Coated Glass Narrative:

<u>SLIDE</u> <u>1</u>
This presentation is the result of the collaboration of flat glass manufacturers – or as referred to in the glass and glazing industry, float glass manufacturers. The companies who participated in the development of this presentation are:

- AGC Glass Company
- Guardian Glass, LLC
- Pilkington North America, Inc.
- Vitro Architectural Glass

<u>SLIDE</u> <u>2</u>
GANA is a registered provider with the ***The American Institute of Architects Continuing Education Systems.*** This course on Coated Glass fundamentals is registered and accredited by the American Institute of Architects, and 1 CEU is awarded to architects for completing this presentation.

<u>SLIDE</u> <u>3</u>
The learning objectives for today's session include the following topics:

- Why glass is coated?
- Glass surface terminology
- Review of coatings for optical and solar performance
- Understand solar and thermal performance: common terminology
- Cost savings associated with using coated glass
- Special purpose surface modifying coatings
- A process overview of sputtered and pyrolytic coatings
- Review other uses of coated glass

Let's get started…

<u>SLIDE</u> <u>4</u>
The first question asked might be "why coat the glass at all?"

Coatings are designed to impart specific properties to the visible portion of the spectrum which is 380 to 780 nanometers, in terms of reflection and transmission, which are otherwise known as optical filters.

Coatings can significantly improve solar and thermal performance of the glass, without modifying the glass itself, by modifying the reflectance and transmittance properties of the glass.

There are also coatings that are designed to change the surface characteristics of the glass, examples are hydrophilic and hydrophobic coatings, and microscopically rough surfaces for light scattering.

SLIDE 5
Coatings may also serve as filters.

Coatings can change the transmission, reflection and absorption characteristics at different wavelengths of the solar spectrum, altering what the human eye perceives. Remember % transmission plus % reflection plus % absorption will always equal 100%. The visible appearance of the glass may be altered by:

- varying light transmission or,
- varying light reflection or
- changing the color of transmitted or reflected visible light in the visible spectrum.

Coatings can change solar and thermal performance of glass by:

- reducing the amount of the UV spectrum transmitted through the glass or,
- reducing the near infrared portion of the spectrum (which is felt as heat) that is transmitted through glass or
- reflecting far-infrared energy.

Basically, coatings can be designed to modify the look and thermal performance of glass.

SLIDE 6
Other uses for coatings include changing the surface properties of the glass in order to:

- Improve surface abrasion effects (for instance diamond-like coatings)
- Reduce the reflectivity for commercial, solar or lighting applications
- Improve resistance to chemical attack or create barrier layers to change the surface chemistry effects
- Change the surface effects of glass that is exposed to moisture, making it hydrophobic or hydrophilic (for instance low-maintenance glass).

SLIDE 7
Coatings can be applied to different surfaces of glass. For instance,

- Monolithic or one piece of glass has two surfaces available (those being the air side or upper side of glass that is made at a float glass plant and tin side, which is the bottom side of glass exposed to the tin bath).
- Laminated glass consists of two pieces of glass bonded together with an organic interlayer, and has 4 surfaces that are available for coatings, the outer surfaces and the inner surfaces bonded to the organic interlayer.

SLIDE 8
Perhaps the most important use of coatings is for insulating glass units – typically called IGU. If the IGU is double glazed it has two (2) glass lites with four (4) surfaces available for coating. If the IGU includes a laminated glass lite, or is triple glazed with three (3) lites, there are six surfaces available for coatings – all of which may impart different properties to the final IGU product.

SLIDE 9
This shows the surface numbers applied to a monolithic piece of glass. They are numbered surface 1 and surface 2 starting from the outside or weather side to the inside or interior of the building. Each piece of glass has two surfaces which get a number, no matter the construction.

SLIDE 10
Here is a typical laminated glass construction where the surfaces are numbered from 1 to 4 from the exterior to the interior of a building. The interlayer is not numbered.

SLIDE 11
This diagram depicts a typical dual pane Insulating Glass Unit, where the surfaces are numbered from 1 to 4, from the exterior to interior of a building. In this example, a low-e coating is located on surface #2. The cavity in the center is sealed and is not exposed to the outside air.

SLIDE 12
There are two widely employed methods for coating glass.

- Pyrolytic or hard coat glass is produced by APCVD method of condensing a chemical vapor on the hot glass surface within the float process.
- Sputtered glass coatings, sometimes referred to as soft-coat, are produced by the MSVD process in large area high vacuum coaters as a separate process to the float production. Metal and semi-conductor layers are alternatively layered upon the glass surface. Properties of the final glass product are highly controllable, including reflection, solar control, IR reflection, color, surface durability and other properties.

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SLIDE 13
Pyrolytic glass coatings start as liquid chemical compositions directly deposited on a very hot glass surface, usually in the tin bath or just after it. The coating is fused to the glass and imparts a very hard surface once cool.

SLIDE 14
Pyrolytic glass is produced in the APCVD (atmospheric pressure chemical vapor deposition) process incorporated into the float line. The chemical composition becomes molten on the surface of the hot glass forming a polycrystalline surface layer.

SLIDE 15
The pyrolytic coatings are metallic oxides, usually consisting of a fluorine doped tin composition that has electrical conductivity properties. As the coatings are fused to the glass surface they are very durable. The hard coating provides a surface that makes this type of glass easy to transport and store, and is readily heat strengthened or tempered.

SLIDE 16
Pyrolytic coatings are very forgiving in challenging environments, resisting corrosion. This type of coating can be specified for monolithic and Surface #1 use.

SLIDE 17
To summarize, pyrolytic coatings are known for their;

- Durability in a wide range of environments
- Shelf life
- Tempering ease with largely unchanged appearance
- Scratch resistance during processing
- Bendable
- Largely unaffected during the fabrication processes
- Moderate performance as low-E coatings
- Coatings can be used internally or externally in an IG or monolithically
- Often used in conjunction with tinted glass to improve solar performance.

SLIDE 18
Pyrolytic coatings are most often used where handling or environment are in question. They are also used where Solar Heat Gain is more important that U-factor.

SLIDE 19
The other major coating technology, widely known as sputtered coatings, or sometimes referred to as soft coat.

Sputtering is a process whereby an ionized gas molecule is accelerated toward a metallic or semi-conductor target material under high vacuum, the momentum of the gas molecule dislodges a target atom, which is transferred to the glass surface. The material being sputtered builds up atomic layer by atomic layer. A magnetic field is created to drive the ionized gas toward the target, which is the name of the process: Magnetron Sputtering.

SLIDE 20
There are two process variants used to sputter.

The first is known as non-reactive sputtering. In this case an inert ionized gas molecule is propelled toward a pure substance target, and the target material is deposited on the glass unchanged.

The second is known as reactive sputtering. In this case a reactive gas (like oxygen) is blended into the vacuum chamber, thereby causing a reaction with the metal atom as it passes from the target to the glass surface.

SLIDE 21
This picture depicts what is going on inside the high vacuum chamber of magnetron sputtering equipment. In general you can see the gas flows in through gas bars along the length of the target. The magnets mounted behind the target create a plasma zone which energizes the gas molecules in order to impart momentum high enough to knock the target atoms loose. On the bottom you can see the glass passing under the target, where the target atoms or molecules are building up.

SLIDE 22
There are benefits associated with sputtering.

- The key difference with pyrolytic coatings is the ability to engineer coatings layer by layer. Each layer having a specific purpose. This opens up a range of options to the coating engineer in order to enhance or suppress a given characteristic.
- The high performance sputter coatings can provide optimized solar control or low-E properties which maximize savings opportunities.
- They are spectrally selective in order to allow for daylighting applications.
- There are a range of products that can be cut, edge seamed and tempered from stock sheets.
- Another benefit is better control of the aesthetics of the glass in architectural applications.
- Finally, certain sputtered coatings are being designed to resist the abrasive effects that early coatings exhibited. This places them more into the realm of user friendly in terms of fabricating and even for monolithic and exterior IG surfaces.

SLIDE 23
Uses of sputtered coatings include:

- High performance coatings for commercial and residential buildings, specifically designed for thermal and aesthetic characteristics.
- Adjustable aesthetic properties to provide sharp optics with specific color rendering.
- Scratch resistant coatings for use in high traffic or interior applications.
- Moisture and soap scum resistance for use as shower enclosure.
- Heat treatable coatings – allowing for stock sheet cut down, edge treatment, tempering and lamination.
- Certain coatings can be bent.
- Good availability globally.

SLIDE 24
More uses of sputtered coatings are for:

- Moisture and soap scum resistance for use as shower enclosure.
- Heat treatable coatings – allowing for stock sheet cut down, edge treatment, tempering and lamination.
- Certain coatings can be bent.
- Good availability globally.

SLIDE 25

Coatings may be used to produce highly reflective surfaces or mirrors. Mirrors are the second most important coating after low-E coating.

In North America most mirrors are silvered mirrors, while in Europe aluminum was used until the mid-80's.

More than 900 million sq. ft. of mirror is produced each year.

SLIDE 26

Back side or second surface mirrors are produced using a wet coating process that employs mirror paint. The paint is applied as a wet film on the glass and then is dried in a furnace operation. Applications include interior and commercial mirror products, automotive and solar products like bent mirror reflectors.

SLIDE 27

Mirrors can also be first surface, which means the reflective coating surface faces the eye. First surface mirrors are produced by sputtering highly reflective coatings such as chrome or aluminum onto the glass surface. Applications of first surface mirror include the electronic equipment, solar and automotive markets.

SLIDE 28

A chemical reduction method known as "electroless plating" is used to apply copper and silver. The chemicals are applied through a spraybar onto the glass surface. Many metals can be deposited using this method but silver is the most common.

SLIDE 29

First surface mirrors can be produced in a large area vacuum sputtering coater. Metal targets such as aluminum or chromium are used within the coater to sputter ultra-thin metal layers onto the glass surface. As a first surface product, a double reflective image is avoided when compared to the second surface mirror – which means most of the visible light is directly reflected which equates to a higher percentage of reflected light.

SLIDE 30

Another method of producing first surface mirror is by using the APCVD or pyrolytic method within a float furnace. This particular coating is sometimes referred to as hard-coat glass. A pyrolytic reflective product is partially reflective, allowing visible light transmission such as two-way or transparent mirror applications.

SLIDE 31

The purpose of transparent mirrors is to create an environment that allows for unobtrusive observation. These are used in interior settings and are primarily used when discreetness is necessary.

SLIDE 32

More examples of two-way mirror include uses such as focus group observation, police line-up, security and surveillance applications.

SLIDE 33

How can the glass be modified with coatings? Coatings are designed to impart various properties to glass such as for solar control, reflected color, visible effects and low E or infra-red reflection aspects.

SLIDE 34

There are many coating products designed to impart a wide variety of visual and thermal aspects to glass. Coatings are used to improve thermal and solar performance, control heat transfer through the glass with low-E coatings and impart aesthetic changes to visible light such as color and reflectivity.

SLIDE 35

Glass properties are altered with the addition of a coating. Generally this can be thought of in terms of adding value to the glass product in some way. Coatings are designed and manufactured to impart a change to the performance of standard float glass types, and are generally manufactured by two processes, the APCVD or pyrolytic process on a float line, and sputtered off-line in an MSVD or large area vacuum coater. Two important products are reflective and low-E glass.

SLIDE 36

There is a reason that window and door manufacturers' offer coated glass in their products. Studies show that fenestration products represent the greatest heat losses in a building. This pie chart shows typical residential heat loss, with fenestration accounting for 41% of the dwellings heat loss. Considering that energy is becoming more expensive, conserving it is one way for the building owner to save money. The product most used to conserve energy loss through glass is a low-e product.

SLIDE 37

Low-e glass is designed for a thermal performance improvement. Low-e glass used in fenestration products improves its U-value. This improvement works in two ways. It can limit the amount of solar heat gain into a building in the summer in southern climates, or it can reflect heat back into a building in the winter in northern climates.

SLIDE 38

Low-e glass is designed to allow daylight to be transmitted into the building at a specified amount or percent transmission known as visible light transmission. Low-e glass also blocks a certain percentage of UV transmission – which can be damaging to furnishings and interior surfaces.

SLIDE 39

A certain amount of solar energy is transmitted through the fenestration product to the interior of the building. The coating design engineer has the ability to impart changes to the glass properties such as:

1. Visible light transmission or VLT which affects daylighting amount and glare.

2. UV transmission (damage to surfaces, flooring and fabrics)

SLIDE 40

The coating design engineer also has the ability to impart changes to:

- IR transmission (heat)
- As noted here, total Solar Energy Transmission is the sum of UV, VLT and Near-IR wavelengths passing through the coated glass.

SLIDE 41

Solar energy is the energy transmitted in the range of 300 to 2500 nanometers. Solar transmittance is defined as the percentage of ultraviolet, visible and near infrared energy within the solar spectrum that is transmitted through the glass. This describes how much UV, visible and Near-IR energy is allowed inside a building through its glass. Solar energy can be transmitted, reflected, or absorbed by the glass.

SLIDE 42

Emittance refers the amount of heat a surface can radiate. A so-called perfect **black body** can emit heat at a value of 1. A perfect non-radiant product would thus have a rating of 0. Low-e glass is designed to have as low a value as possible. High performance low-E glass products have been designed to have an emissivity of less than 0.04.

U-factor (sometimes referred as U-value) is a calculation of the amount of heat conducted through a material or series of materials. The lower the number the better the material or assembly is at blocking heat transfer. For instance, standard float glass has a U-factor close to 1 Btu per hour - foot squared - degree Fahrenheit, whereas a high performance low-e product used in a well-designed dual pane IG construction can improve U-factor significantly, up to 4 times better!

SLIDE 43

R-value is the inverse of U-value. It is usually used to measure and denote a low thermal conductive building material such as fiberglass insulation. The higher the number, the better the material is at reducing heat transfer.

Solar heat gain coefficient is the ratio of solar heat gain entering the space through the fenestration product to the incident solar radiation. It includes directly transmitted solar heat and absorbed solar radiation, which is then re-radiated, conducted or convected into the space. More simply put, it is a ratio that includes directly transmitted solar heat and re-radiated absorbed solar radiation.

Shading coefficient is a measure of the heat gain through glass from solar radiation. Specifically, the shading coefficient is the ratio between the solar heat gain for a particular type of glass and that of 1/8" thick clear glass. In effect, the lower the number, the better the performance. 1/8" clear glass would have a shading coefficient of approximately 1.

SLIDE 44

Light-to-solar gain ratio identifies a product's visible light transmitted divided by its solar heat gain coefficient (SHGC).

Relative heat gain (RHG) is a measure of solar gain combined with a product's U-value or conductive heat gain.

SLIDE 45
This illustrates the typical improvements over several factors which are possible by incorporating a low-e coated glass into a fenestration product.

SLIDE 46
This slide shows the electromagnetic spectrum. Most of us think of visible light as a color rainbow. However, we are all aware of UV light (tanning bed) or short wave IR (your home oven). The visible spectrum is just a thin slice of the overall spectrum.

Of the electromagnetic spectrum, the solar spectrum consisting of the ultraviolet, visible and near infrared energy is from about 300 to 2500 nanometers.

The visible light spectrum as seen by humans is from 380 to 780 nanometers.

SLIDE 47
This graph shows the visible spectrum (the rainbow arrow) and the transmission effects of a sputtered coating with a single, double and triple silver layer.   The sputtered coating with silver layers allows MOST of the visible light to be transmitted; however transmission of UV and IR is greatly reduced. If it is not transmitted – it means it is absorbed or reflected back to the source environment.

SLIDE 48
This graph represents the reflective properties of sputtered low-e coatings made up of single, double and triple silver layers.

SLIDE 49
This is the Energy Star map version 6 for the US as of November 2017. The US and Canadian Energy Star program is utilized by the commercial and residential markets as a value proposition or product differentiator. Different fenestration products are designed for a given region and performance requirements, or may be designed to be universally used in any region. Low-e coating provide a means to obtain the energy requirements of a given region.

SLIDE 50
The northern region is driven by U-value performance and if possible high solar heat gain in the farthest north. Products are driven by best thermal performance or U-value below 0.27 and in general high solar heat gain – but without a specific requirement. Low-E coatings may be specified for the 3rd surface to improve SHGC. Additionally in the coldest regions, a surface four coating may be specified to further improve thermal performance.

SLIDE 51
The north central region includes both heating and cooling loads, so is neither dominated by U-factor or solar heat gain requirements. In general, a good U-value of less than 0.3 and medium SHG below 0.40 are required.

SLIDE 52
The south central region includes heating - but consists mostly of cooling loads, so is neither dominated by U-factor or solar heat gain requirements. In general, a good U-factor, less than 0.30, with a better SHGC value below 0.25 is required.

SLIDE 53

The southern region is dominated by cooling load. U-factor is not dominant with a requirement of 0.40 or lower. Rather a low SHGC is required at less than 0.25. Low SHGC may mean sacrificing visible light transmission; however, lower levels of light transmission to reduce glare in a building may be desirable.

SLIDE 54

In summary,

- Low-e coatings are now required across all climate zones, to either help meet low SGHC requirements in the South, or the low U-factor requirements in the North.
- Low-e coatings are necessary to economically produce glazing products which meet code requirements that become ever more stringent.
- The commercial market continues to utilize an ever expanding line of low-e products which provide an ever increasing level of performance.
- Rising energy costs drive performance enhancements in glass products; however, the downstream channel including the building owner are often uninformed about what the coatings are and how they can best be specified and used.

SLIDE 55

This section will address a building energy savings simulation that compares high performance fenestration product use.

SLIDE 56

The building being simulated is located in Chicago and Miami – with the properties as shown.

SLIDE 57

6mm monolithic clear float glass is to be compared with 6mm clear / 6mm clear IG and 6mm coated / 6mm clear IG combinations.

SLIDE 58

This chart shows a performance comparison for various glazing options. Different applications and different regions of the country use different combinations of glass in the IGU to maximize the benefits desired. For instance, the chart shows that a double silver sputter coated glass in an IGU provides the best U-factor with a fairly high visible light transmission.

The numbers referenced on the vertical axis will be used again in subsequent slides.

SLIDE 59

The cost saving components that can be applied to the example building include:

- A smaller HVAC system can be specified, thereby saving capital costs.
- Reduced electrical consumption for cooling.
- Reduced natural gas consumption for heating.

SLIDE 60

This shows the one-time cost savings for a specified HVAC system for various types of glass for a building in Chicago versus the same building in Miami.

#4: Medium Light Transmission Single Silver Low-E
#6: Med-Low Light Transmission Single Silver Low-E
#3: High Light Transmission Double Silver Low-E
#5: High Reflectance, Med. Transmission Single Silver Low-E
#7: Low Light Transmission Reflective/Solar Control

For Chicago, the biggest savings in HVAC cost is associated with choosing a low solar gain, reflective type sputtered coating which is calculated at $28,000. For comparison, the one-time savings over choosing a typical double silver low-E sputtered coating is 40%.

By contrast, for the building in Miami, any coating provides a decent savings in a cooling dominated region, but again the highly reflective low solar gain coating provides the biggest savings.

SLIDE 61
Annual energy savings for both buildings is compared. It can be seen that there is a bigger gain possible in a cooling dominated climate, as the cost for cooling is greater when compared to the cost of heating.

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#3: High Light Transmission Double Silver Low-E
#5: High Reflectance, Med. Transmission Single Silver Low-E
#7: Low Light Transmission Reflective/Solar Control

In Chicago the best thermal performance is obtained by specifying a single silver solar control sputtered coating, however, light transmission is reduced.

For Miami, the best performance comes from specifying a typical high performance solar control sputtered coating which significantly cuts down solar gain.

SLIDE 62
This chart shows the 10 year return based on both the one-time HVAC capital expense savings and energy savings. It should be clear that the annual energy savings dominates the total savings.

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#3: High Light Transmission Double Silver Low-E
#5: High Reflectance, Med. Transmission Single Silver Low-E
#7: Low Light Transmission Reflective/Solar Control

In Chicago the best performance is obtained by specifying a single silver solar control sputtered coating for a total savings amount of over $115,000.

For Miami, the best performance comes from specifying a typical high performance solar control sputtered coating which provided a total 10 year savings of over $196,000.

SLIDE 63

From the previous results, it should be clear that specifying the right coating can yield a decent return on incremental investment. Balancing performance with aesthetics is a decision that can be made in conjunction with the glass supplier.

This example shows that choosing a high performance double silver low-E sputtered coating for Chicago yields an annual savings of $8600 and provides a payback period of 2.3 years. The same building in Miami with a Single Silver Solar Control low-E sputtered coating provides a calculated annual savings of $13,100 and has a payback period of 1.2 year.

SLIDE 64

As a summary,

- Tremendous energy cost savings are realized by specifying high performance coatings.
- The ROI can be further improved by specifying a tinted lite in place of the clear lite.

SLIDE 65

There are other coatings that can provide benefits over uncoated glass. A Diamond-like Coating (DLC) imparts characteristics that include abrasion resistance, hydrophobic or hydrophilic properties.

SLIDE 66

DLC coatings have been optimized for shower enclosures to reduce the amount of soap scum and other shower products from sticking to the glass surface, making it easier to clean.

SLIDE 67

One of the properties of glass is that there are alkaline earth ions throughout its amorphous structure. When the glass is exposed to moisture, these ions are drawn out of the glass to the surface and create compounds which stain the glass surface affecting light transmission. Surface of glass can also be affected by concentrated bases such as sodium hydroxide or hydrofluoric and phosphoric acid.

Coatings can be applied to the glass surface to protect it from the above affects.

SLIDE 68

UV coatings can help protect interiors from the sun's action of bleaching and fading of colors and actually destroying organic compounds.

SLIDE 69

There are coatings which are designed for exterior applications that impart low maintenance aspects to the surface. There is a photo-chemical effect and a surface tension effect.

SLIDE 70

Low maintenance glass products employ photocatalytic properties which in combination with moisture and UV radiation from the sun decompose organic materials that are on the surface.

UV radiation is reflected from many surfaces and is also present on cloudy days – so the process is working most of the time.

SLIDE 71

The surface properties of low maintenance products can impart a sheeting or droplet action when moisture is present. The hydrophilic property of these coatings causes the decomposed residue to be washed off the glass surface – for instance during a rain. This sheeting action also helps the glass dry faster and with fewer droplet spotting or streaking.

SLIDE 72

This picture depicts the difference between normal droplet formation on the glass and the hydrophilic action of low maintenance glass.

SLIDE 73

In summary the features of low maintenance glass include:

- A photocatalytic action to decompose organic materials that are on the glass surface.
- A hydrophyllic action that sheets water to allow for better cleaning affect
- Durable surface
- Some improvement in thermal and optical properties versus clear glass

SLIDE 74

The benefits of low maintenance glass include:

- The breakdown and loosening of organic dirt over time on the coating surface.
- A sheeting action that allows for better rinsing
- Faster surface drying with minimized spotting
- Reduction in UV transmittance.
- Potential reduction in SHGC.

SLIDE 75

Here is a depiction of the sheeting action of low maintenance glass on the right compared with conventional uncoated glass on the left.

SLIDE 76

There are resources available to learn more about coated glass

- *Glass Informational Bulletins*
- *Glazing Manual*
- *Laminated Glazing Reference Manual*
- *Specifiers Guide to Architectural Glass*
- *And of course your coated glass supplier*

SLIDE 77

Of course there are many resources on the web, including:

- The Insulating Glass Manufacturers Alliance *www.igmaonline.org*
- American Architectural Manufacturers Association *www.aamanet.org*
- ASTM International *www.astm.com*
- National Glass Association *www.glass.org*

SLIDE 78

There are several Software resources available to manufacturers and fabricators. They include:

- The International Glazing Database (IGDB)
  - Optics
  - RESFEN
  - THERM
  - WINDOW
    - From Lawrence Berkley Labs at www.windows.lbl.gov

Also check with your glass supplier – they have many programs available to customers which incorporate the properties of their specific coated glass products into design programs.

SLIDE 79

This is a reminder of the objectives we intended to address today.

- Why glass is coated
- Glass surface terminology
- Descriptions of coatings for optical and solar performance
- Solar and thermal performance and associated terminology
- The cost savings benefits of employing coated glass in buildings
- Surface modified coatings
- The glass sputtering and pyrolytic coating processes
- Other types and uses of coated glass

Are there any questions?

SLIDE 80

Again, this course on Coated Glass fundamentals is registered and accredited by the American Institute of Architects, and 1 CEU is awarded to architects for completing this presentation. Be sure to complete the sign-in sheet if you haven't done so already. Provide your AIA # if you wish to receive credit, and also mark the appropriate column to indicate if you wish to be emailed a PDF certificate from GANA.

SLIDE 81

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