U.S. Department of Energy Office of Legacy Management Calibration Facilities – 12103

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ABSTRACT

This paper describes radiometric calibration facilities located in Grand Junction, Colorado, and at three secondary calibration sites. These facilities are available to the public for the calibration of radiometric field instrumentation for in-situ measurements of radium (uranium), thorium, and potassium. Both borehole and handheld instruments may be calibrated at the facilities. Aircraft or vehicle mounted systems for large area surveys may be calibrated at the Grand Junction Regional Airport facility. These calibration models are recognized internationally as stable, well-characterized radiation sources for calibration. Calibration models built in other countries are referenced to the DOE models, which are also widely used as a standard for calibration within the U.S. Calibration models are used to calibrate radiation detectors used in uranium exploration, remediation, and homeland security.

INTRODUCTION

The U.S. Department of Energy (DOE) and its predecessor agencies constructed all of the calibration facilities described herein [1] for radiometric field instruments used for uranium exploration. In the 1980s, as uranium exploration slowed, the prevalent use of the facilities were for (1) the development of methods used to determine the extent of radioactive contamination and (2) calibrations related to remedial actions. The fact that facilities designed for uranium exploration could be used for remediation of radium contamination is made possible by the commonality of the radiometric measurement technique for both uranium and radium. Numerous sites contaminated with uranium mill tailings and byproduct material from uranium processing were characterized, cleaned up, and verified using equipment calibrated at these facilities. Concentration units were expressed in units of picocuries/gram of radium when the facilities were mainly used for radium remediation. Due to renewed recent interest in uranium mining, grade assignment values expressed in units of percent by weight equivalent uranium oxide (eU_3O_8) are again available [2]. The use of equipment calibrated at these sites allows the determination of numerical data with traceable quantitative values.

HISTORY

In 1943 the Grand Junction, Colorado, property was purchased to support uranium procurement for the Manhattan Project. In the 1950s the Grand Junction office became the U.S. Atomic Energy Commission center for uranium exploration and procurement, where pioneering work in using gamma logs to determine in-situ uranium ore grades was conducted, including construction of the first calibration models and development of grade determination methods [3]. During the 1970s the National Uranium Resource Evaluation program was based in the Grand Junction facility. This program, designed to determine the extent of uranium resources in the United States, included numerous geophysical well logging research and development projects.[1] Calibration models were constructed to support the research and evaluation and were made available for general industry use. Several remote calibration facilities were constructed during the uranium boom of the 1970s in uranium production regions. Facilities in New Mexico, Texas, and Wyoming were built to allow more frequent and cheaper access to calibration facilities (Figure 1). A fourth set of calibration models was installed at the DOE's Hanford, Washington, Site but is used for on-site federally owned equipment only.

Figure 1. Locations of DOE calibration facilities.

In 1988 Grand Junction was designated the DOE "program office for disposal site long-term surveillance and maintenance." The DOE Office of Legacy Management (LM) retained the calibration models facilities as a legacy program in Grand Junction.

CALIBRATION MODEL CONSTRUCTION

Calibration models are constructed of concrete blended with known amounts of naturally occurring radioactive material [4]. Various blends of uranium ore, monazite sand (thorium), and orthoclase feldspar (potassium) are mixed to create models with the characteristics desired. Both radiometric and chemical assays were used to verify the final properties after the mixtures are placed. Spectrometers used to determine radiometric grades are calibrated using certified counting standards from the DOE New Brunswick Laboratory for traceability. Calibration models built in other countries are referenced to the DOE models. Radioactive materials licenses are not required, as all materials used in the construction of the models are naturally occurring radioactive material.

[1] Well logging refers to the process of collecting information about the rock units intercepted by a borehole. Logging entails suspending an instrument package in a borehole by a cable and recording the instrument readings as the instrument package (referred to as a logging tool, sonde, or probe) is moved up and down the borehole.

A typical borehole model contains a barren zone of concrete below an enriched zone of concrete and ore uniformly blended together. A second barren zone is poured above the enriched zone (Figure 2). This enables detractor response across sharp boundaries to be modeled [1].

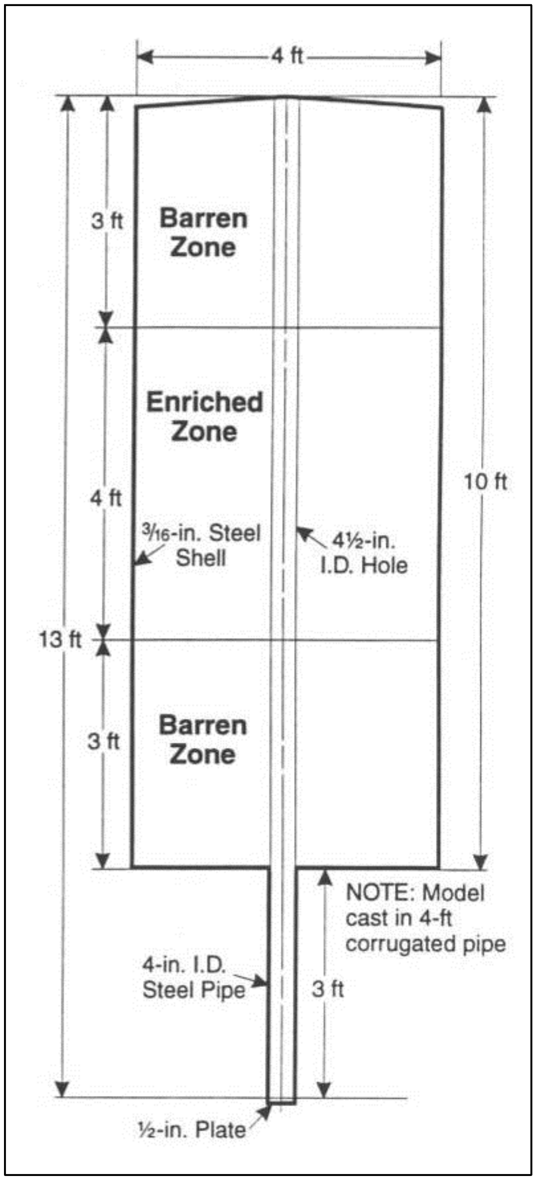

Figure 2. Cross section of a typical borehole calibration model.

The facilities consist of pads and borehole models with the following characteristics:

- Cylinders approximately 1.2 m (4 feet) in diameter by 0.6 m (2 feet) high, referred to as "scintillometer pads," "spectrometer pads," or simply "pads." Pads are located at the three secondary sites (New Mexico, Texas, and Wyoming).
- Large-area slabs, 9.1 m by 12.2 m (30 feet by 40 feet) in area and 0.46 m (1.5 feet) thick, are referred to as "airport pads" because they are located at the Grand Junction Regional Airport in Grand Junction, Colorado.

- Cylinders and other equivalent configurations, approximately 1.2 m (4 feet) in diameter and up to 9.1 m (30 feet) deep and containing boreholes along their axes, are referred to as "borehole models" or simply "models."

CALIBRATION MODEL APPLICATIONS

The DOE calibration models are used to calibrate radiation detection instruments such as well-logging equipment and handheld meters. Common uses are for equipment used in uranium exploration, regulatory activities, remediation activities, and radiation-detection for homeland security. As detection systems can drift or degrade over time or with handling, periodic calibration is required to maintain the reliability of the data.

For typical uranium exploration and production logging, a natural gamma detector is calibrated against the known uranium concentrations in the calibration models. These are referred to as **gross gamma** systems because all gamma rays are counted, regardless of the source. A user collects gamma count rates on a low concentration model and calculates proportionality constant to convert count rates to apparent grades of %U_3O_8. The proportionality constant is referred to as a K factor. The N-3 borehole model, constructed in Grand Junction in 1958, is the international standard for determining the K-factor of downhole logging equipment [4, 5].

In higher grade environments, some of the gamma counts are lost due to coincidence and instrument effects. Gamma ray detection systems have a tiny amount of time during which the actual scintillation must die down and allow the system to reset for the next gamma ray. In systems that send electrical pulses on the cable to surface instruments, pulses that occur almost simultaneously will be counted as a single pulse. Therefore, in a zone of high ore grade, a system can be functionally dead to incoming gamma rays, causing the indicated count rate to be lower than the actual rate. This can result in underestimating the amount of ore in a given zone. Borehole models with varying levels of ore grades allow count rates to be determined for dead time corrections. Use of a smaller volume, or shielded detector, in a zone that has high activity will yield a more accurate result.

These same principles apply to detector calibration methods for environmental remediation in which count rates are converted to equivalent Ra-226 in picocuries per gram (pCi/g). [2] However, for this application the user is mostly interested in radionuclide concentrations at the cleanup levels, at which there is no significant loss of the gamma signal and a dead time correction is not required.

Basic calibration models were designed for the uranium logging industry with a 11.4 cm (4.5 inch) borehole down the axis of the model. At the secondary facilities in New Mexico, Texas, and Wyoming, 11.4 cm is the only hole size available. At the Grand Junction facility there are several models of with various hole sizes that can be used to generate borehole size and water factor correction curves [1]. Steel casing sections of standard thicknesses are also available at the Grand Junction facility to suspend over the sonde to create casing factor correction curves. Correction factors are important due to the attenuating effect of the water (or drilling mud) and steel casings on gamma rays of different energy levels. Washouts and voids in boreholes are detected using a caliper log that is processed with correction curves to standardize the gamma ray count rates. Downhole data is also processed to correct the count

[2] The apparent grades were assigned to the DOE calibration models for use in North America. In this paper, specific activities may also be converted to becquerels per gram, or Bq/g. One Bq/g is equal to 27 pCi/g.

rates by applying K-factor and dead time corrections so a log of actual uranium content is realized.

Spectral gamma logging systems were developed that could discriminate between gamma emissions from uranium, thorium, and potassium, the three naturally occurring radioactive decay series [6]. This allowed the thorium and potassium contributions to be "stripped" from the gamma emissions from uranium daughters, which is helpful in determining the actual ore content. The systems were developed to count gamma photons of specific energy levels for potassium, uranium (Bi-214), and thorium.

Calibration models can be used to calibrate **high-resolution passive spectral gamma** logging systems, and to determine spectral gamma-ray water-factors [1,6]. The gross gamma calibration models can also be used to check the calibration of these systems. During the National Uranium Resource Evaluation program, much effort went into design and evaluation of spectral gamma ray systems that could identify the specific energy level of the gamma ray. Because decay of uranium produces only few low-energy gamma rays, it is usually detected by counting daughter products such as Bi-214. Bismuth is chemically different than uranium, and it is possible for the uranium to have been removed from the area due to geochemical processes and groundwater flow, leaving behind a zone rich with gamma-emitting daughters with a high gamma signature (this effect is known as disequilibrium). Detection systems using nitrogen-cooled germanium detectors were developed to count gamma emissions from uranium or immediate daughters directly. Several of these systems have been in use by DOE since the mid-1990s at the Hanford, Washington, nuclear facility to determine the depth and types of contamination resulting from Cold War production processes. Recently, high-resolution detectors have been developed that operate at ambient temperatures. The industry used the DOE models to calibrate both types of high-resolution gamma systems.

Standards are also available for the calibration of **fission neutron** logging devices, which allow direct in-situ measurement of uranium in the formation (i.e., there are no disequilibrium effects that might occur if gamma measurements are used and uranium is geochemically separated from radium and other gamma emitters) [7]. As stated above, spectral systems were developed to identify gamma rays based on their specific energy level. An alternate method of uranium ore grade determination uses a fast neutron source inside a borehole. The neutrons induce fission in any uranium present in the formation, which results in emission of additional neutrons. As neutrons are captured by formation materials, capture gamma rays are emitted. Formation materials also are activated, and they emit gamma rays as they return to their rest state. The source is then removed or shut off, and detectors are used to evaluate the prompt or delayed fission neutrons or capture gamma rays (Figure 3).

Several **porosity** models are available [1]. These are constructed of ottawa sand, scioto sandstone, and bluestone sandstone, to allow a range of porosity measurements. A pure water background tank is situated above the Ottowa Sand model to provide another porosity point.

The large area pads constructed at the Grand Junction airport were developed mainly for calibration of aircraft used for uranium exploration. More recent uses have been for aircraft used for homeland security overflights and for remedial investigations involving former uranium mining and milling sites. The pads also offer an infinite area radiation field for calibration of small handheld detector systems used for exploration, environmental remediation, and health physics applications [8]. One recent user calibrated a system designed to be carried by a mule for a remedial investigation in an area with limited vehicle accessibility.

Figure 3. Industry user at Grand Junction fission neutron calibration models.

Methods for calibrating instruments for use in remediation of uranium mill tailings and similar wastes have been developed. These methods assume the waste materials are in equilibrium, minus the uranium. The predominant gamma-emitting daughters are detected. Cleanup standards are usually expressed in pCi/g of Ra-226. Because the calibration models are constructed of uranium ore in equilibrium, the model grades can also be expressed in pCi/g Ra-226 [1, 9].

Users from the Colorado Department of Public Health and Environment calibrate handheld meters used for the ongoing cleanup of properties still contaminated with uranium mill tailings in Grand Junction. Many of these properties were classified as owner refusals during the cleanup, but now have new owners. Any new building permits require a radiation survey or documentation verification, so calibration of the instruments is required. Some mill tailings were left in place in roadways or around utilities. As they are replaced, the tailings are removed and placed in the open tailings repository at the Grand Junction Disposal Site, which was set up in the 1990s under the Uranium Mill Tailings Radiation Control Act.

Much effort is being expended by the federal government to clean up legacy waste on Native American lands that were contaminated during the 1950s, 1960s, and 1970s. Handheld detectors used for some of these sites are routinely calibrated at the Grants, New Mexico, facility. Aircraft used for aerial surveys designed to locate locales with radioactive contamination on Native American lands are calibrated at the large area pads at the Grand Junction airport.

Many resources are expended to evaluate and clean up these sites, and periodic calibration is required for quality control.

TECHNICAL SUPPORT

DOE maintains the documentation developed since the 1950s for the calibration models. Numerous technical documents were also produced during the National Uranium Resource Evaluation program in the 1970s and 1980s. Methods of determining correction curves, K-Factor, dead time, and other factors affecting or interfering with radiation measurements are documented in numerous technical reports. For a period, documents were produced for the Technical Measurements Center program, which developed procedures to measure radium in soil and water as part of the Uranium Mill Tailings Remedial Action project. Copies of many of these documents are available on the LM website at: http://www.lm.doe.gov/land/calibration.htm

Questions about use of or access to the calibration models can be referred to contractor staff at (970) 248-6000.

ADMINISTRATION AND OPERATION

The calibration facilities are available for use free of charge to domestic and foreign investigators at five sites located throughout the U.S. (Figure 1). The primary calibration facilities are located in Grand Junction, Colorado, and secondary facilities are located in Casper, Wyoming; Grants, New Mexico; and George West, Texas. Borehole models at all of the sites are kept locked to prevent unauthorized access. Keys are available to authorized users by contacting the DOE contractor, which is responsible for site security. Foreign nationals must be escorted by a U.S. citizen when using any of the facilities.

Access to the Grand Junction airport pads has changed since the Transportation Security Administration revised rules for access. The pads are located on a leased taxiway and several Grand Junction staff now have required training and airport security clearance to act as escorts for users. Several local contractors also have clearance and may be contracted to act as an escort if a lengthy period of use is required. Prior notice is requested before a user visits the pads to allow scheduling of the required escort.

DOE inspects each site annually to verify conditions and to update any maintenance that may be needed. Users of the sites are strongly encouraged to report their use to DOE and also to report any issues such as broken gates, damaged fences, weeds, etc. A link on the LM website has been set up to allow automatic e-mail notice of use to the Grand Junction office. Routine maintenance, such as vacuum sweeping at the airport pads, weed removal, sign replacement, or painting, is performed as needed. To reduce travel costs, most of these activities are scheduled when an LM crew is in the area to sample groundwater or perform annual inspections.

As the usage graph indicates (Figure 2), calibration facilities activity is tied closely to the price of uranium. After the March 2011 events in Japan, industry use fell off, but there remains a steady flow of users. A new uranium mill planned to be built in Colorado will likely increase user visits as many of the mill's feed mines are located south of Grand Junction. An alternate method of mining uranium is In Situ Recovery (ISR). In this method, solution mining is used to recover the uranium without mine shafts and the attendant surface disturbances. This method is only practicable where groundwater and orebody conditions make it feasible. Many of the recent users of the calibration sites in Texas and Wyoming are calibrating geophysical systems for delineation of ISR well fields.

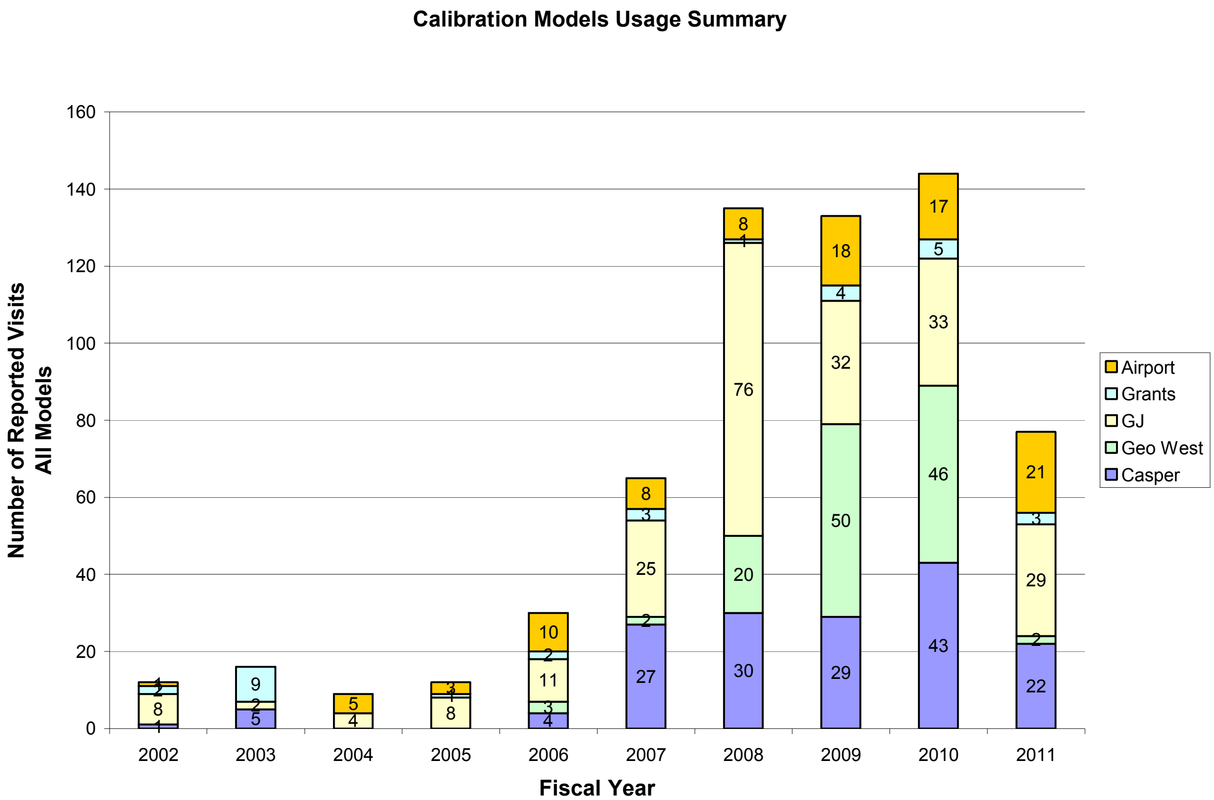

Figure 2. Calibration models usage summary.

The financial worth of uranium mining companies is frequently based on drilling programs to determine the extent and quality of an ore deposit. Numerous geophysical borehole logs retained from prior drilling projects in the 1970s have been correlated with logs from recent drilling activity to verify or fill data gaps in order to determine the location and grade of ore bodies. Calibration of equipment at the DOE facilities, along with the comparison of geophysical data to known, traceable standards, allows data to meet the Canadian National Instrument (NI) 43-101 requirements or other ore reserve determination standards. NI 43-101 is a mineral resource classification scheme used for the public disclosure of information relating to mineral properties. It is recognized as a data quality standard by financial systems such as Canadian stock exchanges. Credible ore reserve estimates are necessary for exploration companies to seek capitalization for development. Federal ownership of the calibration facilities provides impartiality for users.

The last of the calibration models were constructed in the 1980s. The models are not costly to maintain and allow DOE to provide assistance to the front end of the uranium fuel cycle. Alternate uses based on the calibration of equipment used to clean up sites contaminated by radioactive waste have become as important as the original planned use for uranium exploration. Constructing replacement devices today would be very expensive and face regulatory hurdles.

REFERENCES

The following references were inserted into this paper as active hyperliinks. They are all posted at http://www.lm.doe.gov/land/calibration.htm.

1. Field Calibration Facilities for Environmental Measurement of Radium, Thorium, and Potassium (June 1994)
2. Grade Assignments for Models Used for Calibration of Gross-Count Gamma-Ray Logging Systems (December 1983)
3. Gamma-Ray Logging Workshop (February 1981)
4. Data Compendium for the Logging Test Pits at the ERDA Grand Junction Compound (December 1975)
5. Borehole Logging Methods for Exploration and Evaluation of Uranium Deposits (1967)
6. Parameter Assignments for Spectral Gamma-Ray Borehole Calibration Models (April 1984)
7. Logging Calibration Models for Fission Neutron Sondes (September 1981)
8. Exposure-Rate Calibration Using Large-Area Calibration Pads (September 1988)
9. Abbreviated Total-Count Logging Procedures for Use in Remedial Action (December 1982)