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UCOR-4443-R1

Performance Test and Validation Plan for the Neutron Slab Counter

This document is approved for public
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UCOR-4443-R1

Performance Test and Validation Plan for the Neutron Slab Counter

Date Issued - December 2013

Prepared for the
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Office of Environmental Management

URS | CH2M Oak Ridge LLC
Managing and Safely Delivering the Department of Energy's Vision
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Performance Test and Validation Plan for the Neutron Slab Counter	**UCOR-4443-R1**
	December 2013

USQD Review Determination	☒ USQD ☐ UCD ☐ CAT X ☐ Exempt (Select Criteria below.) USQD/UCD/CAT X No.: USQD-MS-CX-REPORTS-1074 Rev.1	
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Exhibit L Mandatory Contractor Document	☐ No (No PCCB Reviewer Signature Required) ☐ Yes (Requires review by the Proforma Change Control Board.)	
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REVISION LOG

Revision Number	Description of Changes	Pages Affected
1	Corrected equations 4-2, 4-3, 5-1, 5-2, 5-7, 5-8, 5-10, 5-22, 5-28. Edited equations 5-29, 5-30 and included clarifying text. Added equation 5-20a with clarifying text. Changed 7.2 and incorporated revised calibration point locations. Updated table 4, clarifying required QA and background frequencies and added required MCNP simulations for compressor volute source location uncertainty determination. Added 1/4 radius source position to set of verification measurements (table 5).	10, 13, 14, 15, 16, 17, 22, 24, 26, 27, 28, 29
0	Initial issue of document.	All

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CONTENTS

FIGURES

TABLES

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ACRONYMS

DQO	data quality objective
MCNP	Monte Carlo N-Particle Transport Code
MDA	minimum detectable activity
NDA	nondestructive assay
NSC	neutron slab counter
PTVP	Performance Test and Validation Plan
PTVR	Performance Test and Validation Report
RSD	relative standard deviation
TMU	total measurement uncertainty
UNCS	Uranium Neutron Counting System
VDC	volts direct current
WRM	Working Reference Material

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1. INTRODUCTION

This Performance Testing and Validation Plan (PTVP) presents the technical basis for the use of the neutron slab counter (NSC) for quantitative nondestructive assay (NDA) measurements of compressor volutes from the K-25/K-27 Buildings.

This PTVP prescribes a set of measurements required to calibrate and demonstrate sufficiency of the NSC for its intended purpose of quantitative NDA measurements of compressor volutes. The measurements taken according to this plan will be documented in a Performance Test and Validation Report (PTVR). Analysis of the collected data will be performed and documented in a Performance Test and Validation Evaluation. If the performance objectives are met, a commissioning report will be prepared establishing the uses and limitations of the NSC for its intended purpose.

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2. SYSTEM DESCRIPTION

The NSC is a passive neutron counting system that consists of two slab detectors independently connected to the required electronics for total neutron counting. The measured neutrons come primarily from alpha particles from the uranium (U) source inducing an (α,n) reaction with fluorine. The primary source of alpha particles in enriched uranium is from the decay of U-234. If the chemical form of the uranium and the U-235/U-234 ratio are known, the amount of U-235 can be determined.

The NSC is designed to measure U-235 holdup in compressor volutes packaged on specifically designed pallets by direct, neutron measurements (see Fig. 1). A typical volute can be approximated as a 12.5-in. tall cylinder approximately 65 in. in diameter (see Fig. 2). The largest dimension is the length of the pallet, 71 in.

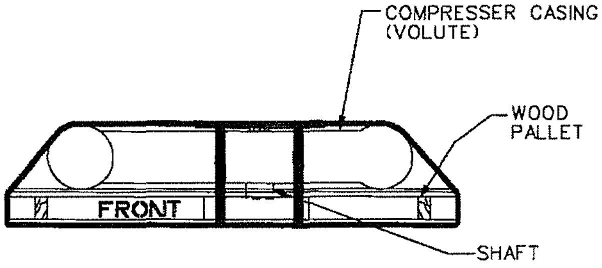

Fig. 1. Compressor volute and pallet assembly.

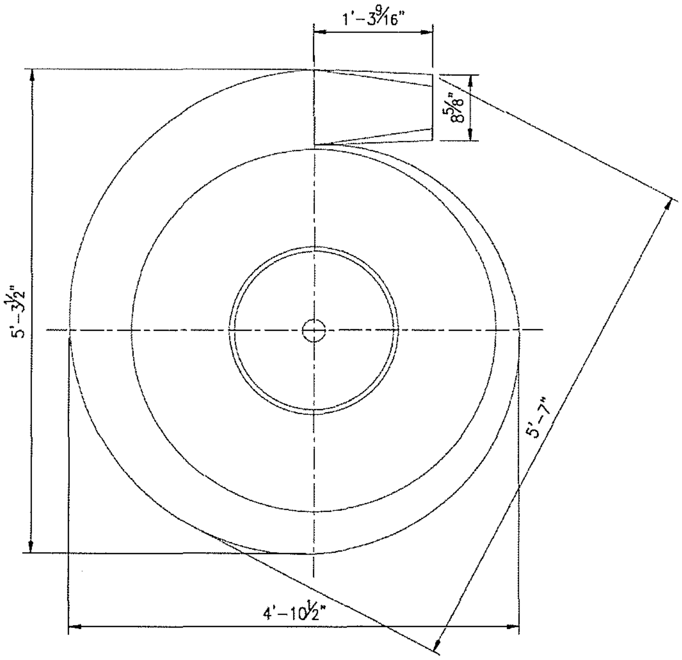

Fig. 2. Compressor volute sketch prepared for design of mock volute.

The size of the active volume of the NSC is defined as 72 × 72 × 12.5 in. The performance test measurements and system calibration are designed such that the source is constrained within this active volume. Draft sketches of the NSC are provided in Figs. 3 and 4. Each slab detector face is positioned 36 in. from the nearest face of the volute.

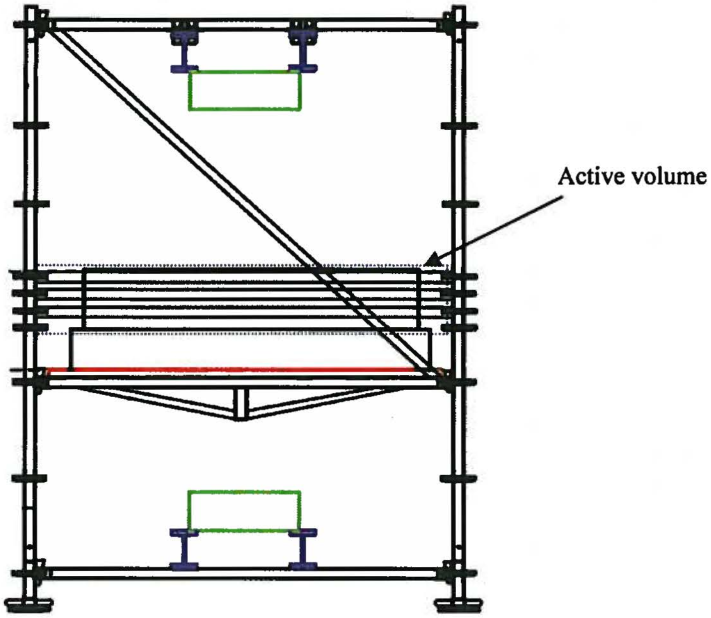

Fig. 3. NSC—side view.

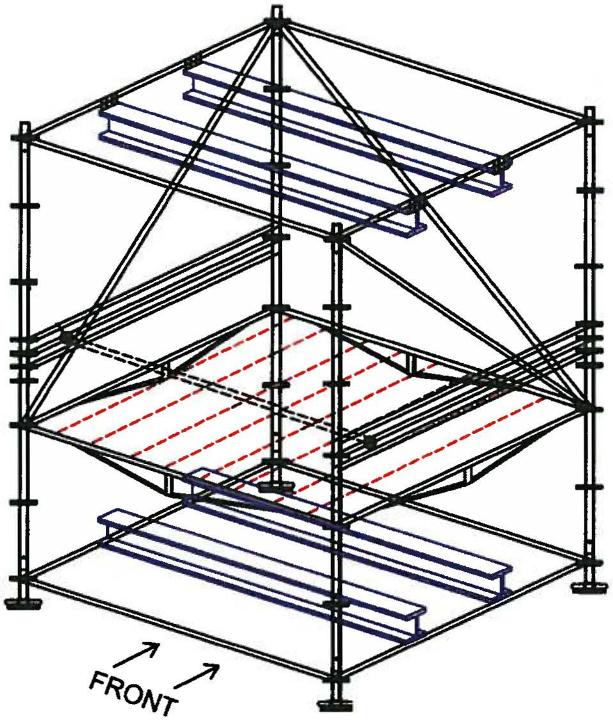

Fig. 4. NSC—isometric view.

A standard slab detector has five 1-in. diameter helium 3 (He-3) detector tubes, each approximately 2 ft in length. The tubes are pressurized to four atmospheres and fitted with a preamp/discriminator. The five detector tubes are centered in a polyethylene moderator casing that is approximately 22-in. tall, 12-in wide, and 4-in. deep. Each poly detector module is wrapped with 1/32 in. of cadmium (Cd), then 4 in. of additional polyethylene. This configuration is designed to reduce the detected thermal neutrons from background. The signals from the preamp/discriminator modules are fed through a pulse stretcher module to scalers (the E-600 units), which tally the counts from the detectors. The E-600 unit also provides +5 volts direct current (VDC) for the amplifier and high voltage (nominally 1700 VDC) for the detectors. A pulse stretcher between the amplifier output and the E-600 scaler enables the scaler to reliably count the 50 nsec output pulses from the preamp/discriminator.

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3. THEORY OF OPERATION

3.1 BACKGROUND

During the uranium enrichment process at K-25/K-27, uranium hexafluoride (UF_6) was used in the cascade to selectively increase the amount of U-235 from the naturally occurring fraction of about 0.7% to over 93%. With the shutdown of the facility, it became necessary to locate and quantify the uranium holdup in the piping and equipment in order to safely remove deposits of significance or determine that the remaining amounts of U-235 are below regulatory limits. U-235 can be directly measured by detecting the characteristic gamma rays emitted from this isotope at 186 keV, but gamma rays are severely attenuated by dense materials. This attenuation must be accounted for and factored into any quantitative gamma ray measurement of the uranium. For objects of significant physical density (i.e., compressor volutes) it is often impossible to obtain a useable signal from passive gamma ray emissions. In these cases, one can, as an alternative, measure the neutrons arising from interactions of α-particles from decay of uranium on lighter materials (fluorine or oxygen) associated with the uranium compounds, notably UF_6 or uranyl fluoride (UO_2F_2).

The majority of the α-particles come from U-234; however, at lower U-235 enrichment fractions, the contributions from the other uranium isotopes become more significant and should also be accounted for. The quantitative mass calculation of U-235 requires that the U-235 enrichment fraction be known and a corresponding ratio of U-235 to U-234 be available. He-3 is used in the neutron detector tubes because of its very large cross section for thermal neutrons, whereby the incoming neutron interacts with a He-3 nucleus, changing it to H-3 and emitting a proton. This interaction releases about 764 keV of energy, which is carried away by the proton and triton in a ratio of 3:1. Both resulting particles collide with He-3 atoms and strip off electrons, which can then be accelerated by the voltage on the detector wire to give a current pulse from the neutron detector. Since the interaction probability of such a reaction is very small, except for very slow-moving neutrons, it is necessary to slow down the neutrons from the (α,n) reaction (which are produced with average energies over 1 MeV). This "moderating" process is accomplished by embedding the neutron detectors in a polyethylene block. The hydrogen atoms in the polyethylene undergo elastic collisions with the incoming high-energy neutrons, which then lose energy with each collision. When these high-energy neutrons have undergone several such collisions, they are sufficiently slowed down to be detected in the helium-filled tubes. The number of neutrons thus detected is determined by the masses of the uranium isotopes, the number of lighter atoms in chemical combination with the uranium (notably fluorine and oxygen), the efficiency of the helium detectors to moderate and detect the incoming high-energy neutrons, and the probability of the detector module to intersect the neutrons emitted from the sample (i.e., geometric cross section of the detector modules). In summary, the neutron slab detector has the advantage of being relatively insensitive to attenuating materials in the sample and in having generally smaller and better-characterized backgrounds as compared to gamma measurement systems. Conversely, it suffers the disadvantages of dealing with a much diminished signal (there are fewer neutrons than gamma rays) and the necessity of requiring the input parameter of U-235 enrichment fraction and the corresponding U-235 to U-234 ratio.

3.2 BACKGROUND MEASUREMENTS AND CORRECTIONS

Background neutrons occur as a result of neutron-emanating materials in the area, from natural background, and from spallation neutrons created by the interaction of high energy cosmic protons with materials (mostly metals) in near-field structures, and the metal matrix of the components subject to holdup measurement. A compressor volute surrogate will be used for determining the required background corrections for each measurement performed. This background correction will include the natural background contribution and the spallation neutron contribution. The surrogate volute should be of the same size and weight as a typical compressor volute to appropriately quantify the background.

Two background situations can occur.

1. If a measurement is to be made of a bare Working Reference Material (WRM) source (i.e. for calibration purposes), then a background determination of the empty calibration space is required.
2. If a measurement is to be made of a compressor volute, a background determination of the calibration space with the surrogate volute in place is required.

The following describes the calculation of the net count rate due to a WRM source (for calibration or calibration verification only):

$$n = \left(\frac{F_1}{t_{F_1}} + \frac{F_2}{t_{F_2}} \right) - \left(\frac{B_1}{t_{B_1}} + \frac{B_2}{t_{B_2}} \right) \tag{3-1}$$

n (c/s) is the net count rate due to a WRM source.

F_1 (c) is the total neutron counts from slab detector 1 collected within time t_{F_1} (s), due to a WRM source.

F_2 (c) is the total neutron counts from slab detector 2 collected within time t_{F_2} (s), due to a WRM source.

B_1 (c) is the total background neutron counts from slab detector 1 collected within time t_{B_1} (s), without the surrogate volute in place.

B_2 (c) is the total background neutron counts from slab detector 2 collected within time t_{B_2} (s), without the surrogate volute in place.

The following describes the calculation of the net count rate due to a holdup source in a compressor volute (for calibration verification with a source in the mock-volute or for actual volute measurement):

$$r = \left(\frac{V_1}{t_{V_1}} + \frac{V_2}{t_{V_2}} \right) - \left(\frac{C_1}{t_{C_1}} + \frac{C_2}{t_{C_2}} \right) \tag{3-2}$$

r (c/s) is the net count rate due to a holdup source in a compressor volute.

V_1 (c) is the total neutron counts from slab detector 1 collected within time t_{V_1} (s), due to a holdup source in a compressor volute.

V_2 (c) is the total neutron counts from slab detector 2 collected within time t_{V_2} (s), due to a holdup source in a compressor volute.

C_1 (c) is the total background neutron counts from slab detector 1 collected within time t_{C_1} (s), with the surrogate volute in place.

C_2 (c) is the total background neutron counts from slab detector 2 collected within time t_{C_2} (s), with the surrogate volute in place.

4. CALIBRATION

4.1 CALIBRATION SOURCE

The fundamental U-235 quantification process of the passive neutron slab detector is the recording of neutrons derived from the thermalization of fast neutrons produced by U-234(α,n) reactions on (primarily) fluorine and other components of the holdup source. As the U-235 enrichment fraction of the holdup source decreases, the relative proportion of neutrons generated from U-234 alpha particle decay decreases and the proportion of neutrons from U-235 and U-238 alpha particle decay and spontaneous fission increases. The intensity of these reactions is most dependent on the chemical composition of the uranium compound in the source and the presence of adulterants that could affect the reaction rate. The most conservative chemical form is UO_2F_2, since it has the fewest target fluorine atoms. Adulterants can suppress the neutron production rate (through attenuation of the α-particles) only if it is interstitially or chemically contained in the UO_2F_2 source matrix. Many studies have shown that water of hydration is the adulterant that will most greatly affect the neutron production rate.

Since neither the chemical form of the uranium nor the hydration state of the material is known with certainty in an unknown holdup source, a calibration source composed of UO_2F_2 in a stable hydrate form should be used. This is the most conservative assumption with respect to the possible chemical forms of uranium (e.g. UO_2F_2, uranium tetrafluoride [UF_4], UF_6), and the hydration state (of UO_2F_2) for the quantification of U-235.

4.2 CALIBRATION SPACE

The NSC is designed for the specific purpose of NDA measurement of compressor volutes in a specified configuration (i.e. horizontally oriented on the pallet). The NSC efficiency over the defined calibration space will be determined through direct measurement of the WRM3 fully hydrated UO_2F_2 source at a number of specified locations. The NSC volute calibration space efficiency will be indirectly developed using Monte Carlo N-Particle Transport Code (MCNP) calculations. The indirect determination of the NSC efficiency will be adjusted to the measured efficiency by the ratio of the direct measurements over the MCNP-determined efficiency in the empty calibration space.

4.3 CALIBRATION SPACE EFFICIENCY

A set of calibration points will be defined that reasonably encompass the locations where holdup sources might be expected. A direct measurement and an MCNP calculation of intrinsic chamber efficiency will be performed for each point. At each point, the measured efficiency of the chamber can be expressed as:

$$\varepsilon_{i,S,Measaured} = \frac{WF_{235}}{m_{cal,U235} \cdot \left(WF_{234} \cdot R_{n-234} + WF_{235} \cdot R_{n-235} + WF_{238} \cdot R_{n-238}\right)} \cdot n_i \qquad (4\text{-}1)$$

where $\varepsilon_{i,S,Measured}$ is the measured efficiency of the NSC with the WRM3 source at the i^{th} calibration point

$m_{cal,U235}$ is the known mass of U-235 in the calibration standard

n_i is the net count rate (c/s) is the net count rate due to a WRM source at the i^{th} calibration point

WF_j is the weight fraction of the j^{th} uranium isotope

$$WF_j = \frac{M_j}{M_U}$$

M_j is the mass of the j^{th} uranium isotope and M_U is the mass of total uranium.

R_{n-j} is the n/s/g of the j^{th} uranium isotope including neutrons from both (α,n) reactions with fluorine and spontaneous fission.

The MCNP generated efficiencies should be determined for the WRM3 calibration source at the specified calibration points; thus, at each of the i calibration points, a MCNP efficiency, $\varepsilon_{i,S,MCNP}$ should be calculated.

4.3.1 Average Efficiency

The average measured efficiency and average MCNP efficiency are defined as:

$$\bar{\varepsilon}_{S,Measured} = \frac{1}{m}\sum_{i=1}^{m} \varepsilon_{i,S,Measured} \tag{4-2}$$

$$\bar{\varepsilon}_{S,MCNP} = \frac{1}{m}\sum_{i=1}^{m} \varepsilon_{i,S,MCNP} \tag{4-3}$$

4.3.2 Volume Weighted Average Efficiency

Each calibration space point can be assigned a fraction of the total volume of the calibration space based on the proportion of the space to which this calibration space point represents. The volume fraction of the i^{th} calibration space point is defined as vf_i; thus, the volume weighted average efficiencies are defined as:

$$\bar{\varepsilon}_{S,Measured,VW} = \sum_{i=1}^{m} \varepsilon_{i,S,Measured} \cdot vf_i \tag{4-4}$$

$$\bar{\varepsilon}_{S,MCNP,VW} = \sum_{i=1}^{m} \varepsilon_{i,S,MCNP} \cdot vf_i \tag{4-5}$$

4.3.3 Normalization of Monte Carlo Generated Efficiencies for Detector Wall and Discriminator Effects

Monte Carlo calculations of the response of the NSC to neutrons assume that any absorption reaction of a neutron with He-3 produces a "count" in the detection system. The specific reaction in question is

$${}_2^3He + {}_0^1n \rightarrow {}_1^3H + {}_1^1p$$

The tritium nucleus and proton deposit their kinetic energy in the detector gas by creating a large number of free electrons, which are subsequently collected by the positive electrode in the detector, producing a small current pulse in the system.

Because many of these reactions occur near the walls or ends of the detector and the mean free path of the tritium nucleus or the proton is significant compared to the detector dimensions, a significant fraction of the protons or tritium nuclei deposit a portion of their energy in the walls of the detector. Interactions that deposit a significant fraction of their kinetic energy in the wall of the detector, such that the energy deposition in the detector gas is below the discriminator setting, are not counted.

The magnitude of the detector wall and discriminator effects is believed to be relatively insensitive to the nature of the item being measured. This is due to the fact that the neutrons being counted are in near thermal equilibrium with the detector module materials, and the thermal neutron flux in the detector module is relatively isotropic due to the large number of collisions that occur during thermalization in the detector module. The MCNP efficiency calculation for the compressor volute will therefore be normalized by comparing Monte Carlo calculations of efficiency for the empty calibration space with efficiency measurements of this same configuration. The operative equation will thus be:

$$\varepsilon_{V,NSC} = \varepsilon_{V.MCNP} \cdot \frac{\bar{\varepsilon}_{S,Measured}}{\bar{\varepsilon}_{S,MCNP}} \tag{4-6}$$

where $\varepsilon_{V,NSC}$ is the normalized efficiency of the NSC for a compressor volute.

$\varepsilon_{V.MCNP}$ is the MCNP calculated efficiency for a compressor volute.

$\bar{\varepsilon}_{S,Measured}$ is the average measured efficiency for the empty calibration space of the NSC.

$\bar{\varepsilon}_{S,MCNP}$ is the average calculated MCNP efficiency for the empty calibration space of the NSC.

4.4 NSC QUANTITATIVE U-235 MASS DETERMINATION – WRM SOURCE

The following equation defines the quantitative U-235 calculation for a bare WRM source placed in the NSC.

$$m_{U235,S} = \frac{WF_{235}}{\bar{\varepsilon}_{S,Measured,VW} \cdot \left(WF_{234} \cdot R_{n-234} + WF_{235} \cdot R_{n-235} + WF_{238} \cdot R_{n-238}\right)} \cdot n_i \tag{4-7}$$

4.5 NSC QUANTITATIVE U-235 MASS DETERMINATION—COMPRESSOR VOLUTE

The following equation defines the quantitative U-235 calculation for a compressor volute placed in the NSC, or for a WRM source placed inside the mock volute for calibration verification purposes.

$$m_{U235,V} = \frac{WF_{235}}{\varepsilon_{V,NSC} \cdot \left(WF_{234} \cdot R_{n-234} + WF_{235} \cdot R_{n-235} + WF_{238} \cdot R_{n-238}\right)} \cdot r_i \tag{4-8}$$

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5. MINIMUM DETECTABLE ACTIVITY AND TOTAL MEASUREMENT UNCERTAINTY

5.1 COUNTING STATISTICS

The uncertainty due to counting statistics for the measurement of a bare WRM source (equation 3-1) is:

$$\sigma_n = \sqrt{\frac{F_1}{t_{F_1}^2} + \frac{F_2}{t_{F_2}^2} + \frac{B_1}{t_{B_1}^2} + \frac{B_2}{t_{B_2}^2}} \tag{5-1}$$

The uncertainty due to counting statistics for the measurement of a holdup source in a compressor volute (equation 3-2) is:

$$\sigma_r = \sqrt{\frac{V_1}{t_{V_1}^2} + \frac{V_2}{t_{V_2}^2} + \frac{C_1}{t_{C_1}^2} + \frac{C_2}{t_{C_2}^2}} \tag{5-2}$$

The relative standard deviations of these uncertainty terms are given below:

$$\%RSD_{CS,S} = \frac{\sigma_n}{n} \cdot 100\% \tag{5-3}$$

$$\%RSD_{CS,V} = \frac{\sigma_r}{r} \cdot 100\% \tag{5-4}$$

The standard deviation can also be presented in terms of U-235 mass:

$$\sigma_{CS,S}(gU235) = \frac{\%RSD_{CS,S}}{100\%} \cdot m_{U235,S} \tag{5-5}$$

$$\sigma_{CS,V}(gU235) = \frac{\%RSD_{CS,V}}{100\%} \cdot m_{U235,V} \tag{5-6}$$

5.2 CALIBRATION COUNTING STATISTICS

The calibration counting statistics for the empty calibration space are defined by:

$$\sigma_{CCS,S}^2 = \left(\frac{WF_{235}}{m_{cal,U235} \cdot \left(WF_{234} \cdot R_{n-234} + WF_{235} \cdot R_{n-235} + WF_{238} \cdot R_{n-238} \right)} \right)^2 \cdot \sum_{i=1}^{m} \left(\sigma_{n_i}^2 vf_i^2 \right) \tag{5-7}$$

The calibration counting statistics for the compressor volutes are based on the MCNP generated data via:

$$\sigma_{CCS,V}^2 = \left(\frac{WF_{235}}{m_{cal,U235} \cdot \left(WF_{234} \cdot R_{n-234} + WF_{235} \cdot R_{n-235} + WF_{238} \cdot R_{n-238} \right)} \right)^2 \cdot \left(\frac{V_{MCNP}}{t_{V,MCNP}^2} \right) \tag{5-8}$$

V_{MCNP} are the total number of neutrons recorded in the slab detector 1 and slab detector 2 as generated by the MCNP simulations in time $t_{V,MCNP}$. Note that $m_{cal,U235}$ in equation 5-7 is defined by the calibration source and in equation 5-8 is defined by the source input to MCNP for the volute efficiency determination.

The corresponding relative standard deviations can be obtained via:

$$\%RSD_{CCS,S} = \frac{\sigma_{CCS,S}}{\bar{\varepsilon}_{S,Measured,VW}} \cdot 100\% \tag{5-9}$$

$$\%RSD_{CCS,V} = \frac{\sigma_{CCS,V}}{\varepsilon_{V,MCNP}} \cdot 100\% \tag{5-10}$$

The calibration counting statistics standard deviation can also be presented in terms of U-235 mass:

$$\sigma_{CCS,S}(gU235) = \frac{\%RSD_{CCS,S}}{100\%} \cdot m_{U235,S} \tag{5-11}$$

$$\sigma_{CCS,V}(gU235) = \frac{\%RSD_{CCS,V}}{100\%} \cdot m_{U235,V} \tag{5-12}$$

5.3 CALIBRATION SOURCE MASS UNCERTAINTY

The calibration source has a reported standard deviation on the U-235 mass contained in the source, σ_{CM}. Thus, the relative standard deviation of the calibration source mass can be defined as:

$$\%RSD_{CM} = \frac{\sigma_{CM}}{m_{cal,U235}} \cdot 100\% \tag{5-13}$$

The uncertainty in the calibration source mass can also be provided in terms of g U-235 for each of the measurement configurations: empty (S) and volute (V):

$$\sigma_{CM,S}(gU235) = \frac{\%RSD_{CM}}{100\%} \cdot m_{U235,S} \tag{5-14}$$

$$\sigma_{CM,V}(gU235) = \frac{\%RSD_{CM}}{100\%} \cdot m_{U235,V} \tag{5-15}$$

5.4 SOURCE LOCATION UNCERTAINTY

The variance of the measured efficiency over the calibration space points is comprised of variability, due to source location and the statistical uncertainty associated with the calibration measurements.

$$\sigma_{\varepsilon,S}^2 = \sigma_{SL,S}^2 + \sigma_{CCS,S}^2 \tag{5-16}$$

$\sigma^2_{\varepsilon,S}$ is the variance in the measured efficiencies over the 11 calibration points.

$\sigma^2_{SL,S}$ is the variance contribution from unknown source location.

$\sigma^2_{CCS,S}$ is the variance contribution due to calibration counting statistics.

$$\sigma^2_{\varepsilon,S} = \sum_{i=1}^{m} \frac{1}{(m-1)} \cdot \left(\varepsilon_{i,S,Measured} - \bar{\varepsilon}_{S,Measured,VW}\right)^2 \qquad (5\text{-}17)$$

$$\sigma_{SL,S} = \sqrt{\sigma^2_{\varepsilon,S} - \sigma^2_{CCS,S}} \qquad (5\text{-}18)$$

The relative standard deviation due to source location uncertainties in the empty NSC is:

$$\%RSD_{SL,S} = \frac{\sigma_{SL,S}}{\bar{\varepsilon}_{S,Measured,VW}} \cdot 100\% \qquad (5\text{-}19)$$

The source location uncertainty for the empty NSC can be provided in terms of g U-235:

$$\sigma_{SL,S}(gU235) = \frac{\%RSD_{SL,S}}{100\%} \cdot m_{U235,S} \qquad (5\text{-}20)$$

The relative source location uncertainty for a compressor volute should be defined based on a set of MCNP efficiencies determined by placing a source at different points throughout the volute and evaluating the variance of those efficiencies. Once the relative standard deviation is determined, it can be converted to g U-235 using equation 5-20a.

$$\sigma_{SL,V}(gU235) = \frac{\%RSD_{SL,V}}{100\%} \cdot m_{U235,V} \qquad (5\text{-}20a)$$

5.5 BACKGROUND VARIABILITY

The environmental neutron background is subject to pseudo-random variability on an hour-by-hour or day-by-day basis. This variability is postulated to result from:

- Variability in the cosmic ray flux impinging on metal structures in the vicinity of the NSC, creating variability in the spallation neutron background rate.
- Movement of process gas components in the vicinity of the NSC.
- Changes in atmospheric conditions.

A sufficient number of background counts should be collected over the course of the calibration and testing period. The variance of this set of background measurements is comprised of the variability of the environmental neutron background and the counting statistics uncertainty associated with the background measurements.

$$\sigma^2_{BR} = \sigma^2_{BVR} + \sigma^2_{BCSR} \qquad (5\text{-}21)$$

σ_{BR}^2 variance of the set of background data collected during the calibration activities, defined by:

$$\sigma_{BR}^2 = \frac{1}{(G-1)} \cdot \sum_{k=1}^{G} \left(\frac{B_k}{T_k} - \overline{B}_R \right)^2 \qquad (5\text{-}22)$$

Where G is the total number of backgrounds being evaluated for which the corresponding background count totals are B_k and the count times are T_k.

The following quantities can then be defined:

$$\overline{B} = \frac{1}{G} \cdot \sum_{k=1}^{G} B_k \text{, } \overline{T} = \frac{1}{G} \cdot \sum_{k=1}^{G} T_k \text{, and } \overline{B}_R = \frac{1}{G} \cdot \sum_{k=1}^{G} \frac{B_k}{T_k}$$

σ_{BVR}^2 is the unquantified variance observed in the background due to environmental effects.

σ_{BCSR}^2 is the variance due to the counting statistics of the background measurements, which can be approximated by:

$$\sigma_{BCSR}^2 = \frac{\overline{B}}{\overline{T}^2} \qquad (5\text{-}23)$$

The unexplained variance in the observed background can then be quantified via:

$$\sigma_{BVR}^2 = \sigma_{BR}^2 - \sigma_{BCSR}^2 \qquad (5\text{-}24)$$

Converting the background variability to grams of U-235 yields:

$$\sigma_{BV,S}(gU235) = \sigma_{BVR} \cdot \frac{WF_{235}}{\varepsilon_{S,Measured,VW} \cdot \left(WF_{234} \cdot R_{n-234} + WF_{235} \cdot R_{n-235} + WF_{238} \cdot R_{n-238} \right)} \qquad (5\text{-}25)$$

$$\sigma_{BV,V}(gU235) = \sigma_{BVR} \cdot \frac{WF_{235}}{\varepsilon_{V,NSC} \cdot \left(WF_{234} \cdot R_{n-234} + WF_{235} \cdot R_{n-235} + WF_{238} \cdot R_{n-238} \right)} \qquad (5\text{-}26)$$

5.6 MINIMUM DETECTABLE ACTIVITY

The minimum detectable activity for the empty NSC (S) and for a compressor volute (V) are defined below:

$$MDA_S(gU235) = \frac{WF_{235}}{\varepsilon_{S,MeasuredVW} \cdot \left(WF_{234} \cdot R_{n-234} + WF_{235} \cdot R_{n-235} + WF_{238} \cdot R_{n-238} \right)} \cdot \left[\frac{k^2}{t_F} + 2k\sigma_{B,S} \sqrt{1 + \frac{t_B}{t_F}} \right] \qquad (5\text{-}27)$$

$$MDA_V(gU235) = \frac{WF_{235}}{\varepsilon_{V,NSC} \cdot \left(WF_{234} \cdot R_{n-234} + WF_{235} \cdot R_{n-235} + WF_{238} \cdot R_{n-238} \right)} \cdot \left[\frac{k^2}{t_V} + 2k\sigma_{B,V} \sqrt{1 + \frac{t_C}{t_V}} \right] \qquad (5\text{-}28)$$

The related background uncertainty terms are defined below:

$$\sigma_{B,S}^2 = \frac{B_1 + B_2}{t_B^2} + \sigma_{BVR}^2 \tag{5-29}$$

$$\sigma_{B,V}^2 = \frac{C_1 + C_2}{t_C^2} + \sigma_{BVR}^2 \tag{5-30}$$

The background variance calculations in equations 5-29 and 5-30 treat a given NSC background as a single total neutron count, $B_1 + B_2$ or $C_1 + C_2$ collected over a time period defined as: $t_B = t_{B_1} = t_{B_2}$ or $t_C = t_{C_1} = t_{C_2}$.

5.7 TOTAL MEASUREMENT UNCERTAINTY

The total measurement uncertainty for a bare WRM source placed in the NSC is given by:

$$TMU_S(gU235) = \sqrt{[\sigma_{CS,S}(gU235)]^2 + [\sigma_{CCS,S}(gU235)]^2 + [\sigma_{CM,S}(gU235)]^2 + [\sigma_{SL,S}(gU235)]^2 + [\sigma_{BV,S}(gU235)]^2} \tag{5-31}$$

The total measurement uncertainty for a WRM source placed in the mock volute, or for a compressor volute is:

$$TMU_V(gU235) = \sqrt{[\sigma_{CS,V}(gU235)]^2 + [\sigma_{CCS,V}(gU235)]^2 + [\sigma_{CM,V}(gU235)]^2 + [\sigma_{SL,V}(gU235)]^2 + [\sigma_{BV,V}(gU235)]^2} \tag{5-32}$$

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6. DATA QUALITY OBJECTIVES

BJC/OR-2966, *Data Quality Objectives for Quantitative Nondestructive Assay of K25/K-27 Uranium,* specifies reasonable quality standards to ensure NDA measurements taken using the NSC satisfy quality criteria for minimum detectible activity (MDA), precision, and accuracy. By meeting these criteria, measurements taken with the system can be considered adequate with sufficient confidence (95%) for end users to make decisions about the overall management and disposition of uranium-bearing materials arising from K-25/K-27 deactivation and decommissioning activities. The data quality objectives (DQOs) are objectives so that the instruments can be tested for performance of MDA, precision, and accuracy.

Further: "To demonstrate compliance with the DQOs for NDA, K-25/K-27 NDA must, at a minimum, evaluate and document NDA methods and processes. Documentation shall include but is not limited to; technical studies, instrument characterization measurement data, traceable source data, data acquisition routines, data reduction routines, analytical methods (e.g., Monte Carlo N-Particle modeling), software description and testing, method capability, DQO compliance summaries, implementing procedures, instrument procurement requirements, quality control measures, total measurement uncertainty (TMU) verification (per the *NDA Program Description*, BJC/OR-1856), and participation in blind measurement test programs (per ES-5004, *Oak Ridge Sample Management Office Nondestructive Assay Performance Evaluation Plan*)."

With the end user DQOs, the K-25/K-27 Project can develop and implement methods to acquire and certify that generated data will meet the needs of the end user.

The DQO for the NSC is to provide quantitative U-235 values with a 95% uncertainty margin that can be evaluated against the decision limits for end users. The DQO MDA is 50% of the transportation limit of 252g U-235, or 126g U-235. Note that the Environmental Management Waste Management Facility limit for compressor volutes of 350g U-235 will also be satisfied under the defined DQO.

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7. INSTRUMENT AND METHOD QUALIFICATION

"Instrument Qualification establishes the fundamental relationship of the instrument response (usually counts) to a known isotopic mass and is performed in accordance with accepted NDA protocols as described in ASTM C1592-04[1], utilizing primary (traceable to a national measurement base) calibration standards. Full documentation of the qualification technique and results are documented and submitted for independent technical review" (BJC/OR-2966).

Method Qualification establishes the operational limits and applicable utility of the instrument or measurement system. The NSC capability is to be demonstrated through measurements of well-characterized standards in configurations that confirm the adequacy of performance and serve to develop the MDA and the TMU (BJC/OR-2966).

The instrument qualification process that follows is designed to achieve the following objectives:

- To determine average calibration efficiency
- To determine source position effects on average calibration efficiency
- To verify that the system will return an acceptably accurate calculated value for the a well-characterized UO_2F_2 standard
- To validate the MCNP model efficiency calculation and derive a correction to the observed efficiency of the NSC

The method qualification process evaluates the response of the NSC under a variety of scenarios and compares the quantitative result of a compressor volute measurement in the Uranium Neutron Counting System (UNCS) with the quantitative result for that same volute as measured in the NSC.

7.1 INSTRUMENT SETUP

Table 1. Instrument setup test requirements

Performance test	Performance method
Prepare instrument for routine operation.	Verify NSC configuration for use. 1. Confirm that detectors and electronics are properly functioning and that the high voltage is properly adjusted. Identify and use a measurement control check source: 1. Place the identified measurement source within the NSC (specify the location of the source in the setup results). 2. Evaluate the measurement control result with respect to the established check source limits (pass at $\leq 2\sigma$) or perform replicate (minimum of six) measurement control measurements to establish this limit.

---

[1] ASTM C159-04 has been superseded by ASTM C1592/C1592M-09, *Standard Guide for Making Quality Nondestructive Assay Measurements*.

7.2 CALIBRATION

The NSC should be calibrated with the WRM3, which is traceable to the national measurement base, and consists of a known quantity of fully hydrated UO_2F_2. The source certificate is provided in Appendix A.

The measured calibration efficiency of the NSC is obtained by:

1. Placing the WRM3 source at specified locations within the active volume of the NSC.
2. Measuring the total neutron count on each of the two slab detectors.
3. Reporting the number of neutrons detected by the system detector and electronics.
4. Correlating this measured value to the known U-235 mass of the standard.
5. The system efficiency is mapped over 11 locations (see Fig. 5 and Table 2a) and the average measured efficiency can be determined.

The calibration measurements provide the basis for calculation of the measured efficiency of the NSC. This measured efficiency is then compared to a calculated efficiency generated using MCNP to derive an adjustment factor. This adjustment factor can then be utilized to correct MCNP-derived efficiencies obtained for the compressor volute measurement configuration.

During the initial set of measurements under revision 0 of this PTVP, an adjustment to the calibration point locations was made. The originally planned calibration point locations (Table 2) were specified to cover the entire counting volume of the NSC; however, the location of the holdup source material in compressor volutes will not extend to the outer edges of this volume. The original specification of calibration point locations included points outside of the known volume of the compressor volute itself. Furthermore, these calibration point locations were near the edges of the field of view of the NSC leading to an increased variability in the measured efficiency.

A revised set of calibration points was defined which placed the calibration points at one half the distance from the center to the edge of the calibration space (i.e. +/- 18 inches), the z axis values remained unchanged (see Table 2b and Fig. 6). These measurements were performed prior to revision 1 of this document being completed; therefore, the NSC Performance Test and Validation Report (NDA-13-0622) and NSC Performance Test and Validation Evaluation (UCOR-4527) includes measurements and analyses for both sets of calibration point locations.

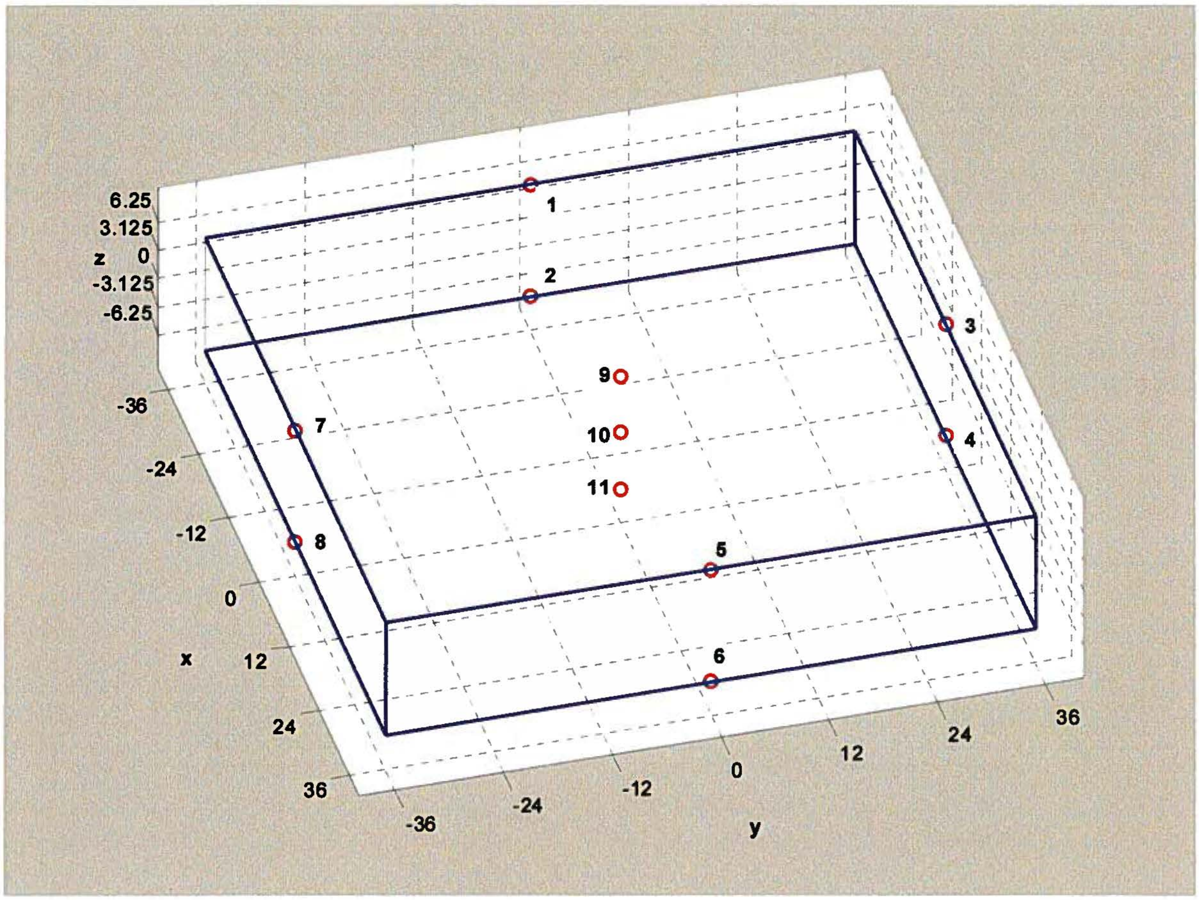

Fig. 5. NSC calibration points (all dimensions are in inches).

Table 2a. NSC calibration points

Pt. number	x (inches)	y (inches)	z (inches)	Volume fraction[1]
1	-36	0	6.25	0.093276
2	-36	0	-6.25	0.093276
3	0	36	6.25	0.093276
4	0	36	-6.25	0.093276
5	36	0	6.25	0.093276
6	36	0	-6.25	0.093276
7	0	-36	6.25	0.093276
8	0	-36	-6.25	0.093276
9	0	0	6.25	0.062000
10	0	0	0	0.129794
11	0	0	-6.25	0.062000

[1] The volume fraction calculation is provided in Appendix B.

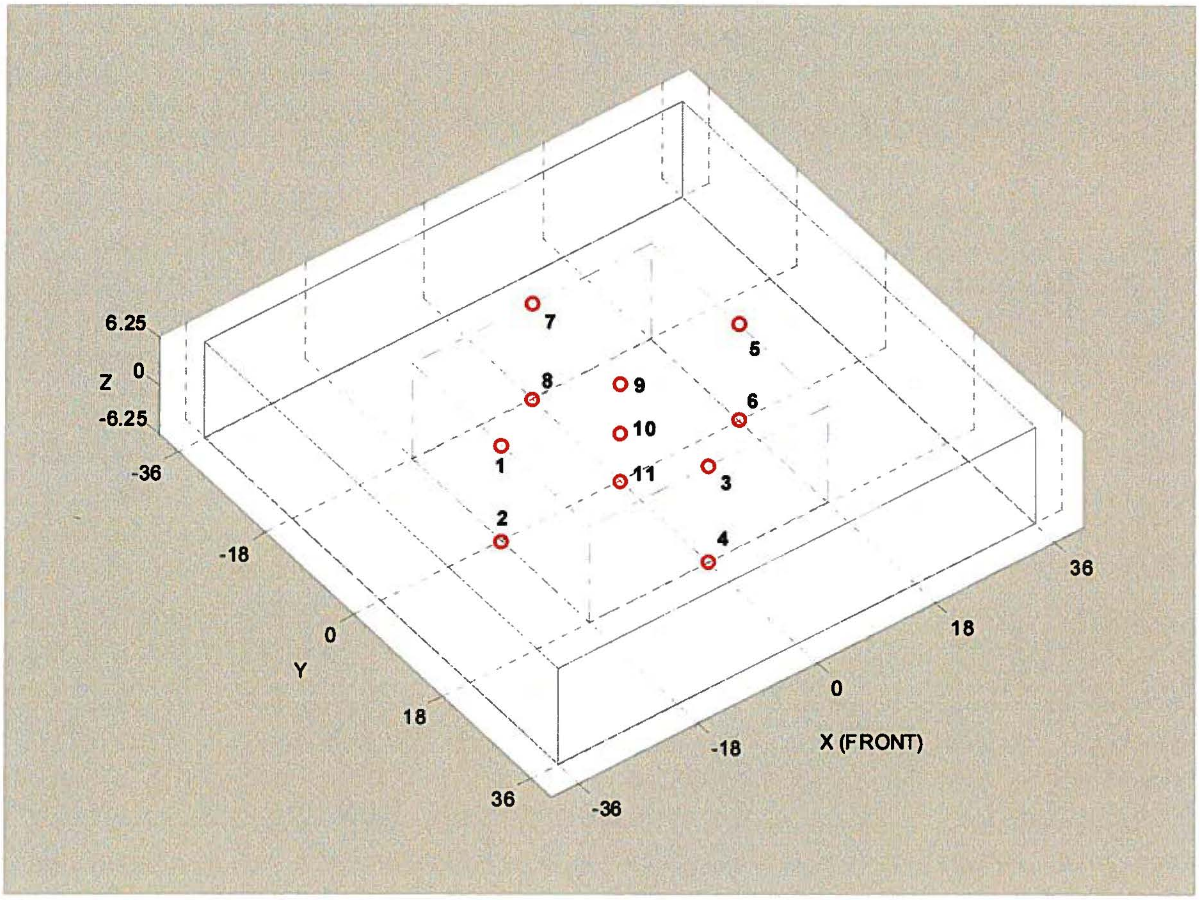

Fig. 6. NSC calibration points – revised locations (all dimensions are in inches).

Table 2b. NSC calibration points (revised locations)

Pt. number	x (inches)	y (inches)	z (inches)	Volume fraction[1]
1	-18	0	6.25	0.116698
2	-18	0	-6.25	0.116698
3	0	18	6.25	0.116698
4	0	18	-6.25	0.116698
5	18	0	6.25	0.116698
6	18	0	-6.25	0.116698
7	0	-18	6.25	0.116698
8	0	-18	-6.25	0.116698
9	0	0	6.25	0.015500
10	0	0	0	0.035419
11	0	0	-6.25	0.015500

[1] The volume fraction calculation is provided in Appendix B.

The average calibration efficiency and uncertainty of the NSC for compressor volutes is obtained by running multiple MCNP simulations over the expected range of holdup in the compressor volutes. Figure 6 depicts the source locations for the compressor volute. Table 3 presents the detailed inputs for the planned range of simulation runs. In addition, the calibration source definition is provided in Table 3. For each of the 11 calibration source locations, an MCNP simulation will be required. The total number of MCNP simulations required is 27; 8 different source strengths at 20% U-235 enrichment, 8 different source strengths at 3% U-235 enrichment, and 11 different calibration source locations with the calibration source (WRM3).

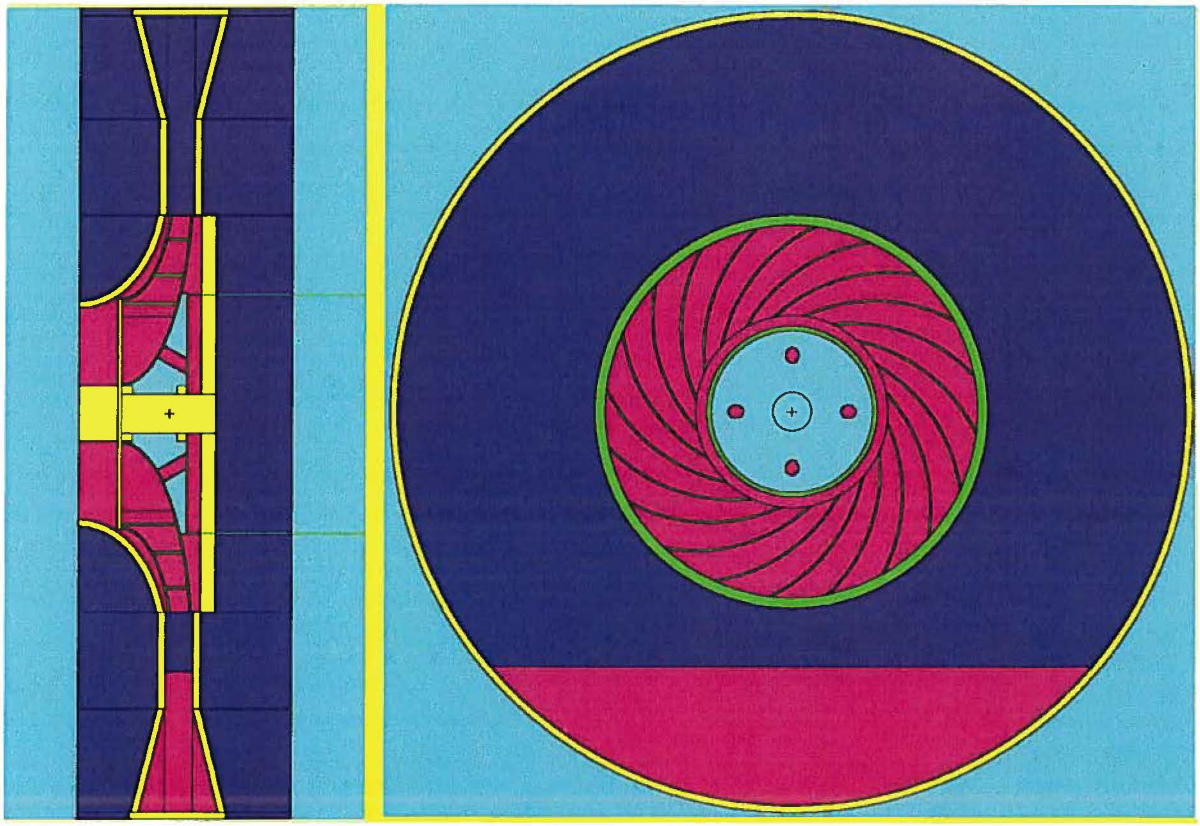

Fig. 7. Source location for Monte Carlo simulation of compressors.
(not to scale)

Table 3. Description of planned MCNP simulations

Item	^{235}U Enrichment (%)	Mass (g)			
		^{235}U	^{234}U	^{238}U	U
Volute[1]	**20**	25	0.16	99.84	125
		50	0.33	199.67	250
		100	0.65	399.35	500
		200	1.30	798.70	1000
		400	2.61	1597.39	2000
		600	3.91	2396.09	3000
		800	5.22	3194.78	4000
		1000	6.52	3993.48	5000
Volute[1]	**3**	25	0.16	808.17	833.33
		50	0.32	1616.35	1666.67
		100	0.64	3232.70	3333.33
		200	1.28	6465.39	6666.67
		400	2.55	12930.78	13333.33
		600	3.83	19396.17	20000.00
		800	5.11	25861.56	26666.67
		1000	6.39	32326.95	33333.33
WRM3[2]	45.52	105.60	0.71	125.59	231.90

[1] For simulations of the volute, the source should be represented as five point sources distributed throughout the seal (one in the center and four at one-half the radius at the 3, 6, 9, and 12 o'clock positions).

[2] Eleven simulations will be required with the WRM3 source at each of the calibration source locations (see Table 2b).

The calibration test requirements are outlined in Table 4.

Table 4. Calibration test requirements

Performance test	Performance method
Calibration measurements	Confirm the operational readiness of the NSC. Perform the following measurements: 1. Perform a Measurement Control Measurement 2. Perform a background measurement for the empty NSC. 3. Place the WRM3 in the empty NSC at one of the 11 calibration measurement positions, as defined in Table 2b. 4. Repeat Step 3 for the remaining 10 positions, as defined in Table 2b. 5. Perform a Measurement Control Measurement Note: If these measurements are performed over multiple days, a beginning and ending control measurement should be performed each day. The minimum control measurement frequency is one measurement per 24 hours (+/- 6 hours). Background measurements must be performed on the same day as the item measurement. 6. Perform the MCNP simulations at each of the 11 calibration points defined in Table 2b with the WRM3 calibration source. 7. Perform the MCNP simulations as defined in Table 3 for the compressor volute.

	8. Perform an additional set of MCNP simulations with a point source in a compressor volute. The number of point locations should be sufficiently large to evaluate the source location uncertainty of the NSC. 9. Compute the NSC efficiencies, according to equations 4-1, through 4-6.

7.3 CALIBRATION VERIFICATION AND PERFORMANCE TEST MEASUREMENTS

Verification of the initial calibration, meeting the requirements of Table 4, is performed by measuring well-characterized uranium standards, in this case a UO_2F_2 standard. The standard is measured using routine measurement protocols and the reported values are compared to the known standard value to derive the system accuracy (%R). The measured standard is placed inside a mock volute, which was specifically designed to mimic the physical configuration of the compressor volutes to be measured in the NSC. The mock volutes were engineered with cylindrical penetrations for placement of WRM sources during calibration verification activities. This configuration provides information to identify the uncertainty in the measurement induced by source position, develops the matrix absorption and moderation effects, and serves to validate the MCNP model for source location, matrix absorption, and matrix moderation effects.

The NSC is being calibrated for the specific purpose of quantifying U-235 holdup in compressor volutes; thus, an adequate calibration confirmation measurement is to place a hydrated WRM source in the center of the mock volute and confirm that the quantitative result is within an expected tolerance of the known value. Table 5 includes a variety of measurements to not only verify the calibration, but also to evaluate the performance of the NSC under other conditions.

Table 5. Calibration verification and performance test requirements

Performance test	Performance method
Verify that the instrument will return an appropriately accurate U-235 value for the well-characterized UO_2F_2 standard.	Confirm the operational readiness of the NSC. Perform the following measurements: 1. Perform a Measurement Control Measurement 2. Perform a background measurement for the empty NSC. 3. Place the WRM3 in the center of the empty NSC and measure the source. 4. Perform a background measurement for the empty NSC. 5. Place the WRM7 in the center of the empty NSC and measure the source. 6. Perform a background measurement with the mock volute in the NSC. 7. Place the WRM3 in the center of the mock volute and measure the source. 8. Repeat Steps 6 and 7 two more times. 9. Perform a background measurement with the mock volute in the NSC. 10. Place the WRM3 in the mock volute at a radial distance from the center of ¼ of the radius of the mock volute and measure the source. 11. Repeat Steps 9 and 10 two more times. 12. Perform a background measurement with the mock volute in the NSC. 13. Place the WRM3 in the mock volute at a radial distance from the center of ½ of the radius of the mock volute and measure the source. 14. Repeat Steps 12 and 13 two more times. 15. Perform a background measurement with the mock volute in the NSC. 16. Place the WRM3 in the mock volute at a radial distance from the center of ¾ of the radius of the mock volute and measure the source. 17. Repeat Steps 15 and 16 two more times. 18. Perform a background measurement with the mock volute in the NSC. 19. Place the WRM7 in the center of the mock volute and measure the source. 20. Repeat Steps 18 and 19 two more times. 21. Perform a background measurement with the mock volute in the NSC. 22. Place the WRM7 in the mock volute at a radial distance from the center of ¼ of the radius of the mock volute and measure the source. 23. Repeat Steps 21 and 22 two more times. 24. Perform a background measurement with the mock volute in the NSC. 25. Place the WRM7 in the mock volute at a radial distance from the center of ½ of the radius of the mock volute and measure the source. 26. Repeat Steps 24 and 25 two more times. 27. Perform a background measurement with the mock volute in the NSC. 28. Place the WRM7 in the mock volute at a radial distance from the center of ¾ of the radius of the mock volute and measure the source. 29. Repeat Steps 27 and 28 two more times. 30. Perform a Measurement Control Measurement Note: If these measurements are performed over multiple days, a beginning and ending measurement control measurement should be performed each day. Background measurements preceding item measurements must be performed on the same day as the item measurement. Quantitative analysis 31. Compute the quantitative U-235 mass for each verification

	measurement. 32. Calculate the measured bias for each calibration verification measurement and evaluate the total average bias for all calibration verification measurements.
WRM7 is a working reference material that was prepared by MCLinc (MCLinc 2008) and has a known uranium form and known uranium isotope mass values. A source certificate was not generated for WRM7; therefore it is not used as a calibration source, it is only used to perform verification measurements.	

7.4 CALIBRATION CONFIRMATION

A final confirmation test should be performed by taking advantage of the known optimal configuration of the UNCS and the pedigree of its quantitative results. A compressor volute with a quantitative U-235 mass >100g U-235 (quantified as the UNCS nominal value), should be removed from the compressor base and arranged on a pallet according to the process defined for the preparation of compressor volutes from the K-25 Building for shipment to Nevada National Security Site. The compressor volute loaded onto the pallet should be measured in the UNCS and the NSC. Calibration confirmation requires that the two quantitative results agree within the uncertainties of the instruments and quantitative methodologies.

8. QUALITY RECORDS

All measurements performed under this PTVP shall be compiled in a PTVR. Both the PTVP and PTVR shall be maintained in accordance with PROC-OS-1001, *Records Management Including Document Control.*

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9. REFERENCES

ASTM C1592/C1592M-09. *Standard Guide for Making Quality Nondestructive Assay Measurements,* 2009, American Society for Testing and Materials, West Conshohocken, PA.

BJC/OR-1856. *NDA Program Description, Oak Ridge Environmental Management, Accelerated Cleanup Project*, 2010, Bechtel Jacobs Company LLC, Oak Ridge, TN.

BJC/OR-2966. *Data Quality Objectives for Quantitative Nondestructive Assay of K-25/K-27 Uranium*, 2008, Bechtel Jacobs Company LLC, Oak Ridge, TN.

MCLinc 2008, Preparation and Testing Report for Technical Support to NDA Source Specification, Prepared by Materials and Chemistry Laboratory, MCLinc Project # BJC001990, Final Report, 5/14/2008.

NDA-13-0622, K-1066 F Pad: 10/25/2013: Neutron Slab Counter: Performance Test and Validation Report, UCOR NDA.

PROC-ES-5004. *Oak Ridge Sample Management Office Nondestructive Assay Performance Evaluation Plan*, latest revision, URS | CH2M Oak Ridge LLC, Oak Ridge, TN.

——PROC-OS-1001. *Records Management Including Document Control*, latest revision.

UCOR-4527, *Neutron Slab Counter Performance Test and Validation Evaluation.*

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APPENDIX A.
WRM3 SOURCE CERTIFICATE

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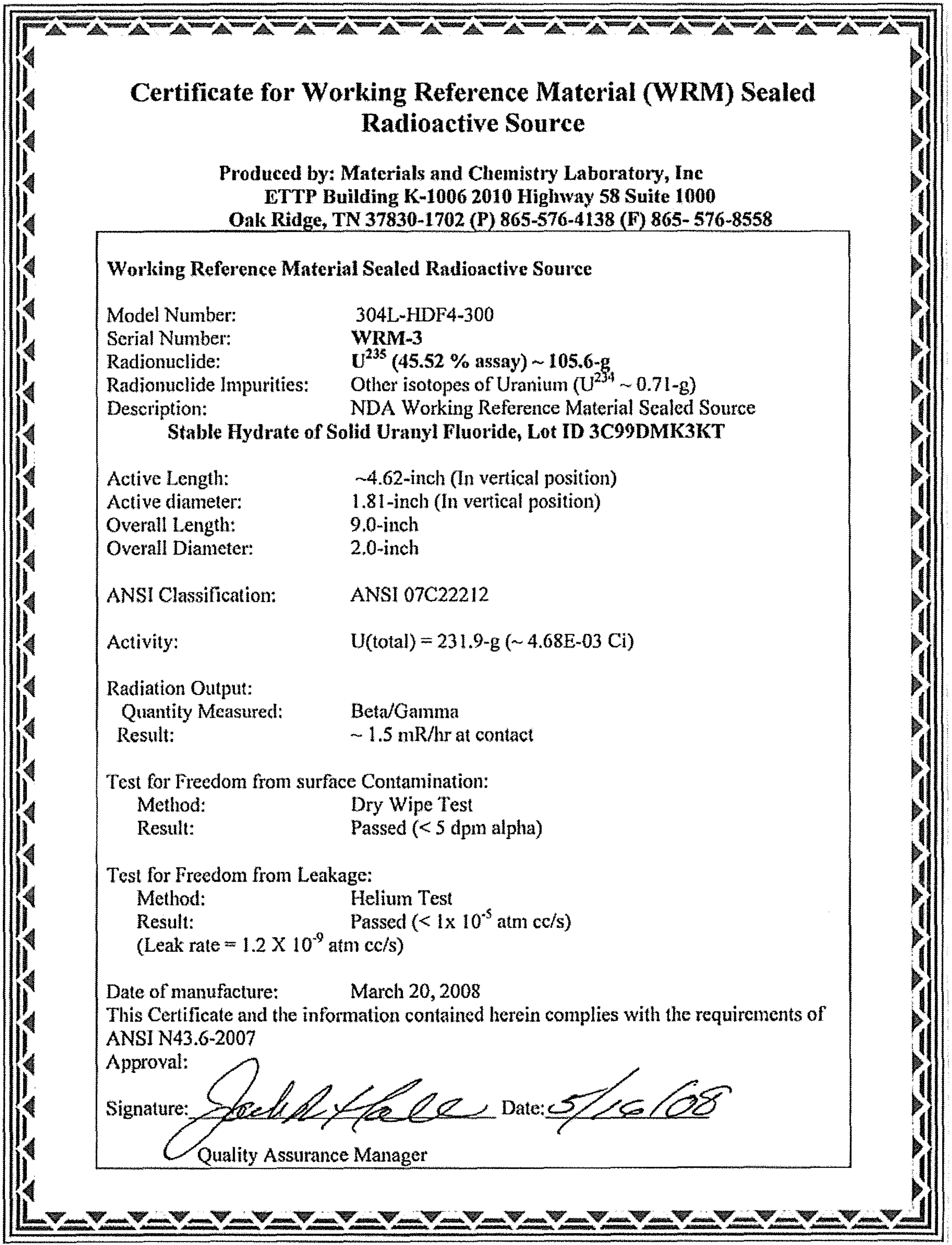

Certificate for Working Reference Material (WRM) Sealed Radioactive Source

Produced by: Materials and Chemistry Laboratory, Inc
ETTP Building K-1006 2010 Highway 58 Suite 1000
Oak Ridge, TN 37830-1702 (P) 865-576-4138 (F) 865- 576-8558

Working Reference Material Sealed Radioactive Source

Model Number:	304L-HDF4-300
Serial Number:	**WRM-3**
Radionuclide:	**U^{235} (45.52 % assay) ~ 105.6-g**
Radionuclide Impurities:	Other isotopes of Uranium (U^{234} ~ 0.71-g)
Description:	NDA Working Reference Material Sealed Source

Stable Hydrate of Solid Uranyl Fluoride, Lot ID 3C99DMK3KT

Active Length:	~4.62-inch (In vertical position)
Active diameter:	1.81-inch (In vertical position)
Overall Length:	9.0-inch
Overall Diameter:	2.0-inch

ANSI Classification: ANSI 07C22212

Activity: U(total) = 231.9-g (~ 4.68E-03 Ci)

Radiation Output:
Quantity Measured: Beta/Gamma
Result: ~ 1.5 mR/hr at contact

Test for Freedom from surface Contamination:
Method: Dry Wipe Test
Result: Passed (< 5 dpm alpha)

Test for Freedom from Leakage:
Method: Helium Test
Result: Passed (< 1x 10^{-5} atm cc/s)
(Leak rate = 1.2 X 10^{-9} atm cc/s)

Date of manufacture: March 20, 2008

This Certificate and the information contained herein complies with the requirements of ANSI N43.6-2007

Approval:

Signature: Date: 5/16/08

Quality Assurance Manager

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APPENDIX B.
NSC VOLUME FRACTION CALCULATIONS

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Volume Fraction Calculation Algorithm

In order to determine the overall volume weighted average efficiency of the neutron slab counter calibration space, the efficiency determinations at each of the calibration source locations need to be weighted by the volume of the calibration space associated with each calibration source location. The basic process is outlined below:

1. Define the geometry of the calibration space via a set of minimum and maximum values for dimensions: x,y,z.
2. Specify a cube size for the analysis.
3. Obtain the coordinates of the geometric centers of all of the cubes that make up the calibration space.
4. Define the calibration source locations (x,y,z) within the calibration space.
5. Compute the distance between each cube center and all of the calibration source locations across the calibration space.
6. For each cube, determine the calibration source location that presents the minimum distance to the geometric center of the cube and assign the given cube to the corresponding source location.
7. If more than one calibration source location has the same minimum distance, then assign a fraction of 1/k to each of the k calibration space locations that share the minimum distance.
8. Repeat for all cubes in the calibration space.
9. Count the number of cubes assigned to each source location and divide by the total number of cubes to determine the volume fraction associated with each calibration source location.

Algorithm Details:

```
% INPUT DEFINITION
% Define Increment (CUBE SIZE)
dd=0.1; % 0.1 inch cube size
% Define object geometry
xmin=-36;
xmax=36;
ymin=-36;
ymax=36;
zmin=-6.25;
zmax=6.25;

% Specify Calibration Source Locations
%% FOR AN ALTERNATE SET OF CALIBRATION POINT LOCATIONS, THe INPUT "CP" SHOULD
%% BE UPDATED, ALL OTHER SETTINGS REMAIN UNCHANGED
% Column 1: Location Number
% Column 2: X-coordinate
% Column 3: Y-Coordinate
% Column 4: Z-Coordinate

CP=[1   -36 0   6.25
2   -36 0   -6.25
3   0   36  6.25
4   0   36  -6.25
5   36  0   6.25
6   36  0   -6.25
```

```
7   0   -36 6.25
8   0   -36 -6.25
9   0   0   6.25
10  0   0   0
11  0   0   -6.25];
```

% Run algorithm to obtain the volume fraction associated with each calibration source %location.

[block_fraction]=vol_est_final (dd,CP,xmin,xmax,ymin,ymax,zmin,zmax);

% OUTPUTS

%block_fraction, a vector of volume fractions for each calibration source location

FUNCTION DEFINITION

```
function [block_fraction]=vol_est_final(dd,CP,xmin,xmax,ymin,ymax,zmin,zmax);

% Create vectors of block centers for all dimensions
x=[(xmin+(dd/2)):dd:xmax]
nx=length(x);

y=[(ymin+(dd/2)):dd:ymax]
ny=length(y);

z=[(zmin+(dd/2)):dd:zmax]
%z=0;
nz=length(z);

%Number of blocks
NB=nx*ny*nz;

%Extract Calibration Points from Cal Point MAtrix

XCP=CP(:,2);
YCP=CP(:,3);
ZCP=CP(:,4);
NUMCP=size(CP,1);

k=0;kk=0;
NCP=zeros(NB,2);
for ix=1:nx;
    fprintf(['x iteration  ', num2str(ix) '\n\n'])
for iy=1:ny;

for iz=1:nz;
    bl_coord=[x(ix) y(iy) z(iz)];
    % Compute distances
    for j=1:NUMCP;
        cp_coord=[XCP(j) YCP(j) ZCP(j)];
        D(j)= sqrt(sum((bl_coord-cp_coord).^2));

    end;
```

```
    % Find minimum distance and assign weight to appropriate Calibration
Source Location
    minD=min(D);
    NCPt=find(D==minD);
    if length(NCPt)==1;
        k=k+1;
        NCP(k,:)=[NCPt 1];
    else
        for q=1:length(NCPt);
            k=k+1;
            NCP(k,:)=[NCPt(q)   (1/length(NCPt)) ];
        end
    end

end;

end
end

% Tally and compute fraction associated with each calibration source
% location
for m=1:NUMCP;
    cpind=find(NCP(:,1)==m);
    num_blocks(m)=sum(NCP(cpind,2));
    block_fraction(m)=num_blocks(m)/NB;
end;
```

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