ENGIE Experience with Additive Manufacturing and Related Nuclear Applications

US NRC Workshop on Advanced Manufacturing Technologies for Nuclear Applications
7 December 2020

Arne CLAES
Steve NARDONE

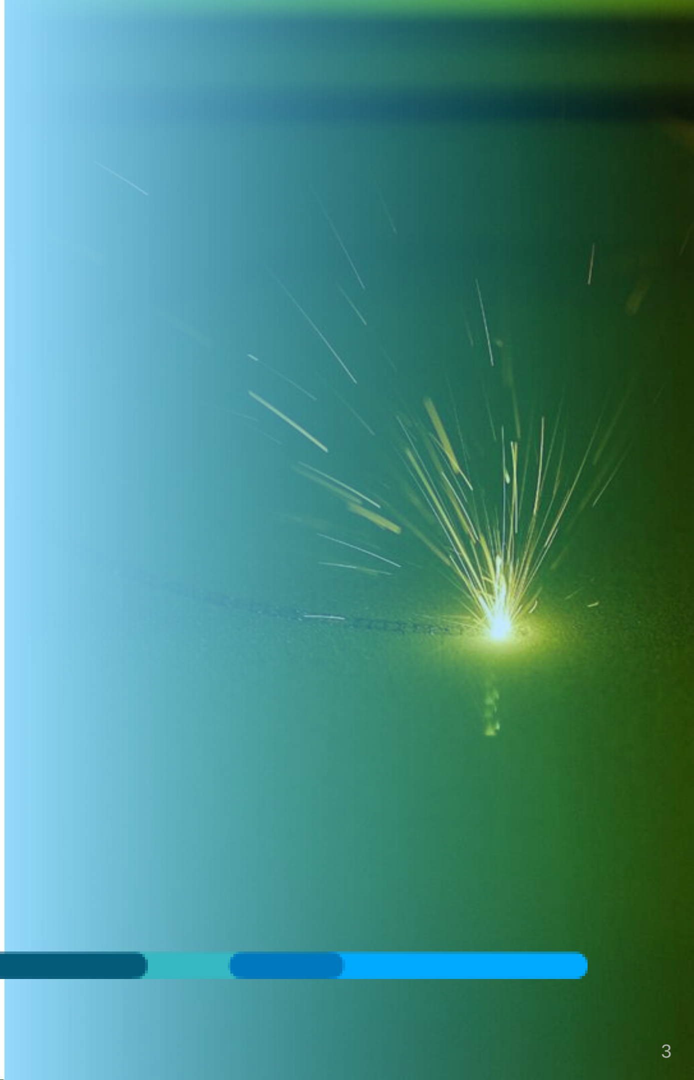
ENGIE Experience with Additive Manufacturing and Related Nuclear Applications

- Additive Manufacturing @ ENGIE
- ENGIE Qualification Approach for Laser Powder Bed Fusion Process
- Implementation of qualification approach to tackle ENGIE obsolescence challenges

Additive Manufacturing @ ENGIE

ENGIE Laborelec

ENGIE Electrabel

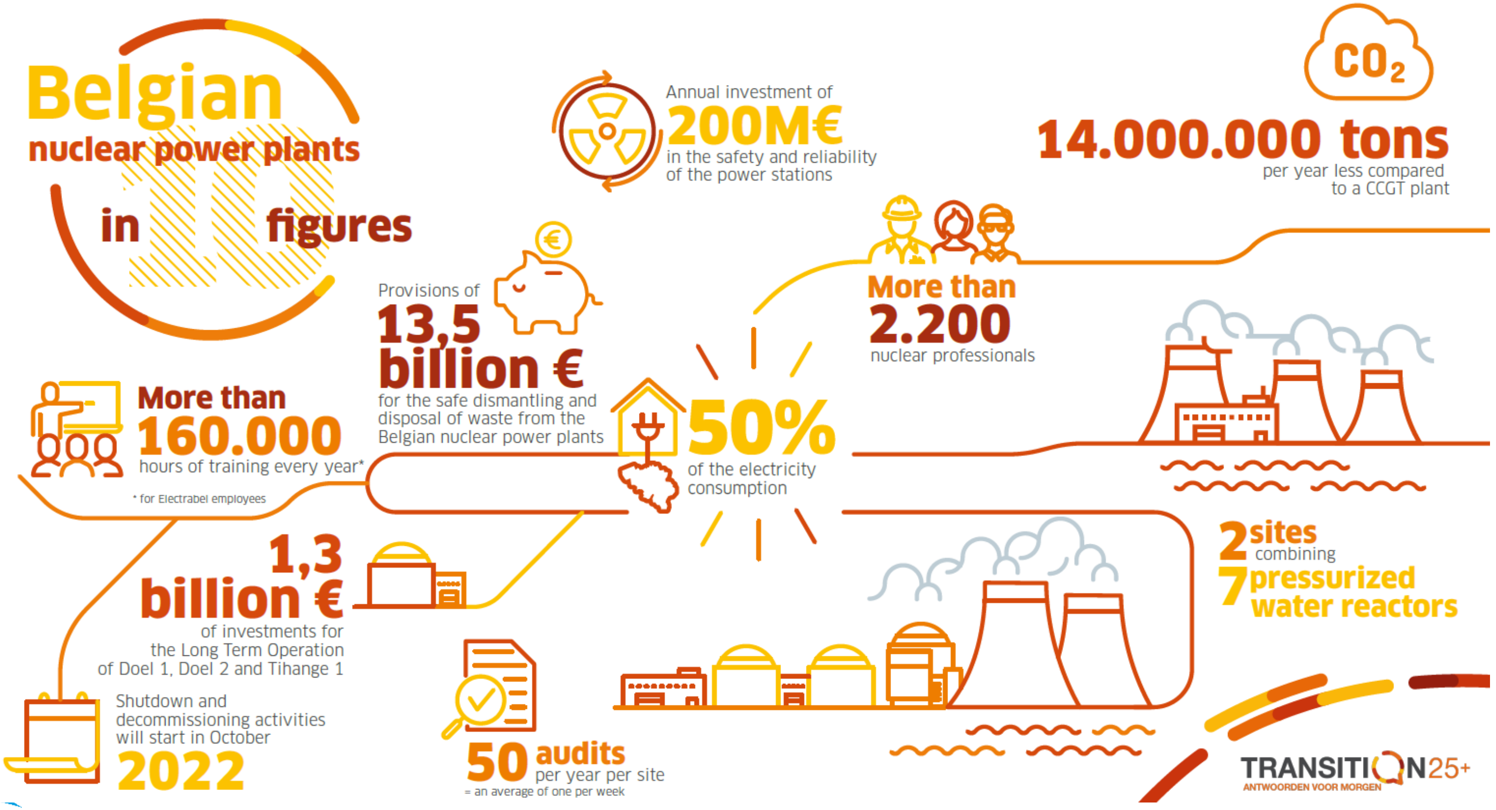


ENGIE Laborelec

In a nutshell

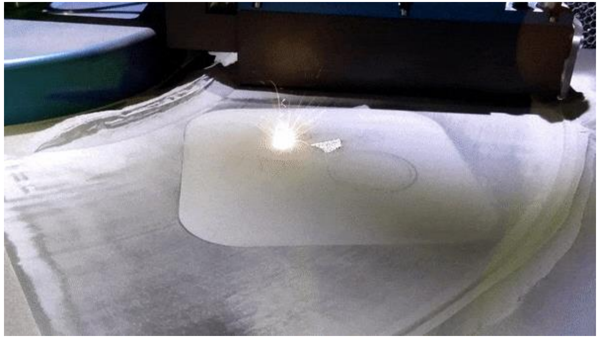
- ENGIE Laborelec is a leading **expertise** and **research** center in **electrical power technology**.
- Founded in 1962, the company has **over 55 years** experience in the power sector.
- ENGIE Laborelec is a **cooperative company** with ENGIE and independent grid operators as shareholders.
- Our competencies cover the **entire electricity value chain**: generation, transmission & distribution, RES, storage, usage of the energy for the industry and other end-users.
- We put a strong focus on the **energy transition** and the 3D's : **decentralization**, **decarbonization** and **digitalization**.
- We offer **specialized services**, R&D and **global solutions** in each of these domains, to companies in **all parts of the world**.

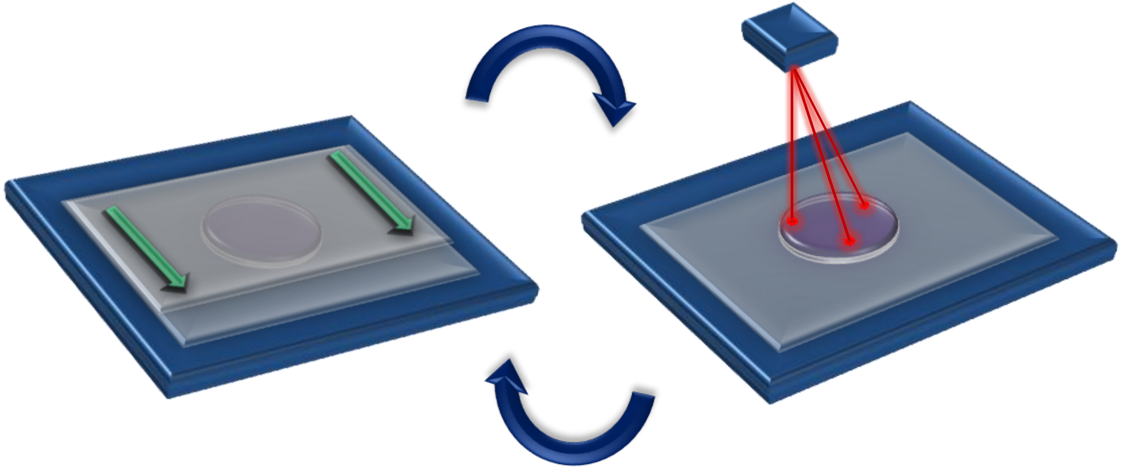
ENGIE Electrabel in a nutshell



This webinar deals exclusively with the Laser Powder Bed Fusion process

Local fusion of successive metal powder layers using a high energy laser.





Simple facts

Production of 10mm-cube using 50µm-layer thickness requires:

- *200 meters of scanned lines !*
- *200 layers !*
- *Fast and local welding process with high heating/cooling cycles*

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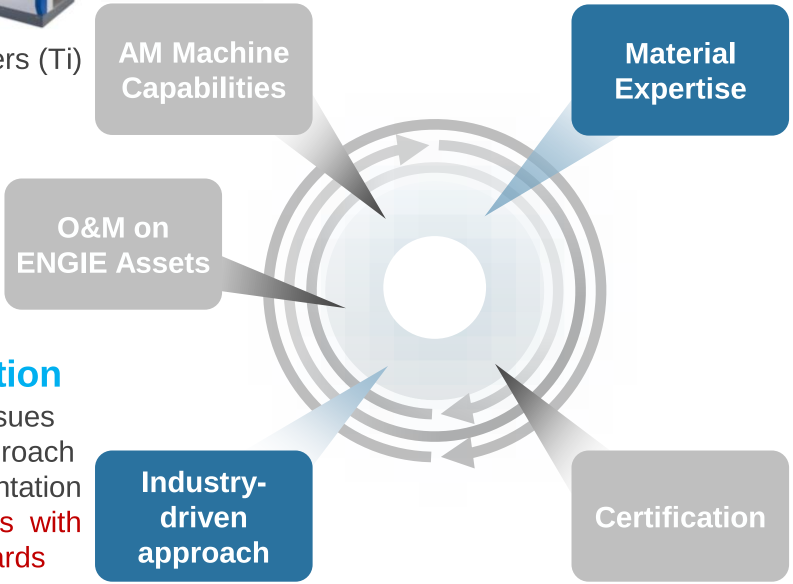
Additive Manufacturing as key enabler for operational excellence
Launch of ENGIE AM Expertise Centre in late 2015

Fe-, Ni-, Al-based AM powders (Ti)



Laboratories

> Materials laboratories
> Non-destructive testing (inspection & qualification)
> AM Powder lab

Materials Technology

> QA/QC of inspection campaigns
> Multidisciplinary projects for thermal/nuclear power plants
> Maintenance plan optimisation and revision

> Implementation in industrial environment
> Obsolescence management in ENGIE assets

Foster industrialization

> Tackle obsolescence issues
> Functionality-driven approach
> Validation & Implementation of high-end applications with high qualification standards

Certification Project

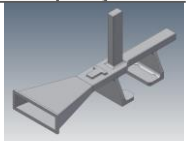
> Technological bricks: feedstock / Process / AM Material Performance
> Materials certificates 3.1 & 3.2
> Proactive approach before release of future EN 13445 Part 14

Key milestones in high-end applications @ ENGIE

Commissioning 2nd machine

Commissioning 3rd machine & Powder Lab

Redesign & Validation of radio-frequency antenna



Radio-frequency design by ENGIE

1st AM valve body (non-safety classified pressure retaining part) installed in nuclear power station

BoP in NPP

Nuclear

HORIZON 2020

NUCOBAM:
Nuclear components based on Additive Manufacturing

2015 | 2016 | 2017 | 2018 | 2019 | 2020

Commissioning 1st machine

1st Qualification of static part & Field Testing in ENGIE CCGT

Flow Swirler for condenser air extraction pump, obsolete part

1st AM part for robot inspection in nuclear primary circuit

Production & delivery of 12 parts from 10 days to 49 hours

Tooling in NPP

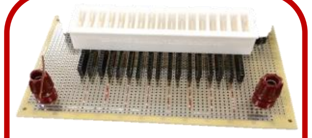
Installation of pressure regulation valve part in ENGIE CCGT

AM Facility Qualification by Lloyd's Register

CERTIFIED
LR
ADDITIVE MANUFACTURING FACILITY QUALIFICATION

Powder Lab, Facility and produced material

Nuclear



5,10 and 20-year qualification of 3D printed terminal blocks for safety function purpose

Additive Manufacturing Product Quality
High-Level Overview

Process Reproducibility
- From machine to machine (same SLM brand)
- From machine to machine (different SLM brand)

Process Repeatability
- Consistent product quality from build job to build job
- Powder management, storage and reuse

Process Stability
- Consistent product quality throughout the build height
- Consistent product quality on the entire build plate

Process Qualification
- Process parameters optimization
- Sensitivity analysis
- Transferability from coupons to industrial part

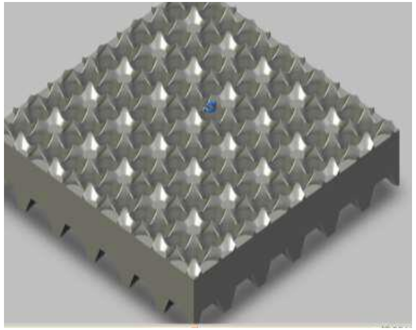
NUCOBAM: NUclear COmponents Based on Additive Manufacturing Horizon 2020 Nuclear Fission and Radiation Protection Research

Nuclear

HORIZON 2020

- **Context:** State-of-the-art **nuclear design codes** and assessment procedures do not take into consideration the Additive Manufacturing Technologies
- **Objectives:**
  - Establish a qualification methodology for AM nuclear components to be proposed for standardization and to be communicated to nuclear design code committees
  - Develop a manufacturing plan that ensures and demonstrates process stability, repeatability and reproducibility that meet nuclear quality standards
  - Demonstrate that laser powder bed fused material performance meets qualification requirements
  - Demonstrate that in-core AM use case meets its safety-related function and operational requirements
  - Assess the operational performance of ex-core AM components regarding safety-related function and operational requirements
  - Disseminate and prepare the exploitation of results with nuclear industries and regulatory bodies in support to codification and industrialization of AM
- **Key information:**
  - Project Duration: 48 months (Oct. 2020 – Sept. 2024)
  - Total Budget: 3,9M€
  - AM machines: Laborelec (SLM500), CEA (SLM280), VTT (SLM125) and AMRC (AM250)

Gate Valve DN25 (ex-core pressure retaining application)



Debris Filtering component from fuel assembly (in-core part)

EDF, cea, SCK•CEN, IRSN, framatome, NAVAL GROUP, TRACTEBEL ENGIE, Ramén Valves, VTT, Ciemat, ENGIE Laborelec, NUCLEAR AMRC, NATIONAL NUCLEAR LABORATORY

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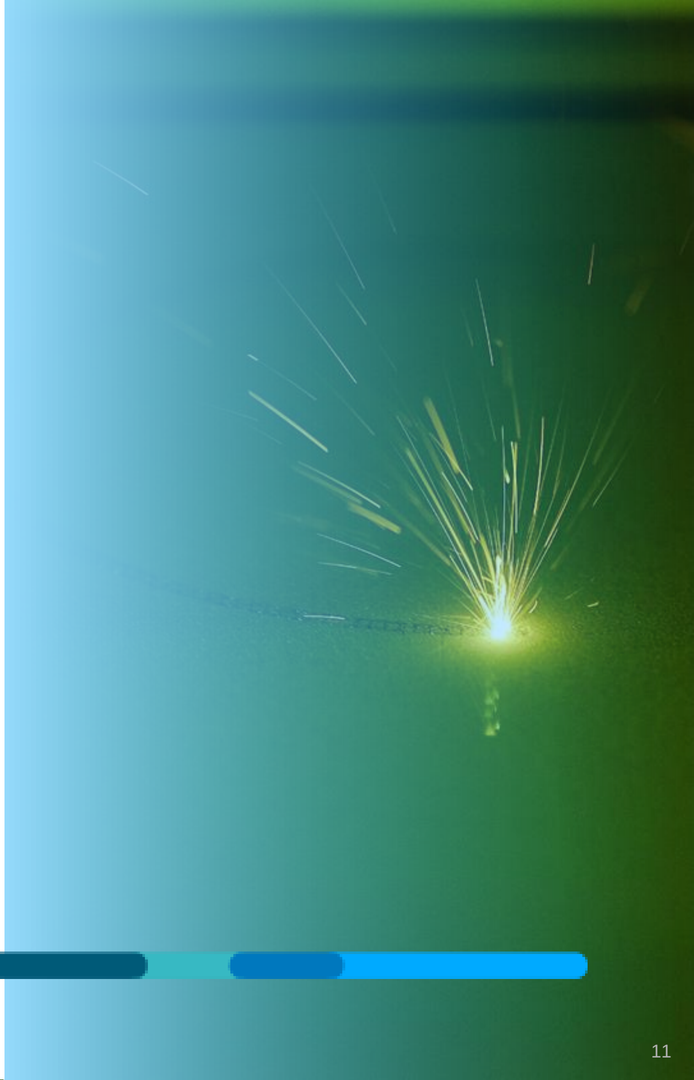
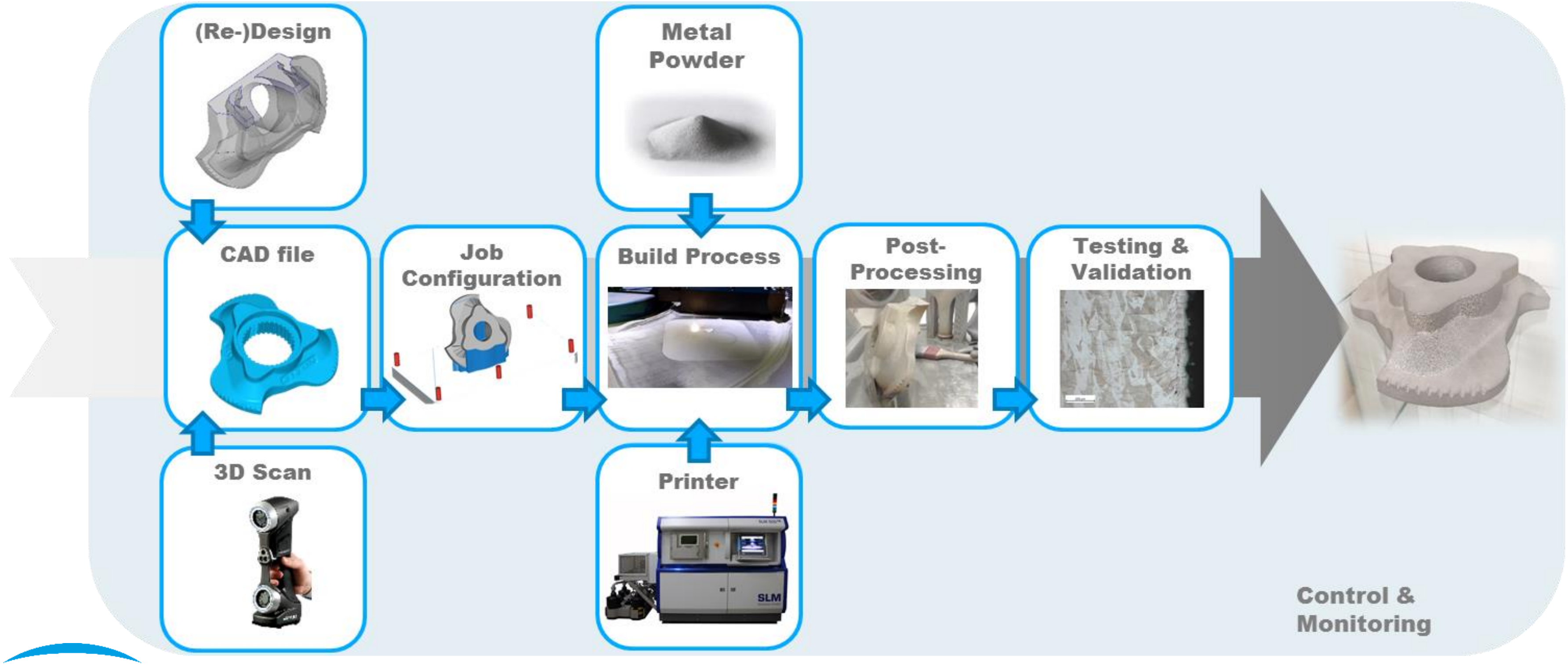
ENGIE Qualification Approach for Laser Powder Bed Fusion Process

Laborelec

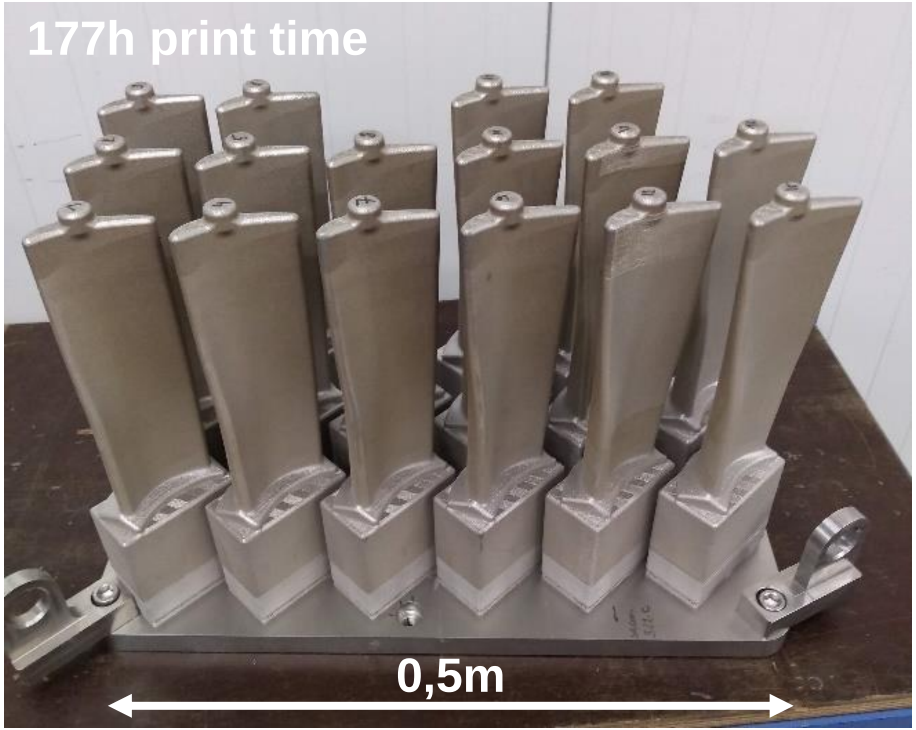
Electrabel



What can go wrong along the whole value chain ?



Challenges for production of high-end components and large productions runs



Ensuring process stability, quality & reproducibility over the long term for large production runs:

- **Large components**
- **Heavily-loaded build platform**

SIM FATAM Project https://www.sim-flanders.be/project/fatam-icon

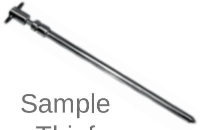
What can go wrong along the whole value chain ?

Ensuring process stability, quality & reproducibility over the long term for large production runs :

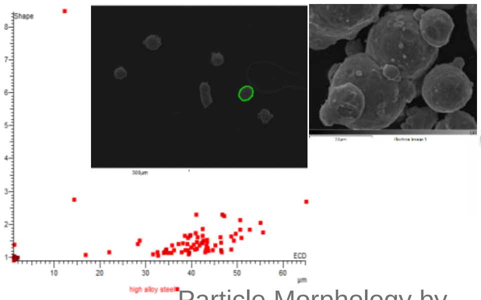
- Influence of powder batch
- Powder storage & recycling
- Influence of build location
- Influence of build height
- Transferability from coupons to industrial part
- From build job to build job

Material Feedstock for Laser Powder Bed Fusion

Standardization & acceptance criteria



Sample Thief



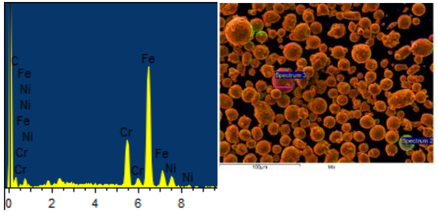
Particle Morphology by Scanning Electron Microscopy

Hall flow, Carney flow and apparent density

Sample Divider

Particle Size Distribution by Laser Diffraction

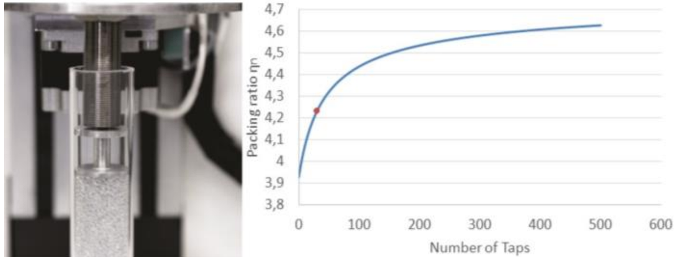
Mechanical Sieving



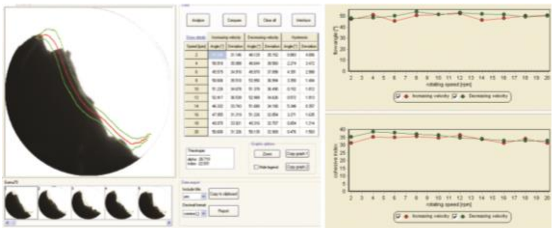
Semi-quantitative chemical analysis by Scanning Electron Microscopy

Archimedes density testing

Metal Powder Characterization based on ASTM F3049-14



Semi-automatized tapped density method producing compaction curve as a function of number of taps for a SLM metal powder



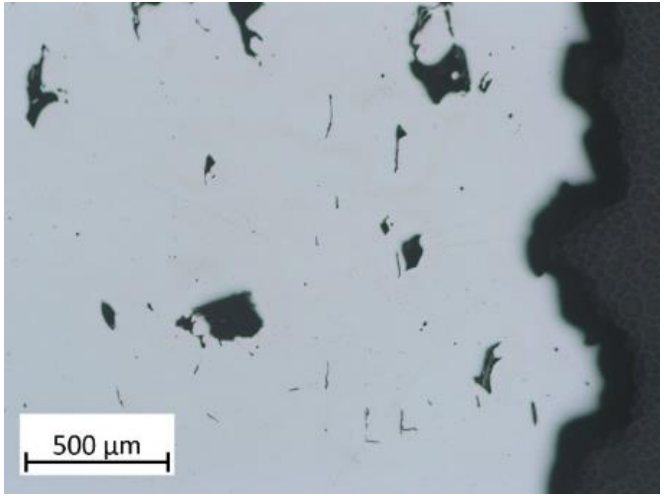
Automated measurements of dynamic angle of repose, providing cohesive index and flowing angles for different shearing stresses

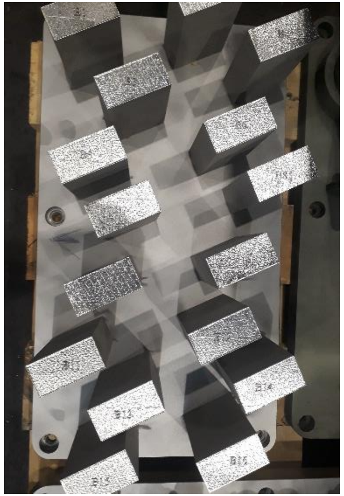
Rheometer, shear cell, wall friction

New Metal Powder Characterization Methods

What can go wrong along the whole value chain ?

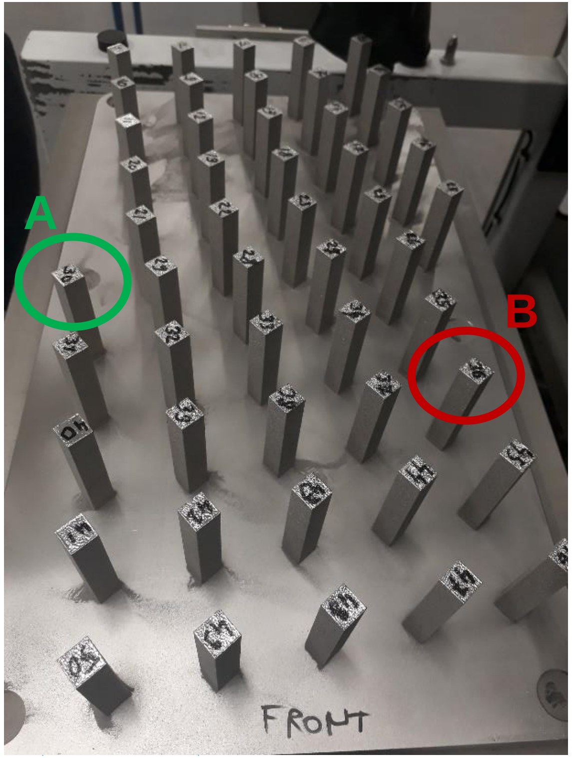
Influence of build location & build height



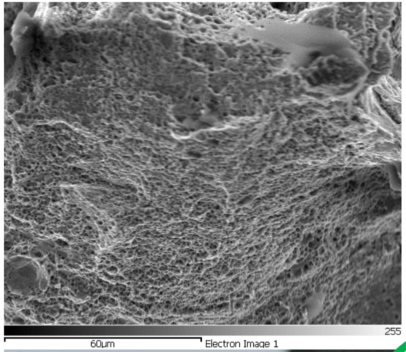


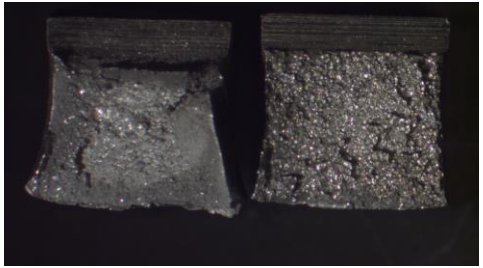
Large quality discrepancy for heavy-loaded platform without careful machine fine-tuning, even with optimal laser process parameters

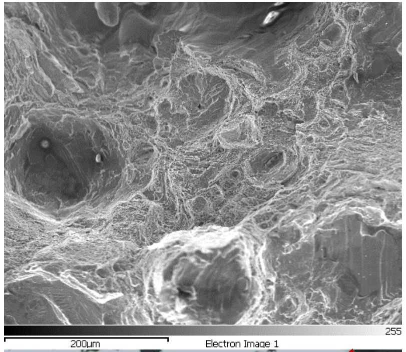
Process Stability
Challenge: Homogeneous properties over the platform !

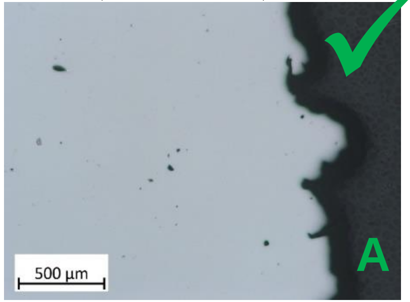


Large quality discrepancy for heavy-loaded platform without careful machine fine-tuning, <u>even with optimal laser process parameters</u>

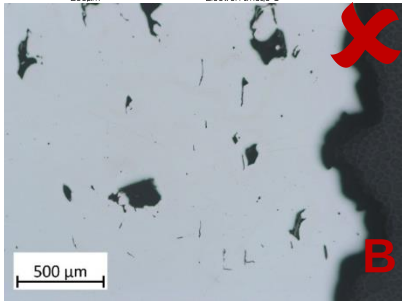




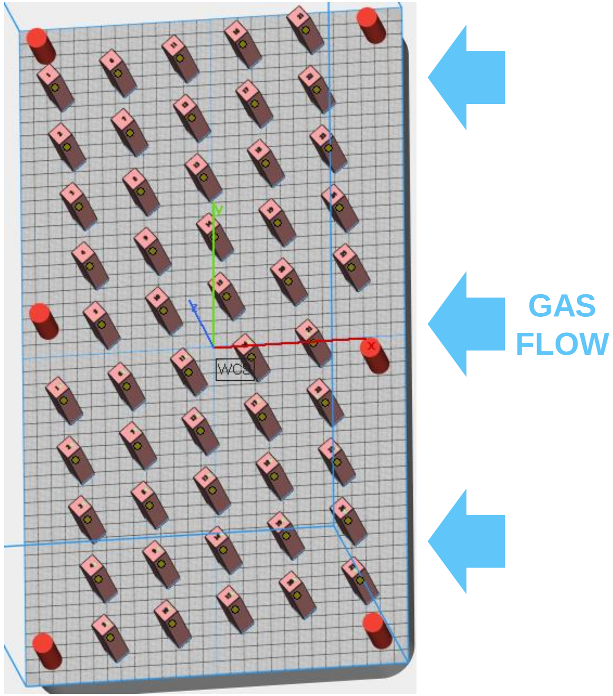




<u>Impact testing</u>
136 J vs. 16 J



Process Stability
Challenge: Homogeneous properties over the platform !



Charpy V-notch toughness values over the build platform using optimized laser process parameters

	87	70	61	66	32
	54	74	49	75	47
	79	76	69	54	61
	73	77	89	47	35
	73	33	52	60	45
76	71	85	78	49	
65	65	92	64	39	
61	82	56	35	42	
58	47	50	25	27	
40	49	33	23	24	

Charpy V-notch toughness in Joule

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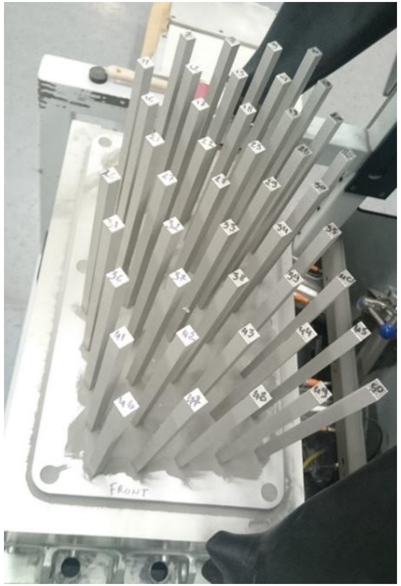
Process Stability over build height & Process Transferability

Full height samples

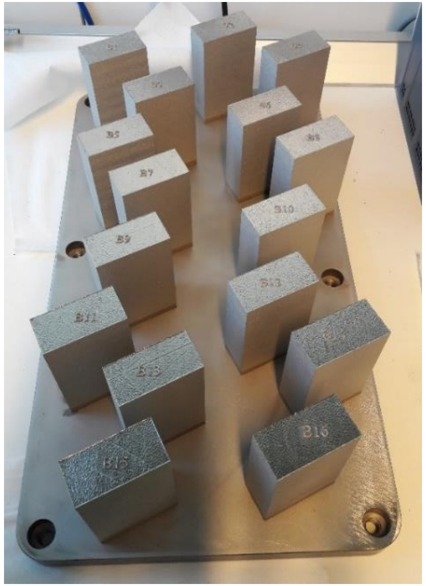
Process Stability
- Consistent product quality throughout the build height

	107	108	104	109	108
	110	109	103	115	128
	104	111	104	135	140
	100	102	114	133	76
	113	106	87	121	55
112	111	109	112	118	
107	106	97	118	99	
111	118	112	142	85	
106	108	111	114	132	
104	102	110	116	130	



Big blocks

Process Qualification
- Transferability from coupons to industrial part



	yield strength (MPa)	tensile strength (MPa)	elongation (%)	reduction of area (%)
average	434	571	45.8	59.9
stdev	18	26	6.5	11.1

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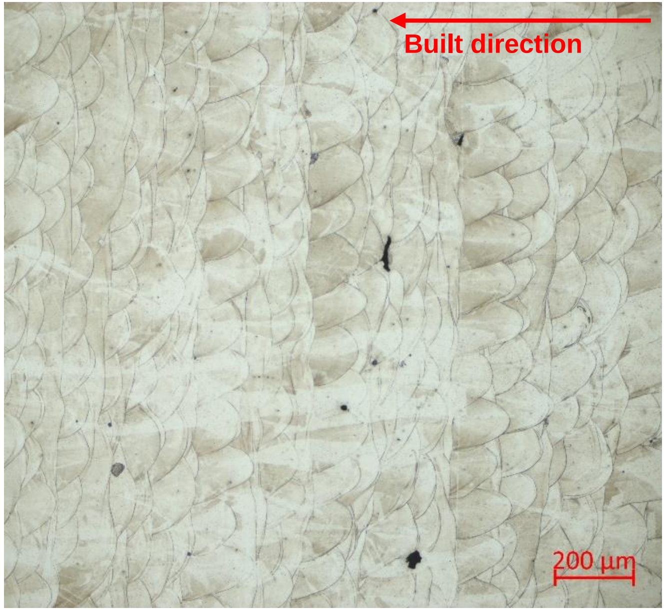
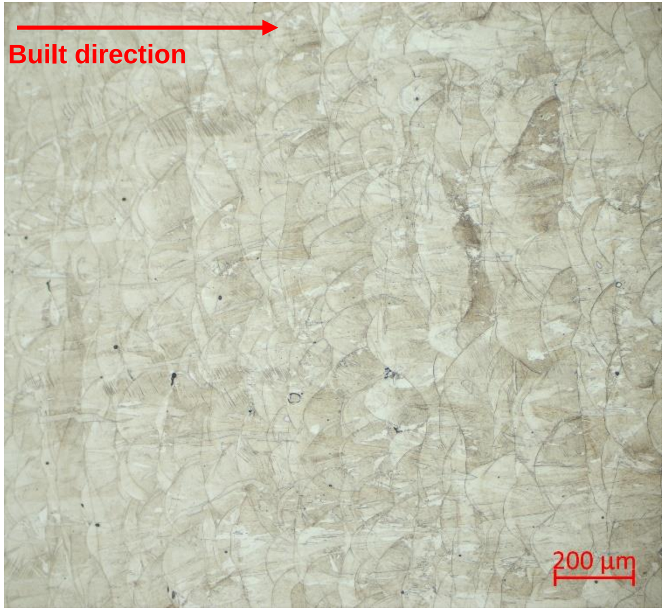
Process Stability over build height & Process Transferability
Microstructure

Before gas flow upgrade



After gas flow upgrade



After gas flow upgrade and corresponding parameter optimisation, the visible melt pools after etching seem to be less pronounced and more homogeneous in size

ENGIE Certification Project

Successful ENGIE Facility and Powder Lab Certification by Lloyd's Register on 10.09.2019

- Technological bricks:
  - Feedstock
  - Process
  - AM Material Performance
- Material certificates 3.1 & 3.2
- Proactive approach before release of future EN 13445-14

Relative Archimedes Density – Laborelec Procedure LBE04113339

	Average	Standard deviation	Comments
Results	99,43%	0,13%	8 measurements of 15mmx15mmx15mm cubes from qualification platform

Tensile properties

		Condition	Yield Strength 0,2%	Ultimate Tensile Strength	Elongation at break A5	Reduction of Area	Comments
ASTM F3184-16	*Min.*	*Solution annealed*	*205 MPa*	*515 MPa*	*30%*	*30%*	*In all build directions*
Results – XY build direction		Solution annealed	379 ± 8 MPa	614 ± 3 MPa	48 ± 2 %	60 ± 3 %	Based on 5 specimens for each build direction, as per ASTM E23 with Ø6mm
Results – 45° build direction			382± 3 MPa	606 ± 3 MPa	52 ± 2 %	63 ± 3 %	
Results – Z build direction			370± 7 MPa	566 ± 9 MPa	57 ± 3 %	65 ± 3 %	

Hardness

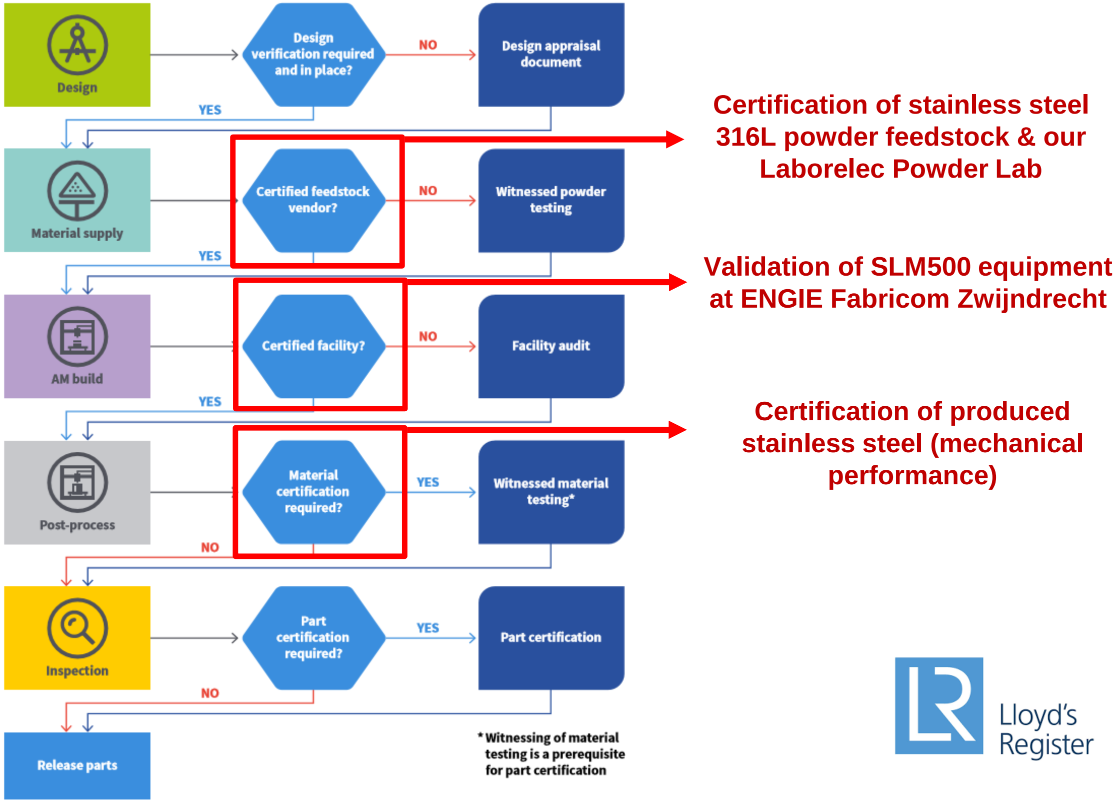
		Condition	Measurement	Comments
ASTM F3184-16		*Not mentioned*		
ASTM A240/A240M–06b	*Max,*	*Solution annealed*	*217 HB*	
Results		Solution annealed	185 ± 8 HV0,5	*16 measurements per cube on 2 cubes*

Charpy V-notch impact testing

	Condition	Charpy Impact Energy	Lateral expansion	Comments
ASTM F3184-16	*Not mentioned*			
Results – XY build direction	Solution annealed	122J / 130J / 132J	1,78mm / 1,82mm / 1,88mm	Based on 3 specimens for each build direction, as per ASTM E23

ENGIE Certification Project

- **Our Main Goal**
  - Achieving ENGIE AM Facility Qualification & Material Certification
  - Material Certificate linking Powder Batch, Machine/Process & Formed Material



- Delivery of material certificate 3.1 or 3.2 for 316L material under Lloyd's Register label

Lloyd's Register

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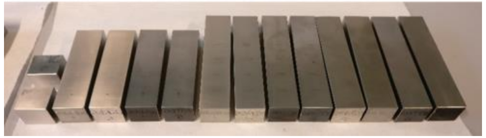
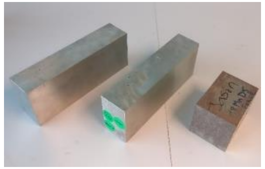
Additive Manufacturing Product Quality and Control

Off-line / non-destructive



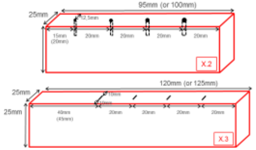
- Material properties determine inspectability for UT and EC
  - New manufacturing technology leads to unique challenges and material properties
  - Codes and regulations require inspection of critical components
  - Benchmark AM material against industry-standard materials (forging and casting)

Industry-standard material



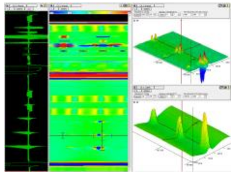
AM material

Fabrication of standardized blocks with reference defects

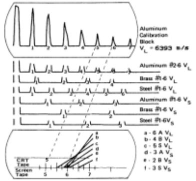


Ultrasound testing

Eddy current testing



Calculate material properties



Benchmark against industry standard

Young modulus
Signal to noise
Absorption
Sound velocity
Anisotropy
Electrical conductivity

Qualification approach to tackle ENGIE obsolescence challenges

Non-safety classified pressure retaining part installed in nuclear power station

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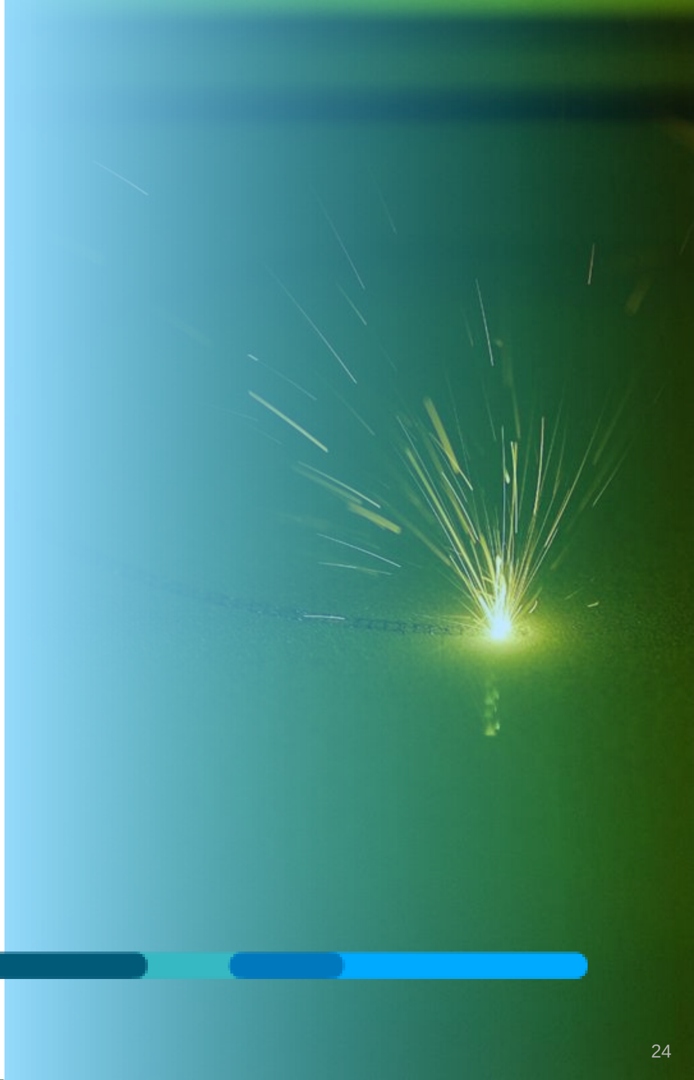
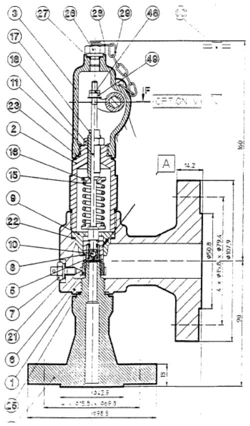


Problem Statement
Tackling obsolescence in NPP - CW-VV0592 in KCD3



- Outage Unit 3 at Doel NPP
- Voluntary test of non-safety pressure relief valves in secondary circuit
- Disassembly of the valve showed corrosion and damage
- Obsolescence status: unknown
  - Non-safety related
  - Body was never on stock
  - Low install base (1 location)
- Considered solutions
  - Order original body ► Valve appeared obsolete
  - Equivalent stock replacement ► No equivalent model on stock
  - Order new equivalent model ► Lead time 24 weeks (> outage deadline)
- Reverse Engineering & Metal Additive Manufacturing

Reverse Engineering incorporating Metal Additive Manufacturing

Reverse engineering

ORIGINAL ITEM INFORMATION	
	KCD3 - CW-VV0592
Component ID	
Item short tekst	
Manufacturer	
Manufacturer Part Number	
Install base (Functional Location)	
Item description	

REVERSE ENGINEERING SUMMARY	
Studied replacement item:	3D printed valve body
Component ID	
Manufacturer	
Manufacturer Part Number	
Perimeter of applicability	
Item description	

TRACTEBEL ENGIE

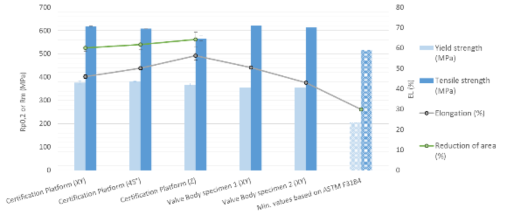
SPECIFICATION

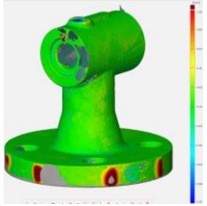
INTERNAL

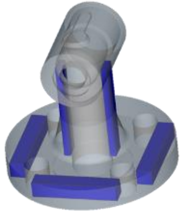
Project: N - PARTS REDESIGN & BUILD

HEAT TREATMENT CERTIFICATE

Customer	Element Materials Technology
Project	JOB500 320C
Ordernumber	27005-01
Ordernumber SH	19-44117
Material	
Certificate nr.	19-030







Day 1

Generation of 3D Model

Redaction of Test Specs & Obsolescence Dossier

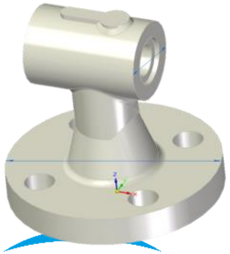
Manufacturing Plan & Printing

Post-processing

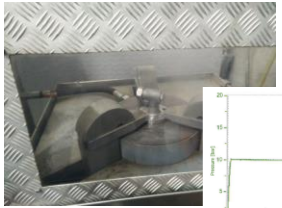
Day 12

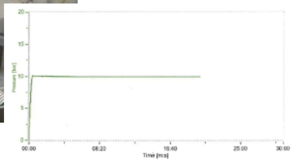
Functional Testing on Industrial Valve

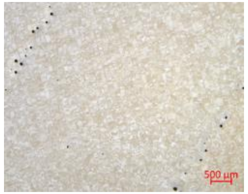
Destructive Testing on Sacrificial Valve

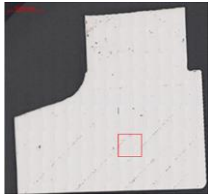


CERTIFIED LR ADDITIVE MANUFACTURING FACILITY QUALIFICATION









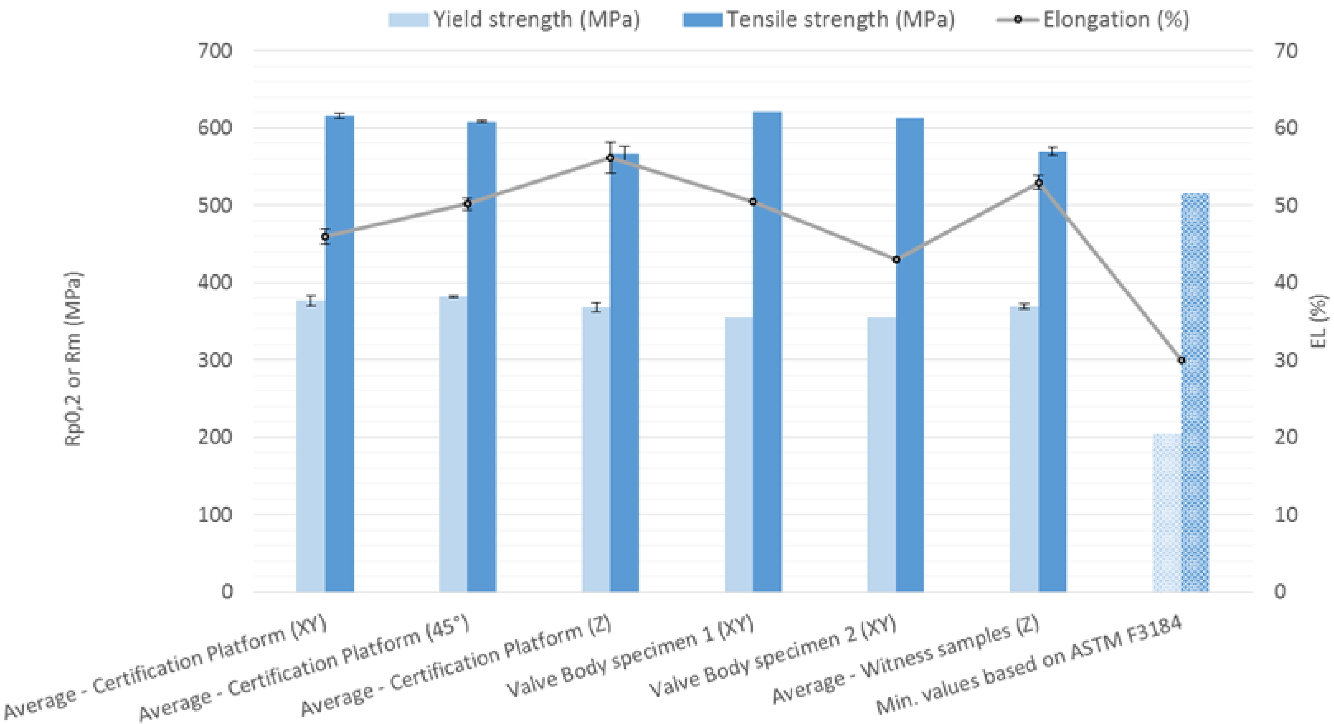
ENGIE Laborelec

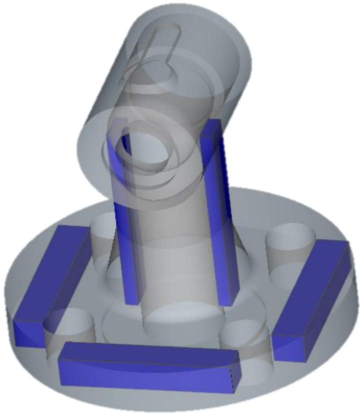
Reverse Engineering incorporating Metal Additive Manufacturing

The use of 'Additive technology' (3D printing) has been used to solve an obsolescence issue on valve PKD-D3/CW-VV0592. The valve body was recreated using a metal printing technique. While testing to ISO 17296-3 standard was not carried out, an alternative standard was used (ASTM F3303 – 18 & F3184 – 16). The WANO reviewer was not familiar with the ASTM standards, but the ISO standard may be more appropriate in this situation as it is more focussed on the testing of printed components for different situations. Thorough analysis information was available, and testing had been carried out to ascertain if the valve body would withstand the pressures required, prior to installation. This approach is seen as innovative and ground breaking in the Nuclear Industry.

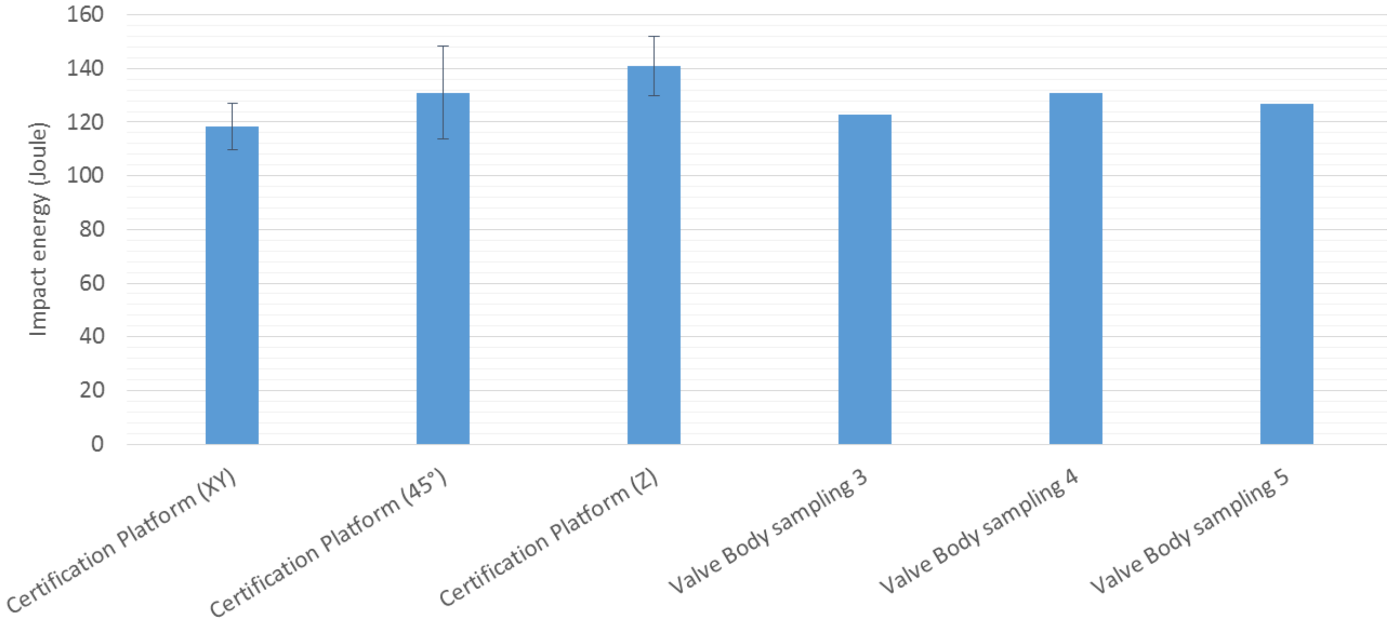
ENGIE Laborelec

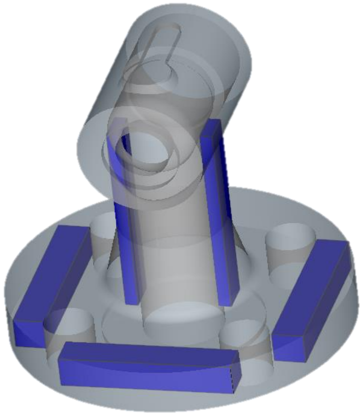
Reverse Engineering incorporating Metal Additive Manufacturing
Process stability, reproducibility





Reverse Engineering incorporating Metal Additive Manufacturing
Process stability, reproducibility





Reverse Engineering incorporating Metal Additive Manufacturing

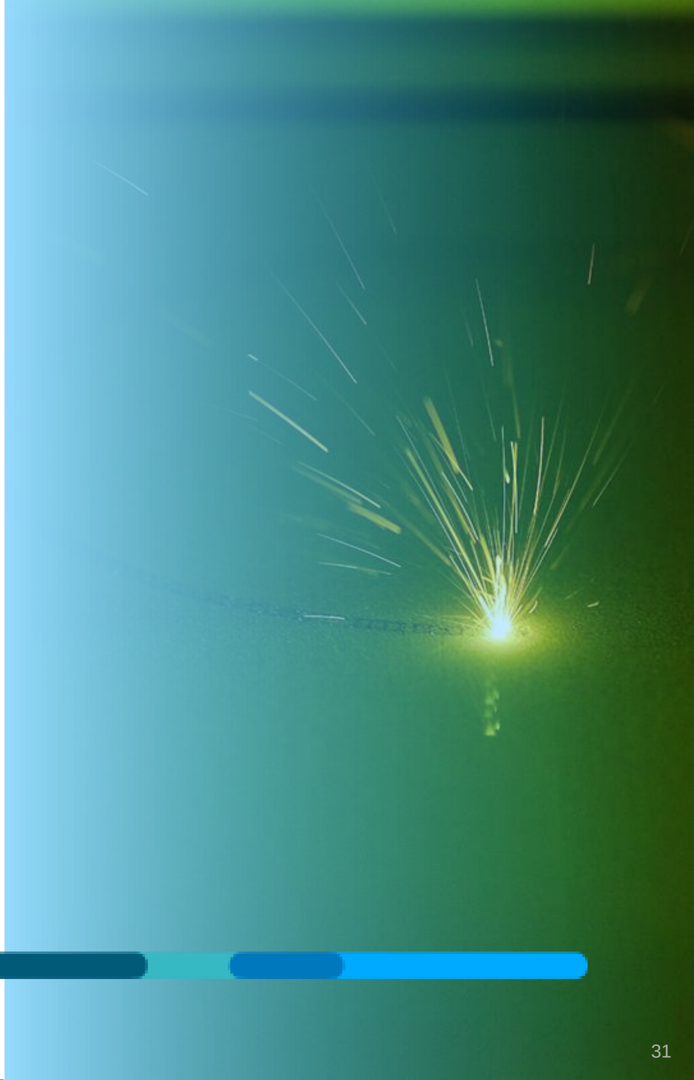
Laborelec

Qualification approach to tackle ENGIE obsolescence challenges

Safety classified terminal blocks for Belgian nuclear power station

ENGIE Laborelec

ENGIE Electrabel

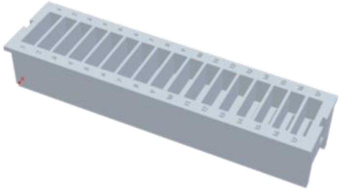


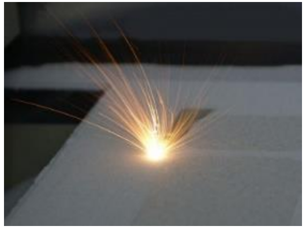
CNT Qualification & Obsolescence

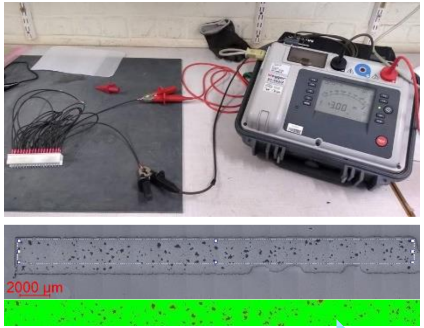
Nuclear Qualification of Electrical Equipment: Qualification of 3D printed terminal blocks

RSQ 56.00

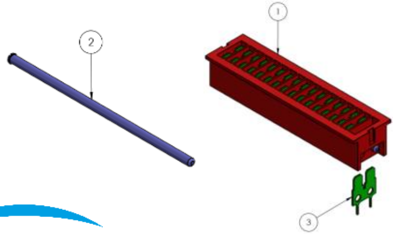
Platine MTI à circuit imprimé _ Carte à relais EDB CA 1080A720 (voir photos en Annexe 01).
Numéro d'article : 720BGAAAAA (*Référence inconnue chez TEC*)

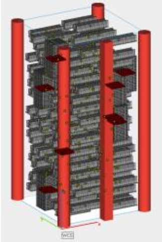






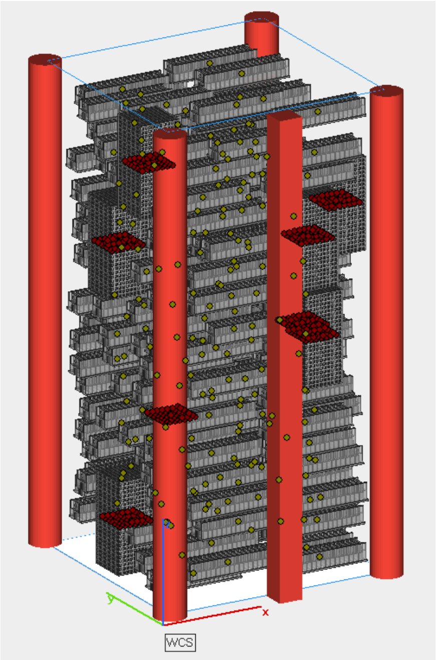
- Obsolescence ✓
- Terminal Block Design ✓
- Terminal Block Geometry for Additive Manufacturing ✓
- Build Preparation ✓
- Production ✓
- Qualification by Tractebel/Laborelec (ongoing)



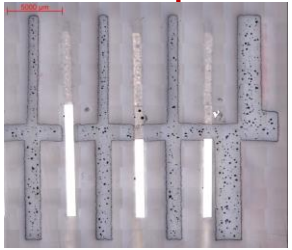


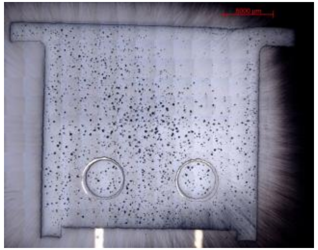
CNT Qualification & Obsolescence
Nuclear Qualification of Electrical Equipment: Qualification of 3D printed terminal blocks

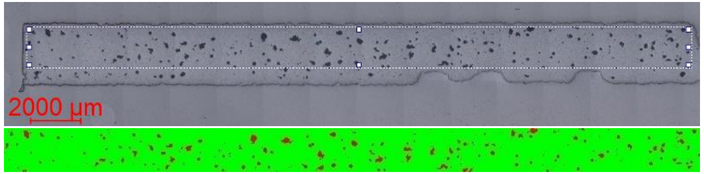
Build Preparation

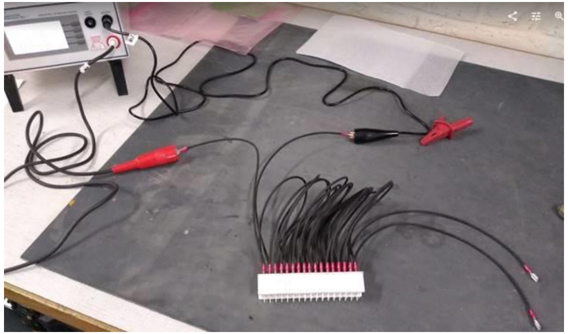


Qualification by Tractebel/Laborelec
(ongoing)









Any Questions ?

Laborelec

Electrabel