# Independent Verification of Non-Destructive Assay Characterization Results at the East Tennessee Technology Park K-25 Building and Lessons Learned - 9271

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## ABSTRACT

This paper describes the results and lessons learned from the independent verification (IV) of the non-destructive assay (NDA) program development and implementation at the former K-25 Gaseous Diffusion Plant located in Oak Ridge, Tennessee. NDA gamma and neutron measurements were used to detect and quantify uranium-235 (U-235) hold-up in process gas piping and equipment. The data were used to satisfy multiple objectives, including demonstrating compliance with criticality safety limits and waste acceptance criteria for two disposal facilities. The independent verification effort was two-fold, and included technical reviews of program documents and implementing procedures as well as independent NDA field measurements. The process of performing IV resulted in numerous lessons learned that serve as valuable input for the planning of future uranium enrichment facility decommissioning projects.

## INTRODUCTION

The K-25 building, also known as the Oak Ridge K-25 Gaseous Diffusion Plant, is located in the East Tennessee Technology Park (ETTP) in Oak Ridge, Tennessee. The K-25 Building was the original gaseous diffusion facility constructed for uranium enrichment with operations beginning in 1945. Since permanent operational shutdown in 1985, the structure has severely deteriorated resulting in it being unsafe for continued surveillance and maintenance. The building contains an extensive network of uranium enrichment process equipment that is contaminated with U-235 and other radionuclides.

Building K-25 was constructed as part of the World War II Manhattan Engineering District project. Construction began in 1943 and the facility began operations in 1945 to produce enriched uranium as part of the war effort. Uranium enrichment is the process whereby the natural uranium isotopic makeup consisting of U-234, U-235, and U-238 is altered via physical and chemical processes to enrich the abundance of the U-235 isotope. Uranium enrichment for national defense needs continued until 1964 at which time operations were shut down, with the exception of the purge cascades which operated until 1977.

The U-shaped building has a construction footprint of 147,000 square meters ($m^2$) divided among east and west wings and a north building. The structure has four levels consisting of the Vault level, Cell level, Pipe Gallery level and Operating level. The building is constructed of concrete, reinforced concrete, structural steel, and transite or brick siding. The building is subdivided into 54 sub-buildings that are further sub-divided into anywhere from 6 to 22 process cells, with each cell normally containing six stages. The stages are groupings of converters, compressors, and motors. Stages and cells are connected via process gas piping (PGP). There are approximately 500,000 linear meters of varying internal diameter PGP inside of Building K-25. The majority of the PGP is less than 0.15 meters in diameter. Dependent upon building area, the uranium enrichment of residual hold-up within the PGP varies up to greater than 90%.

In 2002, the U.S. Department of Energy (DOE) established an Accelerated Cleanup Project (ACP) to address contaminated DOE Oak Ridge Reservation (ORR) facilities. The intent of the project is to meet Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) goals to reduce risk to human health and the environment and eliminate the potential for releases of contaminants from these structures. The largest component of the ACP is demolition to slab of the K-25 Building at the ETTP. The decommissioning, decontamination and demolition of this enormous facility, the largest building in the DOE complex, represents a tremendous challenge.

The DOE's prime contractor for the K-25 project has conducted multiple activities that are required for decommissioning and safe demolition of the structure, including removal of high risk equipment (HRE) that could pose safety hazards during the demolition of the structure. The remaining process equipment and components are to be removed following building demolition and will be segregated from building debris for disposal at an appropriate waste management facility. In order to characterize the amount of uranium-235 hold-up in the process gas piping and equipment (PGP&E), the DOE contractor employed both physical sampling and NDA measurements. The development and implementation of the NDA program was performed over a period of several years and presented numerous technical and logistical challenges, with the ultimate goal of assuring that criticality incredible (CI) limits and waste acceptance criteria (WAC) for disposal facilities are met.

In 2006, the DOE Oak Ridge Office (ORO) requested that the Oak Ridge Institute for Science and Education (ORISE) provide IV support for the ETTP K-25 Decontamination and Decommissioning (D&D) project.

## INDEPENDENT VERIFICATION OBJECTIVES

The objectives of the IV for the K-25 NDA program were two-fold. The first objective was to conduct independent technical reviews and in-process inspections/verifications to assess the adequacy of the contractor's uranium hold-up measurement program. The second objective was to perform independent evaluations and measurements of residual U-235 quantities within the Building K-25 PGP.

## INDEPENDENT VERIFICATION PROCEDURES

### Independent Technical Reviews and In-Process Inspections

ORISE performed an in-process technical review of the K-25 NDA program from November 2006 to November 2008. Independent verification activities during this phase involved participation in four management assessments to evaluate the technical and programmatic aspects of the contractor's NDA program, which included gamma and neutron measurement methods utilized for the quantification of enriched uranium in process gas piping and equipment.

The independent technical evaluation also involved reviews of the technical basis for the instrumentation and methodology used to conduct NDA measurements. DOE's prime contractor employed four main instrumentation systems to quantify the uranium content in the K-25 equipment, including the Hold-up Measurement System 4 (HMS 4), Uranium Neutron Counting System (UNCS), In-Situ Object Counting System (ISOCS), and a slab neutron counting system.

The HMS 4 was used to quantify the amount of U-235 in PGP in the K-25 building. The HMS4 uses a lead shielded and collimated NaI detector with an associated multi-channel analyzer. The gram quantity of U-235 is calculated by the HMS4 software.

The UNCS is used to count items after they have been removed from the building. The UNCS is housed in a large concrete enclosure and consists of 80 neutron detectors that are placed on the walls, floor, and ceiling of the chamber to establish a $4\pi$ counting geometry. The system is calibrated using an enriched uranium source with the calibration data being entered into a computer system that will calculate the results in grams of U-235.

The ISOCS was used to quantify the amount of U-235 in boxes, line recorder stations, and bottles of material removed from PGP&E. The ISOCS uses a high purity germanium crystal detector with a multi-channel analyzer. The data are calculated using the ISOCS software that takes into account the geometry of the item and material and the shielding of the gamma ray photons due to the item.

The slab neutron counting system was used to measure the amount of U-234 and then calculate the amount of U-235 in objects in the K-25 building. The system consists of five tubes that are filled with He-3 at a pressure of four atmospheres that are surrounded by polyethylene. The instrument is attached to a pulse stretcher and ratemeter to detect neutrons that have been slowed in the polyethylene. A computer program is used to calculate the efficiency for the detection of neutrons based on the size of the item to be counted. The computer code is used in conjunction with a calibration that is done using Cf-252 which spontaneously emits neutrons.

Legacy data collected in the 1988-1989 timeframe were used to characterize the converters and compressors that existed in the K-25 Building at that time. These measurements were performed using the instruments and procedures available at that time. The pedigree of these data (e.g. daily source checks, backgrounds, and quality assurance measurements) was missing or inadequate. Therefore, the contractor utilized the UNCS to validate these historical data.

In order to assure breadth and consistency, ORISE reviewed the NDA program plan and data quality objectives (DQOs), instrument-specific technical basis documents, and implementing procedures (referred to as Work Instructions) for each system.

## Independent Verification Measurements

ORISE initiated IV radiological field survey activities at the K-25 building in 2008. The objective of the survey was to assess the reliability and adequacy of the contractor's characterization results for the PGP. The DOE's prime contractor utilized the HMS4 to quantify the hold-up of enriched uranium in PGP. The resulting data were used to demonstrate compliance with the CI limits. ORISE also opted to utilize the HMS4 to perform IV measurements in order to validate the contractor's results. Therefore, the first step in the IV process for this phase was to develop a robust measurement program, including a performance test and validation plan (PTVP) and performance test and validation report (PTVR), for the specialized instrument. Extensive field testing was performed to assure data quality. A measurement plan with project-specific DQOs was developed. The DQOs for the IV were as follows:

> <u>Step 1, problem</u>: The verification must assess the reliability and adequacy of the contractor's PGP characterization results to ensure CI.
>
> <u>Step 2, decisions</u>: Are the contractor's procedures sufficiently robust to determine a conservative uranium hold-up gram quantity per unit length of PGP as well as to identify isolated hold-ups exceeding the allowable gram quantity to maintain criticality incredibility?
>
> <u>Step 3, decision inputs</u>: The decision inputs included 1) extensive in-process reviews and evaluations of the contractor's NDA program, 2) determination of a conservative NaI detector

scan minimum detectable concentration (MDC) for U-235 within PGP, 3) gamma scanning results and 4) non-destructive assay measurement results.

Step 4, study boundaries: The study boundaries were the PGP within randomly selected K-25 cells.

Step 5, decision rules: The ORISE verification project-specific plan (PSP) included multiple decision rules that were dependent upon the security issues regarding availability of the contractor's data. The first three proposed rules were based on the comparison of the verification units' results to the contractor's results via hypothesis testing. However, the contractor reported hold-up measurement results as the minimum detectable activity (MDA) for cases where a result was less than the MDA. Only values above the MDA were reported as an actual result. Therefore, a direct comparison of the contractor's mean U-235 hold-up for a cell to the verification results via a hypothesis test was not possible as originally described in the verification project-specific plan (PSP). In place of this approach, ORISE relied on a direct comparison of the means, with the contractor's mean constructed from primarily MDA values as the majority of the measurement results were less than MDA. Therefore, the expected direct comparison would be to the contractor's mean that is biased high relative to the actual average hold-up quantity. Secondly, ORISE collected five measurements for direction comparison with the contractor's data from locations where the contractor reported positive results. Lastly, individual measurements were evaluated against two criteria. Individual verification measurements were first compared with the CI limit. Next they were compared with the contractor's result for the same pipe section location. If these conditions were satisfied, then acceptance of the contractor's data for the respective verification sub-unit (cell) was recommended.

Step 6, decision errors: The two possible verification data errors were to incorrectly conclude that CI limits had not been met when the condition was true (Type I error) or conversely concluding the CI limits had been met when the condition was false (Type II error).

Step 7, survey design optimization: The survey design was optimized to collect the appropriate data based on the procedures detailed on the following pages.

There were approximately 360 cells within the west side of Building K-25. ORISE randomly selected approximately 10% of the cells for verification surveys of the associated PGP. ORISE used the contractor's pipe naming nomenclature for referencing specific PGP.

NaI detectors coupled to ratemeters with audible indicators were used to perform gamma scans of 100% of the accessible PGP within each verification cell. Locations in excess of an *a priori*-determined action level were marked or otherwise noted in accordance with security requirements for follow-up investigations.

ORISE collected a statistically-based number of U-235 hold-up measurements within each selected cell's PGP in order to estimate the mean. The number of random measurements ranged from 6 to 12 per cell. Judgmental measurements were generally performed at one to three locations in cells where gamma scans identified localized areas of elevated direct radiation. The contractor's data for the verification units were used as the planning inputs when determining the number of verification measurement locations.

ORISE originally planned to perform a statistical evaluation of the difference between the ORISE measurement mean and the contractor's mean for each verification unit via a Welch's two sample t test at a predetermined confidence interval. However, the contractor's data contained quantified results only for those measurements that exceeded the MDA. All other results, which predominated, were reported as MDA values. Therefore, an actual mean and standard deviation could not be calculated from the contractor's data. As a result, the verification data were compared directly with the PGP CI limits of less than seven grams of U-235 per foot for PGP with an outer diameter (OD) of three to four inches; ten grams per foot limit for an OD of four to six inches; fourteen grams per foot for an OD of six to ten inches; and 22 grams per foot for an OD of greater than ten inches. Most of the PGP verified were three to six inches OD. The individual random and judgmental measurements were initially compared with the most restrictive PGP criteria of 7 grams per foot established for CI conditions. Verification hold-up measurements were performed for direct data comparison at five of the contractor's measurement locations in one verification unit at locations with measurable quantities of U-235 (i.e., above MDA).

## INDEPENDENT VERIFICATION RESULTS

As a result of the technical reviews and in-process inspections, ORISE determined that there were numerous programmatic issues and opportunities for improvement. A summary of these observations as well as the IV measurement results are described in the subsequent sections.

### Independent Technical Reviews and In-Process Inspections

The early finding that resulted from the DOE assessments was that the ETTP NDA program did not utilize the DQO process to ensure that the data collected were of the appropriate type, quantity, and quality for the intended decision making applications. The assessment team noted that the two distinct users of the NDA data, including the CI determination team and the waste disposal team, had not collaborated to assure that the generated NDA data met the required parameters for use. Furthermore, there existed a lack of technical rigor in the technical documents that ensured the NDA data were valid for use. One technical issue identified was that radiological control (RadCon) technicians, who were not trained in NDA measurement methods, were performing data collection to quantify the amount of U-235 in the PGP&E. In addition, the technicians were utilizing RadCon instrumentation that was not qualified for NDA measurement use. The associated programmatic issue identified was that the NDA program was under the RadCon organizational umbrella and not defined as a separate technical group.

During later assessments, it was determined that while the contractor had established a separate NDA group to perform hold-up measurements with appropriate instrumentation (including the HMS4), the contractor had not completed performance tests to demonstrate that this instrumentation had adequate sensitivity relative to the CI limits. This same issue existed for all instrumentation utilized by the NDA group to perform CI measurements.

Another major programmatic issue that existed was the apparent disconnect between the NDA program documents and the implementing procedures. The root cause of this issue was the fact that the NDA program manager and personnel did not work closely with the NDA field team, which was managed by a subcontractor. As a result, many of the requirements specified in the program documents were not included in the work instructions. In addition, ad hoc changes were made to the procedures to correct technical issues identified in the field. However, because the field changes were not documented and/or evaluated by a procedure review team, there was neither assurance that the change was technically correct nor carried through to all of the program documents and procedures. One example of this was the change in the methodology from scanning the pipe using a NaI ratemeter to quantify the amount of uranium hold-up in the pipes to conducting scanning using the HMS4 system. While the NDA field team agreed that this change was warranted, the justification for the change was not documented, the work instructions were not updated, and the NDA program documents were not revised.

**Independent Verification Measurements**

Gamma scans of the exterior of the PGP readily identified pipe locations with elevated gamma radiation levels indicating the presence of suspected uranium deposits. Gamma radiation levels for much of the scanned pipe runs were comparable to the ambient background gamma levels.

Verification survey results were initially compared with the most restrictive limit of 7 grams U-235 per foot of PGP. Of the 255 verification measurements, only two exceeded this limit. The contractor had previously identified these locations as exceeding the CI limit and the sections were later removed.

The results of the comparison measurements are provided below in Table I.

Table I. Comparative Measurement Results (grams U-235)

| Location # | Ratio (contractor result to ORISE result) |
|---|---|
| **1** | 0.4 |
| **2** | 2.6 |
| **3** | 1.2 |
| **4** | 0.9 |
| **5** | 0.9 |

Of the five comparative measurements, two were not in agreement (locations 1 and 2) and the remaining three locations (locations 3, 4, and 5) agreed within the statistical uncertainty of the measurement procedure. Location 2 was on a valve. When the ORISE measurement parameters were established for these measurements, the additional metal thickness associated with valves was not input. The thicker metal input parameter that the contractor used for valves resulted in a higher contractor-reported quantity. The difference observed for location 1 is believed to be the result of difficulties in determining the exact contractor measurement location on the particular pipe evaluated. The remaining three locations provide evidence that the contractor's result were accurate.

The collective IV results clearly supported the conclusion that uranium deposits within the K-25 PGE and PGP were below the CI limits established for the project.

## LESSONS LEARNED

The overarching lesson learned is that the DQO process is essential to the success of any measurement program. The iterative DQO process is the tool for systematic planning to generate performance and acceptance criteria for all data types. Using a team approach to walk through the seven step process assures that the end use requirements for the type, quantity, and quality of data will be met. All data users should be represented at DQO workshops or sessions, and the problem statements should be carefully defined. In addition, all interested parties, including regulators and their technical support staff, should participate in the DQO sessions. For the case of the K-25 NDA program, there were two distinct problem statements, with the first pertaining to the fact that U-235 hold-up in PGP&E potentially exceeded the CI limit and the second pertaining to the fact that U-235 hold-up potentially exceeded the waste acceptance criteria for the disposal sites. If all end users of the data would have collaborated on defining the problem statements, there would have been assurance that each program's goals were being met. By the time the lack of DQOs for the NDA program was identified, thousands of data points had been collected that could not be validated. After a complete rework of the NDA program and procedures and a review of existing data, it was determined that the majority of the data could be used for the intended purpose. However, the lack of up-front collaboration ultimately resulted in several months delay in the project schedule.

A second programmatic lesson learned pertains to the importance of establishing a separate and distinct program for the performance of specialized measurements to be used for a specific purpose. During the early phases of the project, a formal NDA program and organization did not exist, and the project managers relied on the field technicians to assure that the NDA data were of the appropriate type, quality, and quantity to satisfy both CI and waste disposal limits. However, without a formal program and specified DQOs, there was an incomplete understanding of end use requirements to determine the appropriate measurement methods and parameters. The end result was that there was no assurance that the data could be used to support the CI determination or waste disposition. In addition, the changes to field procedures often went undocumented, leading to additional questions regarding consistency in data collection methods and data reliability. For the case of the K-25 NDA program, an NDA program and organization should have been developed prior to the performance of any data collection. Organization responsibilities should have been defined and program documents and test and validation plans should have been written and reviewed prior to implementation. In addition, the subcontractor's implementing procedures should have been reviewed by the contractor's procedure review committee to assure consistency with the program documents.

A third programmatic lesson learned is that all instrument systems should be commissioned prior to use. This process consists of developing a technical basis for why the measurement system is appropriate for the intended application. A PTVP for each measurement system should be developed that describes the tests that are to be conducted to verify that the calibration methods are correct, the capability of the system to meet the DQOs, the algorithms for calculating the data, and a determination of the total measurement uncertainty for each type of measurement. Again, the output of the DQO process provides clearly defined criteria that must be met for the specific use. For the K-25 NDA program, the CI limits, waste acceptance criteria, and acceptable parameters for both, together with the consideration of contaminants of concern (primarily U-235) and field conditions and geometries should have been the primary inputs to the decision as to the appropriate instrumentation types and data collection methods. While the NDA field technicians were knowledgeable of the contaminants of concern and field conditions and the appropriate instrumentation types, they were neither concerned with nor aware of the required MDCs and required confidence levels for the CI determination and waste disposition.

## CONCLUSION

The D&D of the K-25 building was a complex, full-scale demolition of the oldest and largest gaseous diffusion building in the DOE complex. As part of an independent technical review, ORISE performed extensive technical evaluations, in-process program assessments and audits, and technical programmatic recommendations to ensure that the contractor's criticality incredible program was a robust, technically defensible DQO-based process. Concurrent with these assessments, independent surveys and measurements of uranium holdups in process gas piping were performed. The ultimate objective of this technical support was to validate that the contractor had adequately documented criticality incredible conditions prior to the onset of structural demolition activities. The conclusion of the extensive review is that the NDA data for K-25 PGE is technically sound and meets the defined DQOs for the project. In addition, the independent verification results clearly support the conclusions that uranium deposits that remained within process gas equipment and pipes were below the criticality incredible limits established for the project.

The knowledge and lessons learned gained from validating the NDA program will not only contribute to the successful completion of the K-25 project, but will also benefit future demolition activities within the DOE complex.