INNOVATIVE TECHNOLOGY
Summary Report

DOE/EM-0518

On-Line, Real-Time Alpha Radiation Measuring Instrument

Industry Programs and Subsurface Contaminants Focus Area

Prepared for

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Innovative Technology Summary Report

On-Line, Real-Time Alpha Radiation Measuring Instrument

OST/TMS ID 312

Industry Programs and
Subsurface Contaminants Focus Area

Demonstrated at
Oak Ridge National Laboratory, Y-12 Plant (Bear Creek Valley)
East Fork Poplar Creek and
City of Oak Ridge Municipal Wastewater Treatment Plant
Oak Ridge, Tennessee

INNOVATIVE TECHNOLOGY
Summary Report

Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine if a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at http://ost.em.doe.gov under "Publications."

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SECTION 1

SUMMARY

Technology Summary

Problem

The Department of Energy (DOE) must ensure that effluent waters leaving contaminated DOE sites do not affect the public's safety or health. Alpha-emitting radioisotopes, such as Uranium-238 (^{238}U), Uranium-234 (^{234}U) and Plutonium-239 (^{239}Pu), are carcinogens with very low limits in water regulated by the U.S. Environmental Protection Agency (EPA). Uranium (U) also has a high chemical toxicity. The EPA proposed maximum concentration limit for uranium in public drinking water supplies is 20 parts per billion (ppb) which is 30 pCi/l, equivalent to an emission of 58 alphas per minute in 1 liter of water. For reference, the world's sea water has a uniform uranium concentration of 3.3 ppb.

Currently, surface and ground waters at contaminated DOE sites are monitored for alpha emitters (and other contaminants) by intermittent sampling, with analysis at a central laboratory. Shortcomings of the current approach include:

- Spikes (high, intermittent values) are often undetected
- High cost
- Long time delay between sampling and data availability
- Expensive archiving of samples required and multiple handling and processing steps involvedmake this approach susceptible errors and mistakes.

Solution

Thermo Power Corporation (Thermo Power) has demonstrated a new technology which permits sensitive counting of alpha emitters in water, providing high-resolution alpha spectrometry. Individual radionuclides can be assayed simultaneously, based on their different alpha energies. This new technology provides the basis for an on-line, near real-time monitor of alpha-emitting radionuclides, both for effluent streams leaving DOE sites and for process streams.

How It Works

The technology provides an on-line, in situ method of collecting and concentrating dissolved radioactive species on a solid surface, allowing for rapid quantification of the specific, alpha-emitting species with a solid-state, silicon detector. For 1 ppb U, the instrument cycle time will be approximately 30 minutes. For 10 parts per million (ppm) U, it can be as short as approximately five minutes. Initial development of this technique involved simultaneous collection and quantification of the radioisotopes directly on the silicon detector, providing an energy resolution equivalent to conventional electroplating techniques. The Thermo Alpha Monitor (TAM), shown in Figure 1, has been proven to be accurate with laboratory and field tests, with both naturally-occurring and transuranic alpha emitters.

Figure 1. Thermo Alpha Monitor

Advantages Over The Baseline

The baseline technology for measurement of alpha radiation in water samples is manual sample collection and laboratory analysis. Intermittent samples are chemically preserved, entered into a chain-of-custody infrastructure, packaged for shipping, and then sent to a central or off-site laboratory for analysis. The primary advantage of the TAM is the rapid availability of analysis results, which can significantly improve operations. Use of this monitor may offer a highly desirable reduction of occupational exposure to radionuclides by automating their analyses in wastewaters, thereby reducing handling of environmental samples. Cost reduction for sampling and analysis should result due to decreased sampling and analysis time. Additionally, the TAM can provide radionuclide analysis at lower detection limits than currently available using baseline technologies.

Advantages of using the TAM include:

- Rapid and accurate analyses
- Dramatic reduction in end-to-end alpha monitoring costs
- Results can be automatically archived electronically

Capabilities of the TAM include:

- Isotopic analyses, allowing discrimination of naturally-occurring radionuclides (radon daughters)
- Capable of analyzing waste and process water (National Pollution Discharge Elimination System [NPDES]) discharges
- Surface and ground water monitoring, with future extension to solid samples, non-aqueous liquids, gas streams, and solid surfaces

Potential Markets

There are four markets that the TAM can service. These markets are the DOE, the U.S. Department of Defense (DoD), commercial/municipal users, and international users. DOE, which represents the primary market for TAM, identified multiple needs for alpha monitoring of liquids, then subsequently funded the development program for this instrument to meet these needs. The sustainable DOE market size has been estimated to total $10 million/year. The DoD has over 1200 contaminated sites, with an estimated remediation cost of $35 billion. This market represents approximately $1.8 million/year of TAM sales. Thousands of potential users may be found in the commercial/municipal market. These include nuclear power plants, hospitals and related health care institutions, public drinking water supply systems, academic institutions, manufacturers, analytical laboratories, waste disposal companies and other service firms. International customers represent a fourth distinct market for the TAM instrument. The estimated 1995 global sales of environmental instrumentation were $2.5 billion; 46% of these sales were in the U.S. Consequently, the international market for TAM is expected to be significant, and can be estimated to be approximately equal in size to the domestic U.S. market, or $11.8 million/year.

Demonstration Summary

Field testing of the TAM was conducted at several locations within Oak Ridge National Laboratory (ORNL). Tests were conducted to evaluate the response of the instrument to a range of water chemistries, contaminant concentrations, and radioisotopes. Tests were conducted utilizing surface water, groundwater, and process waters to detect alpha emitters, primarily uranium, in a " near real time," automated mode. Waters tested included the waste water treatment plant influent and effluent, the East Fork of Poplar Creek, a surface water site and a groundwater monitoring well. Samples ranged from less than 10 ppb to about 100 ppb of uranium.

The TAM was successfully demonstrated on water 100 times below the EPA's proposed safe drinking water limit - down to under 1 pico Curie per liter (pCi/l). The instrument analyzed isotopic U levels on samples from five sites. The demonstration extended the isotopic detection limit of the TAM to 10 parts per trillion (ppt) natural U (15 femto Curies per liter fCi/l]). In addition, the technology responded to 20 ppb natural U (30 pCi/l) in under 30 minutes.

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Other

All published Innovative Technology Summary Reports are available on the OST Web site at http://em-50.em.doe.gov under "Publications." The Technology Management System, also available through the OST Web site, provides information about OST programs, technologies, and problems. The OST Reference # for TAM is 312.

SECTION 2

TECHNOLOGY DESCRIPTION

Overall Process Definition

The TAM 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. Figure 2 presents a schematic of the TAM technology. The field-deployed TAM consists of the following primary components:

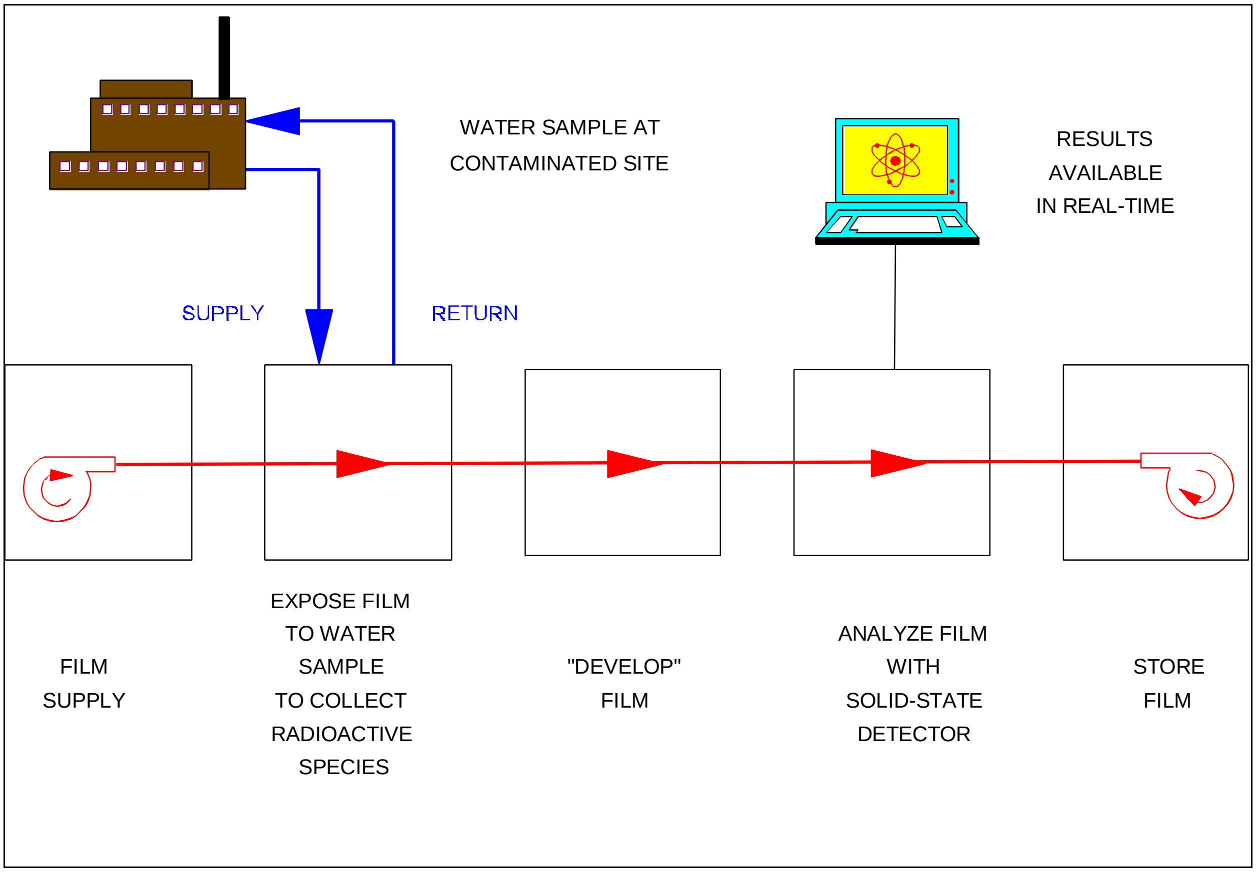

Figure 2. Thermo Alpha Monitor (TAM)

- 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.)

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. The energy lost by ionizing radiation, such as alpha particles, in semiconductor detectors results in the formation of ions (electron-hole pairs). 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 10 times as many ion pairs in the semiconductor solid as in gas, and the statistics are thus about 3 times better than for gas ionization detectors. In addition, the smaller distances involved in collection allow for higher electric fields and faster collection times.

Under this 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 simultaneously, based on their different alpha energies. This new instrument provides the basis for an on-line, near real-time monitor of alpha-emitting radionuclides in water streams for both effluent streams leaving DOE sites and process streams. During the Final Phase of the program, the laboratory instrument was converted into an automated, field deployable instrument. The prototype instrument was field tested and demonstrated for the detection of U and other alpha-emitters in water streams.

System Operation

Operation

The basic principle of operation is presented in Figure 3. To analyze a sample, the proprietary TAM film is installed into the waterproof chamber. 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 deionized (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 or 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

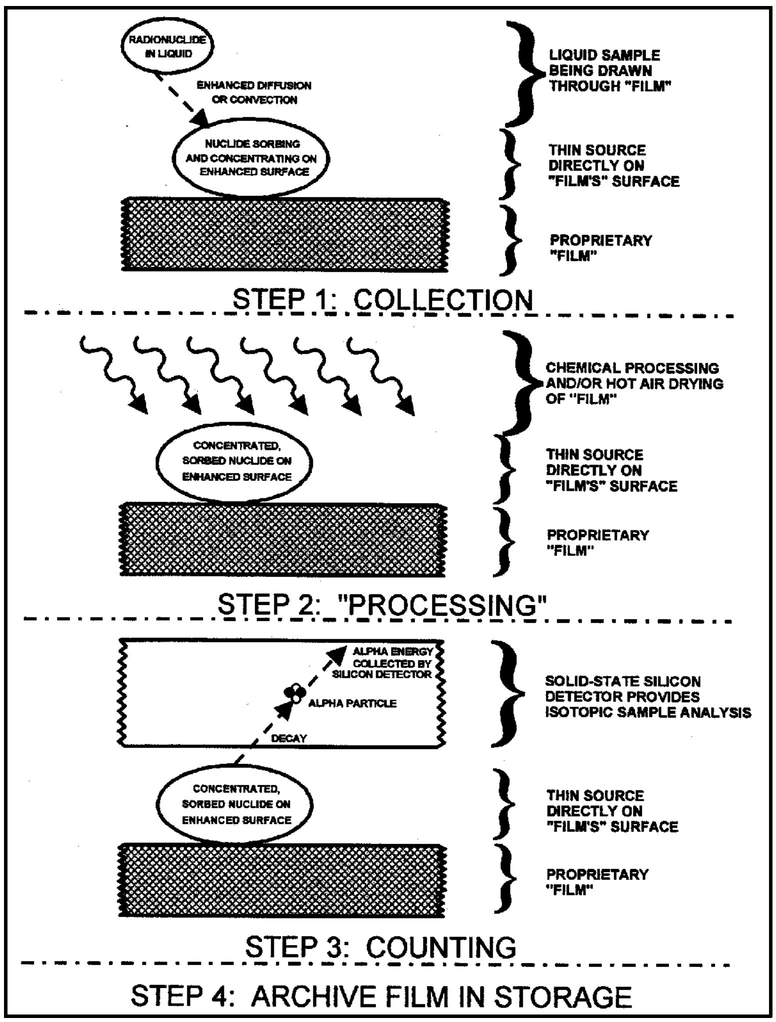

Figure 3. Basic Principle of Operation

generation. 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. Figure 4 presents results of counts for a residential deep well water sample, indicating the excellent alpha energy resolution and the applicability to a wide range of alpha-emitting radionuclides.

The response time of the instrument is directly related to the U concentration in the aqueous stream being monitored. The instrument will automatically total the ^{238}U, ^{235}U, and ^{234}U peaks and measure the time required to reach 10 (for approximately ± 40% statistical accuracy) to 100 counts (for approximately ± 15% statistical accuracy). For 1 ppb U, 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.

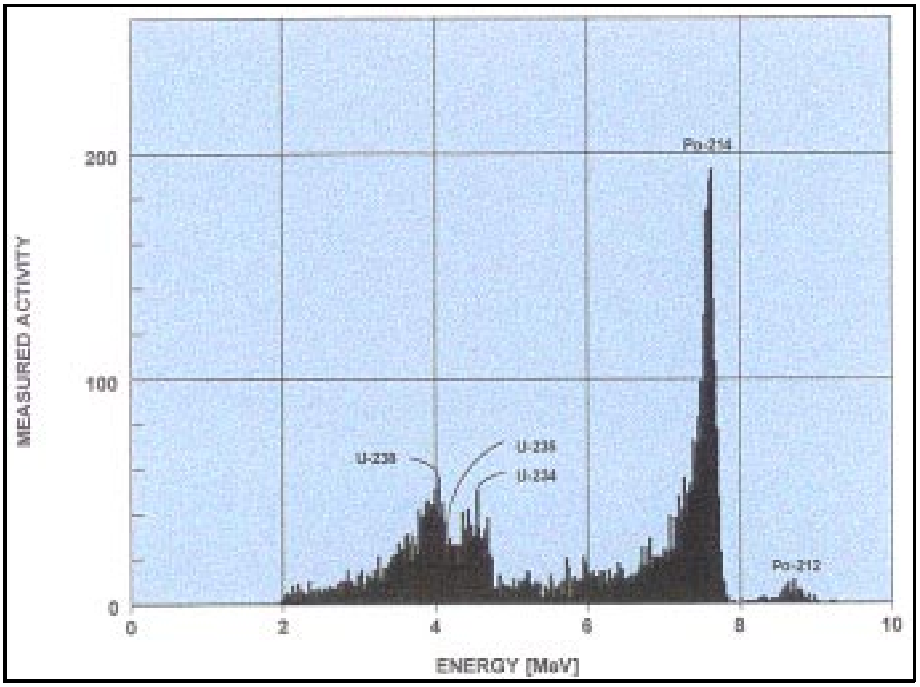

Figure 4. TAM laboratory results, Massachusetts groundwater, 2ppb (1.5 pCi/l) Total Uranium.

User Interface

The TAM is designed to be controlled by a standard personal computer that has been integrated with the instrument's cabinet. The computer runs under the Windows operating system. The software has different password protected security levels, allowing varying levels of control. At the lowest level, the user is limited to viewing the operation and sequence of events as they occur. 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 instrument's operation in case of an emergency.

Main Menu

Once the user has successfully logged on, the "Main Menu" appears, as shown in Figure 5. Depending on security access, the user may use a mouse to click on any of the option buttons on the screen.

Analysis Screen

The "Analysis" screen presents a summary of information about present operating conditions as well as current and historical data.

Status Screen

The "TAM Status" Screen shows, in moderate detail, the current status of the instrumentation in a control panel format. Under each chamber, there are indicator lights which show the status or mode of operation for each chamber. Figure 6 shows a sample Status screen.

Detailed Component Status Screens

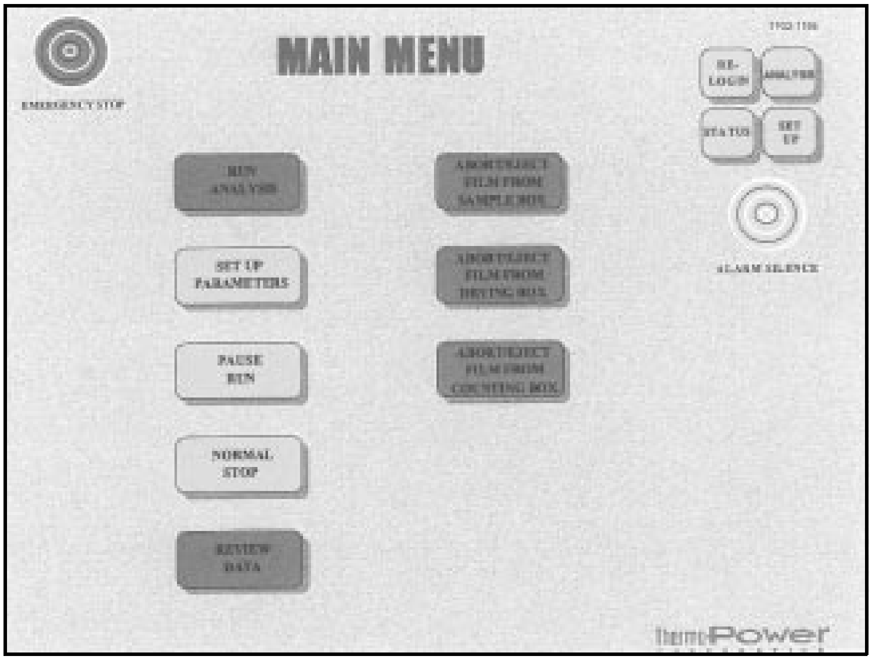

Figure 5. TAM Main Screen

An additional feature of the instrument 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 "TAM Status" screen, a detailed screen will be displayed. This enables the user to determine which, if any, of the components need attention when an alarm is triggered.

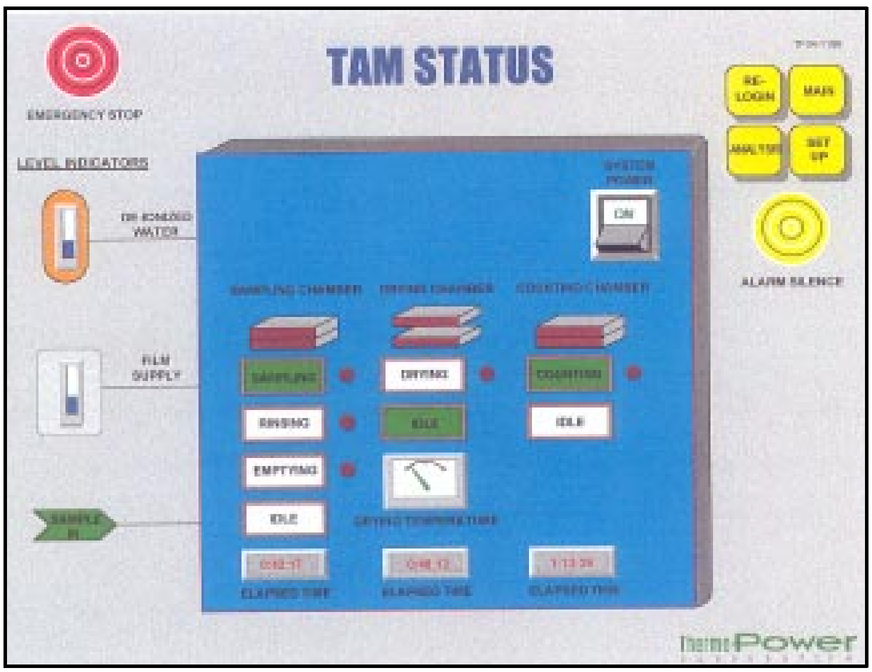

Figure 6. TAM Status Screen

SECTION 3

PERFORMANCE

Demonstration Plan

Field testing was conducted at the Oak Ridge Reservation (ORR). The water streams sampled included groundwater, surface water, and process wastewaters. The field testing plans included continuous monitoring with the instrument to determine U and other radioisotope concentration. The field testing plans included analysis of variance with time as well as excursions above regulatory limits. Conventional analysis of stream samples were also performed during field testing for comparison with TAM results.

Tests were conducted at five locations, in order to evaluate the response of the instrument to a range of water chemistries, contaminant concentrations, and radioisotopes. The ground, surface, and process water sources were selected as being representative of expected water conditions at the major areas of use across the DOE complex. Three of the test locations were off the DOE-ORR, and two of the sites were on the ORR.

The primary test locations were at the City of Oak Ridge Municipal Wastewater Treatment Plant (MWTP). Influent and effluent water from the MWTP was available for testing, while nearby East Fork Poplar Creek (EFPC) provided a source of surface water. Both the city's influent and the EFPC are partially derived from the DOE-ORR, as the effluent from the ORR Y-12 site is routed to the MWTP for treatment, and the source of the EFPC is on the Y-12 site. Radioactivity in these water streams is due to DOE-ORR discharges, as well as the several civilian/commercial users of radioactive materials at Oak Ridge. The secondary test sites included a surface water source (SS-5) and a groundwater well (GW-684) located on the ORR in the Bear Creek Valley (BCV). Both contained water that was at background levels of U (30 pCi/l, or 40-70 ppb total U).

The test sequence for each site was as follows:

1.) Install and checkout the field test unit at the test location.

2.) Operate instrument at each site to obtain one to two samples of the water stream of interest. Report the results for all alpha-emitting radionuclides detected. Take a minimum of two spot samples for analysis by two conventional methods: 1) total U by kinetic phosphorescence [KPA] and 2) gross alpha precipitation) for elemental and isotopic content for direct comparison with the instrument results. Parameters to be studied in the testing included:

   a) Reliability and life of detector instrument
   b) Stability and reproducibility of instrument (if duplicate samples are taken)
   c) Automated operation cycle and control of instrument
   d) Water chemistry (measure pH of sample to verify it is in an acceptable range)
   e) Radioisotope type (within limits of those available at Oak Ridge)

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

Results

The results (given in Table 1) show that this instrument can detect U and other alpha emitters at low levels within reasonable accuracy. Two analyses were performed at the EFPC and MWTP effluent using the field test unit. A single analysis was performed at the MWTP influent, the Y-12 BCV SS-5 site, and the Y-12 BCV GW-684 site. The pH for each sample was within normal operating tolerances of the field test unit. Three to four spot samples were taken during the course of almost every field test unit run, to demonstrate reproducibility of results. Only a single spot sample was taken during the course of the

Table 1. Complete field test results for total Uranium (expressed as pCi/l)

Sample	Laboratory Kinetic Phosphorescence (KPA)	Laboratory Isotopic-Alpha	Thermo Alpha Monitor for Liquids
MWTP Effluent “A” Sample # 1	0.21	-1.4	
MWTP Effluent “A” Sample # 2	0.20		
MWTP Effluent “A” Sample # 3	0.27	-1.6	
Average, or Field Test Unit	0.22	-1.5	0.49
MWTP Effluent “B” Sample # 1	0.23	0.38	
MWTP Effluent “B” Sample # 2	0.22		
MWTP Effluent “B” Sample # 3	0.22	-1.44	
Average, or Field Test Unit	0.23	-0.53	0.31
MWTP Influent Sample	0.51	-1.5	0.64
EFPC “A” Sample # 1	3.7	4.0	
EFPC “A” Sample # 2	3.8		
EFPC “A” Sample # 3	3.8	1.8	
Average, or Field Test Unit	3.7	2.9	2.3
EFPC “B” Sample # 1	3.9	2.1	
EFPC “B” Sample # 1 - Duplicate	3.9	4.3	
EFPC “B” Sample # 2	4.0		
EFPC “B” Sample # 3	3.9	3.0	
Average, or Field Test Unit	3.9	3.1	1.8
BCV GW-684 Sample # 1	22	24	
BCV GW-684 Sample # 2	22		
BCV GW-684 Sample # 3	21		
BCV GW-684 Sample # 4	21	28	
Average, or Field Test Unit	21	26	16
BCV SS-5 Sample #1	45	60	
BCV SS-5 Sample #1 - Duplicate	45	62	
BCV SS-5 Sample #2	44		
BCV SS-5 Sample #3	45		
BCV SS-5 Sample #4	44	55	
Average, or Field Test Unit	45	59	13

MWTP influent test run, due to a repeated clogging of the sample pre-filter screen, which limited the amount of sample that could be obtained.

Based on the results obtained from this field demonstration, this instrument meets the DOE need for detection of alpha emitters in the field. The field demonstration was conducted for a one week period, instead of the planned 30 days, due to resource constraints. While the instrument operated as planned in this 7-day period, more thorough testing is recommended for long-term reliability and life of the detection instrument. The instrument, including automated features, were demonstrated in the presence of Oak Ridge personnel. While automated features were operated successfully, these features are no longer considered critical, and, in fact, would increase the sales price of a commercial instrument with little or no benefit to the end user. Raw data is comprised of results of counts that provide radioisotope types. For the Oak Ridge demonstration, data analysis lead to the values for total uranium given in Table 1.

Closer examination of the data in Table 1 reveals the following:

- The field test instrument was able to produce reliable isotopic results at the lowest uranium levels that were measured, which were 60% above the KPA analyses. The isotopic uranium analysis was unable to detect any uranium in the MWTP samples. Consequently, the sample size (0.1 liter) used in the isotopic uranium analysis was not large enough to provide the required sensitivity.
- For the two highest uranium levels, the isotopic uranium analysis produced results that were 27%greater than the KPA test results for the BCV samples.
- The KPA test results were largest for the EFPC surface water samples. The isotopic uranium analysis results were 22% below the KPA analysis, while the field test instrument results were 47% below the KPA analysis for these samples.

The general trends that were evidenced by these observations were:

- Analysis results from all three methods can be ranked from lower levels to higher levels. From lowest to highest, this average ranking was as follows:
  - Oak Ridge Municipal Wastewater Treatment Plant effluent - 0.14 pCi/l
  - Oak Ridge Municipal Wastewater Treatment Plant influent - 0.28 pCi/l
  - East Fork Poplar Creek - 2.6 pCi/l
  - Y-12 Bear Creek Valley groundwater well GW-684 - 18 pCi/l
  - Y-12 Bear Creek Valley surface water site SS-5 - 37 pCi/l
- Relative to the KPA total uranium analysis method, the isotopic uranium analysis method produced results that were biased low at low uranium levels (below 10 pCi/l), and biased high at higher uranium levels (above 10 pCi/l).
- Relative to the KPA total uranium analysis method, the field test instrument produced results that were biased high at low uranium levels (below 10 pCi/l), and biased low at higher uranium levels (above 10 pCi/l).

SECTION 4

TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Competing Technologies

Manual Sample Collection/Off-site Laboratory Analysis

The baseline technology for measurement of alpha radiation in water samples is manual sample collection and off-site laboratory analysis. Intermittent samples are collected from surface and/or ground waters, chemically preserved (by the addition of acid), entered into a chain-of-custody infrastructure, packaged for shipping, and then sent to a laboratory for analysis. The analytical procedure involves separation and concentration of alpha-emitting radionuclides from the water sample, either by precipitation or evaporation. The alpha-emitting radionuclides are plated on a planchet and counted in a vacuum using a silicon wafer semiconductor detector. The results are subjected to Quality Assurance/Quality Control (QA/QC) procedures, converted to the radionuclide concentration, pCi/l, and reported to the requester.

There are several shortcomings of this approach. With this monitoring process, only intermittent data is 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. With increased 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. While this would certainly reduce immediate costs of analysis, much information would be lost and high excursion of alpha-emitting radionuclides could occur between samples without anyone being aware of it.

There is also a significant time delay between sampling and data availability with the baseline approach. Several days generally pass between the time a sample is submitted and receipt of results of the analysis. While an immediate procedure can be used in the event of an emergency, “rush” samples must be limited because of their high cost. This delay can have serious consequences. For instance, changes in the water’s composition may not be detected for days and in the instance of thermal treatment, D&D, or site remediation operations, delays can result in wasted effort and impede progress since the operating personnel are unaware of the true current conditions.

The baseline approach of intermittent sampling and laboratory analysis is also prone to errors due to the complexity of the process. Improper sampling procedures can be used, the analysis can be faulty, and the data reduction or reporting can be inaccurate. Elimination of the many sequential steps involved with the conventional approach, by use of automatic on-line monitoring will reduce the opportunity for errors.

Alternative Monitoring Technologies

A number of monitoring instruments are available commercially or are currently under development. Table 2 summarizes the features of the TAM in comparison with other on-line and off-line instruments and methods, including both non-commercial and commercially available units. 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. 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.

Table 2. Current Monitor Summary

Device/Method	Commercially Available ?	On-Line ?	Drinking Water U ?	Capital Cost	Other
Thermo Power's Thermo Alpha Monitor (TAM)	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 Radio-active 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

Technology Applicability

The DOE must ensure that on-site process waters and effluent waters leaving DOE sites do not affect the safety or health of its employees, contractors, or the public. TAM is applicable to a multitude of needs for alpha monitoring of liquids at DOE sites. It will serve to monitor effluent streams to ensure compliance with regulatory limits. It will also be suitable for process control of remediation as well as D&D operations, such as monitoring scrubber or rinse water radioactivity levels. It would be applicable for assaying other liquids, such as oil, or solids after proper preconditioning. Rapid isotopic alpha monitoring is also possible using this technology. Current lab procedures have long turnaround times and lower sensitivity, whereas this technology has the capability of rapid feedback over a broad range of radioisotopes.

The DoD also has over 1200 contaminated sites where this technology could be utilized. TAM may also be used in the commercial/municipal market to fulfill monitoring needs at nuclear power plants, hospitals and related health care institutions, public drinking water supply systems, academic institutions, manufacturers, analytical laboratories, waste disposal companies, and other service firms.

Patents/Commercialization/Sponsor

Research and development of the Thermo Power's technology was sponsored by the U.S. Department of Energy's Federal Energy Technology Center (FETC). Demonstration of the TAM was conducted in conjunction with the City of Oak Ridge Municipal Wastewater Treatment Plant and the DOE's Oak Ridge National Laboratory (ORNL).

Patent Number 5,652,013, "Chemical Enhancement of Surface Deposition," has been granted to Thermo Power, and assigned to the DOE. A second patent has been applied for and is pending. Greater rights to the technology, including these two patents, have been granted by DOE to Thermo Power for certain consideration. The consideration includes $50,000 of Thermo Power cost sharing that has been expended to date, and an additional $50,000 of cost sharing that will be provided in the next several years to commercialize the technology.

SECTION 5

COST

Methodology

Cost information for the TAM technology, as presented, is based on data obtained from the technology developer. Data for the baseline technology and competing technologies was obtained from personnel in the field, and from R.S. Means *Environmental Remediation Cost Data - Unit Cost, 4th Annual Edition*.

The baseline technology is manual sample collection and off-site laboratory analysis. 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 cost scenario presented below reflects the cost of on-line, near real-time sampling and analysis using the TAM versus the baseline of water sampling followed by analysis at a contracted laboratory. Both options will be evaluated for the analysis of isotopic U at two frequencies: 1 sample/day and 6 samples day. Long-term operation and maintenance costs were discounted to present value using real discount rates from Appendix C of Office of Management and Budget Circular No. A-94, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*, assuming a 30-year project life.

TAM Cost Assumptions

The cost savings from a TAM monitor is dependent on sampling frequency by the end user. The estimated cost to purchase a single unit is $25,000. Some labor is required for operation and maintenance, and for tracking/evaluation/archiving of results. The TAM operating costs include operating supplies (film and de-ionized water), replacement parts (primarily detectors), and site overhead which is estimated to be 8 hours per week for replenishing supplies, calibrating and maintaining the instrument.

Baseline Cost Assumptions

The baseline method considered here is manual sample collection and off-site laboratory analysis. The total cost incurred using the baseline method includes the cost for transport to the laboratory, sample collection, preparation and laboratory analysis. Standard turnaround time is typically 10 working days, but can vary from one laboratory to another. The laboratory cost is much higher if an expedited analysis is required, such as a 24- or 48-hour turnaround time. Laboratory surcharges for expedited analysis can be as high as 50-100% of the standard cost. A significant amount of the total cost for the baseline method is related to collecting the sample, labeling it, properly preparing it for transport to the laboratory, entering the results in a database and evaluating the results.

Costs for the baseline technology are derived from actual costs incurred by the Fernald Environmental Management Project (FEMP) during routine sampling and analysis at the site. Regardless of the media (groundwater, surface water, stream, influent or effluent), it is assumed that the sampling, labeling, and shipping time required is similar to that required for routine groundwater sampling at the FEMP. Under current contract at the FEMP, isotopic U in water is routinely sampled and analyzed at an off-site laboratory for a cost of $129 per sample (Energetics, Inc. 1999).

A typical FEMP groundwater sampling crew consists of three people who work 10-hour shifts. Sample management at the FEMP is performed manually and includes sample shipping/handling, data entry/archiving, and reporting at a cost of $28 per each isotope group analyzed per sample (Energetics, Inc. 1999).

Cost Analysis

TAM Costs

Table 3 includes a summary of capital and operating costs for utilization of the TAM technology at the frequencies of 1 and 6 samples per day. Operating supplies for the TAM include films at the cost of $50/sample. The cost for replacement parts during operation and maintenance of the unit is estimated to be $5,000 per year. Additionally, site overhead at $75 per hour results in a weekly maintenance cost of $600.

Table 3. Annual operating costs of TAM vs. baseline

Conventional laboratory analysis			TAM analysis		
Frequency (Samples/day)	1	6	Frequency (Samples/day)	1	6
Annual site overhead ($)	65,150	390,900	Annual Operating supplies ($)	18,250	109,500
Annual laboratory analysis ($)	47,090	282,540	Annual Replacement parts (primarily detectors, $)	5,000	5,000
			Annual Site Overhead ($)	31,200	31,200
Total annual cost ($)	112,240	673,440	Total annual cost ($)	54,450	145,700

Table 4. Life Cycle costs (per sample) of TAM vs. baseline

	Conventional laboratory analysis		TAM analysis	
Frequency (Samples/day)	1	6	1	6
Capital Cost ($)	N.A.	N.A.	25,000	25,000
Total annual isotopic U analysis cost ($)	112,240	673,440	54,450	145,700
Total life-cycle present value ($)	518,460	3,110,750	276,520	698,020
Total samples collected	1,825	10,950	1,825	10,950
Net present value per sample collected and analyzed ($)	284	284	152	64

Note: 5-year net present value (7/99) is based on a real discount rate of 2.7% (Office of Management and Budget 1992)

Baseline Costs

Typical rates for sampling at the FEMP are $35/hr and 3 person sample crews work 10 hr/day. Based on this crew size, 7 water samples can be collected each day. Therefore, it would take approximately 4.3 person hours to collect each sample. Sample management is approximately $28/isotope group per sample collected.

Life-Cycle Cost

The most meaningful assessment of cost savings for this scenario is comparison of life-cycle cost (LCC) per sample for the TAM based on the varying sample frequencies. Table 4 summarizes LCC analysis for both the TAM and the baseline. The LCC is calculated by adding the capital costs to the present value of the discounted operation and maintenance costs over 5 years (assumed lifetime of instrument). The real interest rate for discounting the operation and maintenance costs is 2.7 percent (Office of Management and Budget 1992).

Cost Conclusions

Based on stated assumptions for each alternative, the following conclusions are presented:

- The analysis indicates significant cost savings when comparing the application of TAM to the baseline method of manual sampling and laboratory analysis.
- A fully-automated analysis instrument such as the TAM represents the best method for providing low-cost, long-term remote environmental data acquisition and reporting.
- Cost savings from use of TAM increase with increased sampling frequency.
- Annual sampling costs for a sampling frequency of 1 sample per day using TAM are less than one half of costs for manual sample collection and laboratory analysis.
- Annual sampling costs for a sampling frequency of 6 samples per day using TAM are less than one fourth of costs for manual sample collection and laboratory analysis.

Best management practices generally dictate that the option with the lowest total cost be used. Perhaps 2/3 of the total cost of environmental monitoring is associated with the manual steps of sample collection, sample preservation, entry into the chain of custody system, shipping to the laboratory, and sample analysis. The cost for conventional analyses may also restrict the number of samples analyzed to a less than desirable level in many instances. In addition to providing continuous, rather than intermittent concentrations, an on-line, near real-time monitor such as TAM will be cost effective, relative to the use of conventional laboratory analysis. As is illustrated by Table 3 , the cost savings of the TAM monitor is dependent upon the sampling frequency. Cost benefits can be realized at a sampling rate as low as once per day, but become more dramatic as the sampling frequency increases.

In addition to the direct cost savings provided by utilization of the TAM, secondary cost savings will be realized due to the availability of near real-time data of high quality. Near real-time data will allow for more efficient operation of treatment systems, remediation efforts, and decontamination activities, thereby resulting in cost savings. In remediation operations, immediate availability of data on process operations speeds up the remediation operations, thus reducing costs. Indirect cost savings would also be realized by avoidance of work delays that often result from the slow turnaround time of the baseline technology.

Furthermore, continuous monitoring of effluent streams and near real-time data would allow for proactive, rather than reactive, response to concentration increases or exceedence of discharge limits. Continuous, near real-time data will minimize the occurrence of serious accidental release of radionuclides and thus, protect the environment and the public and also prevent expensive clean-up activities. However, while the on-line TAM does provide the capability for continuous sampling if needed, this may not be cost effective or required in most situations.

SECTION 6

REGULATORY AND POLICY ISSUES

Regulatory Considerations

The high quality, near real-time data generated by the TAM will increase stakeholder ability to monitor and control discharges. Ultimately, the TAM will help stakeholders comply with regulatory discharge limits and minimize exceedences. Field experience with the monitor will eventually eliminate the need for "check" samples, as the monitor becomes an accepted and standard method, thus reducing the hazards and secondary wastes associated with sample collection. However, TAM results must first be proven to be accurate and then be accepted by regulators

Additionally, the monitor provides greater control and assurance of Final Remediation Level (FRL) compliance and ALARA (As Low As Reasonably Achievable) compliance by reducing worker exposure to waste streams, as well as to chemicals in laboratory analysis.

Stakeholder, regulatory, and tribal issues and permitting requirements will all affect the technology in a positive fashion, by creating a stakeholder "pull" that accelerates the development and deployment of the technology. Stakeholders and regulators generally prefer on-line analysis and testing over a schedule of periodic grab or composite samples, for the increased level of confidence that develops from continuous sampling.

Safety, Risks, Benefits, and Community Reaction

Worker and Community Safety

- Risk to the public, workers and the environment will be greatly reduced by continuously monitoring all effluent streams for U 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.
- The monitor will have a positive effect on occupational health and safety because the handling of samples will be minimized by the automated, on-line monitor.

Environmental Impact

- Application of the on-line, near 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 effluent waters leaving the site. Such continuous and near real-time monitoring will be particularly beneficial during remediation actions when the site is disturbed and unexpected releases might occur.

Socioeconomic Impacts and Community Perception

- The on-line, near 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.

SECTION 7

LESSONS LEARNED

Implementation Considerations

- 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 manual sample collection and subsequent laboratory analysis.
- TAM may also be utilized on-site, but not on-line to quickly analyze samples taken from several locations.

Technology Limitations

- While the TAM was developed for monitoring water, it would be applicable to other liquids, such as oil, or solids after proper preconditioning.

Needs for Future Development

- Improve 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.
- Incorporate user feedback into an improved design to meet end-user needs.
- Conduct additional comprehensive field tests of the instrument to determine the endurance characteristics of the monitor when it is used by personnel in the field.
- Conduct additional testing so that results can be validated for accuracy and gain agency acceptance.

Technology Selection Considerations

- Sampling frequency determines cost effectiveness of technology.

APPENDIX A

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