+	2.4E-1	pCi/L
	950228-074	02/29195	0.00E0	2.3E-1	pCi/L
	950330-088	03/30/95	0.00E0+	2.0E-1	pCi/L
	950428-055	04/28/95	1.61E-1+	1.9E-1	pCi/L
Potassium-40	950330-088	03/30/95	1.04E2	5.2E1	pCi/L
Prep (PCB-)	950330-N8	03/30/95			
Prep (PCB-)	940831-057	08/31/94			
	940930-135	09/30/94			
	941031-041	10/31/94			
	941130-083	11/30/94			
	941229-010	12/29/94			
Technetium-99	940729-049	07/29/94	-1.08E1+	3.6E1	pCi/L
	940931-057	09/31/94	4.22E0+	3.7E1	pCi/L
	940930-135	09/30/94	3.73E0+	3.7E1	pCi/L
	941031-041	10/31/94	5,32E-1+	2.1E1	pCi/L
	941130-083	11/30/94	1.20E1+	2.1E1	pCi/L
	941229-010	12/29/94	-4.90E0	2.1E1	pCi/L
	950131-070	01/31/95	3.03E1+	2.2E1	pCi/L
	950228-074	02/28/95	3.18E1	2.1E1	pCi/L
	950330-088	03/30/95	3.39E0-+	2..1E1	pCi/L
	950428-055	04/28/95	7.30E1	2..2E1	pCi/L
Thorium-234	940930-135	09/30/94	5.75E2Hi	6.9E2	pCi/L
Uranium-234	940729-049	07/29/94	7.41E-1+	7.41E-1	pCi/L
	940831-057	08/31/94	3.86E-1	5.8E-1	pCi/L
	940930-135	09130/94	1.74E0	7.2E-1	pCi/L
	941031-041	10/31/94	1.79E-1+	7.2E-1	pCi/L
	941130-083	11/30/94	5.85E-1	3.5E-1	pCi/L

Parameter	Sample	Date	Results	Error	Units
K901A (continued)					
Uranium-234	941229-010	12/29/94	1.49E0	6.3E-1	pCi/L
	950131-070	01/31/95	1.01E0+	4.9E-1	pCi/L
	950228-074	02/29/95	1. 15E0	6.1E-1	pCi/L
	950330-088	03/30/95	1.30E0	6.3E-1	pCi/L
	950428-055	04/28/95	7.04E-1*	3.9E-1	pCi/L
Uranium-235	940729-049	07/29/94	1.2lElE	6.8E1	pCi/L
	940831-057	09/31/94	1.35ElE	9.1E1	pCi/L
	940930-135	09/30/94	3.38E0E	9.3E1	pCi/L
	941031-041	10/31/94	1.63E1E	3.9E1	pCi/L
	941130-083	11/30/94	-1.41E1F	1.5E1	pCi/L
	941229-010	12/29/94	-4.87E-1F	6.0E0	pCi/L
	950131-070	01/31/95	2.96E0E	6.0E0	pCi/L
	950228-074	02/29/95	-1.28E01F	6.0E0	pCi/L
	950330-088	03/30/95	3.99E0E	6.0E0	pCi/L
	950428-055	04/28/95	4.80E-1E	6.0E0	pCi/L
Uranium-236	940729-049	07/29/94	0.00E0+	6.4E-1	pCi/L
	940831-057	08/31/94	0.00E0	4.5E-1	pCi/L
	940930-135	09/30/94	1.29E-1	1.8E-1	pCi/L
	941031-041	10/31/94	8.96E-2+	1.8E-1	pCi/L
	941130-083	11/30/94	5.32E-2+	1.1E-1	pCi/L
	941229-010	12/29/94	-5.71E-2	2.3E-1	pCi/L
	950131-070	01/31/95	5.92E-2+	1.2E-1	pCi/L
	950228-074	02/28/95	0.00E0	2.0E-1	pCi/L
	950330-088	03/30/95	1.18E-1	1.7E-1	pCi/L
	950428-055	04/28/95	5.41E-2+	1.1E-1	pCi/L
Uranium-238	940729-049	07/29/94	3.70E-1	5.2E-1	pCi/L
	940831-057	08/31/94	3.86E-1*	4.5E-1	pCi/L
	940930-135	09/30/94	6.46E-1	4.5E-1	pCi/L
	941031-041	10/31/94	9.85E-1	5.9E-1	pCi/L
	941130-083	11/30/94	7.45E-1	4.OE-1	pCi/L
	941229-010	12/29/94	9.14E-1	5.1E-1	pCi/L
	950131-070	01/31/95	6.51E-1	3.9E-1	pCi/L
	950228-074	02/28/95	1.03E1	4.9E-1	pCi/L
	950330-088	03/30/95	7.11E-1	4.1E-1	pCi/L
	950428-055	04/28/95	7.04E-1+	3.9E-1	pCi/L

Parameter	Sample	Date	Results	Error	Units
WFPC					
Alpha Activity	940714-017	07/13/94	3.19E-1	B.0E-1	pCi/L
	940817-139	08/17/94	-1.66E-1	1.1E0	pCi/L
	940930-141	09/30/94	-8.64E-4+	5.8E-1	pCi/L
	941021-020	10/20/94	5.80E-1	5.6E-1	pCi/L
	941124-006	11/23/94	2.49E0	3.0E0	pCi/L
	941207-100	12/07/94	-1.85E0	1.5E0	pCi/L
	950126-010	01/25/95	3.78E-1	1.1E0	pCi/L
	950228-073	02/28/95	-5.01E-1	7.0E-1	pCi/L
	950316-004	03/15/95	3.69E-1	1.0E0	pCi/L
	950426-308	04/26/95	-8.96E-2	6.9E-1	pCi/L
	950511-145	05/11/95			
Beta Activity	940714-017	07/13/94	3.73E0	2.3E0	pCi/L
	940817-139	08/17/94	3.67E0	2.5E0	pCi/L
	940930-141	09/30/94	3.46E0+	1.9E0	pCi/L
	941021-020	10/20/94	4.35E0	1.8E0	pCi/L
	941124-006	11/23/94	4.52E0	4.0E0	pCi/L
	941207-100	12/07/94	1.93E0	2.1E0.	pCi/L
	950126-010	01/25/95	2.74E0	2.0E0	pCi/L
	950228-073	02/28/95	1.78E0	1.7E0	pCi/L
	950316-004	03/15/95	-2.14E-1	1.9E0	pCi/L
	950426-308	04/26/95	1.93E0	1.7E0	pCi/L
	950511-145	05/11/95			
Cesium-137	940714-017	07/13/94	-7.1 1E1F	8.5E1	pCi/L
	940817-139	09/17/94	-1.24ElF	3.4E1	pCi/L
	940930-141	09/30/94	7.35E1E	7.7E1	pCi/L
	941021-020	10/20/94	1.74E1F	8.2E1	pCi/L
	941124-006	11/23/94	3.3 1E0E	1.1E1	pCi/L
	941207-100	12/07/94	1.00E-1E	1.lEl	pCi/L
	950126-010	01/25/95	-2.35ElF	5.7E1	pCi/L
	950228-073	02/28/95	2.40E0E	1.1E1	pCi/L
	950316-004	03/15/95	7.01E-1E	1.0E1	pCi/L
	950426-308	04/26/95	-3.21E0F	1.1E1	pCi/L
	950511-145	05/11/95			pCi/L
Dissolved Solids	950330-101	03/30/95	130		mg/L
Neptunium-237	940714-017	07/13/94	0.00E0	4.0E-1	pCi/L
	940817-139	09/17/94	0.00E0	6.3E-1	pCi/L
	940930-141	09/30/94	1.80E-1+	2.5E-1	pCi/L
	941021-020	10/20/94	-9.11E-2	3.6E-1	pCi/L
	941124-006	11/23/94	2.37E-1	3.5E-1	pCi/L
	941207-100	12/07/94	8.19E-2	2.8E-1	pCi/L
	950126-010	01/25/95	-6.99E-2	3.1E-1	pCi/L
	950228-073	02/28/95	2.13E-1	3.2E-1	pCi/L
	950316-004	03/15/95	2.10E-1	2.4E-1	pCi/L

Parameter	Sample	Date	Results	Error	Units
WFPC (continued)					
Neptunium-237	950426-308	04126/95	3.65E-2	7.3E-2	pCi/L
	950511-145	05/11195			pCi/L
Plutonium-238	940714-017	07/13/94	0.00E0	4.9E-1	pCi/L
	940817-139	08/17/94	-2.00E-1	8.0E-1	pCi/L
	940930-141	09/30/94	0.00E0	3.4E-1	pCi/L
	941021-020	10/20/94	-9.96E-2	4.0E-1	pCi/L
	941124-006	11/23/94	2.21E-1	2.6E-1	pCi/L
	941207-100	12/07/94	-7.64E-2	3.1E-1	pCi/L
	950126-010	01/25/95	1.35E-1	3.8E-1	pCi/L
	950228-073	02/28/95	-1.33E-1	3.0E-1	pCi/L
	950316-004	03/15/95	4.56E-1C	3.7E-1	pCi/L
	950426-308	04/26/95	-2.82E-2	1.1E-1	pCi/L
	950511-145	05/11/95			
Plutonium-239	940714-017	07/13/94	0.00E0	4.9E-1	pCi/L
	940817-139	09/17/94	0.00E0	6.9E-1	pCi/L
	940930-141	09/30/94	9.84E-2+	2.0E-1	pCi/L
	941021-020	10/20/94	0.00E0	3.5E-1	pCi/L
	941124-006	11/23/94	-1.47E-1	3.3E-1	pCi/L
	941207-100	12/07/94	0.00E0	2.6E-1	pCi/L
	950126-010	01/25/95	0.00E0	2.3E-1	pCi/L
	950228-073	02/28/95	0.00E0	2.3E-1	pCi/L
	950316-004	03/15/95	7.60E-2	2.6E-1	pCi/L
	950426-308	04/26/95	0.00E0	9.8E-2	pCi/L
	950511-145	05/11/95			pCi/L
Technetium-99	940714-017	07/13/94	1.97E1	3.7E1	pCi/L
	940817-139	08/17/94	7.79E1	3.9E1	pCi/L
	940930-141	09/30/94	5.82E1+	3.8E1	pCi/L
	941021-020	10/20/94	5.16E1	2.2E1	pCi/L
	941124-006	11/23/94	9.81E0	2.1E1	pCi/L
	941207-100	12/07/94	4.30E0	2.1E1	pCi/L
	950126-010	01/25/95	4.06E1	2.2E1	pCi/L
	950228-073	02/28/95	1.37E1	2.1E1	pCi/L
	950316-004	03/15/95	2.13E1	2.2E1	pCi/L
	950426-308	04/26/95	1.51E1	8.7E0	pCi/L
	950511-145	05/11/95			
Thorium-234	950316-004	03/15/95	1.06E2i	1.1E2	pCi/L
Uranium-234	940714-017	07/13/94	2.30E-1	4.6E-1	pCi/L
	940817-139	09/17/94	1.82E-1	3.6E-1	pCi/L
	940930-141	09/30/94	-3.12E-1*	4.1E-1	pCi/L
	941021-020	10/20/94	1.58E-1	2.2E-1	pCi/L
	941124-006	11/23/94	1.83E-1	2.7E-1	pCi/L
	941207-100	12/07/94	-4.20E-1	3.6E-1	pCi/L

Parameter	Sample	Date	Results	Error	Units
WFPC (continued)					
Uranium-234	950126-010	01/25/95	5.82E-2	4.2E-1	pCi/L
	950228-073	02/29/95	2.21E-1	3.8E-1	pCi/L
	950316-004	03/15/95	2.18E-1	2.7E-1	pCi/L
	950426-308	04/26/95	1.89E-1	2.0E-1	pCi/L
	950511-145	05/11/95			pCi/L
Uranium-235	940714-017	07/13/94	4.13E0E	9.1E1	pCi/L
	940817-139	08/17/94	-9.56E0F	6.8E1	pCi/L
	940930-141	09/30/94	2.75E0E	9.2E1	pCi/L
	941021-020	10/20/94	2.64E1E	9.1E1	pCi/L
	941124-006	11/23/94	-9.26E0F	1.5E1	pCi/L
	941207-100	12/07/94	8.84E0E	1.5E1	pCi/L
	950126-010	01/25/95	1.2lElE	7.7E1	pCi/L
	950228-073	02/29/95	-3.14E0F	1.5E1	pCi/L
	950316-004	03/15/95	-3.21E0F	1.5E1	pCi/L
	950426-308	04/26/95	-5.33E0F	1.5E1	pCi/L
	950511-145	05/11/95			pCi/L
Uranium-236	940714-017	07/13/94	0.00E0	6.5E-1	pCi/L
	940817-139	08/17/94	-1.82E-1	7.3E-1	pCi/L
	940930-141	09/30/94	7.79E-2	1.6E-1	pCi/L
	941021-020	10/20/94	-7.91E-2	3.2E-1	pCi/L
	941124-006	11/23/94	0.00E0	2.1E-1	pCi/L
	941207-100	12/07/94	0.00E0	2.1E-1	pCi/L
	950126-010	01/25/95	0.00E0	2.0E-1	pCi/L
	950228-073	02/29/95	0.00E0	1.9E-1	pCi/L
	950316-004	03/15/95	0.00E0	1.9E-1	pCi/L
	950426-308	04/26/95	0.00E	1.1E-1	pCi/L
	950511-145	05/11/95			pCi/L
Uranium-238	940714-017	07/13/94	-2.30E-1	9.2E-1	pCi/L
	940817-139	08/17/94	0.00E0	6.3E-1	pCi/L
	940930-141	09/30/94	-2.34E-1	3.8E-1	pCi/L
	941021-020	10/20/94	0.00E0	2.2E-1	pCi/L
	941124-006	11/23/94	0.00E0	2.1E-1	pCi/L
	941207-100	12/07/94	-6-00E-2	2.4E-1	pCi/L
	950126-010	01/25/95	-2.33E-1	3.3E-1	pCi/L
	950228-073	02/28/95	1.1OE-1	1.6E-1	pCi/L
	950316-004	03/15/95	0.00E0	1.9E-1	pCi/L
	950426-308	04/26/95	1.26E-1	1.5E-1	pCi/L
	950511-145	05/11/95			pCi/L

Parameter	Sample	Date	Results	Error	Units
WFPCD					
Alpha Activity	950126-009	01/25/95	-7.44E-2+	1.0E0	pCi/L
Beta Activity	950126-009	01/25/95	5.99E-1+	1.9E0	pCi/L
Cesium-137	950126-009	01/25/95	1.14E1E	2.1E1	pCi/L
Neptunium-237	950126-009	01/25/95	-7.43E-2+	3.3E-1	pCi/L
Plutonium-238	950126-009	01/25/95	6.65E-2	3.5E-1	pCi/L
Plutonium-239	950126-009	01/25/95	6.65E-2	1.3E-1	pCi/L
Technetium-99	950126-009	01/25/95	1.86E1+	2.1E1	pCi/L
Uranium-234	950126-009	01/25/95	0.00E0+	3.9E-1	pCi/L
Uranium-235	950126-009	01/25/95	5.83E0E	3.9E1	pCi/L
Uranium-236	950126-009	01/25/95	5.67E-2+	1.1E-1	pCi/L
Uranium-238	950126-009	01/25/95	-2.27E-1+	3.2E-1	pCi