A Methodology for Calculating Meteorological Channel Accuracies

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1. Introduction

A number of regulatory guidance documents provide specifications concerning the accuracy of meteorological measurements at commercial nuclear power facilities. A listing of some of these accuracy specifications is provided in Exhibit 1. Many nuclear power plant licensees have made licensing commitments to these accuracy specifications. For example, Millstone Nuclear Power Station[1] has made commitments to Regulatory Guides 1.23[1] and 1.97[2] in the Final Safety Analysis Report (FSAR). In addition, Millstone Station's Unit 2 Technical Specifications includes minimum instrument accuracies as a Limiting Condition of Operation (LCO).[2]

Guidance for determining meteorological monitoring system accuracies is provided in Section 6.1 of ANSI/ANS-2.5-1984[3]. ANS-2.5 defines system accuracy as the composite accuracy reflecting the errors introduced by sensor, cable, signal conditioner, temperature environment for signal conditioning and recording, recorders, and data reduction process. The system accuracy is determined by the root sum of the squares (RSS) method considering the error contributions of system components from the sensors through the recording system. The RSS is calculated by squaring each error, summing the squared errors, and taking the square root of the sum. For time averaged values, those parts of the error budget which are random in nature may be decreased from their instantaneous value by dividing by the square root of the number of samples used to define the average value.

The intent of this paper is to describe the methodology used by Millstone Station to show that its primary tower meteorological instrumentation (specifically, the wind speed, wind direction, temperature, and delta-temperature channel computer displays) is designed to meet the minimum accuracy specifications contained in Regulatory Guides 1.23 and 1.97. This methodology is based, in part, on the system accuracy determination methodology presented in ANSI/ANS-2.5-1984.

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[1] Millstone Station is a three-unit commercial nuclear power plant located in southeastern Connecticut on the shoreline of Long Island Sound.

[2] Millstone Station's Unit 2 LCO lists minimum accuracy specifications for the wind speed (±0.22 mph), wind direction (±5°), and delta-temperature (±0.18°F). These are the same instrument accuracy specifications presented in Regulatory Guide 1.23.

2. System Description

2.1. System Layout

The Millstone Station primary meteorological monitoring system utilizes a 450-foot high guyed tower instrumented as follows:

MEASUREMENT	APPROXIMATE MEASUREMENT HEIGHTS (feet above ground level)
Wind Speed	33 ft, 142 ft, 374 ft, 447 ft
Wind Direction	33 ft, 142 ft, 374 ft, 447 ft
Temperature	33 ft, 64 ft, 447 ft
Delta-Temperature	142-33 ft, 374-33 ft, 447-33 ft
Dew Point	33 ft, 64 ft, 447 ft
Solar Radiation	5 ft

All signals from the tower's sensors are routed through signal line surge protectors to signal translators located in a nearby instrument shelter. The signal translators convert the sensor signals to a 0-5 Volt dc output over the full instrument range for output to a set of analog and digital recorders.

A schematic of the Millstone Station primary meteorological tower data link configuration is provided in Exhibit 2. The translator outputs are monitored directly by strip chart recorders located in the instrument shelter. An Environmental Data Acquisition Network (EDAN) computer located in the instrument shelter also directly monitors the translator outputs. The EDAN computer routinely downloads its data to a host EDAN computer at corporate headquarters where the data are archived and available for display on any computer connected to Northeast Utilities' Wide Area Network. In addition, an EDAN computer with a unique Station Emergency Response Organization (SERO) data display is available in the onsite Emergency Operations Facility (EOF). Instantaneous data values as well as 15-minute average data values are available via the EDAN computer. The 15-minute averaged EDAN data are compiled from 180 instantaneous samples (e.g., sampling rate: once per five seconds)

Each unit's Plant Process Computer (PPC) also has a link to the translator outputs for the purpose of compiling and displaying selected data in each unit's Control Room. These links employ analog-to-frequency conversion, multiplexing, a phone line connection, de-multiplexing, and frequency-to-analog conversion. Each Plant Process Computer displays instantaneous data values as well as 15-minute average data values. The Unit 1 and Unit 2 Plant Process Computers derive their 15-minute average data from 180 instantaneous samples (e.g., sampling rate: once per five seconds) whereas the Unit 3 Plant Process Computer derives its 15-minute average data from 15 instantaneous samples (e.g., sampling rate: once per minute).

2.2. System Components

2.2.1. Wind Speed

The wind speed sensors consist of a Climatronics heavy-duty aluminum three-cup anemometer assembly (P/N 101287) attached to a Climatronics F460 transducer (P/N 100075). The transducer is a 30-hole light chopper with a LED photodetection device that provides a frequency output directly proportional to the wind speed. The manufacturer has provided the following accuracy specifications for the transducer/cup combination:

Accuracy	±0.15 mph or ±1.0% of true air speed, whichever is greater

Signals from the wind speed transducers are provided to Climatronics wind speed translators (P/N 100078-1) located in the instrument shelter. These translators convert the signals from the wind speed transducers into 0 to 5 Volt dc signals for output to the recorders. The manufacturer has provided the following accuracy specifications for the wind speed translators:

Conversion Accuracy	±0.05%
Temperature Coefficient	±0.005% per °F max
Operating Range	0 to 100 mph

2.2.2. *Wind Direction*

The wind direction sensors consist of Climatronics vanes attached to Climatronics F460 transducers (P/N 100076). The transducer is a precision low-torque potentiometer that provides a voltage output directly proportional to the wind direction. The manufacturer has provided the following accuracy specifications for the transducer/vane combination:

Accuracy	±2°

Signals from the wind direction transducers are provided to Climatronics wind direction translators (P/N 100077) located in the instrument shelter. These translators convert the signals from the wind direction transducers into 0 to 5 Volt dc signals for output to the digital and analog recorders. The manufacturer has provided the following accuracy specifications for the wind direction translators:

Conversion Accuracy	±0.05%
Temperature Coefficient	±0.005% per °F max
Operating Range	0 to 540°

2.2.3. *Temperature*

Ambient temperature is measured using Climatronics platinum 4-wire calibrated Resistance Temperature Detectors (RTDs) (P/N 100826) with matched translators mounted in Teledyne Geotech Model 327 motor-aspirated temperature shields. The manufacturer has provided the following accuracy specifications for temperature sensors:

Accuracy (including linearity)	±0.18°F

The manufacturer has provided the following accuracy specifications for the temperature shields:

Radiation Error[3]	<0.2°F

Climatronics temperature translators (P/N 101400) located in the instrument shelter convert the non-linear resistance versus temperature relationship of the sensor into a 0 to 5 Volt dc signal for

[3] Under a test radiation intensity of 1.56 gm-cal/cm^2/min.

output to the recorders. The manufacturer has provided the following accuracy specifications for the temperature translators:

Conversion Accuracy (6 months)	±0.045°F
Linearity Error	±0.05% max
Temperature Coefficient	±0.005% per °F max
Operating Range	-30 to 110°F

2.2.4. Delta-Temperature

Delta-temperature is measured using the same model Climatronics platinum 4-wire RTDs with matched translators and Teledyne Geotech Model 327 motor-aspirated temperature shields used to measure ambient temperature.

Climatronics platinum delta-temperature translators (P/N 101400-1) are used in conjunction with the delta temperature RTD and the output from the reference level (33-ft) Climatronics temperature translator. The delta-temperature translators subtract the reference temperature translator input from the temperature difference RTD inputs and output the results as 0 to 5 Volts dc signals for output to the recorders. The manufacturer has provided the following accuracy specifications for the delta-temperature translators:

Conversion Accuracy (6 months)	±0.045°F
Linearity Error	±0.05% max
Temperature Coefficient	±0.005% per °F max
Operating Range	-10 to 18°F

2.2.5. Digital Recorders

The overall uncertainty of the analog-to-digital conversion process for the Plant Process Computers (PPC) and for EDAN is assumed to be bounded by the accuracy of each computer's analog input cards. Each of these computers was installed at different times and, as such, each represents a different technology. Northeast Utilities (NU) computer personnel have estimated the following accuracy statistics for the Millstone Station computers:

	Unit 1 PPC	Unit 2 PPC	Unit 3 PPC	EDAN
Conversion Accuracy	±0.67%	±0.05%	±0.02%	±0.10%

The links between the translator cards and the plant process computers employ analog-to frequency converters, multiplexers, a phone line, de-multiplexers and frequency-to-analog converters. It is estimated that this combination of telemetry equipment has the following uncertainty:

Accuracy (including drift and temperature effects)	±0.22%

3. Potential Sources of Error

A guidance document developed by Northeast Utilities (NU) for calculating the uncertainties of instrumentation loops[4] served as the basis for calculating the meteorological channel accuracies presented in this paper. To determine the overall uncertainty of an instrument loop, a number of potential error sources should be considered to determine their possible effects. Individual errors are expressed as a percentage of the channel span and are then combined to determine a total probable loop error. Errors that are *random* and independent are combined statistically using the square root of the sum of the squares; systematic or *bias* errors are added algebraically. For determining the error of time averaged values, those random errors that can fluctuate within the averaging period are divided by the square root of the number of samples before taking the square root of the sum of the squares. A list of all the system component accuracies described in the following sections is provided in Exhibit 3.

According to NU's guidance document, the preferred sources for errors are manufacturers' published data. Unless stated otherwise, manufacturer's data for random errors are assumed to be $\pm 2\sigma$ values (i.e., assuming a normal error distribution, the error of the system will be within the stated value 95.5% of the time).

The following potential sources of error were considered when developing channel accuracies for the Millstone Station primary meteorological monitoring system:

3.1. Process Measurement Accuracy (PMA)

This term includes errors in the variable measurement up to, but excluding, the sensor. The temperature measurement error resulting from solar heating effects is considered a *bias* process measurement error. The maximum error in temperature measurements due to solar heating of the aspirated radiation shield is 0.2°F. Expressed as a percent of span, PMA_{TP} is determined as follows:

$$PMA_{TP} = +\frac{0.2°F}{140°F} \times 100\% = +0.14\%$$

Note that solar heating effects are assumed not to affect the delta-temperature process measurement accuracies because the same bias error is assumed to affect both delta-temperature sensors equally.

3.2. Sensor Calibration Accuracy (SCA)

This term accounts for the accuracy to which the sensor can be calibrated

The accuracy of the wind speed sensors is ±0.15 mph or ±1% of true air speed, whichever is greater. This is considered a *random* error that can fluctuate during the averaging period. Since the 1% criterion dominates above 15 mph, this criterion is chosen as the bounding criterion. Since Regulatory Guide 1.97 (Rev. 2) requires a 0.5 mph accuracy up to 25 mph, SCA_{WS} is determined at 25 mph. Expressed as a percent of span, SCA_{WS} is determined as follows:

$$SCA_{WS} = \pm \frac{25mph \bullet 1\%}{100mph} \times 100\% = \pm 0.25\%$$

The accuracy of the wind direction sensors is ±2° and is considered a *random* error that can fluctuate during the averaging period. Expressed as a percent of span, SCA_{WD} is determined as follows:

$$SCA_{WD} = \pm \frac{2°}{360°} \times 100\% = \pm 0.56\%$$

The accuracy of the RTD temperature sensors is equal or better than 0.18°F and is considered a *random* error that can fluctuate during the averaging period. Expressed as a percent of span, SCA_{TP} is determined as follows:

$$SCA_{TP} = \pm \frac{0.18°F}{140°F} \times 100\% = \pm 0.13\%$$

The RTD temperature sensors also have a *bias* error due to self-heating effects. Although Climatronics does not publish data on the self-heating effects of their RTDs in air, other platinum RTD manufacturers estimate a self-heating error of 0.12°F for meteorological applications. Expressed as a percent of span, SCA/SH_{TP} is determined as follows:

$$SCA / SH_{TP} = + \frac{0.12°F}{140°F} \times 100\% = +0.09\%$$

Note that self-heating effects are assumed not to affect the delta-temperature sensor calibration accuracies because the same bias error is assumed to affect both delta-temperature sensors equally.

3.3. *Sensor Drift (SD)*

This term accounts for variations in the sensor accuracy during the period between instrument calibrations and is considered a *random* error that can fluctuate during the averaging period.

The wind speed sensor consists of a mechanical chopper and photosensor that produces an output frequency proportional to wind speed. As such, there is no drift mechanism in this measurement technique. Likewise, the wind direction sensor is a precision potentiometer and variation of the resistance with time will not affect the ratio of the two segments of the potentiometers. As such, there is also no drift mechanism in this measurement technique.

For the RTDs, sensor drift is specified as better than or equal to ±0.09°F over a year. Since system calibrations at Millstone Station are performed quarterly, a conservative estimate of SD_{TP} expressed as a percent of span is as follows

$$SD_{TP} = S_{DT} = \pm \frac{0.09°F}{140°F} \times 100\% = \pm 0.06\%$$

3.4. *Rack Calibration Accuracy (RCA)*

This term accounts for the accuracy to which rack-mounted signal conditioning components can be calibrated. It is considered a *random* error that can fluctuate during the averaging period.

The accuracy of the data translators used for wind speed and wind direction is specified as ±0.05%. Expressed as a percent of span, RCA_{WS} and RCA_{WD} are determined as follows:

$$RCA_{WS} = RCA_{WD} = \pm 0.05\%$$

The accuracy of the data translators used for temperature and delta-temperature measurements represents a combination of the translators' conversion accuracy (±0.045°F) and linearity error (±0.05%). Expressed as a percent of span, RCA_{TP} and RCA_{DT} are determined as follows:

$$RCA_{TP} = \pm\sqrt{\left(\frac{0.045°F}{140°F}\times 100\%\right)^2 + (0.05\%)^2} = \pm 0.06\%$$

$$RCA_{DT} = \pm\sqrt{\left(\frac{0.045°F}{28°F}\times 100\%\right)^2 + (0.05\%)^2} = \pm 0.17\%$$

The data telemetry equipment linking the translators and the Plant Process Computers has an accuracy of ±0.22%. Expressed as a percent of span, RCA_{PPC} is defined as:

$$RCA_{PPC} = \pm 0.22\%$$

3.5. *Rack Drift (RD)*

This term accounts for variations in the rack-mounted signal conditioning component accuracies during the period between instrument calibrations. It has already been accounted for as part of the translator and telemetry equipment accuracy terms.

3.6. *Rack Temperature Effects (RTE)*

This term accounts for the error due to the difference in temperature when rack-mounted signal conditioning equipment is calibrated versus normal operating temperature. This term is considered a *random* error that does not fluctuate during the averaging period.

The instrument shelter containing the translators is monitored and an alarm is generated whenever pre-established limits (60°F to 80°F) are exceeded. Therefore, the maximum difference between normal operating temperature and the temperature at calibration is taken as 15°F. Given a translator temperature coefficient of ±0.005% per °F for each measurement channel and a 15°F change in the instrument shelter, RTE expressed as a percent of span is determined as follows:

$$RTE_{WS} = RTE_{WD} = RTE_{TP} = RTE_{DT} = \pm\frac{0.005\% \bullet 15°F}{°F} = \pm 0.08\%$$

3.7. *Overall Digital Accuracy (ODA)*

This term accounts for the overall accuracy of computing devices and is derived from an analysis that combines error sources such as analog-to-digital conversion, precision of computation, rounding or truncation, etc. It is considered a *random* error that can fluctuate during the averaging period. The ODA for each computer system is as follows:

$$ODA_{PPC1} = \pm 0.67\%$$

$$ODA_{PPC2} = \pm 0.05\%$$

$$ODA_{PPC3} = \pm 0.02\%$$

$$ODA_{EDAN} = \pm 0.10\%$$

3.8. *Measurement and Test Equipment Error (MTE)*

This term accounts for errors introduced by the test equipment and is considered a *random* error that does not fluctuate during the averaging period. Since the calibration of the meteorological instrumentation at Millstone Station utilizes instrumentation (e.g. digital voltmeters) with accuracy equal to or better than ±0.1%, MTE is determined as follows:

$$MTE = \pm 0.10\%$$

4. Calculated Channel Accuracies

4.1. Wind Speed

4.1.1. Instantaneous Values

The total probable error for the instantaneous wind speed data (TPE/WS_{INST}) in each of the computer systems is given by combining the sensor calibration accuracy SCA_{WS}, rack calibration accuracies RCA_{WS} and RCA_{PPC}, rack temperature effects RTE_{WS}, maintenance and test equipment accuracy MTE, and overall digital accuracy for each computer system ODA as follows:

$$TPE/WS_{INST/PPC1} = \pm\sqrt{SCA_{WS}^2 + RCA_{WS}^2 + RTE_{WS}^2 + MTE^2 + RCA_{PPC}^2 + ODA_{PPC1}^2}$$
$$= \pm\sqrt{(0.25\%)^2 + (0.05\%)^2 + (0.08\%)^2 + (0.10\%)^2 + (0.22\%)^2 + (0.67\%)^2}$$
$$= \pm 0.76\%$$

$$TPE/WS_{INST/PPC2} = \pm\sqrt{SCA_{WS}^2 + RCA_{WS}^2 + RTE_{WS}^2 + MTE^2 + RCA_{PPC}^2 + ODA_{PPC2}^2}$$
$$= \pm\sqrt{(0.25\%)^2 + (0.05\%)^2 + (0.08\%)^2 + (0.10\%)^2 + (0.22\%)^2 + (0.10\%)^2}$$
$$= \pm 0.37\%$$

$$TPE/WS_{INST/PPC3} = \pm\sqrt{SCA_{WS}^2 + RCA_{WS}^2 + RTE_{WS}^2 + MTE^2 + RCA_{PPC}^2 + ODA_{PPC3}^2}$$
$$= \pm\sqrt{(0.25\%)^2 + (0.05\%)^2 + (0.08\%)^2 + (0.10\%)^2 + (0.22\%)^2 + (0.02\%)^2}$$
$$= \pm 0.36\%$$

$$TPE/WS_{INST/EDAN} = \pm\sqrt{SCA_{WS}^2 + RCA_{WS}^2 + RTE_{WS}^2 + MTE^2 + ODA_{EDAN}^2}$$
$$= \pm\sqrt{(0.25\%)^2 + (0.05\%)^2 + (0.08\%)^2 + (0.10\%)^2 + (0.10\%)^2}$$
$$= \pm 0.30\%$$

At wind speeds up to 25 mph, the maximum wind speed errors for each computer system expressed in mph are as follows:

$$TPE/WS_{INST/PPC1} = (\pm 0.76\%) \times 100mph = \pm 0.76mph$$

$$TPE/WS_{INST/PPC2} = (\pm 0.37\%) \times 100mph = \pm 0.37mph$$

$$TPE/WS_{INST/PPC3} = (\pm 0.36\%) \times 100mph = \pm 0.36mph$$

$$TPE/WS_{INST/EDAN} = (\pm 0.30\%) \times 100mph = \pm 0.30mph$$

4.1.2. *Time Averaged Values*

The total probable error for time-averaged values (TPE/WS_{AVG}) was determined by dividing those random errors that can fluctuate during the averaging period by the square root of the number of samples (n) before taking the square root of the sum of the squares as follows:

$$TPE/WS_{AVG/PPC1} = \pm\sqrt{\frac{SCA_{WS}^2}{n} + \frac{RCA_{WS}^2}{n} + RTE_{WS}^2 + MTE^2 + \frac{RCA_{PPC}^2}{n} + \frac{ODA_{PPC1}^2}{n}}$$

$$= \pm\sqrt{\frac{(0.25\%)^2}{180} + \frac{(0.05\%)^2}{180} + (0.08\%)^2 + (0.10\%)^2 + \frac{(0.22\%)^2}{180} + \frac{(0.67\%)^2}{180}}$$

$$= \pm 0.14\%$$

$$TPE/WS_{AVG/PPC2} = \pm\sqrt{\frac{SCA_{WS}^2}{n} + \frac{RCA_{WS}^2}{n} + RTE_{WS}^2 + MTE^2 + \frac{RCA_{PPC}^2}{n} + \frac{ODA_{PPC2}^2}{n}}$$

$$= \pm\sqrt{\frac{(0.25\%)^2}{180} + \frac{(0.05\%)^2}{180} + (0.08\%)^2 + (0.10\%)^2 + \frac{(0.22\%)^2}{180} + \frac{(0.10\%)^2}{180}}$$

$$= \pm 0.13\%$$

$$TPE/WS_{AVG/PPC3} = \pm\sqrt{\frac{SCA_{WS}^2}{n} + \frac{RCA_{WS}^2}{n} + RTE_{WS}^2 + MTE^2 + \frac{RCA_{PPC}^2}{n} + \frac{ODA_{PPC3}^2}{n}}$$

$$= \pm\sqrt{\frac{(0.25\%)^2}{15} + \frac{(0.05\%)^2}{15} + (0.08\%)^2 + (0.10\%)^2 + \frac{(0.22\%)^2}{15} + \frac{(0.02\%)^2}{15}}$$

$$= \pm 0.15\%$$

$$TPE/WS_{AVG/EDAN} = \pm\sqrt{\frac{SCA_{WS}^2}{n} + \frac{RCA_{WS}^2}{n} + RTE_{WS}^2 + MTE^2 + \frac{ODA_{EDAN}^2}{n}}$$

$$= \pm\sqrt{\frac{(0.25\%)^2}{180} + \frac{(0.05\%)^2}{180} + (0.08\%)^2 + (0.10\%)^2 + \frac{(0.10\%)^2}{180}}$$

$$= \pm 0.13\%$$

At wind speeds up to 25 mph, the maximum wind speed errors for each computer system expressed in mph are as follows:

$$TPE/WS_{AVG/PPC1} = (\pm 0.14\%) \times 100mph = \pm 0.14mph$$

$$TPE/WS_{AVG/PPC2} = (\pm 0.13\%) \times 100mph = \pm 0.13mph$$

$$TPE/WS_{AVG/PPC3} = (\pm 0.15\%) \times 100mph = \pm 0.15mph$$

$$TPE/WS_{AVG/EDAN} = (\pm 0.13\%) \times 100mph = \pm 0.13mph$$

4.2. Wind Direction

4.2.1. Instantaneous Values

The total probable error for the instantaneous wind direction data (TPE/WD_{INST}) in each of the computer systems is given by combining the sensor calibration accuracy SCA_{WD}, rack calibration accuracies RCA_{WD} and RCA_{PPC}, rack temperature effects RTE_{WD}, maintenance and test equipment accuracy MTE, and overall digital accuracy ODA for each computer system as follows:

$$TPE/WD_{INST/PPC1} = \pm\sqrt{SCA_{WD}^2 + RCA_{WD}^2 + RTE_{WD}^2 + MTE^2 + RCA_{PPC}^2 + ODA_{PPC1}^2}$$
$$= \pm\sqrt{(0.56\%)^2 + (0.05\%)^2 + (0.08\%)^2 + (0.10\%)^2 + (0.22\%)^2 + (0.67\%)^2}$$
$$= \pm 0.91\%$$

$$TPE/WD_{INST/PPC2} = \pm\sqrt{SCA_{WD}^2 + RCA_{WD}^2 + RTE_{WD}^2 + MTE^2 + RCA_{PPC}^2 + ODA_{PPC2}^2}$$
$$= \pm\sqrt{(0.56\%)^2 + (0.05\%)^2 + (0.08\%)^2 + (0.10\%)^2 + (0.22\%)^2 + (0.10\%)^2}$$
$$= \pm 0.63\%$$

$$TPE/WD_{INST/PPC3} = \pm\sqrt{SCA_{WD}^2 + RCA_{WD}^2 + RTE_{WD}^2 + MTE^2 + RCA_{PPC}^2 + ODA_{PPC3}^2}$$
$$= \pm\sqrt{(0.56\%)^2 + (0.05\%)^2 + (0.08\%)^2 + (0.10\%)^2 + (0.22\%)^2 + (0.02\%)^2}$$
$$= \pm 0.62\%$$

$$TPE/WD_{INST/EDAN} = \pm\sqrt{SCA_{WD}^2 + RCA_{WD}^2 + RTE_{WD}^2 + MTE^2 + ODA_{EDAN}^2}$$
$$= \pm\sqrt{(0.56\%)^2 + (0.05\%)^2 + (0.08\%)^2 + (0.10\%)^2 + (0.10\%)^2}$$
$$= \pm 0.59\%$$

Expressed in degrees, the error for wind direction in each computer system is as follows:

$$TPE/WD_{INST/PPC1} = (\pm 0.91\%) \times 540° = \pm 4.9°$$

$$TPE/WD_{INST/PPC2} = (\pm 0.63\%) \times 540° = \pm 3.4°$$

$$TPE/WD_{INST/PPC3} = (\pm 0.62\%) \times 540° = \pm 3.3°$$

$$TPE/WD_{INST/EDAN} = (\pm 0.59\%) \times 540° = \pm 3.2°$$

4.2.2. *Time Averaged Values*

The total probable error for time-averaged values (TPE/WD_{AVG}) was determined by dividing those random errors that can fluctuate during the averaging period by the square root of the number of samples (n) before taking the square root of the sum of the squares as follows:

$$TPE/WD_{AVG/PPC1} = \pm\sqrt{\frac{SCA_{WD}^2}{n} + \frac{RCA_{WD}^2}{n} + RTE_{WD}^2 + MTE^2 + \frac{RCA_{PPC}^2}{n} + \frac{ODA_{PPC1}^2}{n}}$$

$$= \pm\sqrt{\frac{(0.56\%)^2}{180} + \frac{(0.05\%)^2}{180} + (0.08\%)^2 + (0.10\%)^2 + \frac{(0.22\%)^2}{180} + \frac{(0.67\%)^2}{180}}$$

$$= \pm 0.14\%$$

$$TPE/WD_{AVG/PPC2} = \pm\sqrt{\frac{SCA_{WD}^2}{n} + \frac{RCA_{WD}^2}{n} + RTE_{WD}^2 + MTE^2 + \frac{RCA_{PPC}^2}{n} + \frac{ODA_{PPC2}^2}{n}}$$

$$= \pm\sqrt{\frac{(0.56\%)^2}{180} + \frac{(0.05\%)^2}{180} + (0.08\%)^2 + (0.10\%)^2 + \frac{(0.22\%)^2}{180} + \frac{(0.10\%)^2}{180}}$$

$$= \pm 0.14\%$$

$$TPE/WD_{AVG/PPC3} = \pm\sqrt{\frac{SCA_{WD}^2}{n} + \frac{RCA_{WD}^2}{n} + RTE_{WD}^2 + MTE^2 + \frac{RCA_{PPC}^2}{n} + \frac{ODA_{PPC3}^2}{n}}$$

$$= \pm\sqrt{\frac{(0.56\%)^2}{15} + \frac{(0.05\%)^2}{15} + (0.08\%)^2 + (0.10\%)^2 + \frac{(0.22\%)^2}{15} + \frac{(0.02\%)^2}{15}}$$

$$= \pm 0.20\%$$

$$TPE/WD_{AVG/EDAN} = \pm\sqrt{\frac{SCA_{WD}^2}{n} + \frac{RCA_{WD}^2}{n} + RTE_{WD}^2 + MTE^2 + \frac{ODA_{EDAN}^2}{n}}$$

$$= \pm\sqrt{\frac{(0.56\%)^2}{180} + \frac{(0.05\%)^2}{180} + (0.08\%)^2 + (0.10\%)^2 + \frac{(0.10\%)^2}{180}}$$

$$= \pm 0.13\%$$

Expressed in degrees, the error for wind direction in each computer system is as follows:

$$TPE/WD_{AVG/PPC1} = (\pm 0.14\%) \times 540° = \pm 0.8°$$

$$TPE/WD_{AVG/PPC2} = (\pm 0.14\%) \times 540° = \pm 0.8°$$

$$TPE/WD_{AVG/PPC3} = (\pm 0.20\%) \times 540° = \pm 1.1°$$

$$TPE/WD_{AVG/EDAN} = (\pm 0.13\%) \times 540° = \pm 0.7°$$

4.3. Temperature

4.3.1. Instantaneous Values

The total probable error for the instantaneous temperature data (TPE/TP_{INST}) in each of the computer systems is given by combining the process measurement accuracy PMA_{TP}, sensor calibration accuracy SCA_{TP} (including self-heating effects SCA/SH_{TP}), sensor drift SD_{TP}, rack calibration accuracy RCA_{TP} and RCA_{PPC}, rack temperature effects RTE_{TP}, maintenance and test equipment accuracy MTE, and overall digital accuracy for each computer system ODA as follows:

$$TPE/TP_{INST/PPC1} = \pm\sqrt{SCA_{TP}^2 + SD_{TP}^2 + RCA_{TP}^2 + RTE_{TP}^2 + MTE^2 + RCA_{PPC}^2 + ODA_{PPC1}^2}$$
$$+ PMA_{TP} + SCA/SH_{TP}$$
$$= \pm\sqrt{(0.13\%)^2 + (0.06\%)^2 + (0.06\%)^2 + (0.08\%)^2 + (0.10\%)^2 + (0.22\%)^2 + (0.67\%)^2}$$
$$+0.14\% + 0.09\% = \pm 0.73\% + 0.23\% = -0.50\% \rightarrow +0.96\%$$

$$TPE/TP_{INST/PPC2} = \pm\sqrt{SCA_{TP}^2 + SD_{TP}^2 + RCA_{TP}^2 + RTE_{TP}^2 + MTE^2 + RCA_{PPC}^2 + ODA_{PPC2}^2}$$
$$+ PMA_{TP} + SCA/SH_{TP}$$
$$= \pm\sqrt{(0.13\%)^2 + (0.06\%)^2 + (0.06\%)^2 + (0.08\%)^2 + (0.10\%)^2 + (0.22\%)^2 + (0.10\%)^2}$$
$$+0.14\% + 0.09\% = \pm 0.31\% + 0.23\% = -0.08\% \rightarrow +0.54\%$$

$$TPE/TP_{INST/PPC3} = \pm\sqrt{SCA_{TP}^2 + SD_{TP}^2 + RCA_{TP}^2 + RTE_{TP}^2 + MTE^2 + RCA_{PPC}^2 + ODA_{PPC3}^2}$$
$$+ PMA_{TP} + SCA/SH_{TP}$$
$$= \pm\sqrt{(0.13\%)^2 + (0.06\%)^2 + (0.06\%)^2 + (0.08\%)^2 + (0.10\%)^2 + (0.22\%)^2 + (0.02\%)^2}$$
$$+0.14\% + 0.09\% = \pm 0.29\% + 0.23\% = -0.06\% \rightarrow +0.52\%$$

$$TPE/TP_{INST/EDAN} = \pm\sqrt{SCA_{TP}^2 + SD_{TP}^2 + RCA_{TP}^2 + RTE_{TP}^2 + MTE^2 + ODA_{EDAN}^2}$$
$$+ PMA_{TP} + SCA/SH_{TP}$$
$$= \pm\sqrt{(0.13\%)^2 + (0.06\%)^2 + (0.06\%)^2 + (0.08\%)^2 + (0.10\%)^2 + (0.10\%)^2}$$
$$+0.14\% + 0.09\% = \pm 0.22\% + 0.23\% = +0.01\% \rightarrow +0.45\%$$

Expressed in °F, the error for temperature in each computer system is as follows:

$$TPE/TP_{INST/PPC1} = (-0.50\% \rightarrow +0.96\%) \times 140°F = -0.70°F \rightarrow +1.34°F$$

$$TPE/TP_{INST/PPC2} = (-0.08\% \rightarrow +0.54\%) \times 140°F = -0.11°F \rightarrow +0.76°F$$

$$TPE/TP_{INST/PPC3} = (-0.06\% \rightarrow +0.52\%) \times 140°F = -0.08°F \rightarrow +0.73°F$$

$$TPE/TP_{INST/EDAN} = (+0.01\% \rightarrow +0.45\%) \times 140°F = +0.01°F \rightarrow +0.63°F$$

4.3.2. *Time Averaged Values*

The total probable error for time-averaged values (TPE/TP_{AVG}) was determined by dividing those random errors that can fluctuate during the averaging period by the square root of the number of samples (n) before taking the square root of the sum of the squares as follows:

$$TPE/TP_{AVG/PPC1} = \pm\sqrt{\frac{SCA_{TP}^2}{n} + \frac{SD_{TP}^2}{n} + \frac{RCA_{TP}^2}{n} + RTE_{TP}^2 + MTE^2 + \frac{RCA_{PPC}^2}{n} + \frac{ODA_{PPC1}^2}{n}}$$
$$+ PMA_{TP} + SCA/SH_{TP}$$
$$= \pm\sqrt{\frac{(0.13\%)^2}{180} + \frac{(0.06\%)^2}{180} + \frac{(0.06\%)^2}{180} + (0.08\%)^2 + (0.10\%)^2 + \frac{(0.22\%)^2}{180} + \frac{(0.10\%)^2}{180}}$$
$$+ 0.14\% + 0.09\% = \pm 0.14\% + 0.23\% = +0.09\% \rightarrow 0.37\%$$

$$TPE/TP_{AVG/PPC2} = \pm\sqrt{\frac{SCA_{TP}^2}{n} + \frac{SD_{TP}^2}{n} + \frac{RCA_{TP}^2}{n} + RTE_{TP}^2 + MTE^2 + \frac{RCA_{PPC}^2}{n} + \frac{ODA_{PPC2}^2}{n}}$$
$$+ PMA_{TP} + SCA/SH_{TP}$$
$$= \pm\sqrt{\frac{(0.13\%)^2}{180} + \frac{(0.06\%)^2}{180} + \frac{(0.06\%)^2}{180} + (0.08\%)^2 + (0.10\%)^2 + \frac{(0.22\%)^2}{180} + \frac{(0.10\%)^2}{180}}$$
$$+ 0.14\% + 0.09\% = \pm 0.13\% + 0.23\% = +0.10\% \rightarrow +0.36\%$$

$$TPE/TP_{AVG/PPC3} = \pm\sqrt{\frac{SCA_{TP}^2}{n} + \frac{SD_{TP}^2}{n} + \frac{RCA_{TP}^2}{n} + RTE_{TP}^2 + MTE^2 + \frac{RCA_{PPC}^2}{n} + \frac{ODA_{PPC3}^2}{n}}$$
$$+ PMA_{TP} + SCA/SH_{TP}$$
$$= \pm\sqrt{\frac{(0.13\%)^2}{15} + \frac{(0.06\%)^2}{15} + \frac{(0.06\%)^2}{15} + (0.08\%)^2 + (0.10\%)^2 + \frac{(0.22\%)^2}{15} + \frac{(0.02\%)^2}{15}}$$
$$+ 0.14\% + 0.09\% = \pm 0.15\% + 0.23\% = +0.08\% \rightarrow +0.38\%$$

$$TPE/TP_{AVG/EDAN} = \pm\sqrt{\frac{SCA_{TP}^2}{n} + \frac{SD_{TP}^2}{n} + \frac{RCA_{TP}^2}{n} + RTE_{TP}^2 + MTE^2 + \frac{ODA_{EDAN}^2}{n}}$$
$$+ PMA_{TP} + SCA/SH_{TP}$$
$$= \pm\sqrt{\frac{(0.13\%)^2}{180} + \frac{(0.06\%)^2}{180} + \frac{(0.06\%)^2}{180} + (0.08\%)^2 + (0.10\%)^2 + \frac{(0.10\%)^2}{180}}$$
$$+ 0.14\% + 0.09\% = \pm 0.13\% + 0.23\% = +0.10\% \rightarrow +0.36\%$$

Expressed in °F, the error for temperature in each computer system is as follows:

$$TPE / TP_{AVG/PPC1} = (+0.09\% \rightarrow +0.37\%) \times 140°F = +0.13°F \rightarrow +0.52°F$$

$$TPE / TP_{AVG/PPC2} = (+0.10\% \rightarrow +0.36\%) \times 140°F = +0.14°F \rightarrow +0.50°F$$

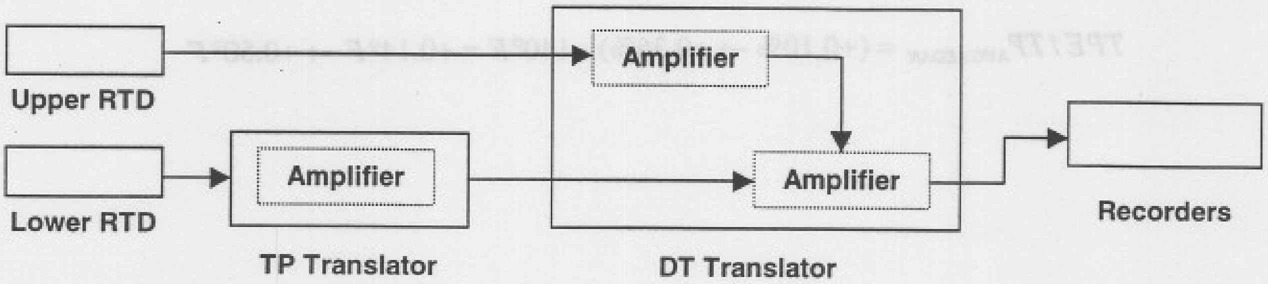
$$TPE / TP_{AVG/PPC3} = (+0.08\% \rightarrow +0.38\%) \times 140°F = +0.11°F \rightarrow +0.53°F$$

$$TPE / TP_{AVG/EDAN} = (+0.10\% \rightarrow +0.36\%) \times 140°F = +0.14°F \rightarrow +0.50°F$$

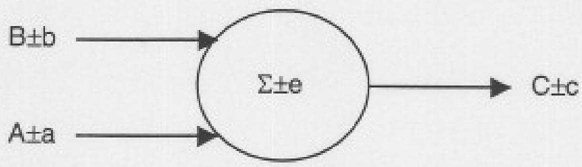
4.4. Delta-Temperature

4.4.1. Instantaneous Values

The delta-temperature measurements are made using a translator that acts as a "summing amplifier"; that is, the reported measurement is a result of the difference between two temperature measurements:



Reference [4] provides the following equation for estimating instrument errors when summing amplifiers are used:



$$C = k_2 B - k_1 A;$$
$$c = \sqrt{(k_1 a)^2 + (k_2 b)^2 + e^2}$$

where the capital letters (A, B, and C) are in terms of a fraction of the transmitted signal, the small case letters (a, b, c, and e) represent errors in percent of span, and k_1 and k_2 are scaling constants. Assuming each RTD has a range of -30°F to +110°F and the delta-temperature translator has a range of -10°F to +18°F:

$$Temp_{RTDA} = -30°F + 140°F \times A$$

$$Temp_{RTDB} = -30°F + 140°F \times B$$

$$DT_{RTDB-RTDA} = -10°F + 28°F \times C$$

Then:

$$DT_{RTDB-RTDA} = Temp_{RTDB} - Temp_{RTDA}$$

$$-10°F + 28°F \times C = (-30°F + 140°F \times B) - (-30°F + 140°F \times A)$$

$$28°F \times C = 140°F \times B - 140°F \times A + 10°F$$

$$C = 5°F \times B - 5°F \times A + 0.357°F$$

Therefore, the scaling constants and k_1 and k_2 are:

$$k_1 = 5$$
$$k_2 = 5$$

The error terms a and b associated with the lower and upper RTD measurements are a combination of sensor calibration accuracy SCA_{TP} and sensor drift SD_{TP} as follows:

$$a = b = \sqrt{SCA_{TP}^2 + SD_{TP}^2 + RCA_{TP}^2 + RTE_{TP}^2}$$
$$= \sqrt{(0.13\%)^2 + (0.06\%)^2 + (0.06\%)^2 + (0.08\%)^2} = 0.17\%$$

The error term e associated with the delta-temperature translator is a combination of rack calibration accuracy RCA_{DT} and rack temperature effects RTE_{DT} as follows:

$$e = \sqrt{RCA_{DT}^2 + RTE_{DT}^2} = \sqrt{(0.17\%)^2 + (0.08\%)^2} = 0.19\%$$

The error term c representing the delta-temperature channel error from the RTD sensors to the delta-temperature translator output is as follows:

$$c = \sqrt{(k_1 a)^2 + (k_2 b)^2 + e^2} = \sqrt{(5 \times 0.17\%)^2 + (5 \times 0.17\%)^2 + (0.19\%)^2} = 1.22\%$$

The total probable error for the instantaneous temperature data (TPE/DT_{INST}) in each of the computer systems is given by combining the translator output accuracy c with maintenance and test equipment accuracy MTE and overall digital accuracy ODA for each computer system as follows:

$$TPE / DT_{INST/PPC1} = \pm\sqrt{c^2 + MTE^2 + RCA_{PPC}^2 + ODA_{PPC1}^2}$$
$$= \pm\sqrt{(1.22\%)^2 + (0.10\%)^2 + (0.22\%)^2 + (0.67\%)^2} = \pm 1.41\%$$

$$TPE / DT_{INST/PPC2} = \pm\sqrt{c^2 + MTE^2 + RCA_{PPC}^2 + ODA_{PPC2}^2}$$
$$= \pm\sqrt{(1.22\%)^2 + (0.10\%)^2 + (0.22\%)^2 + (0.10\%)^2} = \pm 1.25\%$$

$$TPE / DT_{INST/PPC3} = \pm\sqrt{c^2 + MTE^2 + RCA_{PPC}^2 + ODA_{PPC3}^2}$$
$$= \pm\sqrt{(1.22\%)^2 + (0.10\%)^2 + (0.22\%)^2 + (0.02\%)^2} = \pm 1.25\%$$

$$TPE / DT_{INST/EDAN} = \pm\sqrt{c^2 + MTE^2 + ODA_{EDAN}^2}$$
$$= \pm\sqrt{(1.22\%)^2 + (0.10\%)^2 + (0.10\%)^2} = \pm 1.23\%$$

Expressed in °F, the error for delta-temperature in each computer system is as follows:

$$TPE / DT_{INST/PPC1} = (\pm 1.41\%) \times 28°F = \pm 0.39°F$$

$$TPE / DT_{INST/PPC2} = (\pm 1.25\%) \times 28°F = \pm 0.35°F$$

$$TPE / DT_{INST/PPC3} = (\pm 1.25\%) \times 28°F = \pm 0.35°F$$

$$TPE / DT_{INST/EDAN} = (\pm 1.23\%) \times 28°F = \pm 0.34°F$$

4.4.2. *Time Averaged Values*

The total probable error for time-averaged values (TPE/DT_{AVG}) was determined by dividing those random errors that can fluctuate during the averaging period by the square root of the number of samples (n) before taking the square root of the sum of the squares as described below.

The error terms a and b associated with the lower and upper RTD measurements are a combination of sensor calibration accuracy SCA_{TP} and sensor drift SD_{TP} as follows:

For PPC1, PPC2, and EDAN computers:

$$a = b = \sqrt{\frac{SCA_{TP}^2}{n} + \frac{SD_{TP}^2}{n} + \frac{RCA_{TP}^2}{n} + RTE_{TP}^2}$$

$$= \sqrt{\frac{(0.13\%)^2}{180} + \frac{(0.06\%)^2}{180} + \frac{(0.06\%)^2}{180} + (0.08\%)^2} = 0.08\%$$

For the PPC3 computer:

$$a = b = \sqrt{\frac{SCA_{TP}^2}{n} + \frac{SD_{TP}^2}{n} + \frac{RCA_{TP}^2}{n} + RTE_{TP}^2}$$

$$= \sqrt{\frac{(0.13\%)^2}{15} + \frac{(0.06\%)^2}{15} + \frac{(0.06\%)^2}{15} + (0.08\%)^2} = 0.09\%$$

The error term e associated with the delta-temperature translator e is a combination of rack calibration accuracy RCA_{DT} and rack temperature effects RTE_{DT} as follows:

For PPC1, PPC2, and EDAN computers:

$$e = \sqrt{\frac{RCA_{DT}^2}{n} + RTE_{DT}^2} = \sqrt{\frac{(0.17\%)^2}{180} + (0.08\%)^2} = 0.08\%$$

For the PPC3 computer:

$$e = \sqrt{\frac{RCA_{DT}^2}{n} + RTE_{DT}^2} = \sqrt{\frac{(0.17\%)^2}{15} + (0.08\%)^2} = 0.09\%$$

The error term c representing the delta-temperature channel error from the RTD sensors to the delta-temperature translator output is as follows:

For PPC1, PPC2, and EDAN computers:

$$c = \sqrt{(k_1 a)^2 + (k_2 b)^2 + e^2} = \sqrt{(5 \times 0.08\%)^2 + (5 \times 0.08\%)^2 + (0.08\%)^2} = 0.57\%$$

For the PPC3 computer:

$$c = \sqrt{(k_1 a)^2 + (k_2 b)^2 + e^2} = \sqrt{(5 \times 0.09\%)^2 + (5 \times 0.09\%)^2 + (0.09\%)^2} = 0.64\%$$

The total probable error for the average temperature data (TPE/DT_{AVG}) in each of the computer systems is given by combining the translator output accuracy c with maintenance and test equipment accuracy MTE and overall digital accuracy ODA for each computer system as follows:

$$TPE/DT_{AVG/PPC1} = \pm\sqrt{c^2 + MTE^2 + \frac{RCA_{PPC}^2}{n} + \frac{ODA_{PPC1}^2}{n}}$$

$$= \pm\sqrt{(0.57\%)^2 + (0.10\%)^2 + \frac{(0.22\%)^2}{180} + \frac{(0.67\%)^2}{180}} = \pm 0.58\%$$

$$TPE/DT_{AVG/PPC2} = \pm\sqrt{c^2 + MTE^2 + \frac{RCA_{PPC}^2}{n} + \frac{ODA_{PPC2}^2}{n}}$$

$$= \pm\sqrt{(0.57\%)^2 + (0.10\%)^2 + \frac{(0.22\%)^2}{180} + \frac{(0.10\%)^2}{180}} = \pm 0.58\%$$

$$TPE/DT_{AVG/PPC3} = \pm\sqrt{c^2 + MTE^2 + \frac{RCA_{PPC}^2}{n} + \frac{ODA_{PPC3}^2}{n}}$$

$$= \pm\sqrt{(0.64\%)^2 + (0.10\%)^2 + \frac{(0.22\%)^2}{15} + \frac{(0.02\%)^2}{15}} = \pm 0.65\%$$

$$TPE/DT_{AVG/EDAN} = \pm\sqrt{c^2 + MTE^2 + \frac{ODA_{EDAN}^2}{n}}$$

$$= \pm\sqrt{(0.57\%)^2 + (0.10\%)^2 + \frac{(0.10\%)^2}{180}} = \pm 0.58\%$$

Expressed in °F, the error for delta-temperature in each computer system is as follows:

$$TPE / DT_{AVG/PPC1} = (\pm 0.58\%) \times 28°F = \pm 0.16°F$$

$$TPE / DT_{AVG/PPC2} = (\pm 0.58\%) \times 28°F = \pm 0.16°F$$

$$TPE / DT_{AVG/PPC3} = (\pm 0.65\%) \times 28°F = \pm 0.18°F$$

$$TPE / DT_{AVG/EDAN} = (\pm 0.58\%) \times 28°F = \pm 0.16°F$$

5. *Conclusion*

Exhibit 4 presents the resulting calculated wind speed, wind direction, temperature, and delta-temperature accuracies for instantaneous and time-averaged values for each of the four different computer readouts. A review of the inputs and final results of this analysis leads to the following general conclusions:

- For instantaneous values, the components with the largest sources of error for the wind speed and direction channels tend to be the wind sensors. For the temperature and delta-temperature channels using calibrated RTDs with matched translator cards, all components tend to provide similar sources of error.

- Older generation computer and telemetry technology can also provide significant sources of error for instantaneous values.

- Time averaging significantly improves channel accuracies, even at relatively low sampling frequencies. For example, the calculated total probable error for the instantaneous delta-temperature values exceed the Regulatory Guide 1.23 accuracy specifications whereas the calculated total probable error for the time-averaged delta-temperature values meet the Regulatory Guide 1.23 accuracy specifications.

6. References

1. U.S. Nuclear Regulatory Agency, "Onsite Meteorological Programs," Safety Guide 23 (Regulatory Guide 1.23, Rev. 0), February 17, 1972.

2. Nuclear Regulatory Commission, "Instrumentation for Light-Water-Cooled Nuclear Power Plants to Assess Plant and Environs Conditions During and Following An Accident," Regulatory Guide 1.97, Revision 2, December 1980.

3. American Nuclear Society, "Standard for Determining Meteorological Information at Nuclear Power Sites," ANSI/ANS-2.5-1984, September 14, 1984.

4. Northeast Utilities Service Company, "Guidelines for Calculating Instrument Uncertainties," Specification SP-ST-EE-286, Revision 6.

EXHIBIT 1

Regulatory Guidance Meteorological Instrumentation Accuracy Specifications

Channel	Reg. Guide 1.23 Rev. 0	Reg. Guide 1.97 Rev. 2	Reg. Guide 1.97 Rev. 3	ANSI/ANS-2.5 1984[1]
Wind Speed	±0.5 mph (time averaged values)	±0.5 mph for WS < 25 mph	±0.5 mph for WS < 5 mph ±10% for WS > 5 mph	±0.5 mph for WS < 5 mph ±10% for WS > 5 mph (time averaged values)
Wind Direction	±5° (instantaneous values)	±5°	±5°	±5° (time averaged values)
Temperature	±0.9°F (time averaged values)	NA	NA	±0.9°F (time averaged values)
Delta-Temperature	±0.18°F (time averaged values)	±0.27°F per 50m	±0.27°F per 50m	±0.27°F per 50m (time averaged values)

[1] The accuracies shown are applicable to digital systems. For analog systems, error limits are the same as those listed except that the limits of accuracy for wind speed and direction records are 1.5 time those listed for digital systems.

EXHIBIT 2

Millstone Station Primary Meteorological Tower Data Link Configuration

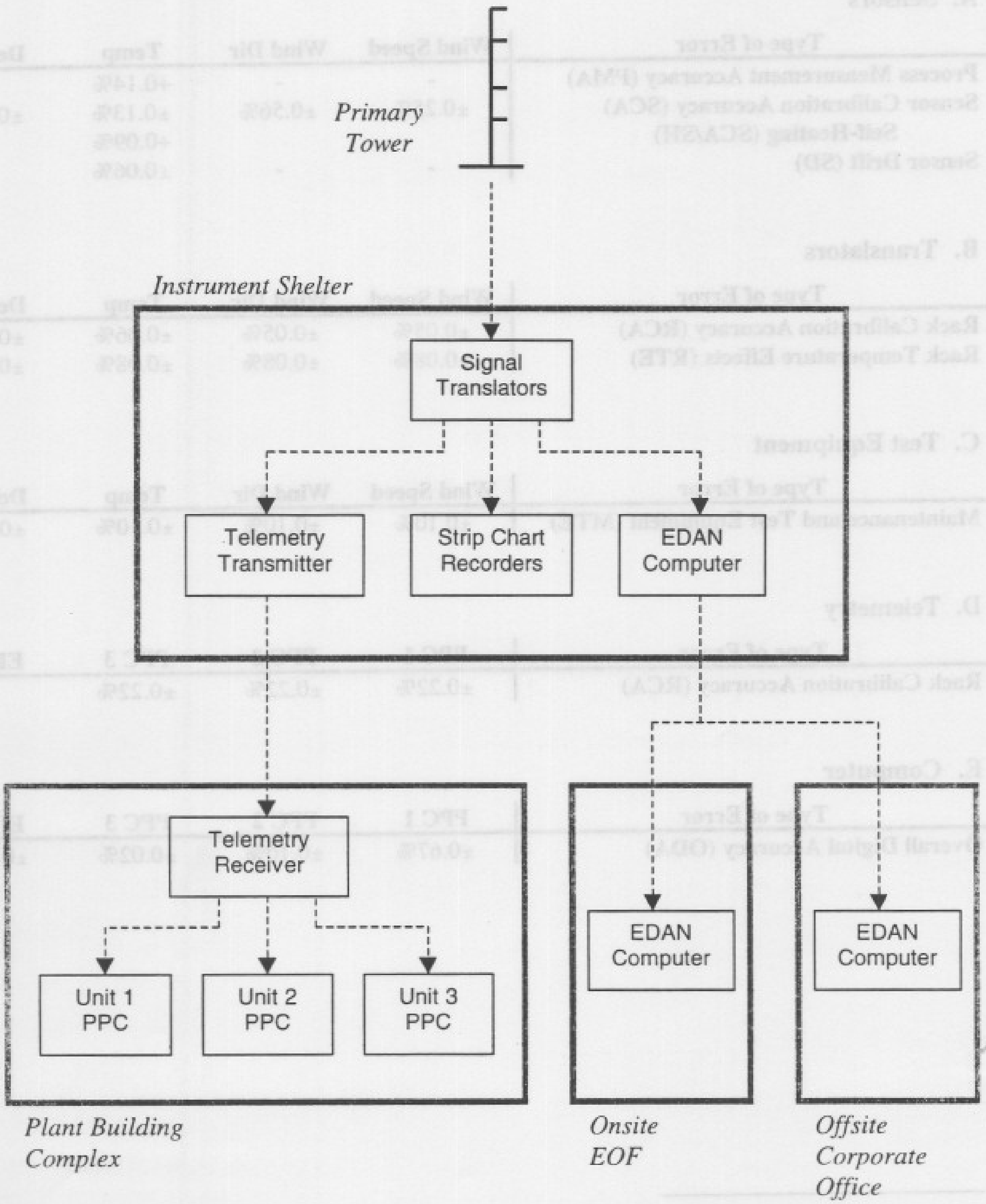


EXHIBIT 3

Millstone Station Meteorological Monitoring System Component Accuracies[1]

A. Sensors

Type of Error	Wind Speed	Wind Dir	Temp	Delta-T
Process Measurement Accuracy (PMA)	-	-	+0.14%	-
Sensor Calibration Accuracy (SCA)	±0.25%	±0.56%	±0.13%	±0.13%
Self-Heating (SCA/SH)			+0.09%	
Sensor Drift (SD)	-	-	±0.06%	-

B. Translators

Type of Error	Wind Speed	Wind Dir	Temp	Delta-T
Rack Calibration Accuracy (RCA)	±0.05%	±0.05%	±0.06%	±0.17%
Rack Temperature Effects (RTE)	±0.08%	±0.08%	±0.08%	±0.08%

C. Test Equipment

Type of Error	Wind Speed	Wind Dir	Temp	Delta-T
Maintenance and Test Equipment (MTE)	±0.10%	±0.10%	±0.10%	±0.10%

D. Telemetry

Type of Error	PPC 1	PPC 2	PPC 3	EDAN
Rack Calibration Accuracy (RCA)	±0.22%	±0.22%	±0.22%	-

E. Computer

Type of Error	PPC 1	PPC 2	PPC 3	EDAN
Overall Digital Accuracy (ODA)	±0.67%	±0.10%	±0.02%	±0.10%

[1] All accuracies are presented as a percent of span. Random errors are identified with "±" signs; bias errors are identified with either a "+" or "-" sign.

EXHIBIT 4

Resulting Calculated Instrument Accuracies

CHANNEL	INSTANTANEOUS VALUES				TIME-AVERAGED VALUES				RG 1.23 SPECS[1]
	PPC1	PPC2	PPC3	EDAN	PPC1	PPC2	PPC3	EDAN	
Wind Speed[2] (mph)	±0.76	±0.37	±0.36	±0.30	±0.14	±0.13	±0.15	±0.13	±0.5
Wind Direction (°)	±4.9	±3.4	±3.3	±3.2	±0.8	±0.8	±1.1	±0.7	±5
Temperature (°F)	-0.70 to +1.34	-0.11 to +0.76	-0.08 to +0.73	+0.01 to +0.63	+0.13 to +0.52	+0.14 to +0.50	+0.11 to +0.53	+0.14 to +0.50	±0.9
Delta-Temp (°F)	±0.39	±0.35	±0.35	±0.34	±0.16	±0.16	±0.18	±0.16	±0.18

[1] Regulatory Guide 1.23 wind speed, temperature, and delta-temperature accuracy specifications are applicable to time-averaged values; the wind direction accuracy specifications are applicable to instantaneous values.

[2] The listed wind speed accuracies are applicable for 25 mph wind speeds.