Applied Radiation and Isotopes 122 (2017) 47–56

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

A Monte Carlo modeling alternative for the API Gamma Ray Calibration Facility

J.E. Galford

Halliburton Energy Services, 3000 North Sam Houston Parkway East, Houston, TX 77032-3219, USA

ARTICLE INFO

Keywords:
API unit
API Calibration Facility
Monte Carlo
MCNP
Natural radioactivity

ABSTRACT

The gamma ray pit at the API Calibration Facility, located on the University of Houston campus, defines the API unit for natural gamma ray logs used throughout the petroleum logging industry. Future use of the facility is uncertain. An alternative method is proposed to preserve the gamma ray API unit definition as an industry standard by using Monte Carlo modeling to obtain accurate counting rate-to-API unit conversion factors for gross-counting and spectral gamma ray tool designs.

1. Introduction

The American Petroleum Institute (API) Calibration Facility for Nuclear Logs, located on the University of Houston campus, opened for operation on June 24, 1959 (Belknap et al., 1959). It includes a pit containing stacked slabs of quarried limestone and an adjacent pit comprised of three 2.44 m (8 ft) layers of cement having relatively low- and high-radioactivity levels. The facility was intended to provide calibration standards to unify log responses among service companies for neutron porosity and natural gamma ray logs. The pits were used to establish API units for both types of logs. For gamma ray logs, the API unit was defined as 1/200th of the difference between responses from the high-activity and the lowermost low-activity zones. The API unit definition for neutron porosity logs was not retained after the 1960s, and all modern neutron porosity logs are now calibrated in porosity units. The API unit remains the industry standard for gamma ray logs, and a newly defined unit is unlikely to gain favor after almost 60 years of usage.

When the API gamma ray pit was designed and built, logging-while-drilling (LWD) instruments had not been conceptualized, and only modest-sized wireline tools were required to operate in the known logging environments at that time. Consequently, the pit was designed with a borehole that accommodated contemporary tools with little allowance for the development of larger wireline tools or most LWD tools. The 12.446 cm (4.9 in.) inside diameter of the casing barely accommodates tools recently developed for deepwater Gulf of Mexico exploration, and future wireline tools for high-pressure logging environments might exceed the capabilities of the API facility.

The facility is rapidly deteriorating because of its age. During the last decade, corrosion has completely destroyed the steel casing that protruded at one time from the pit at the surface. While the condition of the steel casing below the surface is unknown, corrosive processes are probably also at work within the pit. Because the presence of the steel casing is an integral part of the API unit definition, any subsurface deterioration of the casing that might be occurring is gradually altering the definition of the API unit, and at some point, the pit will become unusable.

The university expressed its desire to reclaim the API facility location at a meeting of the Society of Petrophysicists and Well Log Analysts Nuclear Special Interest Group held in October 2014. The land occupied by the facility is valuable to the university, which wants to repurpose the site for construction of new laboratories and teaching facilities.

A Nuclear Special Interest Group committee of service company representatives was formed to investigate the possibility of relocating the neutron and gamma ray pits. The committee concluded it was possible to move the neutron pit to another location or store its quarried blocks for future dispensation. The cost to relocate the gamma ray pit was researched, and the committee concluded sufficient funding could not be secured to move the pit because of the current business climate. The committee also recognized that successful relocation of the pit without damage was improbable given the size, construction, and unknown internal condition of the structure.

The gamma ray pit will become unusable or inaccessible at some point in the future, and a suitable replacement is needed. The API Natural Gamma Ray Spectroscopy Logging Calibration Facility, also located on the University of Houston campus, is a possible alternative to the API gamma ray pit. However, the pits at the spectroscopy calibration facility have not been characterized and sanctioned as industry calibration standards for total gamma ray logs. The work presented

---

E-mail address: Jim.Galford@Halliburton.com.

http://dx.doi.org/10.1016/j.apradiso.2017.01.004
Received 1 August 2016; Received in revised form 19 December 2016; Accepted 11 January 2017

here was motivated by the need to preserve the API unit for the future.

A Monte Carlo modeling scheme to simulate natural gamma ray logging instrument responses at the API facility is described that can be used to verify the calibration of existing tools or calibrate new instruments. Results for several wireline scintillation instruments manufactured by one service provider show the proposed method is a viable alternative to the empirical API facility calibration procedure. The technique can be applied to tools produced by other manufacturers by combining tool-specific geometry, materials, and electronics details with the API facility geometry, material descriptions, gamma ray source definitions, and the tally specifications included herein.

2. Model development

Monte Carlo modeling of natural gamma ray logging tools has been steadily practiced for the last 30–35 years (Wahl, 1983; Flanagan et al., 1991). In the past, the main use of Monte Carlo modeling for these tools focused on simulating the influences of borehole environmental effects on individual responses to thorium, uranium, and potassium. Absolute response sensitivities to thorium, uranium, and potassium signals for oilfield natural gamma ray spectroscopy tools have typically been derived from measurements performed in constructed formations containing known elemental concentrations. The process outlined herein can also be used to calculate absolute sensitivity factors for oilfield spectroscopy tools. Hendricks et al. (2002) used Monte Carlo modeling to derive calibrated thorium, uranium, and potassium spectral shapes for radiation monitoring applications. However, the primary goal of this effort was directed toward calculating total counting rate responses for sources comprised of thorium, uranium, and potassium mixtures that can be used to obtain counting rate-to-API unit conversion factors for several wireline tool designs. This was achieved by using Monte Carlo simulations to emulate tool responses for the low- and high-activity zones of the API Calibration Facility.

The Monte Carlo N-Particle (MCNP) code developed by the Los Alamos National Laboratory was used to perform the simulations for this study. MCNP is a general-purpose, continuous-energy, generalized-geometry, time-dependent, coupled-particle Monte Carlo transport code that can be used in several modes (Briesmeister, 2000). For this study, a photon-only transport mode was selected.

The MCNP input files, or models, contain information about geometry and descriptions of materials, location, and characteristics of the photon sources representing the elemental composition of the low- and high-activity zones in the gamma ray pit. Development of the models used in this study began with a review of available information regarding the construction and composition of the API Calibration Facility gamma ray pit. Belknap et al. (1959) documented several details that were useful when creating the MCNP models, such as information about the geometry of the pit, a list of materials used in the high-activity concrete mixture, and laboratory results from analyses performed on concrete samples collected during construction of the high-activity zone.

2.1. Geometry

Fig. 1 shows the planned design of the gamma ray calibration pit. The design consisted of three 2.44 m (8 ft) thick layers of concrete that are 1.22 m (4 ft) in diameter and surrounded by a corrugated pipe. A steel, 13.97 cm (5.5 in.), 0.253 kg cm^{-1} (17 lbm ft^{-1}) casing passes through the three concrete layers to a depth of 4.57 m (15 ft) below the bottom low-activity zone. The designers considered the radial depth of investigation of gamma ray logs and the longest known detector length at the time of construction when settling upon the thickness and diameter of the concrete layers.

The geometry of the low- and high-activity models used for this investigation consisted of a 13.97 cm (5.5 in.) diameter iron casing with a 0.77216 cm (0.304 in.) wall thickness surrounded by concrete to a radius of 60 cm (23.6 in.) and spanning a height of 120 cm (47.2 in.).

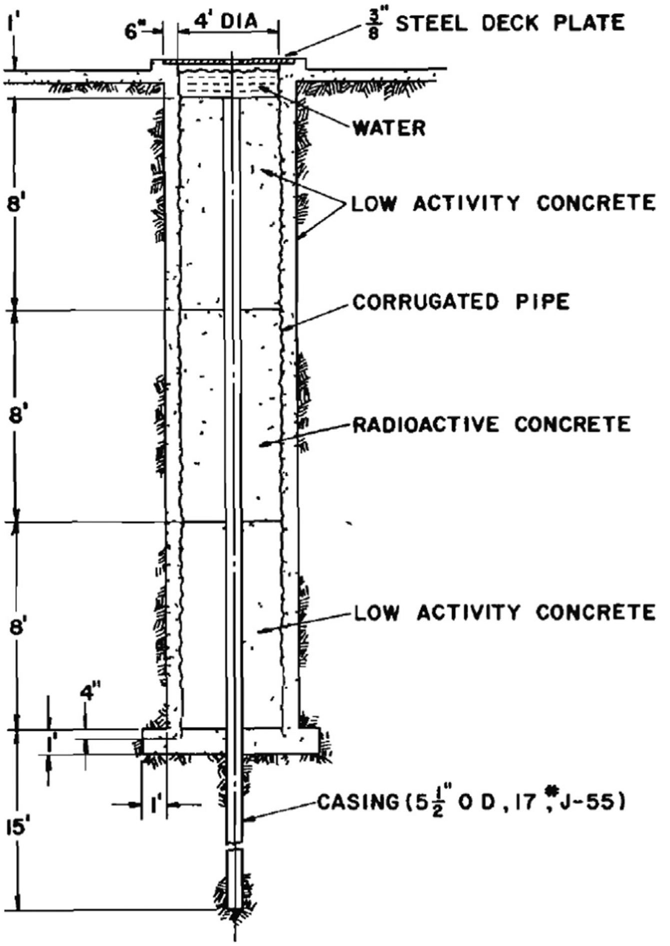

Fig. 1. Gamma ray log calibration pit (after Belknap et al., 1959).

2.2. Concrete compositions

Most of the information required to construct MCNP descriptions of the concrete materials for the high- and low-activity layers can be found in the documentation of the gamma ray pit construction (Belknap et al., 1959). Important details, such as the density of the concrete mixture and calculated mass quantities of the major components of the high-activity concrete mixture, were combined with information from other sources to prepare an atomic-level description of the high-activity concrete mixture, as shown by the calculations in Appendix A.

Unfortunately, Belknap et al. (1959) did not document the low-activity concrete mixture; however, they briefly describe it as a neat Portland cement mixture. Their report makes it clear that a sufficient quantity of dry cement for all three layers was purchased from a single source. Based on these two pieces of information, a separate concrete atomic description was created for the low-activity zone. The density of the low-activity concrete was assumed to be the same as the high-activity mixture, and the mixture was comprised of water and dry cement combined according to estimated weight fraction proportions.

2.3. Elemental concentrations

Reliable thorium, uranium, and potassium concentrations are needed to accurately simulate logging tool responses for each zone of the gamma ray pit.

As reported by Belknap et al. (1959), the API subcommittee assigned concentration values of 24 ppm thorium, 13 ppm uranium,