IMEKO International Measurement Confederation

Technical Committee TC10 Testing, Diagnostics & Inspection

Scalable Computed Tomography analysis for Additive Manufacturing

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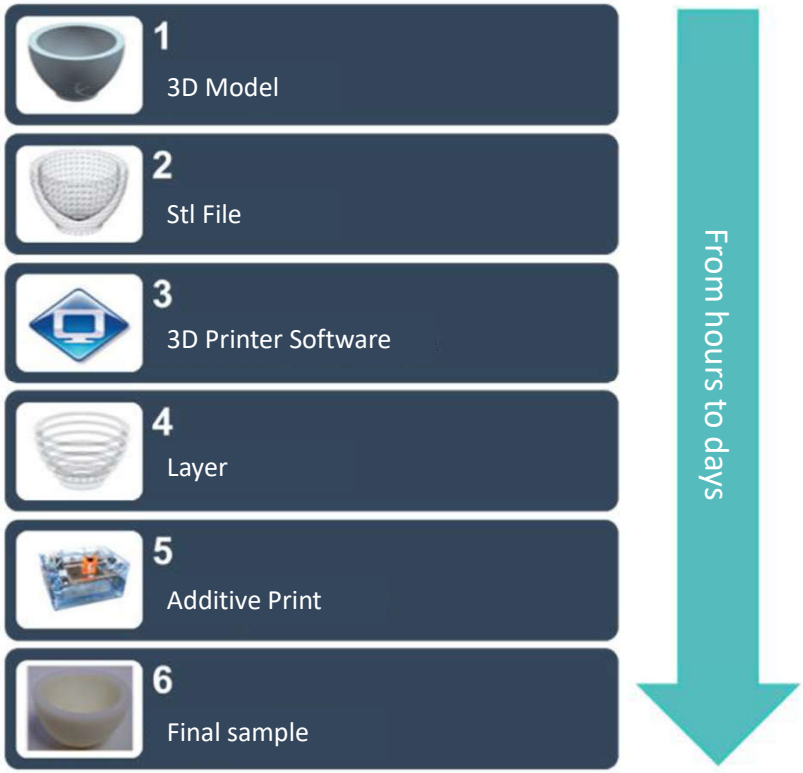
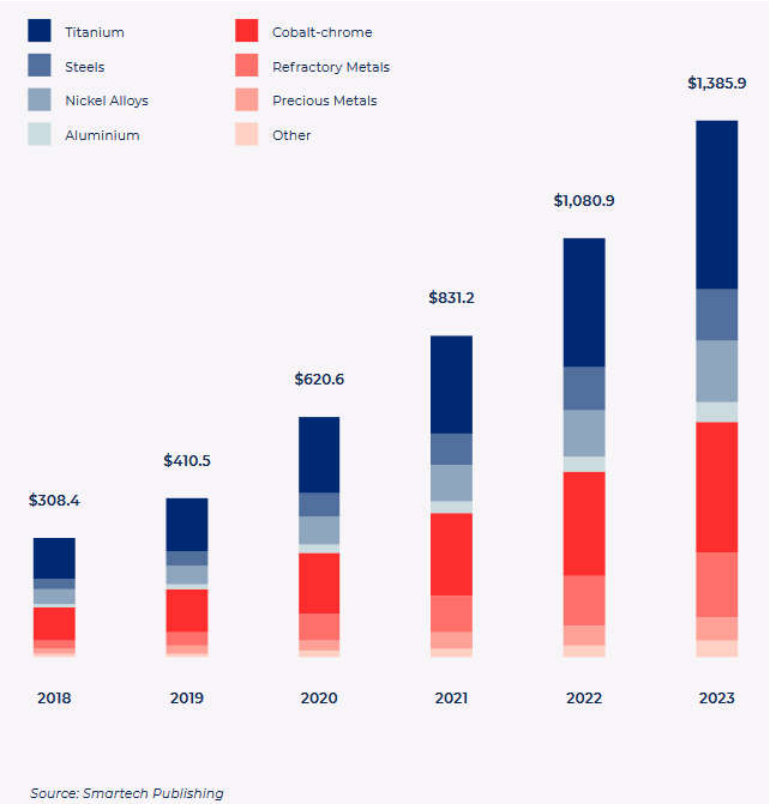
ADDITIVE MANUFACTURING: ESSENTIAL

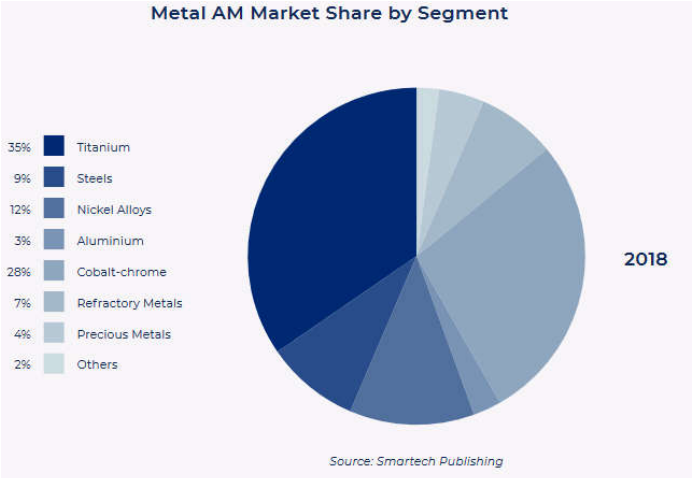
How It works?: Additive Manufacturing (AM) is an appropriate name to describe the technologies that build 3D objects by adding layer-upon-layer of material, whether the material is plastic, metal, concrete or others. Common to AM technologies is the use of a computer, 3D modeling software (Computer Aided Design or CAD), machine equipment and layering material. Once a CAD sketch is produced, the AM equipment reads in data from the CAD file and lays downs or adds successive layers of liquid, powder, sheet material or other, in a layer-upon-layer fashion to fabricate a 3D object[1].

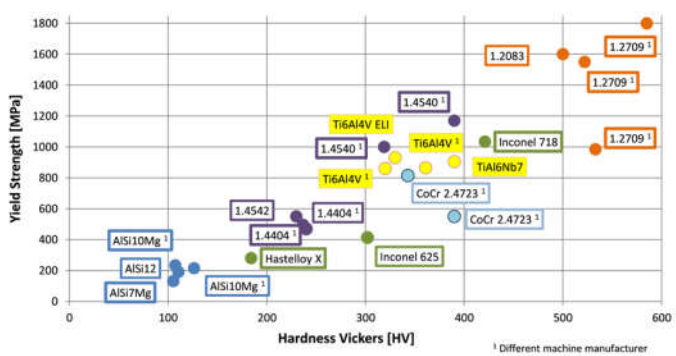


[1]http://additivemanufacturing.com/basics/

ADDITIVE MANUFACTURING: MATERIALS







More than 40% of used materials are high density materials

https://www.smartechanalysis.com/wp-content/uploads/2018/11/3dpbm-x-smartech-am-opportunities-in-metal.pdf

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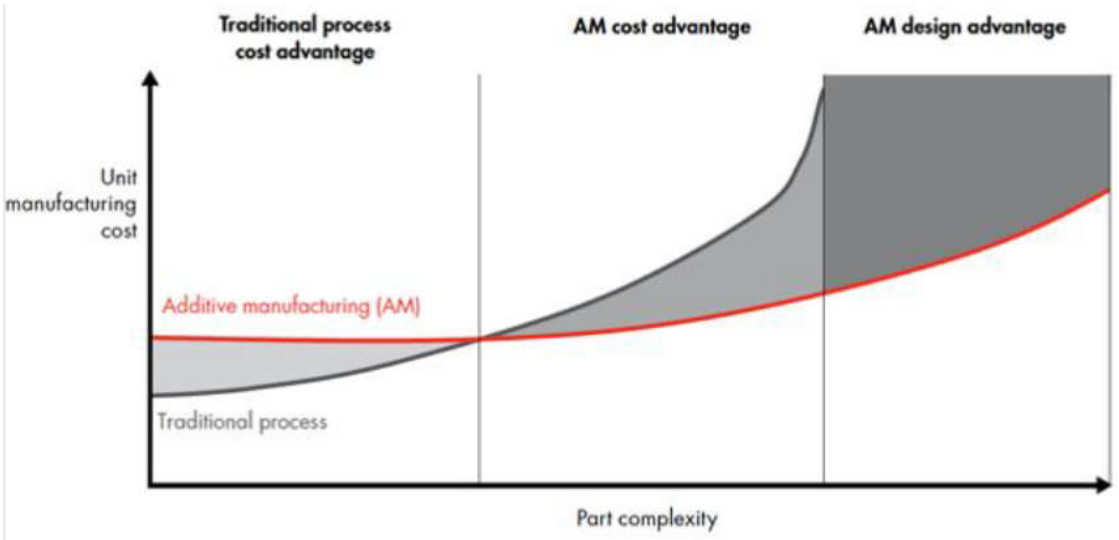
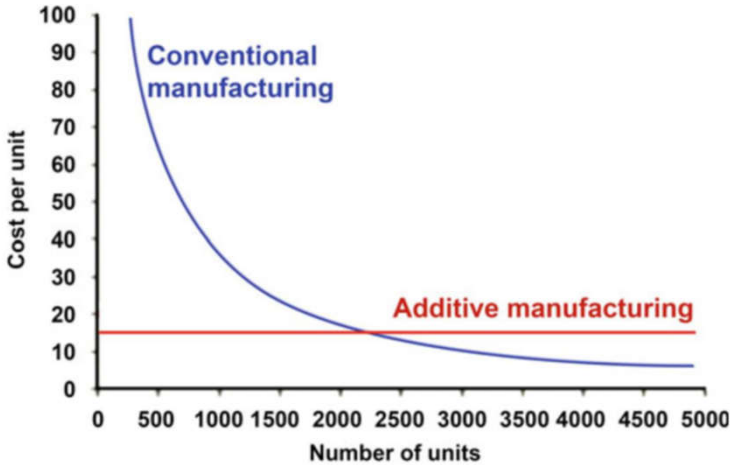
ADDITIVE MANUFACTURING: ADVANTAGES





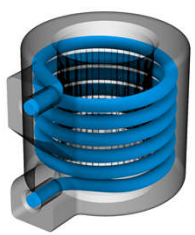


Image courtesy of EOS

How can we inspect these complex components?

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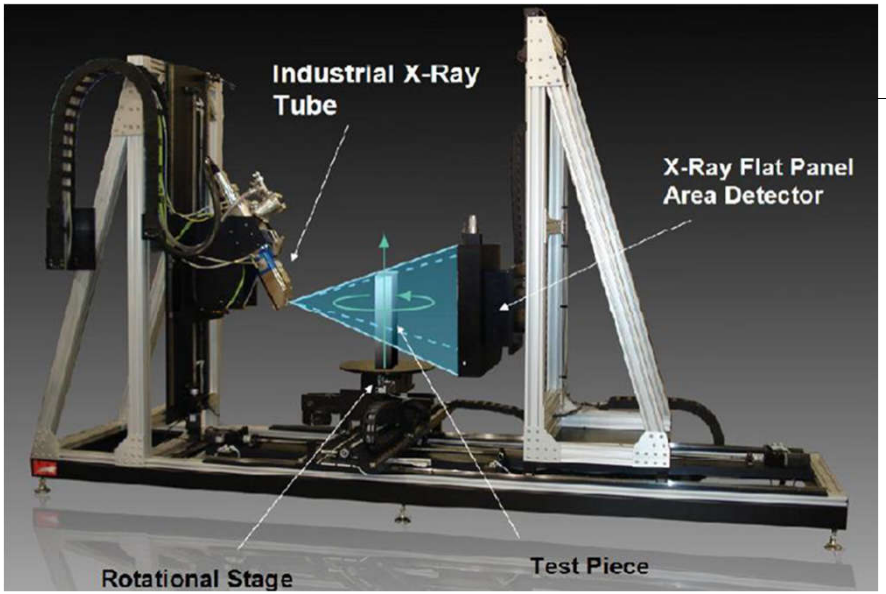
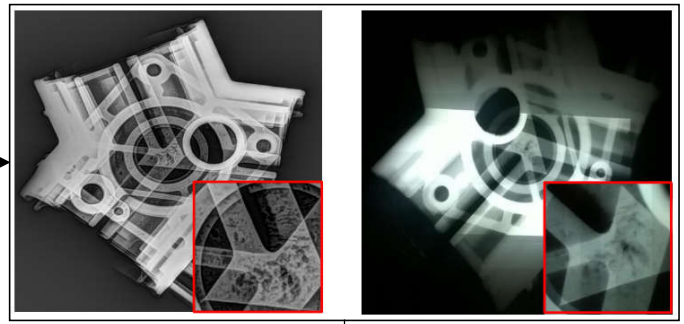
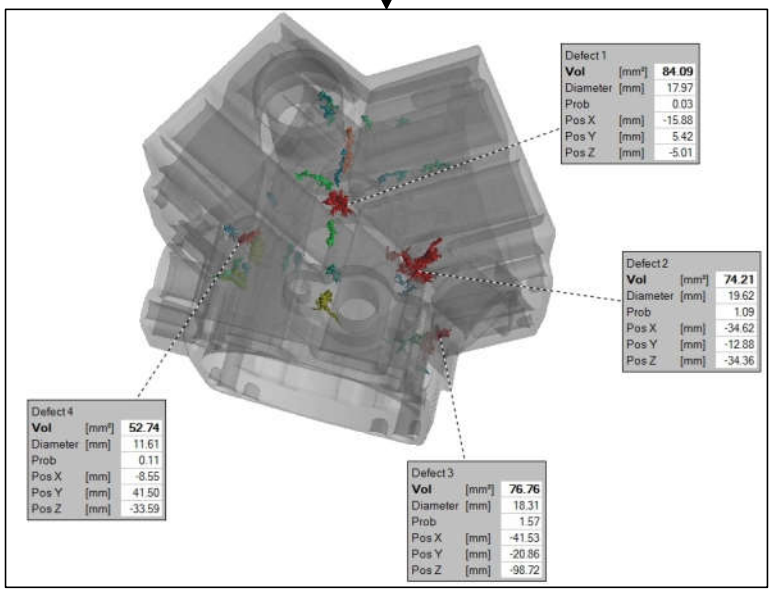
CT SCAN: ESSENTIAL



From standard Radiography



To CT Scan



How It works?: During a CT Scan, multiple projections are taken in a systematic way: the images are acquired from a number of different viewing angles obtained with the rotation of the sample. It's possible to obtain radiographic imaging because different materials have different X-ray attenuation coefficients and the X-ray linear attenuation coefficients are represented as different CT grey values. From these value it's possible to obtain a virtual 3D volume of a sample via reconstruction algorithms

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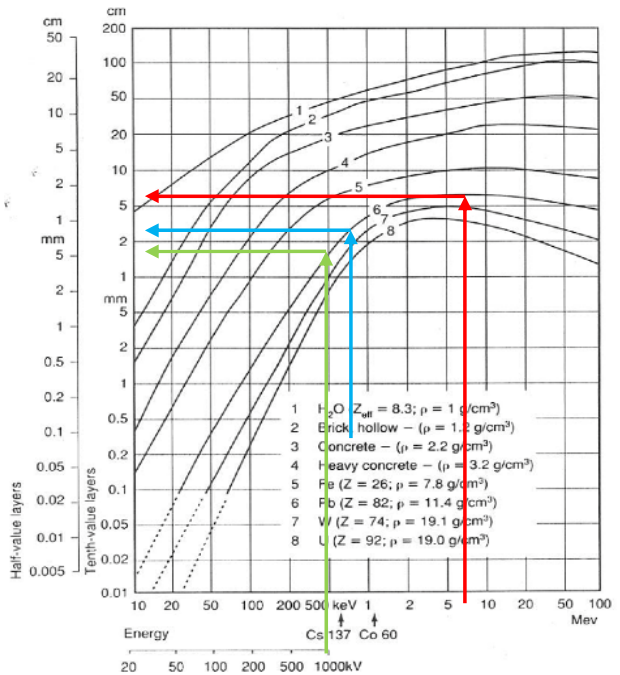
SOLUTION… D7 6 MEV LINAC



Manipulator:	6-Axes granite-based
Variable FDD:	1500 – 4000 mm
Scanning envelope:	D = 1000 mm, H = 2000 mm
Max payload:	200 kg
Max dose rate:	2.5 Gy/min @ 3 MeV, 9.0 Gy/min @ 6 MeV
High resolution Line Detector Array:	length 600 mm, pixel pitch 200 µm
3K Flat Panel Detector 4343 HE:	active area 417 x 417 mm, pixel pitch 139 µm

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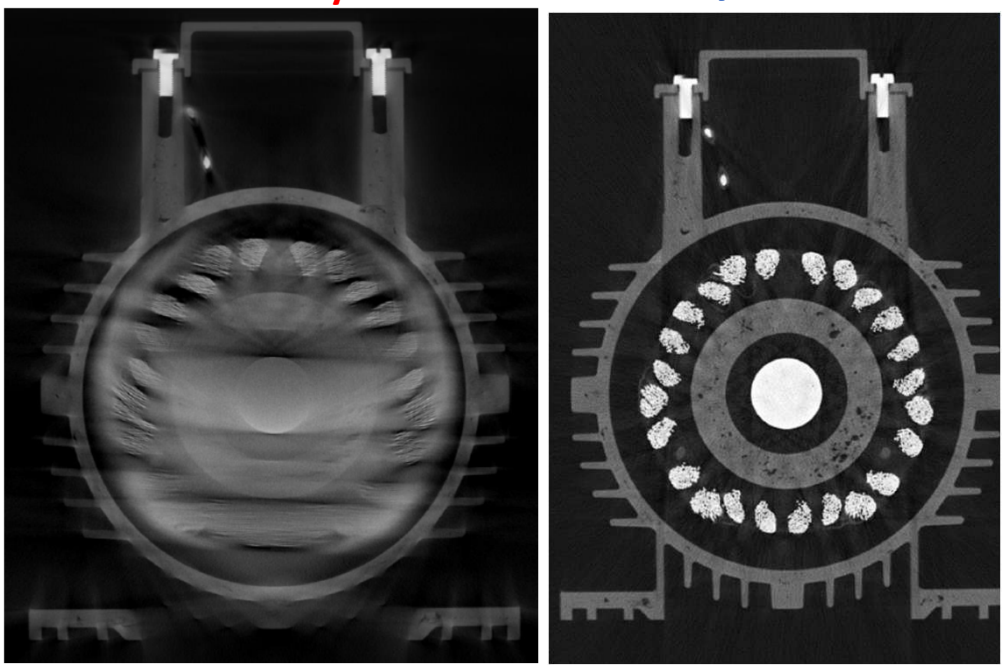
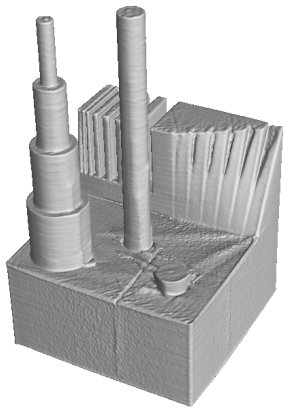
SCALABLE COMPUTED TOMOGRAPHY ANALYSIS FOR ADDITIVE MANUFACTURING

450keV X-ray tube CT System

6MeV LINAC CT System

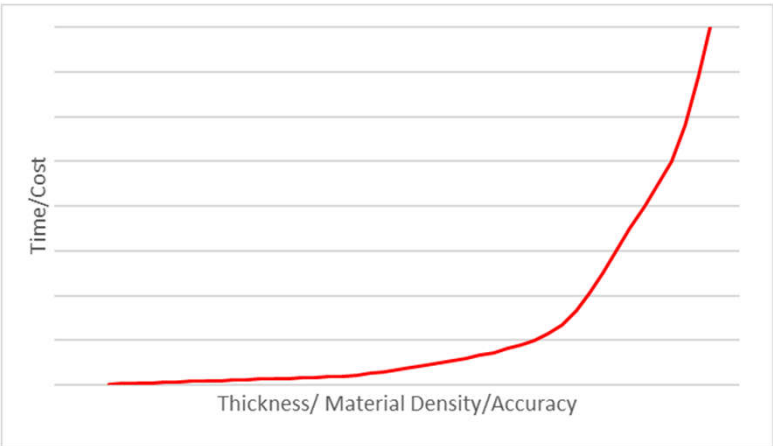


Electric Engine



Sample made by additive manufacturing in INCONEL 718

BUT EVERYTHING ISN'T GOLD



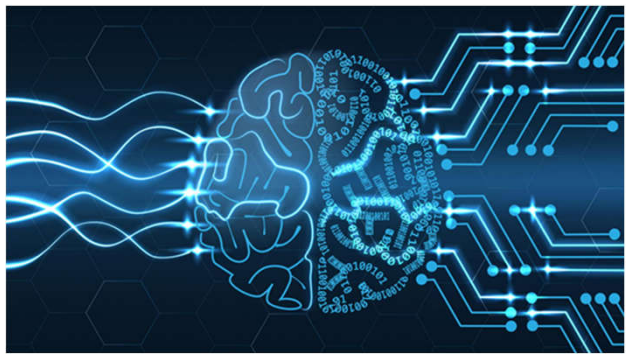
Increasing thickness of the sample, density and accuracy will increase the time for a scan, the time for the 3D Volume inspection (both defect and metrology analysis) and the costs. But this isn't a problem with prototype sample or R&D in general. This is a big problem when we need to perform a recurrent inspection in the production phase of a sample made by Additive Manufacturing or a standard process.

SOLUTION

AUTOMATION OF THE SYSTEM

SOFTWARE:
MACRO & BATCH PROCESSING

AUTOMATION OF THE PROCESS



AI FOR DEFECT ANALYSIS

Tomographic Systems @ TEC Eurolab

2013

NSI X5000 CT SYSTEM
Scan volume: D = 500 mm, H = 1200 mm
Max payload: 90 kg
Max resolution: 5 µm

SOURCE: X-Ray WorX 240	
X-Ray Tube Typology	Open, microfocus
Maximum Voltage	240 kV
Maximum Power	350 W
Focal Spot Size	5 µm

FLAT PANEL DETECTOR: Varian 2520 DX	
Pixel pitch	127 µm
Sensible Surface	250x200 mm
Maximum Acquisition Speed	12.5 fps - 30 binning
Greyscale resolution	16 bit
Scintillator	Cesium

2016

NSI X7500 CT SYSTEM
Scan volume: D = 1500 mm, H = 3000 mm
Max payload: 250 kg
Max resolution: 70 µm

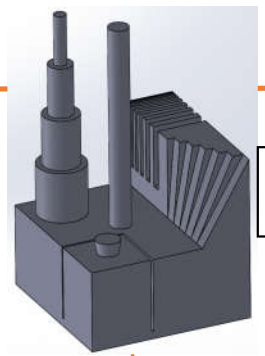
SOURCE: Varian HPX 450-11	
X-Ray Tube Typology	Closed, minifocus
Maximum Voltage	450 kV
Maximum Power	1500 W
Focal Spot Size	0.4 mm

FLAT PANEL: PE XRD 1621 AN14 ES	
Pixel pitch	200 µm
Sensible Surface	400x400 mm
Maximum Acquisition Speed	15 fps - 30 binning
Greyscale resolution	16 bit
Scintillator	DRZ + (Gadox)

LDA: Detection Technology 0.4iHE2-922	
Pixel pitch	400 µm
Length	92 cm
Integration time	30-1550 fps

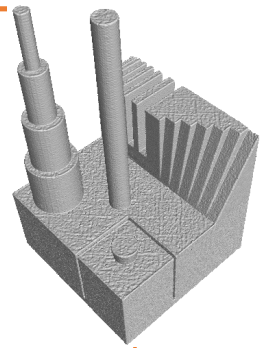
NORTH STAR IMAGING NSI AN ITW COMPANY

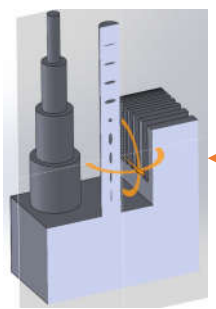
System performance comparison: an example

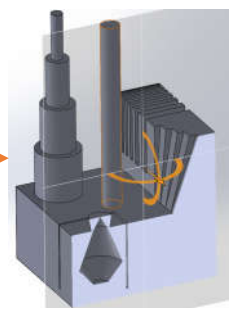


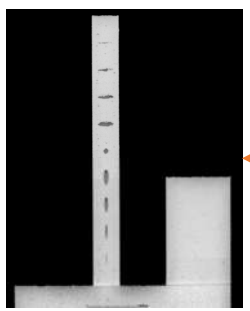
Stampa 1:
AlSi12

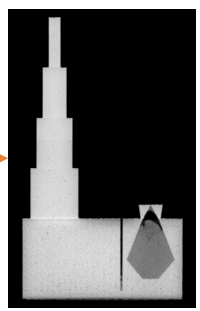
CT Scan:
X7500 System











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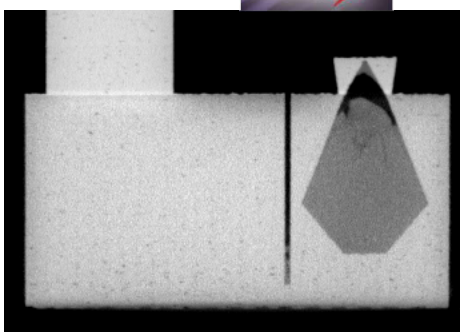
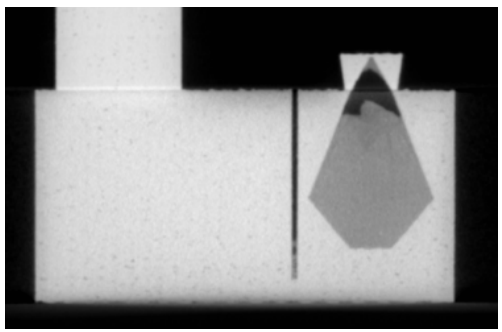
System performance comparison: an example

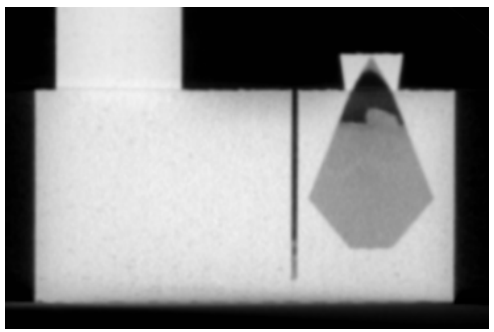
35 µm

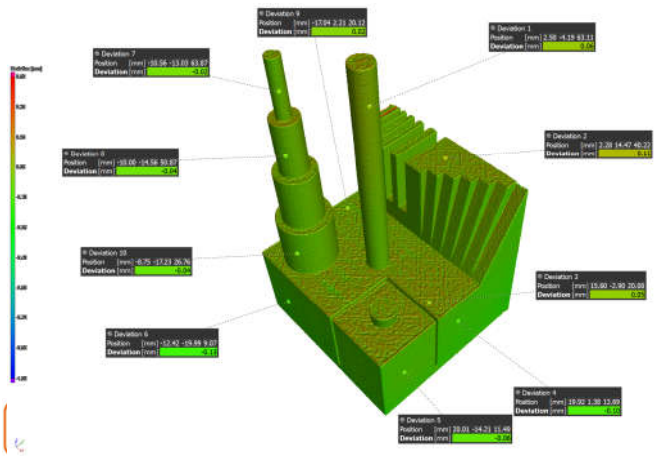


70 µm

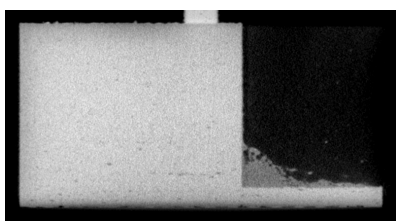


150 µm



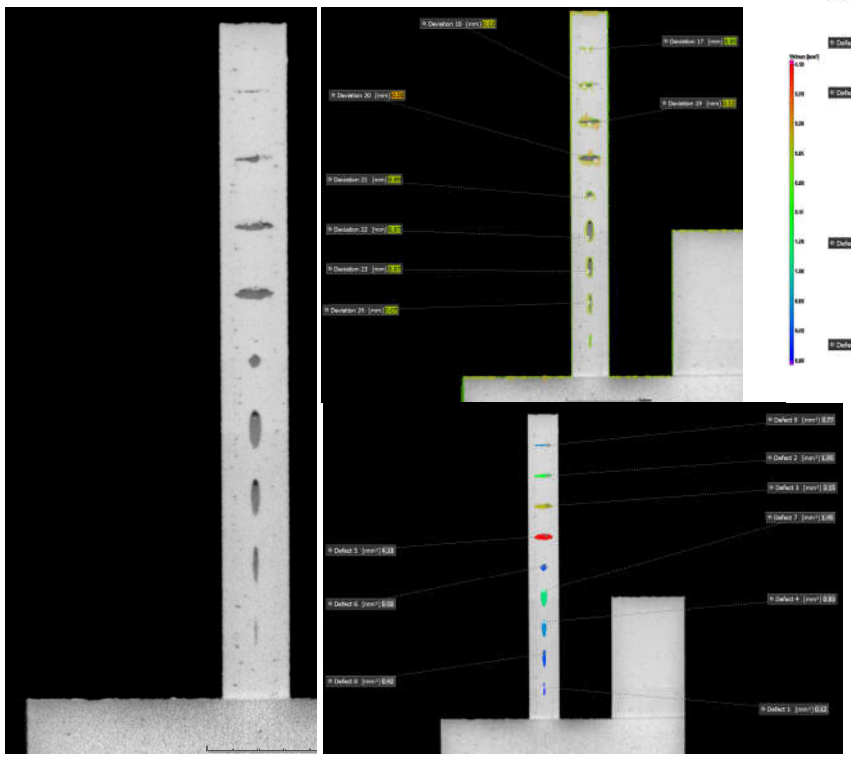


CAD Comparison analysis

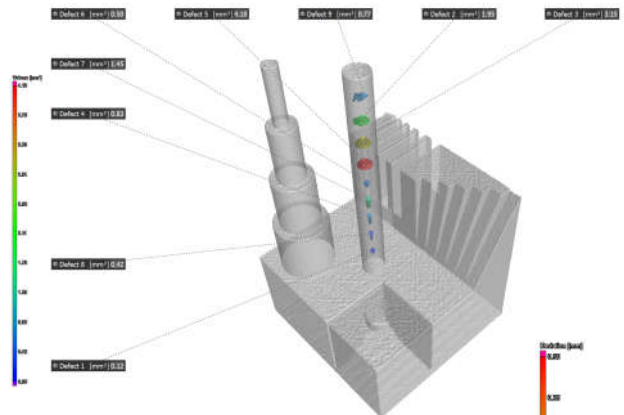


Residual powder

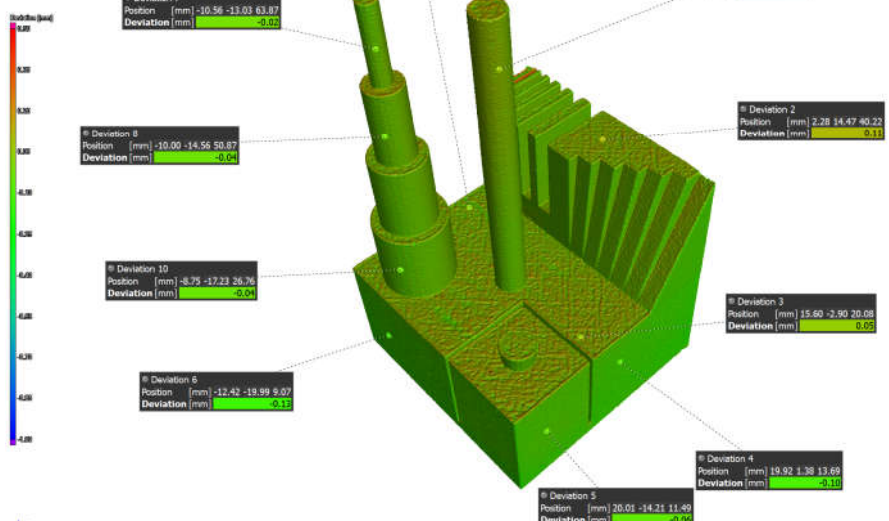
System performance comparison: an example



POROSITY ANALYSIS



CAD COMPARISON



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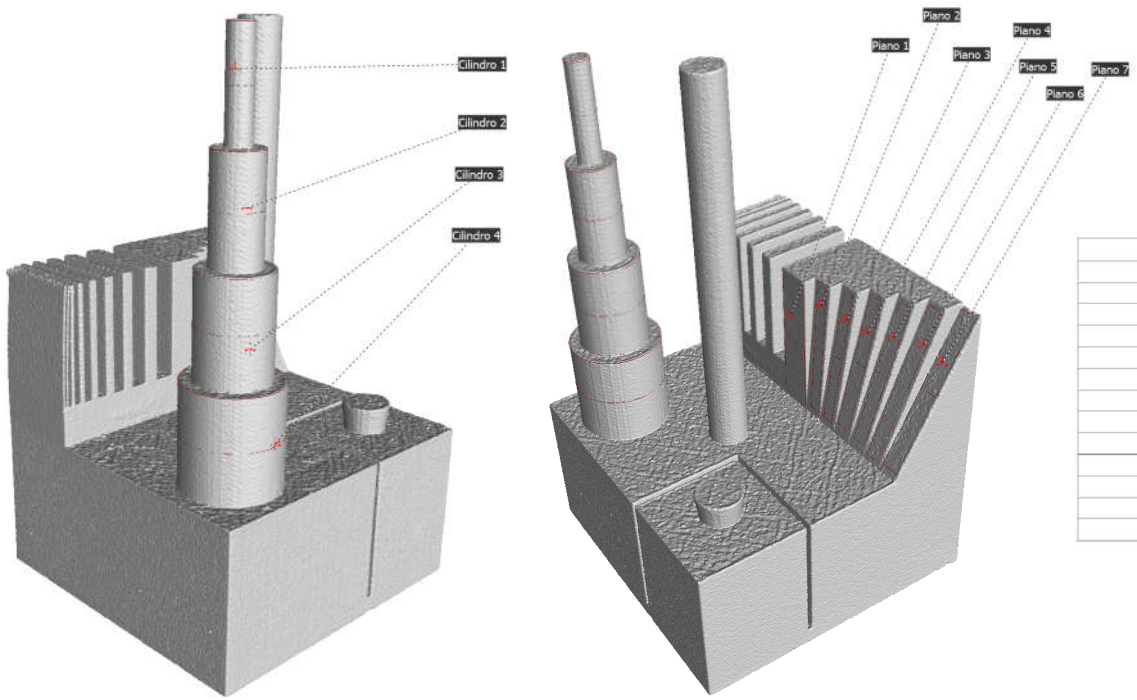
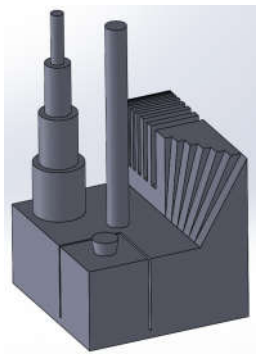
System performance comparison: an example

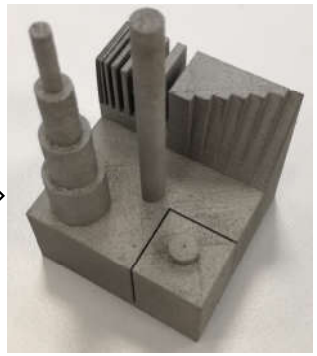


Name	Type	Source A	Act. value [mm/deg]
Feature 1	Diameter	Cylinder 1	3.01 mm
Feature 2	Diameter	Cylinder 2	6.00 mm
Feature 3	Diameter	Cylinder 3	8.99 mm
Feature 4	Diameter	Cylinder 4	11.97 mm
Feature 5	Coaxiality	Cylinder 2	0.09 mm
Feature 6	Coaxiality	Cylinder 3	0.19 mm
Feature 7	Coaxiality	Cylinder 4	0.23 mm
Feature 8	Angle	Plane 2	4.99 deg
Feature 9	Angle	Plane 3	9.99 deg
Feature 10	Angle	Plane 4	14.98 deg
Feature 11	Angle	Plane 1	19.96 deg
Feature 12	Angle	Plane 1	24.93 deg
Feature 13	Angle	Plane 7	30.88 deg

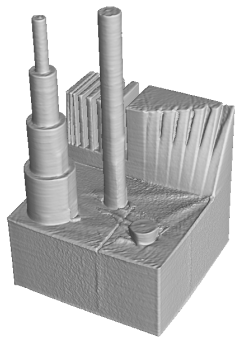
System performance comparison: an example

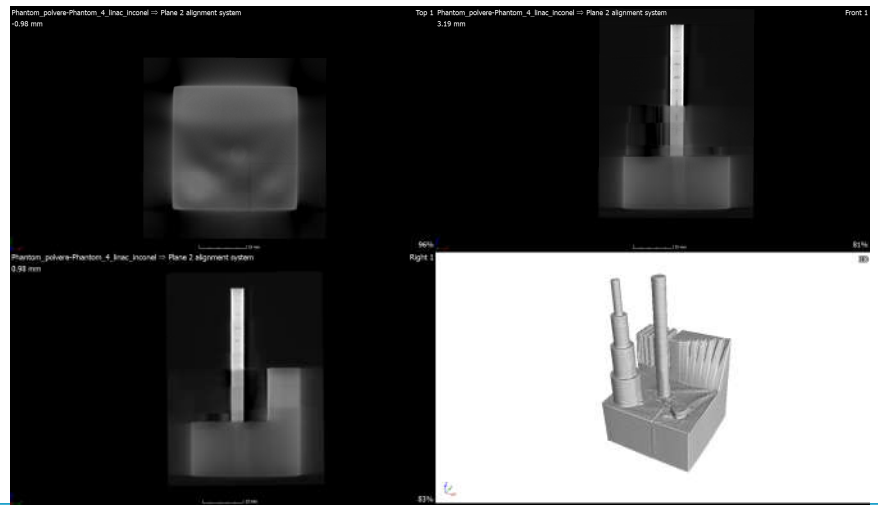


Stampa 12
Inconel 718



CT Scan:
X7500 System





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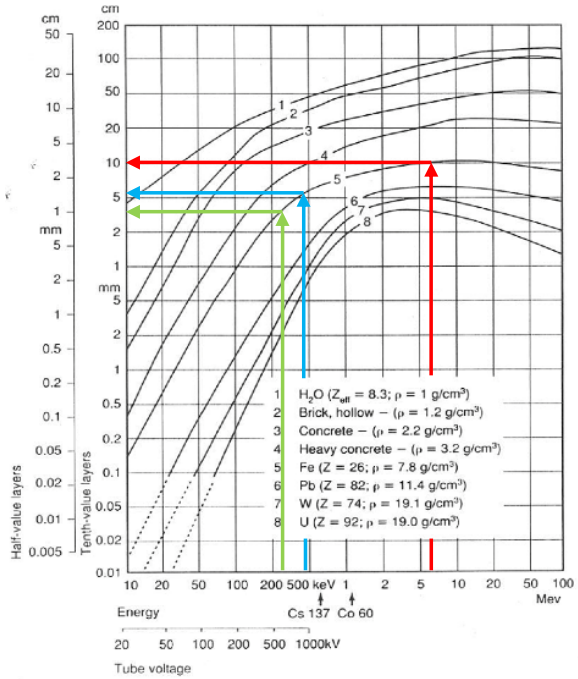
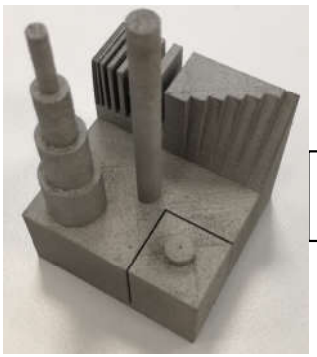
Linear Accelerator for CT inspection

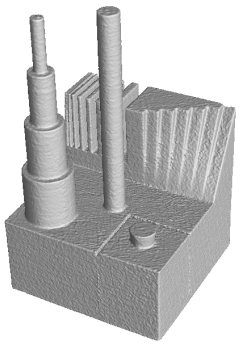
Marzo 2019: D7 6 MEV LINAC

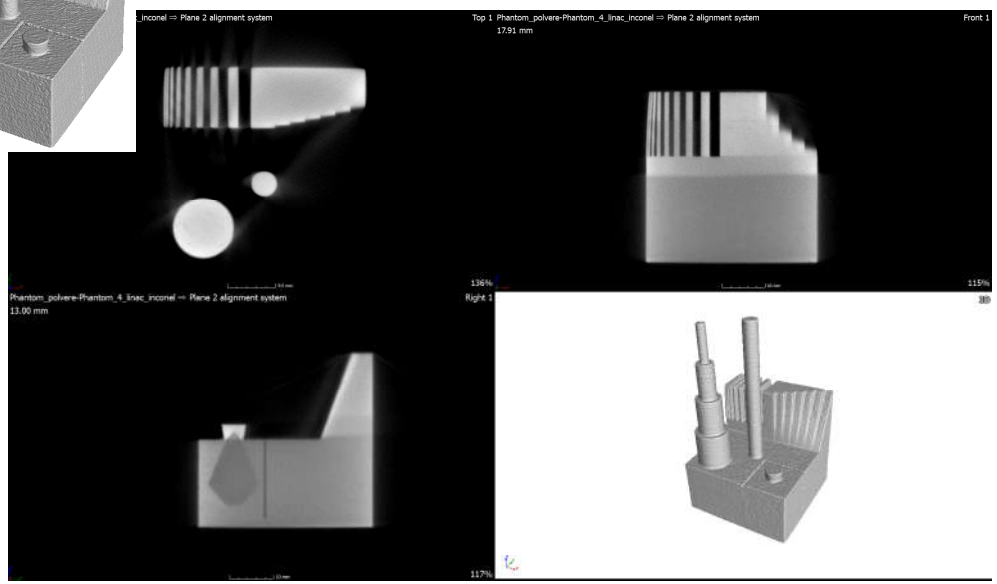


System performance comparison: an example



CT Scan:
Linac System





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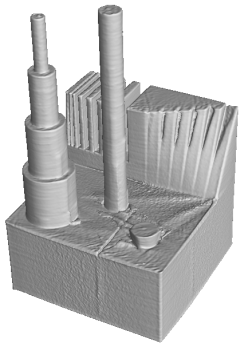

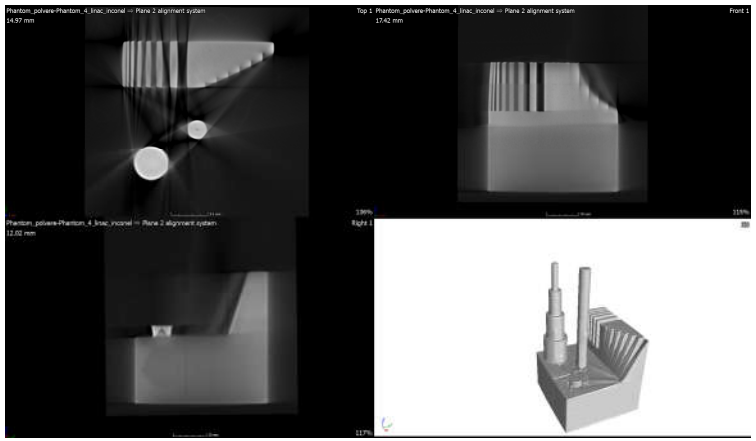

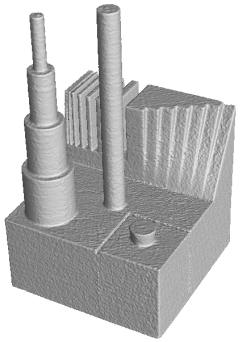

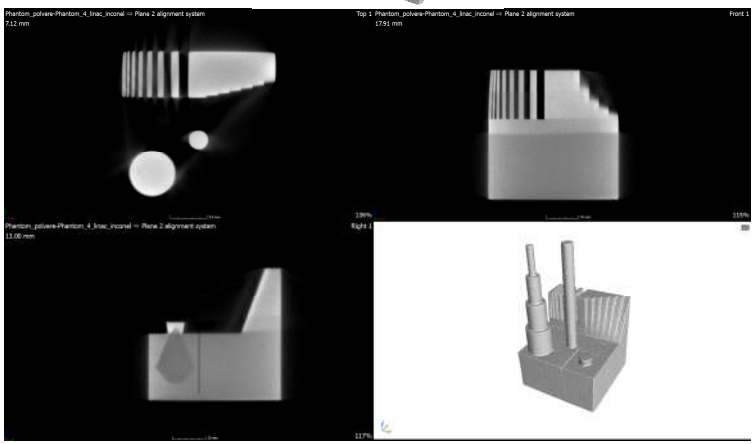

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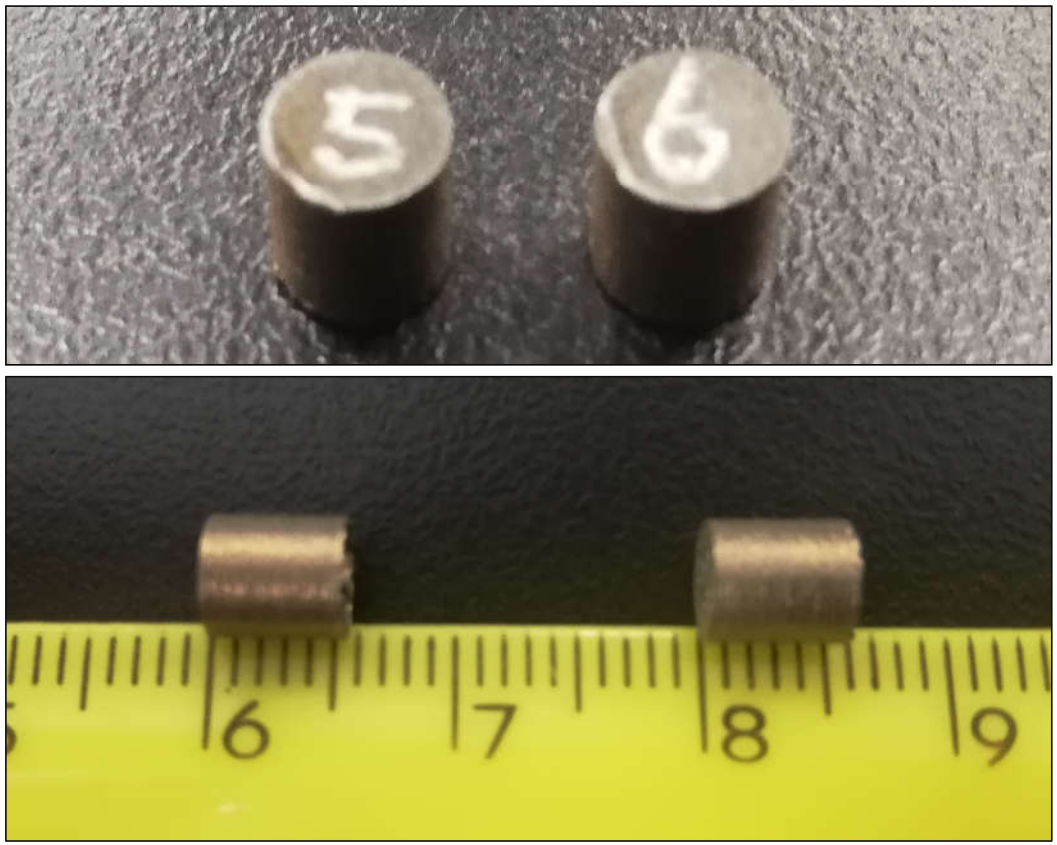
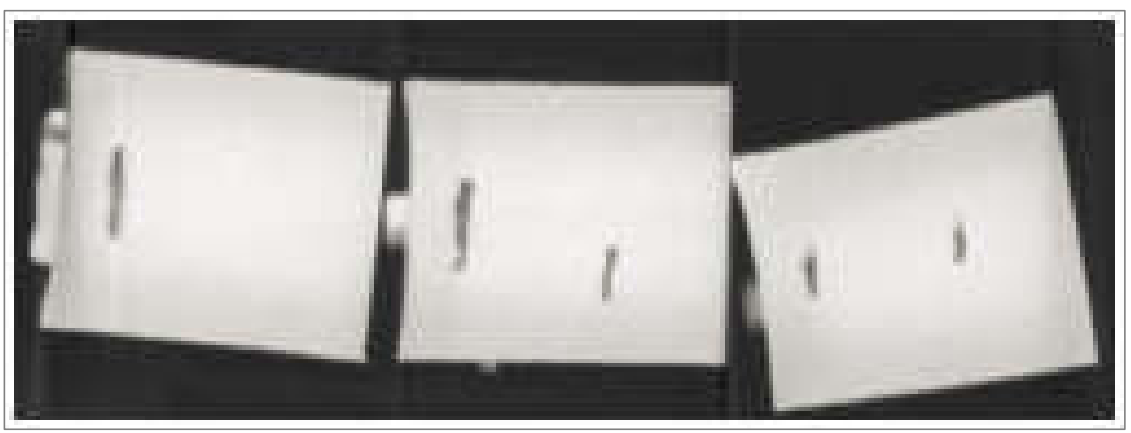


AM test samples sent to TEC Eurolab from SAFRAN

6 MeV LINAC CT: to boldly scan...

SAFRAN

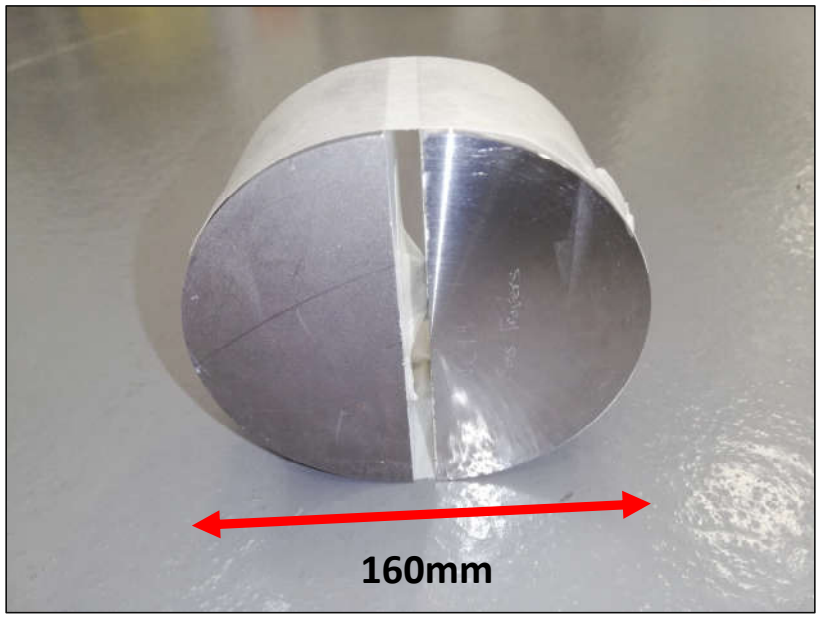


High resolution imaging of the internal defects (200 micron width)

…what is (very) difficult to detect!

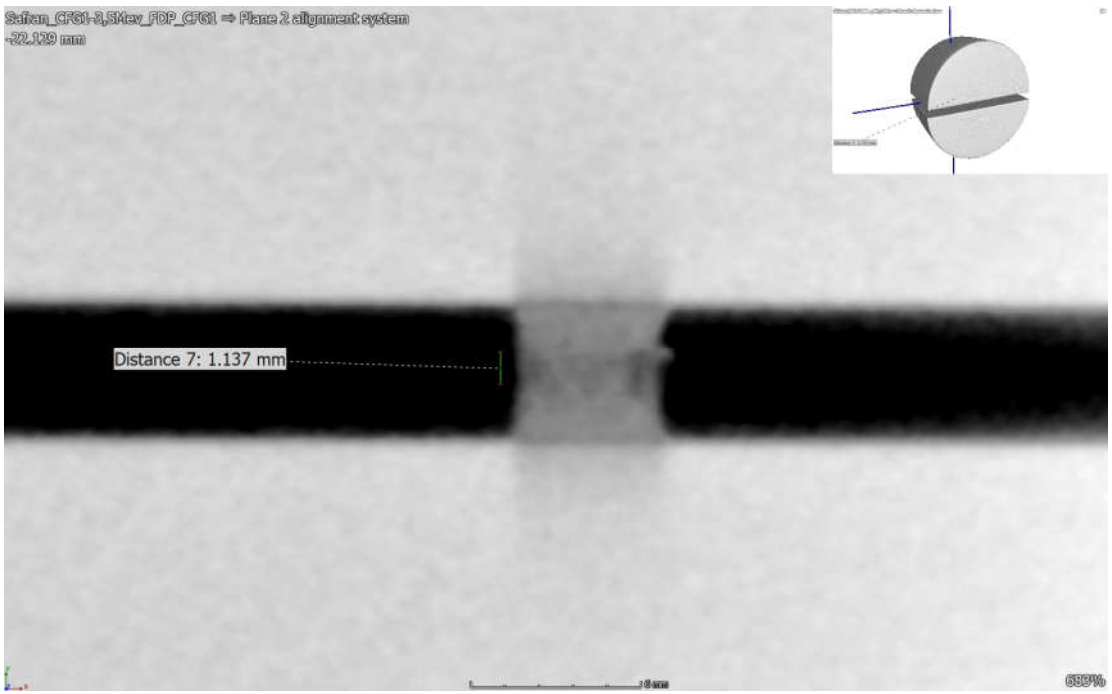
SAFRAN

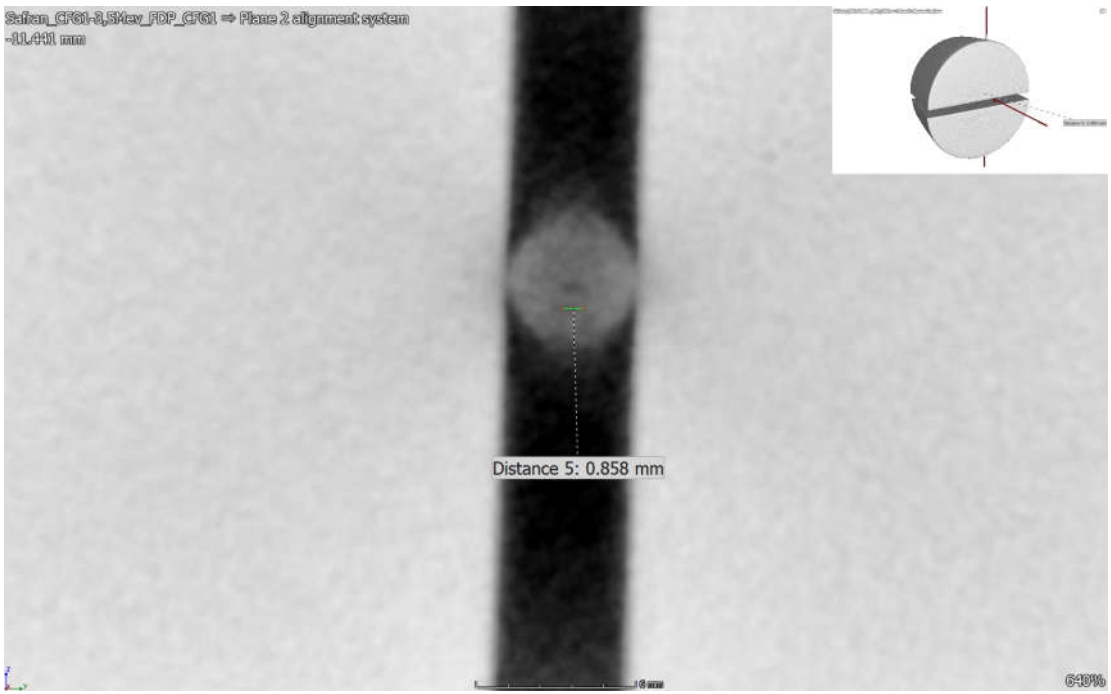
80 mm Inconel 718 full shielding



Test samples position and CT axis orientation

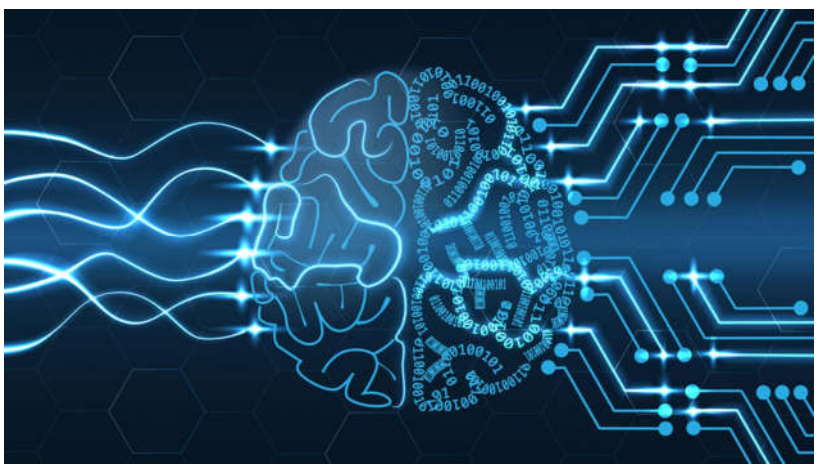
6 MeV LINAC CT Inspection of shielded test samples

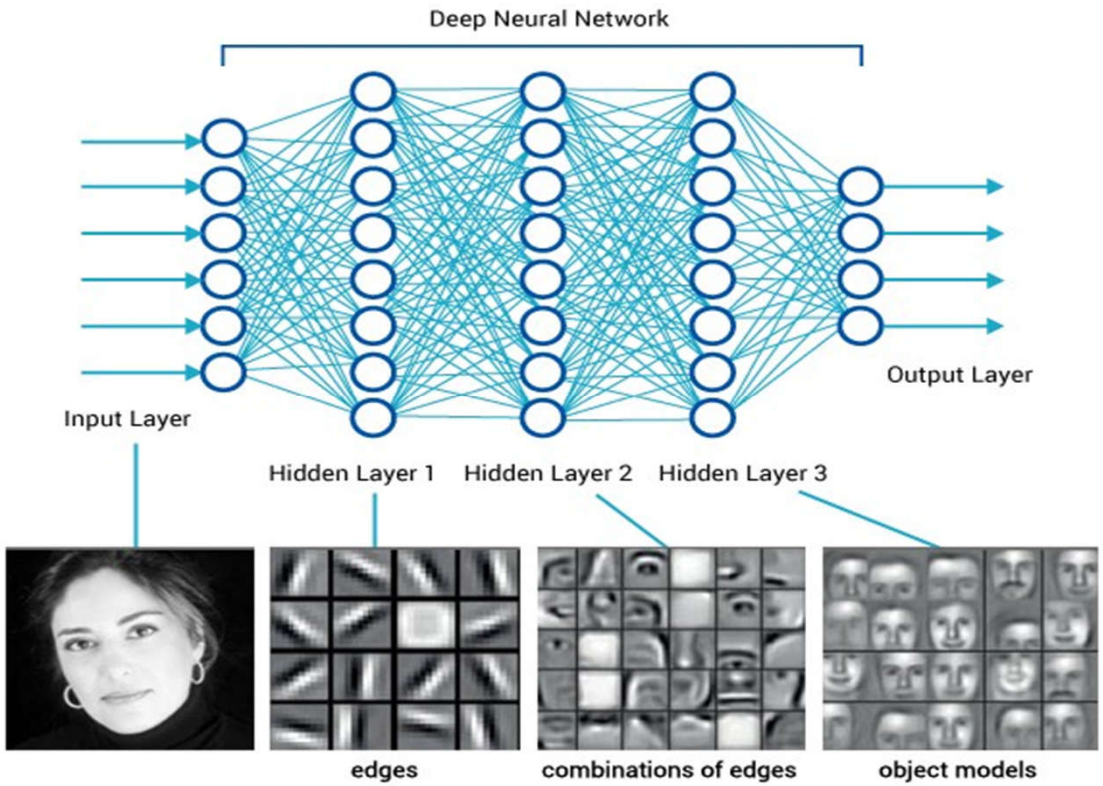




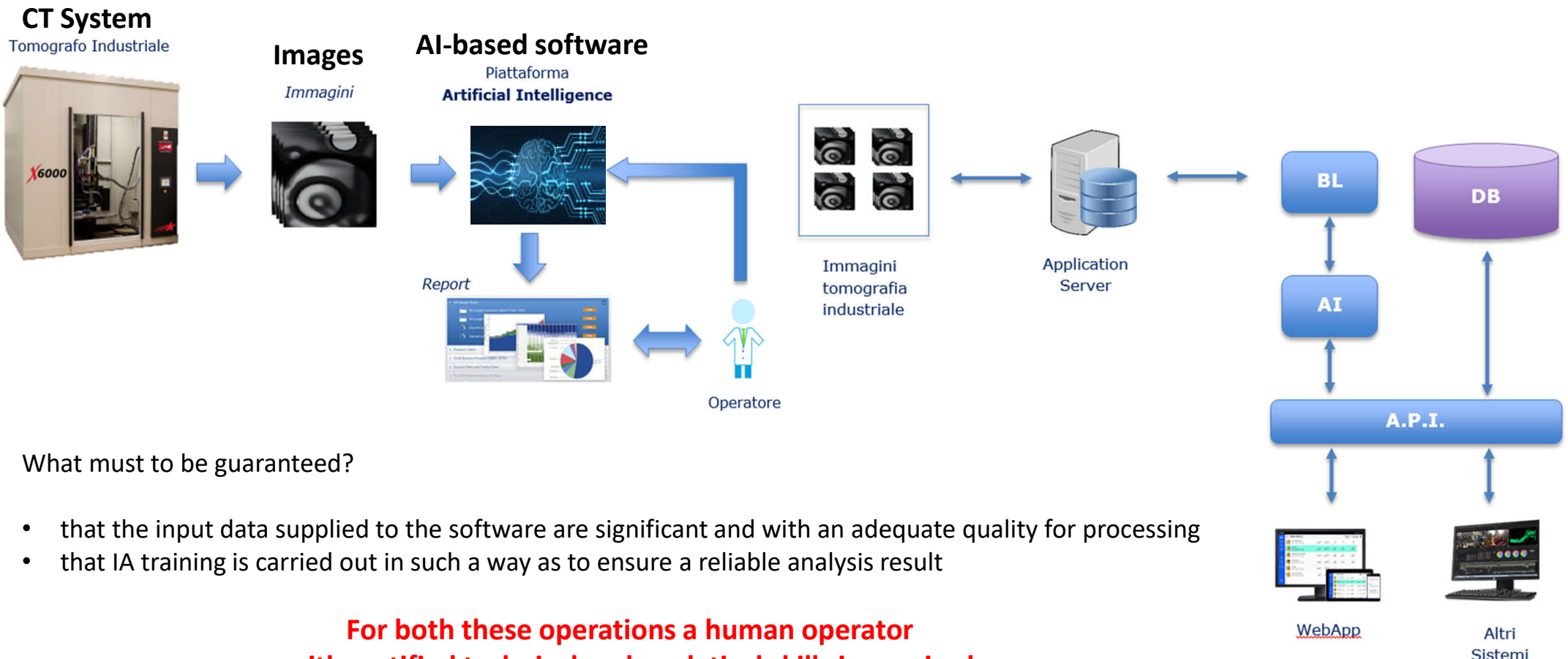
Defects detected and measured though 6 MeV CT scan

Artificial Intelligence: How does it work?





SCALABLE COMPUTED TOMOGRAPHY ANALYSIS FOR ADDITIVE MANUFACTURING

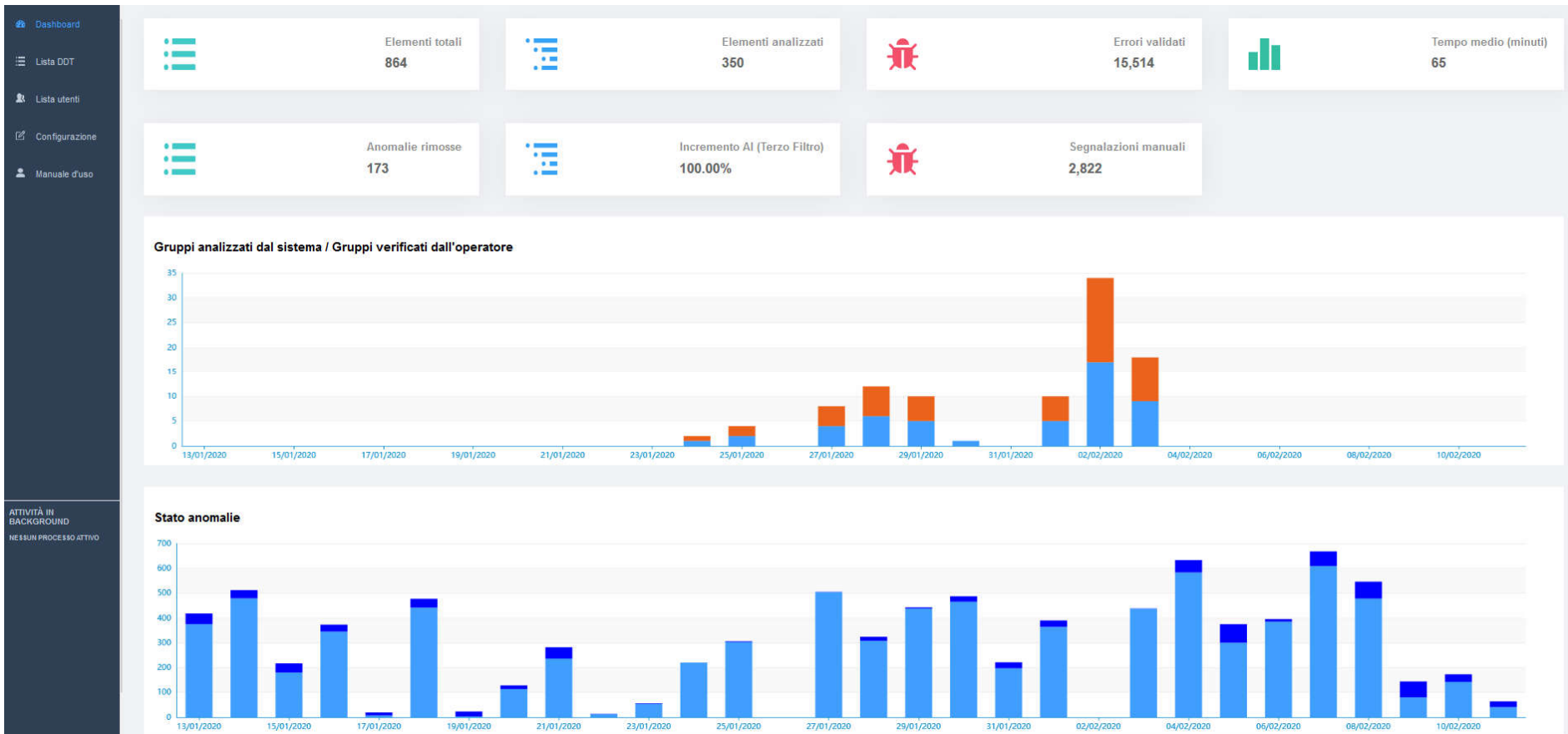


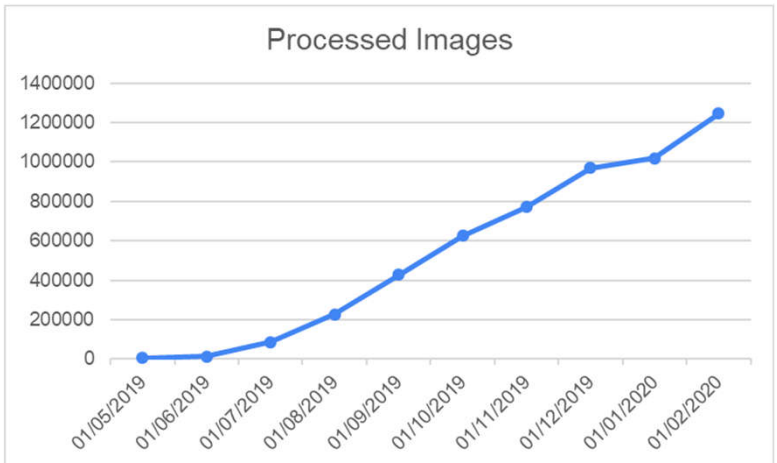
What must to be guaranteed?

- that the input data supplied to the software are significant and with an adequate quality for processing
- that IA training is carried out in such a way as to ensure a reliable analysis result

For both these operations a human operator with certified technical and analytical skills is required

New AI-based software interface

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1000000
800000
600000
400000
200000
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01/06/2019
01/07/2019
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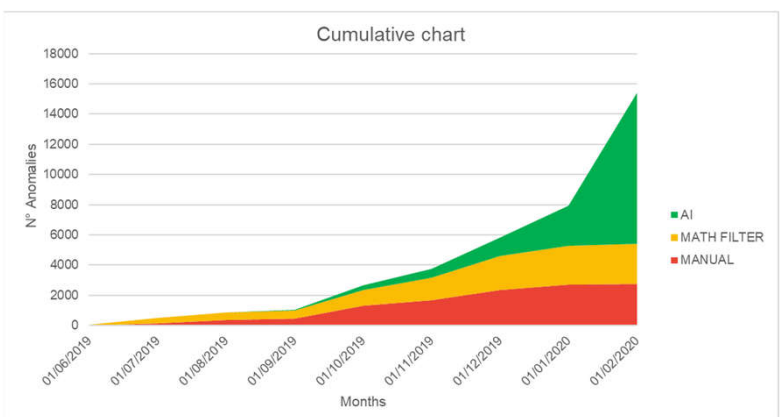
01/02/2020


Cumulative chart
N° Anomalies
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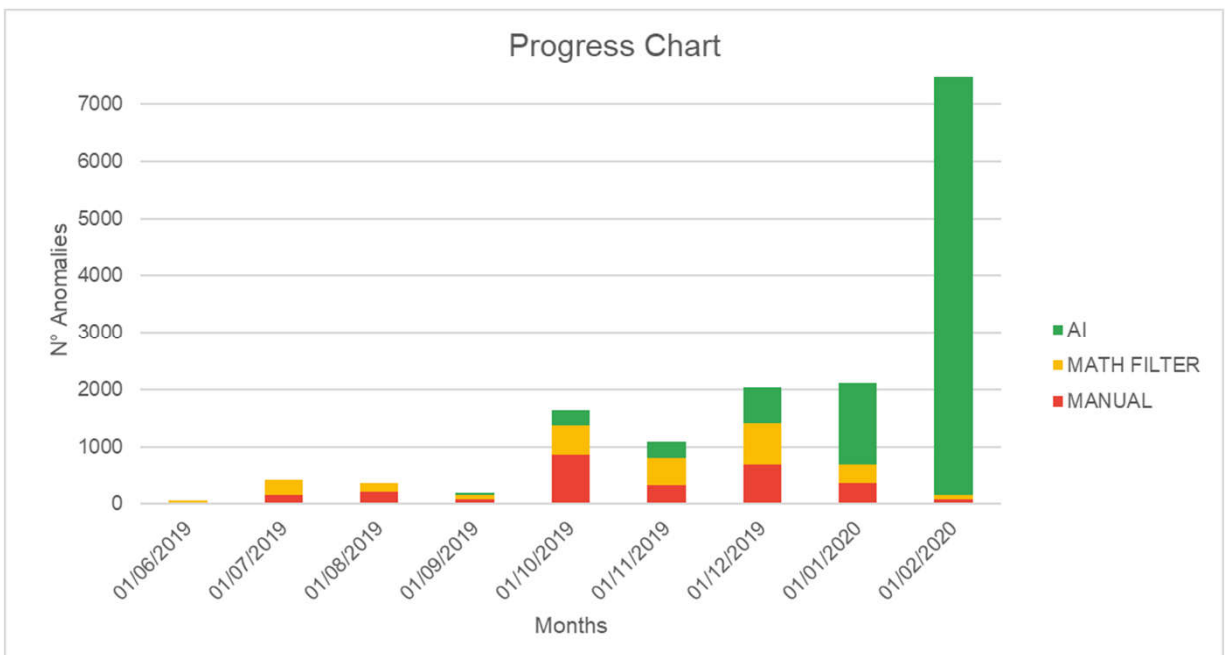
16000
14000
12000
10000
8000
6000
4000
2000
0
01/06/2019
01/07/2019
01/08/2019
01/09/2019
01/10/2019
01/11/2019
01/12/2019
01/01/2020
01/02/2020
Months
AI
MATH FILTER
MANUAL

VALIDATO

VALIDATO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6000
5000
4000
3000
2000
1000
0
01/06/2019
01/07/2019
01/08/2019
01/09/2019
01/10/2019
01/11/2019
01/12/2019
01/01/2020
01/02/2020
Months
AI
MATH FILTER
MANUAL

CONCLUSION

eurolab
IMEKO International Measurement Confederation
Technical Committee TC10 Testing, Diagnostics & Inspection

What's next step?

- Additive manufacturing technologies are increasingly adopted as tools to find innovative solutions to a wide variety of engineering problems
- The evolution of diagnostic technologies for component control must evolve to remain in line with the growth trends observed for production technologies
- Computed tomography is a powerful tool for controlling complex components, like many parts produced using additive technologies; however, its ability to generate large amounts of data requires an important technological evolution in the ability to interpret such data
- The use of AI-based software can be a valuable tool to process large amounts of data and assist the operator in controlling a component, ensuring greater reliability and increased productivity
- It is necessary to define more clearly how AI-based software will impact the process of control and validation of produced parts from a legal point of view.