

# Portable X-Ray Fluorescence Spectrometer

Deactivation and Decommissioning  
Focus Area



*Prepared for*  
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# Portable X-Ray Fluorescence Spectrometer

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Deactivation and Decommissioning  
Focus Area



*Demonstrated at*  
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## ***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 Description

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This report describes the application of portable X-ray fluorescence (XRF) spectrometry to characterize materials related to decontamination and decommissioning (D&D) of contaminated facilities. Two portable XRF instruments manufactured by TN Spectrace were used in a technology evaluation as part of the Large-Scale Demonstration Project (LSDP) held at the Chicago Pile-5 Research Reactor (CP-5) located at Argonne National Laboratory (ANL). The LSDP is sponsored by the U.S. Department of Energy (DOE), Office of Science and Technology, Deactivation and Decommissioning Focus Area (DDFA). The objective of the LSDP is to demonstrate innovative technologies or technology applications potentially beneficial to the D&D of contaminated facilities. The portable XRF technology offers several potential benefits for rapid characterization of facility components and contaminants, including significant cost reduction, fast turnaround time, and virtually no secondary waste. Field work for the demonstration of the portable XRF technology was performed from August 28 - September 3, 1996 and October 30 - December 13, 1996.

The XRF analyzers use X-ray fluorescence data to provide rapid, non-destructive, real-time, elemental information on a variety of materials that may include surfaces, soils, liquids, or thin films. X-ray fluorescence is a phenomenon in which atoms of a given chemical element emit characteristic X-rays when excited by radiation having an energy close to, but greater than, the binding energy of the element's inner shell electrons. Because every element has a different electron shell configuration, the energy spectrum of each element's characteristic X-rays is unique to the element. Consequently, by measuring the peak energies of X-rays emitted by a sample exposed to an appropriate radiation source, it is possible to identify the elements present in the sample. Moreover, because the intensity of the characteristic X-ray emission is proportional to the number of atoms being excited, the X-ray fluorescence spectrum can also be used to measure each element's concentration.

Field portable X-ray fluorescence analyzers utilize sealed radioisotope sources to provide the excitation radiation needed to induce emission of fluorescent X-rays. The analyzers are typically configured to include a device for exposing a sample to the excitation source, a detector and energy-dispersive analyzer to acquire and record the fluorescent X-ray energy spectrum, and a data processor to convert the spectral data to elemental concentrations. In the LSDP demonstration, measurements were made with two units from TN Spectrace. These included the TN Lead Analyzer (designed to analyze for lead in matrices such as soil, paint and paint chips, surface dust, or air filters) and the TN Spectrace 9000 (designed to determine the elemental composition of a broad range of materials for environmental applications, industrial quality control, and other uses). Figure 1 shows the TN Spectrace 9000 equipment.



Figure 1. TN spectrace equipment.

The TN Lead Analyzer uses the radioisotope source Cd-109 for sample excitation. Besides lead, it can also identify and measure several other metals, including arsenic, chromium, iron, copper, zinc, and manganese. The Spectrace 9000 uses three radioactive isotopes (Fe-55, Cd-109, and Am-241) to provide a wider range of excitation energies capable of analyzing for elements of atomic number 16 (sulfur) through 92 (uranium). Applications software installed by the manufacturer allows the simultaneous determination of 25 elements including lead and other heavy metals of regulatory concern. Both analyzers utilize a high-resolution mercuric iodide semiconductor detector that is operated at moderately subambient temperature provided by a low power thermoelectric (Peltier) cooler in the instrument's measurement probe. The instruments may be operated from a 110 VAC power line or rechargeable battery pack.

The XRF equipment is small, light-weight, and readily transportable for on-site measurements. It can be operated in either an in-situ mode where the instrument probe is positioned directly on the sample material to be analyzed or in an intrusive mode where a portion of the sample is presented to the instrument in a thin-windowed plastic cup that is placed over the measurement probe and beneath a swing-down safety shield.

A substantial portion of the effort and cost associated with the decommissioning of DOE or commercial facilities involves determining facility characteristics regarding the chemical identity of components or contaminants and monitoring the progress of activities carried out to remediate any problems that exist. Typical practice in such characterization work is to extract samples for off-site laboratory analysis. This sampling and analysis process is not only costly, but also involves a delay between collection of the samples and availability of data for making decisions about sufficiency of the sampling or actions to be taken. The portable X-ray fluorescence analyzers are designed to provide rapid, real-time information on metals in facility components or contaminants. This information has the potential to allow investigation and remediation decisions to be made on site more efficiently, and can reduce the number of samples that need to be submitted for costly laboratory analysis. Although the use of the XRF technology cannot completely displace the baseline technology of collecting samples for analysis by regulator-approved laboratory methods, the XRF analyzer offers considerable advantages in cost and time when used as a screening tool to identify areas of potential concern, to help define the boundaries of a contaminated area, to track the progress of remediation efforts, or to guide waste management strategies.

## **Technology Status**

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The XRF analyzer technology is well-established and commercial instruments are available from a number of manufacturers. The various commercial systems typically involve a similar configuration of basic components, but differ in their specific detector technology, mechanisms for sample presentation, and approach to data processing. Each may have particular advantages or disadvantages in a specific application.

The TN Spectrace instruments used for the LSDP demonstration are products of a manufacturer that has produced field-portable and laboratory-grade XRF technologies since 1988 for a broad range of applications. The TN Lead Analyzer was released in 1993 specifically for measuring lead in a variety of matrices such as soils, paint and paint chips, surface dust and air filters. The Spectrace 9000 analyzer was released in 1992 for environmental applications.

In recent years, the XRF analyzers have been applied with increasing frequency to environmental characterization and remediation measurements, particularly in analysis of heavy metal contaminants in soils. In 1995, the U.S. Environmental Protection Agency (EPA) supported a study of innovative XRF technology at two Superfund sites to characterize the performance of the latest models of commercially available XRF analyzers. This demonstration found the XRF analyzers to be effective tools for field-based analysis of soil samples for metals contamination. The data from these trials provided background material for the creation of a draft method (Method 6200) proposed for inclusion in the EPA SW-846 methods manual. This method (*Field Portable X-ray Fluorescence Spectrometry for the Determination of Elemental Concentrations in Soil and Sediment*) provides guidance for users of XRF for



environmental characterization. It is a screening method to be used with confirmatory analysis by EPA-approved laboratory methods. The XRF method's main strength is as a rapid field-screening procedure.

For the LSDP demonstrations, a single test engineer from ANL operated each XRF system. Other ANL personnel from the CP-5 facility, the Environment, Safety, and Health (ESH) Department, or the Environmental Management Operations (EMO) Department provided support in the areas of health physics (HP), industrial hygiene (IH), waste management (WM), and safety engineering. Demonstration data for benchmarking was provided by ANL and data for cost analysis was provided by ANL and TN Spectrace. Cost analysis was performed by the U.S. Army Corps of Engineers, and benchmarking activities were performed by ICF Kaiser.

## Key Results

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The key results of the demonstration are as follows:

- In situations where the precision, accuracy, and detection limits of the XRF technology are consistent with the data quality objectives of a site characterization project, XRF is a fast, powerful, and cost effective technology for identifying and measuring concentrations of chemical elements, particularly metals.
- The instruments used in the demonstration were light-weight and convenient to operate in the field. Software was easy to operate for both instrument control and data transfer from instrument memory to personal computer.
- Performance of the instruments was consistent with vendor specifications. Multiple measurements on individual samples gave reproducible results.
- Counting times of 100 to 400 sec gave sufficient sensitivity to identify major constituents during surface characterization measurements, including the detection of lead in paint. In some applications, longer count times might be advantageous to provide lower detection limits or better accuracy. Much longer count times could be used in many situations without mitigating the throughput advantage of XRF over baseline technologies involving intrusive sampling and laboratory analysis.
- Paint containing lead was found on surfaces at two locations in the CP-5 mezzanine area.
- Direct analysis of used HEPA filters was unsuccessful because the structural configuration of the filters includes a wire-mesh screen that encloses the filter medium and prevented positioning of the instrument probe on the contaminated surface. Some intrusive sampling could be necessary to apply the XRF technology to certain types of materials.
- Results from the XRF measurements might not be perfectly comparable to measurements by the baseline technology because the XRF systems respond to total concentrations of a given element while the baseline technology measures only the acid-soluble portion.

## Contacts

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### **Licensing Information**

No licensing or permitting activities were required to support this demonstration.

### **Web Site**

The CP-5 LSDP Internet address is <http://www.strategic-alliance.org>.



## SECTION 2

# TECHNOLOGY DESCRIPTION

### System Configuration and Operation

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Field portable X-ray fluorescence analyzers operate on the principle of energy dispersive X-ray fluorescence spectrometry whereby the characteristic energy components of the excited X-ray spectrum are analyzed directly via their energy proportional response in the X-ray detector. Energy dispersion affords highly efficient full spectrum measurement which enables the use of low intensity excitation sources (such as radioisotopes) and compact design battery-powered field-portable instruments. Many XRF instrument designs based on various energy dispersive detector technologies are now widely used for composition analysis in the industrial and environmental arenas. Such applications make particularly good use of the non-destructive nature of the XRF measurement technique. The technique is best applied to samples that are homogeneous on the scale of the X-ray penetration. Typical X-ray penetration depths might range from about 0.1 to 1 mm for the X-rays of most targeted metal analytes in facility component or environmental samples.

Field portable X-ray fluorescence analyzers use sealed radioisotope sources to irradiate samples with gamma rays having an energy appropriate to exciting electronic transitions in the elements contained in the sample. When the sample is irradiated with these gamma rays, the source photons undergo either scattering or absorption by atoms in the sample. When an atom absorbs the source photons, the incident radiation dislodges electrons from the innermost electron shells of the atom, creating vacancies. These electron vacancies are filled by electrons cascading in from outer electron shells. Electrons in outer shells have higher energy states than inner shell electrons and the outer shell electrons give off energy as they cascade down to the inner shell vacancies. This rearrangement of electrons results in emission of X-rays characteristic of the given atom. This emission of X-rays is termed X-ray fluorescence.

Commercial XRF analyzers typically consist of two component parts. One is the probe unit, which contains one or more radioisotope excitation sources and the energy proportional detector. The other is the electronics unit that collects signals from the detector, processes these data to record the XRF emission spectrum, converts the spectral information into information on element identities and concentrations, and stores information related to the measurement. Different manufacturers may use different types of detectors, including gas-filled proportional detectors or solid state detectors. Generally, the spectral resolution of gas-filled proportional detectors is not as good as that of the solid state devices. The gas-filled detectors are, however light-weight and rugged. Common solid state detectors include mercuric iodide ( $\text{HgI}_2$ ), silicon pin diode, and lithium drifted silicon. For measurement, the sample is positioned in front of a window on the probe unit where it can be exposed to the excitation source. Sample positioning can be done in one of two ways, termed in-situ or intrusive. In the in-situ mode, the probe window is placed in direct contact with the material surface to be analyzed. In the intrusive mode, a portion of the material is placed in a sample cup which is then positioned at the probe window for analysis.

Several approaches are used for calibrating XRF analyzers. One method is to use fundamental parameters based on the physics of the excitation of target analytes and the emission of X-rays. Another method is to perform an empirical calibration based on site-specific calibration standards analyzed by an appropriate reference method. Because XRF emission from a particular element can be strongly dependent on the nature of the sample matrix and interfering elements that might be present, the site-specific standards are selected to have similar matrix characteristics to unknown samples that would be analyzed.



The TN Spectrace instruments used in the LSDP demonstrations use a mercuric iodide semiconductor detector that achieves a manganese  $K_{\alpha}$  X-ray resolution of better than 300 eV. The detector is operated at a moderately subambient temperature controlled by a low power thermoelectric (Peltier) cooler in the measurement probe. The probe also contains the radioisotope excitation sources. The TN Lead Analyzer contains one 5 mCi Cd-109 source while the TN Spectrace 9000 contains three sources, including Fe-55 (50 mCi), Cd-109 (5 mCi), and Am-241 (5 mCi). Each source is encapsulated and housed in a metal turret with additional lead shielding inside the probe. Each source can be individually or sequentially positioned under software control to expose the sample to excitation radiation through a sealed, one-inch diameter window in the face of the probe. The source induced fluorescence from the sample passes back through the window and is intercepted by the  $HgI_2$  detector. The detector quantifies the energy of each characteristic emission X-ray and builds a spectrum of analyte peaks on a 2048-channel multichannel analyzer, which is contained in the electronics unit. The probe is 12.7 cm x 7.6 cm x 21.6 cm and weighs 1.9 kg.

Spectral data are communicated to the electronics unit through a 6-foot long flexible cable. Software in the electronics unit integrates the X-ray peaks and converts peak areas to selected concentration units that can be  $\mu\text{g}/\text{cm}^2$ , mg/kg, or percent. The electronics unit will store and display both numerical results and spectra from each measurement. As many as 300 sets of numerical data and 120 spectra can be stored before being downloaded to a personal computer using a RS-232 interface cable. The electronics unit is 32 cm x 30 cm x 10 cm and weighs 6.7 kg.

The electronics unit can be operated from a battery or from an alternating current electric line via a plug-in adapter. The batteries last approximately 4 to 5 hours and require a minimum of 14 hours to fully recharge.

A moderate level of skill and training is required to operate the equipment. Training should include the theoretical background of XRF analysis and applications of the analyzer to be used. Because the analyzers contain radioisotope sources that emit radiation of X-ray energy, operators also need to be familiar with basic principles of radiation safety. The radioisotope sources are permanently sealed within high-strength capsules that are certified for industrial use. The TN instruments are sold under a general license, meaning that the analyzers are designed and constructed in a way that anyone operating them in a manner consistent with the instruction manuals will not be exposed to harmful radiation levels as determined by the Nuclear Regulatory Commission (NRC). Background radiation during normal operation of the instruments is well below occupational exposure limits. It should be noted, however, that the radiation output of the excitation sources requires that the probe be always handled with care and that the probe should never be pointed at a person while a source is exposed.

The Spectrace 9000 can analyze for up to 25 different elements simultaneously. The metals analyzed at CP-5 included the following:

Silver (Ag)	Arsenic (As)
Barium (Ba)	Calcium (Ca)
Cadmium (Cd)	Cobalt (Co)
Chromium (Cr)	Copper (Cu)
Iron (Fe)	Mercury (Hg)
Potassium (K)	Manganese (Mn)
Molybdenum (Mo)	Nickel (Ni)
Lead (Pb)	Rubidium (Rb)
Antimony (Sb)	Selenium (Se)
Tin (Sn)	Strontium (St)
Thorium (Th)	Titanium (Ti)
Uranium (U)	Zinc (Zn)
Zirconium (Zr)	

The technology is non-destructive and generates virtually no secondary waste.



## SECTION 3

# PERFORMANCE

### Demonstration Plan

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The demonstration of the field portable X-ray fluorescence analyzer technology was conducted per the approved test plan *CP-5 Large-Scale Demonstration Project: Test Plan for Field Test One of the Accelerated Facility Characterization Process Using Portable X-ray Fluorescence at CP-5*, and the approved test plan *CP-5 Large-Scale Demonstration Project: Test Plan for the Demonstration of HEPA Filter Analysis by Portable X-ray Fluorescence Spectrometry*.

In the first demonstration, the Spectrace Lead Analyzer and the Spectrace 9000 unit were used to examine the elemental composition of a variety of surfaces, surface coatings, and smears in four rooms in the CP-5 Reactor Mezzanine Area. The principal objective of the demonstration was to establish that the XRF systems were capable of rapidly providing compositional analysis data for a large number of locations. The XRF analyzers were used to screen the facility for hidden or abraded non-radioactive contaminants such as lead or heavy metals. The Spectrace Lead Analyzer was used to monitor only lead at selected locations, while the Spectrace 9000 was operated in a mode that allowed the simultaneous evaluation of 25 metals.

In the second demonstration, the Spectrace 9000 instrument was applied to the determination of heavy metal contaminants on high efficiency particulate air (HEPA) filter media and the results were compared with data available from standard baseline procedures involving laboratory digestion of the HEPA filter media and analysis by atomic spectroscopy methods. Measurements with the portable XRF system were carried out in three operating situations to provide (1) an evaluation of the XRF technology during measurements with homogenized composite samples typically used in the baseline technology; (2) demonstration of the feasibility of making XRF measurements on HEPA filters "in the field" using intact filters removed from service at the CP-5 reactor facility; and (3) evaluation of an alternative operational approach with the XRF technique by analyzing samples excised from the CP-5 HEPA filters during waste handling operations.

### Performance

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#### Surface Characterization Measurements

The surface characterization measurements taken in August, 1996 in the CP-5 facility showed the XRF instruments to be very easily moved from location to location and easy to operate. The instruments were operated in a fundamental parameter calibration mode using application software installed by the vendor. The units did not require any special setup for operations to begin. They and their operators from ANL were ready to proceed within five minutes of arrival. Lead measurements with the Spectrace Lead Analyzer were completed on sixteen paint samples in the four rooms within an hour and a half of setup. Twenty eight additional locations were examined with the Spectrace 9000 within four hours of setup. The longer time required for analysis with the Spectrace 9000 arises from the use of sequential analyses at each location with each of the three available excitation sources to provide data for the range of 25 elements rather than the one element (lead) measured with the Lead Analyzer. Measurements were made on floors, walls, and air ducts, either by placing the instrument probe in direct contact with the surface of interest or by taking smear samples from dirty surfaces and analyzing the residue on the smears. Information on sample locations was recorded in instrument memory along with the measurement data. Both types of information were transferred to a personal computer for review and compilation after the demonstration activities were done.



In general, results of the surface measurements showed only the presence of expected components on the surfaces examined. Such results included high calcium responses for concrete and an elevated zinc response from smear samples taken from a galvanized metal air duct. In two locations, the Spectrace 9000 indicated elevated lead levels in the paint on metal doors. Results from the Spectrace Lead Analyzer confirmed this finding, which indicates a probable need for remedial action on these doors.

The field screening characterization measurements with the XRF instruments can be compared with a baseline technology involving intrusive sampling of each surface and sending the samples to a chemical analysis laboratory for elemental determinations. The XRF analyzers have a substantial cost advantage over the baseline technology as shown in Section 5 of this report. However, the primary advantage of the XRF technology in a field screening operation is its ability to make individual measurements quickly (i.e., only a few minutes per location) and to provide results that are immediately available to guide decisions regarding further sampling or subsequent actions such as waste management activities. The technology could be used conveniently to identify component materials and differentiate, for example, stainless steel from mild steel alloys or to locate lead-containing paint or lead anchors in walls. With the baseline technology, days or weeks elapse between collecting the samples and results being available for review and action. The low cost, speed, and convenience of the portable XRF measurements encourages a high sampling density relative to the baseline methods and helps provide better definition of facility characteristics. The XRF technology cannot completely replace the baseline technology because it is not sufficiently sensitive or accurate to substitute for sampling and analysis by regulator-approved methods in many situations. It can, however, be used with great advantage to help guide a judicious and prudent use of intrusive samples to optimize the effectiveness the characterization process.

#### HEPA Filter Analysis

The HEPA filters under consideration for this study were those currently in use at the CP-5 facility. This type of HEPA filter is a 2-foot square by 1-foot deep wooden frame that supports a pleated, paper-like filter medium. In general, such filters are positioned in the air exhaust vents of facilities where potential particulate emissions must be controlled, including laboratories, laboratory hoods, or reactor facilities. The HEPA filters may accumulate substantial quantities of hazardous substances during their use. Hence, used filters must be fully characterized to assign a proper hazard classification and ensure that pertinent disposal requirements are met. Current analysis procedures consist of excising a portion of the filter medium, manually cutting the excised portion of the medium into small pieces, mixing the pieces to ensure homogeneity, and subsampling for subsequent analysis. This procedure is time-consuming and expensive, and may expose personnel to radioactivity and hazardous material. The possibility of using the XRF technology for an in-situ or site analysis was perceived as a means to greatly reduce potential exposure and waste disposal costs.

The demonstration activities were carried out in three phases. These included:

- a series of measurements on homogenized composite samples typically used for the baseline analysis technology
- field measurements on intact HEPA filters previously removed from service at the CP-5 reactor facility
- laboratory measurements on samples excised from the CP-5 filters during waste-handling operations.

The XRF measurements were made with the TN Spectrace 9000 spectrometer using count times of 100 sec for the Fe-55 source, 200 sec for the Cd-109 source, and 100 sec for the Am-241 source. Although its broad range of excitation energies allows the Spectrace 9000 to analyze for up to 25 elements simultaneously, the HEPA filter characterization studies focused mainly on the heavy metals from the Resource Conservation and Recovery Act's (RCRA) Toxicity Characteristic List (As, Ba, Cd, Cr, Pb, Hg, Se, and Ag), which are the analytes normally targeted in measurements with the baseline technology.



The first phase of demonstration activities was carried out in a laboratory setting. Measurements were made with the portable XRF instrument on 19 homogenized HEPA filter composite samples that had been previously prepared and analyzed by conventional methods. For the XRF measurements, a portion of each finely cut and mixed filter medium composite was transferred to a polyethylene bag, the XRF instrument probe was positioned on top of the bag of sample material, and the XRF spectrum of the sample was acquired. Data was stored in the instrument computer for later downloading into a personal computer for compilation and review. The probe was then moved to a different location on the sample and another measurement was made. Data was collected from two to four locations on each sample to provide information on measurement variability. Two samples that were analyzed early in the sequence were reanalyzed at the end to evaluate reproducibility of the results. In all, 68 measurements were made on the 19 samples over a period of five work days.

The second phase of the demonstration took place in November, 1996. In this activity, two intact HEPA filters that had previously been removed from service at the CP-5 reactor facility were transferred to a waste-handling area in Building 306 by Environmental Management Operations (EMO) mechanics and were analyzed with the portable XRF spectrometer. The field measurements were made by positioning the probe of the XRF instrument on the flat face of each HEPA filter and recording the XRF spectrum. Three measurements were made at each of two locations on each filter – one location had the probe positioned at the center of the filter face and the other had the probe near the edge of the filter face toward one of the corners. These measurement data were collected through the plastic wrapping that enclosed each filter.

The third phase of demonstration activities involved carrying out XRF measurements on the pleat samples excised by the EMO mechanics, and analyzing portions of the pleats by the baseline laboratory methods.

The TN Spectrace 9000 XRF Analyzer produced repeatable and reproducible measurement values. All data from multiple readings taken in a given set of operating circumstances were the same within the uncertainty limits provided by the instrument software algorithms. For the few samples that were analyzed in the laboratory days apart, values agreed remarkably well, especially if one allows for probable nonuniformity in the material that was analyzed (cut and mixed composites of samples from up to 12 separate HEPA filter units).

Because no standards were available that contained the analytes of interest in a matrix similar to the HEPA filter medium, the XRF instrument was operated using an internal calibration program corresponding to a soil matrix. Recognizing that this program might not be well suited to the conversion of fluorescence intensity to mass concentration, the correlation between the XRF data and results from the baseline technology was evaluated. In the laboratory measurements on HEPA filter composite samples, two RCRA-metal elements (Ba and Pb) were routinely detected by the XRF spectrometer. The Cr channel from the Fe-55 source often showed high values for chromium in the HEPA filter samples, but with large standard deviations that made the values obviously questionable. Some elements (As, Se, Ag) were not present in the filters at concentrations detectable by the baseline technology and were not found by the XRF system, either. The elements Cd, Cr, and Hg were present at concentrations easily measurable by the baseline technology, but were not detected with the XRF spectrometer. Cadmium and chromium have relatively poor detection limits with the XRF system and, because their concentrations were low in the samples, the failure of the XRF spectrometer to detect them is not surprising. By using longer counting times with the individual excitation sources, detection of these elements might be improved. Sensitivity of the XRF spectrometer for mercury is adequate, but concentration levels of regulatory concern for this element are quite low, corresponding to a threshold level of 4 mg/kg in a solid matrix. The XRF system might not be useful in characterizing mercury contamination at these levels.



The results for barium and lead from the laboratory comparison between the XRF and baseline technologies were informative. Relative to the baseline measurement of barium, the XRF results showed smaller differences among the HEPA filter samples, and frequently indicated higher concentrations than those found with the baseline method. This observation is readily understandable given knowledge that (1) certain glass-fiber HEPA filter media contain barium as a substantial constituent (up to 5.5 % as BaO) and (2) the HEPA filter composite samples that were analyzed in this comparison were prepared from historic HEPA filter waste accumulated at the ANL site over a number of years. Thus, the composite samples certainly contained varying amounts of barium present as a glass-fiber component. Because the XRF technology is sensitive to the total amount of an element present in a sample material while the baseline measurements determine only the portion of an element that is brought into solution, lower results from the baseline method would be expected. Use of the XRF technology to characterize HEPA filters in D&D operations would have to account for effects of indigenous constituents such as the barium encountered in this case. HEPA filters manufactured in recent years do not contain a substantive barium component.

The results obtained for lead in the laboratory measurements on the HEPA filter composites showed a better correlation with the baseline measurements, although the XRF results for some of the samples gave values substantially above those obtained from laboratory measurements. It cannot be determined from the data whether these results indicate the existence of matrix effects that enhance the XRF response, or whether they arise from acid insoluble phases that prevent dissolution of the lead during digestion in the baseline technology, or whether some other effect is at work. Both these results and the results for barium described above demonstrate that the XRF technology is not perfectly comparable to the baseline technology. Still, one may conclude that the XRF measurements provide a potentially valuable screening tool since we did not identify any probable false-negative results.

The field-test application of the XRF spectrometer to screening of intact HEPA filters proved to have only limited value. On the one hand, it served to demonstrate the ease with which the XRF spectrometer could be transported to a field setting, the convenience of making repetitive measurements with the system, and the consistency of results of the system. However, it was found after the measurements were made that the structural configuration of the HEPA filters was inappropriate to credible analysis of the filter medium by placing the XRF probe in the positions that were used in the measurements. The problem with positioning the probe on the flat filter face is that the filter medium is enclosed on each side by a wire mesh screen that prevents the probe from coming in direct contact with the filter medium. The results from measurements made on the intact filters showed a very large response for zinc, probably arising from the galvanized surface of the wire mesh. This response demonstrates that data might be obtained from a correct positioning of the probe, but would require that the wire mesh be cut away to permit direct placement of the probe in contact with the filter medium. Because of contamination on the filter, such an operation would have to be carried out under proper containment. In an actual D&D environment, developing such a procedure could well be worthwhile to exploit the capabilities of the XRF system.

Results from the laboratory measurements on the HEPA filter pleats taken from the CP-5 filters were similar to results from measurements on the HEPA filter composite samples analyzed in the first phase of activities. Measurements with the XRF system on the flat pleat sections were very convenient to make and showed no significant differences between locations on a given pleat. Among the RCRA metals, only barium and lead were consistently indicated by the XRF spectrometer. Analysis of portions of each pleat with the baseline method also showed these elements to be present. Lead concentrations were essentially the same on the two pleats examined, while barium was different in the two by approximately a factor of two; responses from the XRF system tracked concentrations from the baseline methods (i.e., the lead values were the same for the two pleats, while the barium values showed the same relative difference between the two pleats). Measurements on the pleats with the portable XRF spectrometer could easily have been made in the field at the location where the pleats were excised from the filter units. Thus, sampling and analysis of one or a few pleats during handling operations with the HEPA filters might provide a viable approach to site evaluation of HEPA filter contamination when the XRF system is used.



The following conclusions may be drawn from the HEPA filter analyses carried out during this demonstration:

- The Spectrace 9000 portable X-ray fluorescence analyzer was generally simple to operate in both laboratory and field settings. Under the operating conditions used in the demonstration studies, the XRF system did not provide the same level of sensitivity as the baseline technology for several elements of interest, including Cd, Cr, and Hg. Longer counting times and/or better selection of sample configuration during measurements with the XRF spectrometer would be expected to improve performance of the XRF system.
- Comparability between the baseline technology and the XRF analyzer is subject to matrix effects such as occurrence of an element of interest in a form not rendered soluble by the digestion procedure used in the baseline methods. The XRF responds to the total concentration of the element, regardless of its chemical form. Because the regulatory basis for hazards classification is derived from the baseline methods, XRF analysis cannot simply displace the baseline technology in general. The portable X-ray fluorescence spectrometer is best used as a field screening tool to identify potential contamination, segregate highly contaminated from less contaminated materials, or define the boundaries of an area of contamination.
- In the characterization of HEPA filter contaminants, the XRF spectrometer does not appear able to allow simple direct measurement without some type of intrusive manipulation of the HEPA filter unit. This might entail cutting the wire mesh from a portion of the filter so the XRF probe could be placed on the filter medium, or might involve excising a few pleats from the filter and examining the pleats with the XRF analyzer. Although not as attractive as the concept of direct, non-intrusive sampling that was tried in this demonstration, operations of this kind would still provide significant savings in time, effort, and cost over generating excised samples and sending them to the laboratory for analysis by chemical methods.



## SECTION 4

# TECHNOLOGY APPLICABILITY AND ALTERNATIVE TECHNOLOGIES

### Technology Applicability

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The portable X-ray fluorescence analyzers are applicable to a wide range of site characterization and remediation activities where the elemental composition of materials or contaminants is of interest. They can be applied to solid, liquid, thin-film, and powder samples. The XRF technology can be used to qualitatively identify specific component materials by virtue of their elemental composition. For example, the XRF analyzers may be used to differentiate between mild and stainless steels, to identify coatings such as zinc in galvanized metal or cadmium plating, to locate lead anchors in walls, or to test for the presence of lead-based paint. The technology has been used extensively for field screening of soils contaminated with heavy metals. It has also been used in industrial applications such as determining vanadium in high density polyethylene plastics, calcium in butyl rubber, wear metals in oils, metals in plating baths, and in measuring the thickness and composition of coatings. The technology is particularly well-suited to survey or screening measurements because of its ready portability, short analysis time, and immediately available results. Although it cannot completely replace intrusive sampling and laboratory analysis of samples by regulator-approved methods in many environmental characterization or waste management operations, it can help reduce the number of required laboratory measurements by providing data to support strategic sampling and analysis plans for these activities.

Advantages of the portable X-ray fluorescence analyzer technology:

- applicable to a wide range of materials including solids, liquids, thin films and powders
- capable of simultaneous determination of multiple elements ranging in atomic number from sulfur to uranium
- easily carried by a single operator from one location to another in the field
- only moderate training required to carry out operations
- rapid analysis and immediately available results encourage high sampling density and lower cost
- EPA Method 6200 for soil analysis provides guidance on quality control measures
- the system is non-destructive and generates little or no waste and
- the system is rugged for field use.

Limitations of the portable X-ray fluorescence analyzer technology:

- not useful for “light” elements with atomic number less than 32 (e.g., Li, Be, Na, Mg, Al, Si, P)
- detection limits are above the Toxicity Characteristic regulatory level for most RCRA analytes
- results might not be comparable to reference methods that measure acid soluble contaminants rather than total concentrations
- chemical matrix effects and overlapping X-ray emission lines can cause interferences that affect reliability
- sample must present a flat, smooth surface that allows the window of the probe to be in direct contact with the sample.



## **Competing Technologies**

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Although there are alternative commercial XRF analyzers that compete with the TN Spectrace systems used in this demonstration, there are no technologies currently available that compete with the general technology of field portable X-ray fluorescence for elemental analysis in the field. The technology against which the XRF analyzers may be compared is a baseline technology involving conventional intrusive sampling and sending the samples to a chemical analysis laboratory for elemental determinations. In the case of heavy metal contaminants, this baseline might involve collection of samples by coring surfaces or components, taking scrapings of surface coatings, or collecting samples in bottles or on filters. The samples would usually have to be packaged for shipment to the laboratory. Analysis would typically involve determination of mercury by manual cold vapor technique and determination of other metals by inductively coupled plasma atomic emission spectrometry. Activities associated with such baseline technology operations would include mobilization of a sampling crew, collection of samples, transport of samples to the laboratory, analysis of the samples, and reporting of results. These activities are likely to require additional materials (e.g., containers), and to generate secondary waste.

The XRF technology cannot completely replace the baseline technology for characterization of contaminated areas or materials for several reasons. For example, some regulatory requirements demand characterization measurements by specific methods. Moreover, the XRF detection limits or accuracy might not meet the data quality objectives of specific characterization or remediation projects. Nevertheless, the XRF technology is an effective field screening tool to identify contaminated areas and define the extent of contamination. The XRF technology permits acquisition of many data points in a short time with small cost per data point. Application of the XRF technology has the potential to help accrue large cost savings by guiding optimum sampling and analysis strategies that reduce the number of samples sent for laboratory analysis. A significant advantage of the XRF technology is its ability to provide immediate measurement results. With the baseline technology, a typical turnaround time of days to weeks is needed before data become available. This delay can increase project costs if the results indicate a need for additional sampling or revisions of plans for D&D of problem areas.

Direct comparison of the XRF and baseline technologies is difficult because the two methodologies have different, albeit overlapping applicability in the characterization process. The main strength of the XRF technology is as a rapid field screening procedure that produces results with sufficient accuracy to allow documentation of facility characteristics or contamination. It cannot substitute for approved methods of confirmatory sampling and laboratory analysis. In a characterization scenario, the best advantage of the XRF technology is realized by using it as a tool to survey facility characteristics and provide information that will help minimize the sampling and laboratory analysis required to satisfy regulatory or other concerns.

## **Patents/Commercialization/Sponsor**

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No issues related to patents, commercialization, or sponsorship are pending.



## SECTION 5

# COST

### Introduction

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This cost analysis summarizes and evaluates the innovative technology and estimates the potential for savings relative to a baseline technology. This analysis strives to develop realistic estimates that represent work within the DOE complex. However, this is a limited representation of actual cost, because the analysis uses only data observed during the demonstration. Some of the observed costs are omitted or adjusted to make the estimates more realistic. These adjustments are allowed only when they will not distort the fundamental elements of the observed data (i.e. do not change the productivity rate, quantities, work elements, and so forth,) and eliminates only those activities which are atypical of normal D&D work. Descriptions contained in later portions of this analysis detail the changes to the observed data. The Technical Data Report for this technology provides additional cost information.

### Methodology

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This cost analysis compares portable XRF spectrometers, used for real-time elemental analysis of solid surfaces, to a baseline technology consisting of sampling solid surfaces and analyzing the samples at an on-site lab. In addition, this analysis compares costs for using portable XRF detectors to analyze the elemental composition of HEPA filters to a baseline consisting of traditional destructive core sampling and on-site laboratory analysis of the HEPA filters.

Data collected during the demonstration included:

- activity duration,
- work crew composition,
- equipment used to perform the activity, and
- training courses required and taken (excluded from analysis).

The following baseline documents were used as references:

- *Decommissioning Cost Estimate for Full Decommissioning of the CP-5 Reactor Facility*, prepared for Argonne National Laboratory by Nuclear Energy Services, Inc., June 1992,
- Activity Cost Estimate (ACE) backup sheets, dated 5/15/96, for CP-5 decommissioning, and
- current information from ANL's Analytical Chemistry Laboratory.

The baseline technology was not included in the CP-5 LSDP demonstration. Efforts have been applied in setting up the baseline cost analysis to assure unbiased and appropriate production rates and costs. Specifically, a team consisting of members from the Strategic Alliance (ICF Kaiser, an ANL D&D technical specialist, and a test engineer for the demonstration) and the U.S. Army Corps of Engineers (USACE) have reviewed the estimate assumptions to ensure a fair comparison.

The basic activities being analyzed come from the *Hazardous, Toxic, Radioactive Waste Remedial Action Work Breakdown Structure and Data Dictionary* (HTRW RA WBS), United States Army Corps of Engineers, 1996. The HTRW RA WBS was developed by an interagency group and its use in this analysis provides consistency to established national standards.



Some costs are omitted from this analysis so that it is easier to understand and to facilitate comparison with costs for individual sites. The ANL indirect expense rates for common support and materials are omitted from this analysis. Overhead rates for each DOE site vary in magnitude and in the way they are applied. Decision makers seeking site specific costs can apply their site's rates to this analysis without having to retract ANL's rates. This omission does not sacrifice the cost savings accuracy because overhead is applied to both the innovative and baseline technology costs. Engineering, quality assurance, administrative costs and taxes on services and materials are also omitted from this analysis for the same reasons indicated for the overhead rates.

The standard labor rates established by ANL for estimating D&D work are used in this analysis for the portions of the work performed by local crafts. Additionally, the analysis uses an eight hour work day with a five day week.

## Summary of Cost Variable Conditions

The DOE complex presents a wide range of D&D work conditions. The working conditions for an individual job directly affect the manner in which D&D work is performed and, as a result, the costs for an individual job are unique. The innovative and baseline technology estimates presented in this analysis are based upon a specific set of conditions or work practices found at CP-5, and are presented in Table 1. This table is intended to help the technology user identify work items which can result in cost differences.

**Table 1. Summary of cost variable conditions**

<b>Cost Variable</b>	<b>XRF Fluorescence Technology</b>	<b>Baseline - Sampling &amp; Lab Testing</b>
<b>Scope of Work</b>		
Type of material sampled	Surfaces of walls, floors, ceilings, door knobs, and air ducts; also HEPA filters	Assumed to be surfaces of walls, floors, ceilings, door knobs, and air ducts; also HEPA filters
Location of sample areas	CP-5 Building for surface sampling and Building 306 for HEPA filter sampling	Assumed to be the CP-5 Building for surface sampling and Building 306 for HEPA filter sampling
Sampling methodology	Samples are taken by direct readings with the XRF detectors; In the case of HEPA filters, readings are taken through a protective plastic wrapping around the HEPA filter	Surface samples are taken by scraping, abrading, or using smears. Samples from HEPA filters are taken by coring filters with a hole saw bit on a power drill. All samples are then placed into bottles, plastic bags or containers, and transported to the on-site chemistry lab
Analysis of samples and results	Samples are analyzed during direct readings; Each reading yields an X-ray emission spectrum that detects qualitative and quantitative information on up to 25 elements, in the case of the Spectrace 9000, and lead only, in the case of the TN Lead Analyzer; Spectra are stored in the on-board memory of the detectors for later interpretation and transcription to other presentation formats	Samples are analyzed in the ANL Analytical Chemistry Lab using acid digestion and atomic spectroscopy; Results focus on detecting and quantifying 8 heavy metal elements regulated as toxic under RCRA; Results are documented and recorded in accordance with U.S. EPA approved methods for the SW-846 Standard Protocol

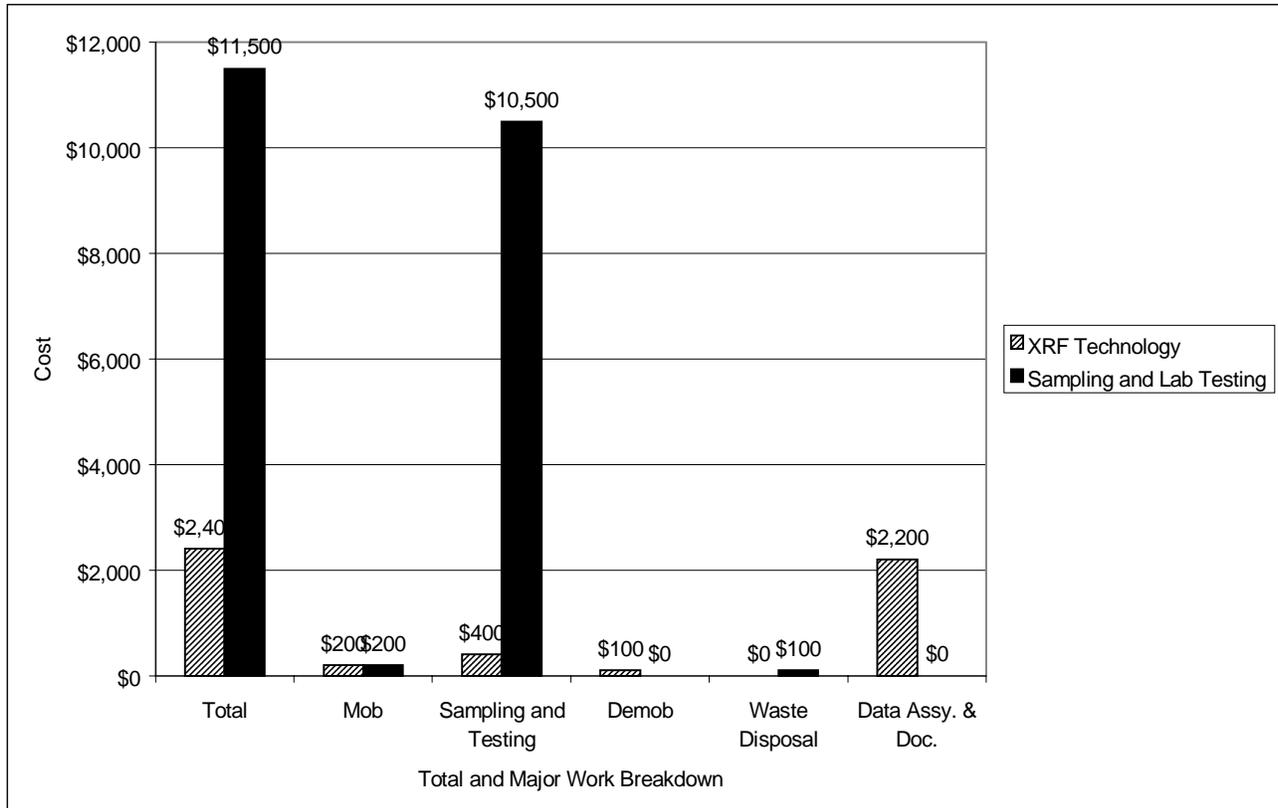


Work Environment		
Level of contamination in the test areas	The demonstration area is not a radiation area. Any contamination that might be present is fixed	It is assumed the demonstration area is not a radiation area. Any contamination that might be present is fixed
Work Performance		
Technology acquisition means	Equipment is assumed to be owned by ANL for use by site HPTs	Uses the existing ANL Analytical Chemistry Lab facilities and equipment; All associated costs are factored into lab test rates
Compliance requirements	Achieves the level of a detailed field screening activity, but presently not sufficient for regulatory documentation to demonstrate the absence of heavy metal contamination	Meets all requirements for regulatory documentation of heavy element contamination
Accuracy of sampling analysis	<p>Increasing the sampling analysis time will increase the accuracy or sensitivity of the results. For the demonstration, the goal was to use both XRF devices in a conventional screening mode achieving good accuracy. Average sampling analysis times for the various uses are as follows:</p> <ul style="list-style-type: none"> <li>• TN Lead Analyzer (surface) 200 sec/sample</li> <li>• Spectrace 9000 (surface) 200 sec/sample 300 sec/sample (Cd-109 source: 200 sec Fe-55 source: 50 sec Am-241 source: 50 sec)</li> <li>• Spectrace 9000 (HEPA Filter) 200 sec/sample 400 sec/sample (Cd-109 source: 200 sec Fe-55 source: 100 sec Am-241 source: 100 sec)</li> </ul>	Assumed to be of an accuracy and sensitivity to meet EPA approved methods for the SW-846 Standard Protocol
Scale of production	The number of samples taken will have little impact on the cost per sample since the same activity must be performed for every sampling event	Due to high lab costs and long turnaround times, large characterization jobs would strive to reduce or consolidate the number of samples receiving lab analysis. This effort must balance the number of samples analyzed with facility objectives for accuracy and regulatory compliance



## Potential Savings and Cost Conclusions

For the conditions and assumptions established for this cost comparison, the innovative technology was approximately 30% of the cost of the baseline alternative. The following chart summarizes the cost comparison between the portable XRF technology and the baseline technology consisting of sampling and laboratory testing:



**Figure 2. Cost comparison summary.**

The Spectrace Pb Analyzer costs approximately \$30,000 and the Spectrace 9000 approximately \$40,000.

Sampling and laboratory analysis is used as the baseline for cost comparison to the XRF technology because, historically, it has been the primary technology used at ANL for identifying areas of heavy element contamination. This cost comparison equates the number of samples analyzed in the lab to the number of samples analyzed with the XRF during the demonstration. For a real-life scenario, it is reasonable to assume that efforts would be made to take fewer samples for lab analysis. Another possibility for a real-life scenario is that an equal number of samples would be taken, but these would then be consolidated into fewer representative samples for lab analysis.

Direct comparison of the relative costs of the portable XRF technology to the baseline technology is difficult because the two methodologies have different, albeit overlapping applicability in the characterization process. The main strength of the XRF technology is as a rapid field screening procedure that produces results with enough accuracy to allow for documentation of heavy element contamination. Presently, however, it cannot substitute for EPA approved methods of confirmatory sampling and laboratory analysis that are usually required when characterizing surfaces for heavy element contaminants. Thus, in a characterization scenario, true cost savings from the XRF technology can be realized by using it as a tool to locate and quantify contamination in order to minimize the sampling and lab analysis required under current regulations. A reasonable scenario, for example, would be to use the XRF technology to rapidly quantify and qualify surface contamination in rooms and areas where no previous sampling or characterization has been done or to monitor progress in removing contamination during a remediation effort. Armed with information from an XRF field screening, facility personnel can then plan for a judicious use of sampling and lab analysis to add detail to the characterization and to meet regulatory verification requirements. The magnitude of savings from such a scenario will depend on the specific circumstances of a particular application as well as data quality objectives for sample analysis, and will probably be unique for each DOE installation. Potential technology users should refer to Table 1 to understand what conditions and assumptions are driving costs for this comparison.



## SECTION 6

# REGULATORY/POLICY ISSUES

### Regulatory Considerations

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The regulatory/permitting issues related to the use of the portable X-ray fluorescence analyzer technology at the ANL CP-5 Research Reactor are governed by the following DOE Orders and safety and health regulations:

- DOE Orders

- DOE 5400.5                      Radiation Protection of the Public and the Environment
- DOE 5480.11                  Radiation Protection for Occupational Workers
- DOE 5820.2A                  Radioactive Waste Management

- Occupational Safety and Health Administration (OSHA) 29 CFR 1926

- 1926.300 to 1926.307        Tools - Hand and Power Electrical
- 1926.400 to 1926.449        Electrical - Definitions
- 1926.28                        Personal Protective Equipment
- 1926.53                        Ionizing Radiation
- 1926.55                        Gases, Vapors, Fumes, Dusts and Mists
- 1926.102                       Eye and Face Protection
- 1926.103                       Respiratory Protection

- OSHA 29 CFR 1910

- 1910.211 to 1910.219        Machinery and Machine Guarding
- 1910.241 to 1910.244        Hand and Portable Powered Tools and Other Hand-Held Equip.
- 1910.301 to 1910.399        Electrical - Definitions
- 1910.132                        General Requirements (Personal Protective Equipment)
- 1910.133                        Eye and Face Protection
- 1910.134                        Respiratory Protection

In addition to these regulations, the XRF equipment is subject to regulation by NRC as a device containing quantities of radioactive material. The approach utilized by the regulator in assuring the safety of a manufactured device containing radioactive material is to regulate the manufacturer. The inherent safety of the device is studied and conditions of assuring its safety are contained in a specific license under which the device is manufactured and distributed. The user must also be licensed either by a Specific License or a General License prior to receiving the device. Most users accept the Spectrace 9000 Analyzer under General License, which is issued in all regulations.

The radioisotope sources in the XRF analyzers are required to be leak tested at intervals not to exceed six months. TN Spectrace automatically notifies users of its instruments when leak tests are due and will provide leak test kits for this purpose. The analyzers must be within current leak test prior to any shipment.

The baseline technology would be subject to the waste characterization requirements for low level wastes as specified by disposal facilities used by ANL. These include:

- *Hanford Site Solid Waste Acceptance Criteria:*                      WHC-EP-0063-4
- *Barnwell Waste Management Facility Site Disposal Criteria:*        S20-AD-010
- *Waste Acceptance Criteria for the Waste Isolation Pilot Plant:*      WIPP-DOE-069



## **Safety, Risks, Benefits, and Community Reaction**

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The portable X-ray fluorescence analyzer technology is generally quite safe to operate. Identified hazards include those typical of working in industrial situations with electrical powered instrumentation. A special concern is the potential for exposure to radiation from the excitation source. The TN Spectrace analyzers are sold under a general license, meaning that the analyzers are designed and constructed in such a way that anybody operating them in accordance with the instruction manual will not be exposed to harmful radiation levels as defined by the NRC.

The use of the portable X-ray fluorescence analyzer technology rather than the baseline technology would have little impact on community safety, environmental, or socioeconomic issues. Any such impacts would be mostly favorable relative to the baseline technology due to reduced disruption of the affected facility, reduced physical hazards, reduced noise and dust emissions, and reduced waste transport and disposal.



## SECTION 7

# LESSONS LEARNED

### Implementation Considerations

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- Portable X-ray fluorescence analyzer technology is well-established with several vendors providing commercial instruments.
- Units are easy to operate and conveniently carried by one operator from one field location to another.
- Portable XRF can be used for qualitative identification of component elements as well as quantitative measurement of element concentrations.
- Portable XRF can be used in in-situ or intrusive sampling modes.
- Instrument vendors will provide advice and support for specific applications.
- Planning must consider available sensitivity and accuracy relative to project-specific data quality objectives. Count times and excitation sources may be selected to optimize throughput relative to quality needs.
- The XRF probe is 12.7 cm x 7.6 cm x 21.6 cm and weighs 1.9 kg. The electronics unit is 32 cm x 30 cm x 10 cm and weighs 6.7 kg.

### Technology Limitations and Needs for Improvement

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- Samples must be homogeneous to the depth of X-ray penetration (0.1 to 1 mm).
- Portable XRF is not useful for light elements with atomic number below 32 (e. g., Li, Be, Na, Mg, Si, P).
- Portable XRF can be subject to chemical matrix interferences and interferences from overlapping emission lines in X-ray spectrum from some elements.
- Portable XRF must be used in conjunction with confirmatory analysis by laboratory methods in regulatory applications.
- Data analysis costs may be reduced by developing and automated system of report generation. Currently, data assembly and documentation is the most costly element of the XRF technology.

### Technology Selection Considerations

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- Portable XRF can provide rapid, non-destructive, real-time elemental information on facility components or contaminants. The technology permits analysis of many locations in a short time at low cost per location.
- Portable XRF is applicable to a wide range of materials including solids, liquids, thin films, and powders.
- Portable XRF is not a substitute for regulator approved methods of confirmatory sampling and analysis.
- Portable XRF is most effective as a rapid field-screening procedure that produces results of sufficient accuracy to document facility characteristics and to guide development or implementation of strategic sampling and analysis by conventional methods.



## APPENDIX A

### REFERENCES

- Strategic Alliance for Environmental Restoration, *CP-5 Large Scale Demonstration Project, Test Plan for the Demonstration of Elemental Analysis of Surfaces by Portable X-Ray Fluorescence Spectrometry (XRF)*, Argonne National Laboratory, August 1996.
- Strategic Alliance for Environmental Restoration, *CP-5 Large Scale Demonstration Project, Test Plan for the Demonstration of HEPA Filter Analysis by Portable X-Ray Fluorescence Spectrometry (XRF)*, Argonne National Laboratory, November 1996.
- Strategic Alliance for Environmental Restoration, *CP-5 Large Scale Demonstration Project, Technical Data Report for the Portable X-Ray Fluorescence Technology Demonstration*, Commonwealth Edison, September, 1996.
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- Occupational Safety and Health Administration, (OSHA). 1974. 29 CFR 1910, *Occupational Safety and Health Standards*.
- Occupational Safety and Health Administration, (OSHA). 1979. 29 CFR 1926, *Occupational Safety Regulation for Construction*.



## APPENDIX B

# ACRONYMS AND ABBREVIATIONS

ACE	Activity Cost Estimate (Sheets)
ALARA	As Low As Reasonably Achievable
DDFA	Deactivation and Decommissioning Focus Area
Decon	Decontamination
Demo	Demonstration
Demob	Demobilization
DOE-CH	DOE- Chicago
Eq	Equal
Equip	Equipment
ER	Environmental Restoration
FCCM	Facilities Capital Cost Of Money
FETC	Federal Energy Technology Center
HEPA	High Efficiency Particulate Air
H&S	Health And Safety
HPT	Health Physics Technician
HR	Hour
HTRW	Hazardous, Toxic, Radioactive Waste
ICT	Integrating Contractors Team
LF	Lineal Feet (Foot)
LLW	Low Level Waste
LS	Lump Sum
mCi	MilliCurie
Min	Minute
mm	Millimeter
Mob	Mobilization
NESP	National Environmental Studies Project
OT	Overtime
PCs	Protective Clothe(S) (Clothing)
PLF	Productivity Loss Factor
PPE	Personal Protective Equipment
Qty (Qty)	Quantity
RA	Remedial Action
RCRA	Resource Conservation and Recovery Act
SAFSTOR	Safe Storage
SF	Square Feet (Foot)
UCF	Unit Cost Factor
UOM	Unit Of Measure
USACE	U.S. Army Corps Of Engineers
WBS	Work Breakdown Structure
XRF	Field Portable X-ray Fluorescence (Technology)



## APPENDIX C

### TECHNOLOGY COST COMPARISON

This appendix contains definitions of cost elements, descriptions of assumptions and computations of unit costs that are used in the cost analysis.

#### **Innovative Technology - XRF Detector (Spectrace 9000 & TN Spectrace)**

##### **MOBILIZATION (WBS 331.01)**

###### **Set Up Equipment for Day's Use**

This cost element provides for turning on the equipment, checking the battery charge, and running self diagnostics and source checks before using. The activity cost is measured as one each.

##### **D&D CHARACTERIZATION (WBS 331.17)**

###### **Measure with the TN Lead Analyzer**

This cost element includes using the device to sample for lead containing paint on wall, floor, door and other miscellaneous surfaces. Results are yielded by placing the probe of the device in direct contact with the surface to be sampled. Results are qualitative in nature. The activity cost is calculated on a per sample (each) basis.

###### **Measure Heavy Element Contamination with the Spectrace 9000**

This cost element includes using the device to sample walls, floors and other solid surfaces for the presence of 25 different elements. Sampling includes changing the mode of the device to utilize three different radioisotope sources depending on the element to be detected. Results are yielded by placing the probe of the device in direct contact with the surface to be sampled. Results are qualitative in nature. The activity cost is calculated on a per sample (each) basis.

###### **Measure HEPA Filter Contamination with the Spectrace 9000**

This cost element includes using the device to sample HEPA filters that are left inside their protective bags. HEPA filters are sampled for lead, mercury, and silver oxide contamination. Results are qualitative in nature. The activity cost is calculated on a per sample (each) basis. Specifically, six samples on each of two HEPA filters were taken for a total of 12 samples.

##### **DEMOBILIZATION (WBS 331.21)**

###### **Survey-Out Equipment and Decontaminate**

This cost element provides for radiological survey of the equipment by a site HPT to assure that contaminated equipment does not leave the site and includes costs for decontamination. Costs include equipment stand-by time plus HPT labor. The activity cost is measured as one each.



## D&D DATA ASSEMBLY & DOCUMENTATION (WBS 331.17)

### Compile, Interpret & Review Data

This cost element includes accessing stored analysis results held in the memory of the XRF onboard computers, printing it out, interpreting it, and transcribing it into a computer generated spread sheet file.

### **COST ANALYSIS**

Costs for demonstration of the Spectrace 9000 Portable XRF Detector and the TN Lead Analyzer innovative technologies are based on using the devices in areas where radiological contamination is fixed (i.e., not removable), thus, it is not necessary for operators of the detectors to be outfitted in anticontamination personal protective equipment (PPE). For the demonstration, the Spectrace 9000 was used to identify and quantify 25 different elements on various surfaces including walls, floors, and ceilings. The TN Lead Analyzer was used to detect only the presence of lead and is used at spot locations of suspected lead contamination, such as floors and walls coated with lead paint and ductwork contaminated with lead dust. Finally, the Spectrace 9000 was used to take non-destructive measurements on HEPA filters to identify and quantify eight heavy metals regulated under the RCRA. Locations and time durations for the demonstration activities are summarized in the following table:

**Table C.1 - Summary of demonstration results**

Activity/Device	Building/Room(s)	No. of Sample Locations Measured	Productivity Rate (Min/Sample)
Measure Surface Contamination w/Spectrace 9000 Portable XRF	CP-5/C-201,C-202,C-204,C-206	26	4.5
Measure for the Lead Content of Paint w/the TN Lead Analyzer	CP-5/C-201,C-202,C-204,C-206	16	8
Measure HEPA Filter Contamination w/Spectrace 9000 Portable XRF	306/Waste Handling Area	12	15

Since both the Spectrace 9000 and TN Lead Analyzer devices are capable of taking direct analysis readings on homogeneous materials, such as paint coatings and so on, it was not necessary to remove and consolidate the surface coating of these materials in order to get an accurate reading. All surface sampling for the demonstration was conducted using this direct read, or non-intrusive, method. Likewise, readings on HEPA filters were taken without having to remove the sealed plastic bag that surrounded each filter. (Analysis was made on HEPA filter samples that were removed from collection locations and stored in ANL's Waste Management Operations waste handling area in Building 306). Analysis results with the XRF devices are accurate to micrograms per square centimeter ( $\mu\text{g}/\text{cm}^2$ ) or milligram per kilogram concentration levels.

Both the Spectrace 9000 and the TN Lead Analyzer XRF Portable Detectors are owned by ANL. Thus, equipment costs for the demonstration are based on an hourly rate. The assumptions for projecting the demonstration costs for the XRF technology to reflect a commercial cost are summarized as follows:



- Both the Spectrace 9000 and the TN Lead Analyzer XRF Detectors are owned by ANL.
- Each device is operated by only one HPT.
- The Spectrace 9000 is used to determine the identity and quantity of up to 25 elements by taking direct analysis readings on solid surfaces and HEPA filters.
- Readings on HEPA filters are taken through the protective plastic bag in which they are stored.
- The TN Lead Analyzer is used to quantify areas of suspected lead contamination.
- Analysis is for field screening purposes. (Sample collection and documentation procedures are minimal).
- Costs for anticontamination PPE are omitted since radioactive contamination in the test areas is fixed.
- Productivity loss factors are not considered.
- Calibration for each device is conducted once daily before beginning sampling work for that day.
- One pre-work safety meeting is held before beginning all sampling work.
- Hourly equipment rates are calculated using a discount rate of 5.8% (per OMB Circular A-94) and are based on the following data provided by the manufacturer and the ANL site:
  - \* Purchase price of the Spectrace 9000 XRF detector is \$58,000.00 (1997 pricing);
  - \* Purchase price of the TN Lead Analyzer is \$39,500.00 (1997 pricing);
  - \* Both detectors have an anticipated service life of 10 years each;
  - \* Both detectors have a yearly use rate of 1000 hours each;
  - \* An acquisition cost of 9.3% is added to of the purchase price of both detectors;
  - \* No salvage value is used for either detector.
- Times to move the XRF detectors from area to area or room to room are accounted for in the sampling time.
- Breaks are not accounted for in the sampling time.
- Demobilization consists of surveying-out the detectors and is done only once at the completion of all analysis work.
- Oversight expenses incurred by engineering, quality assurance, and administrative activities are omitted.

Based on these assumptions, the activities, quantities, production rates and costs observed during the demonstration are shown in Table C-2.



**TABLE C-2  
COST SUMMARY - X-RAY FLUORESCENCE DETECTOR**

Work Breakdown Structure (WBS)	Unit Cost (UC)				Total Quantity (TQ)	Unit of Measure	Total Cost (TC) <sup>1</sup>	Comments		
	Labor Hours	Labor Rate	Equipment Hours	Equipment Rate					Other	Total Unit Cost
<b>MOBILIZATION (WBS 331.01)</b>							<b>Subtotal:</b>	<b>\$92.17</b>		
Calibrate Equipment for Day's Use	0.5000	\$56.00	0.5000	\$16.34		\$36.17	1	Each	\$36.17	Based on 15 min. each to calibrate the two pieces of equipment
Prework Safety Review	1.0000	\$56.00				\$56.00	1	Each	\$56.00	
<b>CHARACTERIZATION (WBS 331.17)</b>							<b>Subtotal:</b>	<b>\$822.69</b>		
Measure with the TN Lead Analyzer	0.2500	\$56.00	0.0750	\$6.81		\$14.51	16	Each	\$232.17	
Measure Heavy Element Contamination with the Spectrace 9000	0.2500	\$56.00	0.1300	\$9.53		\$15.24	26	Each	\$396.21	
Measure HEPA Filter Contamination with the Spectrace 9000	0.2500	\$56.00	0.2300	\$9.53		\$16.19	12	Each	\$194.30	Six measurements were taken on each of two HEPA filters. Some replication exists in these measurements due to inconsistent readings from the XRF device
<b>DEMOBILIZATION (WBS 331.21)</b>							<b>Subtotal:</b>	<b>\$28.00</b>		
Survey-out Devices	0.5000	\$56.00	0.5000			\$28.00	1	Each	\$28.00	
<b>DATA ASSEMBLY &amp; DOCUMENTATION (WBS 331.17)</b>							<b>Subtotal:</b>	<b>\$2,268.00</b>		
Compile, Interpret & Review Data	07500	\$56.00				\$42.00	54	Each	\$2,268.00	

(1) TC = UC \* TQ

The labor rate of \$56.00/hr is based on an unburdened rate for an HPT at the ANL site.

**TOTAL: \$3,210.86**



## **Baseline Technology - Sampling and Laboratory Testing**

### **MOBILIZATION (WBS 331.01)**

#### **Mobilize for Sampling**

This cost element provides for generating a plan for location of samples and removal methods to be used as well as acquiring the tools and equipment necessary for taking the samples. It also accounts for time required to suit up in PPE in order to take the HEPA filter samples. The activity cost is measured as one (each) per day of sampling.

#### **Pework Safety Review**

This cost element provides for a pre-sampling meeting to establish and review safety protocol for physical removal of samples from radiologically contaminated surfaces and HEPA filters. The cost is measured as a one each for the entire sampling activity.

### **D&D CHARACTERIZATION (WBS 331.17)**

#### **Take Surface Scrape Samples or Lab Testing**

This cost element includes abrading or scraping the sample surface to remove paint coating or small amounts of surface material itself and placing the removed material in a marked plastic bag for lab analysis. The activity cost is measured on a per sample (each) basis.

#### **Transport Surface Samples to the On-Site Lab**

This cost element is for transit time for getting samples to the lab and is measured as one (each) per day of sampling.

#### **Conduct Laboratory Analysis on the Surface Samples**

This cost element includes EPA approved methods for laboratory analysis of heavy metal elements as conducted by the Analytical Chemistry Laboratory at ANL. (Laboratory procedures are described in more detail herein). The activity cost is measured on a per sample basis and represents the ANL lab rate to run a complete heavy metal element sweep including waste disposal.

#### **Core HEPA Filters for Sample Composites**

This cost element includes using a reciprocating saw to remove cores from HEPA filters and requires the worker be fully clothed in PPE. (Procedure described in more detail herein). The activity cost is measured on a per core (each) basis.

#### **Transport HEPA Filters to Lab for Analysis**

This cost element is for transit time for getting cores to the lab and is measured as one (each) per day of sampling.

#### **Assemble Core Samples into Composites and Conduct a Lab Heavy Metal Analysis**

This cost element includes converting the core samples taken in the field into two composite samples for analysis by the Analytical Chemistry Laboratory at ANL. The activity cost is measured on a per sample basis and represents the ANL lab rate for a filter composite which includes compositing, analysis, and waste disposal.



## **Personal Protection Equipment for HEPA Sampling**

This cost element provides for the personal protective clothing used during the HEPA filter coring activity and is measured on a per day of use basis.

### **WASTE DISPOSAL (WBS 331.18)**

#### **Dispose of PPEs**

This activity cost is measured on a per each basis for a full suit of PPE.

### **COST ANALYSIS**

There are currently no other field screening technologies available that perform comparable functions to the portable XRF technology. Thus, the XRF is compared to a baseline technology consisting of conventional sampling and laboratory determination of pertinent elements by acid digestion of samples and atomic spectroscopy measurements on the digestate solutions. To emulate the results achieved with the XRF innovative technology, the laboratory analysis focuses on heavy metal analytes from the Resource Conservation and Recovery Act's (RCRA) Toxicity Characteristic list. These elements (As, Ba, Cd, Cr, Pb, Hg, Se, and Ag) are of high concern in determining the hazards classification of wastes and represent a frequently monitored suite of metal analytes. Laboratory analyses are assumed to be made using U.S. EPA approved methods as described in "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods," U.S. EPA SW-846, Third Edition, September 1986 and subsequent updates. In particular, the baseline technology assumes determination of mercury by Method 7471A [Mercury in Solid or Semisolid Waste (Manual Cold Vapor Technique)] and determination of other metals by Method 6010A (Inductively Coupled Plasma Atomic Emission Spectroscopy) after digestion by Method 3050A (Acid Digestion of Sediments, Sludges, and Soils).

No actual demonstration was conducted for the baseline technology so a direct cost comparison with the XRF technology cannot be made. Instead, cost values for baseline activities are derived from historical costs at ANL. These include costs for scraping, abrading, or using smears to gather the surface samples, costs for coring HEPA filters for composite samples, and lab costs for analyzing each sample by the procedures described above..

For surface sampling, costs are broken down into time for decontamination technicians to mobilize, take the samples, package them, and then transport them to the lab. Lab costs for surface samples include sample preparation, sample analysis, compilation of lab results, and disposal of secondary waste generated by the sample analysis. All lab work is assumed conducted by analytical chemists.

HEPA filter sampling operations are conducted in the containment area of Building 306 by decontamination technicians. Because coring the HEPA filters for samples has the potential for causing airborne release of radioactive contaminants and other types of hazards, technicians will be fully clothed in anticontamination PPE. This is consistent with current practices at ANL. Sampling activities include mobilizing and suiting up in anticontamination PPE, cutting individual filters with a coring hole saw to obtain core samples, and packaging the core samples for shipment to the lab. Lab costs include chopping and mixing together cores from several HEPA filters in order to make composite samples, composite sample analysis, compilation of lab results, and disposal of secondary waste. All lab work is assumed conducted by analytical chemists.

All baseline technology costs are premised on using the site analytical chemistry lab at ANL. It should be noted that there are costs embedded in ANL's lab rate related to the potential for radioactive contamination. Although these costs are not specifically identified, it is reasonable to assume that other site labs in the DOE complex and commercial labs, licensed by the NRC to accept radioactive material, will have similar costs factored into their rates.



Assumptions for formulating the baseline cost estimate are summarized as follows:

- All sampling is done by decontamination technicians.
- One pre-work safety meeting is held before beginning all sampling work.
- Surface sampling consists of removing coatings such as paint, varnish, and etc. by scraping or abrading with hand-held tools.
- HEPA filter sampling is conducted in the containment area of Building 306 and consists of taking cores out of several filters with a hole saw attachment to a hand-held power drill.
- Decontamination technicians will be fully-clothed in anticontamination PPE while taking HEPA filters core samples.
- Times to move between sampling areas are included in the sampling time.
- Lab analysis is for field screening purposes, consequently quality assurance and detailed reporting are minimal.
- Consolidation of core samples and lab analysis of all samples is conducted at the ANL analytical chemistry lab.
- Samples are analyzed in the lab by acid digestion and atomic spectroscopy measurements on the digestate solution.
- Laboratory costs are based on ANL's 1997 site rates.
- All lab work is conducted by analytical chemists.
- Productivity loss factors are not considered.
- Costs for compiling lab results and putting them into a report are included in the sample analysis costs.
- The total number of samples taken in the field and analyzed in the lab equals the total number of readings taken with the innovative XRF technology in order to form an equitable basis for cost comparison.

Based on these assumptions, the activities, quantities, production rates and other costs associated with the baseline technology are listed in Table C-3.



**TABLE C-3  
COST SUMMARY - BASELINE TECHNOLOGY**

Work Breakdown Structure (WBS)	Unit Cost (UC)				Total Quantity (TQ)	Unit of Measure	Total Cost (TC) <sup>1</sup>	Comments	
	Labor Hours	Rate	Equipment Hours	Rate					Other
<b>MOBILIZATION (WBS 331.01)</b>							<b>Subtotal: \$100.80</b>		
Mobilize for Sampling	0.5000	\$33.60			\$33.60	2	Each	\$67.20	Done once per day before sampling activities (assumes sampling occurs over 2 days)
Pework Safety Review	1.0000	\$33.60			\$33.60	1	Each	\$33.60	Done only once before beginning sampling work
<b>SAMPLING &amp; TESTING (WBS 331.02)</b>							<b>Subtotal: \$11,416.73</b>		
Take surface scrape samples for lab testing	0.2500	\$33.60			\$8.40	42	Each	\$352.80	
Transport surface samples to the on-site lab	0.5000	\$33.60			\$16.80	2	Each	\$33.60	Done once per day at the completion of sampling
Conduct a laboratory heavy metal analysis on the surface samples					\$250.00	42	Each	\$10,500.00	Based on ANL's lab rate for multielement analysis & includes testing, waste disposal and documentation
Core HEPA filters for sample composites	1.0000	\$33.60			\$33.60	2	Each	\$67.20	Based on taking 1 core from each of 2 HEPA filters
Transport HEPA cores to the on-site lab for analysis	0.5000	\$33.60			\$16.80	1	Each	\$16.80	
Assemble core samples into composites and conduct a lab heavy metal analysis					\$200.00	2	Each	\$400.00	Based on ANL's lab rate for each filter composite & includes cost of compositing, analysis, documentation, & waste disposal
PPE for HEPA filter sampling					\$46.33	1	Each	\$46.33	Based on one set of PPE used one day
<b>WASTE DISPOSAL (WBS 331.18)</b>							<b>Subtotal: \$105.56</b>		
Dispose of PPEs					52.78	2	Each	\$105.56	From 1996 ACE, Table 2.0, page 1.11 of 1.33

(1) TC = UC \* TQ

The labor rate of \$33.60/hr is based on an unburdened rate for an ANL Decontamination Technician.

**TOTAL: \$11,623.09**

