NISTIR 7659

# Phase III: Evaluation of an Acceptance Sampling Method for 2D/3D Building Plans

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# Abstract

The General Services Administration (GSA) established the National 3D-4D-BIM (Three dimensional-Four Dimensional Building Information Model) Program in 2003. A part of the program involves 3D imaging, and the National Institute of Standards Technology (NIST) was contracted by GSA to assist them in this area. The past GSA-NIST collaboration consisted of:

- Phase I - "BIM Guide for 3D Imaging" (Cheok and Lytle, 2009). This document was prepared to provide a general introduction to 3D imaging and its implementation on GSA projects for GSA project managers.
- Phase II – Updating of the "BIM Guide for 3D Imaging" based on industry feedback. Additionally, a method for objectively assessing the deliverables from 3D imaging data (in this case 2D plans) was developed and documented in "Guidelines for Accepting 2D Building Plans" (Cheok, et al., 2008). This method provides a systematic answer to the question:

  *Are the dimensional deviations from the derived 2D plans within the specifications stated in the contract?*

The current effort, Phase III, is the subject of this report. In Phase III, the focus is on evaluating and demonstrating the method proposed in Phase II using an actual GSA facility. In particular, the objective of Phase III is to determine practical/feasible limits for the tolerances (***T***), sample size (***n***), and the maximum percent of the population (***P***) out-of-spec that is acceptable for GSA. In brief, a total of 285 measurements were obtained from a GSA 3D imaging project site by NIST and CMU (Carnegie Mellon University). These measurements were then compared to corresponding measurements extracted from 2D plans or 3D models. Several thousands of simulations were run for different combinations of samples (i.e., to randomize the data sampling) for a given set of ***n***, ***P***, and ***T***. The data collection, data analysis, and findings from Phase III are presented in this report.


UNITS USED IN THIS REPORT

It is the policy of NIST to use SI units in all of its publications. The units in this report are given in U.S. standard units (with SI units given within parenthesis) as these units are preferred by the project sponsor.

# Contents

# 1 Introduction

The U.S. General Services Administration (GSA) Office of the Chief Architect is conducting on-going research in the use of 3D-4D-BIM (Three dimensional – Four dimensional Building Information Model) technologies. Specifically, GSA is investigating the use of three-dimensional (3D) imaging technologies (e.g., laser scanning) to capture existing conditions of government facilities. The use of 3D imaging technology is a relatively new technology for the types of application that are of interest to GSA. Thus, there are currently neither standards nor guidelines for this technology. However, there are on-going efforts (e.g., ASTM E57 – 3D Imaging Systems) to develop these standards and guidelines.

In the interim, GSA has been involved in developing guidance for GSA project managers to assess the application of 3D imaging in GSA projects. As a part of this effort, GSA contracted the National Institute of Standards and Technology (NIST) to contribute to the development of the guidance documents. This collaboration resulted in the publication of:

- Phase I and II - "BIM Guide for 3D Imaging" (Cheok and Lytle, 2009). The initial draft was the outcome of Phase I, and the draft was revised based on input from the 3D imaging community in Phase II. This document provides a general introduction to and guidance for 3D imaging to GSA project managers.

- Phase II - "Guidelines for Accepting 2D Building Plans" (Cheok, et al., 2008). The objective of this document is to aid GSA in the objective assessment of the deliverables from 3D imaging data – in particular, 2D building plans. The guideline provides a systematic answer to the question:

  *Are the dimensional deviations from the derived 2D plans within the specifications stated in the contract?*

In Phase III, the focus is on evaluating and demonstrating the procedure developed from Phase II using an actual GSA facility. In particular, the objective is to determine practical/feasible limits for the tolerances (***T***), sample size (***n***), and the maximum percent of the population (***P***) out-of-spec that is acceptable for GSA. To satisfy the objective, it was necessary to obtain field measurements from a facility and then comparing these measurements to corresponding measurements extracted from 2D plans or 3D models. Several thousands of simulations were run for different combinations of samples (i.e., to randomize the data sampling) for a given set of ***n***, ***P***, and ***T***. The data collection, data analysis, and findings from Phase III are presented in this report.

Section 2 of this report outlines the acceptance sampling method developed in Phase II. Section 3 describes the data collection process. The data analysis and sampling strategies used for the simulations are described in Section 4. Section 5 presents and discusses the findings. A summary of the project is given in Section 6. The data collected in the field is given in Appendix A. A table listing the upper limits

(***p***) on % Defective in Population for all the sample sizes used in this report is given in Appendix B. The results of all the runs performed are tabulated in Appendix C.

# 2 Summary of Phase II

The report "Guidelines for Accepting 2D Building Plans" (Cheok, et al., 2008) details a method utilizing Acceptance Sampling to either accept or reject a 2D building plan. An outline of this method is reproduced below for convenience.

1. *Determine and list each measurement type (name and description) that is important.*
2. *Specify how the measurements are to be made. This step includes:*
    a. *Specifying the type of instrument used to obtain the measurements*
    b. *Proof of calibration of the instrument and any required in-field checks*
    c. *Describing how the measurements are to be obtained. For example,*
        i. *Are measurements to be made multiple times and reporting the average?*
        ii. *If a door width is to be measured, where should be the measurements be made?*
3. *Specify the criteria for conformity for each type of measurement. Clearly describe when the measurement is "in-spec" or "out-of-spec" (defective).*
4. *Develop the sampling plan*
    a. *Define tolerance, **T***
    b. *Define **P***
    c. *Define sample size, **n***
5. *Select Experiment Design*
    a. *Randomized Acceptance Sampling*
    b. *Stratified Randomized Acceptance Sampling*
6. *Develop in conjunction with a statistician an Experiment Design based on the Response Types and Factors.*
    a. *If there are no existing plans, then the determination of which measurements to make will have to be performed manually. For example, manually identify the doors, randomly select the required number of doors.*
    b. *If there are existing plans, then the determination of the measurements may be performed prior to the fieldwork. There is on-going research to automate this process, i.e., automatically extract the doors from the plans, generate the list, and randomly select the doors.*
7. *Execute Experiment Design*
8. *Analyze the data to obtain **d** (number of defects)*
9. *Use upper limit table (see Appendix B, Table B1) to Accept or Reject. If Reject,*
    a. *Reject deliverable, OR*
    b. *Conduct additional sampling, OR*
    c. *Contractor corrects errors and re-submits plans and GSA conducts acceptance sampling plan again*

The work in Phase III focuses on the parameters listed in Step 4 above (***T***, ***P***, and ***n***), where:

- ***T***, the tolerance, is the maximum deviation that a measurement could have before GSA would declare the measurement to be "out-of-spec". Deviation = 2D/3D measurement – reference value.

- ***P*** is the maximum percent of the population that is out-of-spec that is acceptable to GSA. This value answers the question:

  *For GSA to accept a 2D Plan, what is the largest percent defective (out-of-spec) of the whole population that would be acceptable to GSA?*

- ***n*** is the number of measurements that will be made by an inspector; statistically, ***n*** is referred to as the "sample size". This number will depend largely on time and cost that GSA is willing to expend to perform the quality check.

At this time, there is no guidance on what are appropriate values for the above parameters, i.e., what is feasible or practical. The effort described in this report will provide initial guidance to the questions:

*How many measurements are needed?*

*What is an acceptable percent of out-of-spec?*

*What is a practical tolerance?*

The remainder of this Phase III report consists of the documentation of the application of the Acceptance Sampling methodology developed in Phase II to a specific site.

# 3 Data Collection

## 3.1 Facility Description

A GSA 3D imaging project was used to help evaluate practical/feasible values for ***T***, ***P***, and ***n***. The facility is a utility plant which provides electricity and hot water for a federal government campus. The rooms in the facility could be categorized as either offices or mechanical equipment rooms. The 2D plans as supplied by GSA are given in Figure 1 (1st floor), Figure 2 (2nd floor), and Figure 3 (roof).

One of the objectives of the GSA 3D imaging project was:

> "... *to create an accurate current-condition record of the existing building conditions. The deliverables from the interior scanning will be used primarily for verification and comparison of spatial data and area measurements. The 3D imaging at this location will provide 2D CAD plans, elevations and 3D geometric models and/or BIM required to document as-built conditions, including details of the interior spaces*."[1]

The GSA specified tolerance for the deliverables from the service provider for all of the measurements that will be used in this report is 1 in (25.4 mm).

[1] Taken from GSA's scope-of-work for the 3D imaging project.

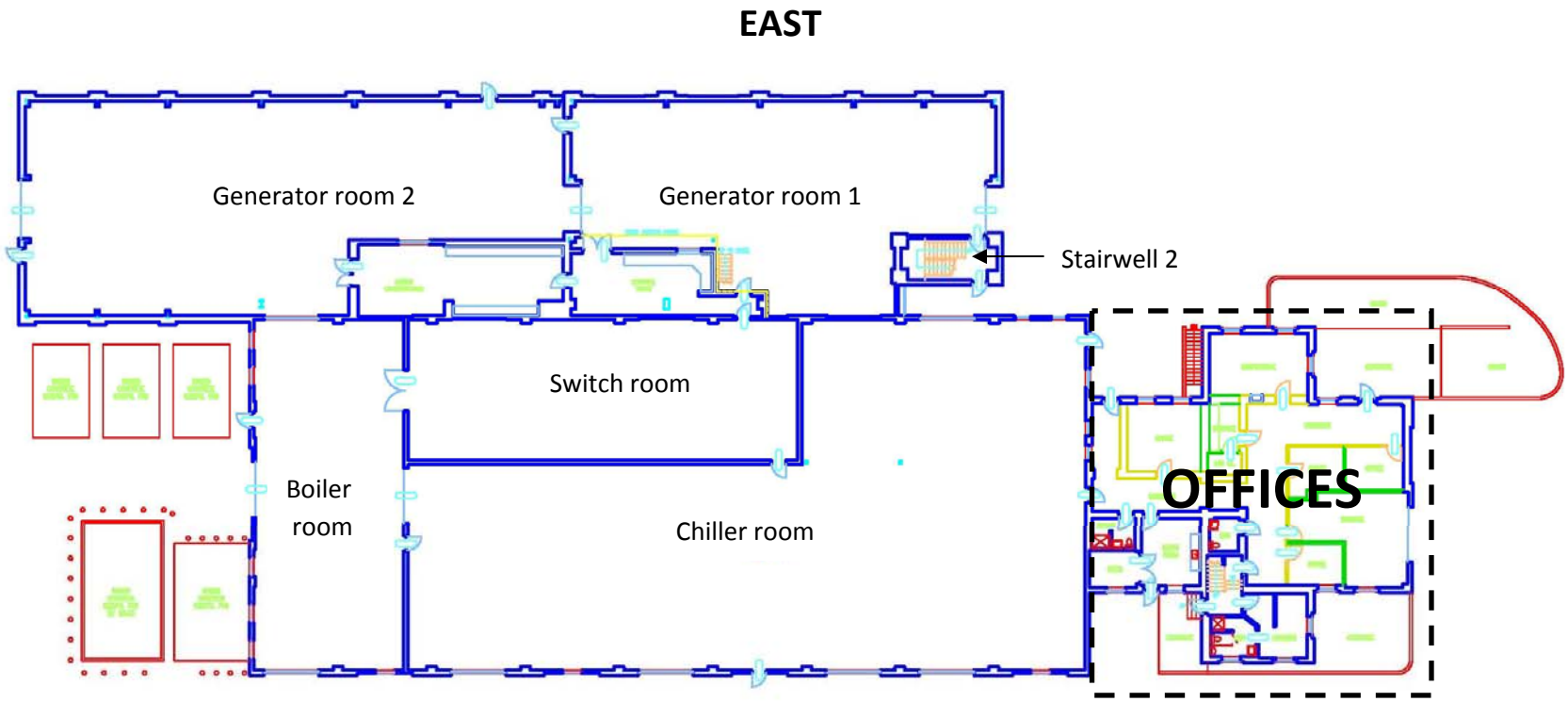


**Figure 1. First Floor Plan of GSA Facility.**

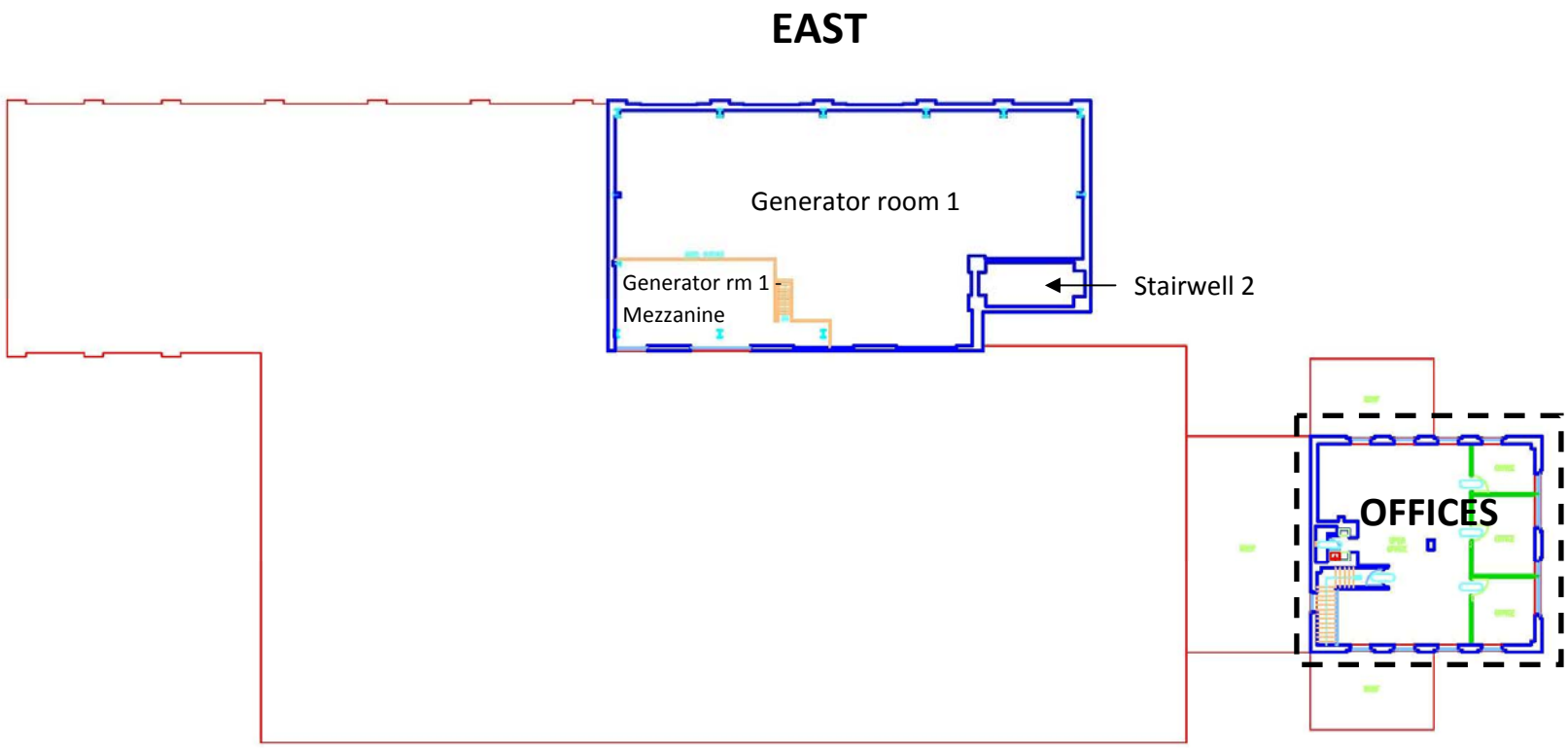


**Figure 2. Second Floor Plan of GSA Facility.**

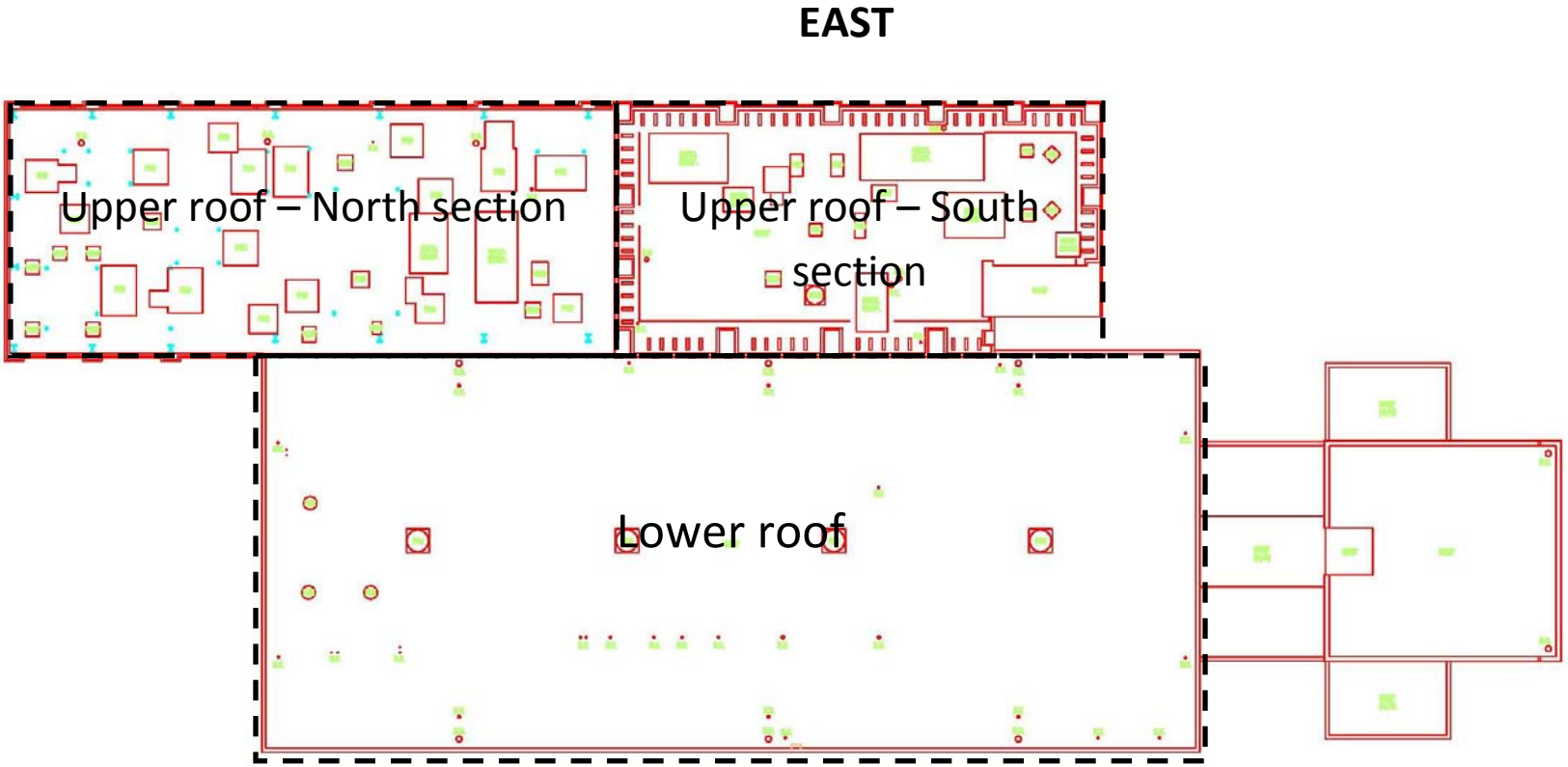


**Figure 3. Roof Plan of GSA Facility.**

## 3.2 Manual Data Collection

The measurements of interest to GSA were interior room dimensions. GSA was also interested, to a lesser extent, in pipe dimensions, equipment dimensions, and exterior dimensions.

The original intent was to take as many measurements as possible in 2 to 3 days. Prior to going out to the site, GSA sent the 2D plans to NIST. In preparation for the fieldwork, measurements in each room were identified to ensure that no particular area was left out and that somewhat even sampling occurred among the different rooms.

### 3.2.1 1st Data Collection, February 2009

In February 2009, NIST researchers collected the data to be compared with the measurements from the 2D plans or 3D model (2D/3D measurements will be used henceforth); this effort occurred at the same time that the service provider was scanning the facility. A team of researchers from Carnegie Mellon University (CMU) was also at the site collecting measurements for a related GSA project. The types of measurements obtained were: room dimensions (width and height), window widths and heights, distance between objects (e.g., columns, equipment and wall), pipe diameters, and pipe circumferences. Two hundred and forty-two (242) measurements were obtained from the interior and exterior of the building and on the roof.

For the majority of the 242 measurements, the measurement was repeated where the number of repeats varied from two to eight; some measurements did not have repeats. To clarify, a measurement is the average of the repeated measurements of the dimension of interest. For example, if the dimension of interest was a door width, the door width was measured three times: near the top of the door, middle of the door, close to the bottom of the door. The average of these three measurements was used to represent the NIST/CMU measurement for that door width; this constitutes one of the 242 measurements – NOT three of the 242 measurements.

As mentioned in the previous paragraph, most of the linear measurements such as window widths, door widths, and wall lengths were made at three different locations: high, medium, low where high was approximately 6 ft (1.8 m), low was close to the floor or bottom of the window, and medium was in between the high and low locations. These locations may have varied due to the presence of obstacles; for example, a “low” measurement may have been taken a few feet above the floor because there were boxes along the wall. When obstacles prevented the taking of measurements from three different locations, either three measurements were made from approximately the same location or less than three measurements were made.

The locations of the measurements were marked on the 2D plans. The measurements and descriptions of the measurement locations were manually recorded. Additionally, photos were taken of some of the locations.

The linear measurements (except for three measurements: measurements labeled R-3 to R-5 in Table A1, Appendix A) were made with a laser distance meter with a manufacturer specified accuracy of ± 0.06 in (±1.5 mm). The measurements R-3 to R-5 were made with a measuring tape as the laser distance meter could not measure the distance due to a combination of long distance and weak return signal from a dark surface. Small pipe diameters were measured with a digital micrometer with a manufacturer specified accuracy of ±0.001 in (±0.002 mm). Pipe circumference was measured by wrapping a strip of plastic tape around the pipe and then measuring the length of the plastic tape with a measuring tape. An estimate of the uncertainty of the measurements made with a measuring tape is 0.1 %.

Since these manual measurements were obtained at the same time as the site was scanned, some of the manual measurements did not have corresponding measurements in the 2D plans or 3D model as the objects were not modeled. The number of measurements without corresponding plan data was 23.

#### *3.2.1.1 Comparison of Manual Measurements*

The CMU data were made available to NIST and vice versa. Of the 242 NIST measurements, there were a total of 15 corresponding measurements in the two data sets. The differences between the corresponding NIST and CMU measurements are given in Table 1.

**Table 1. Comparison of Available NIST and CMU Corresponding Measurements.**

| Index | Label | NIST Measurements | | CMU Measurements | | |
|---|---|---|---|---|---|---|
| | | # of repeats | Average, m ($s^{**}$ in mm) | # of repeats | Average, m ($s$ in mm) | Difference = (NIST – CMU), in (mm) |
| 1 | I-28 | 2 | 11.879 (0.0) | 5 | 11.875 (0.9) | 0.14 (3.6) |
| 2 | I-30 | 3 | 2.596 (4.0) | 6 | 2.597 (3.5) | -0.01 (-0.2) |
| 3 | I-32 | 3 | 10.230 (1.0) | 6 | 10.227 (4.3) | 0.12 (3.2) |
| 4 | I-34 | 3 | 2.663 (3.2) | 6 | 2.666 (6.1) | -0.14 (-3.5) |
| 5 | I-65 | 3 | 6.402 (0.6) | 10 | 6.408 (9.7) | -0.23 (-5.9) |
| 6 | I-66 | 3 | 4.020 (3.2) | 10 | 4.014 (5.1) | 0.22 (5.6) |
| 7 | I-69 | 3 | 2.985 (2.9) | 10 | 2.982 (4.2) | 0.14 (3.5) |
| 8 | I-76 | 3 | 4.397 (7.2) | 10 | 4.399 (5.3) | -0.08 (-2.0) |
| 9 | I-77 | 3 | 3.811 (3.0) | 10 | 3.8146 (4.6) | -0.14 (-3.6) |
| 10 | I-79 | 3 | 2.680 (5.7) | 10 | 2.675 (6.6) | 0.23 (5.8) |
| 11 | I-81 | 3 | 7.035 (1.2) | 4 | 7.037 (1.5) | -0.08 (-2.1) |
| 12 | I-82 | 3 | 1.872 (8.1) | 8 | 1.868 (7.7) | 0.13 (3.3) |
| 13 | I-153 | 2 | 13.412 (2.8) | 5 | 13.197 (1.9) | 8.48 (215.4) |
| 14 | E-5 | 3 | 3.057 (1.2) | 10 | 3.0576 (2.5) | -0.01 (-0.3) |
| 15 | E-19 | 3 | 3.651 (1.5) | 5 | 3.653 (3.1) | -0.08 (-2.1) |
| $^{**}$ Standard deviation of the average. | | | | | | |

As seen in Table 1, the differences for 14 of the 15 measurements were less than 0.24 in (6 mm). For one of the measurements, Index = 13, the difference was large and equal to 8.48 in (215.4 mm). To resolve this discrepancy, the corresponding 2D/3D measurement was used. The difference between the NIST measurement and the corresponding 2D/3D measurement was -0.09 in (-2.4 mm); it was therefore concluded that the CMU measurement may have been a measurement of a different dimension.

The average of the absolute values of the difference (without the outlier, Index 13) was 0.14 in (3.2 mm) with a standard deviation of 0.07 in (1.9 mm). There were 29 other measurements from CMU that were not "duplicate" measurements (i.e., measurements listed in Table 1), and these 29 measurements were combined with the NIST measurements.

### 3.2.2 2nd Data Collection, October 2009

After an initial analysis of the data, there were 30 measurements (28 from NIST and 2 from CMU) where the difference between the NIST or CMU measurements and the extracted measurements from the 2D plans or 3D model was more than 2 in (50.8 mm). To verify the manual measurement values, NIST re-visited the site and re-measured the 30 measurements in October 2009. Five of the 30 measurements were not obtained.

Of the 25 measurements that were repeated, 23 were essentially the same as the data collected in the 1st data collection. Of the two measurements that were different between the 1st and 2nd data collection, one was from NIST and one was from CMU. The one from NIST differed by 2.2 in (55 mm). The NIST values from the 2nd data collection were closer to those extracted from the 3D model and therefore, these values were used. The values from the 2nd data collection for the CMU measurement differed by 7.9 in (200 mm) and were closer to the value extracted from the 3D model; the values from the 2nd data collection were therefore used. In addition to obtaining the 25 repeated measurements, 31 additional measurements were made to augment the number of measurements obtained in the 1st data collection.

### 3.2.3 Data Description

A total of 285 measurements were available for analysis – 256 from NIST and 29 from CMU. These measurements are given in Appendix A – Field Measurements, Table A1. In Table A1, a measurement label beginning with:

- I = Interior measurement
- E = Exterior measurement
- R = Roof measurement

The measurements were further grouped into several categories, e.g., Office or not-office, interior or exterior. The number of measurements in each of the categories are shown in Table 2. The classification of each individual measurement is given in Appendix A – Field Measurements, Table A2.

**Table 2. Measurement Categories.**

| General Categories | # of Measurements |
|---|---|
| **1. Office vs. Not Office** | |
| Office = measurements obtained in areas labeled offices in Figures 1 to 3. | 100 |
| Not office = measurements obtained in areas not labeled offices in Figures 1 to 2; exterior and roof measurements are excluded. | 117 |
| **2. Interior vs. Exterior** | |
| Interior = measurements obtained inside the buildings | 217 |
| Exterior = measurements obtained outside the buildings | 68 |
| **3. Measurement length** (see Figure 4 for further breakdown) | |
| Short = distances < 6 ft 6.7 in (2 m) | 67 |
| Medium = 6 ft 6.7 in (2 m) ≤ distances < 26 ft 3 in (8 m) | ??3 |
| Long = distances ≥ 26 ft 3 in (8 m) | 45 |
| **4. Measurement Type** | |
| Horizontal | 219 |
| Vertical | 51 |
| Circumference/Radius | 15 |
| **5. Room "Type"** | |
| Boiler room | 13 |
| Chiller room | 25 |
| Exterior (exterior and roof) | 68 |
| Generator room 1 | 15 |
| Generator room 2 | 21 |
| Miscellaneous (Control room, Spare room, Stairwell 2) | 17 |
| Office (all areas labeled offices in Figures 1 to 3) | 100 |
| Switch room | 26 |

A breakdown of the field measurements by length is shown in Figure 4. As seen in the figure, the number of long distance measurements was low as the ability to obtain these measurements was reduced by obstructions. This was especially true for the Chiller, Boiler, and Generator (#1) rooms.

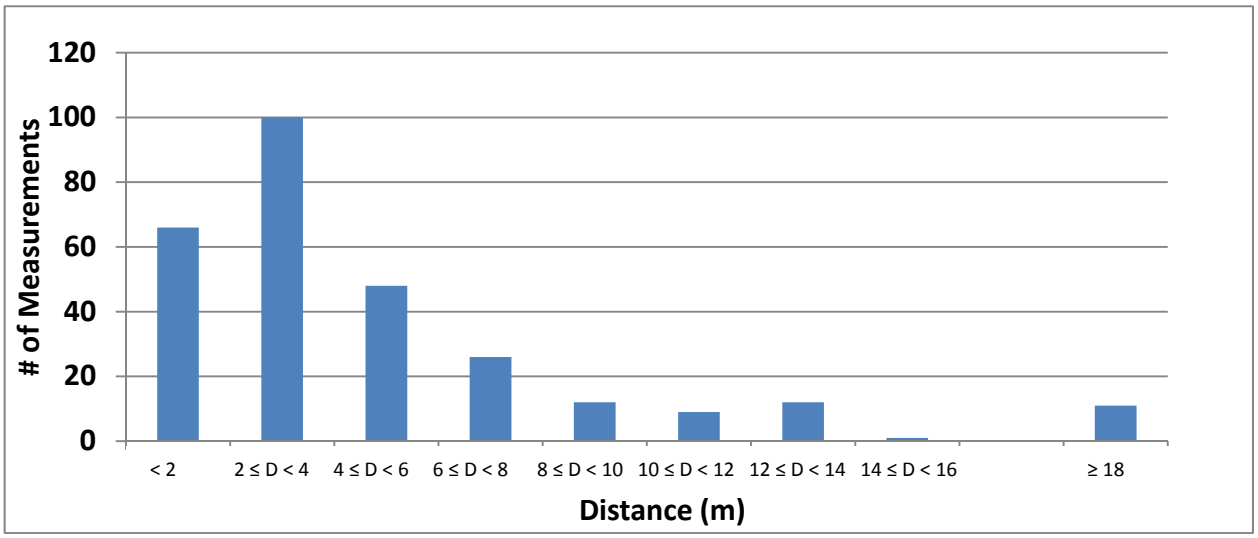


**Figure 4. Breakdown of Measurements by Distance.**

# 4 Data Analysis

## 4.1 In-Spec and Out-of-Spec Determination

As described in Section 6 of (Cheok, et al., 2008), each of the NIST/CMU measurements was compared with the corresponding measurement from the 2D plan or 3D model provided by the service provider. To determine if the difference was in-spec ("In") or out-of-spec ("Out"), two criteria were used.

The first criteria was based on the tolerance. The differences between the NIST/CMU measurements and the 2D/3D measurements were compared to a given tolerance to determine if the 2D/3D measurements were "In" (in-spec) or "Out" (out-of-spec) of tolerance.

A measurement was considered "In" if the absolute value of the difference between the NIST/CMU measurement and the 2D/3D measurement was less than or equal to the tolerance, and it was "Out" if the absolute value of the difference between the NIST/CMU measurement and the 2D/3D measurement was greater than the tolerance.

$$|\Delta| = \left| \text{Measurement}_{\text{NIST/CMU}} - \text{Measurement}_{\text{2D/3D}} \right| \leq \text{Tolerance} \rightarrow \text{In}$$

$$|\Delta| = \left| \text{Measurement}_{\text{NIST/CMU}} - \text{Measurement}_{\text{2D/3D}} \right| > \text{Tolerance} \rightarrow \text{Out}$$

where

$\text{Measurement}_{\text{NIST/CMU}}$ = Measurement made by NIST/CMU.

$\text{Measurement}_{\text{2D/3D}}$ = Measurement extracted from the 2D plans or 3D model.

Tolerance = value specified by GSA, e.g., 1 in (25.4 mm).

The second criteria was based on the statistical uncertainty of the NIST/CMU measurements. A measurement was considered "In" if the absolute value of the difference between the NIST/CMU measurement and the 2D/3D measurement was less than the standard deviation of the mean of the measurement multiplied by the upper 95 % confidence limit for the mean. A measurement was considered "Out" if the absolute value of the difference between the NIST/CMU measurement and the 2D/3D measurement was greater than the standard deviation of the mean of the measurement multiplied by the upper 95 % confidence limit for the mean as follows:

$$|\Delta| = \left| \text{Measurement}_{\text{NIST/CMU}} - \text{Measurement}_{\text{2D/3D}} \right| \leq s_{\bar{y}} \times t_{0.975,\ \upsilon} \rightarrow \text{In}$$

$$|\Delta| = \left| \text{Measurement}_{\text{NIST/CMU}} - \text{Measurement}_{\text{2D/3D}} \right| > s_{\bar{y}} \times t_{0.975,\ \upsilon} \rightarrow \text{Out}$$

where

$s_{\bar{y}}$ = standard deviation of the mean of the NIST/CMU measurements

= $s/\sqrt{\text{number of repeats}}$

$s$ = standard deviation of the data

$\bar{y}$ = mean of the data

$t_{0.975,\upsilon}$ = 97.5 % percentile of a two-sided t-distribution with $\upsilon$ degrees of freedom.

$\upsilon$ = number of repeats – 1

If the decision is "In" based on one criteria and "Out" based on the other criteria, the final decision is "In". Therefore, the only time when the final decision is to Reject is when the decision is Reject for both criteria.

To obtain the standard deviation for those measurements that were only measured once (i.e., no repeats), the average of the relative standard deviations for all the other measurements was used to determine the standard deviation for a single measurement. The average of the relative standard deviations of the data for this study is 0.10 %. The relative standard deviation is defined as:

$$s_{rel} = \frac{s}{\bar{y}}$$

Therefore, the relative standard deviation, $s_{rel}$, for a single measurement is set equal to 0.10 %. For example, if the measurement was 8 ft 2.4 in (2.5 m), the estimated standard deviation for this single measurement is:

$$\text{For } n = 1, s = s_{rel} \;\therefore\quad s = (0.10/100) \times (8 \times 12 + 2.4)$$
$$= 0.001 \times 98.4$$
$$= 0.0984 \text{ in } (2.5 \text{ mm})$$

Conservatively, the $t_{0.975,\upsilon}$ for a single measurement is set equal to that for $t_{0.975,\upsilon}$ for $\upsilon$ = 2 or $t_{0.975,\upsilon}$ = 12.706 for a measurement with no repeats.

## 4.2 Influence of *n*, *T*, *P*, and Sampling Strategy on the Decision

To determine the influence of ***T*** and ***P*** on the decision, a range of ***T*** and ***P*** values was used. The tolerances, ***T***, used were:

***T*** = 0.5 in (12.7 mm), 0.75 in (19.1 mm), 1 in (25.4 mm), 2 in (50.8 mm)

The following ***P*** (maximum percent of the population that is out-of-spec that is tolerable to GSA) values were used:

***P*** = 5 %, 10 %, 15 %, 20 %

The upper limits for the percent defective in the population with 95% Confidence are given in Appendix B, Table B1. These values are used to determine the Accept/Reject decision based on ***P***, ***d*** (# defects or out-of-spec), and ***n***. Note that ***d*** is only dependent on ***T***. The colored lines in Table B1 correspond to the different levels of ***P***.

For given combinations of ***T*** and ***P***, eight sampling strategies were implemented to evaluate the effect of sample size, ***n***. Since only "one" large sample set (***N*** = 285) was obtained in the field, the effect of varying the sample size was simulated by sub-sampling from the "one" large sample set. The sub-sampling (taking ***n*** measurements from ***N*** where ***n*** < ***N***) enables the randomization of the selection of the measurements. For a sub-sample size of ***n***, the number of all possible combinations out of ***N*** samples is:

$$\binom{N}{n} = \frac{N!}{n!\ \ (N-n)!}$$

The eight sampling strategies are described below.

1. *<u>All measurements (285 measurements available)</u>*

   This sampling method is the Randomized Acceptance Sampling method where all the measurements are selected randomly. Sample sizes used: ***n*** = 50, 75, 100, 125, 150, 175, 200, 225, 250, 285. For each ***n*** (except for ***n*** = 285 where only one run could be performed), randomly select ***n*** measurements 400 times (randomized sampling) out of the 285 measurements.

2. *<u>All Offices only (100 measurements available)</u>*

   This strategy allows for the simulation of projects where the building(s) consisted of office spaces only. A randomized sampling method was implemented.

   Sample sizes used: ***n*** = 50, 75, 100. For each ***n*** (except for ***n*** = 100 where only one run could be performed), randomly select ***n*** measurements 400 times (randomized sampling) out of the 100 measurements.

3. *<u>All Not Offices only (117 measurements available)</u>*

   This strategy allows for the simulation of projects where the buildings did not contain office spaces and where the environment was less structured. A randomized sampling method was implemented.

Sample sizes used: ***n*** = 50, 75, 100, 117. For each ***n*** (except for ***n*** = 117 where only one run could be performed), randomly select ***n*** measurements 400 times (randomized sampling) out of the 117 measurements.

4. *Equal number of measurements for each room type (Table 2, General Category 5)*

This sampling method is the Stratified Randomized Acceptance Sampling. The stratification is based on room type. The room types used were: Boiler room, Chiller room, Exterior, Generator room 1, Generator room 2, Miscellaneous, Office, Switch room.

Sample sizes used: ***n*** = 48 (***k*** = 6 measurements/ room type), 64 (***k*** =8 measurements/room type), 80 (***k*** =10 measurements/room type), 104 (***k*** =13 measurements/room type).

For each ***n*** (except for ***n*** = 104 where only one run could be performed), randomly select ***k*** measurements out of the number of measurements available for that room type 200 times (randomized sampling). For example, for ***n*** = 64 and room type = Chiller room,

A. Randomly select ***k*** = 8 measurements out of 25 measurements available for the Chiller room (see Table 2) measurements.

B. Repeat Step A for remaining room types where the number of measurements available will vary based on the room type (see Table 2).

C. Repeat Steps A and B 200 times.

5. *Offices or Not Offices (Table 2, General Category 1)*

This sampling method is the Stratified Randomized Acceptance Sampling. The stratification is based on whether the measurement was from an office space (more structured environment) or not office space (less structured environment).

Sample sizes used: ***n*** = 50, 75, 100, 125, 150, 175, 200, 217. For a given sample size, ***n***, the number of Office (100) or Not Office (117) measurements selected were based on the proportion of Office and Not Office measurements. That is, for a given ***n***

***i*** = # of office measurements = ***n*** * (Total # of Office/217) = ***n*** * (100/217)

***j*** = # of Not office measurements = ***n*** * (Total # of Not Office/217) = ***n*** * (117/217)

For each ***n*** (except for ***n*** = 217 where only one run could be performed), randomly select ***i*** and ***j*** measurements 400 times (randomized sampling) out of the 100 Office and 117 Not Office measurements, respectively.

6. *Interior or Exterior (Table 2, General Category 2)*

This sampling method is the Stratified Randomized Acceptance Sampling. The stratification is based on whether the measurement was an Interior or Exterior measurement.

Sample sizes used: ***n*** = 50, 75, 100, 125, 150, 175, 200, 225, 250, 285. For a given sample size, ***n***, the number of Interior (217) or Exterior (68) measurements selected were based on the proportion of Interior and Exterior measurements. That is, for a given ***n***

***i*** = # of Interior measurements = ***n*** * (Total # of Interior/285) = ***n*** * (217/285)

***j*** = # of Exterior office measurements = ***n*** * (Total # of Exterior/285) = ***n*** * (68/285)

For each ***n*** (except for ***n*** = 285 where only one run could be performed), randomly select ***i*** and ***j*** measurements 400 times (randomized sampling) out of the 217 Interior and 68 Exterior measurements, respectively.

7. *Measurement length (Table 2, General Category 3)*

This sampling method is the Stratified Randomized Acceptance Sampling. The stratification is based on measurement length.

Sample sizes used: ***n*** = 50, 75, 100, 125, 150, 175, 200, 225, 250, 285. For a given sample size, ***n***, the number of Long (45), Medium (173), or Short (67) measurements selected were based on the proportion of Long, Medium, and Short measurements. That is, for a given ***n***

***i*** = # of Long measurements = ***n*** * (Total # of Long/285) = ***n*** * (45/285)

***j*** = # of Medium measurements = ***n*** * (Total # of Medium/285) = ***n*** * (173/285)

***m*** = # of Short measurements = ***n*** * (Total # of Short/285) = ***n*** * (67/285)

For each ***n*** (except for ***n*** = 285 where only one run could be performed), randomly select ***i***, ***j***, and ***m*** measurements 400 times (randomized sampling) out of the 45 Long, 173 Medium, and 67 Short measurements, respectively.

8. *Measurement Type (Table 2, General Category 4)*

This sampling method is the Stratified Randomized Acceptance Sampling. The stratification is based on measurement type – horizontal vs. vertical.

Sample sizes used: ***n*** = 50, 75, 100, 125, 150, 175, 200, 225, 250, 270. For a given sample size, ***n***, the number of Horizontal or Vertical measurements selected were based on the proportion of Horizontal (219) and Vertical (51) measurements. That is, for a given ***n***

***i*** = # of Horizontal measurements = ***n*** * (Total # of Horizontal/270) = ***n*** * (219/270)

***j*** = # of Vertical measurements = ***n*** * (Total # of Vertical/270) = ***n*** * (51/270)

For each ***n*** (except for ***n*** = 270 where only one run could be simulated), randomly select ***i*** and ***j*** measurements 400 times (randomized sampling) out of 219 Horizontal and 51 Vertical measurements, respectively.

Comparisons of Strategy 1 with Strategies 4 to 8 will allow for the comparison of randomized sampling versus stratified randomized acceptance sampling described in (Cheok, et al., 2009).

# 5 Results and Discussion

During the study, two sources of discrepancy between the manual and 2D/3D measurements were discovered. One discrepancy involved measurements of the floor to ceiling distances in the "Not Office" areas. There were eight such measurements – these measurements are indicated in Appendix A, Table A1. All floor-to-ceiling measurements ("Not Office" and "Office") were obtained from three locations around the room, and the average of the measurements at the three locations was used to compare with the 2D/3D measurement. The ceilings in the "Not Office" areas were sloped, and this slope may have caused some of the floor-to-ceiling measurements in the "Not Office" areas to be out-of-spec. Of the eight measurements, there were five instances when the floor-to-ceiling measurements in the "Not Office" areas were out-of-spec.

The other discrepancy involved measurements of windows where the window had interior and exterior faces. There were 14 such measurements, indicated in Appendix A, Table A1. The 3D model that was generated was based on modeling the points for the exterior face of the window. Two of the 14 measurements were in-spec for $\boldsymbol{T} \geq 0.5$ in (12.7 mm). To be consistent with the other extracted measurements, the 14 measurements extracted from the 2D/3D model were used in the analysis, i.e., the measurements as extracted from the point clouds (obtained from the service provider) were not used. Note that a check of the measurements as obtained from the point cloud for six of the 14 window measurements indicated that these six measurements would be in-spec for $\boldsymbol{T} \geq 0.5$ in (12.7 mm) if the interior point clouds were used to generate the 2D/3D model.

## 5.1 General Findings

Figure 5 and Table 3 categorizes the measurements based on the magnitude of the differences between the NIST/CMU measurements and the 2D/3D measurements. In Figure 5, the x-axis labels were abbreviated for clarity. The value associated with the column labeled "1/2" is the number of measurements where the difference is 0.5 in (12.7 mm) or less; the value associated with the column labeled "3/4" is the number of measurements where the difference is greater than 0.5 in (12.7 mm) and less than or equal to 0.75 in (19.1 mm), etc.

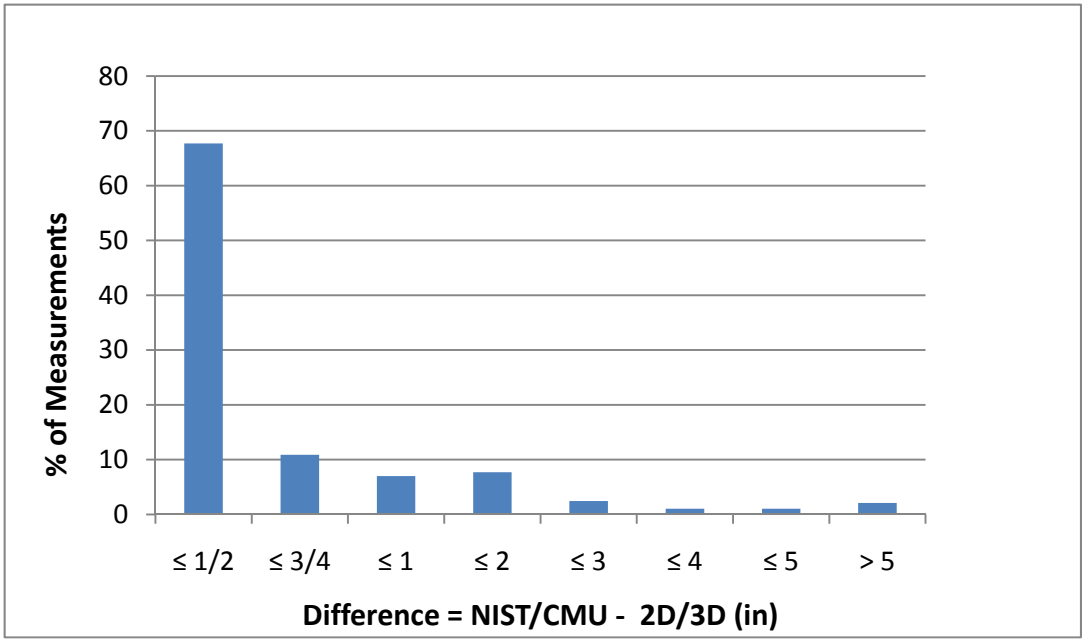


**Figure 5. Histogram of the Differences Between the NIST/CMU and 2D/3D Measurements.**

**Table 3. Magnitude of Differences between the Manual and 2D/3D Measurements.**

| Difference, in (mm) | # of Measurements | % of Measurements | Cumulative % |
|---|---|---|---|
| ≤1/2 (12.7 ) | 193 | 68 | 68 |
| ≤ 3/4 (19.1) | 31 | 11 | 79 |
| ≤ 1 (25.4) | 20 | 7 | 86 |
| ≤ 2 (50.8) | 22 | 8 | 93 |
| ≤ 3 (76.2) | 7 | 2 | 96 |
| ≤ 4 (101.6) | 3 | 1 | 97 |
| ≤ 5 (127.0) | 3 | 1 | 98 |
| > 5 (127.0) | 6 | 2 | 100 |

As shown in Table 3, the difference between the NIST/CMU and the 2D/3D plans for 68 % of the measurements was less than or equal to 0.5 in (12.7 mm) and for 86 % of the measurements, the difference was 1 in (25.4 mm) or less.

To determine broad trends in the measurements, several plots of the data were made, Figures 6 to 9. In these plots, the ratio of the number of out-of-spec in a given category to the total number of measurements in that category is plotted against the tolerance.

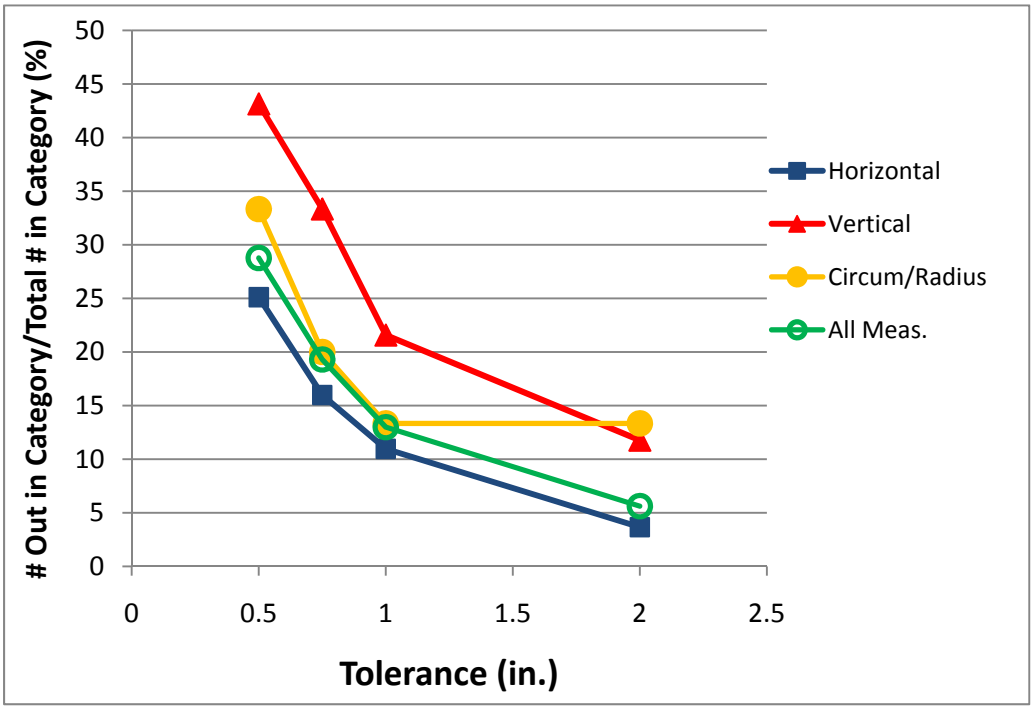


**Figure 6. Type of Measurement: Horizontal, Vertical, and Circumference/Radius Measurements.**

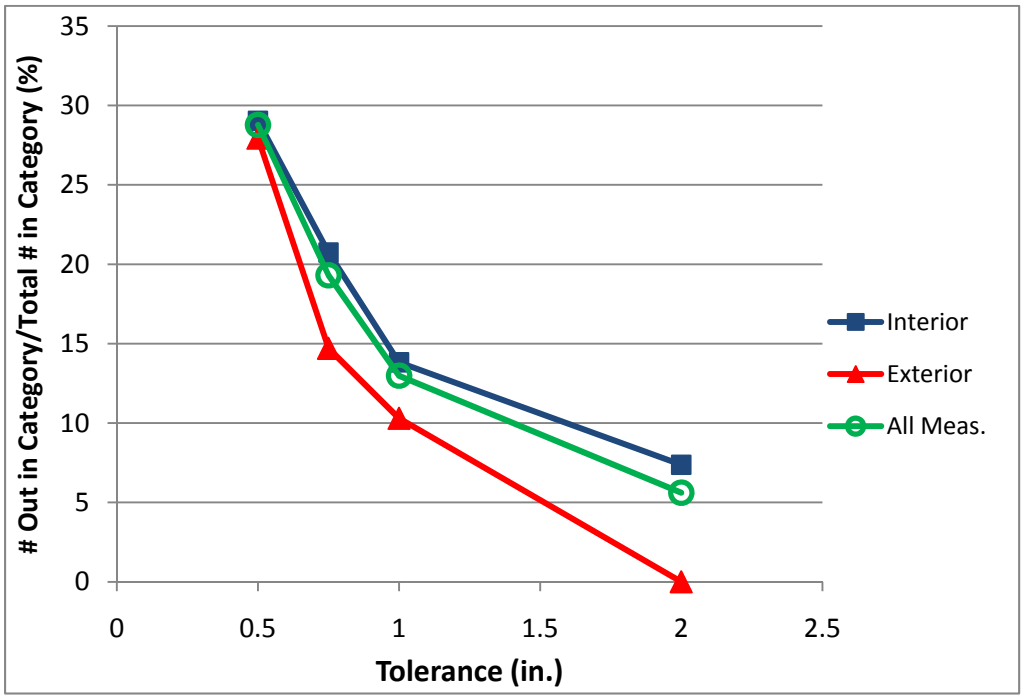


**Figure 7. Interior vs. Exterior Measurements.**

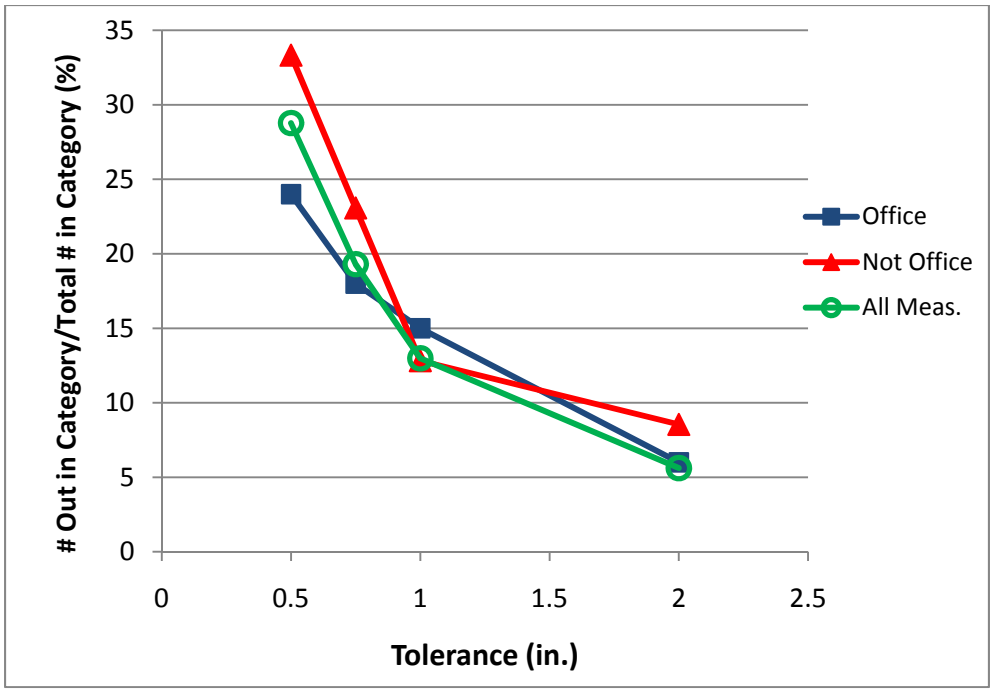


**Figure 8. Office vs. Not Office Measurements.**

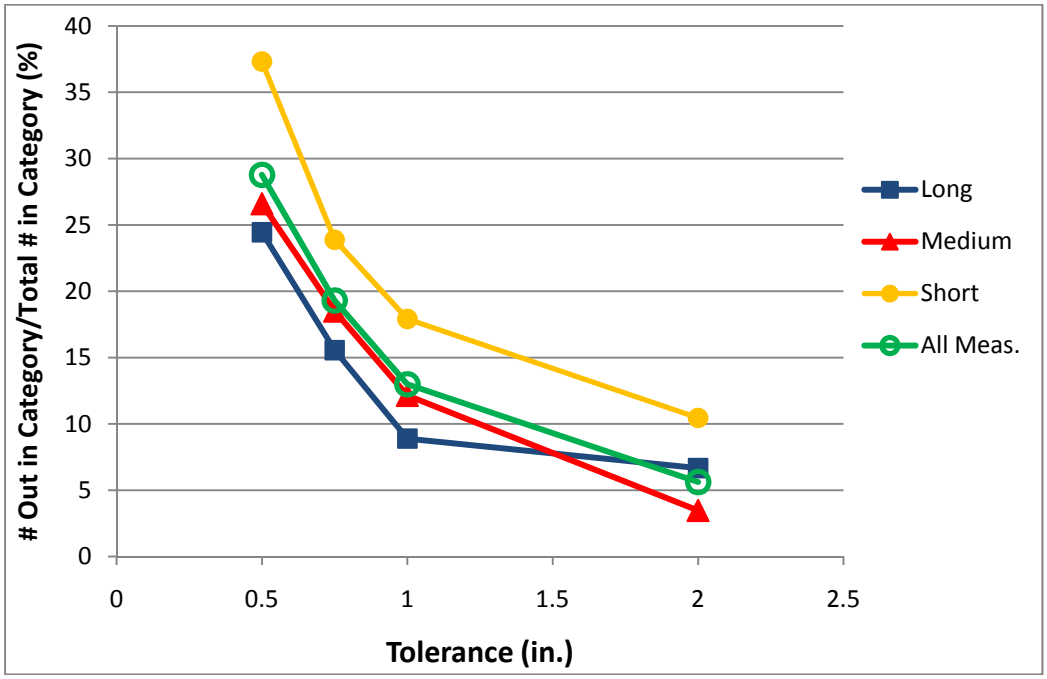


**Figure 9. Measurement Length: Long, Medium, Short.**

As seen in Figures 6 to 9, the most obvious trend is that the vertical measurements appear to have more out-of-spec measurements than the horizontal measurements (Figure 6). The long distance measurements also had fewer out-of-spec measurements, and the short distance measurements had more out-of-spec measurements (Figure 9). The reason why more short distance measurements are out-of-spec may be because nine out of the 12 out-of-spec measurements for the windows (see Section 5) were categorized as "Short" distance measurements. It also appears that the Exterior measurements had fewer out-of-spec measurements than the interior measurements (Figure 7). There was no trend for Not-office vs. Office measurements (Figure 8).

## 5.2 Discussion of the Results for the Different Strategies

The results of all the runs for all eight strategies are given in Appendix C, in Tables C1 to C6. Explanations of the nomenclature used in these tables are as follows:

1. % Accept: Out of the 1, 200, or 400 runs, the percentage of runs that GSA would accept the deliverable for a given ***n***, ***T***, and ***P***.

2. Avg # defects: The average number of defects from the 200 or 400 runs.

3. Std defects: The standard deviation of the defects based on the 200 or 400 runs. This value is set to zero when the number of runs is one.

4. Max. defects: The number of defects above which the deliverable is rejected for a given ***n*** and ***P.*** This number is obtained from Appendix B, Table B1.

   Example:

   For ***n*** = 200, and ***P*** = 10 %, the maximum number of defects = 12. Based on ***T*** = 1 in, if the number of the out-of-spec (defects) measurements were ≤ 12 then Accept, otherwise Reject.

For each of the eight strategies, when all the measurements in a given category are used (i.e., no other combinations are possible), only one run was possible. The assumption made in this report is that this case is the same as when ***n*** equals the population size (i.e., this is the closest to the population size in this study).

In the following sections, the eight strategies are put into two groups: A = Strategies 1, 5, 6, 7, 8 and B = Strategies 2, 3, 4. The grouping is based on the maximum sample size in each of the strategies. The strategies in Group A has maximum sample sizes of larger than 200 while the maximum sample sizes for strategies in Group B are about 100.

### 5.2.1 Strategies 1, 5 to 8

A general schematic for the decisions as they relate to ***T*** and ***P*** is shown in Figure 10. As shown in Figure 10, for the combinations of very low ***T*** and ***P***, the decision would, in general, be to always Reject and for combinations of high T and P, the decision would be to always Accept. In the regions labeled "Reject" and "Accept" in Figure 10, the sample sizes are not critical (but a reasonable number is still required, for example, 60). However, the sample sizes are important in the region marked "Mixed Decisions" in Figure 10.

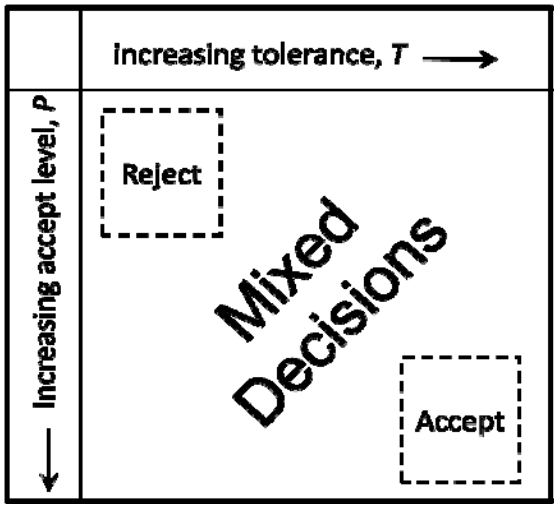


**Figure 10. Decisions Relative to *T* and *P***

For Strategies 1 and 5 to 8, the decisions for given ***T*** and ***P*** values are shown in Table 4. In Table 4, a cell labeled "Reject" or "Accept" means that the decision for Strategies 1, 5, 6, 7, 8 was to Reject or Accept, respectively; a cell labeled "Mixed" means that some of the decisions for strategies were to Reject and some were to Accept. Note that the required tolerances for the 3D imaging project used in this study were 1 in (25.4 mm) and 2 in (50.8 mm). Given this requirement, the decisions to Reject for tolerances of 0.75 in (19.1 mm) or less are to be expected as meeting tighter tolerances requires more time and, therefore, higher costs.

The sample sizes listed for the Accept decisions indicate the minimum sample sizes beyond which the decision would not have changed (if there were minimum sample different sizes, the largest value was chosen and is given in Table 4). The minimum sample size was taken as the sample size at which the % Accept vs. ***n*** line flattened out (see Figure 11). For example, in Figure 11, examining the red solid line (***T*** = 2 in [50.8 mm], ***P*** = 15 %), the minimum sample size is 125 – that is, the decision does not change for larger sample sizes. The boxes where the sample sizes are not given are the trivial cases – where the decision is always to reject regardless of sample size.

**Table 4. Decisions for Strategies 1 and 5-8 for given *T* and *P* values.**

| ***P*** **(%)** | ***T*, Tolerance, in (mm)** | | | |
|---|---|---|---|---|
| | **0.5 (12.7)** | **0.75 (19.1)** | **1 (25.4)** | **2 (50.8)** |
| **5** | Reject | Reject | Reject | Reject |
| **10** | Reject | Reject | Reject | Mixed ($n \geq 250$)[2] |
| **15** | Reject | Reject | Reject ($n \geq 225$) | Accept ($n \geq 175$) |
| **20** | Reject | Reject ($n \geq 150$) | Accept ($n \geq 225$) | Accept ($n \geq 100$) |

Some combinations of ***n***, ***T***, and ***P*** are plotted in Figure 11; the other combinations given in Table C1 are not shown in Figure 11 for purposes of clarity – the decisions in these cases were to Reject and the "% Accept" equaled zero for all sample sizes for the given combinations of ***n***, ***T***, and ***P***[3].

[2] Of the five strategies, there were four decisions to Accept and one (Strategy 5) to Reject.

[3] This same note applies to similar plots for Strategies 5 to 8.

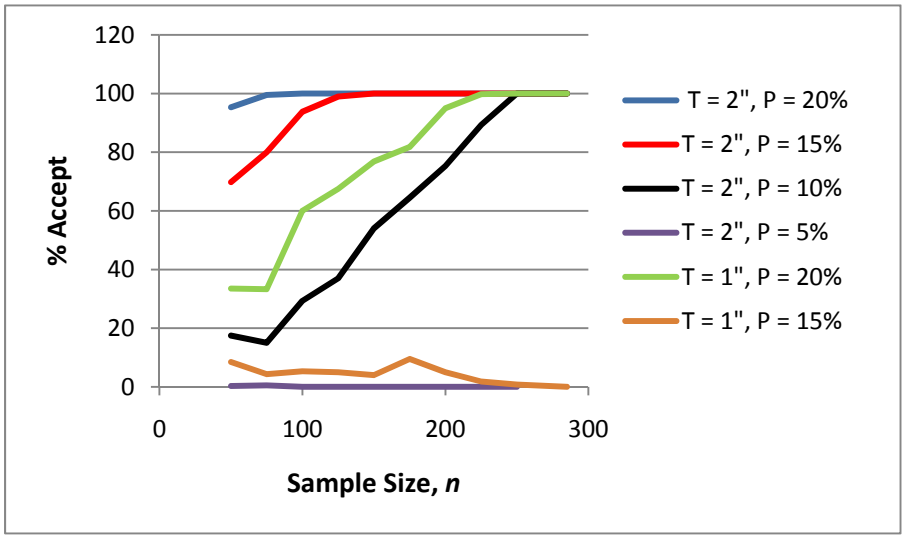


**Figure 11. Dependence of "% Accept" on *n*, *T*, and *P* for Strategy 1.**

For high tolerance [***T*** = 2 in (50.8 mm)] and high acceptance level (***P*** = 20 %), the decision is to Accept regardless of the sample size. However, for the same ***T***, the sample size becomes important as ***P*** decreases. The black line, ***T***= 2 in (50.8 mm) and ***P*** = 10 %, in Figure 11 is used to as an illustration of this. Since the decision for ***n*** = 285 is to Accept, it is assumed that this decision is true for ***n*** < 285 (see Section 5.2) for this combination of ***T*** and ***P***. From Figure 11, for ***n*** ≤ 150, the "% Accept" ≤ 54 %. This means that a correct decision is made less than or equal to 54 % of the time or an incorrect decision is made greater than or equal to 46 % of the time.

Note that there is a minimum sample size for a desired value of ***P*** or conversely, for a given sample size, there is a minimum value of ***P***. This minimum sample size is dictated by the values in the "Upper Limit Table on % Defective" (Table B1). Since the number of defects cannot be less than zero, the first row, ***d*** = 0, of Table B1 will dictate the minimum ***n*** or the minimum ***P*** value. The relationship between the minimum ***n*** and ***P*** is shown graphically in Figure 12.

For example, if ***P*** = 5 %, then the minimum sample size is 58 (see green dotted line in Figure 12). If only a smaller sample size is available, then a larger ***P*** will have to be tolerated. For example, if ***n*** = 30, then the minimum ***P*** is 9.5 % (see red dashed line in Figure 12). For situations when ***d*** = 0, it should be noted that decisions to Accept can only occur if no defects are found in the samples and the ***p*** is less than ***P***, otherwise Reject.

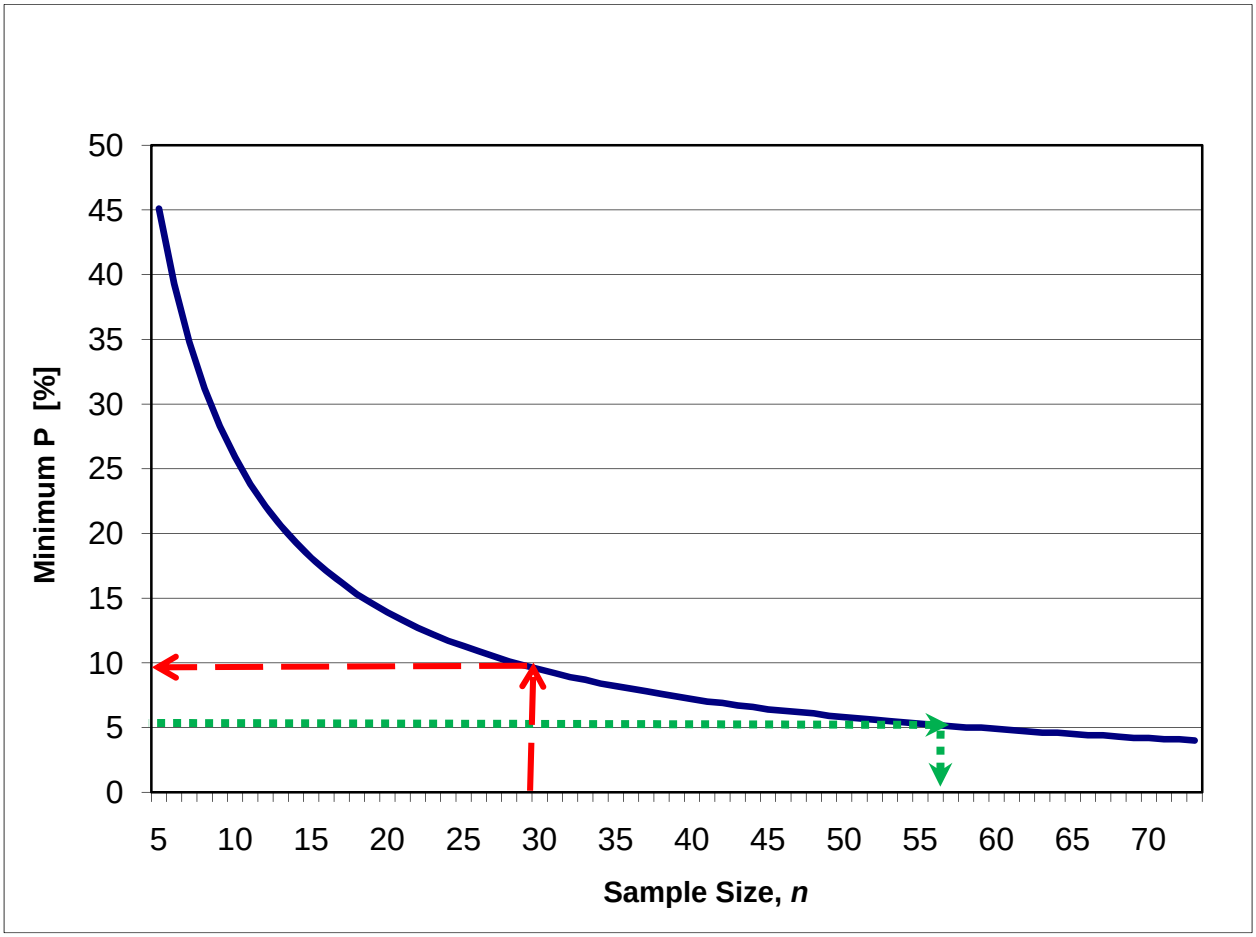


**Figure 12. Defects = 0: Minimum Sample Size, *n*, for a given *P* or the Minimum *P* for a given *n*.**

Plots similar to that shown in Figure 11 for Strategies 5 to 8 are given in Figures 13 to 16.

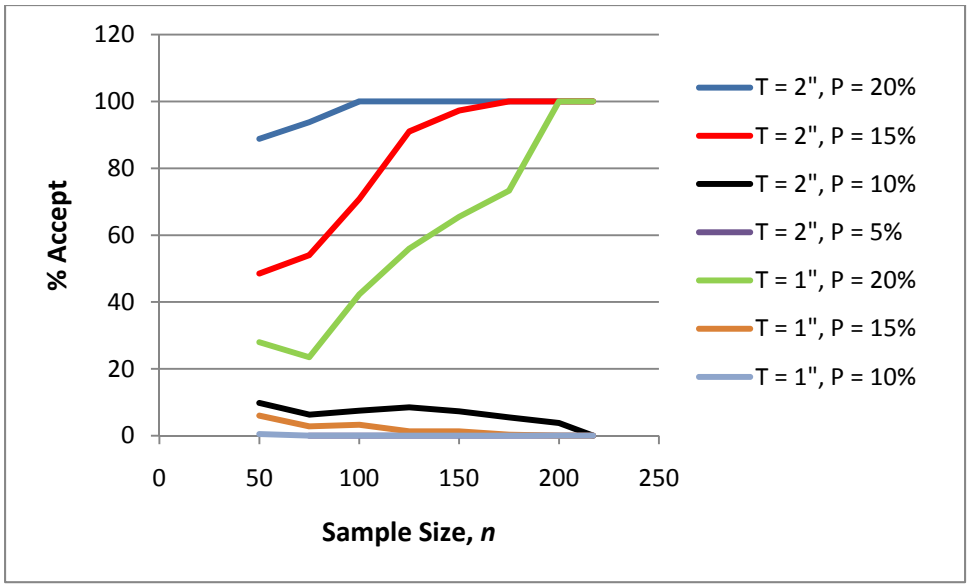


**Figure 13. Dependence of "% Accept" on *n*, *T*, and *P* for Strategy 5.**

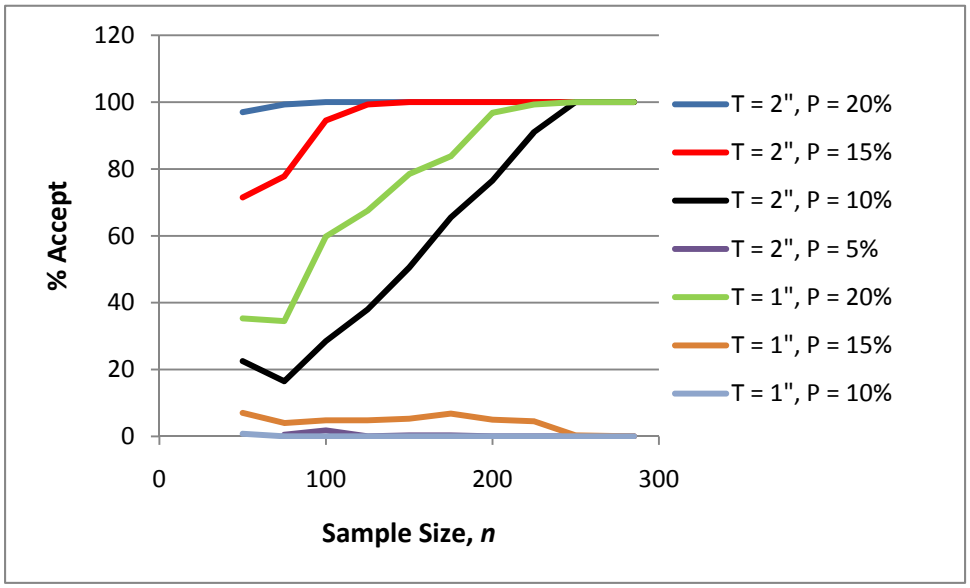


**Figure 14. Dependence of "% Accept" on *n*, *T*, and *P* for Strategy 6.**

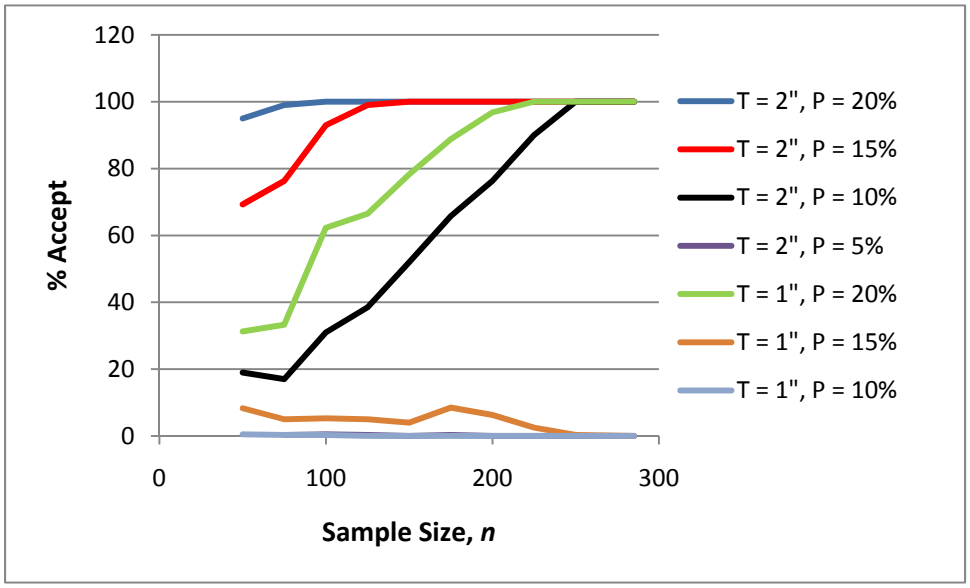


**Figure 15. Dependence of "% Accept" on *n*, *T*, and *P* for Strategy 7.**

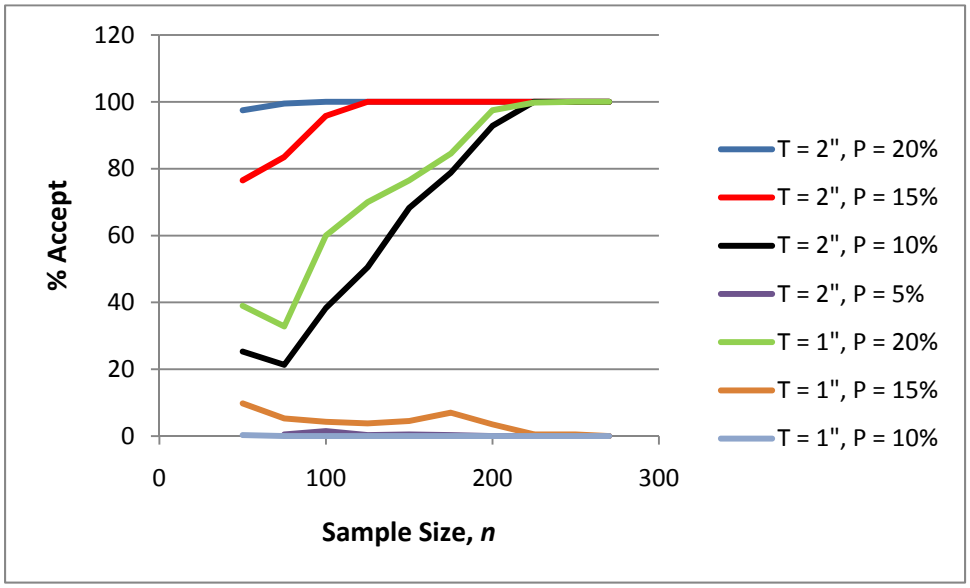


**Figure 16. Dependence of "% Accept" on *n*, *T*, and *P* for Strategy 8.**

To determine the stability or certainty of a decision, the average number of defects (from the 200 or 400 runs) and the standard deviations, σ, of the defects for each combination of ***n***, ***T***, and ***P*** were calculated and are listed in Tables C1 to C6. The maximum number of defects as described in Section 5.2 is also listed in Tables C1 to C6. In essence, the average number of defects is compared to the maximum number of defects. If the difference between these two values is large, then the likelihood that the decision will change based on changes to the samples (i.e., different sample sets used) is minimal (see Pts. A and D in Figure 17). If the difference is small, then the likelihood that the decision will change (i.e., different sample sets were used) is high (see Pts. B and C in Figure 17).

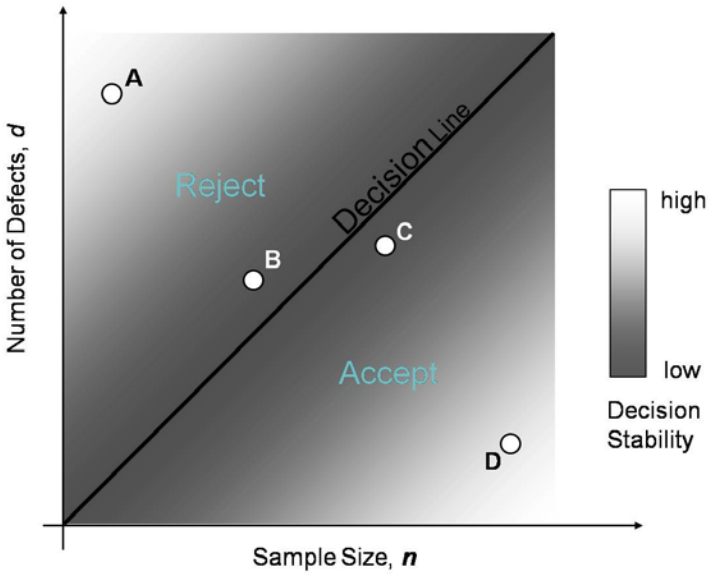


**Figure 17. Conceptualization of Decision Stability.**

In Figure 17, the decision line depends only on ***n*** and ***P***. These decision lines are generated based on the number of defects, as extracted from Appendix B, Table B1, for a given combination of ***n*** and ***P***. The number of defects, ***d***, is only dependent on ***T*** and is independent of ***P***. In Figure 17, if a point lies below the decision line, the decision should be to Accept; if a point lies above the decision line, the decision should be to Reject. The distance of the point from the decision line gives an indication of the stability of the decision as discussed earlier in this paragraph.

Figure 18 is the "stability" plot for Strategy 1. In Figure 18, the thick colored lines without markers represent the "decision" lines for the different levels of ***P***, and the black lines with markers represent average number of defects for each of the 200 or 400 runs for a given combination of ***n*** and ***T***. The error bars are the standard deviations of the defects of the 200 or 400 runs. Two examples are used to illustrate the interpretation of Figure 18.

Example 1:

For ***T*** = 0.5 in (12.7 mm) (black line with square markers), the decision to Reject would likely not change as it is "very far" from any of the decision lines. That is, the closest decision line is for ***P*** = 20 % (red line), and even if the length of the error bars were tripled (3σ), the line would not be below the red line.

Example 2:

The line for ***T*** = 2 in (50.8 mm) (black line with open circle markers) is very close to the line for ***P*** = 10 % (green line) and crosses the green line at about ***n*** = 160. The average number of defects

is above the green line (i.e., Reject) for ***n*** < 160 and is below the green line for ***n*** > 160. Additionally, the green line lies within the error bars for several of the points. This indicates that some of the times, depending on the samples chosen, the decision will change from "Accept" to "Reject" or vice versa.

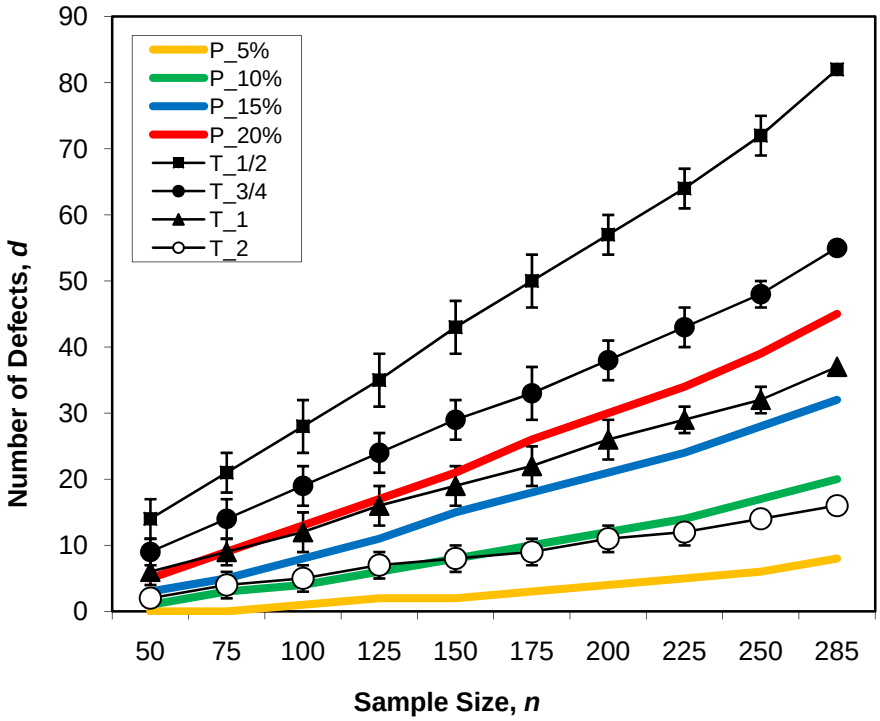


**Figure 18. Decision Stability for Strategy 1.**

Stability plots for Strategies 5 to 8 are given in Figures 19 to 22. The agreement of the results shown in Table 4 and the similarity of the stability plots for Strategies 1 and 5-8 seem to indicate that is no difference between a randomly selected set of samples and a stratified sample set.

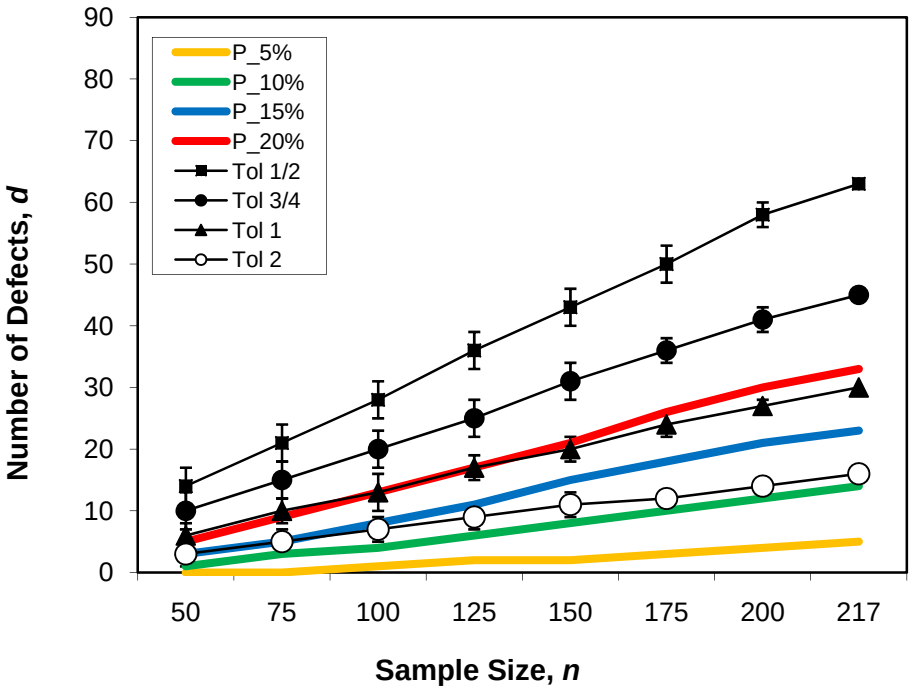


**Figure 19. Decision Stability for Strategy 5.**

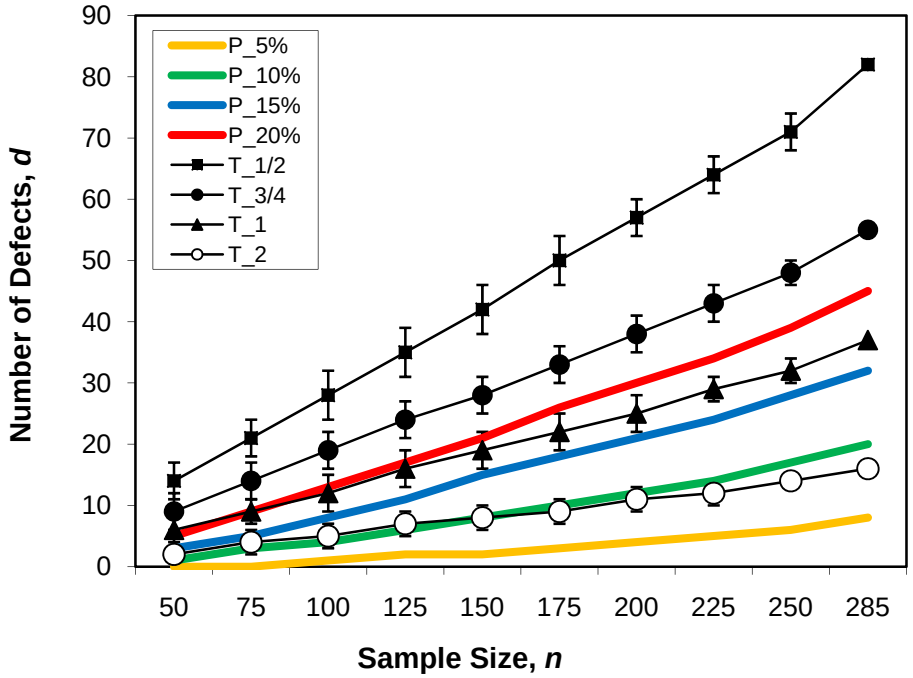


**Figure 20. Decision Stability for Strategy 6.**

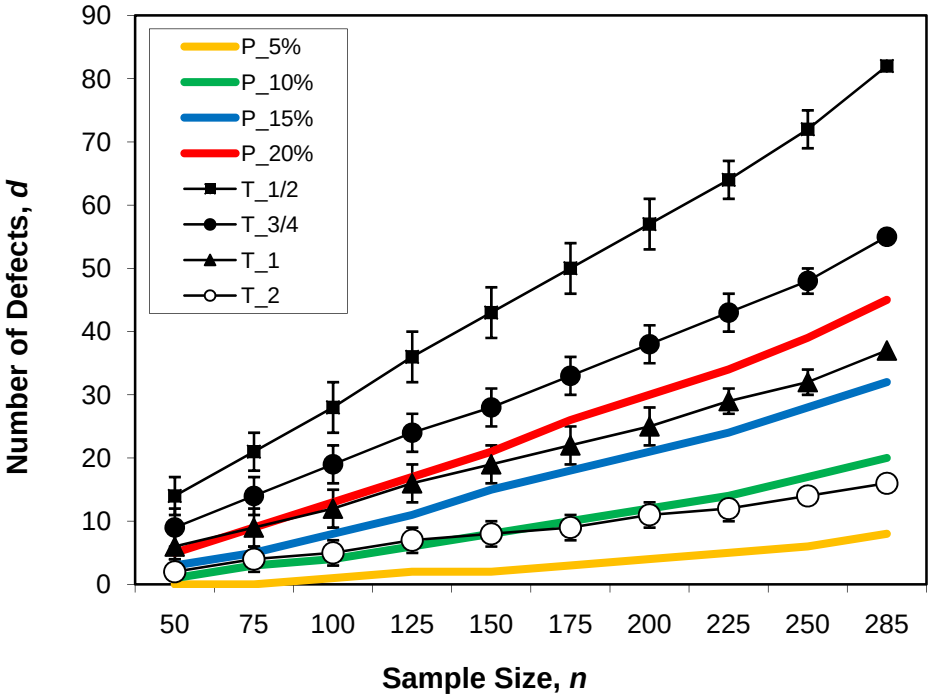


**Figure 21. Decision Stability for Strategy 7.**

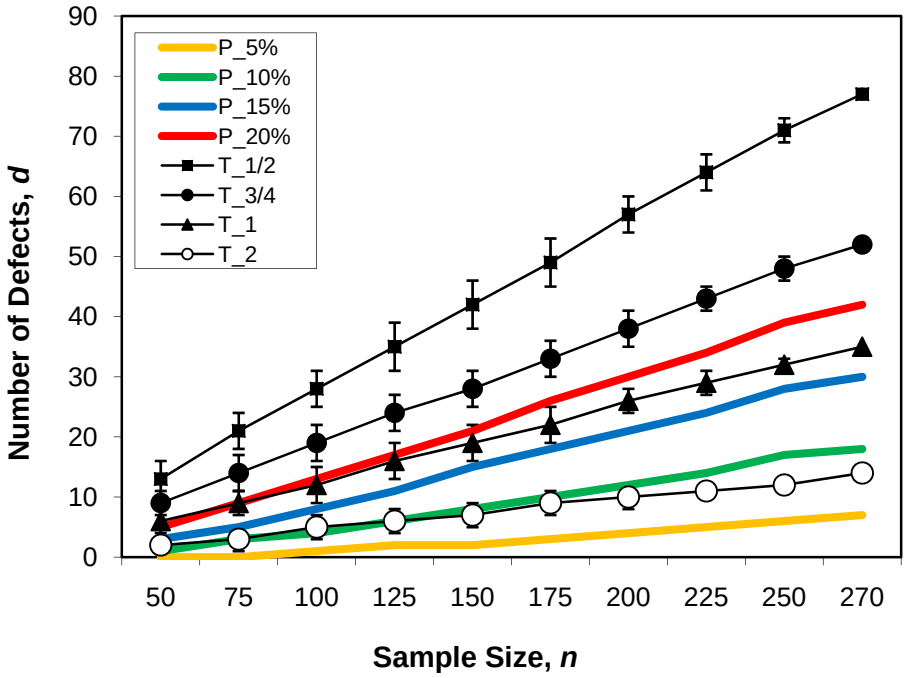


**Figure 22. Decision Stability Plot for Strategy 8.**

It does not appear from the results presented in this section that stratification of the sample affects the decision. The decisions remained basically the same whether the samples were selected randomly (Strategy 1) or if some stratification was used (Strategies 5 to 8).

The data from Table 4 and the Figures 18 to 22 are combined into Table 5. In Table 5, the gray shaded cells indicate regions where the decisions are either mixed and/or the decisions are not as stable (i.e., close to decision lines as shown in Figure 17). For this region, the choice of the sample size may be important. In the region where the cells are not shaded, the decisions are either to always Accept or to always Reject and the decisions are stable (i.e., further away from the decision line in Figure 17). Similar to Figure 17, the further away from the gray region in Table 5, the less important the choice of sample size.

**Table 5. Strategies 1 and 5-8: General Trend for the Importance of Sample Size.**

| ***P*** **(%)** | ***T*, Tolerance, in (mm)** | | | |
|---|---|---|---|---|
| | **0.5 (12.7)** | **0.75 (19.1)** | **1 (25.4)** | **2 (50.8)** |
| **5** | | | | |
| **10** | | | | |
| **15** | | | | |
| **20** | | | | |

White cells = choice of ***n*** not as critical
Gray cells = choice of ***n*** is important

### 5.2.2 Strategy 2, Strategy 3, and Strategy 4

The maximum sample sizes for Strategies 2 to 4 were 100, 117, and 104, respectively. For Strategies 2 to 4, the decisions for given ***T*** and ***P*** values are shown in Table 6. As compared to the Strategies 1 and 5 to 8, the Accept region is reduced likely due to the smaller sample sizes for Strategies 2 to 4. It appears that for smaller sample sizes, unless the requirements for T and P are less stringent, the decision will be to Reject most of the times.

**Table 6. Decisions for Strategies 2 to 4 for given *T* and *P* values.**

| P (%) | Tolerance, in (mm) | | | |
|---|---|---|---|---|
| | **0.5 (12.7)** | **0.75 (19.1)** | **1 (25.4)** | **2 (50.8)** |
| **5** | Reject | Reject | Reject | Reject |
| **10** | Reject | Reject | Reject | Reject |
| **15** | Reject | Reject | Reject | Accept[4] |
| **20** | Reject | Reject | Mixed[5] | Accept (***n*** ≥ 100) |

The "% Accept" as a function of the ***n***, ***T*** and ***P*** are given in Figures 23 to 25.

[4] No minimum sample size is given as no trend was observed for the sample size, i.e., there was no flattening out of the % Accept vs. Sample Size curve.

[5] No minimum sample size is given as no trend was observed for the sample size, i.e., there was no flattening out of the % Accept vs. Sample Size curve. The decisions (2 and 3) for two of the three strategies were to Reject.

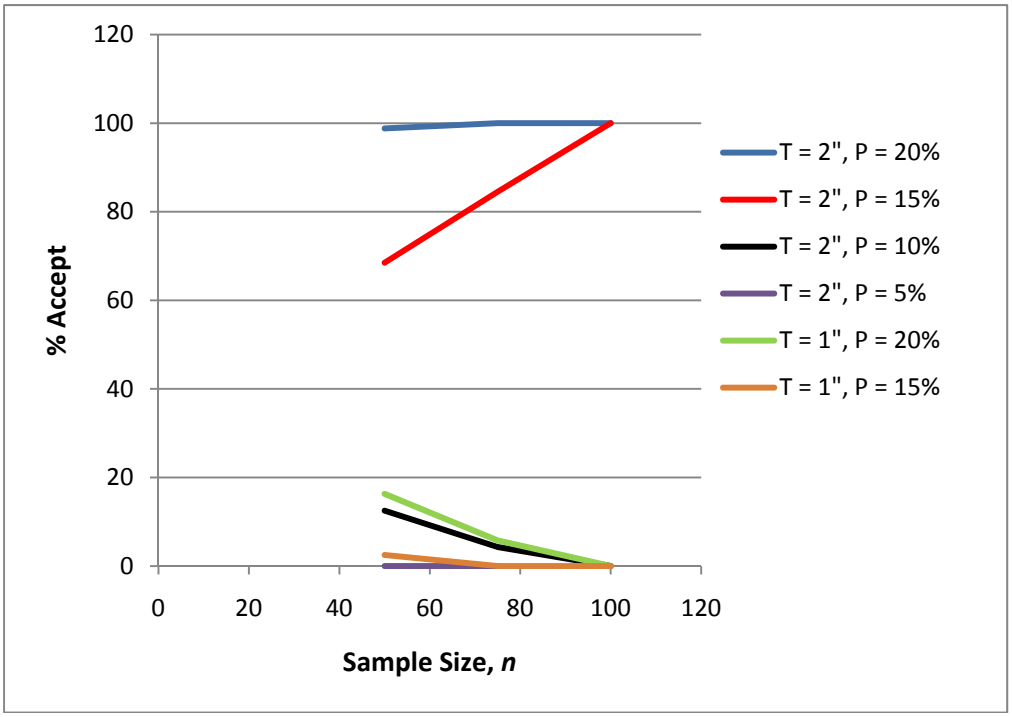


**Figure 23. Dependence of "% Accept" on *n*, *T*, and *P* for Strategy 2.**

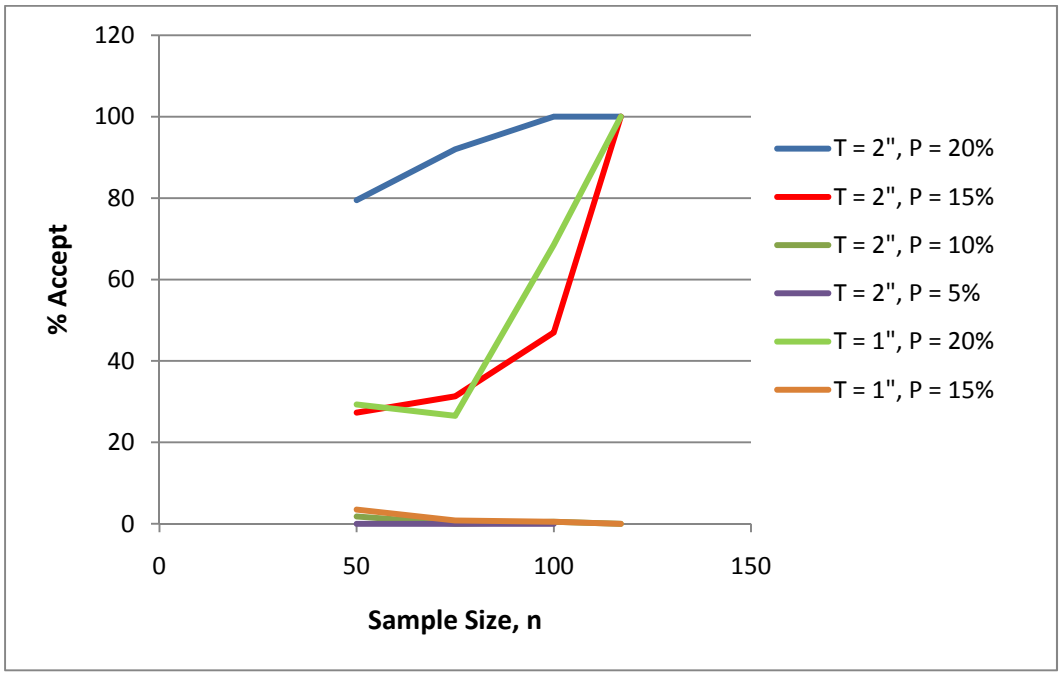


**Figure 24. Dependence of "% Accept" on *n*, *T*, and *P* for Strategy 3.**

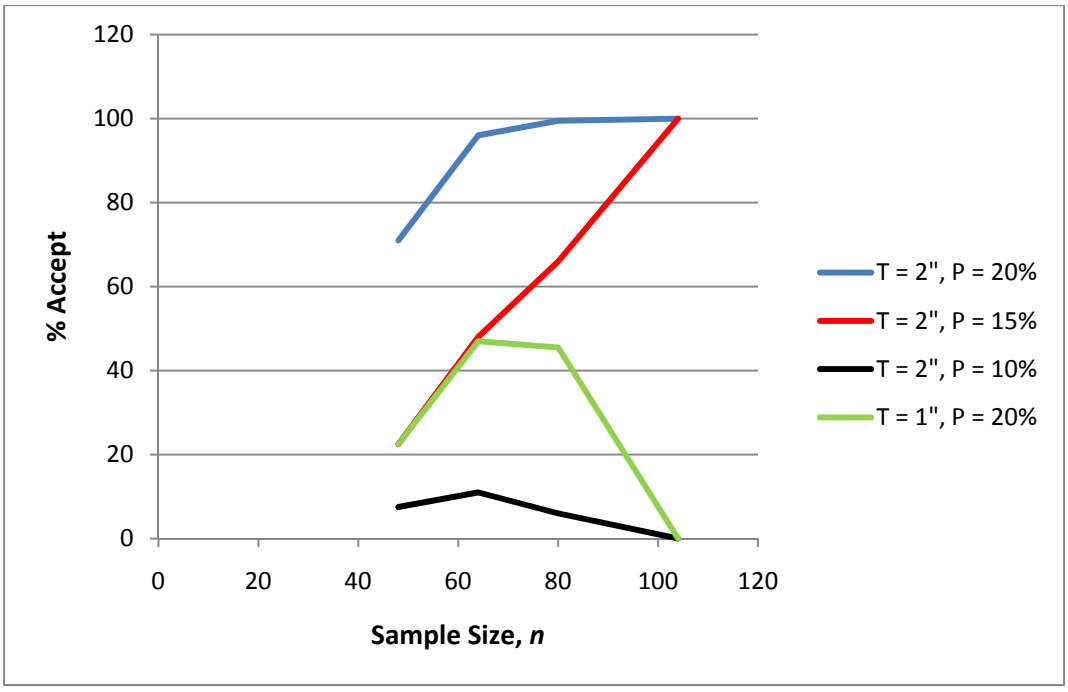


**Figure 25. Dependence of "% Accept" on *n*, *T*, and *P* for Strategy 4.**

# 6 Summary

In Phase II of the NIST/GSA 3D imaging - BIM collaboration, a method was developed for accepting 2D building plans. The focus of this project, Phase III, was on evaluating the method developed in Phase II using an actual GSA project. In particular, the objective was to determine practical/feasible limits for the tolerances (***T***), sample size (***n***), and the maximum percent of the population (***P***) out-of-spec that is acceptable to GSA.

A total of 285 measurements were obtained from a GSA 3D imaging project site by NIST and CMU. These measurements were obtained from the interior and exterior of the buildings. Different types of measurements were made: horizontal, vertical, and non-linear (e.g., circumference of pipes). These measurements were then compared to corresponding measurements extracted from 2D plans or 3D models.

Some sources of discrepancy between the manual and 2D/3D measurements include:

1. Manual measurements
    a. Extraction of the incorrect dimension from 2D/3D model
    b. Incorrect measurement
        i. measurement made from/to flexible surfaces (e.g., roll-up door)
        ii. blunder

2. 3D imaging instrument error
3. Survey control issues
    a. Incorrect control would result in registration errors
    b. If there are two or more service providers on a project, this could be an issue
4. Post-processing
    a. Registration (even if the control points were correct, registration introduces some error)
    b. Simplified model fitted to point cloud data, e.g.,
        i. planes rectified to be perpendicular
        ii. fitting to exterior points instead of interior points – this simplification may be a result of the GSA project requirement
    c. Modeling error
        i. Fitting a plane to the point cloud. If the value of this error were known, it can be accounted for.
        ii. Limitations of the design software – e.g., limited ability to show deflections, small angles.

For given combinations of ***T*** and ***P,*** eight different strategies were used to determine the influence of sample size, ***n***. To determine how ***n***, ***T***, and ***P*** affect the decision, runs with different combinations and levels of these three variables were made. Runs for all combinations for the following levels of ***n***, ***T***, and ***P*** were made:

- ***n*** = 50, 75, 100, 125, 150, 175, 100, 125, 150, 175, 200, 225, 250, 285.
- ***T*** = 0.5 in (12.7 mm), 0.75 in ( 19.1 mm), 1 in (25.4 mm), 2 in (50.8 mm)
- ***P*** = 5 % , 10 %, 15 %, 20 %

Summary of the findings:

- Accept the deliverable for ***T*** = 1 in (25.4 mm) and ***P*** = 20 %, and ***T*** = 2 in (50.8 mm) and ***P*** ≥ 15 %. Is the first instance better than the second instance? As this study only provides one data point (one project and one service provider) no generalization can be made. For future projects, GSA will have to determine which instance better meets the specific project objective: lower tolerance and acceptance of more out-of-spec or higher tolerance and less out-of-spec.

  Note that the required tolerance for the measurements of interest in this project was 1 in (25.4 mm). Therefore, the decisions to Reject for tolerances of 0.75 in (19.1 mm) or less is to be expected.

- The decision does not seem to be affected by the how the samples were selected – randomly vs. stratified. However, it is recommended that some judgment still be used when deciding where to take the samples. For example, if the building has three floors, it is not recommended that samples be taken from only one floor or only two floors.

- Vertical measurements have more out-of-spec measurements than do horizontal measurements.

Based on this one study, the answers to the questions about ***n***, ***T*** and ***P*** are:

1. *How many measurements are needed?*
   The sample sizes are highly dependent on the ***T*** and ***P***. For the instances where the decision was to Accept, the minimum sample size varied from 100 and 225. No further specificity on the sample size is possible at this stage due to the limited scope of the work (one project and one service provider).

   For a desired level of ***P***, there is a minimum sample size. This minimum value is dictated by the by the values in the "Upper Limit Table on % Defective" (Table B1). Since the number of defects cannot be less than zero, the first row, ***d*** = 0, of Table B1 will dictate the minimum ***n*** or the minimum ***P*** value. It should be noted that for these cases, the decision will be to Reject if one or more defects are found.

2. *What is a practical tolerance?*
   For this study, a 1 in (25.4 mm) tolerance is feasible. Again, the required tolerance for the dimensions of interest in the 3D imaging project was 1 in (25.4 mm).

3. *What is an acceptable percent of out-of-spec?*
   For this study, ***P*** is 20 % for ***T*** = 1 in (25.4 mm) or ***P*** = 15 % for ***T*** = 2 in (50.8 mm).

With regard to Questions 2 and 3 above, although ***P*** and ***T*** are independent parameters, their selection should be such that the decision is not trivially pre-determined, i.e., not always Reject or not always Accept (see un-shaded region in Table 5). Also, the choice of ***P*** and ***T*** is based on the project or GSA requirements.

## 6.1 Lessons learned

Some of the lessons learned from this pilot study are:

1. Field measurements:

   a. Record the x, y location of vertical measurements in case of sloped ceilings so that comparable measurements can be made.

   b. Repeat the measurement at least three times.

c. Have 2D plan or 3D model available prior to taking field measurements. The disadvantage is that changes may occur between the time the scanning took place and the generation of the 2D plans and 3D model. For example, a piece of equipment may be moved or modified.

2. Have the service provider extract the measurements from the 2D/3D model to prevent discrepancies as a result of incorrect extraction of the measurements.

## 6.2 Future Work

The work in Phase III constitutes a pilot study and the findings from this study are based on one project and one service provider. As such, the findings from Phase III provide a first realistic indication of practical/feasible limits for ***n***, ***T***, and ***P***. To verify whether these findings/trends are observed in other types of projects (e.g., different building types) and/or service providers, a more in-depth study needs to be conducted. Additional guidance is also needed to determine the types of measurements that are more problematic. This would enable better selection of the types of measurements to make which would result in a smaller sample size without impacting the confidence-level of the decision.

## Acknowledgements

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Cheok, Geraldine S. and Lytle, Alan M. (2009), BIM Guide for 3D Imaging, GSA BIM Guide Series 03, Version 1, Gaithersburg, MD, National Institue of Standards and Technology.

# Appendix A – Field Measurements

**Table A1. Field and 2D Plan/3D Model Measurements.**

| Index | Label | Description | Avg. Measured Distance (m) | t-statistic for 97.5 % pt. | Std. Dev. Of the Average (mm) | 2D plan or 3D Model Meas. (m) | Diff = Avg. Meas. - 2D/3D Meas. (mm) | Tolerance, in (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 0.5 (12.7) | 0.75 (19.1) | 1 (25.4) | 2 (50.8) |
| 1 | I-1 | Office #3 South Wall | 2.694 | 4.303 | 2.028 | 2.705 | -11.4 | In | In | In | In |
| 2 | I-2 | Office #3 East Wall | 3.573 | 4.303 | 0.333 | 3.566 | 7.8 | In | In | In | In |
| 3 | I-3 | Office #3 North Wall | 2.693 | 12.706 | 1.932 | 2.705 | -12.1 | In | In | In | In |
| 4 | I-4 | Office #3 Vertical floor to ceiling (tile, not rib) close to East-North corner | 3.000 | 12.706 | 1.500 | 2.972 | 27.7 | Out | Out | Out | In |
| 5 | I-5 | Office #3 Vertical floor to ceiling (tile, not rib) close to West-North corner | 2.983 | 12.706 | 1.000 | 2.972 | 11.2 | In | In | In | In |
| 6 | I-6 | Office #3 Vertical floor to ceiling (tile, not rib) close to West-South corner | 2.977 | 12.706 | 0.500 | 2.972 | 4.7 | In | In | In | In |
| 7 | I-7 | Office #3 Window Width West side | 1.180 | 2.571 | 0.307 | 1.238 | -57.9 | Out[5] | Out[5] | Out[5] | Out[5] |
| 8 | I-8 | Storage above door North side | 2.730 | 12.706 | 0.500 | 2.731 | -1.0 | In | In | In | In |
| 9 | I-9 | Storage West Wall | 3.718 | 12.706 | 1.000 | 3.718 | 0.1 | In | In | In | In |
| 10 | I-10 | Storage East Wall North side (shorter) | 1.856 | 12.706 | 2.500 | 1.848 | 7.7 | In | In | In | In |
| 11 | I-11 | Storage East Wall South side (longer) | 5.924 | 4.303 | 2.517 | 5.925 | -0.5 | In | In | In | In |
| 12 | I-12 | Storage South Wall | 6.276 | 12.706 | 4.502 | 6.271 | 5.4 | In | In | In | In |
| 13 | I-13 | Storage Vertical close to South-East end | 4.320 | 12.706 | 0.000 | 4.318 | 2.0 | In | In | In | In |
| 14 | I-14 | Storage Vertical close to South-West end | 4.329 | 12.706 | 0.500 | 4.318 | 10.5 | In | In | In | In |
| 15 | I-15 | Storage Vertical North side floor to beam (NOT to ceiling) | 3.010 | 4.303 | 0.577 | 2.997 | 12.8 | Out | In | In | In |
| 16 | I-16 | Men's Locker Room East Wall | 1.889 | 4.303 | 0.882 | 1.892 | -3.6 | In | In | In | In |
| 17 | I-17 | Men's Locker Room West Wall North side | 2.934 | 12.706 | 0.000 | 2.937 | -2.9 | In | In | In | In |
| 18 | I-18 | Men's Locker Room South Wall | 4.176 | 12.706 | 1.000 | 4.169 | 7.2 | In | In | In | In |

| Index | Label | Description | Avg. Measured Distance (m) | t-statistic for 97.5 % pt. | Std. Dev. Of the Average (mm) | 2D plan or 3D Model Meas. (m) | Diff = Avg. Meas. - 2D/3D Meas. (mm) | Tolerance, in (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 0.5 (12.7) | 0.75 (19.1) | 1 (25.4) | 2 (50.8) |
| 19 | I-19 | Men's Locker Room East Wall towards South (no mark on drawing) | 2.064 | 4.303 | 0.333 | 2.073 | -8.9 | In | In | In | In |
| 20 | I-20 | Men's Locker Room Vertical South end at corners | 2.434 | 4.303 | 3.606 | 2.442 | -8.4 | In | In | In | In |
| 21 | I-21 | Stairwell #1 Width of stairwell on East wall, South portion - by the door to the 1st floor | 1.136 | 4.303 | 1.202 | 1.103 | 33.0 | Out | Out | Out | In |
| 22 | I-22 | Stairwell #1, length of stairwell, south portion - near door to 1st floor | 3.889 | 4.303 | 2.186 | 3.893 | -3.2 | In | In | In | In |
| 23 | I-23 | Stairwell #1, width of stairwell on West wall - landing of door to exterior. | 2.243 | 4.303 | 1.155 | 2.242 | 1.5 | In | In | In | In |
| 24 | I-24 | Corridor #2 Level 1 West-East length (shorter) | 9.201 | 4.303 | 1.453 | 9.201 | 0.2 | In | In | In | In |
| 25 | I-25 | Office #2 South Wall | 2.798 | 12.706 | 0.500 | 2.810 | -12.4 | In | In | In | In |
| 26 | I-26 | Office #2 West Wall | 3.561 | 12.706 | 2.000 | 3.562 | -1.3 | In | In | In | In |
| 27 | I-27 | Office #2 Vertical | 2.984 | 4.303 | 2.848 | 2.972 | 12.5 | In | In | In | In |
| 28 | I-28 | Corridor #2 max length West-East direction along North wall | 11.879 | 12.706 | 0.000 | 11.875 | 4.5 | In | In | In | In |
| 29 | I-29 | Corridor #2 West-East direction along North starting from E-N (wooden frame around opening) | 5.163 | 4.303 | 0.577 | 5.159 | 3.6 | In | In | In | In |
| 30 | I-30 | Corridor #2 West Wall (width of corridor) | 2.596 | 4.303 | 2.333 | 2.597 | -0.8 | In | In | In | In |
| 31 | I-31 | Corridor #2 Vertical | 2.971 | 4.303 | 1.202 | 2.972 | -1.1 | In | In | In | In |
| 32 | I-32 | Corridor #1 East Wall full length (NOT from beam at corner) | 10.230 | 4.303 | 0.577 | 10.224 | 6.5 | In | In | In | In |
| 33 | I-33 | Corridor #1 West Wall (to the corner) | 7.620 | 4.303 | 1.202 | 7.620 | -0.3 | In | In | In | In |
| 34 | I-34 | Corridor #1 width next to Exit door | 2.663 | 4.303 | 1.856 | 2.670 | -7.5 | In | In | In | In |
| 35 | I-35 | Corridor #1 Vertical | 2.983 | 12.706 | 1.500 | 2.972 | 10.7 | In | In | In | In |
| 36 | I-36 | Office #1 South Wall | 2.802 | 4.303 | 0.577 | 2.810 | -7.9 | In | In | In | In |
| 37 | I-37 | Office #1 East Wall | 3.787 | 12.706 | 6.000 | 3.791 | -3.9 | In | In | In | In |
| 38 | I-38 | Office #1 Vertical | 2.970 | 4.303 | 4.410 | 2.972 | -2.1 | In | In | In | In |
| 39 | I-39 | Bathroom Level 1 | 2.202 | 12.706 | 1.000 | 2.207 | -4.6 | In | In | In | In |

| Index | Label | Description | Avg. Measured Distance (m) | t-statistic for 97.5 % pt. | Std. Dev. Of the Average (mm) | 2D plan or 3D Model Meas. (m) | Diff = Avg. Meas. - 2D/3D Meas. (mm) | Tolerance, in (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 0.5 (12.7) | 0.75 (19.1) | 1 (25.4) | 2 (50.8) |
| 40 | I-40 | Storage #2 length along South wall | 3.086 | 12.706 | 0.500 | 3.061 | 24.8 | Out | Out | In | In |
| 41 | I-41 | Storage #2 width along West | 1.971 | 12.706 | 1.414 | 1.978 | -7.0 | In | In | In | In |
| 42 | I-42 | Closet length | 2.213 | 4.303 | 0.882 | 2.216 | -3.5 | In | In | In | In |
| 43 | I-43 | Open Office #8 (2nd floor) East-west distance betw'n west wall and stairwell wall | 3.276 | 4.303 | 2.186 | 3.273 | 2.9 | In | In | In | In |
| 44 | I-44 | Open Office #8 along West (to the barrier) | 7.811 | 4.303 | 0.667 | 7.798 | 12.9 | Out | In | In | In |
| 45 | I-45 | Open Office #8 full width along West | 9.136 | 12.706 | 0.500 | 9.125 | 10.6 | In | In | In | In |
| 46 | I-46 | Open Office #8 full length along South | 11.896 | 12.706 | 1.000 | 11.906 | -10.2 | In | In | In | In |
| 47 | I-47 | Open Office #8 width middle window West wall | 1.170 | 2.571 | 0.966 | 1.241 | -71.4 | Out[5] | Out[5] | Out[5] | Out[5] |
| 48 | I-48 | Open Office #8 width along East wall | 9.005 | 12.706 | 0.500 | 9.020 | -15.7 | Out | In | In | In |
| 49 | I-49 | Open Office #8, East-west distance, length of "kitchen-area" wall measured from the open office area | 2.679 | 4.303 | 1.528 | 2.667 | 12.0 | In | In | In | In |
| 50 | I-50 | Open Office #8 opening to the kitchen | 0.844 | 4.303 | 1.667 | 0.848 | -3.4 | In | In | In | In |
| 51 | I-51 | Open Office #8 Vertical (height of opening to the kitchen) | 2.112 | 4.303 | 1.000 | 2.108 | 3.8 | In | In | In | In |
| 52 | I-52 | Office #5 shorter distance to the beam along West wall | 3.461 | 4.303 | 1.000 | 3.477 | -15.6 | Out | In | In | In |
| 53 | I-53 | Office #5 shorter distance to the beam along South wall | 3.809 | 4.303 | 0.577 | 3.791 | 18.1 | Out | In | In | In |
| 54 | I-54 | Office #5 Vertical | 2.423 | 4.303 | 4.055 | 2.423 | 0.8 | In | In | In | In |
| 55 | I-55 | Office #6 North Wall | 4.796 | 4.303 | 0.667 | 4.797 | -1.1 | In | In | In | In |
| 56 | I-56 | Office #6 width along West, next to door | 3.685 | 12.706 | 2.643 | 3.693 | -7.5 | In | In | In | In |
| 57 | I-57 | Office #6 South Wall | 4.783 | 12.706 | 3.431 | 4.785 | -1.7 | In | In | In | In |
| 58 | I-58 | Open Office #8 column to West Wall | 5.680 | 4.303 | 3.180 | 5.632 | 47.2 | Out | Out | Out | In |
| 59 | I-59 | Open Office #8 column width | 0.596 | 4.303 | 0.882 | 0.594 | 1.9 | In | In | In | In |
| 60 | I-60 | Open Office #8 Vertical ceiling higher than the rest of ceiling next to window West wall | 2.925 | 4.303 | 3.844 | 2.950 | -25.0 | Out | Out | In | In |

| Index | Label | Description | Avg. Measured Distance (m) | t-statistic for 97.5 % pt. | Std. Dev. Of the Average (mm) | 2D plan or 3D Model Meas. (m) | Diff = Avg. Meas. - 2D/3D Meas. (mm) | Tolerance, in (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 0.5 (12.7) | 0.75 (19.1) | 1 (25.4) | 2 (50.8) |
| 61 | I-61 | Open Office #8 Vertical lower ceiling | 2.410 | 4.303 | 3.464 | 2.423 | -12.5 | In | In | In | In |
| 62 | I-62 | Stairwell #1 to Office #8, width close to door | 1.145 | 4.303 | 1.528 | 1.149 | -4.4 | In | In | In | In |
| 63 | I-63 | Stairwell #1 window width | 1.214 | 2.776 | 0.490 | 1.270 | -56.0 | Out[5] | Out[5] | Out[5] | Out[5] |
| 64 | I-64 | Stairwell #1 Vertical window height | 2.084 | 2.776 | 0.678 | 2.150 | -66.8 | Out[5] | Out[5] | Out[5] | Out[5] |
| 65 | I-65 | Conference Room West Wall | 6.402 | 4.303 | 0.333 | 6.394 | 7.9 | In | In | In | In |
| 66 | I-66 | Conference Room South Wall | 4.020 | 4.303 | 1.856 | 4.029 | -9.4 | In | In | In | In |
| 67 | I-67 | Conference Room East Wall full length | 6.421 | 4.303 | 1.856 | 6.394 | 26.2 | Out | Out | Out | In |
| 68 | I-68 | Conference Room East Wall from North window (right/south side) to South wall | 4.354 | 12.706 | 0.500 | 4.347 | 6.9 | In | In | In | In |
| 69 | I-69 | Conference Room Vertical | 2.985 | 4.303 | 1.667 | 2.997 | -11.9 | In | In | In | In |
| 70 | I-70 | Office #4 West Wall | 4.774 | 12.706 | 1.000 | 4.782 | -7.6 | In | In | In | In |
| 71 | I-71 | Office #4 South Wall | 4.405 | 12.706 | 0.500 | 4.407 | -2.4 | In | In | In | In |
| 72 | I-72 | Office #4 width right window | 1.174 | 2.571 | 0.894 | 1.270 | -96.0 | Out[5] | Out[5] | Out[5] | Out[5] |
| 73 | I-73 | Office #4 Vertical height of right window | 1.756 | 2.571 | 1.222 | 1.864 | -107.4 | Out[5] | Out[5] | Out[5] | Out[5] |
| 74 | I-74 | Office #4 door width | 1.012 | 4.303 | 0.667 | 0.991 | 21.1 | Out | Out | In | In |
| 75 | I-75 | Mechanical Room South side | 2.434 | 4.303 | 2.333 | 2.423 | 11.1 | In | In | In | In |
| 76 | I-76 | Break Room along North (from West wall NOT West door) | 4.397 | 4.303 | 4.163 | 4.401 | -3.6 | In | In | In | In |
| 77 | I-77 | Break Room West Wall | 3.811 | 4.303 | 1.732 | 3.816 | -5.3 | In | In | In | In |
| 78 | I-78 | Break Room East Wall | 3.819 | 12.706 | 0.500 | 3.816 | 2.2 | In | In | In | In |
| 79 | I-79 | Break Room Vertical | 2.680 | 4.303 | 3.283 | 2.692 | -12.1 | In | In | In | In |
| 80 | I-80 | Corridor #3 doorway width | 1.600 | 4.303 | 1.202 | 1.603 | -3.7 | In | In | In | In |
| 81 | I-81 | Corridor #3, Length of corridor along North Wall | 7.035 | 4.303 | 0.667 | 7.020 | 14.7 | Out | In | In | In |
| 82 | I-82 | Corridor #3 - width of corridor off the north end of corridor #3 | 1.872 | 4.303 | 4.667 | 1.861 | 11.1 | In | In | In | In |
| 83 | I-83 | Generator Room #1 North Wall | 9.571 | 12.706 | 1.000 | 9.571 | 0.0 | In | In | In | In |

| Index | Label | Description | Avg. Measured Distance (m) | t-statistic for 97.5 % pt. | Std. Dev. Of the Average (mm) | 2D plan or 3D Model Meas. (m) | Diff = Avg. Meas. - 2D/3D Meas. (mm) | Tolerance, in (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 0.5 (12.7) | 0.75 (19.1) | 1 (25.4) | 2 (50.8) |
| 84 | I-84 | Generator Room #1 North-South distance between roll-up doors | 26.113 | 4.303 | 0.667 | 26.108 | 4.6 | In | In | In | In |
| 85 | I-85 | Generator Room #1 Distance betw'n west wall (north end of room) and large gray pipe | 4.759 | 2.571 | 18.538 | 4.761 | -2.2 | In | In | In | In |
| 86 | I-86 | Generator Room #1 between blue columns 1 & 2 | 2.772 | 4.303 | 1.333 | 2.767 | 4.7 | In | In | In | In |
| 87 | I-87 | Generator Room #1 short distance along North, next to staircase | 2.815 | 4.303 | 0.333 | 2.826 | -10.4 | In | In | In | In |
| 88 | I-88 | Generator Room #1 short distance along West wall (where doors are located) | 3.248 | 4.303 | 0.577 | 3.242 | 6.3 | In | In | In | In |
| 89 | I-89 | Generator Room #1 Vertical floor to I-beam along Control room wall | 3.450 | 4.303 | 8.413 | 3.466 | -15.8 | In | In | In | In |
| 90 | I-90 | Generator Room #1 Level 2 West-East distance along North | 13.900 | 12.706 | 0.500 | 13.908 | -8.6 | In | In | In | In |
| 91 | I-91 | Generator Room #1 Level 2, east-west distance to Cinder Block "abutment" next to steel column | 5.110 | 2.776 | 0.400 | 5.124 | -14.5 | Out | In | In | In |
| 92 | I-92 | Generator Room #1 Level 2 column to column (web to web) | 6.078 | 4.303 | 0.577 | 6.079 | -0.5 | In | In | In | In |
| 93 | I-93 | Generator Room #1 Level 2 Pipe Size - diameter | 0.115 | 4.303 | 0.038 | 0.114 | 0.7 | In | In | In | In |
| 94 | I-94 | Generator Room #1 Level 2 Circumference of Blue Cylinder above the pipe described in (I-93) | 1.118 | 2.776 | 0.510 | 1.277 | -158.7 | Out | Out | Out | Out |
| 95 | I-95 | Generator Room #1 Level 2 Red Pipe Size circumference by column 1(no mark on drawing) | 1.460 | 12.706 | 1.000 | 1.436 | 23.7 | Out | Out | In | In |
| 96 | I-96 | Generator Room #1 Level 1 the circumference of the gray pipe identified in I-85 | 0.946 | 2.571 | 0.543 | 1.017 | -71.4 | Out | Out | Out | Out |
| 97 | I-97 | Generator Room #1 Level 1 West-East wall distance | 8.535 | 12.706 | 0.500 | 8.531 | 3.3 | In | In | In | In |
| 98 | R-1 | Upper Roof close to Exit door from stairwell East | 5.495 | 2.571 | 2.910 | 5.521 | -26.8 | □□□□O | Out | Out | In |
| 99 | I-100 | Stairwell #2 Top Level East-West distance along South wall | 2.419 | 12.706 | 1.735 | 2.430 | -10.7 | In | In | In | In |
| 100 | I-102 | Stairwell #2 Top Level North-South distance along West wall | 5.259 | 12.706 | 3.000 | 5.280 | -21.0 | In | In | In | In |
| 101 | I-103 | Generator Room #2 column to column (web to web) | 4.537 | 4.303 | 0.333 | 4.559 | -22.6 | Out | Out | In | In |

| Index | Label | Description | Avg. Measured Distance (m) | t-statistic for 97.5 % pt. | Std. Dev. Of the Average (mm) | 2D plan or 3D Model Meas. (m) | Diff = Avg. Meas. - 2D/3D Meas. (mm) | Tolerance, in (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 0.5 (12.7) | 0.75 (19.1) | 1 (25.4) | 2 (50.8) |
| 102 | I-104 | Generator Room #2 West-East distance along North wall | 13.943 | 12.706 | 0.000 | 13.932 | 11.1 | In | In | In | In |
| 103 | I-105 | Generator Room #2 along West wall from North wall to North wall of Spare room | 21.044 | 12.706 | 0.500 | 21.066 | -22.6 | Out | Out | In | In |
| 104 | I-106 | Generator Room #2 West-East distance next to Space Room door | 13.925 | 12.706 | 0.500 | 13.932 | -7.4 | In | In | In | In |
| 105 | I-107 | Generator Room #2 West-East distance between I-beam and Spare Room wall | 4.080 | 4.303 | 1.000 | 4.105 | -25.3 | Out | Out | In | In |
| 106 | I-108 | Generator Room #2 door opening between Generator Rm #2 & Gen Rm #1 | 3.012 | 4.303 | 0.577 | 3.007 | 5.3 | In | In | In | In |
| 107 | I-109 | Generator Room #2 Equipment #1 length | 11.127 | 12.706 | 3.000 | 11.138 | -10.9 | In | In | In | In |
| 108 | I-110 | Generator Room #2  Equipment #2 width South | 2.905 | 12.706 | 0.500 | 2.934 | -29.2 | Out | Out | Out | In |
| 109 | I-111 | Generator Room #2 West-East dist between EQ #2 & EQ #3, South side of EQ#2 | 3.969 | 12.706 | 8.500 | 3.950 | 18.8 | In | In | In | In |
| 110 | I-112 | Generator Room #2 roll-up door to roll up door in Gen. room #1 (Noisy Room) | 61.998 | 2.776 | 4.501 | 62.076 | -77.6 | Out | Out | Out | Out |
| 111 | I-113 | Generator Room #2 exterior of north wall to Spare Room | 4.919 | 12.706 | 2.000 | 4.905 | 13.6 | In | In | In | In |
| 112 | I-114 | Generator Room #2 from Spare Room (near door) exterior wall to black metal pipe (no mark on drawing) | 1.380 | 4.303 | 5.000 | 1.375 | 5.2 | In | In | In | In |
| 113 | I-115 | Spare Room North Wall | 4.727 | 12.706 | 1.000 | 4.740 | -13.3 | Out | In | In | In |
| 114 | I-116 | Spare Room West side short (from North to the middle) | 5.594 | 4.303 | 1.732 | 5.604 | -9.9 | In | In | In | In |
| 115 | I-117 | Spare Room East Wall | 13.300 | 12.706 | 0.500 | 13.294 | 5.8 | In | In | In | In |
| 116 | I-118 | Spare Room South Wall | 3.453 | 12.706 | 0.000 | 3.432 | 20.8 | Out | Out | In | In |
| 117 | I-119 | Spare Room window opening | 2.046 | 4.303 | 0.333 | 2.038 | 8.0 | In | In | In | In |
| 118 | I-120 | Control Room East Wall | 9.219 | 12.706 | 2.500 | 9.246 | -27.1 | In | In | In | In |
| 119 | I-121 | Control Room North Wall above double door to GEN. RM. #1 | 4.036 | 12.706 | 0.000 | 4.035 | 0.6 | In | In | In | In |
| 120 | I-122 | Control Room West Wall max length | 12.462 | 12.706 | 0.500 | 12.481 | -19.4 | Out | Out | In | In |

| Index | Label | Description | Avg. Measured Distance (m) | t-statistic for 97.5 % pt. | Std. Dev. Of the Average (mm) | 2D plan or 3D Model Meas. (m) | Diff = Avg. Meas. - 2D/3D Meas. (mm) | Tolerance, in (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 0.5 (12.7) | 0.75 (19.1) | 1 (25.4) | 2 (50.8) |
| 121 | I-123 | Control Room East Wall in corridor South end | 4.173 | 4.303 | 1.856 | 4.162 | 10.2 | In | In | In | In |
| 122 | I-124 | Control Room width of corridor South end | 1.235 | 4.303 | 1.000 | 1.216 | 19.0 | Out | In | In | In |
| 123 | I-125 | Control Room Vertical | 2.751 | 4.303 | 2.333 | 2.742 | 8.9 | In[4] | In[4] | In[4] | In[4] |
| 124 | I-126 | Switch Room East Wall | 25.303 | 4.303 | 2.333 | 25.317 | -14.1 | Out | In | In | In |
| 125 | I-127 | Switch Room North Wall | 9.135 | 1. | 1.000 | 9.134 | 0.5 | In | In | In | In |
| 126 | I-128 | Switch Room opening of doors to Boiler Room | 2.747 | 4.303 | 1.202 | 2.743 | 3.5 | In | In | In | In |
| 127 | I-129 | Switch Room Vertical, height of door opening (as in I-128) | 2.799 | 2.571 | 1.366 | 2.799 | 0.6 | In | In | In | In |
| 128 | I-130 | Switch Room distance along East between two North-most columns | 5.445 | 12.706 | 0.000 | 5.439 | 6.2 | In | In | In | In |
| 129 | I-131 | Switch Room Vertical floor to ceiling (higher part of corrugated metal sheet) | 6.175 | 4.303 | 3.667 | 6.140 | 35.7 | Out | Out | Out | In |
| 130 | I-132 | Switch Room West Wall | 25.311 | 12.706 | 0.500 | 25.337 | -26.0 | Out | Out | Out | In |
| 131 | I-133 | Switch Room South Wall | 9.136 | 12.706 | 0.500 | 9.119 | 16.9 | Out[4] | In[4] | In[4] | In[4] |
| 132 | I-134 | Switch Room width of Electric Box 2nd from West | 0.623 | 4.303 | 0.577 | 0.616 | 7.1 | In | In | In | In |
| 133 | I-135 | Switch Room Vertical height of Electric Box (as in I-134) | 0.926 | 4.303 | 1.528 | 0.921 | 5.3 | In | In | In | In |
| 134 | I-136 | Switch Room Vertical height to lower flange of I-beam truss in ceiling | 3.953 | 2.571 | 6.041 | 3.650 | 303.3 | Out[4] | Out[4] | Out[4] | Out[4] |
| 135 | I-137 | Switch Room distance along East wall from South wall to the 1st column | 5.158 | 12.706 | 1.500 | 5.156 | 1.3 | In | In | In | In |
| 136 | I-138 | Switch Room distance from West wall to Equipment #2 (no mark on drawing) | 1.392 | 4.303 | 2.082 | 1.395 | -2.6 | In | In | In | In |
| 137 | I-139 | Switch Room aluminum pipe coming out of EQ.#4 (South-most pipe, West row) - diameter | 0.114 | 4.303 | 0.158 | 0.114 | -0.5 | In | In | In | In |
| 138 | I-140 | Switch Room distance between two aluminum pipes (outside-to-outside) South side (in West row) | 0.279 | 4.303 | 0.907 | 0.287 | -8.7 | In | In | In | In |
| 139 | I-141 | Boiler Room East wall | 9.741 | 12.706 | 6.987 | 9.747 | -6.2 | In | In | In | In |
| 140 | I-142 | Boiler Room column to column distance | 5.535 | 2.571 | 2.894 | 5.539 | -4.0 | In | In | In | In |

| Index | Label | Description | Avg. Measured Distance (m) | t-statistic for 97.5 % pt. | Std. Dev. Of the Average (mm) | 2D plan or 3D Model Meas. (m) | Diff = Avg. Meas. - 2D/3D Meas. (mm) | Tolerance, in (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 0.5 (12.7) | 0.75 (19.1) | 1 (25.4) | 2 (50.8) |
| 141 | I-143 | Boiler Room North-South distance between roll-up doors | 9.410 | 2.571 | 1.453 | 9.515 | -105.1 | Out | Out | Out | Out |
| 142 | I-144 | Boiler Room total length | 22.869 | 12.706 | 16.404 | 22.866 | 2.7 | In | In | In | In |
| 143 | I-145 | Boiler Room width close to West wall | 9.749 | 12.706 | 1.000 | 9.747 | 1.7 | In | In | In | In |
| 144 | I-146 | Boiler Room window opening width | 1.247 | 12.706 | 0.500 | 1.245 | 1.9 | In[5] | In[5] | In[5] | In[5] |
| 145 | I-147 | Boiler Room width next to roll up door (closer to West) | 9.629 | 4.303 | 1.528 | 9.636 | -7.1 | In | In | In | In |
| 146 | I-148 | Boiler Room distance column to door along wall | 1.759 | 4.303 | 0.577 | 1.759 | 0.1 | In | In | In | In |
| 147 | I-149 | Boiler Room Vertical floor to ceiling | 6.322 | 2.571 | 65.094 | 6.515 | -193.4 | Out[4] | Out[4] | Out[4] | Out[4] |
| 148 | I-150 | Boiler Room Vertical floor to blue pipe (in front of roll up door south side) | 3.377 | 4.303 | 2.333 | 3.396 | -19.8 | Out | Out | In | In |
| 149 | I-151 | Chiller Room roll up door width North wall | 3.663 | 4.303 | 0.577 | 3.664 | -0.9 | In | In | In | In |
| 150 | I-152 | Chiller Room Vertical roll up door height | 3.803 | 2.571 | 2.613 | 3.824 | -21.6 | Out | Out | In | In |
| 151 | I-153 | Chiller Room total width along North wall (next to roll up door) | 13.412 | 12.706 | 2.000 | 13.414 | -2.4 | In | In | In | In |
| 152 | I-154 | Chiller Room distance between roll up and Exit doors North wall | 0.808 | 4.303 | 1.528 | 0.822 | -14.3 | Out | In | In | In |
| 153 | I-155 | Chiller Room Vertical floor to higher corrugated ceiling North wall by roll up door | 6.520 | 2.571 | 7.565 | 6.438 | 81.9 | Out[4] | Out[4] | Out[4] | Out[4] |
| 154 | I-158 | Chiller Room along East wall distance between 1 & 2 steel columns | 4.500 | 4.303 | 0.000 | 4.501 | -0.6 | In | In | In | In |
| 155 | I-160 | Chiller Room North-South length (between South exit door & North roll up door) | 44.428 | 4.303 | 0.667 | 44.064 | 363.4 | Out | Out | Out | Out |
| 156 | I-161 | Chiller Room from South wall (next to window) to the "middle" wall | 18.418 | 4.303 | 0.577 | 18.440 | -22.4 | Out | Out | In | In |
| 157 | I-162 | Chiller Room width of window #2 (from North) opening in West wall | 1.219 | 4.303 | 0.000 | 1.238 | -19.3 | Out[5] | Out[5] | In[5] | In[5] |
| 158 | I-163 | Chiller Room Vertical height of window #2 (from North) opening in West wall | 2.124 | 4.303 | 1.155 | 2.165 | -41.4 | Out[5] | Out[5] | Out[5] | In[5] |
| 159 | I-164 | Chiller Room tilted lower pipe next to window #2 circumference | 1.278 | 12.706 | 0.000 | 1.281 | -3.1 | In | In | In | In |

| Index | Label | Description | Avg. Measured Distance (m) | t-statistic for 97.5 % pt. | Std. Dev. Of the Average (mm) | 2D plan or 3D Model Meas. (m) | Diff = Avg. Meas. - 2D/3D Meas. (mm) | Tolerance, in (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 0.5 (12.7) | 0.75 (19.1) | 1 (25.4) | 2 (50.8) |
| 160 | I-166 | Chiller Room width of window #3 in West wall | 3.556 | 4.303 | 0.333 | 3.585 | -28.9 | Out[5] | Out[5] | Out[5] | In[5] |
| 161 | I-168 | Chiller Room North pipe next to West door circumference | 1.015 | 12.706 | 0.500 | 1.018 | -3.9 | In | In | In | In |
| 162 | I-170 | Chiller Room East-West width next to West door | 13.416 | 4.303 | 4.726 | 13.424 | -7.9 | In | In | In | In |
| 163 | I-171 | Chiller Room distance between brick columns next to West door | 5.452 | 4.303 | 0.577 | 5.458 | -5.8 | In | In | In | In |
| 164 | I-173 | Chiller Room Vertical floor to lower part of corrugated ceiling next to West wall, South end of #3 window | 6.075 | 4.303 | 5.457 | 6.063 | 12.7 | In[4] | In[4] | In[4] | In[4] |
| 165 | I-175 | Chiller Room distance concrete base #7 East end above floor to East wall | 11.723 | 2.571 | 0.715 | 11.711 | 12.0 | In | In | In | In |
| 166 | I-176 | Chiller Room black vertical (tilted) pipe out of Equipment #8 circumference | 1.025 | 12.706 | 1.000 | 1.012 | 12.6 | In | In | In | In |
| 167 | I-177 | Chiller Room distance South wall to red pipe (next to door) on concrete pad #12 | 2.093 | 4.303 | 0.882 | 2.102 | -8.5 | In | In | In | In |
| 168 | I-178 | Chiller Room distance South wall to blue plate Equipment #13 on concrete pad #13, see also picture P2170007 | 1.167 | 4.303 | 1.155 | 1.175 | -7.7 | In | In | In | In |
| 169 | I-179 | Chiller Room East-West length of concrete base Equipment #11 | 7.212 | 4.303 | 1.333 | 7.204 | 7.6 | In | In | In | In |
| 170 | I-181 | Chiller Room Vertical floor to higher part of corrugated ceiling next to East end of Equipment #11 | 6.494 | 4.303 | 2.028 | 6.484 | 9.5 | In[4] | In[4] | In[4] | In[4] |
| 171 | I-184 | Stairwell #2, ground level width (South most) | 1.510 | 4.303 | 1.528 | 1.499 | 11.4 | In | In | In | In |
| 172 | I-185 | Stairwell #2 ground level depth | 0.635 | 4.303 | 1.333 | 0.641 | -6.0 | In | In | In | In |
| 173 | I-186 | Stairwell #2 ground level full width | 2.663 | 4.303 | 3.180 | 2.667 | -4.3 | In | In | In | In |
| 174 | I-187 | Stairwell #2 ground level full length (North - South distance along East) | 5.282 | 4.303 | 1.202 | 5.274 | 8.0 | In | In | In | In |
| 175 | I-188 | 1st Floor Ladies Bathroom North-south width in the middle of room (above tile) | 1.522 | 2.776 | 0.583 | 1.527 | -5.4 | In | In | In | In |
| 176 | I-189 | 1st Floor Ladies Bathroom West-East width in the middle of room (above tile) | 1.990 | 2.776 | 0.927 | 1.940 | 49.7 | Out | Out | Out | In |

| Index | Label | Description | Avg. Measured Distance (m) | t-statistic for 97.5 % pt. | Std. Dev. Of the Average (mm) | 2D plan or 3D Model Meas. (m) | Diff = Avg. Meas. - 2D/3D Meas. (mm) | Tolerance, in (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 0.5 (12.7) | 0.75 (19.1) | 1 (25.4) | 2 (50.8) |
| 177 | I-190 | 1st Floor Ladies Bathroom Vertical (floor-ceiling) | 2.571 | 4.303 | 3.844 | 2.569 | 1.3 | In | In | In | In |
| 178 | R-3 | Lower Roof North side width | 22.955 | 12.706 | 16.466 | 23.027 | -71.7 | In | In | In | In |
| 179 | R-4 | Lower Roof West side length | 54.317 | 12.706 | 38.962 | 54.178 | 138.8 | In | In | In | In |
| 180 | R-5 | Lower Roof South side width | 23.040 | 12.706 | 16.527 | 22.920 | 119.7 | In | In | In | In |
| 181 | R-7 | Lower Roof South side, dist. Betw'n wall of the facility part to the wall of the office part | 7.307 | 4.303 | 2.963 | 7.306 | 1.7 | In | In | In | In |
| 182 | R-8 | Upper Roof Northern part, South side East corner between columns | 3.932 | 4.303 | 0.882 | 3.969 | -36.4 | Out | Out | Out | In |
| 183 | R-9 | Upper Roof Northern part, distance between the 2 large col. On either side of the stairs to the south portion | 3.208 | 4.303 | 0.333 | 3.172 | 35.8 | Out | Out | Out | In |
| 184 | R-10 | Upper Roof Northern part, center - width of West column at center, next to stairs | 0.929 | 4.303 | 1.856 | 0.937 | -7.3 | In | In | In | In |
| 185 | R-11 | Upper Roof Northern part, center West side distance between columns | 3.210 | 4.303 | 3.055 | 3.197 | 12.8 | In | In | In | In |
| 186 | R-12 | Upper Roof distance from center column to Equipment #1 | 5.807 | 4.303 | 4.256 | 5.807 | -0.4 | In | In | In | In |
| 187 | I-191 | Ladies Bathroom 1st floor - width of opening betw'n the toilet and other room. | 0.826 | 12.706 | 5.354 | 0.822 | 3.3 | In | In | In | In |
| 188 | I-192 | Office #7 2nd floor North-South length at middle of office | 3.681 | 4.303 | 0.882 | 3.693 | -11.9 | In | In | In | In |
| 189 | I-193 | Office #7 2nd floor West-East full width | 2.869 | 4.303 | 0.333 | 2.873 | -4.0 | In | In | In | In |
| 190 | I-194 | Office #7 2nd floor Vertical floor to lower ceiling | 2.424 | 4.303 | 2.906 | 2.423 | 1.1 | In | In | In | In |
| 191 | I-195 | Office #7 2nd floor width of south window opening | 1.109 | 4.303 | 0.882 | 1.111 | -2.6 | In[5] | In[5] | In[5] | In[5] |
| 192 | I-196 | Office #8 2nd floor, East wall, wall width between windows 1 & 2 (the two north-most windows) | 1.406 | 12.706 | 0.000 | 1.365 | 40.7 | Out[5] | Out[5] | Out[5] | In[5] |
| 193 | I-197 | Office #8 2nd floor, coffee room West-East distance closer to North | 1.460 | 12.706 | 2.000 | 1.461 | -0.5 | In | In | In | In |
| 194 | I-198 | Office #8 2nd floor coffee room North-South distance along West side | 1.150 | 4.303 | 0.333 | 1.146 | 3.5 | In | In | In | In |

| Index | Label | Description | Avg. Measured Distance (m) | t-statistic for 97.5 % pt. | Std. Dev. Of the Average (mm) | 2D plan or 3D Model Meas. (m) | Diff = Avg. Meas. - 2D/3D Meas. (mm) | Tolerance, in (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 0.5 (12.7) | 0.75 (19.1) | 1 (25.4) | 2 (50.8) |
| 195 | I-199 | Office #8 2nd floor North-South distance from center column to wall above opening to coffee room | 4.127 | 12.706 | 0.500 | 4.164 | -37.5 | Out | Out | Out | In |
| 196 | I-200 | Office #8 2nd floor, width of north-most window on West wall | 1.185 | 4.303 | 1.333 | 1.235 | -50.4 | Out[5] | Out[5] | Out[5] | In[5] |
| 197 | I-201 | Corridor #3 1st floor East-West wall in front of Break Room closer to North | 2.163 | 4.303 | 1.528 | 2.159 | 4.0 | In | In | In | In |
| 198 | I-202 | Switch Room North-South length Equipment #1 | 13.769 | 4.303 | 2.728 | 13.780 | -10.8 | In | In | In | In |
| 199 | I-203 | Switch Room East-West width of Equipment #1 | 2.420 | 2.571 | 0.333 | 2.368 | 52.2 | Out | Out | Out | Out |
| 200 | I-204 | Switch Room Vertical floor to ceiling (lower part of corrugated metal sheet) | 6.178 | 2.571 | 28.040 | 6.329 | -151.0 | Out | Out | Out | Out |
| 201 | I-205 | Switch Room, aluminum pipe South wall, East side - diameter | 0.044 | 4.303 | 0.120 | 0.043 | 1.6 | In | In | In | In |
| 202 | I-206 | Switch Room, largest aluminum pipe coming out of smaller electrical box in the middle of West wall diameter | 0.073 | 4.303 | 0.032 | 0.060 | 12.9 | Out | In | In | In |
| 203 | I-208 | Generator Room #2 North-South length Equipment #3 (no mark on drawing) | 11.123 | 4.303 | 1.667 | 11.138 | -15.2 | Out | In | In | In |
| 204 | I-209 | Generator Room #2 East-West width Equipment #3 (no mark on drawing) | 2.905 | 4.303 | 3.528 | 2.921 | -15.7 | Out[4] | In[4] | In[4] | In[4] |
| 205 | I-210 | Generator Room #2 distance West-East between concrete pads Equipment #3 & #2 | 3.377 | 4.303 | 1.528 | 3.402 | -25.0 | Out | Out | In | In |
| 206 | E-1 | East side of office Bldg, between Chiller Rm and Conference (North-South distance) | 7.323 | 4.303 | 1.518 | 7.322 | 1.7 | In | In | In | In |
| 207 | E-2 | South-East side of Chiller Room, East-West distance | 5.335 | 3.182 | 0.577 | 5.331 | 4.5 | In | In | In | In |
| 208 | E-3 | West-East width between Chiller Room and Stairwell #2 | 2.000 | 4.303 | 0.577 | 1.984 | 15.6 | Out | In | In | In |
| 209 | E-4 | South wall of Generator Room #1 | 12.565 | 12.706 | 3.500 | 12.554 | 10.6 | In | In | In | In |
| 210 | E-5 | Generator rm 1, width of roll-up door on South wall | 3.057 | 4.303 | 0.667 | 3.067 | -9.7 | In | In | In | In |
| 211 | E-6 | South wall Conference Room (East-West distance) | 4.687 | 4.303 | 0.333 | 4.686 | 1.0 | In | In | In | In |

| Index | Label | Description | Avg. Measured Distance (m) | t-statistic for 97.5 % pt. | Std. Dev. Of the Average (mm) | 2D plan or 3D Model Meas. (m) | Diff = Avg. Meas. - 2D/3D Meas. (mm) | Tolerance, in (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 0.5 (12.7) | 0.75 (19.1) | 1 (25.4) | 2 (50.8) |
| 212 | E-7 | East wall Corridor #1 (North-South distance) | 6.409 | 4.303 | 0.333 | 6.414 | -4.2 | In | In | In | In |
| 213 | E-8 | Garage South wall (east-West distance) | 12.819 | 4.303 | 1.856 | 12.814 | 4.4 | In | In | In | In |
| 214 | E-9 | Garage West wall (North-South distance) | 6.412 | 4.303 | 0.577 | 6.407 | 4.9 | In | In | In | In |
| 215 | E-10 | Men's Locker Room South wall (West-East distance) | 4.676 | 4.303 | 0.882 | 4.683 | -6.8 | In | In | In | In |
| 216 | E-11 | Men's Locker Room West wall (North-South distance) | 7.320 | 4.303 | 0.882 | 7.325 | -4.4 | In | In | In | In |
| 217 | E-12 | Men's Locker Room North wall (West-East distance) | 4.572 | 4.303 | 1.202 | 4.566 | 6.0 | In | In | In | In |
| 218 | E-13 | Chiller Room West wall window (like) opening #6 (North-South distance) | 3.575 | 4.303 | 2.404 | 3.578 | -2.9 | In | In | In | In |
| 219 | E-14 | Chiller Room West wall opening window #5 (North-South distance) | 3.581 | 4.303 | 0.577 | 3.578 | 2.8 | In | In | In | In |
| 220 | E-15 | Chiller Room Vertical South of Exit door in West wall | 7.114 | 4.303 | 0.882 | 7.105 | 8.8 | In | In | In | In |
| 221 | E-16 | Chiller Room Vertical Ht. to Roof - measurement taken South of window #1 in West wall | 7.060 | 4.303 | 0.333 | 7.075 | -15.8 | Out | In | In | In |
| 222 | E-17 | Boiler Room roll up door opening in North wall | 3.663 | 4.303 | 2.186 | 3.656 | 6.7 | In | In | In | In |
| 223 | E-18 | Generator Room #2 North wall | 15.238 | 4.303 | 1.000 | 15.234 | 4.4 | In | In | In | In |
| 224 | E-19 | Generator Room #2, width of roll up door opening on North Wall | 3.651 | 4.303 | 0.882 | 3.654 | -3.8 | In | In | In | In |
| 225 | E-20 | Generator Room #2 North-South distance between columns next to Exit door in East wall | 4.983 | 4.303 | 2.186 | 4.978 | 4.3 | In | In | In | In |
| 226 | I-243 | Corridor #3, length from north wall to south wall | 12.652 | 4.303 | 1.453 | 12.654 | -2.3 | In | In | In | In |
| 227 | I-244 | Bathroom Level 1, North-south distance taken by door | 1.914 | 4.303 | 0.882 | 1.911 | 2.3 | In | In | In | In |
| 228 | I-245 | Open Office #8, Width of south-most window on West wall | 1.180 | 4.303 | 0.882 | 1.151 | 29.4 | Out[5] | Out[5] | Out[5] | In[5] |
| 229 | I-246 | Open Office #8, Distance from column to wall of office #6 | 2.151 | 4.303 | 1.333 | 2.157 | -6.7 | In | In | In | In |
| 230 | I-247 | Stairwell #1, east-west distance of the sloped "railing" wall | 2.365 | 4.303 | 2.000 | 2.372 | -6.7 | In | In | In | In |

| Index | Label | Description | Avg. Measured Distance (m) | t-statistic for 97.5 % pt. | Std. Dev. Of the Average (mm) | 2D plan or 3D Model Meas. (m) | Diff = Avg. Meas. - 2D/3D Meas. (mm) | Tolerance, in (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 0.5 (12.7) | 0.75 (19.1) | 1 (25.4) | 2 (50.8) |
| 231 | I-248 | Switch Room, width of electrical box on south wall, the 2nd box from the east wall. | 0.513 | 4.303 | 0.333 | 0.527 | -14.4 | Out | In | In | In |
| 232 | I-249 | Switch Room, North-south length of Equip. 2 | 11.341 | 4.303 | 0.333 | 11.344 | -2.9 | In | In | In | In |
| 233 | I-250 | Switch Room, North-south length of Equip. 3 | 6.257 | 4.303 | 0.577 | 6.264 | -7.3 | In | In | In | In |
| 234 | I-251 | Switch Room, Diameter of pipe coming out from the bottom of 4th panel on South wall (units = mm) | 0.089 | 4.303 | 0.208 | 0.089 | 0.0 | In | In | In | In |
| 235 | I-252 | Switch Room, Height of the tall "box" (2nd from the door to Chiller room) on the south wall | 2.201 | 4.303 | 1.000 | 2.224 | -23.1 | Out | Out | In | In |
| 236 | I-253 | Switch Room, Length of middle section of Equip. 2 taken from the west side | 4.932 | 4.303 | 3.055 | 4.921 | 10.7 | In | In | In | In |
| 237 | I-254 | Generator Room #2, North-south length of the concrete pad under Equip. 2 | 11.571 | 4.303 | 2.517 | 11.571 | -0.3 | In | In | In | In |
| 238 | I-255 | Generator Room #2, North-south length of the concrete pad under Equip. 3 | 11.573 | 3.182 | 1.493 | 11.568 | 5.1 | In | In | In | In |
| 239 | I-256 | Generator Room #2, North-south distance betw'n cols on the west wall, 2nd span from the north | 4.564 | 4.303 | 0.577 | 4.551 | 12.6 | In | In | In | In |
| 240 | I-257 | Generator Room #2, North-south distance betw'n cols on the East wall, 5th span from the north | 6.081 | 4.303 | 0.333 | 6.063 | 18.0 | Out | In | In | In |
| 241 | I-258 | Generator Room #2, circumference of pipe next to the column (4th from the north wall) on the west wall (Units = cm) | 0.690 | 3.182 | 0.479 | 0.688 | 2.0 | In | In | In | In |
| 242 | I-259 | Boiler Room, Diameter of top horizontal pipe to the west of the door that leads to the Chiller room (units = mm) | 0.073 | 3.182 | 0.144 | 0.089 | -16.1 | Out | In | In | In |
| 243 | I-260 | Boiler Room, East-west length of the concrete pad on SW part of the room | 5.278 | 4.303 | 1.202 | 5.288 | -10.3 | In | In | In | In |
| 244 | I-261 | Boiler Room, North-south width of the concrete pad on the NW part of the room, pad on the west end, nearest the window. | 2.369 | 4.303 | 13.170 | 2.389 | -20.5 | In | In | In | In |
| 245 | I-262 | Chiller Room, East-west distance between the concrete pads under Equip. 7 | 5.107 | 4.303 | 0.577 | 5.112 | -4.7 | In | In | In | In |
| 246 | I-264 | Chiller Room, North-south distance between the columns in front of Equip. 7 | 5.950 | 4.303 | 0.333 | 5.948 | 2.0 | In | In | In | In |

| Index | Label | Description | Avg. Measured Distance (m) | t-statistic for 97.5 % pt. | Std. Dev. Of the Average (mm) | 2D plan or 3D Model Meas. (m) | Diff = Avg. Meas. - 2D/3D Meas. (mm) | Tolerance, in (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 0.5 (12.7) | 0.75 (19.1) | 1 (25.4) | 2 (50.8) |
| 247 | I-265 | Chiller Room, Circumference of bottom pipe exiting large cylindrical equip on north-west end of room (Units = cm) | 1.279 | 3.182 | 0.289 | 1.277 | 1.8 | In | In | In | In |
| 248 | I-266 | Height of door Gen Rm #1 and Gen Rm #2 | 4.914 | 4.303 | 2.517 | 4.916 | -1.7 | In | In | In | In |
| 249 | R-13 | Upper roof, North section, East-west distance betw'n the 2 large cols. closest to the wall in the middle of the roof | 12.544 | 4.303 | 2.309 | 12.548 | -3.6 | In | In | In | In |
| 250 | R-14 | Upper roof, North section, North-south width of top of the equip. on pad #1 | 1.783 | 4.303 | 0.667 | 1.801 | -18.4 | Out | In | In | In |
| 251 | R-15 | Upper roof, South section, "south wall", East-west distance betwn 1st col. To the east on large middle col and the 1st col to the west of the large middle col. | 1.911 | 4.303 | 0.333 | 1.913 | -1.6 | In | In | In | In |
| 252 | E-22 | North-south dist. Of the exterior of the large window on the east wall of Chiller room on the south end | 3.577 | 4.303 | 1.856 | 3.562 | 15.0 | Out | In | In | In |
| 253 | E-23 | East-west distance of the exterior south wall of Chiller room on the west side (wall opposite Men's locker room) | 5.341 | 4.303 | 0.882 | 5.340 | 0.3 | In | In | In | In |
| 254 | E-27 | Ext. meas., Break room - height of door to exterior (door on west wall) | 2.246 | 4.303 | 1.155 | 2.267 | -20.9 | Out | Out | In | In |
| 255 | E-28 | Circumference of horizontal pipe on exterior Pad 3 - NW end of pad (Units = cm) | 0.530 | 3.182 | 0.479 | 0.529 | 1.6 | In | In | In | In |
| 256 | E-29 | Exterior width of the roll-up door in Gen Rm #1 on south wall | 3.059 | 4.303 | 1.202 | 3.067 | -8.4 | In | In | In | In |
| 257 | CMU-1 | Generator rm #2, roll-up door width, ext. meas. | 3.653 | 2.776 | 1.393 | 3.654 | -1.6 | In | In | In | In |
| 258 | CMU-2 | Generator rm #2, roll-up door height, ext. meas. | 4.058 | 2.776 | 0.812 | 4.062 | -4.0 | In | In | In | In |
| 259 | CMU-3 | Generator rm #2, height of door on north wall, ext. meas. | 2.248 | 4.303 | 1.732 | 2.261 | -12.6 | In | In | In | In |
| 260 | CMU-4 | Generator rm #2, width of door on north wall, ext. meas. | 1.027 | 3.182 | 0.707 | 1.035 | -8.1 | In | In | In | In |
| 261 | CMU-5 | Boiler room, width of large window on west wall, ext. meas. | 3.594 | 4.303 | 0.816 | 3.597 | -3.3 | In | In | In | In |

| Index | Label | Description | Avg. Measured Distance (m) | t-statistic for 97.5 % pt. | Std. Dev. Of the Average (mm) | 2D plan or 3D Model Meas. (m) | Diff = Avg. Meas. - 2D/3D Meas. (mm) | Tolerance, in (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 0.5 (12.7) | 0.75 (19.1) | 1 (25.4) | 2 (50.8) |
| 262 | CMU-6 | Boiler room, height of large window on west wall, ext. meas. | 3.083 | 2.365 | 1.035 | 3.100 | -17.4 | Out | In | In | In |
| 263 | CMU-7 | Chiller room, width of window #2 on west wall, ext. meas. | 1.231 | 3.182 | 1.031 | 1.242 | -11.5 | In | In | In | In |
| 264 | CMU-8 | Chiller room, height of window #2 on west wall, ext. meas. | 2.151 | 2.776 | 0.800 | 2.165 | -14.1 | Out | In | In | In |
| 265 | CMU-9 | Ext. meas., west side of bldg., dist. Between wall of chiller room and wall to office part of bldg. | 7.315 | 2.776 | 1.503 | 7.306 | 8.9 | In | In | In | In |
| 266 | CMU-10 | Ext. meas., height of garage door opening on south side of bldg. | 3.416 | 2.776 | 3.458 | 3.454 | -38.0 | Out | Out | Out | In |
| 267 | CMU-11 | Ext. meas., east side of bldg, dist. Betw'n cols. South-most span | 3.456 | 2.776 | 1.304 | 3.448 | 7.9 | In | In | In | In |
| 268 | CMU-12 | Ext. meas., east side of bldg, dist. Betw'n cols. 4th span from the south | 4.967 | 2.776 | 1.643 | 4.966 | 1.3 | In | In | In | In |
| 269 | CMU-13 | Ext. meas., east side of bldg, dist. Betw'n cols. North-most span | 3.457 | 4.303 | 1.155 | 3.470 | -13.3 | Out | In | In | In |
| 270 | CMU-14 | Ext. meas., Gen. Room 2, East wall, door width | 1.023 | 2.776 | 1.631 | 1.006 | 16.9 | Out | In | In | In |
| 271 | CMU-15 | Ext. meas., east side of bldg, door height | 2.243 | 2.776 | 0.735 | 2.249 | -6.7 | In | In | In | In |
| 272 | CMU-16 | Ext. meas., Boiler room, width of roll-up door on north wall - on the outside | 6.105 | 3.182 | 0.629 | 6.107 | -2.4 | In | In | In | In |
| 273 | CMU-17 | Ext. meas., Boiler room, height of roll-up door on north wall - on the outside | 4.031 | 3.182 | 0.645 | 4.027 | 3.0 | In | In | In | In |
| 274 | CMU-18 | Ext. meas., Men's locker room, width of south window on west wall, | 1.247 | 2.776 | 0.374 | 1.240 | 7.0 | In | In | In | In |
| 275 | CMU-19 | Ext. meas., Men's locker room, height of south window on west wall, | 1.712 | 2.776 | 0.678 | 1.727 | -14.8 | Out | In | In | In |
| 276 | CMU-20 | Ext. meas., Office #3, width of window on west wall | 1.240 | 2.776 | 0.316 | 1.240 | 0.2 | In | In | In | In |
| 277 | CMU-21 | Ext. meas., Office #3, height of window on west wall | 2.164 | 2.776 | 0.447 | 2.176 | -12.5 | In | In | In | In |
| 278 | CMU-22 | Ext. meas., dist. Between 2 pipes on the outside of the west wall of Generator rm #2 | 0.629 | 12.706 | 1.500 | 0.624 | 4.6 | In | In | In | In |
| 279 | CMU-23 | Ext. meas., dist. Between 2 vertical brown cylinders outside of west wall of Generator rm #2 | 3.952 | 4.303 | 2.404 | 3.996 | -43.4 | Out | Out | Out | In |

| Index | Label | Description | Avg. Measured Distance (m) | t-statistic for 97.5 % pt. | Std. Dev. Of the Average (mm) | 2D plan or 3D Model Meas. (m) | Diff = Avg. Meas. - 2D/3D Meas. (mm) | Tolerance, in (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 0.5 (12.7) | 0.75 (19.1) | 1 (25.4) | 2 (50.8) |
| 280 | CMU-24 | Ext. meas., Break room - width of door to exterior (door on west wall) | 1.018 | 2.776 | 0.812 | 1.016 | 2.4 | In | In | In | In |
| 281 | CMU-26 | Ext. meas., Generator rm #1, width of roll up door on south wall | 3.058 | 2.776 | 1.122 | 3.058 | -0.7 | In | In | In | In |
| 282 | CMU-27 | Ext. meas., Generator rm #1, height of roll up door on south wall | 4.882 | 2.365 | 3.012 | 4.906 | -23.8 | Out | Out | In | In |
| 283 | CMU-28 | Ext. meas., Chiller room, width of door to exterior on south wall | 1.014 | 2.776 | 1.077 | 0.991 | 23.0 | Out | Out | In | In |
| 284 | CMU-29 | Ext. meas., Chiller room, height of door to exterior on south wall | 2.250 | 2.776 | 1.304 | 2.286 | -36.0 | Out | Out | Out | In |
| 285 | CMU-30 | Ext. meas., Distance from equipment on exterior to wall of boiler room | 6.793 | 3.182 | 0.854 | 6.755 | 37.9 | Out | Out | Out | In |

NOTES:

1. Un-shaded cells (Index 1 – 225) are measurements obtained from the 1st data collection.
2. Light blue shaded cells (Index 226 – 256) are measurements obtained in the 2nd data collection.
3. Yellow shaded cells (Index 257 – 285) are measurements obtained from CMU.
4. Measurements were distances from the floor to the ceiling in the “Not Office” areas. The ceilings in the “Not Office” areas were sloped and the slope may be the cause of the out-of-spec.
5. Window measurements were made based on interior measurements. The 2D/3D model window measurements were based on exterior point cloud and may be the cause of the out-of-spec.

**Table A2. Categorization of Measurements.**

| Index | Label | Description | Groupings | Office/ Not office | Interior/ Exterior | Measurement Distance (Long/ Medium/ Short) | Horiz. Dist/ Vert. Dist / Circumference or Radius |
|---|---|---|---|---|---|---|---|
| 1 | I-1 | Office #3 South Wall | Office | O | I | M | H |
| 2 | I-2 | Office #3 East Wall | Office | O | I | M | H |
| 3 | I-3 | Office #3 North Wall | Office | O | I | M | H |
| 4 | I-4 | Office #3 Vertical floor to ceiling (tile, not rib) close to East-North corner | Office | O | I | M | V |
| 5 | I-5 | Office #3 Vertical floor to ceiling (tile, not rib) close to West-North corner | Office | O | I | M | V |
| 6 | I-6 | Office #3 Vertical floor to ceiling (tile, not rib) close to West-South corner | Office | O | I | M | V |
| 7 | I-7 | Office #3 Window Width West side | Office | O | I | S | H |
| 8 | I-8 | Storage above door North side | Office | O | I | M | H |
| 9 | I-9 | Storage West Wall | Office | O | I | M | H |
| 10 | I-10 | Storage East Wall North side (shorter) | Office | O | I | S | H |
| 11 | I-11 | Storage East Wall South side (longer) | Office | O | I | M | H |
| 12 | I-12 | Storage South Wall | Office | O | I | M | H |
| 13 | I-13 | Storage Vertical close to South-East end | Office | O | I | M | V |
| 14 | I-14 | Storage Vertical close to South-West end | Office | O | I | M | V |
| 15 | I-15 | Storage Vertical North side floor to beam (NOT to ceiling) | Office | O | I | M | V |
| 16 | I-16 | Men's Locker Room East Wall | Office | O | I | S | H |
| 17 | I-17 | Men's Locker Room West Wall North side | Office | O | I | M | H |
| 18 | I-18 | Men's Locker Room South Wall | Office | O | I | M | H |
| 19 | I-19 | Men's Locker Room East Wall towards South (no mark on drawing) | Office | O | I | M | H |
| 20 | I-20 | Men's Locker Room Vertical South end at corners | Office | O | I | M | V |
| 21 | I-21 | Stairwell #1 Width of stairwell on East wall, South portion - by the door to the 1st floor | Office | O | I | S | H |
| 22 | I-22 | Stairwell #1, length of stairwell, south portion - near door to 1st floor | Office | O | I | M | H |

| Index | Label | Description | Groupings | Office/ Not office | Interior/ Exterior | Measurement Distance (Long/ Medium/ Short) | Horiz. Dist/ Vert. Dist / Circumference or Radius |
|---|---|---|---|---|---|---|---|
| 23 | I-23 | Stairwell #1, width of stairwell on West wall - landing of door to exterior. | Office | O | I | M | H |
| 24 | I-24 | Corridor #2 Level 1 West-East length (shorter) | Office | O | I | L | H |
| 25 | I-25 | Office #2 South Wall | Office | O | I | M | H |
| 26 | I-26 | Office #2 West Wall | Office | O | I | M | H |
| 27 | I-27 | Office #2 Vertical | Office | O | I | M | V |
| 28 | I-28 | Corridor #2 max length West-East direction along North wall | Office | O | I | L | H |
| 29 | I-29 | Corridor #2 West-East direction along North starting from E-N (wooden frame around opening) | Office | O | I | M | H |
| 30 | I-30 | Corridor #2 West Wall (width of corridor) | Office | O | I | M | H |
| 31 | I-31 | Corridor #2 Vertical | Office | O | I | M | V |
| 32 | I-32 | Corridor #1 East Wall full length (NOT from beam at corner) | Office | O | I | L | H |
| 33 | I-33 | Corridor #1 West Wall (to the corner) | Office | O | I | M | H |
| 34 | I-34 | Corridor #1 width next to Exit door | Office | O | I | M | H |
| 35 | I-35 | Corridor #1 Vertical | Office | O | I | M | V |
| 36 | I-36 | Office #1 South Wall | Office | O | I | M | H |
| 37 | I-37 | Office #1 East Wall | Office | O | I | M | H |
| 38 | I-38 | Office #1 Vertical | Office | O | I | M | V |
| 39 | I-39 | Bathroom Level 1 | Office | O | I | M | H |
| 40 | I-40 | Storage #2 length along South wall | Office | O | I | M | H |
| 41 | I-41 | Storage #2 width along West | Office | O | I | S | H |
| 42 | I-42 | Closet length | Office | O | I | M | H |
| 43 | I-43 | Open Office #8 (2nd floor) East-west distance betw'n west wall and stairwell wall | Office | O | I | M | H |
| 44 | I-44 | Open Office #8 along West (to the barrier) | Office | O | I | M | H |
| 45 | I-45 | Open Office #8 full width along West | Office | O | I | L | H |
| 46 | I-46 | Open Office #8 full length along South | Office | O | I | L | H |
| 47 | I-47 | Open Office #8 width middle window West wall | Office | O | I | S | H |

| Index | Label | Description | Groupings | Office/ Not office | Interior/ Exterior | Measurement Distance (Long/ Medium/ Short) | Horiz. Dist/ Vert. Dist / Circumference or Radius |
|---|---|---|---|---|---|---|---|
| 48 | I-48 | Open Office #8 width along East wall | Office | O | I | L | H |
| 49 | I-49 | Open Office #8, East-west distance, length of "kitchen-area" wall measured from the open office area | Office | O | I | M | H |
| 50 | I-50 | Open Office #8 opening to the kitchen | Office | O | I | S | H |
| 51 | I-51 | Open Office #8 Vertical (height of opening to the kitchen) | Office | O | I | M | V |
| 52 | I-52 | Office #5 shorter distance to the beam along West wall | Office | O | I | M | H |
| 53 | I-53 | Office #5 shorter distance to the beam along South wall | Office | O | I | M | H |
| 54 | I-54 | Office #5 Vertical | Office | O | I | M | V |
| 55 | I-55 | Office #6 North Wall | Office | O | I | M | H |
| 56 | I-56 | Office #6 width along West, next to door | Office | O | I | M | H |
| 57 | I-57 | Office #6 South Wall | Office | O | I | M | H |
| 58 | I-58 | Open Office #8 column to West Wall | Office | O | I | M | H |
| 59 | I-59 | Open Office #8 column width | Office | O | I | S | H |
| 60 | I-60 | Open Office #8 Vertical ceiling higher than the rest of ceiling next to window West wall | Office | O | I | M | V |
| 61 | I-61 | Open Office #8 Vertical lower ceiling | Office | O | I | M | V |
| 62 | I-62 | Stairwell #1 to Office #8, width close to door | Office | O | I | S | H |
| 63 | I-63 | Stairwell #1 window width | Office | O | I | S | H |
| 64 | I-64 | Stairwell #1 Vertical window height | Office | O | I | M | V |
| 65 | I-65 | Conference Room West Wall | Office | O | I | M | H |
| 66 | I-66 | Conference Room South Wall | Office | O | I | M | H |
| 67 | I-67 | Conference Room East Wall full length | Office | O | I | M | H |
| 68 | I-68 | Conference Room East Wall from North window (right/south side) to South wall | Office | O | I | M | H |
| 69 | I-69 | Conference Room Vertical | Office | O | I | M | V |
| 70 | I-70 | Office #4 West Wall | Office | O | I | M | H |
| 71 | I-71 | Office #4 South Wall | Office | O | I | M | H |

| Index | Label | Description | Groupings | Office/ Not office | Interior/ Exterior | Measurement Distance (Long/ Medium/ Short) | Horiz. Dist/ Vert. Dist / Circumference or Radius |
|---|---|---|---|---|---|---|---|
| 72 | I-72 | Office #4 width right window | Office | O | I | S | H |
| 73 | I-73 | Office #4 Vertical height of right window | Office | O | I | S | V |
| 74 | I-74 | Office #4 door width | Office | O | I | S | H |
| 75 | I-75 | Mechanical Room South side | Office | O | I | M | H |
| 76 | I-76 | Break Room along North (from West wall NOT West door) | Office | O | I | M | H |
| 77 | I-77 | Break Room West Wall | Office | O | I | M | H |
| 78 | I-78 | Break Room East Wall | Office | O | I | M | H |
| 79 | I-79 | Break Room Vertical | Office | O | I | M | V |
| 80 | I-80 | Corridor #3 doorway width | Office | O | I | S | H |
| 81 | I-81 | Corridor #3, Length of corridor along North Wall | Office | O | I | M | H |
| 82 | I-82 | Corridor #3 - width of corridor off the north end of corridor #3 | Office | O | I | S | H |
| 83 | I-83 | Generator Room #1 North Wall | Generator room 1 | NO | I | L | H |
| 84 | I-84 | Generator Room #1 North-South distance between roll-up doors | Generator room 1 | NO | I | L | H |
| 85 | I-85 | Generator Room #1 Distance betw'n west wall (north end of room) and large gray pipe | Generator room 1 | NO | I | M | H |
| 86 | I-86 | Generator Room #1 between blue columns 1 & 2 | Generator room 1 | NO | I | M | H |
| 87 | I-87 | Generator Room #1 short distance along North, next to staircase | Generator room 1 | NO | I | M | H |
| 88 | I-88 | Generator Room #1 short distance along West wall (where doors are located) | Generator room 1 | NO | I | M | H |
| 89 | I-89 | Generator Room #1 Vertical floor to I-beam along Control room wall | Generator room 1 | NO | I | M | V |
| 90 | I-90 | Generator Room #1 Level 2 West-East distance along North | Generator room 1 | NO | I | L | H |
| 91 | I-91 | Generator Room #1 Level 2, east-west distance to Cinder Block "abutment" next to steel column | Generator room 1 | NO | I | M | H |
| 92 | I-92 | Generator Room #1 Level 2 column to column (web to web) | Generator room 1 | NO | I | M | H |

| Index | Label | Description | Groupings | Office/ Not office | Interior/ Exterior | Measurement Distance (Long/ Medium/ Short) | Horiz. Dist/ Vert. Dist / Circumference or Radius |
|---|---|---|---|---|---|---|---|
| 93 | I-93 | Generator Room #1 Level 2 Pipe Size - diameter | Generator room 1 | NO | I | S | C |
| 94 | I-94 | Generator Room #1 Level 2 Circumference of Blue Cylinder above the pipe described in (I-93) | Generator room 1 | NO | I | S | C |
| 95 | I-95 | Generator Room #1 Level 2 Red Pipe Size circumference by column 1(no mark on drawing) | Generator room 1 | NO | I | S | C |
| 96 | I-96 | Generator Room #1 Level 1 the circumference of the gray pipe identified in I-85 | Generator room 1 | NO | I | S | C |
| 97 | I-97 | Generator Room #1 Level 1 West-East wall distance | Generator room 1 | NO | I | L | H |
| 98 | R-1 | Upper Roof close to Exit door from stairwell East | Exterior | E | E | M | H |
| 99 | I-100 | Stairwell #2 Top Level East-West distance along South wall | Misc | NO | I | M | H |
| 100 | I-102 | Stairwell #2 Top Level North-South distance along West wall | Misc | NO | I | M | H |
| 101 | I-103 | Generator Room #2 column to column (web to web) | Generator room 2 | NO | I | M | H |
| 102 | I-104 | Generator Room #2 West-East distance along North wall | Generator room 2 | NO | I | L | H |
| 103 | I-105 | Generator Room #2 along West wall from North wall to North wall of Spare room | Generator room 2 | NO | I | L | H |
| 104 | I-106 | Generator Room #2 West-East distance next to Space Room door | Generator room 2 | NO | I | L | H |
| 105 | I-107 | Generator Room #2 West-East distance between I-beam and Spare Room wall | Generator room 2 | NO | I | M | H |
| 106 | I-108 | Generator Room #2 door opening between Generator Rm #2 & Gen Rm #1 | Generator room 2 | NO | I | M | H |
| 107 | I-109 | Generator Room #2 Equipment #1 length | Generator room 2 | NO | I | L | H |
| 108 | I-110 | Generator Room #2 Equipment #2 width South | Generator room 2 | NO | I | M | H |
| 109 | I-111 | Generator Room #2 West-East dist between EQ #2 & EQ #3, South side of EQ#2 | Generator room 2 | NO | I | M | H |
| 110 | I-112 | Generator Room #2 roll-up door to roll up door in Gen. room #1 (Noisy Room) | Generator room 2 | NO | I | L | H |

| Index | Label | Description | Groupings | Office/ Not office | Interior/ Exterior | Measurement Distance (Long/ Medium/ Short) | Horiz. Dist/ Vert. Dist / Circumference or Radius |
|---|---|---|---|---|---|---|---|
| 111 | I-113 | Generator Room #2 exterior of north wall to Spare Room | Generator room 2 | NO | I | M | H |
| 112 | I-114 | Generator Room #2 from Spare Room (near door) exterior wall to black metal pipe (no mark on drawing) | Generator room 2 | NO | I | S | H |
| 113 | I-115 | Spare Room North Wall | Misc | NO | I | M | H |
| 114 | I-116 | Spare Room West side short (from North to the middle) | Misc | NO | I | M | H |
| 115 | I-117 | Spare Room East Wall | Misc | NO | I | L | H |
| 116 | I-118 | Spare Room South Wall | Misc | NO | I | M | H |
| 117 | I-119 | Spare Room window opening | Misc | NO | I | M | H |
| 118 | I-120 | Control Room East Wall | Misc | NO | I | L | H |
| 119 | I-121 | Control Room North Wall above double door to GEN. RM. #1 | Misc | NO | I | M | H |
| 120 | I-122 | Control Room West Wall max length | Misc | NO | I | L | H |
| 121 | I-123 | Control Room East Wall in corridor South end | Misc | NO | I | M | H |
| 122 | I-124 | Control Room width of corridor South end | Misc | NO | I | S | H |
| 123 | I-125 | Control Room Vertical | Misc | NO | I | M | V |
| 124 | I-126 | Switch Room East Wall | Switch room | NO | I | L | H |
| 125 | I-127 | Switch Room North Wall | Switch room | NO | I | L | H |
| 126 | I-128 | Switch Room opening of doors to Boiler Room | Switch room | NO | I | M | H |
| 127 | I-129 | Switch Room Vertical, height of door opening (as in I-128) | Switch room | NO | I | M | V |
| 128 | I-130 | Switch Room distance along East between two North-most columns | Switch room | NO | I | M | H |
| 129 | I-131 | Switch Room Vertical floor to ceiling (higher part of corrugated metal sheet) | Switch room | NO | I | M | V |
| 130 | I-132 | Switch Room West Wall | Switch room | NO | I | L | H |
| 131 | I-133 | Switch Room South Wall | Switch room | NO | I | L | H |

| Index | Label | Description | Groupings | Office/ Not office | Interior/ Exterior | Measurement Distance (Long/ Medium/ Short) | Horiz. Dist/ Vert. Dist / Circumference or Radius |
|---|---|---|---|---|---|---|---|
| 132 | I-134 | Switch Room width of Electric Box 2nd from West | Switch room | NO | I | S | H |
| 133 | I-135 | Switch Room Vertical height of Electric Box (as in I-134) | Switch room | NO | I | S | V |
| 134 | I-136 | Switch Room Vertical height to lower flange of I-beam truss in ceiling | Switch room | NO | I | M | V |
| 135 | I-137 | Switch Room distance along East wall from South wall to the 1st column | Switch room | NO | I | M | H |
| 136 | I-138 | Switch Room distance from West wall to Equipment #2 (no mark on drawing) | Switch room | NO | I | S | H |
| 137 | I-139 | Switch Room aluminum pipe coming out of EQ.#4 (South-most pipe, West row) - diameter | Switch room | NO | I | S | C |
| 138 | I-140 | Switch Room distance between two aluminum pipes (outside-to-outside) South side (in West row) | Switch room | NO | I | S | H |
| 139 | I-141 | Boiler Room East wall | Boiler room | NO | I | L | H |
| 140 | I-142 | Boiler Room column to column distance | Boiler room | NO | I | M | H |
| 141 | I-143 | Boiler Room North-South distance between roll-up doors | Boiler room | NO | I | L | H |
| 142 | I-144 | Boiler Room total length | Boiler room | NO | I | L | H |
| 143 | I-145 | Boiler Room width close to West wall | Boiler room | NO | I | L | H |
| 144 | I-146 | Boiler Room window opening width | Boiler room | NO | I | S | H |
| 145 | I-147 | Boiler Room width next to roll up door (closer to West) | Boiler room | NO | I | L | H |
| 146 | I-148 | Boiler Room distance column to door along wall | Boiler room | NO | I | S | H |
| 147 | I-149 | Boiler Room Vertical floor to ceiling | Boiler room | NO | I | M | V |
| 148 | I-150 | Boiler Room Vertical floor to blue pipe (in front of roll up door south side) | Boiler room | NO | I | M | V |
| 149 | I-151 | Chiller Room roll up door width North wall | Chiller room | NO | I | M | H |
| 150 | I-152 | Chiller Room Vertical roll up door height | Chiller room | NO | I | M | V |
| 151 | I-153 | Chiller Room total width along North wall (next to roll up door) | Chiller room | NO | I | L | H |
| 152 | I-154 | Chiller Room distance between roll up and Exit doors North wall | Chiller room | NO | I | S | H |

| Index | Label | Description | Groupings | Office/ Not office | Interior/ Exterior | Measurement Distance (Long/ Medium/ Short) | Horiz. Dist/ Vert. Dist / Circumference or Radius |
|---|---|---|---|---|---|---|---|
| 153 | I-155 | Chiller Room Vertical floor to higher corrugated ceiling North wall by roll up door | Chiller room | NO | I | M | V |
| 154 | I-158 | Chiller Room along East wall distance between 1 & 2 steel columns | Chiller room | NO | I | M | H |
| 155 | I-160 | Chiller Room North-South length (between South exit door & North roll up door) | Chiller room | NO | I | L | H |
| 156 | I-161 | Chiller Room from South wall (next to window) to the "middle" wall | Chiller room | NO | I | L | H |
| 157 | I-162 | Chiller Room width of window #2 (from North) opening in West wall | Chiller room | NO | I | S | H |
| 158 | I-163 | Chiller Room Vertical height of window #2 (from North) opening in West wall | Chiller room | NO | I | M | V |
| 159 | I-164 | Chiller Room tilted lower pipe next to window #2 circumference | Chiller room | NO | I | S | C |
| 160 | I-166 | Chiller Room width of window #3 in West wall | Chiller room | NO | I | M | H |
| 161 | I-168 | Chiller Room North pipe next to West door circumference | Chiller room | NO | I | S | C |
| 162 | I-170 | Chiller Room East-West width next to West door | Chiller room | NO | I | L | H |
| 163 | I-171 | Chiller Room distance between brick columns next to West door | Chiller room | NO | I | M | H |
| 164 | I-173 | Chiller Room Vertical floor to lower part of corrugated ceiling next to West wall, South end of #3 window | Chiller room | NO | I | M | V |
| 165 | I-175 | Chiller Room distance concrete base #7 East end above floor to East wall | Chiller room | NO | I | L | H |
| 166 | I-176 | Chiller Room black vertical (tilted) pipe out of Equipment #8 circumference | Chiller room | NO | I | S | C |
| 167 | I-177 | Chiller Room distance South wall to red pipe (next to door) on concrete pad #12 | Chiller room | NO | I | M | H |
| 168 | I-178 | Chiller Room distance South wall to blue plate Equipment #13 on concrete pad #13, see also picture P2170007 | Chiller room | NO | I | S | H |
| 169 | I-179 | Chiller Room East-West length of concrete base Equipment #11 | Chiller room | NO | I | M | H |
| 170 | I-181 | Chiller Room Vertical floor to higher part of corrugated ceiling next to East end of Equipment #11 | Chiller room | NO | I | M | V |
| 171 | I-184 | Stairwell #2, ground level width (South most) | Misc | NO | I | S | H |
| 172 | I-185 | Stairwell #2 ground level depth | Misc | NO | I | S | H |
| 173 | I-186 | Stairwell #2 ground level full width | Misc | NO | I | M | H |
| 174 | I-187 | Stairwell #2 ground level full length (North - South distance along East) | Misc | NO | I | M | H |

| Index | Label | Description | Groupings | Office/ Not office | Interior/ Exterior | Measurement Distance (Long/ Medium/ Short) | Horiz. Dist/ Vert. Dist / Circumference or Radius |
|---|---|---|---|---|---|---|---|
| 175 | I-188 | 1st Floor Ladies Bathroom North-south width in the middle of room (above tile) | Office | O | I | S | H |
| 176 | I-189 | 1st Floor Ladies Bathroom West-East width in the middle of room (above tile) | Office | O | I | S | H |
| 177 | I-190 | 1st Floor Ladies Bathroom Vertical (floor-ceiling) | Office | O | I | M | V |
| 178 | R-3 | Lower Roof North side width | Exterior | E | E | L | H |
| 179 | R-4 | Lower Roof West side length | Exterior | E | E | L | H |
| 180 | R-5 | Lower Roof South side width | Exterior | E | E | L | H |
| 181 | R-7 | Lower Roof South side, dist. betw'n wall of the facility part to the wall of the office part | Exterior | E | E | M | H |
| 182 | R-8 | Upper Roof Northern part, South side East corner between columns | Exterior | E | E | M | H |
| 183 | R-9 | Upper Roof Northern part, distance between the 2 large col. On either side of the stairs to the south portion | Exterior | E | E | M | H |
| 184 | R-10 | Upper Roof Northern part, center - width of West column at center, next to stairs | Exterior | E | E | S | H |
| 185 | R-11 | Upper Roof Northern part, center West side distance between columns | Exterior | E | E | M | H |
| 186 | R-12 | Upper Roof distance from center column to Equipment #1 | Exterior | E | E | M | H |
| 187 | I-191 | Ladies Bathroom 1st floor - width of opening betw'n the toilet and other room. | Office | O | I | S | H |
| 188 | I-192 | Office #7 2nd floor North-South length at middle of office | Office | O | I | M | H |
| 189 | I-193 | Office #7 2nd floor West-East full width | Office | O | I | M | H |
| 190 | I-194 | Office #7 2nd floor Vertical floor to lower ceiling | Office | O | I | M | V |
| 191 | I-195 | Office #7 2nd floor width of south window opening | Office | O | I | S | H |
| 192 | I-196 | Office #8 2nd floor, East wall, wall width between windows 1 & 2 (the two north-most windows) | Office | O | I | S | H |
| 193 | I-197 | Office #8 2nd floor, coffee room West-East distance closer to North | Office | O | I | S | H |
| 194 | I-198 | Office #8 2nd floor coffee room North-South distance along West side | Office | O | I | S | H |
| 195 | I-199 | Office #8 2nd floor North-South distance from center column to wall above opening to coffee room | Office | O | I | M | H |
| 196 | I-200 | Office #8 2nd floor, width of north-most window on West wall | Office | O | I | S | H |

| Index | Label | Description | Groupings | Office/ Not office | Interior/ Exterior | Measurement Distance (Long/ Medium/ Short) | Horiz. Dist/ Vert. Dist / Circumference or Radius |
|---|---|---|---|---|---|---|---|
| 197 | I-201 | Corridor #3 1st floor East-West wall in front of Break Room closer to North | Office | O | I | M | H |
| 198 | I-202 | Switch Room North-South length Equipment #1 | Switch room | NO | I | L | H |
| 199 | I-203 | Switch Room East-West width of Equipment #1 | Switch room | NO | I | M | H |
| 200 | I-204 | Switch Room Vertical floor to ceiling (lower part of corrugated metal sheet) | Switch room | NO | I | M | V |
| 201 | I-205 | Switch Room, aluminum pipe South wall, East side - diameter | Switch room | NO | I | S | C |
| 202 | I-206 | Switch Room, largest aluminum pipe coming out of smaller electrical box in the middle of West wall diameter | Switch room | NO | I | S | C |
| 203 | I-208 | Generator Room #2 North-South length Equipment #3 (no mark on drawing) | Generator room 2 | NO | I | L | H |
| 204 | I-209 | Generator Room #2 East-West width Equipment #3 (no mark on drawing) | Generator room 2 | NO | I | M | H |
| 205 | I-210 | Generator Room #2 distance West-East between concrete pads Equipment #3 & #2 | Generator room 2 | NO | I | M | H |
| 206 | E-1 | East side of office Bldg, between Chiller Rm and Conference (North-South distance) | Exterior | E | E | M | H |
| 207 | E-2 | South-East side of Chiller Room, East-West distance | Exterior | E | E | M | H |
| 208 | E-3 | West-East width between Chiller Room and Stairwell #2 | Exterior | E | E | S | H |
| 209 | E-4 | South wall of Generator Room #1 | Exterior | E | E | L | H |
| 210 | E-5 | Generator Rm 1, width of roll-up door on South wall | Exterior | E | E | M | H |
| 211 | E-6 | South wall Conference Room (East-West distance) | Exterior | E | E | M | H |
| 212 | E-7 | East wall Corridor #1 (North-South distance) | Exterior | E | E | M | H |
| 213 | E-8 | Garage South wall (east-West distance) | Exterior | E | E | L | H |
| 214 | E-9 | Garage West wall (North-South distance) | Exterior | E | E | M | H |
| 215 | E-10 | Men's Locker Room South wall (West-East distance) | Exterior | E | E | M | H |
| 216 | E-11 | Men's Locker Room West wall (North-South distance) | Exterior | E | E | M | H |
| 217 | E-12 | Men's Locker Room North wall (West-East distance) | Exterior | E | E | M | H |

| Index | Label | Description | Groupings | Office/ Not office | Interior/ Exterior | Measurement Distance (Long/ Medium/ Short) | Horiz. Dist/ Vert. Dist / Circumference or Radius |
|---|---|---|---|---|---|---|---|
| 218 | E-13 | Chiller Room West wall window (like) opening #6 (North-South distance) | Exterior | E | E | M | H |
| 219 | E-14 | Chiller Room West wall opening window #5 (North-South distance) | Exterior | E | E | M | H |
| 220 | E-15 | Chiller Room Vertical South of Exit door in West wall | Exterior | E | E | M | V |
| 221 | E-16 | Chiller Room Vertical Ht. to Roof - measurement taken South of window #1 in West wall | Exterior | E | E | M | V |
| 222 | E-17 | Boiler Room roll up door opening in North wall | Exterior | E | E | M | H |
| 223 | E-18 | Generator Room #2 North wall | Exterior | E | E | L | H |
| 224 | E-19 | Generator Room #2, width of roll up door opening on North Wall | Exterior | E | E | M | H |
| 225 | E-20 | Generator Room #2 North-South distance between columns next to Exit door in East wall | Exterior | E | E | M | H |
| 226 | I-243 | Corridor #3, length from north wall to south wall | Office | O | I | L | H |
| 227 | I-244 | Bathroom Level 1, North-south distance taken by door | Office | O | I | S | H |
| 228 | I-245 | Open Office #8, Width of south-most window on West wall | Office | O | I | S | H |
| 229 | I-246 | Open Office #8, Distance from column to wall of office #6 | Office | O | I | M | H |
| 230 | I-247 | Stairwell #1, east-west distance of the sloped "railing" wall | Switch room | NO | I | M | H |
| 231 | I-248 | Switch Room, width of electrical box on south wall, the 2nd box from the east wall. | Switch room | NO | I | S | H |
| 232 | I-249 | Switch Room, North-south length of Equip. 2 | Switch room | NO | I | L | H |
| 233 | I-250 | Switch Room, North-south length of Equip. 3 | Switch room | NO | I | M | H |
| 234 | I-251 | Switch Room, Diameter of pipe coming out from the bottom of 4th panel on South wall (units = mm) | Switch room | NO | I | S | C |
| 235 | I-252 | Switch Room, Height of the tall "box" (2nd from the door to Chiller room) on the south wall | Switch room | NO | I | M | V |
| 236 | I-253 | Switch Room, Length of middle section of Equip. 2 taken from the west side | Generator room 2 | NO | I | M | H |
| 237 | I-254 | Generator Room #2, North-south length of the concrete pad under Equip. 2 | Generator room 2 | NO | I | L | H |

| Index | Label | Description | Groupings | Office/ Not office | Interior/ Exterior | Measurement Distance (Long/ Medium/ Short) | Horiz. Dist/ Vert. Dist / Circumference or Radius |
|---|---|---|---|---|---|---|---|
| 238 | I-255 | Generator Room #2, North-south length of the concrete pad under Equip. 3 | Generator room 2 | NO | I | L | H |
| 239 | I-256 | Generator Room #2, North-south distance betw'n cols on the west wall, 2nd span from the north | Generator room 2 | NO | I | M | H |
| 240 | I-257 | Generator Room #2, North-south distance betw'n cols on the East wall, 5th span from the north | Generator room 2 | NO | I | M | H |
| 241 | I-258 | Generator Room #2, circumference of pipe next to the column (4th from the north wall) on the west wall (Units = cm) | Boiler room | NO | I | S | C |
| 242 | I-259 | Boiler Room, Diameter of top horizontal pipe to the west of the door that leads to the Chiller room (units = mm) | Boiler room | NO | I | S | C |
| 243 | I-260 | Boiler Room, East-west length of the concrete pad on SW part of the room | Boiler room | NO | I | M | H |
| 244 | I-261 | Boiler Room, North-south width of the concrete pad on the NW part of the room, pad on the west end, nearest the window. | Chiller room | NO | I | M | H |
| 245 | I-262 | Chiller Room, East-west distance between the concrete pads under Equip. 7 | Chiller room | NO | I | M | H |
| 246 | I-264 | Chiller Room, North-south distance between the columns in front of Equip. 7 | Chiller room | NO | I | M | H |
| 247 | I-265 | Chiller Room, Circumference of bottom pipe exiting large cylindrical equip on north-west end of room (Units = cm) | Exterior | E | E | S | C |
| 248 | I-266 | Height of door Gen Rm #1 and Gen Rm #2 | Generator room 2 | NO | I | M | V |
| 249 | R-13 | Upper roof, North section, East-west distance betw'n the 2 large cols. closest to the wall in the middle of the roof | Exterior | E | E | L | H |
| 250 | R-14 | Upper roof, North section, North-south width of top of the equip. on pad #1 | Exterior | E | E | S | H |
| 251 | R-15 | Upper roof, South section, "south wall", East-west distance betw'n 1st col. To the east on large middle col and the 1st col to the west of the large middle col. | Exterior | E | E | S | H |
| 252 | E-22 | North-south dist. Of the exterior of the large window on the east wall of Chiller room on the south end | Exterior | E | E | M | H |
| 253 | E-23 | East-west distance of the exterior south wall of Chiller room on the west side (wall opposite Men's locker room) | Exterior | E | E | M | H |
| 254 | E-27 | Ext. meas., Break room - height of door to exterior (door on west wall) | Exterior | E | E | M | V |

| Index | Label | Description | Groupings | Office/ Not office | Interior/ Exterior | Measurement Distance (Long/ Medium/ Short) | Horiz. Dist/ Vert. Dist / Circumference or Radius |
|---|---|---|---|---|---|---|---|
| 255 | E-28 | Circumference of horizontal pipe on exterior Pad 3 - NW end of pad (Units = cm) | Exterior | E | E | S | C |
| 256 | E-29 | Exterior width of the roll-up door in Gen Rm #1 on south wall | Exterior | E | E | M | H |
| 257 | CMU-1 | Generator rm #2, roll-up door width, ext. meas. | Exterior | E | E | M | H |
| 258 | CMU-2 | Generator rm #2, roll-up door height, ext. meas. | Exterior | E | E | M | V |
| 259 | CMU-3 | Generator rm #2, height of door on north wall, ext. meas. | Exterior | E | E | M | V |
| 260 | CMU-4 | Generator rm #2, width of door on north wall, ext. meas. | Exterior | E | E | S | H |
| 261 | CMU-5 | Boiler room, width of large window on west wall, ext. meas. | Exterior | E | E | M | H |
| 262 | CMU-6 | Boiler room, height of large window on west wall, ext. meas. | Exterior | E | E | M | V |
| 263 | CMU-7 | Chiller room, width of window #2 on west wall, ext. meas. | Exterior | E | E | S | H |
| 264 | CMU-8 | Chiller room, height of window #2 on west wall, ext. meas. | Exterior | E | E | M | V |
| 265 | CMU-9 | Ext. meas., west side of bldg., dist. Between wall of chiller room and wall to office part of bldg. | Exterior | E | E | M | H |
| 266 | CMU-10 | Ext. meas., height of garage door opening on south side of bldg. | Exterior | E | E | M | V |
| 267 | CMU-11 | Ext. meas., east side of bldg, dist. Betw'n cols. South-most span | Exterior | E | E | M | H |
| 268 | CMU-12 | Ext. meas., east side of bldg, dist. betw'n cols. 4th span from the south | Exterior | E | E | M | H |
| 269 | CMU-13 | Ext. meas., east side of bldg, dist. betw'n cols. North-most span | Exterior | E | E | M | H |
| 270 | CMU-14 | Ext. meas., Gen. Room 2, East wall, door width | Exterior | E | E | S | H |
| 271 | CMU-15 | Ext. meas., east side of bldg, door height | Exterior | E | E | M | V |
| 272 | CMU-16 | Ext. meas., Boiler room, width of roll-up door on north wall - on the outside | Exterior | E | E | M | H |
| 273 | CMU-17 | Ext. meas., Boiler room, height of roll-up door on north wall - on the outside | Exterior | E | E | M | V |
| 274 | CMU-18 | Ext. meas., Men's locker room, width of south window on west wall, | Exterior | E | E | S | H |
| 275 | CMU-19 | Ext. meas., Men's locker room, height of south window on west wall, | Exterior | E | E | S | V |
| 276 | CMU-20 | Ext. meas., Office #3, width of window on west wall | Exterior | E | E | S | H |
| 277 | CMU-21 | Ext. meas., Office #3, height of window on west wall | Exterior | E | E | M | V |

| Index | Label | Description | Groupings | Office/ Not office | Interior/ Exterior | Measurement Distance (Long/ Medium/ Short) | Horiz. Dist/ Vert. Dist / Circumference or Radius |
|---|---|---|---|---|---|---|---|
| 278 | CMU-22 | Ext. meas., dist. Between 2 pipes on the outside of the west wall of Generator rm #2 | Exterior | E | E | S | H |
| 279 | CMU-23 | Ext. meas., dist. Between 2 vertical brown cylinders outside of west wall of Generator rm #2 | Exterior | E | E | M | H |
| 280 | CMU-24 | Ext. meas., Break room - width of door to exterior (door on west wall) | Exterior | E | E | S | H |
| 281 | CMU-26 | Ext. meas., Generator rm #1, width of roll up door on south wall | Exterior | E | E | M | H |
| 282 | CMU-27 | Ext. meas., Generator rm #1, height of roll up door on south wall | Exterior | E | E | M | V |
| 283 | CMU-28 | Ext. meas., Chiller room, width of door to exterior on south wall | Exterior | E | E | S | H |
| 284 | CMU-29 | Ext. meas., Chiller room, height of door to exterior on south wall | Exterior | E | E | M | V |
| 285 | CMU-30 | Ext. meas., Distance from equipment on exterior to wall of boiler room | Exterior | E | E | M | H |

NOTES:

1. Un-shaded cells (Index 1 – 225) are measurements obtained from the 1st data collection.
2. Light blue shaded cells (Index 226 – 256) are measurements obtained in the 2nd data collection.
3. Yellow shaded cells (Index 257 – 285) are measurements obtained from CMU.

# Appendix B – Upper Limit Table on % Defective in Population

**Table B1. Upper Limit (*p*) on % Defective in Population with (asymmetric) 95 % Confidence.**

| # of defects (*d*) | Sample Size, *n* | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **48** | **50** | **64** | **75** | **80** | **100** | **101** | **104** | **117** | **150** | **175** | **200** | **225** | **250** | **270** | **285** | |
| **0** | 6.1 | 5.8 | 4.6 | 3.9 | 3.7 | 3 | 2.9 | 2.8 | 2.5 | 2 | 1.7 | 1.5 | 1.3 | 1.2 | 1.1 | 1 | |
| **1** | 9.5 | 9.1 | 7.2 | 6.2 | 5.8 | 4.7 | 4.6 | 4.5 | 4 | 3.1 | 2.7 | 2.3 | 2.1 | 1.9 | 1.7 | 1.7 | |
| **2** | 12.5 | 12.1 | 9.5 | 8.2 | 7.7 | 6.2 | 6.1 | 5.9 | 5.3 | 4.1 | 3.6 | 3.1 | 2.8 | 2.5 | 2.3 | 2.2 | |
| **3** | 15.4 | 14.8 | 11.7 | 10 | 9.4 | 7.6 | 7.5 | 7.3 | 6.5 | 5.1 | 4.4 | 3.8 | 3.4 | 3.1 | 2.8 | 2.7 | |
| **4** | 18.1 | 17.4 | 13.7 | 11.8 | 11.1 | 8.9 | 8.8 | 8.6 | 7.7 | 6 | 5.2 | 4.5 | 4 | 3.6 | 3.4 | 3.2 | |
| **5** | 20.7 | 19.9 | 15.7 | 13.5 | 12.7 | 10.2 | 10.1 | 9.8 | 8.8 | 6.9 | 5.9 | 5.2 | 4.6 | 4.2 | 3.9 | 3.7 | |
| **6** | 23.2 | 22.3 | 17.7 | 15.2 | 14.3 | 11.5 | 11.4 | 11.1 | 9.9 | 7.7 | 6.7 | 5.8 | 5.2 | 4.7 | 4.3 | 4.1 | |
| **7** | 25.7 | 24.7 | 19.6 | 16.8 | 15.8 | 12.7 | 12.6 | 12.3 | 10.9 | 8.6 | 7.4 | 6.5 | 5.8 | 5.2 | 4.8 | 4.6 | |
| **8** | 28.1 | 27 | 21.4 | 18.4 | 17.3 | 14 | 13.8 | 13.5 | 12 | 9.4 | 8.1 | 7.1 | 6.3 | 5.7 | 5.3 | 5 | ***P*** = 5 % |
| **9** | 30.4 | 29.3 | 23.3 | 20 | 18.8 | 15.2 | 15 | 14.6 | 13 | 10.2 | 8.8 | 7.7 | 6.9 | 6.2 | 5.7 | 5.4 | |
| **10** | 32.8 | 31.6 | 25.1 | 21.6 | 20.3 | 16.4 | 16.2 | 15.8 | 14.1 | 11 | 9.5 | 8.3 | 7.4 | 6.7 | 6.2 | 5.9 | |
| **11** | 35.1 | 33.8 | 26.8 | 23.1 | 21.7 | 17.6 | 17.4 | 16.9 | 15.1 | 11.8 | 10.2 | 8.9 | 8 | 7.2 | 6.7 | 6.3 | |
| **12** | 37.3 | 36 | 28.6 | 24.6 | 23.2 | 18.7 | 18.5 | 18 | 16.1 | 12.6 | 10.9 | 9.5 | 8.5 | 7.7 | 7.1 | 6.7 | |
| **13** | 39.6 | 38.1 | 30.3 | 26.1 | 24.6 | 19.9 | 19.7 | 19.1 | 17.1 | 13.4 | 11.6 | 10.1 | 9 | 8.1 | 7.5 | 7.2 | |
| **14** | 41.8 | 40.3 | 32.1 | 27.6 | 26 | 21 | 20.8 | 20.2 | 18.1 | 14.2 | 12.2 | 10.7 | 9.6 | 8.6 | 8 | 7.6 | |
| **15** | 44 | 42.4 | 33.8 | 29.1 | 27.4 | 22.2 | 21.9 | 21.3 | 19.1 | 15 | 12.9 | 11.3 | 10.1 | 9.1 | 8.4 | 8 | |
| **16** | 46.1 | 44.5 | 35.5 | 30.6 | 28.8 | 23.3 | 23.1 | 22.4 | 20 | 15.7 | 13.6 | 11.9 | 10.6 | 9.6 | 8.9 | 8.4 | |

| # of defects (*d*) | Sample Size, *n* | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **48** | **50** | **64** | **75** | **80** | **100** | **101** | **104** | **117** | **150** | **175** | **200** | **225** | **250** | **270** | **285** | |
| **17** | 48.3 | 46.5 | 37.1 | 32 | 30.2 | 24.4 | 24.2 | 23.5 | 21 | 16.5 | 14.2 | 12.5 | 11.1 | 10 | 9.3 | 8.8 | |
| **18** | 50.4 | 48.6 | 38.8 | 33.5 | 31.5 | 25.5 | 25.3 | 24.6 | 22 | 17.3 | 14.9 | 13.1 | 11.6 | 10.5 | 9.7 | 9.2 | |
| **19** | 52.5 | 50.6 | 40.5 | 34.9 | 32.9 | 26.6 | 26.4 | 25.6 | 22.9 | 18 | 15.5 | 13.6 | 12.1 | 11 | 10.2 | 9.6 | |
| **20** | 54.5 | 52.6 | 42.1 | 36.3 | 34.2 | 27.7 | 27.5 | 26.7 | 23.9 | 18.8 | 16.2 | 14.2 | 12.7 | 11.4 | 10.6 | 10 | ***P* = 10 %** |
| **21** | 56.6 | 54.6 | 43.7 | 37.8 | 35.6 | 28.8 | 28.5 | 27.8 | 24.8 | 19.5 | 16.8 | 14.8 | 13.2 | 11.9 | 11 | 10.4 | |
| **22** | 58.6 | 56.6 | 45.3 | 39.2 | 36.9 | 29.9 | 29.6 | 28.8 | 25.7 | 20.3 | 17.5 | 15.3 | 13.7 | 12.3 | 11.4 | 10.8 | |
| **23** | 60.6 | 58.5 | 46.9 | 40.6 | 38.2 | 31 | 30.7 | 29.9 | 26.7 | 21 | 18.1 | 15.9 | 14.2 | 12.8 | 11.9 | 11.2 | |
| **24** | 62.6 | 60.5 | 48.5 | 42 | 39.5 | 32.1 | 31.8 | 30.9 | 27.6 | 21.8 | 18.7 | 16.5 | 14.7 | 13.2 | 12.3 | 11.6 | |
| **25** | 64.6 | 62.4 | 50.1 | 43.3 | 40.8 | 33.1 | 32.8 | 31.9 | 28.5 | 22.5 | 19.4 | 17 | 15.2 | 13.7 | 12.7 | 12 | |
| **26** | 66.6 | 64.3 | 51.7 | 44.7 | 42.1 | 34.2 | 33.9 | 33 | 29.5 | 23.2 | 20 | 17.6 | 15.7 | 14.1 | 13.1 | 12.4 | |
| **27** | 68.5 | 66.2 | 53.2 | 46.1 | 43.4 | 35.3 | 34.9 | 34 | 30.4 | 24 | 20.6 | 18.1 | 16.2 | 14.6 | 13.5 | 12.8 | |
| **28** | 70.4 | 68 | 54.8 | 47.4 | 44.7 | 36.3 | 36 | 35 | 31.3 | 24.7 | 21.3 | 18.7 | 16.7 | 15 | 13.9 | 13.2 | |
| **29** | 72.3 | 69.9 | 56.3 | 48.8 | 46 | 37.4 | 37 | 36 | 32.2 | 25.4 | 21.9 | 19.2 | 17.2 | 15.5 | 14.4 | 13.6 | |
| **30** | 74.2 | 71.7 | 57.9 | 50.1 | 47.3 | 38.4 | 38.1 | 37 | 33.1 | 26.1 | 22.5 | 19.8 | 17.6 | 15.9 | 14.8 | 14 | |
| **31** | 76 | 73.5 | 59.4 | 51.5 | 48.5 | 39.5 | 39.1 | 38 | 34 | 26.9 | 23.1 | 20.3 | 18.1 | 16.4 | 15.2 | 14.4 | |
| **32** | 77.8 | 75.3 | 60.9 | 52.8 | 49.8 | 40.5 | 40.1 | 39 | 34.9 | 27.6 | 23.8 | 20.9 | 18.6 | 16.8 | 15.6 | 14.8 | ***P* = 15 %** |
| **33** | 79.6 | 77 | 62.4 | 54.1 | 51.1 | 41.5 | 41.2 | 40 | 35.8 | 28.3 | 24.4 | 21.4 | 19.1 | 17.3 | 16 | 15.2 | |
| **34** | 81.4 | 78.8 | 63.9 | 55.5 | 52.3 | 42.6 | 42.2 | 41 | 36.7 | 29 | 25 | 22 | 19.6 | 17.7 | 16.4 | 15.6 | |
| **35** | 83.2 | 80.5 | 65.4 | 56.8 | 53.6 | 43.6 | 43.2 | 42 | 37.6 | 29.7 | 25.6 | 22.5 | 20.1 | 18.1 | 16.8 | 16 | |
| **36** | 84.9 | 82.2 | 66.8 | 58.1 | 54.8 | 44.6 | 44.2 | 43 | 38.5 | 30.4 | 26.2 | 23.1 | 20.6 | 18.6 | 17.2 | 16.3 | |
| **37** | 86.6 | 83.9 | 68.3 | 59.4 | 56 | 45.7 | 45.2 | 44 | 39.4 | 31.1 | 26.9 | 23.6 | 21.1 | 19 | 17.6 | 16.7 | |
| **38** | 88.2 | 85.5 | 69.7 | 60.7 | 57.3 | 46.7 | 46.2 | 45 | 40.3 | 31.8 | 27.5 | 24.1 | 21.5 | 19.4 | 18 | 17.1 | |
| **39** | 89.9 | 87.1 | 71.2 | 62 | 58.5 | 47.7 | 47.3 | 46 | 41.2 | 32.6 | 28.1 | 24.7 | 22 | 19.9 | 18.4 | 17.5 | |
| **40** | 91.4 | 88.7 | 72.6 | 63.2 | 59.7 | 48.7 | 48.3 | 47 | 42.1 | 33.3 | 28.7 | 25.2 | 22.5 | 20.3 | 18.8 | 17.9 | |

| # of defects (*d*) | Sample Size, *n* | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **48** | **50** | **64** | **75** | **80** | **100** | **101** | **104** | **117** | **150** | **175** | **200** | **225** | **250** | **270** | **285** | |
| **41** | 92.9 | 90.3 | 74 | 64.5 | 60.9 | 49.7 | 49.3 | 47.9 | 43 | 34 | 29.3 | 25.8 | 23 | 20.7 | 19.2 | 18.3 | |
| **42** | 94.4 | 91.8 | 75.5 | 65.8 | 62.1 | 50.7 | 50.3 | 48.9 | 43.8 | 34.7 | 29.9 | 26.3 | 23.5 | 21.2 | 19.6 | 18.6 | |
| **43** | 95.8 | 93.2 | 76.8 | 67 | 63.3 | 51.7 | 51.2 | 49.9 | 44.7 | 35.4 | 30.5 | 26.8 | 23.9 | 21.6 | 20.1 | 19 | |
| **44** | 97.1 | 94.6 | 78.2 | 68.3 | 64.5 | 52.7 | 52.2 | 50.8 | 45.6 | 36.1 | 31.1 | 27.4 | 24.4 | 22 | 20.5 | 19.4 | |
| **45** | 98.3 | 96 | 79.6 | 69.5 | 65.7 | 53.7 | 53.2 | 51.8 | 46.4 | 36.8 | 31.7 | 27.9 | 24.9 | 22.5 | 20.9 | 19.8 | ***P*** = 20 % |
| **46** | 99.3 | 97.2 | 81 | 70.8 | 66.9 | 54.7 | 54.2 | 52.8 | 47.3 | 37.4 | 32.3 | 28.4 | 25.4 | 22.9 | 21.3 | 20.2 | |
| **47** | 99.9 | 98.3 | 82.3 | 72 | 68.1 | 55.7 | 55.2 | 53.7 | 48.2 | 38.1 | 32.9 | 29 | 25.8 | 23.3 | 21.7 | 20.5 | |
| **48** | | 99.3 | 83.6 | 73.2 | 69.2 | 56.7 | 56.2 | 54.7 | 49 | 38.8 | 33.5 | 29.5 | 26.3 | 23.8 | 22.1 | 20.9 | |
| **49** | | 99.9 | 85 | 74.4 | 70.4 | 57.7 | 57.1 | 55.6 | 49.9 | 39.5 | 34.1 | 30 | 26.8 | 24.2 | 22.4 | 21.3 | |
| **50** | | | 86.3 | 75.7 | 71.6 | 58.6 | 58.1 | 56.6 | 50.8 | 40.2 | 34.7 | 30.5 | 27.3 | 24.6 | 22.8 | 21.7 | |
| **51** | | | 87.5 | 76.9 | 72.7 | 59.6 | 59.1 | 57.5 | 51.6 | 40.9 | 35.3 | 31.1 | 27.7 | 25 | 23.2 | 22.1 | |
| **52** | | | 88.8 | 78 | 73.9 | 60.6 | 60 | 58.5 | 52.5 | 41.6 | 35.9 | 31.6 | 28.2 | 25.5 | 23.6 | 22.4 | |
| **53** | | | 90.1 | 79.2 | 75 | 61.6 | 61 | 59.4 | 53.3 | 42.3 | 36.5 | 32.1 | 28.7 | 25.9 | 24 | 22.8 | |
| **54** | | | 91.3 | 80.4 | 76.1 | 62.5 | 62 | 60.3 | 54.2 | 42.9 | 37.1 | 32.6 | 29.1 | 26.3 | 24.4 | 23.2 | |
| **55** | | | 92.5 | 81.6 | 77.3 | 63.5 | 62.9 | 61.3 | 55 | 43.6 | 37.7 | 33.2 | 29.6 | 26.7 | 24.8 | 23.6 | |
| **56** | | | 93.6 | 82.7 | 78.4 | 64.4 | 63.9 | 62.2 | 55.9 | 44.3 | 38.3 | 33.7 | 30.1 | 27.2 | 25.2 | 23.9 | |
| **57** | | | 94.8 | 83.9 | 79.5 | 65.4 | 64.8 | 63.1 | 56.7 | 45 | 38.9 | 34.2 | 30.6 | 27.6 | 25.6 | 24.3 | |
| **58** | | | 95.8 | 85 | 80.6 | 66.4 | 65.8 | 64.1 | 57.5 | 45.7 | 39.5 | 34.7 | 31 | 28 | 26 | 24.7 | |
| **59** | | | 96.9 | 86.1 | 81.7 | 67.3 | 66.7 | 65 | 58.4 | 46.3 | 40.1 | 35.3 | 31.5 | 28.4 | 26.4 | 25 | |
| **60** | | | 97.8 | 87.2 | 82.8 | 68.2 | 67.6 | 65.9 | 59.2 | 47 | 40.6 | 35.8 | 32 | 28.9 | 26.8 | 25.4 | |
| **61** | | | 98.7 | 88.3 | 83.9 | 69.2 | 68.6 | 66.8 | 60.1 | 47.7 | 41.2 | 36.3 | 32.4 | 29.3 | 27.2 | 25.8 | |
| **62** | | | 99.4 | 89.4 | 84.9 | 70.1 | 69.5 | 67.7 | 60.9 | 48.4 | 41.8 | 36.8 | 32.9 | 29.7 | 27.6 | 26.2 | |
| **63** | | | 99.9 | 90.5 | 86 | 71.1 | 70.4 | 68.6 | 61.7 | 49 | 42.4 | 37.3 | 33.3 | 30.1 | 28 | 26.5 | |
| **64** | | | | 91.6 | 87 | 72 | 71.4 | 69.5 | 62.5 | 49.7 | 43 | 37.9 | 33.8 | 30.5 | 28.4 | 26.9 | |
| **65** | | | | 92.6 | 88.1 | 72.9 | 72.3 | 70.4 | 63.4 | 50.4 | 43.6 | 38.4 | 34.3 | 31 | 28.7 | 27.3 | |
| **66** | | | | 93.6 | 89.1 | 73.8 | 73.2 | 71.3 | 64.2 | 51 | 44.2 | 38.9 | 34.7 | 31.4 | 29.1 | 27.6 | |

| # of defects (*d*) | Sample Size, *n* | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **48** | **50** | **64** | **75** | **80** | **100** | **101** | **104** | **117** | **150** | **175** | **200** | **225** | **250** | **270** | **285** | |
| **67** | | | | 94.6 | 90.1 | 74.8 | 74.1 | 72.2 | 65 | 51.7 | 44.7 | 39.4 | 35.2 | 31.8 | 29.5 | 28 | |
| **68** | | | | 95.5 | 91.1 | 75.7 | 75 | 73.1 | 65.8 | 52.4 | 45.3 | 39.9 | 35.7 | 32.2 | 29.9 | 28.4 | |
| **69** | | | | 96.5 | 92.1 | 76.6 | 75.9 | 74 | 66.6 | 53 | 45.9 | 40.4 | 36.1 | 32.6 | 30.3 | 28.8 | |
| **70** | | | | 97.3 | 93.1 | 77.5 | 76.8 | 74.9 | 67.5 | 53.7 | 46.5 | 40.9 | 36.6 | 33.1 | 30.7 | 29.1 | |
| **71** | | | | 98.2 | 94 | 78.4 | 77.7 | 75.8 | 68.3 | 54.4 | 47 | 41.5 | 37 | 33.5 | 31.1 | 29.5 | |
| **72** | | | | 98.9 | 94.9 | 79.3 | 78.6 | 76.7 | 69.1 | 55 | 47.6 | 42 | 37.5 | 33.9 | 31.5 | 29.9 | |
| **73** | | | | 99.5 | 95.8 | 80.2 | 79.5 | 77.5 | 69.9 | 55.7 | 48.2 | 42.5 | 38 | 34.3 | 31.8 | 30.2 | |
| **74** | | | | 99.9 | 96.7 | 81.1 | 80.4 | 78.4 | 70.7 | 56.3 | 48.8 | 43 | 38.4 | 34.7 | 32.2 | 30.6 | |
| **75** | | | | | 97.5 | 82 | 81.3 | 79.3 | 71.5 | 57 | 49.4 | 43.5 | 38.9 | 35.1 | 32.6 | 31 | |
| **76** | | | | | 98.3 | 82.9 | 82.2 | 80.1 | 72.3 | 57.7 | 49.9 | 44 | 39.3 | 35.5 | 33 | 31.3 | |
| **77** | | | | | 99 | 83.7 | 83 | 81 | 73.1 | 58.3 | 50.5 | 44.5 | 39.8 | 36 | 33.4 | 31.7 | |
| **78** | | | | | 99.6 | 84.6 | 83.9 | 81.9 | 73.9 | 59 | 51.1 | 45 | 40.2 | 36.4 | 33.8 | 32.1 | |
| **79** | | | | | 99.9 | 85.5 | 84.8 | 82.7 | 74.7 | 59.6 | 51.6 | 45.5 | 40.7 | 36.8 | 34.2 | 32.4 | |
| **80** | | | | | | 86.3 | 85.6 | 83.5 | 75.5 | 60.3 | 52.2 | 46 | 41.1 | 37.2 | 34.5 | 32.8 | |
| **81** | | | | | | 87.2 | 86.5 | 84.4 | 76.2 | 60.9 | 52.8 | 46.5 | 41.6 | 37.6 | 34.9 | 33.1 | |
| **82** | | | | | | 88 | 87.3 | 85.2 | 77 | 61.6 | 53.4 | 47 | 42.1 | 38 | 35.3 | 33.5 | |
| **83** | | | | | | 88.9 | 88.2 | 86.1 | 77.8 | 62.2 | 53.9 | 47.5 | 42.5 | 38.4 | 35.7 | 33.9 | |
| **84** | | | | | | 89.7 | 89 | 86.9 | 78.6 | 62.9 | 54.5 | 48.1 | 43 | 38.8 | 36.1 | 34.2 | |
| **85** | | | | | | 90.5 | 89.8 | 87.7 | 79.4 | 63.5 | 55.1 | 48.6 | 43.4 | 39.3 | 36.5 | 34.6 | |
| **86** | | | | | | 91.3 | 90.6 | 88.5 | 80.1 | 64.2 | 55.6 | 49.1 | 43.9 | 39.7 | 36.8 | 35 | |
| **87** | | | | | | 92.1 | 91.4 | 89.3 | 80.9 | 64.8 | 56.2 | 49.6 | 44.3 | 40.1 | 37.2 | 35.3 | |
| **88** | | | | | | 92.9 | 92.2 | 90.1 | 81.7 | 65.4 | 56.7 | 50.1 | 44.8 | 40.5 | 37.6 | 35.7 | |
| **89** | | | | | | 93.7 | 93 | 90.9 | 82.4 | 66.1 | 57.3 | 50.6 | 45.2 | 40.9 | 38 | 36.1 | |
| **90** | | | | | | 94.5 | 93.8 | 91.7 | 83.2 | 66.7 | 57.9 | 51.1 | 45.7 | 41.3 | 38.4 | 36.4 | |
| **91** | | | | | | 95.2 | 94.5 | 92.4 | 83.9 | 67.4 | 58.4 | 51.6 | 46.1 | 41.7 | 38.7 | 36.8 | |
| **92** | | | | | | 96 | 95.3 | 93.2 | 84.7 | 68 | 59 | 52.1 | 46.6 | 42.1 | 39.1 | 37.1 | |
| **93** | | | | | | 96.7 | 96 | 94 | 85.4 | 68.6 | 59.6 | 52.6 | 47 | 42.5 | 39.5 | 37.5 | |

| # of defects (*d*) | Sample Size, *n* | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **48** | **50** | **64** | **75** | **80** | **100** | **101** | **104** | **117** | **150** | **175** | **200** | **225** | **250** | **270** | **285** | |
| **94** | | | | | | 97.4 | 96.7 | 94.7 | 86.2 | 69.3 | 60.1 | 53.1 | 47.5 | 42.9 | 39.9 | 37.9 | |
| **95** | | | | | | 98 | 97.4 | 95.4 | 86.9 | 69.9 | 60.7 | 53.6 | 47.9 | 43.3 | 40.3 | 38.2 | |
| **96** | | | | | | 98.6 | 98 | 96.1 | 87.6 | 70.5 | 61.2 | 54.1 | 48.4 | 43.7 | 40.6 | 38.6 | |
| **97** | | | | | | 99.2 | 98.6 | 96.8 | 88.4 | 71.2 | 61.8 | 54.6 | 48.8 | 44.1 | 41 | 38.9 | |
| **98** | | | | | | 99.6 | 99.2 | 97.5 | 89.1 | 71.8 | 62.3 | 55 | 49.3 | 44.6 | 41.4 | 39.3 | |
| **99** | | | | | | 99.9 | 99.6 | 98.1 | 89.8 | 72.4 | 62.9 | 55.5 | 49.7 | 45 | 41.8 | 39.7 | |
| **100** | | | | | | | 99.9 | 98.7 | 90.5 | 73 | 63.5 | 56 | 50.1 | 45.4 | 42.1 | 40 | |

# Appendix C: Simulation Results for all Strategies

**Table C1. Simulation Results for Strategy 1.**

| *T* in (mm) | *P* (%) | # runs => | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sample Size => | 50 | 75 | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 285 |
| 0.5 (12.7) | 5 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 14 | 21 | 28 | 35 | 43 | 50 | 57 | 64 | 72 | 82 |
| | | std defects | 3 | 3 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 0 |
| | | max defects | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 5 | 6 | 8 |
| | 10 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 14 | 21 | 28 | 35 | 43 | 50 | 57 | 64 | 72 | 82 |
| | | std defects | 3 | 3 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 0 |
| | | max defects | 1 | 3 | 4 | 6 | 8 | 10 | 12 | 14 | 17 | 20 |
| | 15 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 14 | 21 | 28 | 35 | 43 | 50 | 57 | 64 | 72 | 82 |
| | | std defects | 3 | 3 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 0 |
| | | max defects | 3 | 5 | 8 | 11 | 15 | 18 | 21 | 24 | 28 | 32 |
| | 20 | % passed | 0.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 14 | 21 | 28 | 35 | 43 | 50 | 57 | 64 | 72 | 82 |
| | | std defects | 3 | 3 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 0 |
| | | max defects | 5 | 9 | 13 | 17 | 21 | 26 | 30 | 34 | 39 | 45 |

| *T* in (mm) | *P* (%) | # runs => | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sample Size => | 50 | 75 | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 285 |
| 0.75 (19.1) | 5 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 9 | 14 | 19 | 24 | 29 | 33 | 38 | 43 | 48 | 55 |
| | | std defects | 2 | 3 | 3 | 3 | 3 | 4 | 3 | 3 | 2 | 0 |
| | | max defects | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 5 | 6 | 8 |
| | 10 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 9 | 14 | 19 | 24 | 29 | 33 | 38 | 43 | 48 | 55 |
| | | std defects | 2 | 3 | 3 | 3 | 3 | 4 | 3 | 3 | 2 | 0 |
| | | max defects | 1 | 3 | 4 | 6 | 8 | 10 | 12 | 14 | 17 | 20 |
| | 15 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 9 | 14 | 19 | 24 | 29 | 33 | 38 | 43 | 48 | 55 |
| | | std defects | 2 | 3 | 3 | 3 | 3 | 4 | 3 | 3 | 2 | 0 |
| | | max defects | 3 | 5 | 8 | 11 | 15 | 18 | 21 | 24 | 28 | 32 |
| | 20 | % passed | 3.5 | 1 | 3.8 | 2.5 | 0.8 | 0.8 | 0.5 | 0 | 0 | 0 |
| | | avg # defects | 9 | 14 | 19 | 24 | 29 | 33 | 38 | 43 | 48 | 55 |
| | | std defects | 2 | 3 | 3 | 3 | 3 | 4 | 3 | 3 | 2 | 0 |
| | | max defects | 5 | 9 | 13 | 17 | 21 | 26 | 30 | 34 | 39 | 45 |
| 1.0 (25.4) | 5 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 6 | 9 | 12 | 16 | 19 | 22 | 26 | 29 | 32 | 37 |
| | | std defects | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 0 |
| | | max defects | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 5 | 6 | 8 |
| | 10 | % passed | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 6 | 9 | 12 | 16 | 19 | 22 | 26 | 29 | 32 | 37 |
| | | std defects | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 0 |
| | | max defects | 1 | 3 | 4 | 6 | 8 | 10 | 12 | 14 | 17 | 20 |
| | 15 | % passed | 8.5 | 4.3 | 5.3 | 5 | 4 | 9.5 | 5 | 1.8 | 0.8 | 0 |
| | | avg # defects | 6 | 9 | 12 | 16 | 19 | 22 | 26 | 29 | 32 | 37 |
| | | std defects | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 0 |
| | | max defects | 3 | 5 | 8 | 11 | 15 | 18 | 21 | 24 | 28 | 32 |
| | 20 | % passed | 33.5 | 33.3 | 60 | 67.5 | 76.8 | 81.8 | 95 | 99.8 | 100 | 100 |
| | | avg # defects | 6 | 9 | 12 | 16 | 19 | 22 | 26 | 29 | 32 | 37 |

| *T* in (mm) | *P* (%) | # runs => | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sample Size => | 50 | 75 | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 285 |
| | | std defects | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 0 |
| | | max defects | 5 | 9 | 13 | 17 | 21 | 26 | 30 | 34 | 39 | 45 |
| 2.0 (50.8) | 5 | % passed | 0 | 0.3 | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 2 | 4 | 5 | 7 | 8 | 9 | 11 | 12 | 14 | 16 |
| | | std defects | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 0 |
| | | max defects | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 5 | 6 | 8 |
| | 10 | % passed | 17.5 | 15 | 29.3 | 37 | 54 | 64.5 | 75.3 | 89.3 | 100 | 100 |
| | | avg # defects | 2 | 4 | 5 | 7 | 8 | 9 | 11 | 12 | 14 | 16 |
| | | std defects | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 0 |
| | | max defects | 1 | 3 | 4 | 6 | 8 | 10 | 12 | 14 | 17 | 20 |
| | 15 | % passed | 69.8 | 80 | 93.8 | 99 | 100 | 100 | 100 | 100 | 100 | 100 |
| | | avg # defects | 2 | 4 | 5 | 7 | 8 | 9 | 11 | 12 | 14 | 16 |
| | | std defects | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 0 |
| | | max defects | 3 | 5 | 8 | 11 | 15 | 18 | 21 | 24 | 28 | 32 |
| | 20 | % passed | 95.3 | 99.5 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| | | avg # defects | 2 | 4 | 5 | 7 | 8 | 9 | 11 | 12 | 14 | 16 |
| | | std defects | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 0 |
| | | max defects | 5 | 9 | 13 | 17 | 21 | 26 | 30 | 34 | 39 | 45 |

**Table C2. Simulation Results for Strategies 2, 3, and 4.**

| *T* in (mm) | *P* (%) | | Strategy 2 | | | Strategy 3 | | | | Strategy 4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | # runs => | 400 | 400 | 1 | 400 | 400 | 400 | 1 | 200 | 200 | 200 | 1 |
| | | Sample Size => | 50 | 75 | 100 | 50 | 75 | 100 | 117 | 48 | 64 | 80 | 104 |
| 0.5 (12.7) | 5 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 11 | 17 | 24 | 16 | 24 | 33 | 39 | 15 | 20 | 24 | 36 |
| | | std defects | 2 | 2 | 0 | 3 | 2 | 2 | 0 | 3 | 3 | 3 | 0 |
| | | max defects | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| | 10 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 11 | 17 | 24 | 16 | 24 | 33 | 39 | 15 | 20 | 24 | 36 |
| | | std defects | 2 | 2 | 0 | 3 | 2 | 2 | 0 | 3 | 3 | 3 | 0 |
| | | max defects | 1 | 3 | 4 | 1 | 3 | 4 | 6 | 1 | 2 | 3 | 5 |
| | 15 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 11 | 17 | 24 | 16 | 24 | 33 | 39 | 15 | 20 | 24 | 36 |
| | | std defects | 2 | 2 | 0 | 3 | 2 | 2 | 0 | 3 | 3 | 3 | 0 |
| | | max defects | 3 | 5 | 8 | 3 | 5 | 8 | 10 | 2 | 4 | 6 | 9 |
| | 20 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 11 | 17 | 24 | 16 | 24 | 33 | 39 | 15 | 20 | 24 | 36 |
| | | std defects | 2 | 2 | 0 | 3 | 2 | 2 | 0 | 3 | 3 | 3 | 0 |
| | | max defects | 5 | 9 | 13 | 5 | 9 | 13 | 16 | 4 | 7 | 9 | 13 |

| *T* in (mm) | *P* (%) | | Strategy 2 | | | Strategy 3 | | | | Strategy 4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | # runs => | 400 | 400 | 1 | 400 | 400 | 400 | 1 | 200 | 200 | 200 | 1 |
| | | Sample Size => | 50 | 75 | 100 | 50 | 75 | 100 | 117 | 48 | 64 | 80 | 104 |
| 0.75 (19.1) | 5 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 8 | 13 | 18 | 11 | 17 | 22 | 27 | 10 | 13 | 16 | 27 |
| | | std defects | 2 | 2 | 0 | 2 | 2 | 2 | 0 | 3 | 2 | 3 | 0 |
| | | max defects | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| | 10 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 8 | 13 | 18 | 11 | 17 | 22 | 27 | 10 | 13 | 16 | 27 |
| | | std defects | 2 | 2 | 0 | 2 | 2 | 2 | 0 | 3 | 2 | 3 | 0 |
| | | max defects | 1 | 3 | 4 | 1 | 3 | 4 | 6 | 1 | 2 | 3 | 5 |
| | 15 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 8 | 13 | 18 | 11 | 17 | 22 | 27 | 10 | 13 | 16 | 27 |
| | | std defects | 2 | 2 | 0 | 2 | 2 | 2 | 0 | 3 | 2 | 3 | 0 |
| | | max defects | 3 | 5 | 8 | 3 | 5 | 8 | 10 | 2 | 4 | 6 | 9 |
| | 20 | % passed | 4.8 | 0 | 0 | 0.3 | 0 | 0 | 0 | 0.5 | 0.5 | 0 | 0 |
| | | avg # defects | 8 | 13 | 18 | 11 | 17 | 22 | 27 | 10 | 13 | 16 | 27 |
| | | std defects | 2 | 2 | 0 | 2 | 2 | 2 | 0 | 3 | 2 | 3 | 0 |
| | | max defects | 5 | 9 | 13 | 5 | 9 | 13 | 16 | 4 | 7 | 9 | 13 |
| 1.0 (25.4) | 5 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 7 | 11 | 15 | 6 | 9 | 12 | 15 | 6 | 7 | 9 | 17 |
| | | std defects | 2 | 2 | 0 | 2 | 2 | 1 | 0 | 2 | 2 | 2 | 0 |
| | | max defects | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| | 10 | % passed | 0 | 0 | 0 | 0.3 | 0 | 0 | 0 | 0.5 | 0 | 0 | 0 |
| | | avg # defects | 7 | 11 | 15 | 6 | 9 | 12 | 15 | 6 | 7 | 9 | 17 |
| | | std defects | 2 | 2 | 0 | 2 | 2 | 1 | 0 | 2 | 2 | 2 | 0 |
| | | max defects | 1 | 3 | 4 | 1 | 3 | 4 | 6 | 1 | 2 | 3 | 5 |
| | 15 | % passed | 2.5 | 0 | 0 | 3.5 | 0.8 | 0.5 | 0 | 1 | 3.5 | 5.5 | 0 |
| | | avg # defects | 7 | 11 | 15 | 6 | 9 | 12 | 15 | 6 | 7 | 9 | 17 |
| | | std defects | 2 | 2 | 0 | 2 | 2 | 1 | 0 | 2 | 2 | 2 | 0 |
| | | max defects | 3 | 5 | 8 | 3 | 5 | 8 | 10 | 2 | 4 | 6 | 9 |
| | 20 | % passed | 16.3 | 5.8 | 0 | 29.3 | 26.5 | 68.5 | 100 | 22.5 | 47 | 45.5 | 0 |
| | | avg # defects | 7 | 11 | 15 | 6 | 9 | 12 | 15 | 6 | 7 | 9 | 17 |
| | | std defects | 2 | 2 | 0 | 2 | 2 | 1 | 0 | 2 | 2 | 2 | 0 |

| *T* in (mm) | *P* (%) | | Strategy 2 | | | Strategy 3 | | | | Strategy 4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | # runs => | 400 | 400 | 1 | 400 | 400 | 400 | 1 | 200 | 200 | 200 | 1 |
| | | Sample Size => | 50 | 75 | 100 | 50 | 75 | 100 | 117 | 48 | 64 | 80 | 104 |
| | | max defects | 5 | 9 | 13 | 5 | 9 | 13 | 16 | 4 | 7 | 9 | 13 |
| 2.0 (50.8) | 5 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 | 0 | 0 |
| | | avg # defects | 2 | 4 | 6 | 4 | 6 | 8 | 10 | 3 | 4 | 5 | 8 |
| | | std defects | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 2 | 2 | 2 | 0 |
| | | max defects | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| | 10 | % passed | 12.5 | 4.3 | 0 | 1.8 | 0 | 0.5 | 0 | 7.5 | 11 | 6 | 0 |
| | | avg # defects | 2 | 4 | 6 | 4 | 6 | 8 | 10 | 3 | 4 | 5 | 8 |
| | | std defects | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 2 | 2 | 2 | 0 |
| | | max defects | 1 | 3 | 4 | 1 | 3 | 4 | 6 | 1 | 2 | 3 | 5 |
| | 15 | % passed | 68.5 | 84.5 | 100 | 27.3 | 31.3 | 47 | 100 | 22.5 | 48 | 66 | 100 |
| | | avg # defects | 2 | 4 | 6 | 4 | 6 | 8 | 10 | 3 | 4 | 5 | 8 |
| | | std defects | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 2 | 2 | 2 | 0 |
| | | max defects | 3 | 5 | 8 | 3 | 5 | 8 | 10 | 2 | 4 | 6 | 9 |
| | 20 | % passed | 98.8 | 100 | 100 | 79.5 | 92 | 100 | 100 | 71 | 96 | 99.5 | 100 |
| | | avg # defects | 2 | 4 | 6 | 4 | 6 | 8 | 10 | 3 | 4 | 5 | 8 |
| | | std defects | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 2 | 2 | 2 | 0 |
| | | max defects | 5 | 9 | 13 | 5 | 9 | 13 | 16 | 4 | 7 | 9 | 13 |

**Table C3. Simulation Results for Strategy 5.**

| T in (mm) | P (%) | # runs => | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 1 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Sample Size => | 50 | 75 | 100 | 125 | 150 | 175 | 200 | 217 |
| 0.5 (12.7) | 5 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 14 | 21 | 28 | 36 | 43 | 50 | 58 | 63 |
| | | std defects | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 0 |
| | | max defects | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 5 |
| | 10 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 14 | 21 | 28 | 36 | 43 | 50 | 58 | 63 |
| | | std defects | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 0 |
| | | max defects | 1 | 3 | 4 | 6 | 8 | 10 | 12 | 14 |
| | 15 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 14 | 21 | 28 | 36 | 43 | 50 | 58 | 63 |
| | | std defects | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 0 |
| | | max defects | 3 | 5 | 8 | 11 | 15 | 18 | 21 | 23 |
| | 20 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 14 | 21 | 28 | 36 | 43 | 50 | 58 | 63 |
| | | std defects | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 0 |
| | | max defects | 5 | 9 | 13 | 17 | 21 | 26 | 30 | 33 |

| T in (mm) | P (%) | # runs => / Sample Size => | 400 / 50 | 400 / 75 | 400 / 100 | 400 / 125 | 400 / 150 | 400 / 175 | 400 / 200 | 1 / 217 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.75 (19.1) | 5 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 10 | 15 | 20 | 25 | 31 | 36 | 41 | 45 |
| | | std defects | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 0 |
| | | max defects | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 5 |
| | 10 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 10 | 15 | 20 | 25 | 31 | 36 | 41 | 45 |
| | | std defects | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 0 |
| | | max defects | 1 | 3 | 4 | 6 | 8 | 10 | 12 | 14 |
| | 15 | % passed | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 10 | 15 | 20 | 25 | 31 | 36 | 41 | 45 |
| | | std defects | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 0 |
| | | max defects | 3 | 5 | 8 | 11 | 15 | 18 | 21 | 23 |
| | 20 | % passed | 3.3 | 1 | 0.8 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 10 | 15 | 20 | 25 | 31 | 36 | 41 | 45 |
| | | std defects | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 0 |
| | | max defects | 5 | 9 | 13 | 17 | 21 | 26 | 30 | 33 |
| 1.0 (25.4) | 5 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 6 | 10 | 13 | 17 | 20 | 24 | 27 | 30 |
| | | std defects | 2 | 2 | 3 | 2 | 2 | 2 | 1 | 0 |
| | | max defects | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 5 |
| | 10 | % passed | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 6 | 10 | 13 | 17 | 20 | 24 | 27 | 30 |
| | | std defects | 2 | 2 | 3 | 2 | 2 | 2 | 1 | 0 |
| | | max defects | 1 | 3 | 4 | 6 | 8 | 10 | 12 | 14 |
| | 15 | % passed | 6 | 2.8 | 3.3 | 1.3 | 1.3 | 0.3 | 0 | 0 |
| | | avg # defects | 6 | 10 | 13 | 17 | 20 | 24 | 27 | 30 |
| | | std defects | 2 | 2 | 3 | 2 | 2 | 2 | 1 | 0 |
| | | max defects | 3 | 5 | 8 | 11 | 15 | 18 | 21 | 23 |
| | 20 | % passed | 28 | 23.5 | 42.3 | 56 | 65.5 | 73.3 | 100 | 100 |
| | | avg # defects | 6 | 10 | 13 | 17 | 20 | 24 | 27 | 30 |
| | | std defects | 2 | 2 | 3 | 2 | 2 | 2 | 1 | 0 |
| | | max defects | 5 | 9 | 13 | 17 | 21 | 26 | 30 | 33 |

| T in (mm) | P (%) | # runs => / Sample Size => | 400 / 50 | 400 / 75 | 400 / 100 | 400 / 125 | 400 / 150 | 400 / 175 | 400 / 200 | 1 / 217 |
|---|---|---|---|---|---|---|---|---|---|---|
| 2.0 (50.8) | 5 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 3 | 5 | 7 | 9 | 11 | 12 | 14 | 16 |
| | | std defects | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 0 |
| | | max defects | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 5 |
| | 10 | % passed | 9.8 | 6.3 | 7.5 | 8.5 | 7.3 | 5.5 | 3.8 | 0 |
| | | avg # defects | 3 | 5 | 7 | 9 | 11 | 12 | 14 | 16 |
| | | std defects | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 0 |
| | | max defects | 1 | 3 | 4 | 6 | 8 | 10 | 12 | 14 |
| | 15 | % passed | 48.5 | 54 | 70.8 | 91 | 97.3 | 100 | 100 | 100 |
| | | avg # defects | 3 | 5 | 7 | 9 | 11 | 12 | 14 | 16 |
| | | std defects | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 0 |
| | | max defects | 3 | 5 | 8 | 11 | 15 | 18 | 21 | 23 |
| | 20 | % passed | 88.8 | 93.8 | 100 | 100 | 100 | 100 | 100 | 100 |
| | | avg # defects | 3 | 5 | 7 | 9 | 11 | 12 | 14 | 16 |
| | | std defects | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 0 |
| | | max defects | 5 | 9 | 13 | 17 | 21 | 26 | 30 | 33 |

**Table C4. Simulation Results for Strategy 6.**

| T in (mm) | P (%) | # runs => | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sample Size => | 50 | 75 | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 285 |
| 0.5 (12.7) | 5 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 14 | 21 | 28 | 35 | 42 | 50 | 57 | 64 | 71 | 82 |
| | | std defects | 3 | 3 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 0 |
| | | max defects | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 5 | 6 | 8 |
| | 10 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 14 | 21 | 28 | 35 | 42 | 50 | 57 | 64 | 71 | 82 |
| | | std defects | 3 | 3 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 0 |
| | | max defects | 1 | 3 | 4 | 6 | 8 | 10 | 12 | 14 | 17 | 20 |
| | 15 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 14 | 21 | 28 | 35 | 42 | 50 | 57 | 64 | 71 | 82 |
| | | std defects | 3 | 3 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 0 |
| | | max defects | 3 | 5 | 8 | 11 | 15 | 18 | 21 | 24 | 28 | 32 |
| | 20 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 14 | 21 | 28 | 35 | 42 | 50 | 57 | 64 | 71 | 82 |
| | | std defects | 3 | 3 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 0 |
| | | max defects | 5 | 9 | 13 | 17 | 21 | 26 | 30 | 34 | 39 | 45 |

| T in (mm) | P (%) | # runs => / Sample Size => | 400 / 50 | 400 / 75 | 400 / 100 | 400 / 125 | 400 / 150 | 400 / 175 | 400 / 200 | 400 / 225 | 400 / 250 | 1 / 285 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.75 (19.1) | 5 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 9 | 14 | 19 | 24 | 28 | 33 | 38 | 43 | 48 | 55 |
| | | std defects | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 0 |
| | | max defects | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 5 | 6 | 8 |
| | 10 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 9 | 14 | 19 | 24 | 28 | 33 | 38 | 43 | 48 | 55 |
| | | std defects | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 0 |
| | | max defects | 1 | 3 | 4 | 6 | 8 | 10 | 12 | 14 | 17 | 20 |
| | 15 | % passed | 0.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 9 | 14 | 19 | 24 | 28 | 33 | 38 | 43 | 48 | 55 |
| | | std defects | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 0 |
| | | max defects | 3 | 5 | 8 | 11 | 15 | 18 | 21 | 24 | 28 | 32 |
| | 20 | % passed | 4 | 1.8 | 2.5 | 3 | 1.8 | 1.3 | 0.3 | 0 | 0 | 0 |
| | | avg # defects | 9 | 14 | 19 | 24 | 28 | 33 | 38 | 43 | 48 | 55 |
| | | std defects | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 0 |
| | | max defects | 5 | 9 | 13 | 17 | 21 | 26 | 30 | 34 | 39 | 45 |
| 1.0 (25.4) | 5 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 6 | 9 | 12 | 16 | 19 | 22 | 25 | 29 | 32 | 37 |
| | | std defects | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 0 |
| | | max defects | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 5 | 6 | 8 |
| | 10 | % passed | 0.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 6 | 9 | 12 | 16 | 19 | 22 | 25 | 29 | 32 | 37 |
| | | std defects | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 0 |
| | | max defects | 1 | 3 | 4 | 6 | 8 | 10 | 12 | 14 | 17 | 20 |
| | 15 | % passed | 7 | 4 | 4.8 | 4.8 | 5.3 | 6.8 | 5 | 4.5 | 0.3 | 0 |
| | | avg # defects | 6 | 9 | 12 | 16 | 19 | 22 | 25 | 29 | 32 | 37 |
| | | std defects | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 0 |
| | | max defects | 3 | 5 | 8 | 11 | 15 | 18 | 21 | 24 | 28 | 32 |
| | 20 | % passed | 35.3 | 34.5 | 59.8 | 67.5 | 78.5 | 83.8 | 96.8 | 99.3 | 100 | 100 |
| | | avg # defects | 6 | 9 | 12 | 16 | 19 | 22 | 25 | 29 | 32 | 37 |
| | | std defects | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 0 |
| | | max defects | 5 | 9 | 13 | 17 | 21 | 26 | 30 | 34 | 39 | 45 |

| T in (mm) | P (%) | # runs => / Sample Size => | 400 / 50 | 400 / 75 | 400 / 100 | 400 / 125 | 400 / 150 | 400 / 175 | 400 / 200 | 400 / 225 | 400 / 250 | 1 / 285 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.0 (50.8) | 5 | % passed | 0 | 0.5 | 1.8 | 0 | 0.3 | 0.3 | 0 | 0 | 0 | 0 |
| | | avg # defects | 2 | 4 | 5 | 7 | 8 | 9 | 11 | 12 | 14 | 16 |
| | | std defects | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 0 |
| | | max defects | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 5 | 6 | 8 |
| | 10 | % passed | 22.5 | 16.5 | 28.5 | 38 | 50.5 | 65.5 | 76.5 | 91 | 100 | 100 |
| | | avg # defects | 2 | 4 | 5 | 7 | 8 | 9 | 11 | 12 | 14 | 16 |
| | | std defects | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 0 |
| | | max defects | 1 | 3 | 4 | 6 | 8 | 10 | 12 | 14 | 17 | 20 |
| | 15 | % passed | 71.5 | 77.8 | 94.5 | 99.3 | 100 | 100 | 100 | 100 | 100 | 100 |
| | | avg # defects | 2 | 4 | 5 | 7 | 8 | 9 | 11 | 12 | 14 | 16 |
| | | std defects | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 0 |
| | | max defects | 3 | 5 | 8 | 11 | 15 | 18 | 21 | 24 | 28 | 32 |
| | 20 | % passed | 97 | 99.3 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| | | avg # defects | 2 | 4 | 5 | 7 | 8 | 9 | 11 | 12 | 14 | 16 |
| | | std defects | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 0 |
| | | max defects | 5 | 9 | 13 | 17 | 21 | 26 | 30 | 34 | 39 | 45 |

**Table C5. Simulation Results for Strategy 7.**

| T in (mm) | P (%) | # runs => / Sample Size => | 400 / 50 | 400 / 75 | 400 / 100 | 400 / 125 | 400 / 150 | 400 / 175 | 400 / 200 | 400 / 225 | 400 / 250 | 1 / 285 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.5 (12.7) | 5 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 14 | 21 | 28 | 36 | 43 | 50 | 57 | 64 | 72 | 82 |
| | | std defects | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 0 |
| | | max defects | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 5 | 6 | 8 |
| | 10 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 14 | 21 | 28 | 36 | 43 | 50 | 57 | 64 | 72 | 82 |
| | | std defects | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 0 |
| | | max defects | 1 | 3 | 4 | 6 | 8 | 10 | 12 | 14 | 17 | 20 |
| | 15 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 14 | 21 | 28 | 36 | 43 | 50 | 57 | 64 | 72 | 82 |
| | | std defects | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 0 |
| | | max defects | 3 | 5 | 8 | 11 | 15 | 18 | 21 | 24 | 28 | 32 |
| | 20 | % passed | 0.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 14 | 21 | 28 | 36 | 43 | 50 | 57 | 64 | 72 | 82 |
| | | std defects | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 0 |
| | | max defects | 5 | 9 | 13 | 17 | 21 | 26 | 30 | 34 | 39 | 45 |

| T in (mm) | P (%) | # runs => / Sample Size => | 400 / 50 | 400 / 75 | 400 / 100 | 400 / 125 | 400 / 150 | 400 / 175 | 400 / 200 | 400 / 225 | 400 / 250 | 1 / 285 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.75 (19.1) | 5 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 9 | 14 | 19 | 24 | 28 | 33 | 38 | 43 | 48 | 55 |
| | | std defects | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 0 |
| | | max defects | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 5 | 6 | 8 |
| | 10 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 9 | 14 | 19 | 24 | 28 | 33 | 38 | 43 | 48 | 55 |
| | | std defects | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 0 |
| | | max defects | 1 | 3 | 4 | 6 | 8 | 10 | 12 | 14 | 17 | 20 |
| | 15 | % passed | 0.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 9 | 14 | 19 | 24 | 28 | 33 | 38 | 43 | 48 | 55 |
| | | std defects | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 0 |
| | | max defects | 3 | 5 | 8 | 11 | 15 | 18 | 21 | 24 | 28 | 32 |
| | 20 | % passed | 5.8 | 1 | 4.3 | 2.8 | 0.8 | 1.3 | 0.8 | 0 | 0 | 0 |
| | | avg # defects | 9 | 14 | 19 | 24 | 28 | 33 | 38 | 43 | 48 | 55 |
| | | std defects | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 0 |
| | | max defects | 5 | 9 | 13 | 17 | 21 | 26 | 30 | 34 | 39 | 45 |
| 1.0 (25.4) | 5 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 6 | 9 | 12 | 16 | 19 | 22 | 25 | 29 | 32 | 37 |
| | | std defects | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 0 |
| | | max defects | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 5 | 6 | 8 |
| | 10 | % passed | 0.5 | 0.3 | 0.3 | 0 | 0 | 0 | 0 | 0 | □ | 0 |
| | | avg # defects | 6 | 9 | 12 | 16 | 19 | 22 | 25 | 29 | 32 | 37 |
| | | std defects | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 0 |
| | | max defects | 1 | 3 | 4 | 6 | 8 | 10 | 12 | 14 | 17 | 20 |
| | 15 | % passed | 8.3 | 5 | 5.3 | 5 | 4 | 8.5 | 6.3 | 2.5 | 0.3 | 0 |
| | | avg # defects | 6 | 9 | 12 | 16 | 19 | 22 | 25 | 29 | 32 | 37 |
| | | std defects | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 0 |
| | | max defects | 3 | 5 | 8 | 11 | 15 | 18 | 21 | 24 | 28 | 32 |
| | 20 | % passed | 31.3 | 33.3 | 62.3 | 66.5 | 78.3 | 88.8 | 96.8 | 100 | 100 | 100 |
| | | avg # defects | 6 | 9 | 12 | 16 | 19 | 22 | 25 | 29 | 32 | 37 |
| | | std defects | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 0 |
| | | max defects | 5 | 9 | 13 | 17 | 21 | 26 | 30 | 34 | 39 | 45 |

| T | P | # runs => | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| in (mm) | (%) | Sample Size => | 50 | 75 | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 285 |
| 2.0 (50.8) | 5 | % passed | 0 | 0.3 | 0.5 | 0.3 | 0 | 0.3 | 0 | 0 | 0 | 0 |
| | | avg # defects | 2 | 4 | 5 | 7 | 8 | 9 | 11 | 12 | 14 | 16 |
| | | std defects | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 0 |
| | | max defects | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 5 | 6 | 8 |
| | 10 | % passed | 19 | 17 | 31 | 38.5 | 52 | 65.8 | 76.3 | 90 | 100 | 100 |
| | | avg # defects | 2 | 4 | 5 | 7 | 8 | 9 | 11 | 12 | 14 | 16 |
| | | std defects | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 0 |
| | | max defects | 1 | 3 | 4 | 6 | 8 | 10 | 12 | 14 | 17 | 20 |
| | 15 | % passed | 69.3 | 76.3 | 93 | 99 | 100 | 100 | 100 | 100 | 100 | 100 |
| | | avg # defects | 2 | 4 | 5 | 7 | 8 | 9 | 11 | 12 | 14 | 16 |
| | | std defects | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 0 |
| | | max defects | 3 | 5 | 8 | 11 | 15 | 18 | 21 | 24 | 28 | 32 |
| | 20 | % passed | 95 | 99 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| | | avg # defects | 2 | 4 | 5 | 7 | 8 | 9 | 11 | 12 | 14 | 16 |
| | | std defects | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 0 |
| | | max defects | 5 | 9 | 13 | 17 | 21 | 26 | 30 | 34 | 39 | 45 |

**Table C6. Simulation Results for Strategy 8.**

| T in (mm) | P (%) | # runs => | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sample Size => | 50 | 75 | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 270 |
| 0.5 (12.7) | 5 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 13 | 21 | 28 | 35 | 42 | 49 | 57 | 64 | 71 | 77 |
| | | std defects | 3 | 3 | 3 | 4 | 4 | 4 | 3 | 3 | 2 | 0 |
| | | max defects | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 5 | 6 | 7 |
| | 10 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 13 | 21 | 28 | 35 | 42 | 49 | 57 | 64 | 71 | 77 |
| | | std defects | 3 | 3 | 3 | 4 | 4 | 4 | 3 | 3 | 2 | 0 |
| | | max defects | 1 | 3 | 4 | 6 | 8 | 10 | 12 | 14 | 17 | 18 |
| | 15 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 13 | 21 | 28 | 35 | 42 | 49 | 57 | 64 | 71 | 77 |
| | | std defects | 3 | 3 | 3 | 4 | 4 | 4 | 3 | 3 | 2 | 0 |
| | | max defects | 3 | 5 | 8 | 11 | 15 | 18 | 21 | 24 | 28 | 30 |
| | 20 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 13 | 21 | 28 | 35 | 42 | 49 | 57 | 64 | 71 | 77 |
| | | std defects | 3 | 3 | 3 | 4 | 4 | 4 | 3 | 3 | 2 | 0 |
| | | max defects | 5 | 9 | 13 | 17 | 21 | 26 | 30 | 34 | 39 | 42 |

| T in (mm) | P (%) | # runs => / Sample Size => | 400 / 50 | 400 / 75 | 400 / 100 | 400 / 125 | 400 / 150 | 400 / 175 | 400 / 200 | 400 / 225 | 400 / 250 | 1 / 270 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.75 (19.1) | 5 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 9 | 14 | 19 | 24 | 28 | 33 | 38 | 43 | 48 | 52 |
| | | std defects | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 0 |
| | | max defects | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 5 | 6 | 7 |
| | 10 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 9 | 14 | 19 | 24 | 28 | 33 | 38 | 43 | 48 | 52 |
| | | std defects | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 0 |
| | | max defects | 1 | 3 | 4 | 6 | 8 | 10 | 12 | 14 | 17 | 18 |
| | 15 | % passed | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 9 | 14 | 19 | 24 | 28 | 33 | 38 | 43 | 48 | 52 |
| | | std defects | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 0 |
| | | max defects | 3 | 5 | 8 | 11 | 15 | 18 | 21 | 24 | 28 | 30 |
| | 20 | % passed | 6.5 | 2 | 3 | 1.8 | 0.5 | 0.8 | 0 | 0 | 0 | 0 |
| | | avg # defects | 9 | 14 | 19 | 24 | 28 | 33 | 38 | 43 | 48 | 52 |
| | | std defects | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 0 |
| | | max defects | 5 | 9 | 13 | 17 | 21 | 26 | 30 | 34 | 39 | 42 |
| 1.0 (25.4) | 5 | % passed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 6 | 9 | 12 | 16 | 19 | 22 | 26 | 29 | 32 | 35 |
| | | std defects | 2 | 2 | 3 | 3 | 3 | 3 | 2 | 2 | 1 | 0 |
| | | max defects | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 5 | 6 | 7 |
| | 10 | % passed | 0.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | avg # defects | 6 | 9 | 12 | 16 | 19 | 22 | 26 | 29 | 32 | 35 |
| | | std defects | 2 | 2 | 3 | 3 | 3 | 3 | 2 | 2 | 1 | 0 |
| | | max defects | 1 | 3 | 4 | 6 | 8 | 10 | 12 | 14 | 17 | 18 |
| | 15 | % passed | 9.8 | 5.3 | 4.3 | 3.8 | 4.5 | 7 | 3.5 | 0.5 | 0.5 | 0 |
| | | avg # defects | 6 | 9 | 12 | 16 | 19 | 22 | 26 | 29 | 32 | 35 |
| | | std defects | 2 | 2 | 3 | 3 | 3 | 3 | 2 | 2 | 1 | 0 |
| | | max defects | 3 | 5 | 8 | 11 | 15 | 18 | 21 | 24 | 28 | 30 |
| | 20 | % passed | 39 | 32.8 | 60 | 70 | 76.5 | 84.5 | 97.5 | 99.8 | 100 | 100 |
| | | avg # defects | 6 | 9 | 12 | 16 | 19 | 22 | 26 | 29 | 32 | 35 |
| | | std defects | 2 | 2 | 3 | 3 | 3 | 3 | 2 | 2 | 1 | 0 |
| | | max defects | 5 | 9 | 13 | 17 | 21 | 26 | 30 | 34 | 39 | 42 |

| T | P | # runs => | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| in (mm) | (%) | Sample Size => | 50 | 75 | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 270 |
| 2.0 (50.8) | 5 | % passed | 0 | 0.5 | 1.5 | 0.3 | 0.5 | 0.3 | 0 | 0 | 0 | 0 |
| | | avg # defects | 2 | 3 | 5 | 6 | 7 | 9 | 10 | 11 | 12 | 14 |
| | | std defects | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 0 |
| | | max defects | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 5 | 6 | 7 |
| | 10 | % passed | 25.3 | 21.3 | 38.3 | 50.5 | 68.3 | 78.8 | 92.8 | 100 | 100 | 100 |
| | | avg # defects | 2 | 3 | 5 | 6 | 7 | 9 | 10 | 11 | 12 | 14 |
| | | std defects | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 0 |
| | | max defects | 1 | 3 | 4 | 6 | 8 | 10 | 12 | 14 | 17 | 18 |
| | 15 | % passed | 76.5 | 83.5 | 95.8 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| | | avg # defects | 2 | 3 | 5 | 6 | 7 | 9 | 10 | 11 | 12 | 14 |
| | | std defects | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 0 |
| | | max defects | 3 | 5 | 8 | 11 | 15 | 18 | 21 | 24 | 28 | 30 |
| | 20 | % passed | 97.5 | 99.5 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| | | avg # defects | 2 | 3 | 5 | 6 | 7 | 9 | 10 | 11 | 12 | 14 |
| | | std defects | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 0 |
| | | max defects | 5 | 9 | 13 | 17 | 21 | 26 | 30 | 34 | 39 | 42 |