DESIGN SPECIFICATIONS FOR A MACHINE-READABLE CONTAINER IDENTIFIER

Jim Garner and Noah Pratt*
Oak Ridge National Laboratory
Oak Ridge, TN 37831

ABSTRACT

Throughout 2016, Oak Ridge National Laboratory investigated direct part marking techniques and barcode readers that would be applicable for a new global UF_6 cylinder identifier. The performance of several commercial-off-the-shelf (COTS) barcode readers was evaluated by varying the size of the barcode, read distance, read angle, surface finish of the material, and marking technique. This study concluded with a recommendation for a 1.4 in. two-dimensional (2-D) Data Matrix barcode that would provide for multiple COTS hand-held barcode readers to read the barcode from an angle of up to 30° over the range of 10–100 cm, as desired by the World Nuclear Transport Institute (WNTI) working group on UF_6 cylinder identification.

This paper provides the rationale for the recommended layout for the global identifier and potential approaches to modifying the 30B and 48Y cylinder nameplates if they included the 10-character global identification number displayed in both textual and 2-D barcode form. Testing has determined that a 1.4 in. Data Matrix barcode would meet industry's desires for a machine-readable feature. If this 2-D barcode is included with a textual form of the global identification number on the 5 in. wide 30B nameplate as suggested by the ANSI N14.1 2012 standard, the 30B nameplate would need to be 2.75 in. longer. If these features were included on a 48Y nameplate, the nameplate would need to be 2.35 in. longer. The authors suggest using Arial font because of its distinct, easy-to-read characters and wide use in direct part marking applications. Using the full width of the 30B and 48Y nameplate with a 0.25 in. margin would allow 44 pt Arial font to be used, which can be read from about 35 ft. If a stand-alone global identifier is used, the authors suggest using a wider plate with 60 pt font, which can be read from about 48 ft.

BARCODE TESTING TO INFORM GLOBAL IDENTIFIER DESIGN DECISIONS

In May of 2014, the World Nuclear Transport Institute (WNTI) formed a working group to evaluate and develop a standard for identifying UF_6 cylinders. Since inception this working group has been trying to better understand features that would enable industry to fully utilize a global UF_6 cylinder identifier with machine-readable features.

Several technologies were considered for the machine-readable feature of the cylinder identifier. Barcodes emerged as the most practical machine-readable feature. While one-dimensional barcodes are common and can include error checking, 2-D barcodes, like the Data Matrix barcode shown in Figure 1, typically include error checking and error correction features, which are not commonly available with one-dimensional barcodes [1]. Figure 1 is an example of a barcode that could be used to represent a 10-character global identification number recommended by the WNTI standard [2]. This 14 × 14 Data Matrix barcode encodes "ABCD123456."

*Subcontracted through Oak Ridge Associated Universities (ORAU).

Figure 1.Example Data Matrix barcode encoding ABCD123456.

Throughout the summer of 2016, Oak Ridge National Laboratory (ORNL) investigated direct part marking techniques and barcode specifications that would be applicable for the UF_6 cylinder global identifier. The testing evaluated how several COTS barcode readers performed when varying the size of the barcode, read distance, read angle, surface finish of the material, and marking technique. For example, one set of tests evaluated the read range of several barcode readers to read a 5 cm 2-D Data Matrix barcode printed on cardstock. Testing continued through the winter of 2017. This paper provides a summary of the testing.

To assess which barcode sizes and surface finishes would work well for the global identifier, the ORNL researchers needed to better understand how users would use the machine-readable features of the global identifier. To elicit feedback, the ORNL team proposed a nominal use case to the WNTI working group. The team proposed that most users would like to be able to read the barcode using a handheld barcode reader 10–100 cm away from the surface and at an angle of up to 30°. The WNTI working group accepted the use case without modification.

Eight COTS 2-D barcode readers were selected to test the concept. The selected readers were chosen based on vendor recommendations for their ability to read markings directly applied to metals. The selected readers, shown in Figure 2, are from several manufacturers and range in cost from $700 to $2,700.

Figure 2. Commercial 2-D barcode readers selected to evaluate the use case.

The authors tested several sizes of 2-D barcodes (2.5 cm, 3.5 cm, 5 cm, 10 cm, and 1.4 in.). Figure 3 shows the 10 cm, 5 cm, and 2.5 cm Data Matrix barcodes that were printed on cardstock and used for testing. The data suggests that a 2.5 cm Data Matrix barcode is too small and a 5 cm barcode is too large for the selected barcode readers to read the barcodes reliably over the entire use case range. However, a 3.5 cm barcode could be read by multiple barcode readers from several vendors over the entire use case range.

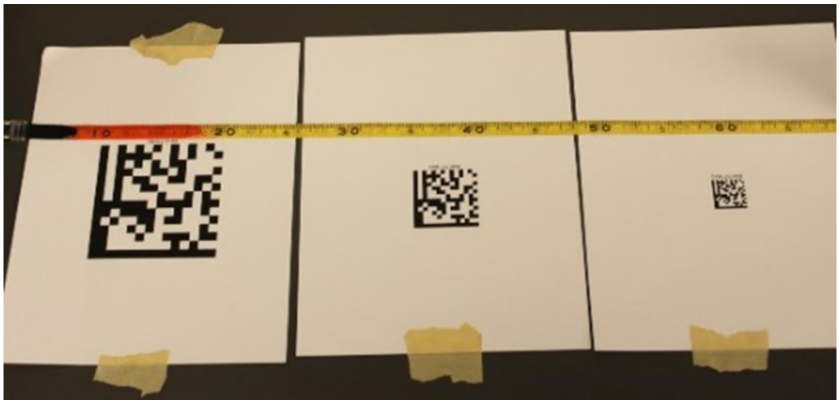

Figure 3. 10 cm, 5 cm, and 2.5 cm Data Matrix barcodes printed on cardstock used for testing.

The ANSI N14.1 standard [5] provides a suggested nameplate layout in inches. Although the sizes of a 3.5 cm barcode and a 1.4 in. barcode are within 2% of each other, the barcode range and angle testing was repeated for a 1.4 in. barcode printed on cardstock to make inclusion with suggested layouts in inches more convenient. The testing results for the 1.4 in. barcode are very similar to those of the 3.5 cm barcode.

The authors also tested how the selected barcode readers performed trying to read a 2-D barcode marked on different metals with different surface treatments and different marking techniques. The following samples were tested (Figure 4):

1. Laser etched stainless sheet with horizontal brushed finish
2. Laser etched stainless sheet with mirror finish
3. Laser etched stainless sheet with vertical brushed finish
4. Laser etched aluminum sheet
5. Laser etched black anodized aluminum sheet
6. Laser etched stainless sheet with ball blasted finish with the CerMark laser marking ink [3]
7. Stainless sheet with dot peen markings
8. Laser etched stainless sheet with ball blasted finish

Figure 4. Global identifier samples used for testing.

The CerMark sample performed well in the tests and should be considered a superior choice compared to the other alternatives. Although the laser etched black anodized aluminum performed well under some circumstances, it performed marginally well when the reader was normal to (directly in front of) the barcode surface. An aluminum identifier should be ruled out because of concerns WNTI working group members raised about welding an aluminum plate to the steel cylinder and questions concerning attachment longevity from different coefficients of expansion between the aluminum and the steel cylinder.

APPLYING TESTING RESULTS TO A SUGGESTED GLOBAL IDENTIFIER

Recommended Barcode Size

As discussed above, the authors tested several sizes of 2-D barcodes and evaluated the performance of different combinations of surface finish and part marking techniques. For the intended use case, the data suggests a 1.4 in. Data Matrix barcode laser etched with CerMark laser marking ink onto a ball blasted stainless steel plate would be very suitable for a UF_6 cylinder global identifier.

Data Matrix barcodes require quiet space around the perimeter of the code. Quiet space is typically defined as negative or white space acting as a buffer from other markings around the barcode. In accordance with ISO/IEC 16022:2006(E), the authors recommend a quiet zone equal to the size of one barcode module (0.1 in.) [4].

PLATE DIMENSIONS

As previously mentioned, the WNTI industry working group is interested in both a stand-alone global identifier, as well as an extended nameplate that would include the new cylinder identification. ANSI N14.1 2012 includes a suggested layout for both 30B and 48Y nameplates. Both of these suggested layouts utilize a 5.0 in. wide stainless nameplate with a 0.25 in. margin between any content and the edge of the plate [5].

Stand-alone Global Identifier

The standalone global identifier will include a 10-character global identification number displayed in both textual and 2-D barcode form. The WNTI standard [2] offered an example global identifier as shown in Figure 5. As shown in Figure 6, the example includes a 1.4 in. 2-D Data Matrix barcode with 0.1 in. quiet zone on all sides. It also includes a 0.25 in. margin between any features and the edge of the plate. To include the recommended barcode, quiet zone, and margin, the global identifier should be at least 2.1 in. tall.

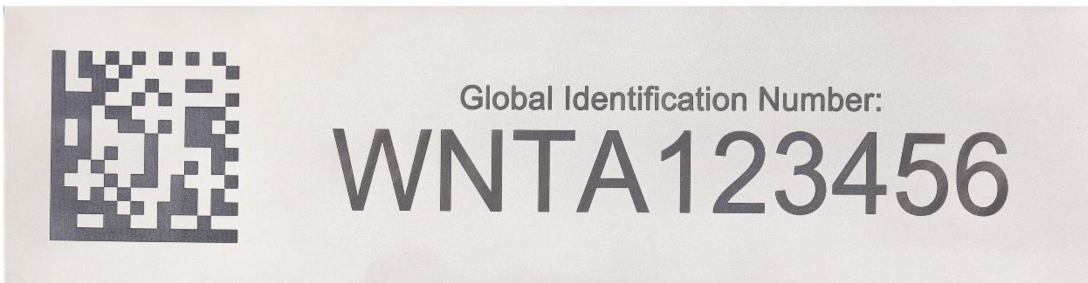

Figure 5. Example global identifier as recommended by the WNTI standard.

To make use of the height of this global identifier, the authors recommend using Arial size 60 pt font. The maximum width of the 10-character global identification number (e.g., WWWW123456) in 60 pt Arial font is approximately 6 in. So, with the recommended barcode, quiet zone, margin, and space for the textual form of the global identification number, the global identifier should be at least 8.1 in. wide. The layout and dimensioning of the suggested stand-alone global identifier is shown in Figure 6.

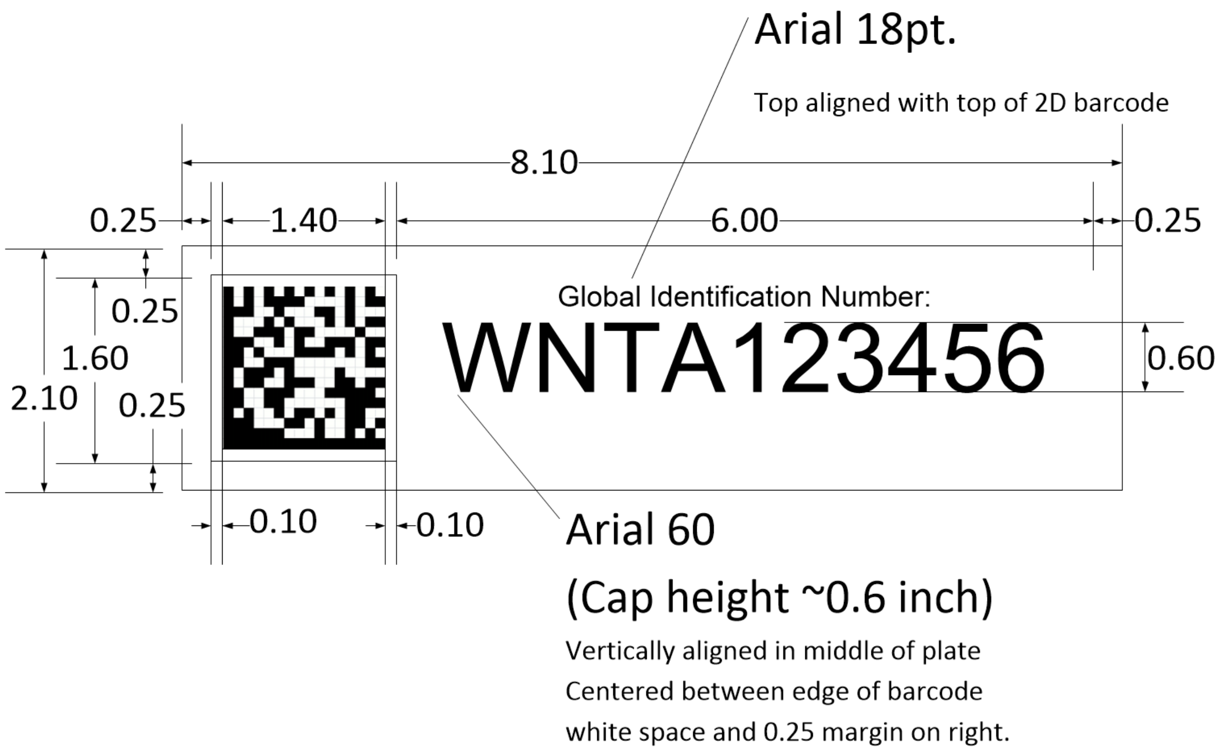

Figure 6. Design specifications for a UF_6 cylinder global identifier.

Recommended 30B Cylinder Nameplate

ANSI N14.1 2012 recommends 30B cylinder nameplates should be 4.5 in. tall and 5 in. wide [5]. As shown in Figure 7, if the authors add the global identification number in textual and 2-D barcode form to the bottom of the existing nameplate, the 30B nameplate would need to be about 2.75 in. taller than the ANSI N14.1 2012 recommended layout.

With the addition of the 10-character global identification number displayed in both textual and 2-D barcode form, a 30B nameplate would be 7.25 in. tall and 5 in. wide.

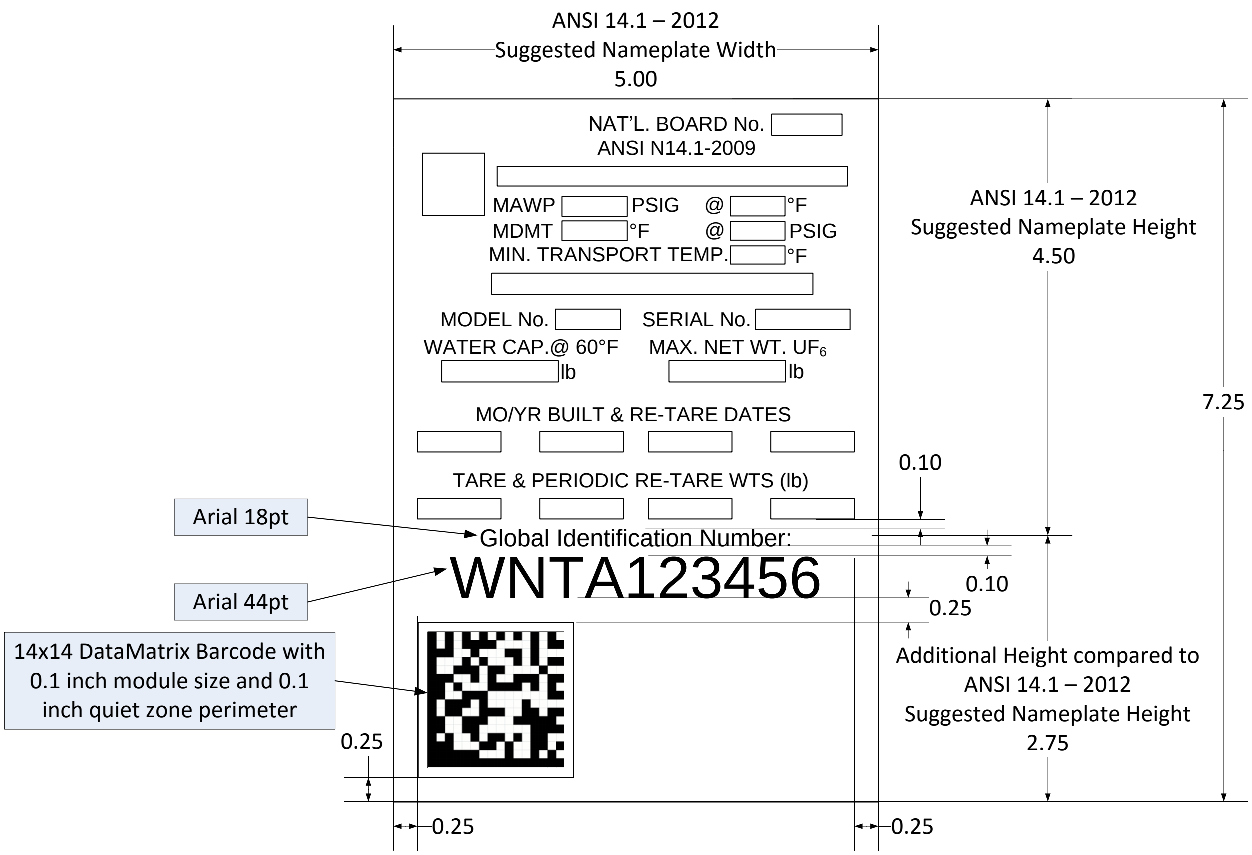

Figure 7. Recommended 30B cylinder nameplate layout incorporating 10-character global identification number displayed in both textual and 2-D barcode forms.

Recommended 48Y Cylinder Nameplate

ANSI N14.1 2012 recommends 48Y cylinder nameplates should be 8 in. tall and 5 in. wide [5]. As shown in Figure 8, if the authors add the global identification number in textual and 2-D barcode form to the bottom of the existing nameplate, the 48Y nameplate would need to be about 2.35 in. taller than the ANSI N14.1 2012 suggested layout.

With the addition of the 10-character global identification number displayed in both textual and 2-D barcode form, a 48Y nameplate would be 10.35 in. tall and 5 in. wide.

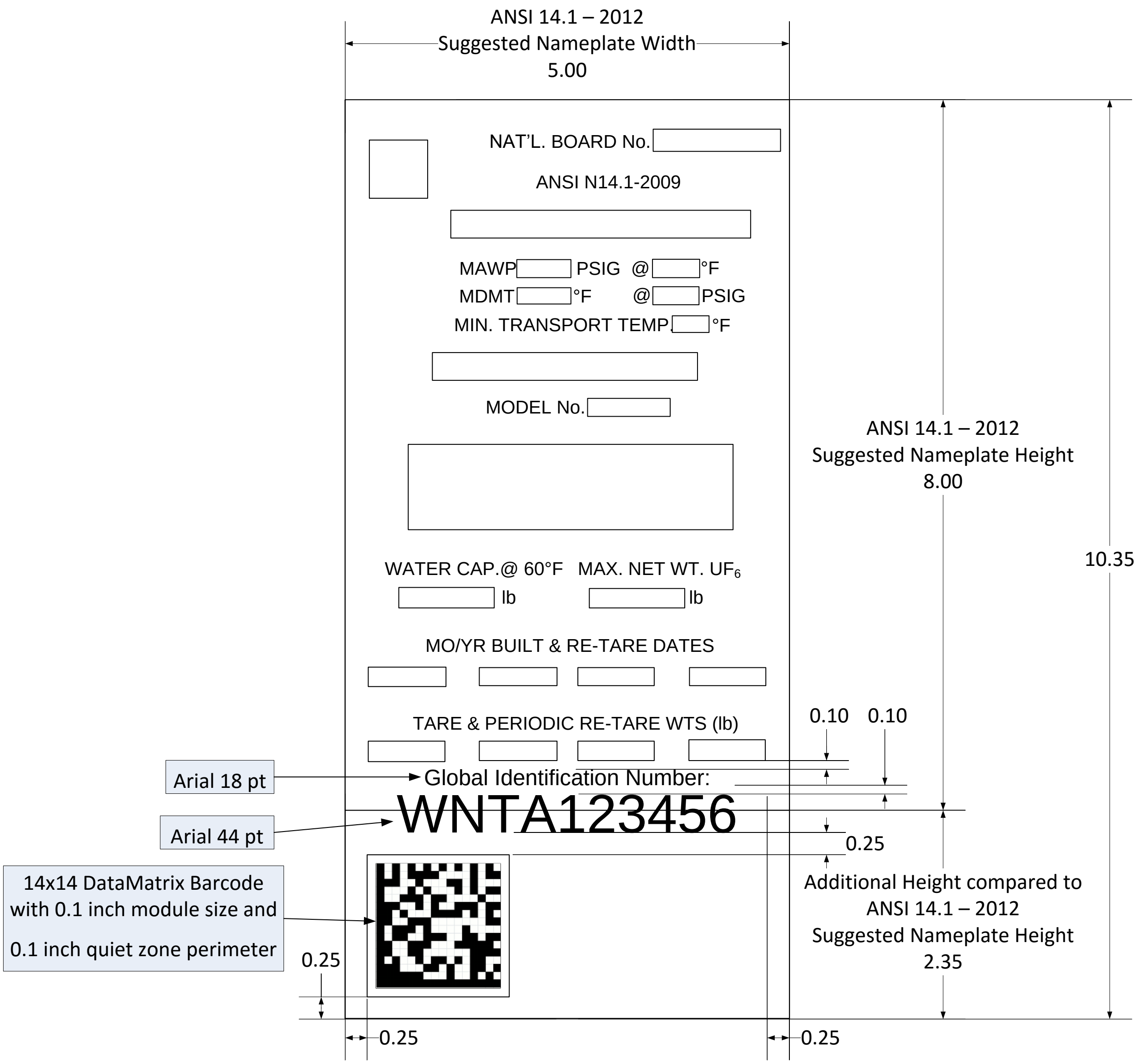

Figure 8. Recommended 48Y cylinder nameplate incorporating 10-character global identification number displayed in both textual and 2-D barcode forms.

Cylinder Identification Text

The authors recommend using 60 pt Arial font on the global identifier, and 44 pt Arial on the 30B and 48Y cylinder nameplates. The authors recommend Arial font for the textual form of the global identification number because of its distinct, easy to read characters and wide use for direct part marking applications, particularly in the aeronautical industry. The WNTI standard [2] calls for a 10-character alphanumeric global identification number consisting of four letters followed by six numbers. The authors evaluated a test string consisting of four of the widest characters (Ws) and 6 numbers to determine that 44 pt font is the largest Arial that will fit on the 5 in. 30B and 48Y cylinder nameplates if a 0.25 in. margin is preserved on either side.

Global Identification Number Text Height

In typography, an inch is commonly divided into 72 pt; so it would seem logical that 72 pt letters would be 1 in. tall, 60 pt letters would be 0.8333 in. tall, and 44 pt letters would be 0.6111 in. tall. However, the cap height (or height of capital letters) for a given font cannot be discerned so simply [6]. As show in Figure 9, capital letters typically will extend from the baseline to the cap line, but some characters may overshoot above the cap line, such as the f in this example, or extend below the baseline, such as the p in this example. Some space is typically reserved above the ascender line and below the descender line.

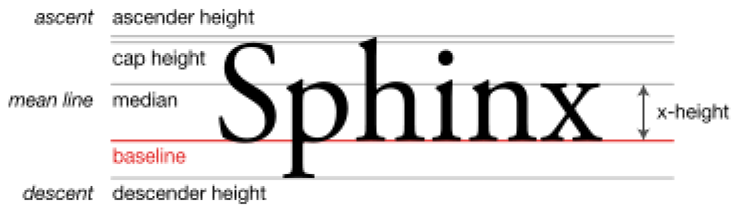

Figure 9. Capital letter size compared to font size [7].

As required in the WNTI standard [2], the global identification number will include four capital letters and no lowercase letters. The authors used Visio to conclude that 60 pt Arial capital letters and numbers are approximately 0.6 in. tall, and 44 pt Arial letters are approximately 0.44 in. tall, which is only about 72% of the height expected from the simple 72 pt:1 in. ratio.

Reading Range of Global Identification Number Text

Many ophthalmologists have used the Snellen chart, shown in Figure 10, to determine a patient's visual acuity. Snellen defined "standard vision" as the ability to recognize one optotype (character) when it subtended 5 min. of arc [8]. Based on this definition, someone with normal vision should be able to decipher 8.86 mm (0.35 in.) tall optotypes (characters) from a distance of 6 m (~20 ft).

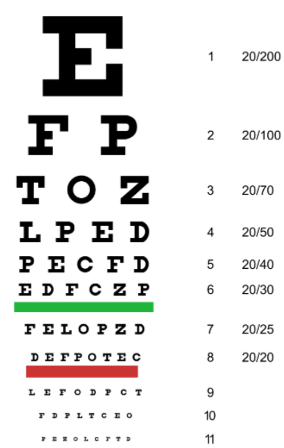

Figure 10. Snellen chart used to determine visual acuity [9].

As shown in Figure 11, following the Snellen definition, if characters are 0.6 in. tall, a viewer with normal visual acuity should be able to read them from a distance, D, when the character subtends at least 5 min. of arc.

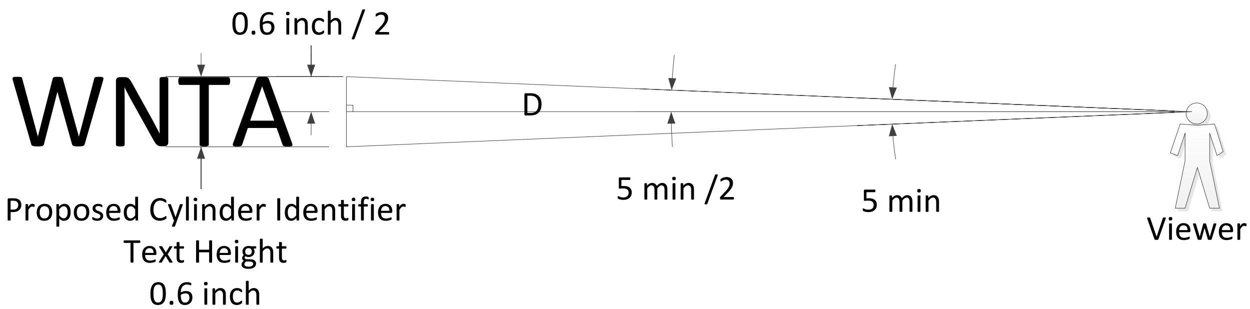

Figure 11. Visual acuity can be estimated.

The distance, D, can be solved for using simple trigonometry for a right triangle provided by Equation (1).

$$tan(\theta) = \frac{opposite}{adjacent} \rightarrow adjacent = \frac{opposite}{tan(\theta)} \quad (1)$$

Equation (2) holds for the global identifier with 60 pt Arial font (0.6 in. tall capital letters), suggesting that a viewer with normal visual acuity would be able to read the global identification number from about 48 ft away. Equation (3) holds for the proposed modified 30B and 48Y cylinder nameplate with the global identification number included using a 44 pt Arial font (0.44 in. tall capital letters), suggesting that a viewer with normal visual acuity would be able to read the global identification number from about 35 ft away.

$$D = \frac{\frac{0.6\ in.}{2}}{tan\left(\frac{5\ min.}{2}\right)} = 572\ in. \sim 48\ ft. \quad (2)$$

$$D = \frac{\frac{0.44\ in.}{2}}{tan\left(\frac{5\ min.}{2}\right)} 420\ in. \sim 35\ ft. \quad (3)$$

SUMMARIES AND CONCLUSIONS

In May of 2014, the WNTI formed a special working group to evaluate and develop a new standard for identifying UF_6 cylinders. Over the last few years this working group has been working to better understand how a global UF_6 cylinder identifier with machine-readable features would impact the industry. In June 2017, WNTI released a standard for UF_6 cylinder identification, which benefited from some of the work presented here.

Throughout 2016 and early 2017, ORNL investigated direct part marking techniques and barcode specifications that would be applicable for a new global UF_6 cylinder identifier. That testing evaluated how several COTS barcode readers performed when varying the size of the barcode, read distance, read angle, surface finish of the material, and marking technique. This research concluded that a 1.4 in. Data Matrix barcode laser etched with CerMark laser marking ink onto a ball blasted stainless steel plate would be very suitable for a UF_6 cylinder global identifier. The testing suggests that this size barcode could support the WNTI working group’s accepted use case (i.e., multiple COTS handheld barcode readers could read the barcode from an angle of up to 30° over the range of 10–100 cm).

To incorporate this size barcode into the new global identifier, the authors recommend using a 2.1 in. tall global identifier. Arial font should be used because of its distinct, easy-to-read characters and wide use for direct part marking applications. The authors suggest using 60 pt Arial font for the textual display of the global identification number on the global identifier. Viewers with normal visual acuity should be able to read this size font from about 48 ft. This size font would suggest the plate should be at least 8.1 in. wide to accommodate the widest possible global identification number.

To incorporate this size barcode into a modified cylinder nameplate that continues to be 5 in. wide, the 30B and 48Y would need to be 2.75 and 2.35 in. longer, respectively. Arial font should be used for the reasons stated above. The authors suggest using 44 pt Arial font for the textual version of the global identification number to fit in the remaining width on the 5 in. wide nameplate. Viewers with normal visual acuity should be able to read 44 pt Arial font from about 35 ft away.

ACKNOWLEGMENTS
This material is based upon work supported by the Department of Energy's NNSA Office of Nonproliferation and Arms Control (NPAC).

The authors would like to also acknowledge Jessica White-Horton's contributions to the barcode testing, which provided a solid foundation for this work.

REFERENCES

1. Stewart, S. L., et al., *Barcode and Direct Part Marking Considerations for Future UF_6 Cylinder Identification Standards*. ORNL.
2. World Nuclear Transport Institute, Standard for *UF_6 Cylinder Identification*. 2017, WNTI: London, United Kingdom. http://www.wnti.co.uk/media/87140/WNTI%20STANDARD%20-%20UF6%20Cylinder%20Identification%20-%20Version%20--%20Final%20-%202017.pdf
3. *LMM6000 Black for Metal (General Purpose)*. Available from: http://www.thermark.com/content/view/36/78/.
4. International Organization for Standardization, ISO/IEC 16022:206 *Information technology — Automatic identification and data capture techniques — Data Matrix bar code symbology specification*. 2006.
5. American National Standards Institute, *N14.1 Nuclear Materials — Uranium Hexafluoride— Packagings for Transport*. 2012.
6. *TrueType fundamentals*. 2017. 4 January 2017; Available from: https://www.microsoft.com/typography/otspec/TTCH01.htm.
7. Naylor, M., *Typography Line Terms*, T. L. Terms.svg, Editor. 2007.
8. Blackwell, C. *Calc Size of 20/20 Letter*. 2008; Available from: http://www.blackwelleyesight.com/eye-math/2020-letter/.
9. Dahl, J., *Typical Snellen Chart to Estimate Visual Acuity*, S. chart.svg, Editor. 2008.