SRNL-STI-2012-00055
Revision 0

Keywords: Turbulence,
Diffusion, Atmospheric
Modeling

Retention: *Permanent*

A Recommended Pasquill-Gifford Stability Classification Method for Safety Basis Atmospheric Dispersion Modeling at SRS

C. H. Hunter

March 2012

Savannah River National Laboratory
Savannah River Nuclear Solutions, LLC
Aiken, SC 29808

Prepared for the U.S. Department of Energy under
contract number DE-AC09-08SR22470.

DISCLAIMER

Printed in the United States of America

Prepared for
U.S. Department of Energy

REVIEWS AND APPROVALS

AUTHOR:

C. H. Hunter, Atmospheric Technologies Date

TECHNICAL REVIEW:

M. J. Parker, CCM, Atmospheric Technologies Date

ADDITIONAL REVIEWER

A. M. Vincent, N&CSE Safety Programs Date

APPROVAL:

L. M. Chandler, Manager Date
Nonproliferation Technologies

EXECUTIVE SUMMARY

Several of the most common methods for estimating Pasquill-Gifford (PG) stability (turbulence) class were evaluated for use in modeling the radiological consequences of SRS accidental releases using the MELCOR Accident Consequence Code System, Ver. 2 (MACCS2). Evaluation criteria included: (1) the ability of the method to represent diffusion characteristics above a predominantly forested landscape at SRS, (2) suitability of the method to provide data consistent with the formulation of the MACCS2 model, and (3) the availability of onsite meteorological data to support implementation of the method

The evaluation resulted in a recommendation that PG stability classification for regulatory applications at SRS should be based on measurements of the standard deviation of the vertical component of wind direction fluctuations, σ_e, collected from the 61-m level of the SRS meteorological towers, and processed in full accordance with EPA-454/R-99-005 (EPA, 2000). This approach provides a direct measurement that is fundamental to diffusion and captures explicitly the turbulence generated by both mechanical and buoyant forces over the characteristic surface (forested) of SRS. Furthermore, due to the potentially significant enhancement of horizontal fluctuations in wind direction from the occurrence of meander at night, the use of σ_e will ensure a reasonably conservative estimate of PG stability class for use in dispersion models that base diffusion calculations on a single value of PG stability class.

Furthermore, meteorological data bases used as input for MACCS2 calculations should contain hourly data for five consecutive annual periods from the most recent 10 years.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

DOE	Department of Energy
NRC	Nuclear Regulatory Commission
EPA	Environmental Protection Agency
ANSI	American National Standards Institute
PG	Pasquill-Gifford
PGT	Pasquill-Gifford-Turner
NWS	National Weather Service
SRDT	Solar Radiation Delta T
MACCS	MELCOR Accident Consequence Code System

1.0 Introduction

Regulatory authorities including the U.S. Nuclear Regulatory Commission (NRC) and the U.S. Department of Energy (DOE) recommend the use of Gaussian atmospheric dispersion models for assessing the consequences of radiological releases into the environment. The Gaussian plume equation that forms the basis of these models is a solution to the following second-order differential equation describing the rate of change of a contaminant's airborne concentration due to advection and diffusion:

$$\frac{\partial X}{\partial t} = - u\,\frac{\partial X}{\partial x} - \frac{\partial \overline{u'X'}}{\partial x} - \frac{\partial \overline{v'X'}}{\partial y} - \frac{\partial \overline{w'X'}}{\partial z} \quad (1)$$

where X is concentration (g/m^3 or Ci/m^3), t is time, and u is the mean wind speed along the x-axis. The terms $\overline{u'X'}$, $\overline{v'X'}$, and $\overline{z'X'}$ represent mean turbulent fluxes of the contaminant along the x, y, and z axis, respectively, as produced by fluctuations in the u, v, and w components of wind speed. A Gaussian solution to eq. (1) is applicable when conditions within the atmospheric boundary layer are assumed to be both homogenous and stationary. Lateral and vertical diffusion produced by the turbulent flux terms in Eq. 1 are represented in the Gaussian solution as the standard deviations of concentration, σ_y and σ_z, respectively. Therefore, both σ_y and σ_z are necessarily functions of time (t), or downwind distance, x = ut (Slade, 1968).

In his seminal 1961 paper, Pasquill provided explicit formulations for determining the lateral and vertical distribution of a contaminant as a function of downwind distance, which he defined as θ and h, respectively, based on direct measurements of turbulence in the form of wind direction fluctuations (turbulence intensity) from a wind vane (Pasquill, 1961). However, for situations in which such measurements were not available, he proposed the use of a set of discrete curves for determining h, with a corresponding table of values for θ, that were applicable to each of six classes of atmospheric turbulence (stability). Pasquill assigned a letter value to each of the curves ranging from A through F, where A represents highly turbulent conditions resulting in vigorous diffusion and F represents conditions with relatively little turbulence and weak diffusion. Furthermore, he specified practical criteria needed to identify the atmospheric conditions represented by each of the curves that were based on routine observations of wind speed, cloud cover and solar insolation. Gifford subsequently reformulated Pasquill's method of defining h and θ to produce the now well-known and widely used curves for σ_y and σ_z (Gifford, 1961).

Since reliable and sufficiently sensitive wind vanes were not widely used at the time (i.e., pre 1960s), and generally acceptable estimates of turbulence intensity could be inferred from standard weather observations taken at National Weather Service stations, atmospheric models intended for widespread, practical use in regulatory applications were developed around the Pasquill-Gifford (PG) curves. For the last several decades, sensitive and reliable wind anemometry has been ubiquitous. Nevertheless, more than fifty years later the PG curves continue to form the basis of dispersion models recommended for use in the nuclear industry, despite the strong encouragement from many leading investigators to base calculations of σ_y and σ_z on direct measurement of turbulence (Hanna, 1977; Pasquill, 1974; Irwin, 1980). Today, organizations such as the American Nuclear Society in their ANSI voluntary consensus standard (ANS, 2010), have strongly advocated for the industry to upgrade to more advanced instrumentation (i.e., sonic anemometers, remote sensors, etc.) that can provide direct measures of turbulence, but cognizant regulators have never acted on these recommendations.

2.0 Overview of Stability (Turbulence) Classification Schemes

The diffusion of an airborne contaminant is a direct function of the intensity of turbulent fluctuations about the mean wind (Eq. 1). Turbulence within the atmospheric boundary layer (the first few thousand feet above ground) is generated through a combination of mechanical and buoyant forces. Mechanical turbulence results from frictional drag (shear stress) exerted on the mean wind by a rough surface. Buoyancy forces generate turbulence in the daytime when strong solar insolation warms the earth's surface, resulting in convectively unstable conditions that enable movement of air parcels in the vertical. At night, surface cooling results in a statically stable boundary layer in which buoyant forces act to suppress vertical motion. The goal of stability (or more appropriately, turbulence) classification schemes is to quantify categories of turbulence intensity, either explicitly through direct measurement, or inferentially by objective parameterizations of mechanical and buoyant forces.

Irwin (1980), in a comprehensive evaluation of methods used to determine PG stability class, groups the prevailing schemes as based on either radiation, stability, or turbulence criteria. The radiation schemes infer turbulence intensity by quantifying incoming solar radiation during the day or outgoing long-wave (infrared) radiation at night, either measured directly or inferred through solar angle and/or cloud cover, along with wind speed. The stability schemes include Monin-Obukhov scaling length or bulk Richardson number, which express stability in terms of ratios of the relative contributions of buoyancy and mechanical turbulence. The resulting values provide a measure of stability and have been related to the PG stability class by several investigators (Gifford, 1976). The delta-temperature (ΔT) method, a stability scheme which expresses the difference in temperature between two vertical levels of the boundary layer, is known to work reasonably well under stable conditions, but often fails to properly characterize atmospheric turbulence under near-neutral (adiabatic) and unstable (super-adiabatic) conditions. Turbulence schemes utilize direct measurement of turbulence, such as the standard deviation of fluctuations in the horizontal (azimuth) or vertical (elevation) components of wind direction (σ_a or σ_e, respectively) measured by a bivane or sonic anemometer.

This report limits the discussion of specific PG stability classification schemes to three schemes most commonly cited by regulatory guidance (NRC, 1972; NRC, 2007; EPA, 2000; DOE, 2004) or consensus standards (ANS, 2010) and widely used in practical application. These are:

- An adaptation of the original Pasquill scheme by Turner (PGT)
- Temperature difference (ΔT)
- Direct turbulence, most commonly in the form of σ_a but extended also to σ_e for the purposes of this evaluation.

In the original Safety Guide 23 (NRC, 1972), the NRC presented criteria for determining stability class based on measurement of ΔT or σ_a. Both sets of criteria also appear in draft Rev. 1 to Regulatory Guide 1.23, with a slight modification to the σ_a criteria. However, users (presumably NRC licensees) were advised to justify their use of schemes other than ΔT. The final version of RG 1.23 Rev. 1, which was not issued until 2007, presents classification criteria for ΔT only. The guide allows licensees to use other methods, but states that *they should be approved by the reviewing authority*. The stated preference for ΔT was given as: (1) *it is an effective indicator for the worst-case stability conditions (e.g. Pasquill stability classes E, F, and G)* and, (2) Gaussian plume models endorsed by NRC for accident analysis, i.e., RG 1.145 (NRC, 1982), are based on *empirically derived plume meander factors from field tracer studies that used ΔT to classify atmospheric stability*.

The Environmental Protection Agency (EPA) presents criteria for four methods: PGT, direct turbulence measurement based on σ_e or σ_a, and the SRDT method which utilizes ΔT (DT) at night and solar radiation (SR) measurements during the day (EPA, 2000). Guidance on methods for stability classification is also provided the American Nuclear Society (ANS, 2010) and the Department of Energy Office of Environment, Safety, and Health (DOE, 2004); however, both publications present each of the methods identified in the NRC and EPA guidance, and state no particular preference for any particular method.

PGT

The turbulence classification method originally proposed by Pasquill, which he termed '*tentative*', was based on qualitative estimates of solar insolation during the day and observations of cloud cover at night, in combination with wind speed measured at a height of 10 meters (Pasquill, 1961). Solar insolation was categorized as strong, moderate, or slight based on estimates of solar angle as a function of the time of day and time of year at the latitude for the site of interest. Turner later refined the Pasquill scheme using more objective criteria. For each hour of data to be processed, categories of solar isolation are determined by an explicit calculation of solar angle, coupled with coincident observations of cloud cover and ceiling height taken at first order National Weather Service stations, to define a net radiation index. The resulting value for this index along with the coincident wind speed determines the final PG class. Since this method requires only standard NWS observations, the PGT scheme has proven to be a practical and widely used approach in situations where on-site meteorological data are not available.

ΔT

A literature review revealed little in the way of discussion on the early development of PG stability classification based on ΔT, although descriptions of the diffusion experiments used by Pasquill to derive or evaluate his dispersion curves, including Prairie Grass, indicate that temperature measurements were available from multiple levels through the lowest few tens of meters above the surface (Barad, 1958). Specific criteria relating values of ΔT to stability class was presented as early as 1972 in Safety Guide 1.23 (NRC, 1972); however, no reference on the origin of these criteria is provided. The ΔT criteria summarized in Safety Guide 23 has carried forward through the current version (NRC, 2007). Gifford (1976) notes that the ΔT method has been shown to have considerable uncertainty in discriminating stability class during conditions characterized by superadiabatic lapse rates, i.e., unstable conditions where temperature decreases at a rate greater than 1°C per 100 meters (daytime with strong solar insolation and light wind). This limitation appears to be recognized by the current version of RG 1.23, where the stated preference for ΔT refers to its performance during stable conditions at night.

It should be emphasized that the EPA does not recognize ΔT as a generally applicable classification scheme in the form presented by the NRC. To overcome the limitation to ΔT noted above, the EPA advocates use of the SRDT scheme, which is based on measured values of solar insolation during the day and a simple ΔT discriminator in combination with wind speed at night (EPA, 2000).

Turbulence Schemes

A stability classification scheme using direct turbulence measurements was first proposed by Cramer, who correlated measurements of σ_a and σ_e with diffusion data collected over a range of atmospheric conditions (Cramer, 1957). Cramer's analysis included data from both the Round Hill and Prairie Grass experiments. Using these data, as well as additional diffusion data from later experiments, Islitzer and Slade refined Cramer's scheme to provide a range of σ_a values that corresponded to each the six PG stabilities A through F (Slade, 1968). In addition, Slade analyzed diffusion data from more than 200 experiments conducted over a range of different surface roughness. He found that when the relative concentration data collected from these experiments were grouped by Pasquill stability class using the values of σ_a suggested by Islitzer and Slade, the median value of observed concentration for each stability class correlated '*reasonably well*' with results derived from the corresponding PG curves. For Slade, the correlation between σ_a and Pasquill stability class was sufficiently strong that the graphical depiction of the PG curves presented in Fig. A.1 of *Meteorology and Atomic Energy* (Slade, 1968) were labeled with the corresponding value of σ_a. Luna and Church (1972) compared PGT stability class derived from National Weather Service observations taken at the Augusta, GA airport with turbulence data collected by the Savannah River Laboratory at the WJBF-TV tower in Beech Island, SC, approximately 15 km west of the SRS. Although considerable scatter was present in the comparisons between individual observations (due in part to significant differences in local topography), the median values of σ_a and σ_e were found to decrease monotonically as the PG class progressed from A through F.

3.0 Selection of a PG Classification Method for Savannah River Site Dispersion Modeling

The evaluation and selection of a PG stability classification method most appropriate for use at SRS was based on a consideration of the following criteria:

- The ability of the method to represent atmospheric diffusion above a predominantly forested landscape characteristic of the SRS, i.e., meets the regulatory guidance for '*representing diffusion throughout the area of interest for dispersion modeling*' (EPA, 2000; ANS, 2010; DOE, 2004),
- Suitability of the method to provide data consistent with the formulation of the intended modeling application, and
- The availability of onsite meteorological data to support implementation of the method.

3.1 General Evaluation of Classification Schemes

Numerous investigators, including Slade (1968), Gifford (1976), Hanna, et al (1977), and Irwin (1980) have discussed the fundamental relationship between wind fluctuations and diffusion. Furthermore, Pasquill considered his stability classification method (later to become the PGT method) simply as '*a means-to-an-end*' when adequate turbulence data were not available (Pasquill, 1961).

Having strongly encouraged the use of turbulence schemes in diffusion analyses, Irwin (1980) evaluates the efficacy of σ_a relative to σ_e and proposes criteria for PG stability classification using σ_e data. During stable conditions, vertical motion is strongly suppressed by buoyancy forces, resulting in a relatively light, but steady turbulence that is driven primarily by mechanical forces, i.e., roughness. Conversely, buoyancy does not suppress lateral motion, and low frequency oscillations (meander) are often seen in the horizontal component of the wind. Furthermore, as the wind speed becomes light (< 2 m/s), the wind direction may become somewhat erratic and the resulting fluctuations can reflect turbulence intensities that more typically occur during the day, i.e., PG stability classes A and B (Gifford, 1976; Luna and Church, 1972). Although measured values of σ_a would correctly represent the lateral diffusion under these circumstances, Gaussian dispersion models commonly use a single PG stability class value that applies to diffusion in both the horizontal and vertical planes. As a result, PG stability classification based on σ_a alone would tend to overestimate diffusion in the vertical, resulting in non-conservative estimates of ground-level concentration. This characteristic of a σ_a – based PG classification was also noted by Napier, et al., (2011). Although Irwin expresses concern over potential operational difficulties in collecting high quality σ_e data, he goes on to conclude that σ_e provides a more robust estimate of the true PG stability class, over the full range of atmospheric conditions, and is preferred to σ_a.

As noted previously, a broadly recognized set of criteria for determining PG stability class based on σ_a was developed during the 1960s (Slade, 1968), and subsequently adopted for use in regulatory applications by the NRC (NRC, 1972; NRC, 1980). In 1980, Irwin (1980) proposed similar criteria for σ_e based on analysis of field data from an experiment conducted near Oceanside, CA (Smith and Howard, 1972). Based on Golder's assertion that turbulence criteria must necessarily depend on measurement height and surface roughness length, Irwin strongly cautioned that the results were specific to characteristics of the Oceanside data set, i.e., a 10-meter measurement height over a surface with roughness of 15 cm.

Irwin goes on to propose a means for generalizing the σ_e criteria (as well as criteria for σ_a) by suggesting an adjustment based on a power law relationship of the form z_o^p (Hanna, et al, 1977). When this relationship is used to describe the effect of roughness on vertical diffusion, values of the exponent, p, range between 0.1 and 0.25 with the higher values appropriate for shorter downwind distances and rougher surfaces (Hanna, eta al, 1977; Napier, et al, 2011). Specifically, Irwin recommended adjusting the σ_e and σ_a criteria by a factor equal to $(z_o/15\text{cm})^{0.2}$ where z_o is the surface roughness for the site where the data are taken and 15 cm is a base roughness, i.e., that of the Oceanside site. A methodology for adjusting the σ_e (or σ_a) criteria for measurement height was not included in Irwin's 1980 report.

Irwin's suggested criteria for σ_e, with appropriate adjustment for surface roughness, was subsequently incorporated in regulatory guidance published by EPA (EPA, 2000). This publication also included the requisite adjustment of both the σ_e and σ_a criteria for measurement height, an adjustment that also took the form of a power law expression. Furthermore, the EPA guidance incorporated criteria previously recommended by Irwin (1980) for performing a final adjustment to the PG stability class determined using σ_a as a function of the coincidental wind speed and time of day. These criteria were based on recommendations proposed by Mitchell and Timbre (1979) who analyzed σ_a and ΔT data from six locations of varying topography. They found that the PG stability class frequency distributions initially derived from σ_a and subsequently adjusted by the proposed wind speed criteria compared well with stabilities derived from either ΔT or PGT. Although buoyant forces limit the effect of meander on the magnitude of σ_e, the EPA guidance also includes an identical set of checks on the σ_e-based criteria to ensure fidelity with Pasquill's original classification scheme.

3.2 SRS Modeling Applications

The PG stability classification method used in safety-basis dose consequence modeling at SRS must be consistent with the current model of record, i.e., the MELCOR Accident Consequence Code System, ver 2. (MACCS2) (DOE, 2004). The MACCS2 code is based on model criteria summarized by the NRC in R.G. 1.145, which, as stated previously, implicitly assumes that the hourly values of PG stability class are derived from ΔT measurements. Since ΔT does not explicitly capture mechanically generated turbulence, MACCS2 has been coded to allow users to apply an enhancement factor for vertical diffusion for ‘rough’ terrain, and to apply RG 1.145 criteria for enhanced diffusion in the horizontal due to the meander that occurs during stable, low wind speed conditions.

As noted, the NRC guidance for stability classification extends the original Pasquill scheme by subdividing PG class F to create a seventh stability class, i.e., class G for extremely stable condition. However, the MACCS2 code limits users to an input of only six stability classes. The practice for safety calculations at SRS has been to include stability class G with F, since the criteria for class G are approximations that do not have an explicit basis in Pasquill’s methodology.

3.3 SRS Meteorological Monitoring Program

Meteorological data at the Savannah River Site are collected from a network of eight ‘area’ towers and the Central Climatology tower (Parker, 1992). The area towers are located in forested areas adjacent to each of the Site’s primary operations areas A, C, D, F, H, K, L, and P. Each area tower is instrumented to measure wind speed, wind direction, air temperature, and dew point temperature at 61-meters above ground level. In addition, air temperature is measured at a height of 2 meters at the area towers. The height of the surrounding forest canopy based on high resolution lidar data collected by the U.S. Forest Service (McGaughey and Reutebuck, 2009) generally ranges between 20 to 25 m (Weber, 2012). Winds are measured using sensitive cup anemometers and bi-directional wind vanes (bivanes). Platinum resistance temperature sensors and lithium chloride dew point probes are co-located in an aspirated radiation shield. All instruments meet or exceed performance specifications identified in applicable regulatory guides (NRC, 2007; EPA, 2000; ANS, 2010). Data are recorded at 1-second intervals, and processed every 15 minutes to produce averages and standard deviations of each measured variable for permanent archival. Since the SRS is primarily forested, the wind instruments were sited above the canopy to meet the general regulatory objective that the data represent the prevailing conditions that affect dispersion. The specific measurement height of 61 meters was chosen to represent conditions at the effluent stack height for most of the major production facilities that have operated at SRS. Although the concern for safety analysis in recent years has shifted to potential releases from shorter stacks characteristic of newer operations facilities or ground-level releases from waste tanks, atmospheric transport to and beyond the SRS boundary must continue to account for travel over a relatively rough forested surface.

The Central Climatology site was designed as a general, multiple-purpose monitoring facility that provides a variety of meteorological data supporting both SRS operations and ATG research programs. This site consists of a 61-m tower located in a flat, relatively open area along the eastern periphery of N-area. A grass surface extends approximately 200 feet in all directions. The area beyond the fence out to roughly 600 ft is characterized by equipment laydown areas, low profile structures, and scattered stands of pine trees (Parker, 1993). Cup anemometers and bi-vanes are located at heights of 4, 18, 36, and 61-meters. Air temperature and dewpoint temperature probes are located at heights of 2, 18, 36, and 61-meters above ground. Additional instruments at ground level measure precipitation, solar and terrestrial radiation, barometric pressure, soil temperature, and evaporation. As with the ‘area’ towers, data are recorded at 1-second intervals and processed every 15-minutes to produce averages and standard deviations for permanent archival.

3.4 SRS Data for PG Stability Classification

The SRS meteorological monitoring program provides data that can support consideration of stability classification using the σ_e, and σ_a, methods or, in limited cases, the ΔT method. The closest available long-term observations of cloud cover and cloud height needed for determining a PGT-based stability class is the NWS station at the Augusta Regional Airport in Augusta, GA, approximately 20 km west of the site. The applicable regulatory guides strongly discourage use of NWS data if suitable onsite data are available.

As stated previously, stability class estimates based on the ΔT method provides consistency with the MACCS2 formulations designed to incorporate sources of turbulence that ΔT is unable to capture, i.e., low wind speed meander at night and surface roughness. Available onsite data for determining ΔT consists of 2-61 m temperature data from the area towers or some combination of the four levels of temperature available from Central Climatology, e.g., 2-61 m, 18-61 m, or 2-36 m. However, the 2 m temperatures measured at the area towers are strongly affected by conditions unique to the local environment below the forest canopy and therefore, do not meet the applicable standards for instrument exposure. Furthermore, the NRC (2007) and the ANS (2010) state that ΔT measurements for stability classification should be taken between 10 m and the height of the primary stack release, with a recommended default height for the second measurement level of 60 m. EPA (2000) states more generally that any measurement used to determine stability class in the atmospheric surface layer should be made at heights between $20z_o$ and $100z_o$ above the surface. For open areas of SRS considered suitable for collecting ΔT data, Weber, et al, (2012) estimates roughness lengths ranging between 0.3 m and 0.7 m. A value for z_o of 0.5 m corresponds to a minimum height of measurement ($20z_o$) of around 10 m. Based on these criteria, the most viable option for determining ΔT would consist of temperature data from the 18-61 m levels of Central Climatology.

Fig. 3-1 shows a comparison of the percent occurrence of stability classes A-G based on ΔT data from the 18-61 m, 2-61 m, and 36-61 m levels of the Central Climatology tower and the 10-60 m levels of Georgia Power’s Plant Vogtle just southwest of SRS. The Plant Vogtle data depicted in this plot was taken from Napier, et al (2011). The Central Climatology temperature data consists of all valid 15-minute average value of temperature collected over the one year period of 2010. Stability class estimates based on the 2-61 m data show relatively high frequencies of A and G stabilities, indicating that the 2m temperatures are strongly influenced by the diurnal extremes of ground surface temperatures. Stability class frequencies based on the 18-61 m and 36-61 m data at Central Climatology are both similar to those based on the Vogtle data, in particular, the 18-61 m ΔT results for the stability classes that are significant in accident analysis (i.e., classes E, F, and G).

While some of the ΔT data from Central Climatology can be expected to provide reasonably representative estimates of stable conditions for the open, mainly grassy surface that characterizes this location, or similar open locations across SRS, the applicability of this data for characterizing diffusion above the prevailing forest canopy is highly uncertain. The physical processes that govern the exchange of heat and moisture within and above a forest canopy are much more complex than for cleared surfaces, and include terms that could have a significant affect on the

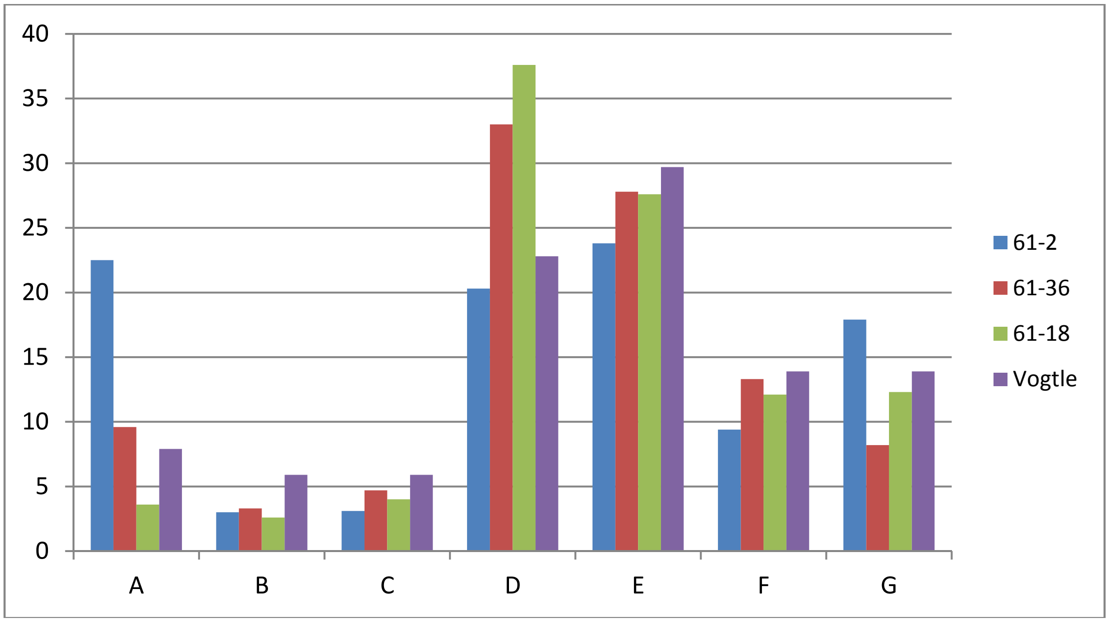

Figure 3-1. Percent Occurrence of PG Stability Class Determined by the ΔT Method for Temperature Measured at Various Levels of Central Climatology and Georgia Power's Plant Vogtle.

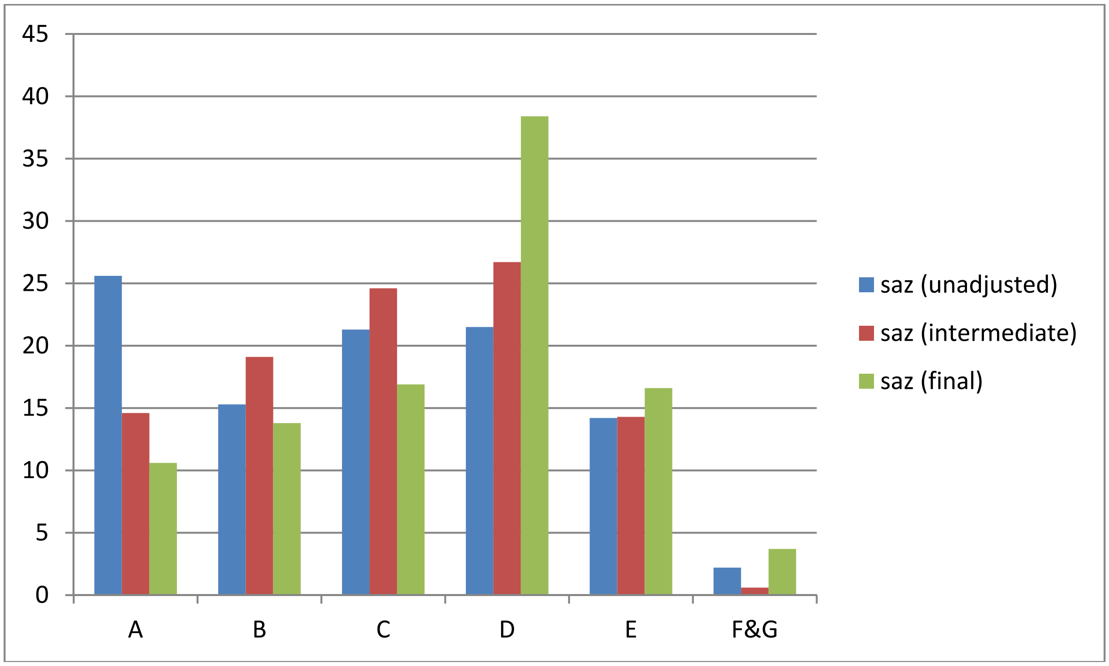

Figure 3-2. Percent Occurrence of PG Stability Class Using σ_a Criteria – Unadjusted, Intermediate, and Final per EPA(2000) Guidance.

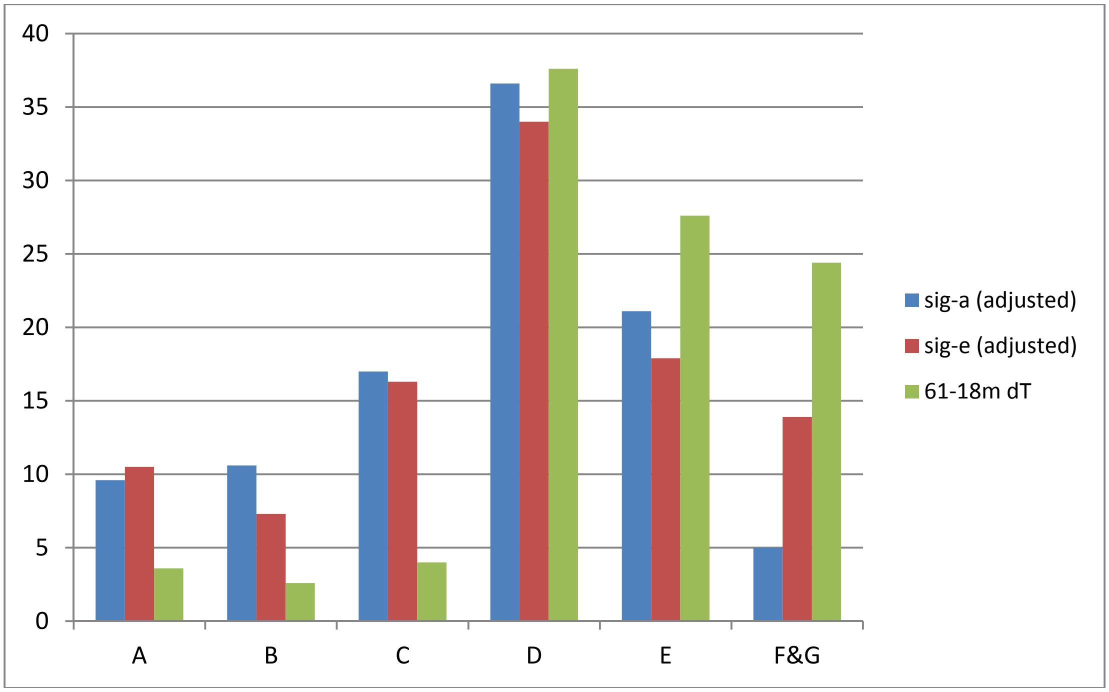

Figure 3-3. Percent Occurrence of PG Stability Class Using σ_a and σ_e Criteria, Adjusted per EPA (2000) Guidance and 18-61m ΔT from Central Climatology.

thermal environment such as radiation exchanges between plant components, transpiration, and vertical variations in evaporation and condensation within the canopy (Stull, 1988). Representative vertical profiles of temperature above the forest canopy, which covers more than 85 percent of the SRS reservation (Murphy, 2012), cannot be determined since none the eight area towers provide the necessary measurements.

Conversely, measured values of σ_a and σ_e from the 61-m level of the area towers provide the only available characterization of turbulence above the SRS's predominant surface and, when processed using EPA guidance to ensure fidelity with Pasquill's original classification scheme, provide results that are compatible with the MACCS2 corrections for meander and surface roughness. Fig. 3-2 illustrates the stepwise impact of implementing the EPA (2000) methodology on PG stability class using σ_a data collected from the H-area tower for the five years 2002-2006. The plots labeled 'unadjusted' shows the percent occurrence of PG stability class (A-F) based on the classification criteria for σ_a recommended by EPA (2000). The plots labeled 'intermediate' depict PG class estimates based on adjustments to the σ_a criteria for a measurement height of 61 m and an assumed roughness length of 100 cm. The plots labeled 'final' include the additional recommended adjustment for wind speed and time of day. The normalization for measurement height and roughness acts in the opposite sense and roughly counterbalance, especially for the stable classes. The final adjustment for wind speed appears to reclassify 17 percent of stability classes A, B, and C as mainly stability D. Stabilities E, F, and G increase by about 5 percent.

Fig. 3-3 shows a comparison of the percent occurrence of PG stability classes A-F based on σ_a and σ_e for the identical H-area dataset, using a full implementation of the EPA methodology. The most significant difference in the results of the two methods is a factor of three increase in stability class F when the classification is based on σ_e. This result suggests that enhanced horizontal fluctuations in wind direction during stable conditions may not be fully captured by the

EPA wind speed criteria, but confirms Irwin's observation that σ_e provides the more conservative estimate of PG stability class for use in dispersion modeling.

Fig. 3-4 shows the percent occurrence of PG stability class by hour of the day using quality assured values of σ_e collected at the H-area tower in 2010 and processed following the EPA guidance. This figure illustrates that a full implementation of the EPA guidance yields results that are consistent with the original Pasquill scheme, i.e., no occurrence of stability classes E, F, and G during the day or stability classes A, B, or C and night.

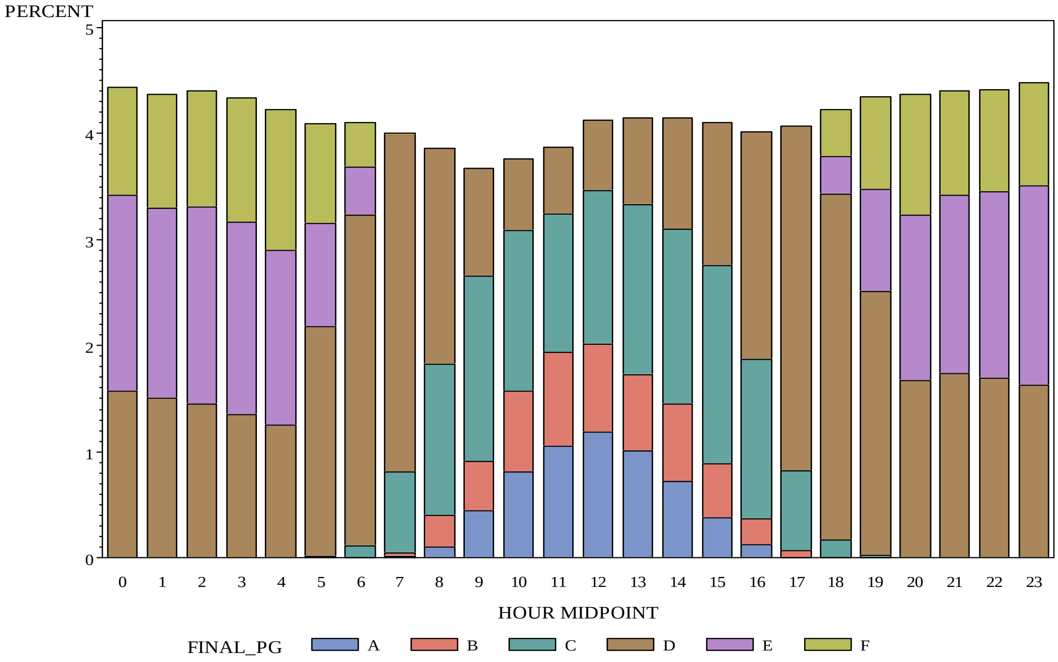

Figure 3-4. Percent Occurrence of PG Stability Class by Hour of the Day Using σ_e Criteria

4.0 Recommended Method for Stability Classification at SRS

Pasquill-Gifford stability classification for use in regulatory modeling applications at SRS, including the MACCS2 model for safety basis assessments, should be based on measurements of σ_e collected from the 61-m level of the SRS meteorological towers, and processed in full accordance with EPA-454/R-99-005 (EPA, 2000). This recommendation is based on an evaluation of the characteristic SRS landscape, the stability classification methods commonly used in regulatory applications with respect to the suitability of the method to provide results that are consistent with model formulations, and the availability of site-specific meteorological data to support implementation of the method. The σ_e approach utilizes measurements that are fundamental to diffusion and captures explicitly the turbulence generated by both mechanical and buoyant forces. Furthermore, due to the potentially significant enhancement of horizontal fluctuations in wind direction at night, σ_e ensures a reasonably conservative estimate of PG stability class for dispersion models that base diffusion calculations on a single value of PG stability class.

Table 1 summarizes SRS-specific criteria for the initial determination of stability class from the σ_e data. The σ_e criteria recommended by EPA (unadjusted) were modified to include prescribed adjustments for a local roughness length (z_o local) and measurement height other than 10 meters. The roughness adjustment consisted of multiplying the lower value of σ_e for each stability class by a factor given by the power law expression

$(z_o\text{-local} / 15\text{ cm})^{0.2}$,

where the value of z_o-local generally representative of the landscape surrounding the SRS area towers is 180 cm (Weber, 2012).

The measurement height adjustment was applied by multiplying the lower value of σ_e for each stability class, adjusted for roughness, by the result of the power law expression,

$((z\text{-}d)/10)^{Pe}$

where z is the height of measurement. The displacement height, d, represents the height above ground where the vertical profile of wind speed extending above the forest canopy, as described by the diabatic wind law, approaches a value of zero. The presence of a zero-plane displacement as the new effective surface is not explicitly described in the EPA guidance, presumably because the vast majority of measurement locations encountered in regulatory applications are not required to be located above forested terrain. However, for surfaces with dense vegetation cover, this adjustment is universally recognized in mathematical descriptions of the atmospheric boundary layer (Stull, 1988) and was recommended for implementation at SRS by Napier, et al, 2011.

For a displacement height representative of the SRS forested landscape, i. e., 18m (Weber, 2012), the effective measurement height (z-d) for evaluating the above power law expression is 61m – 18m, or 43 m. Values for the power law exponent, P_e, as a function of stability class, are taken from EPA (2000).

As noted in the EPA guidance, the suggested methodology for stability classification using σ_e is based on studies that may represent '*fairly ideal circumstances*'. Consequently, the criteria listed in Table 1 will be spot checked against the SRS measurements and adjusted as needed prior to final development of the MACCS2 meteorological data set, as recommended by EPA (2000).

Table 4-1. PG Stability Classification Criteria Using σ_e for SRS Terrain and Measurement Height.

PG Category	σ_e Range (Unadjusted)	SRS-specific σ_e Range (Adjusted)
A	11.5 </= σ_e	19.5 </= σ_e
B	10.0 </= σ_e < 11.5	17.4 </= σ_e < 19.5
C	7.8 </= σ_e < 10.0	13.0 </= σ_e < 17.4
D	5.0 </= σ_e < 7.8	6.7 </= σ_e < 13.0
E	2.4 </= σ_e < 5.0	2.5 </= σ_e < 6.7
F	σ_e < 2.4	σ_e < 2.5

Fig 4-1 shows the stepwise impact of implementing the EPA (2000) methodology on PG stability class using σ_e data collected from the H-area tower for the five years 2002-2006. The definitions for ‘unadjusted’, ‘adjusted’, and ‘final’ are identical to those given in Section 3.4, above. The most significant impact of implementing the EPA methodology is the reclassification of a high frequency of hours of stability class A into more neutral classes. The EPA’s recommended final adjustment of stability class by wind speed and time of day generally has little effect on the σ_e classification, since phenomena such as meander principally influences lateral fluctuations.

Values for P_e given by EPA range from 0.04 to -0.31. The larger negative values apply to stable conditions. The sensitivity of the displacement height, d, on the adjustment for measurement height was evaluated for PG class E, which has a value for P_e of -0.31. For a displacement height of 15 m rather than 18 m, which corresponds to a canopy height of 20m rather than 24m used by Weber (2012), the multiplication factor for the lower value of σ_e varies by less than 3 percent. Therefore, the EPA recommended adjustments to the σ_e criteria are not sensitive to the canopy height estimates.

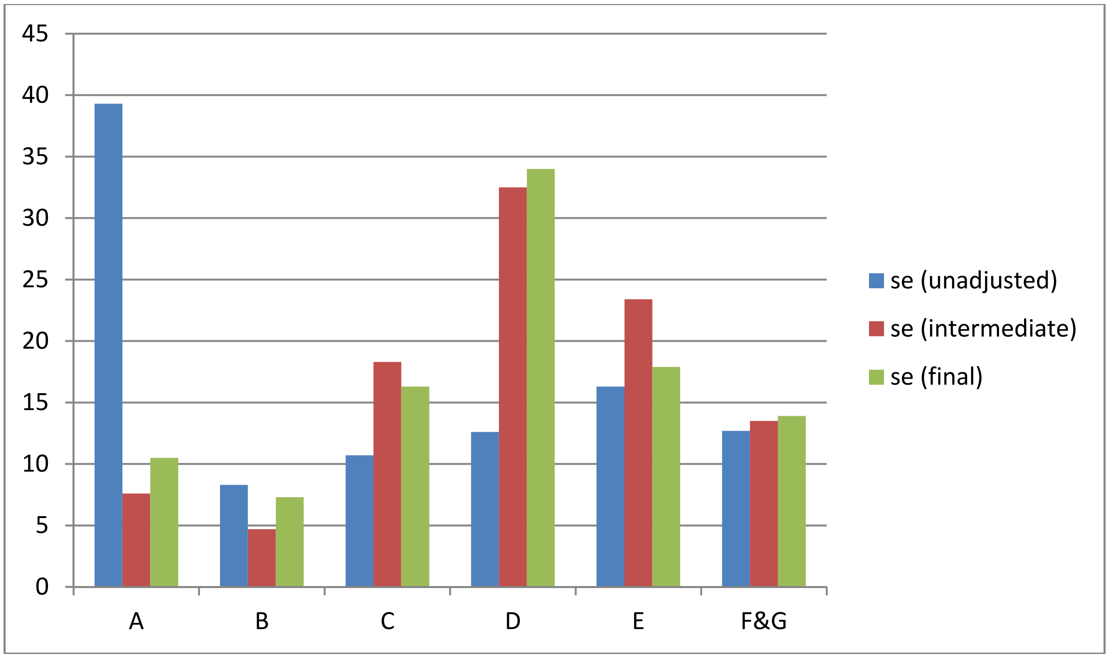

Figure 4-1. Percent Occurrence of PG Stability Class Determined by the σ_e Method - Unadjusted , Intermediate, and Final per EPA (2000) Methodology.

5.0 Recommended Length of Record for Meteorological Data Sets used in Regulatory Modeling

The following summarizes regulatory guidance on the length of the meteorological record for use in dispersion modeling for licensing or other regulatory compliance activity:

NRC (2007) - States that a ***minimum of 3 years of data*** are preferable, and that the data ***should be from the most recent ten years***. No upper limit on record length is given.

ANS (2010) - Meteorological data sets should consist of 3 to 5 years of data.

EPA (2000) - ***Data sets should include 5 consecutive years*** from the most recent readily available record.

Both NRC (2007) and ANS (2005) stipulate that 1 to 2 years of data are acceptable to support construction or preoperational licensing for new facilities.

Historically at SRS, data sets containing 5 consecutive years of quality assured meteorological data are prepared every five years for use in dispersion modeling supporting regulatory compliance. Revised data sets are prepared within 1 year of the end of the new five year period, which ensures that the ten year criteria recommended by the NRC is generally met. This current practice is consistent with the consensus of guidance and should continue in the future.

6.0 References

American National Standard, *Determining Meteorological Information at Nuclear Facilities*, ANSI/ANS-3.11-2005, American Nuclear Society, La Grange Park, IL (2010).

Barad, M. L. (ed.), *Project Prairie Grass, A Field Program in Diffusion*, Geophysical Research Paper, N. 59, Vol. I, II, III, AFCR-TR-58-235(I), Air Force Cambridge Research Center (1958).

Cramer, H. E., *A Practical Method for Estimating the Dispersal of Atmospheric Contaminants*, Proceedings of the First National Conference on Applied Meteorology, October 28-29, 1957, Hartford, Connecticut (1957).

Department of Energy (DOE), *MACCS2 Computer Code Guidance of Documented Safety Analysis. Final Report, DOE-EH-4.2.1.4-MACCS2-Code-Guidance*, Office of Health, Safety, and Security, Washington, SC (2004).

Department of Energy (DOE), *Environmental Regulatory Guide for Radiological Effluent Monitoring and Surveillance*, DOE-EH/0173T, Office of Air, Water and Radiation Protection Policy and Guidance, Washington, DC (2004).

Environmental Protection Agency (EPA), *Meteorological Monitoring Guidance for Regulatory Modeling Applications*, EPA-454/R-99-005, Office of Air Quality Planning and Standards, Research Triangle Park, NC (2000).

Gifford, F. A., *Use of Routine Meteorological Observations for Estimating Atmospheric Dispersion, Nuclear Safety*, Vol. 2, 47-57 (1961).

Gifford, F. A., *Turbulent Diffusion Typing Schemes: A Review*, Nuclear Safety, Vol. 17, No. 1 (1976).

Hanna, S. R. et al, *AMS Workshop on Stability Classification Schemes and Sigma Curves – Summary of Recommendations,* Bulletin of the American Meteorological Society, Vol. 58, No. 12 (1977).

Irwin, J. S., *Estimation of Pasquill Stability Categories*, U. S. Environmental Protection Agency Dispersion Estimate No. 8 (Internal Report), A-80-46 (1980).

Luna, R. E. and H. W. Church, *A Comparison of Turbulence Intensity and Stability Ratio Measurements to Pasquill Stability Classes*, Journal of Applied Meteorology, Vol. 11 (1972).

McGaughey, R. J. and S. E. Reutebuck, *Savannah River Site 2009 LIDAR Project, FY09 Final Report,* Pacific Northwest Research Station, U. S. Forest Service, Seattle, WA. (2009)

Mitchell, A. E. and K. O. Timbre, *Atmospheric Stability Class from Horizontal Wind Fluctuation*, Proceeding of the 72nd Annual Meeting of the Air Pollution Control Association, June 24-29, 1979, Cincinnati, OH. (1979).

Murphy, C.E., P. L. Lee, B. J. Viner, C. H. Hunter, *Recommended Tritium Oxide Deposition Velocity for use in Savannah River Safety Analyses*, SRNL-STI-2012-00128, Savannah River National Laboratory, Aiken, SC (2012).

Napier, B. A., et al, *Final Review of Safety Assessment Issues at Savannah River Site*, S-ESR-G-00015, Rev. 0, Savannah River Nuclear Solutions, Aiken, SC (2011).

Nuclear Regulatory Commission (NRC), *Meteorological Monitoring Programs for Nuclear Power Plants*, Safety Guide 23 (1972).

Nuclear Regulatory Commission (NRC), *Meteorological Monitoring Programs for Nuclear Power Plants*, Regulatory Guide 1.23, Proposed Rev. 1 (1980).

Nuclear Regulatory Commission (NRC), *Meteorological Monitoring Programs for Nuclear Power Plants*, Regulatory Guide 1.23, Rev. 1 (2007).

Nuclear Regulatory Commission (NRC), *Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants*, Regulatory Guide 1.145, Rev.1 (1982).

Parker, M. J., *Meteorological Monitoring Program at the Savannah River Site,* WSRC-TR-93-0106, Westinghouse Savannah River Company, Aiken, SC (1993).

Pasquill, F., *Atmospheric Dispersion Parameters in Gaussian Plume Modeling, Part II. Possible Requirements for Change in the Turner Workbook Values*, U.S. EPA, EPA-600/4-76-030b (1974).

Pasquill, F., The Estimation of the Dispersion of Windborne Material, The Meteorological Magazine, Vol. 90, No. 1063 (1961).

Slade, D. H. (ed.), *Meteorology and Atomic Energy*, TID-24190, U. S. Atomic Energy Commission, Washington, DC (1968).

Smith, T. B., and S. M. Howard, *Methodology for Treating Diffusivity*, Report MRI 72 FR-1030, Meteorology Research, Inc., Altadena, CA (1972).

Stull, R. B., *An Introduction to Boundary Layer Meteorology*, Kluwer Academic Publishers, Dordrecht, the Netherlands (1988).

Weber, A. H., R. J. Kurzeja, and C. H. Hunter, *Roughness Lengths for Savannah River Site* SRNL-STI-2012-00016, Savannah River National Laboratory, Savannah River Nuclear Solutions, Aiken, SC (2012).

Distribution:

D. E. Eyler, 773-A
J. C. Grove, 730-4B
A. E. Burris, 773-A
L. E. Johnson, 707-C
L. M. Chandler, 773-A
A. M. Vincent, 707-C
S. K. Elliott, 707-C
R. L. Buckley, 773-A
S. R. Chiswell, 773-A
R. J. Kurzeja, 773-A
M. J. Parker, 735-7A
B. J. Viner, 773-A
D. W. Werth, 773-A