Optimization Study for Off-Loading the Shearon Harris Spent Nuclear Fuel Pool using Transportable Aging and Disposal (TAD) Canisters Phase II

Senior Design 2 – Spring 2021

Team Members: Mikayla Harkey (mharkey7@uncc.edu), John Gasson (jgasson@uncc.edu), Bhargav Gajjar (bgajjar1@uncc.edu), Albert Shank (ashank3@uncc.edu), Andriy Bilovol (abilovol@uncc.edu), Nathan Pearce (npearce@uncc.edu), Victoria Kuntz (vkuntz@uncc.edu), Sydney Rowan (srowan2@uncc.edu).

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- Examine the feasibility of 3D printing impact limiters for Transportation, Aging, and Disposable Canister Casks as well as Impact Limiters on both a full and prototype scale.
- Examine the possibility for 3D printing with two or more metals to allow signal transmission through the part without penetration.

Process

Research
-Establish what we know, fill in the gaps
-Scholarly Articles
-UNCC Professors
-Government Documents
-Materials Testing

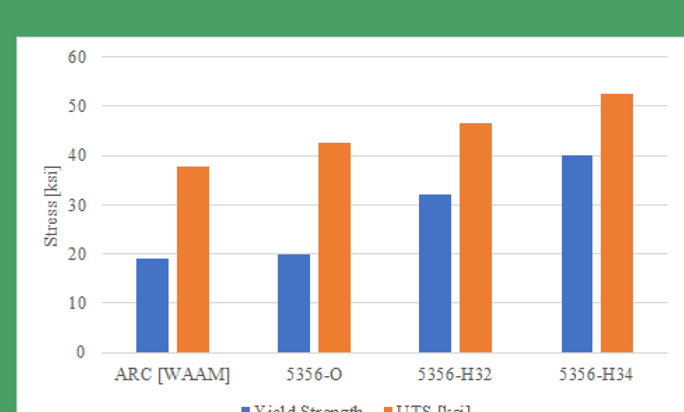
Design
-Iterative Process
-Design change with each informative meeting
-Different design for each manufacturing process
-Based on NRC and DOE regulations

Fabrication
-Research identifies methods
-AHP's identify best methods
-UAM, SPD, DED
-Different methods for prototype and full-scale

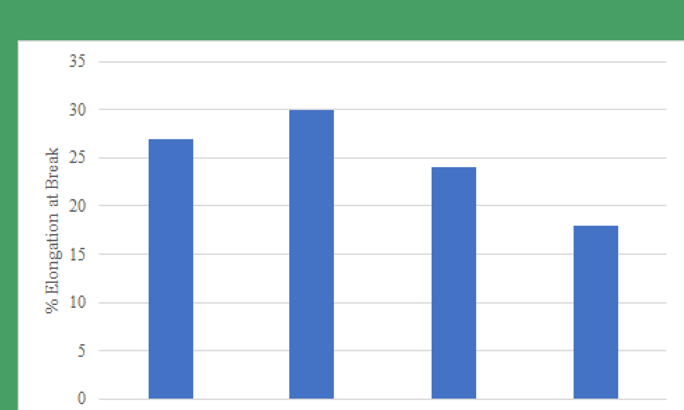
Testing and Analysis
-DOE and NRC specifications
-Digital Simulation/Finite Element Analysis
-Ansys

Material Testing Research

5356 Aluminum
-Tensile Testing ["dogbone" specimens]
-Yield Strength
-Ultimate Tensile Strength
-% Elongation



Purpose
-AM process may alter mechanical properties of our materials
-Incorrect mechanical properties may lead to part failure
-Research conducted to find accurate mechanical properties
-Compare AM vs Traditional



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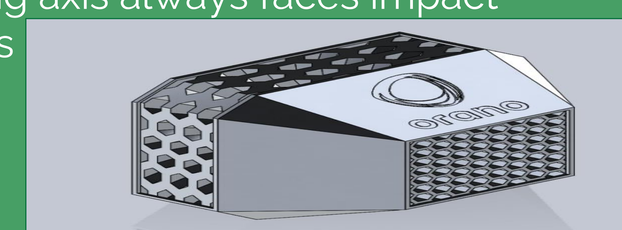
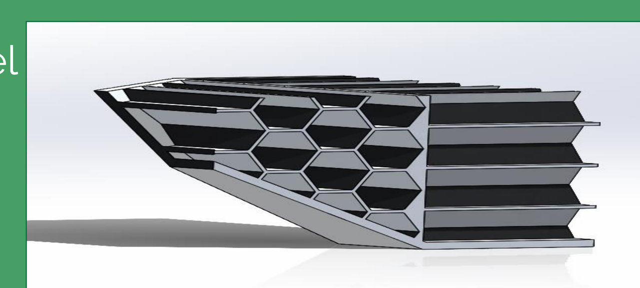
- Research and examine the potential of 3D printing impact limiters with the honeycomb structure and TAD canister primary lid with dissimilar metals
- Research the ability to transmit signal through the primary lid and TAD canister shell using dissimilar metal printing
- Phase III considerations and future implementations

Design and FEA of Impact Limiter

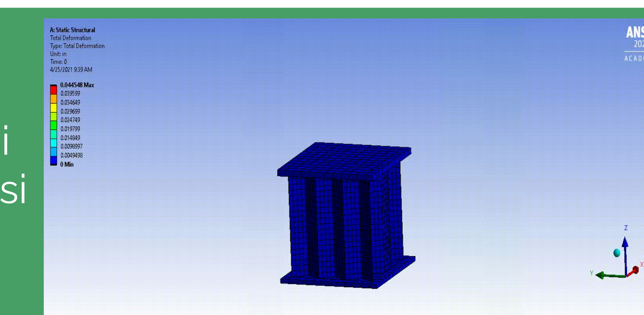
- **Radial Design Honeycomb**
Strong axis always faces impact zones



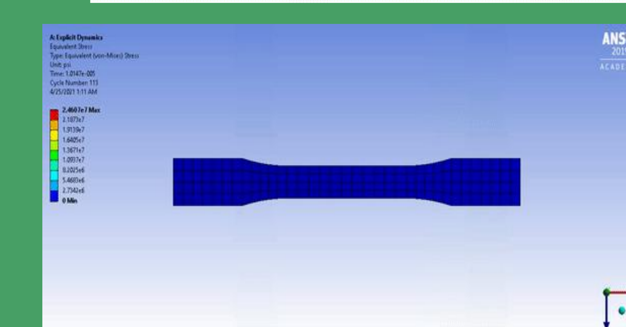
- Proposed corner model for WAAM printing



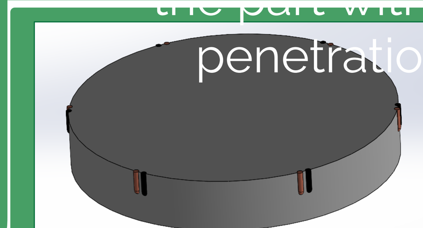
- **Simulated 2'x2' Honeycomb crash test**
8.77 inch deformation at 2000 psi
13.52 inch deformation at 8000 psi



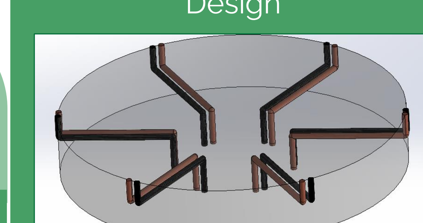
- **Simulated Tensile test**
Yield Strength: 15,420 psi
Tensile strength: 28,310 psi
Young's Modulus: 9,934 ksi
Elongation: 12%



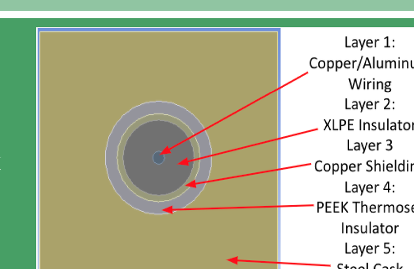
Dissimilar Metal Prototypes and Simulations



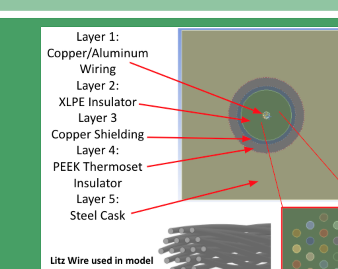
Dissimilar Metal Primary Lid Design


Dissimilar Metal Lid Internal View

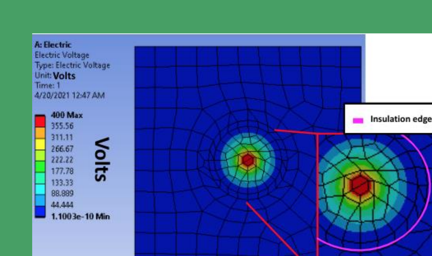
Primary Lid
- Designed with UAM Process from Fabrisonic in mind
- Wires are bent to help with manufacturing restrictions and radiation shielding
- Complex wire designs offer great protection from radiation, heat, corrosion, and EMF interference



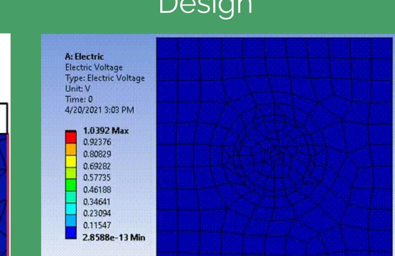
RMD Sensor Wire Design



X-Wave Sensor Wire Design



RMD Sensor Wire Simulation



X-Wave Sensor Wire Simulation

Wire Simulations
- RMD Sensor:
  - 400 V Power Supply
  - 3.5 - 5 V Data Signal
- X-Wave Sensor:
  - 1 Vpp @ 20-30 MHz pulse signal.
- XLPE fully insulates wire.
- Woven Copper shielding protects against EMF interference
- Outer PEEK Plastic adds extra environmental protection while insulating against any possible outer electric contact.

FMEA and Manufacturing Analysis

FAILURE MODE AND EFFECTS ANALYSIS

Item: TAD Canister Lid — Responsibility: V.Kuntz & S.Rowan — FMEA number: 2
Model: Current — Prepared by: V.Kuntz — Page: 1 of 1
Core Team: ORANO_TAD2 — FMEA Date (Orig): 11/18/2020 — Rev: 2

Part Design	Potential Failure Mode	Potential Effect(s)	Sev	Potential Cause(s)	Occ	Current Process Controls	Det	RPN	Recommended Action(s)	Responsibility	Action Results: Actions Taken	Sev	Occ	Det	RPN
TAD Canister Lid	Cracking	Scrap part	8	Stress when printing or temperature expansion	6	None	5	240	Use UAM	Lid Design Team	Use UAM	4	2	5	40
	Warping	Potential to affect signal transmission	5	Stress when printing or temperature expansion	8	None	2	80	Use UAM	Lid Design Team	Use UAM	4	3	2	24
	Print failure	Scrap part	9	Machine error	6	None	1	54	Consult Fabrisonic experts	Manufacturer: Fabrisonics	Use UAM	9	3	1	27
TAD Canister Lid Wiring	Wire shorting	No signal	7	Wire fracture	3	None	1	21	Anodized wire	Lid Design Team	Anodized wire	4	2	1	8
	Inability to transmit signal through wall	No signal	7	Insulation failure	5	None	1	35	Insulate with titanium or ceramic	Lid Design Team	Insulate with titanium or ceramic	6	2	1	12
	Voltage leak	electrocution effect	5	Melted Insulator	2	None	5	50	Choose insulator with high melting temperature. Perform tests.	Lid Design Team	Choose insulator with high melting temperature. Perform tests.	5	1	5	25
	Fraying of insulator/ conductor	No Signal	5	Lid placed on or removed from cask	4	None	1	20	Use embedded wires and use protective metal layer over them.	Lid Design Team	Use embedded wires and use protective metal layer over them.	5	1	1	5
	Electromagnetic Field Interference	Interrupt data signals and break sensors	9	Alternating current	8	None	2	144	add electromagnetic shielding	Lid Design Team	add electromagnetic shielding	9	1	2	18
	Loss of Confinement	Gas and radiation leakage	8	confinement seal; leak where gas can get through	6	None	3	144	Use fabrasonic manufacturing process	Lid Design Team	Use fabrasonic manufacturing process	8	2	3	48
	Insufficient Shielding	Radiation Exposure	9	Insulation breaking down	5	None	3	135	Use ceramic insulators instead of polymers and minimize the size of cross sectional insulator area	Lid Design Team	Use ceramic insulators instead of polymers and minimize the size of cross sectional insulator area	9	2	2	36
	Contraction and Expansion	Break in seal, loss of confinement, pressure on insulators	9	High temperatures affecting resistivity, melting, expansion, and contraction	5	None	3	135	Use ceramics and polymenrs that provide better thermal properties	Lid Design Team	Use ceramics and polymenrs that provide better thermal properties	9	2	3	54

FAILURE MODE AND EFFECTS ANALYSIS

Item: Impact Limiter — Responsibility: V. Kuntz & S.Rowan — FMEA number: 3
Model: Current — Prepared by: V.Kuntz — Page: 1 of 1
Core Team: ORANO_TAD2 — FMEA Date (Orig): 11/21/2020 — Rev: 1

Part Design	Potential Failure Mode	Potential Effect(s)	Sev	Potential Cause(s)	Occ	Current Process Controls	Det	RPN	Recommended Action(s)	Responsibility	Action Results: Actions Taken	Sev	Occ	Det	RPN
Impact Limiter honeycomb structure	Cracking	Decrease in performance	8	Stress when printing	6	None	8	384	Thicker walls, NDT internal testing	Impact Limiter Design Team, Manufacturer	Thicker walls	8	3	8	192
	Warping	Decrease in performance	5	Stress when printing	8	None	8	320	Thicker walls, NDT internal testing	Impact Limiter Design Team, Manufacturer	Thicker walls	5	3	8	120
	Print failure	Scrap part	9	Machine error	6	None	1	54	Consult ARC Specialties experts	Manufacturer: ARC Specialties	N/A	9	6	1	54
Impact Limiter walls	Warping	Decrease in performance	7	Stress when printing	8	None	3	168	Add supports, NDT internal testing	Impact Limiter Design Team, Manufacturer	Add supports	7	3	3	63
	Cracking	Scrap part	8	Stress when printing	6	None	5	240	Add supports, NDT internal testing	Impact Limiter Design Team, Manufacturer	Add supports	8	3	5	120
	Print failure	Scrap part	9	Machine error	6	None	1	54	Consult ARC Specialties experts	Manufacturer: ARC Specialties	N/A	9	6	1	54

FAILURE MODE AND EFFECTS ANALYSIS

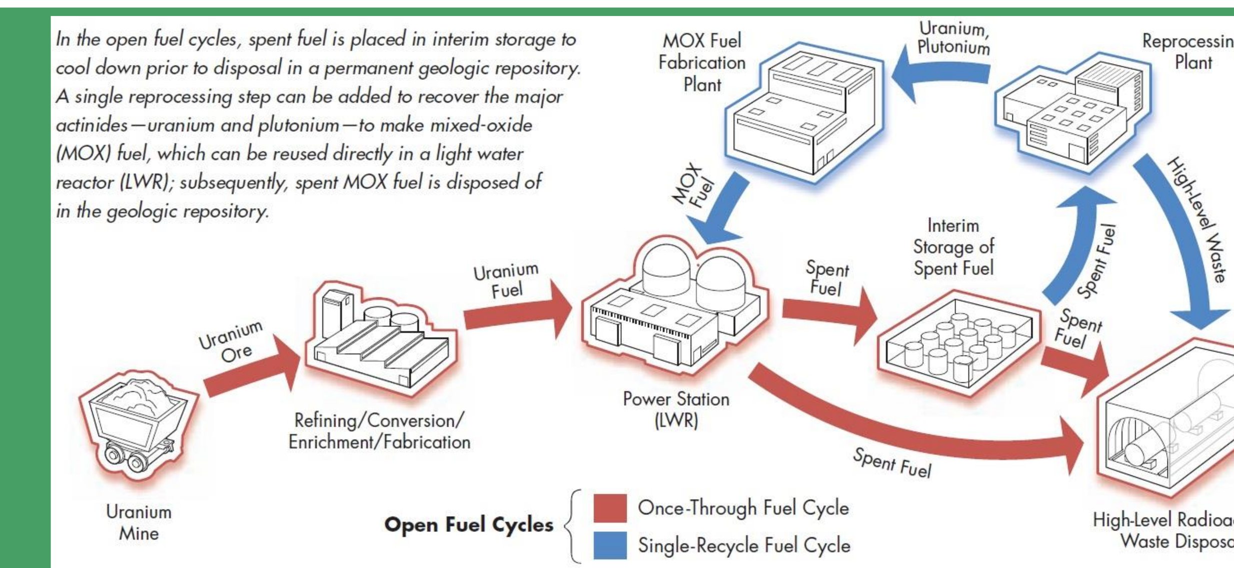
Item: Manufacturing Phase 1 Prints — Responsibility: V.Kuntz & S. Rowan — FMEA number: 4
Model: Current — Prepared by: V.Kuntz — Page: 1 of 1
Core Team: ORANO_TAD2 — FMEA Date (Orig): 11/21/2020 — Rev: 2

Part Design	Potential Failure Mode	Potential Effect(s)	Sev	Potential Cause(s)	Occ	Current Process Controls	Det	RPN	Recommended Action(s)	Responsibility	Action Results: Actions Taken	Sev	Occ	Det	RPN
TAD Canister Shell Wall	Cracking	Scrap part	8	Stress when printing	5	None	5	200	Add internal and external supports	TAD Canister Design Team	Add internal and external supports	5	2	5	50
	Warping	Affect shape of interior canister	5	Stress when printing	8	None	3	120	Add internal and external print supports	TAD Canister Design Team	Add internal and external supports	4	3	3	36
	Print Failure	Scrap part	7	Post print processes	8	None	1	56	Minimize size of print	TAD Canister Design Team	Minimize size of print	7	4	1	28
TAD Canister Basket Walls	Cracking	Scrap part	8	Stress when printing	5	None	5	200	Add internal and external supports	TAD Canister Design Team	Add internal and external supports	5	2	5	50
	Warping	Affect shape of interior canister	5	Stress when printing	8	None	4	160	Add internal and external print supports	TAD Canister Design Team	Add internal and external supports	4	3	4	48
	Print Failure	Scrap part	7	Post print processes	8	None	1	56	Minimize size of print	TAD Canister Design Team	Minimize size of print	7	4	1	28

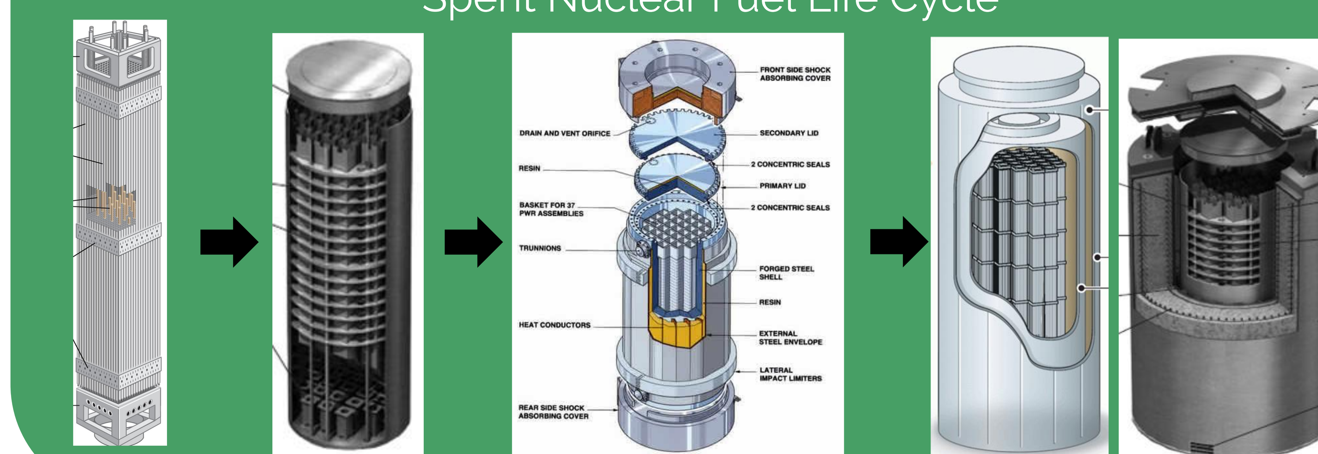
- S=Severity (A number 1-10, 10 is the highest severity)
- O=Occurrence (A number 1-10, 10 is the highest occurrence)
- D=Detection (1-10, 10 is the hardest to detect)

Note: All ratings generated from design review meetings with Fabrisonic, Oerlikon, Aerosint, and ARC specialties as well as case study research and journal publications.

Background



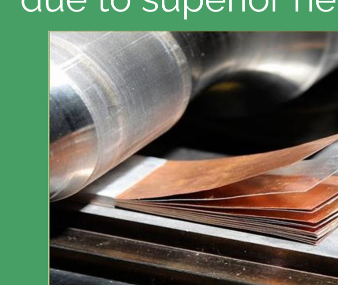
Spent Nuclear Fuel Life Cycle



Fuel Assembly — TAD Canister — TAD with Impact Limiter — Long Term Dry Storage

Full-Scale Applications

- **UAM (Ultrasonic Additive Manufacturing)**
Most viable process for full scale manufacturing of the lid due to superior hermetic seal


Source:https://www.lboro.ac.uk/research/amrg/about/th e7categoriesofadditivemanufacturing/sheetlamination/

- **WAAM (Wire Arc Additive Manufacturing)**
Most viable process for full scale manufacturing of the impact limiter. Easy to scale up


Source:https://www.additivemanufacturing.media/articles/ wire-arc-additive-manufacturing-delivers-low-buy-to-fly-ratios

Lessons Learned

- 3D printing methods for large scale industry purposes are still relatively new and can be extremely expensive depending on the complexity and size of the product required.
- Certain 3D printing methods are incapable of printing certain combinations of materials and as a result this limits manufacturing and cost options.
- Focus groups are important for compiling information from relevant professionals and running project related ideas by other engineers to gather input about design and project improvements.
- When planning projects, more time needs to be given to contact manufacturers and start production earlier in the project timeframe to account for lengthy leadtimes.

Phase III Considerations

Research
-Electroplating with WAAM
-Reducing cost of AM

Fabrication
-Complete printing of phase 2 TN44
-Complete printing of impact limiter honeycomb

Testing
-Crush test honeycomb structure
-Materials testing with FDM
-Materials testing with 17-4 stainless steel
-Continue WAAM materials testing
-Test for anisotropic properties in AM materials

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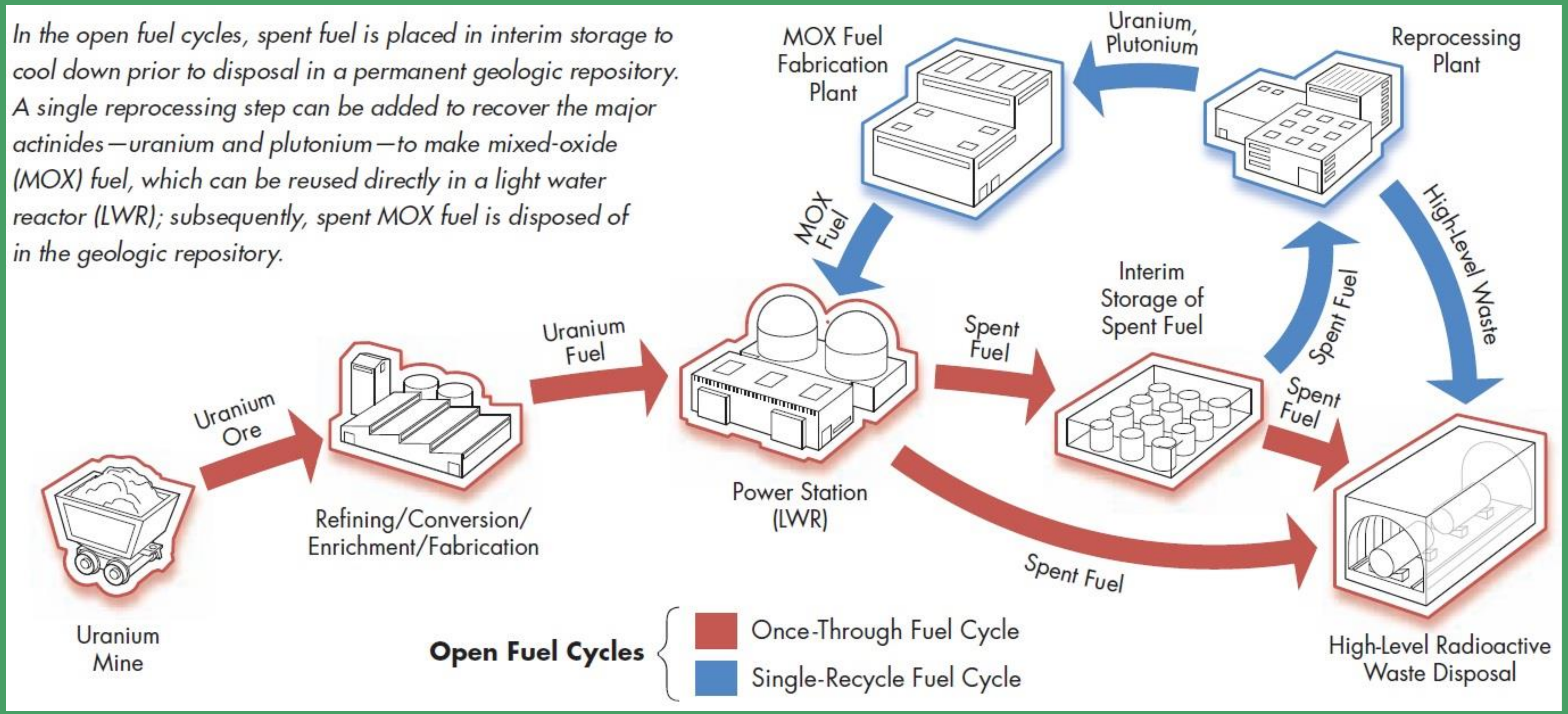

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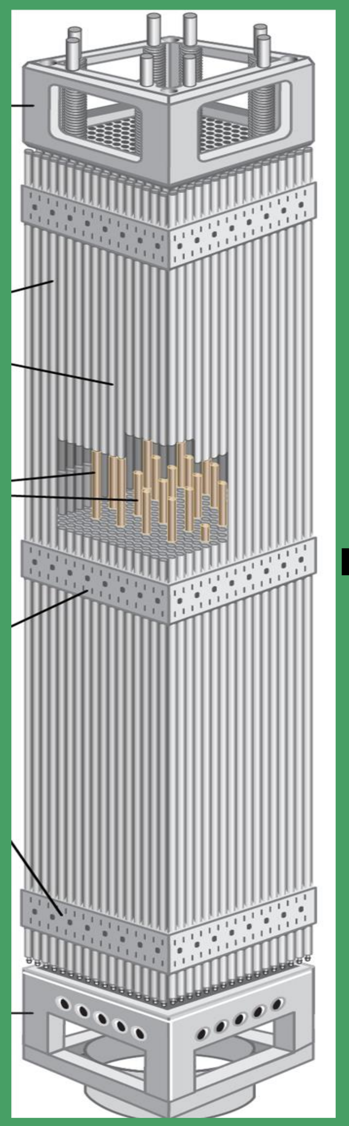
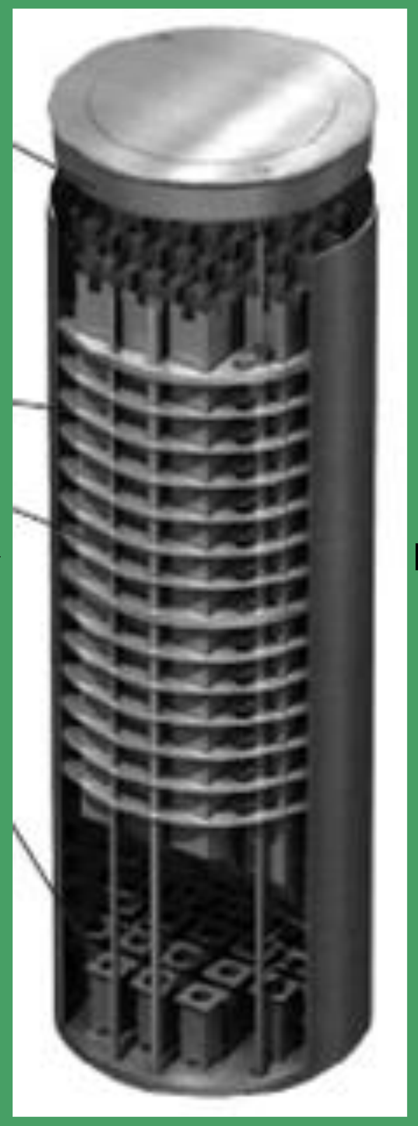
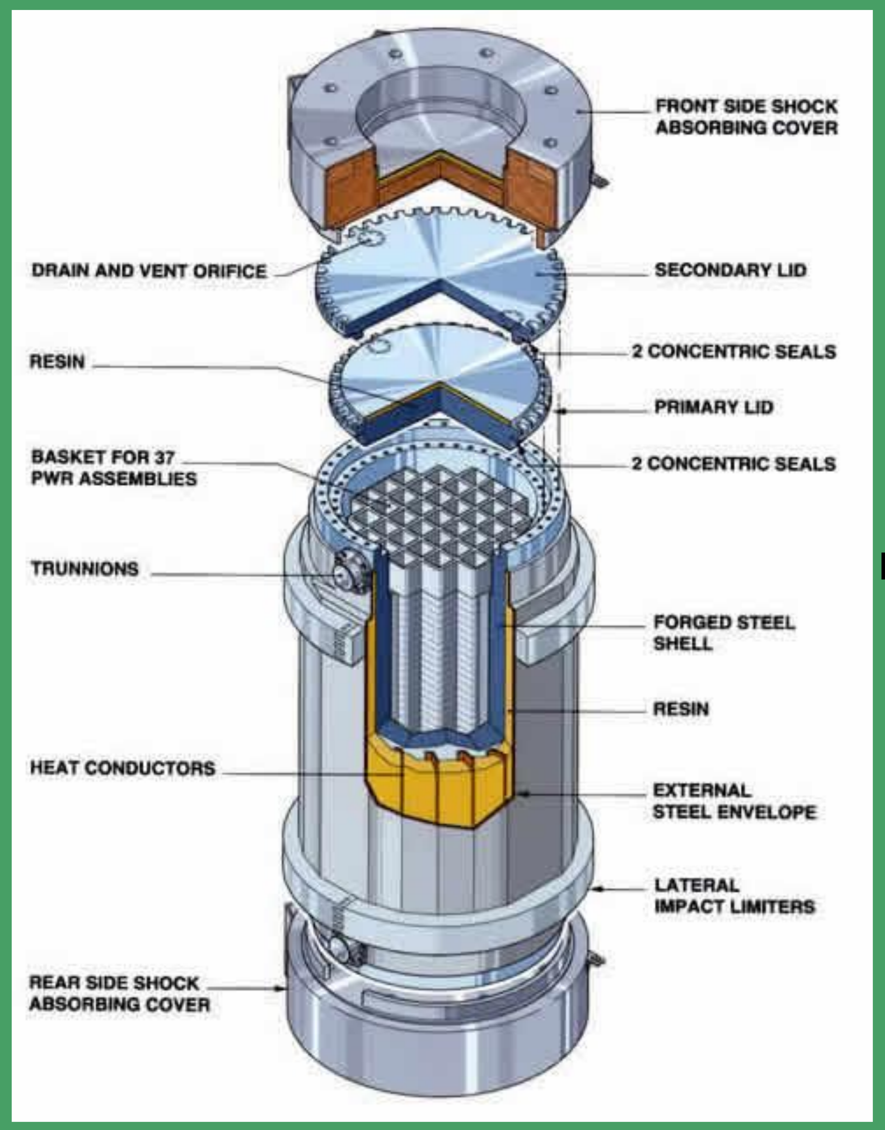


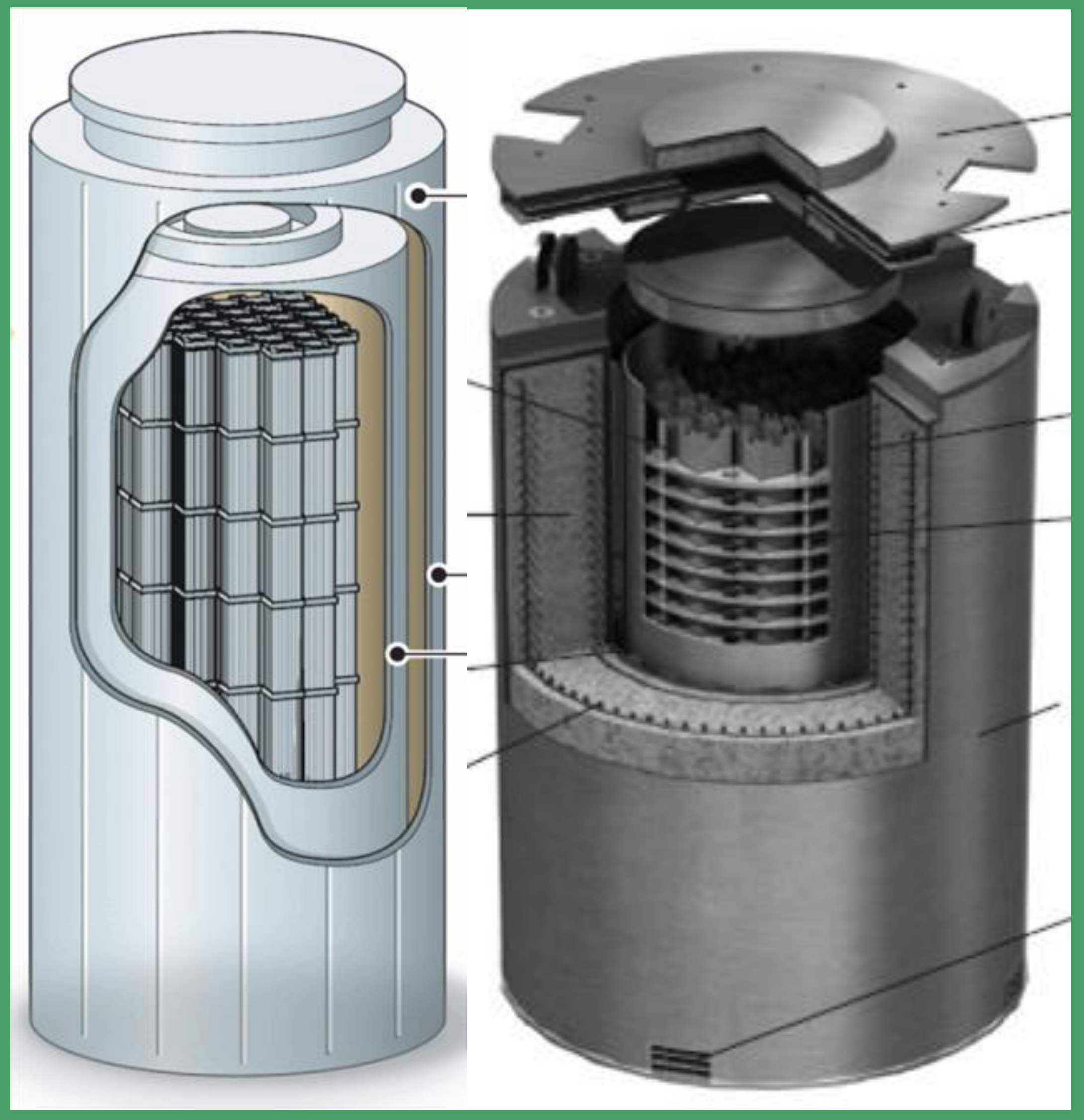
Fuel Assembly



TAD Canister



TAD with Impact Limiter



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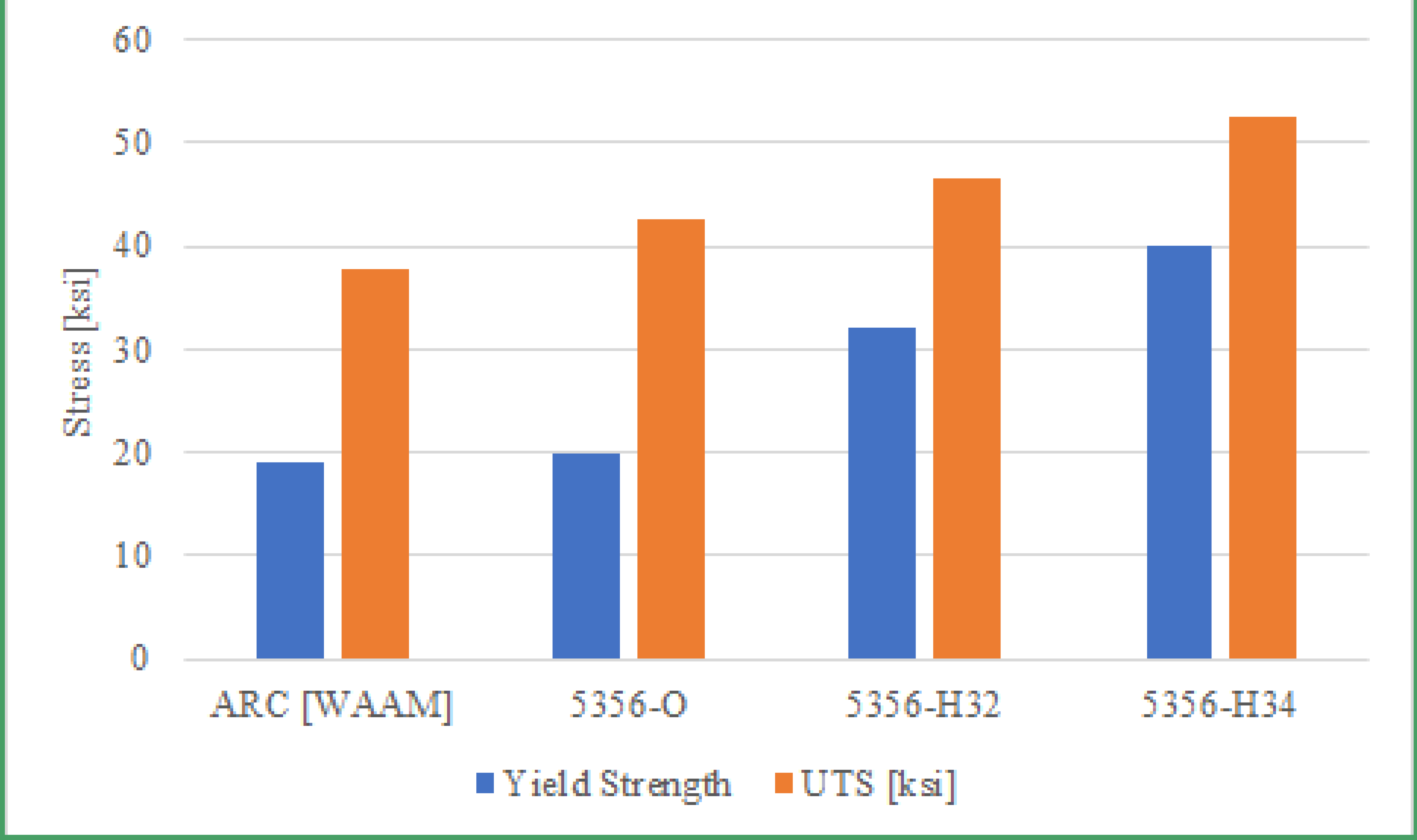

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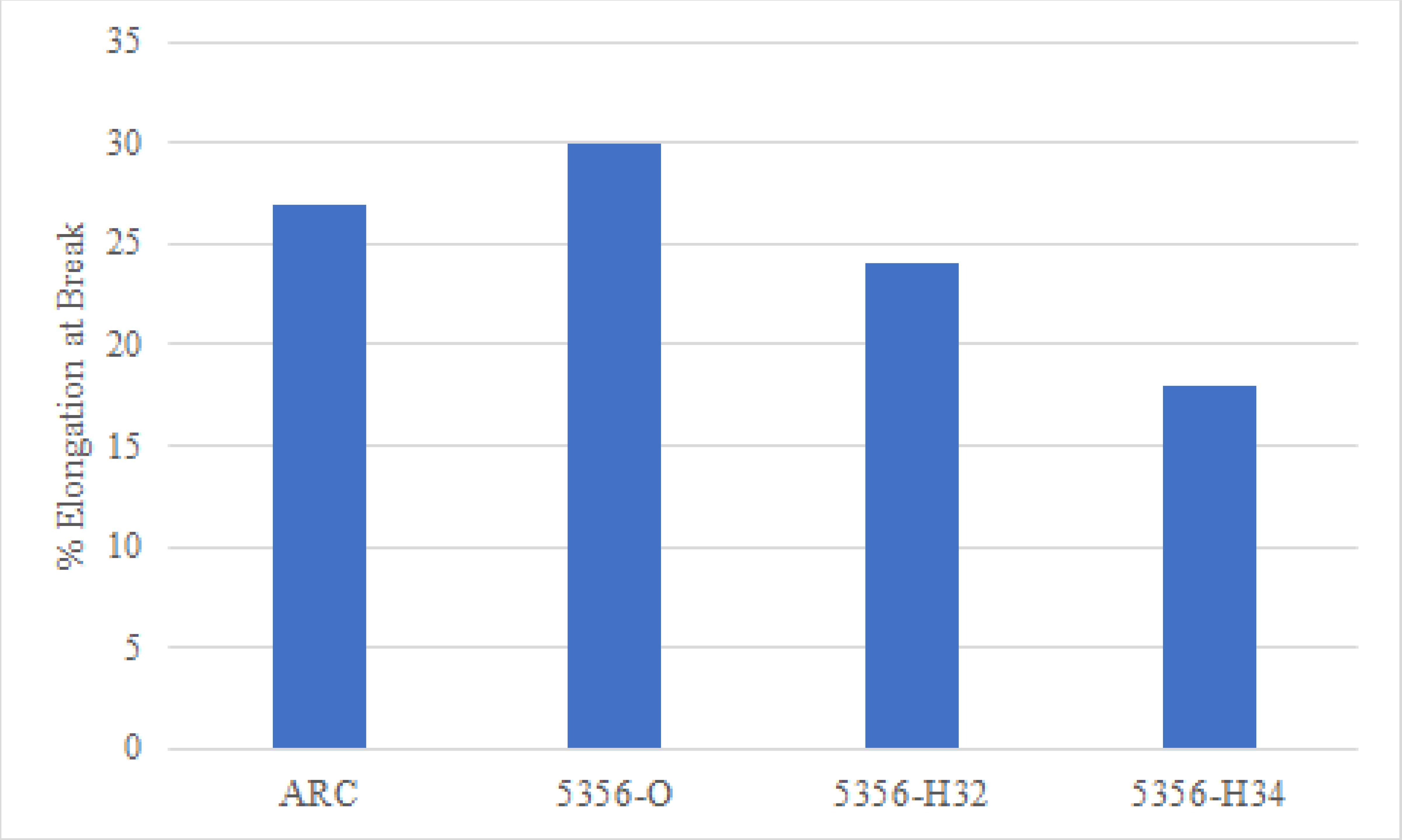

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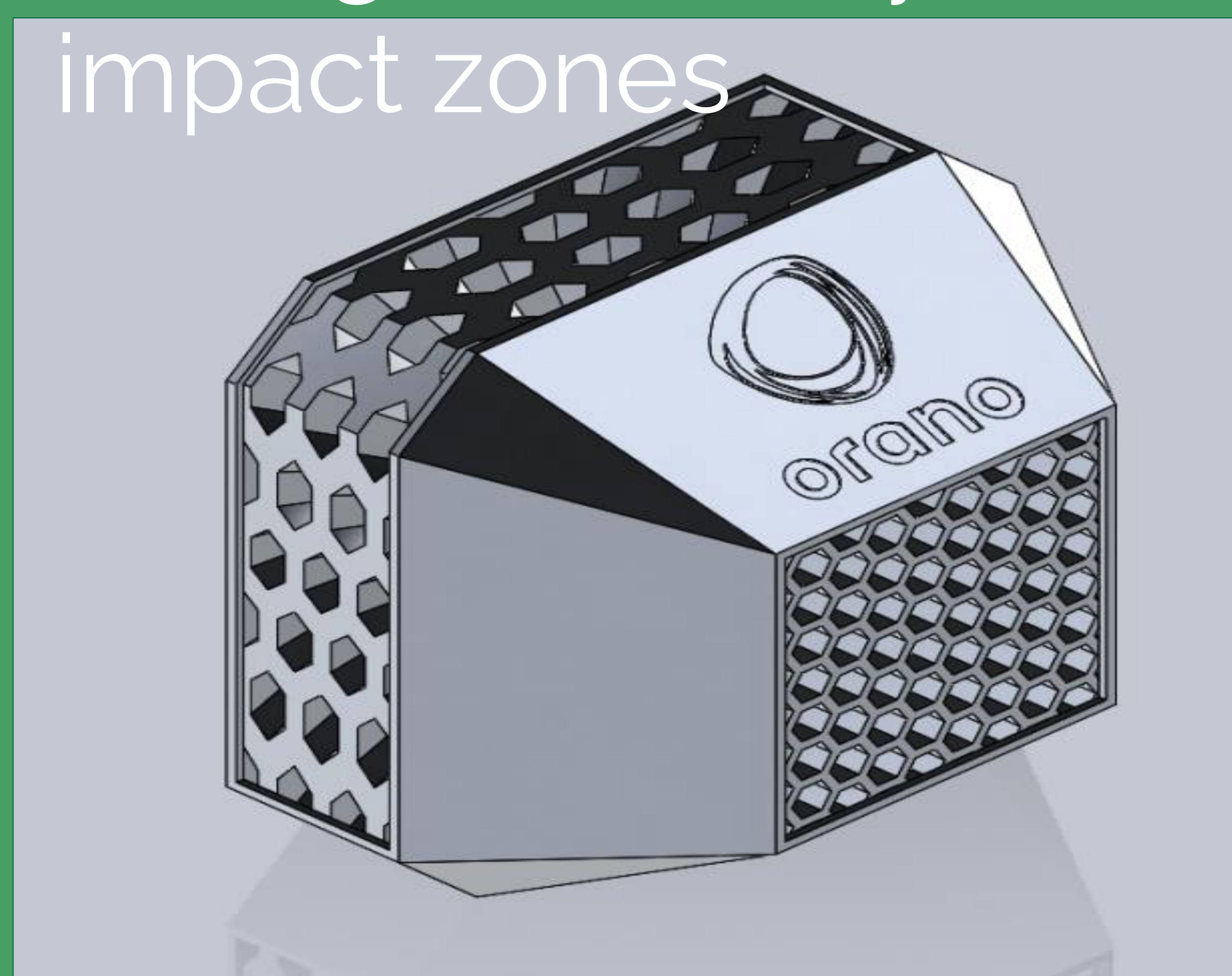

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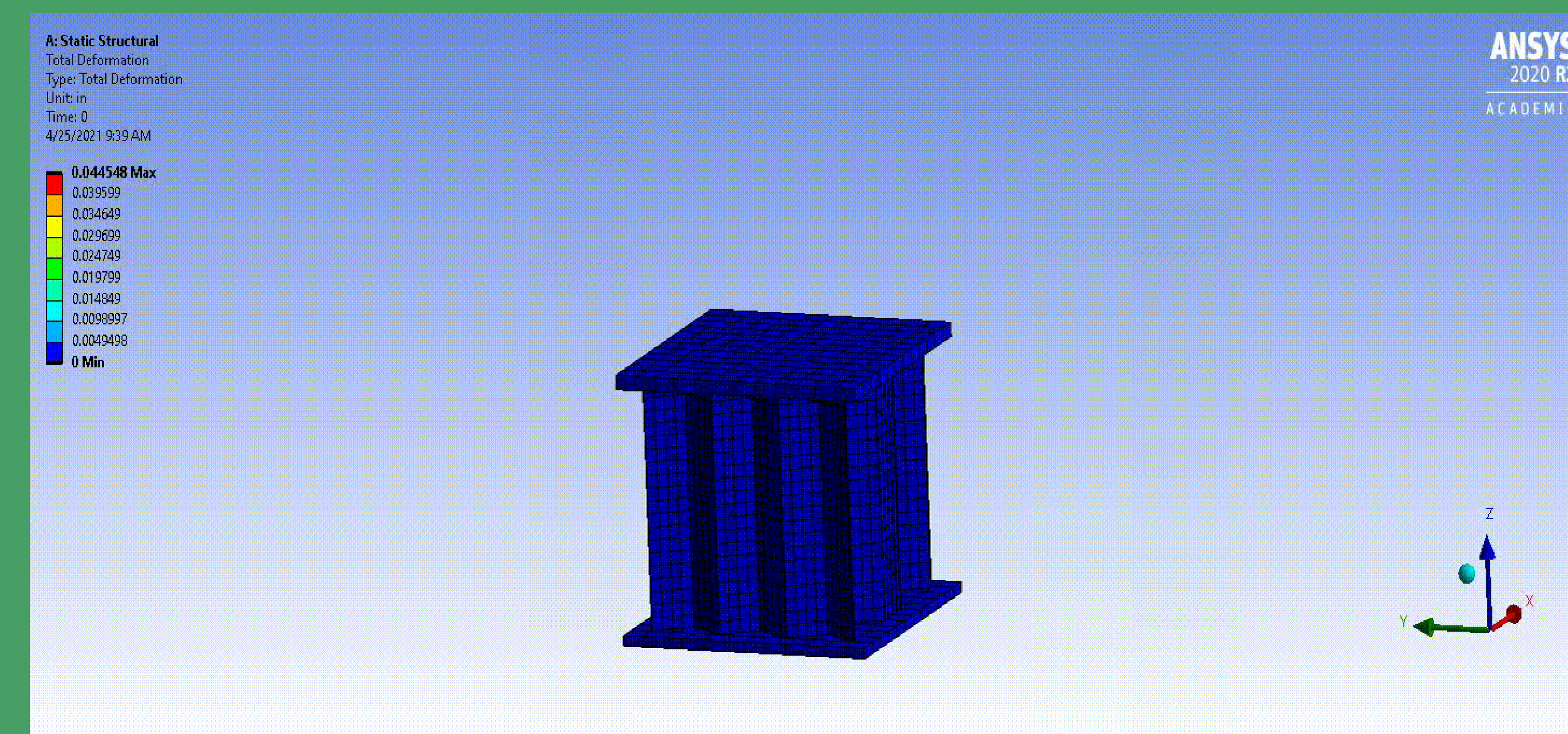

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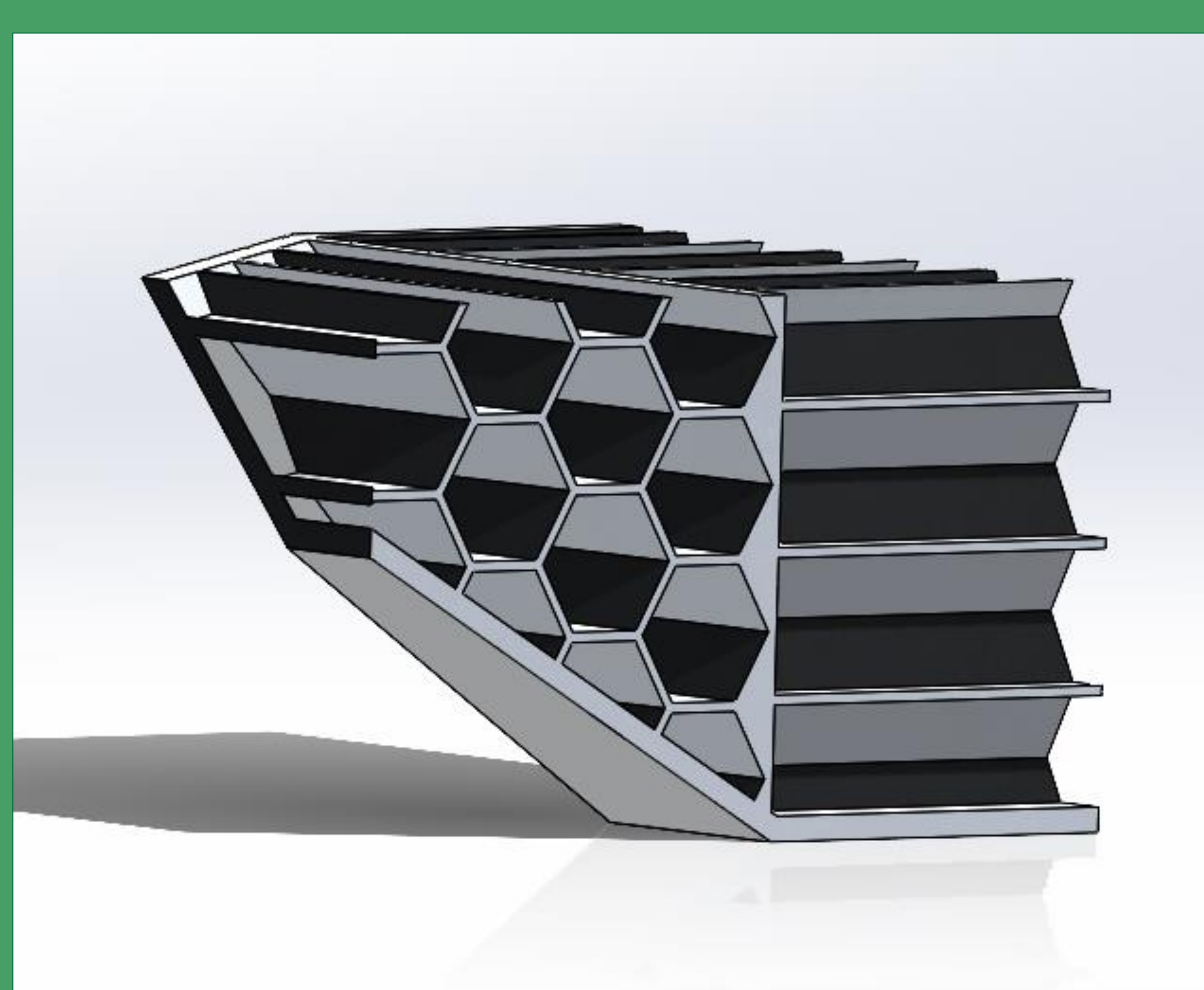

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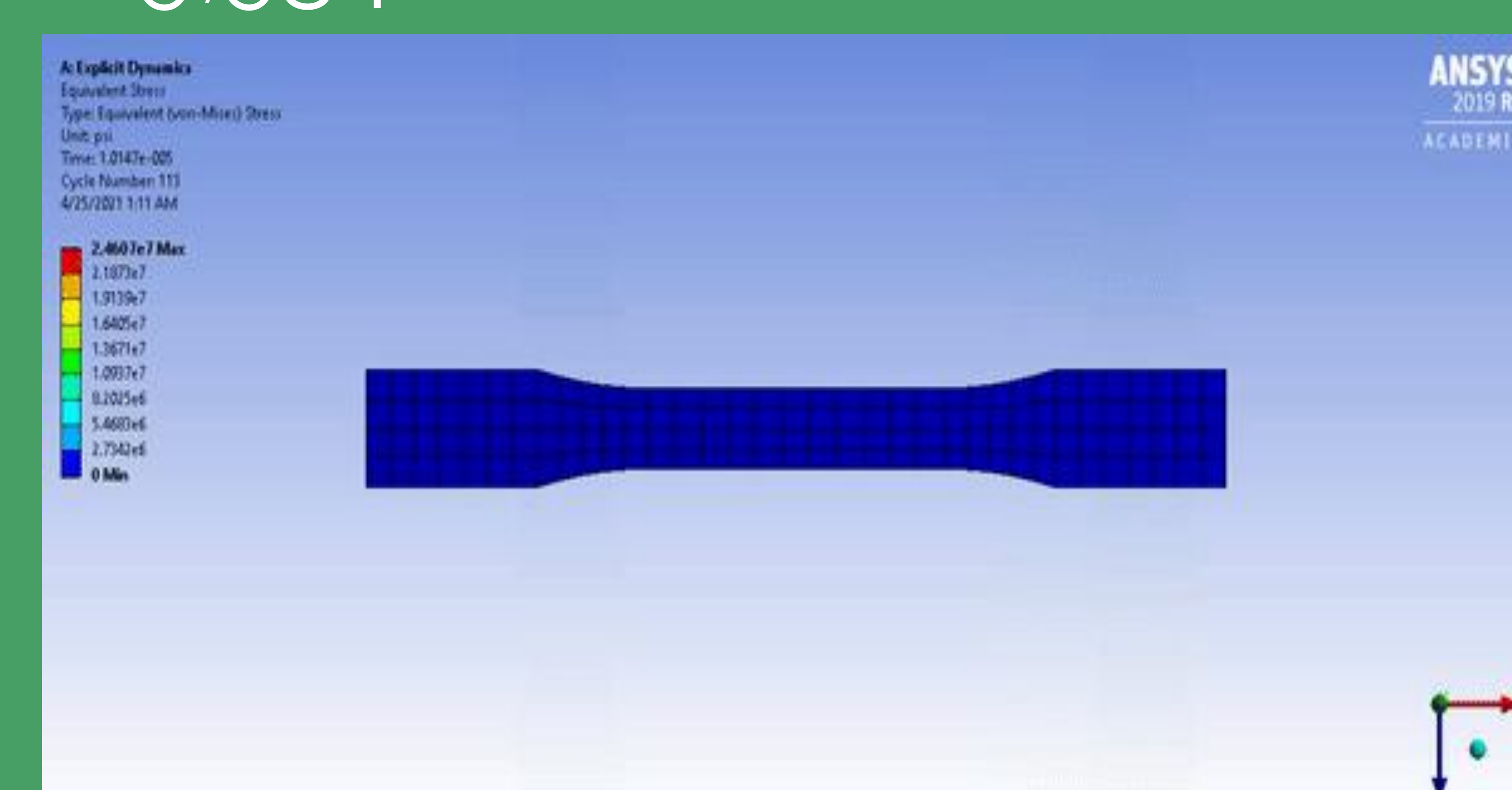

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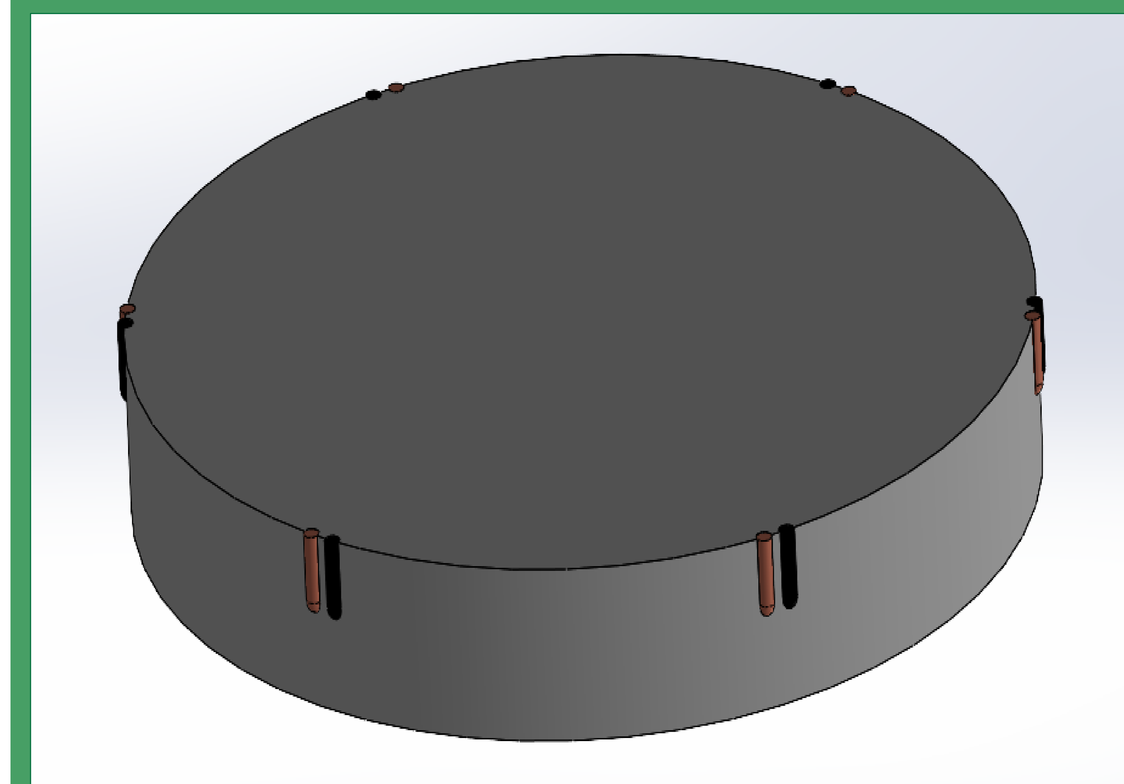
Dissimilar Metal Prototypes



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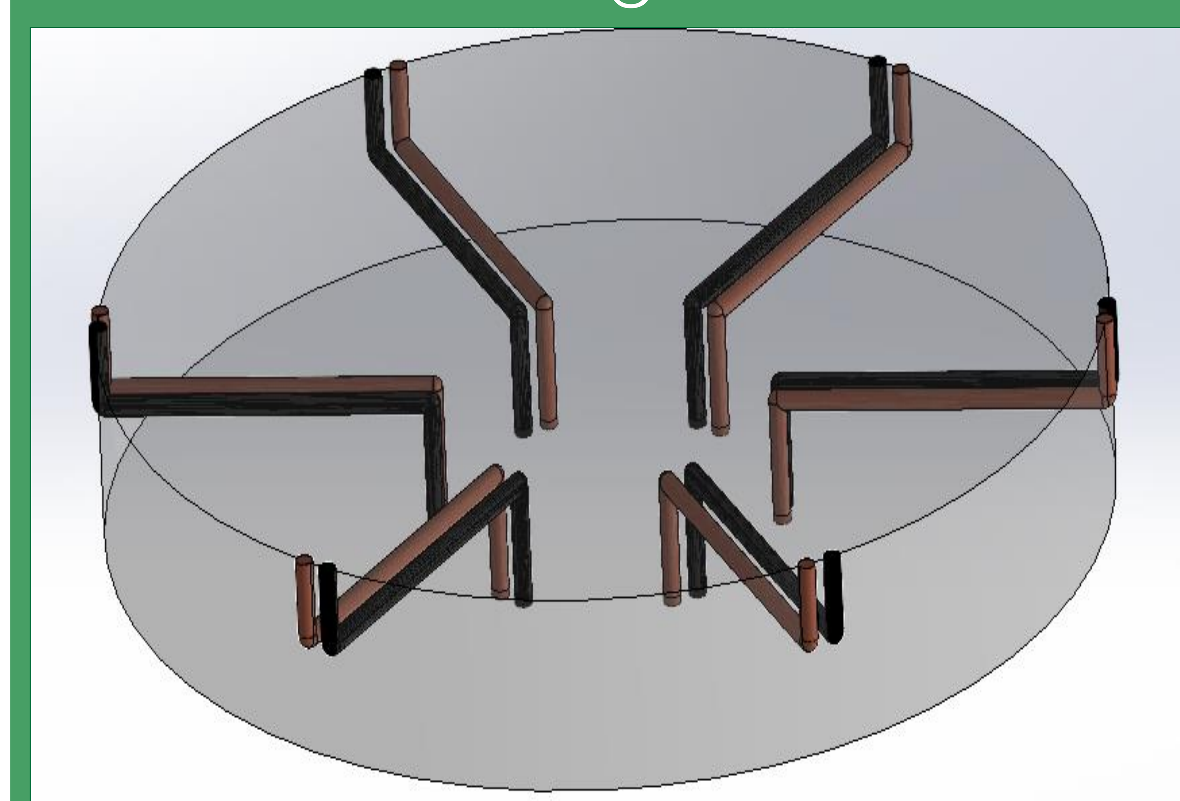

Dissimilar Metal Lid Internal View

Primary Lid

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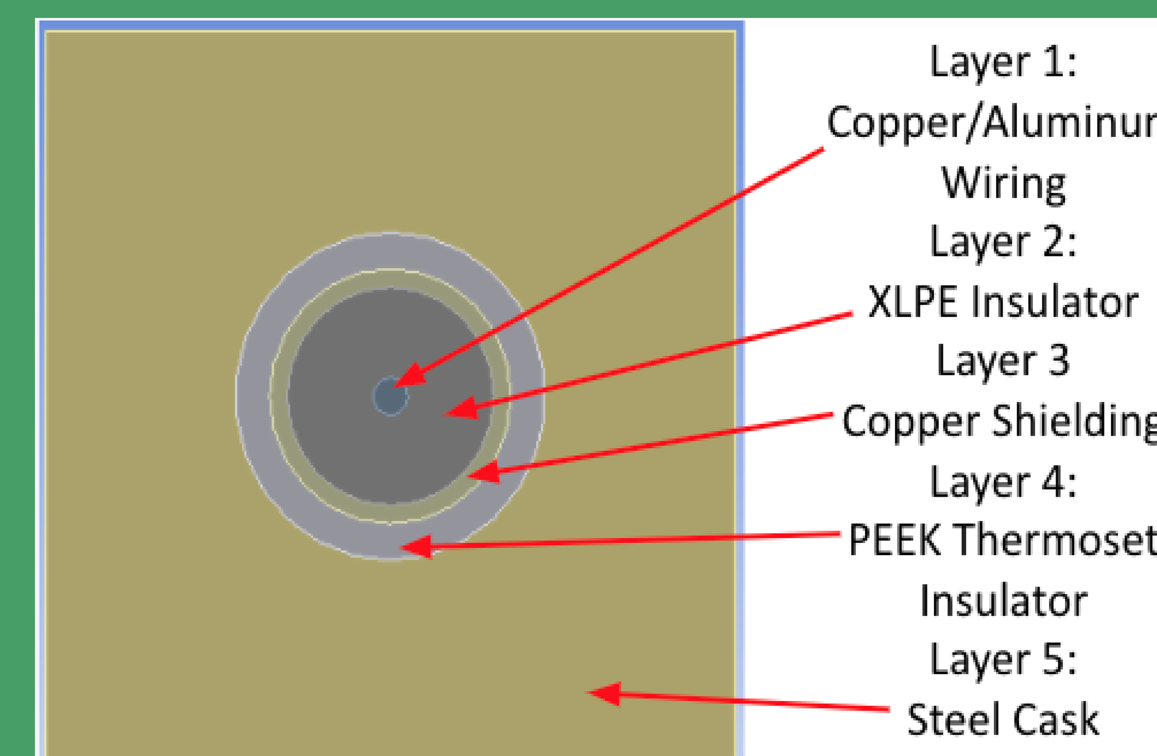
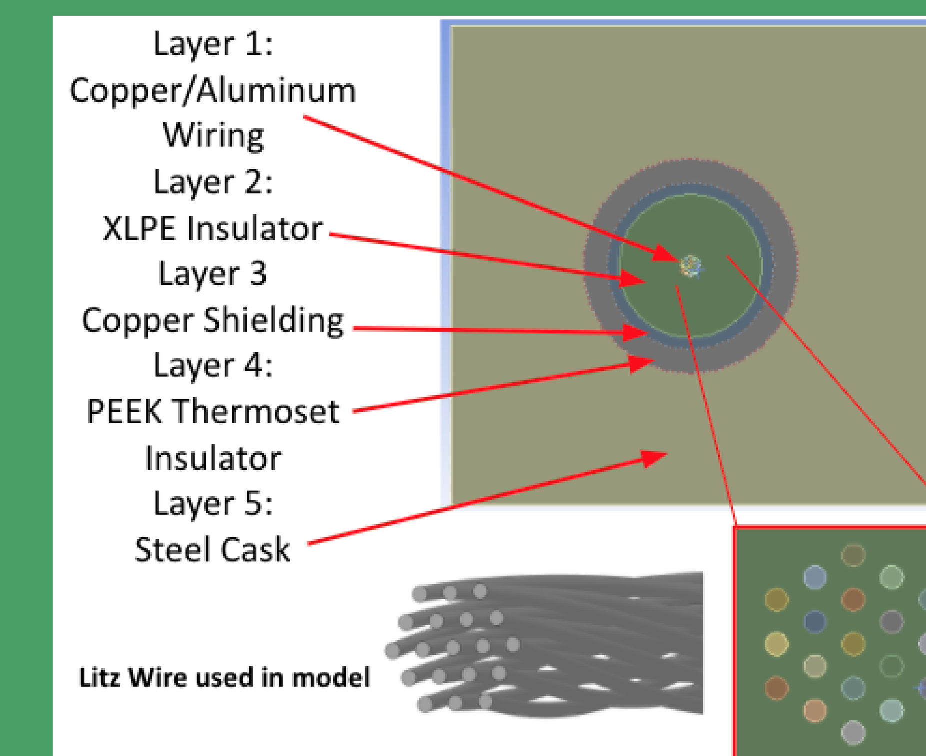
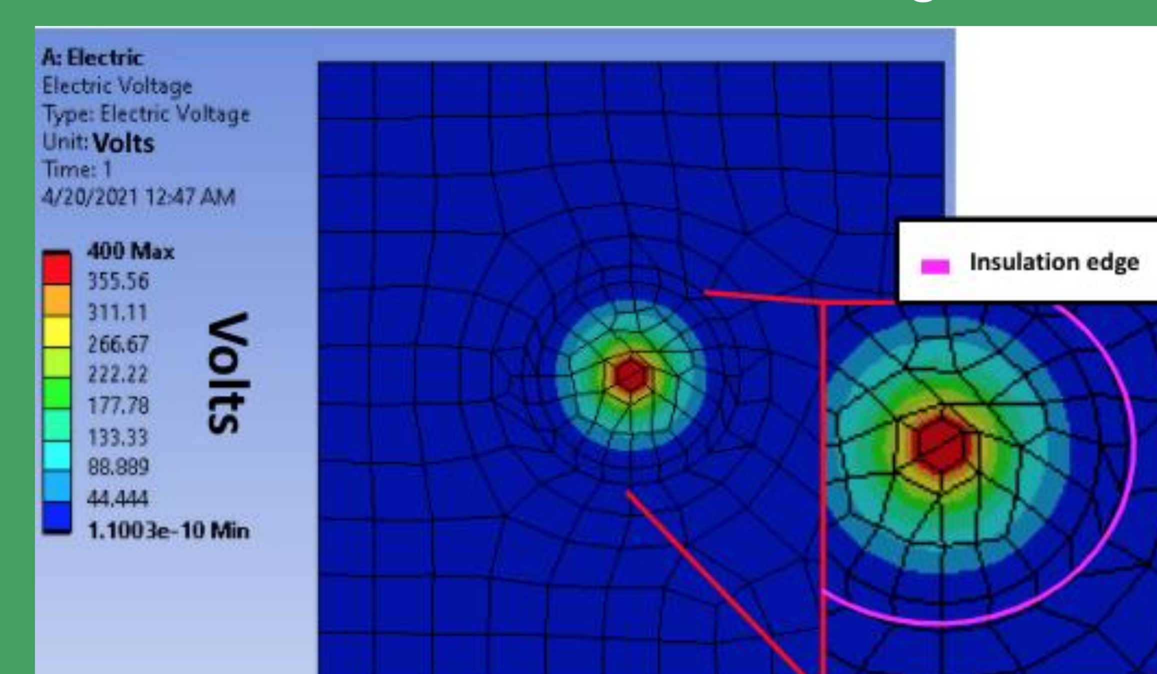


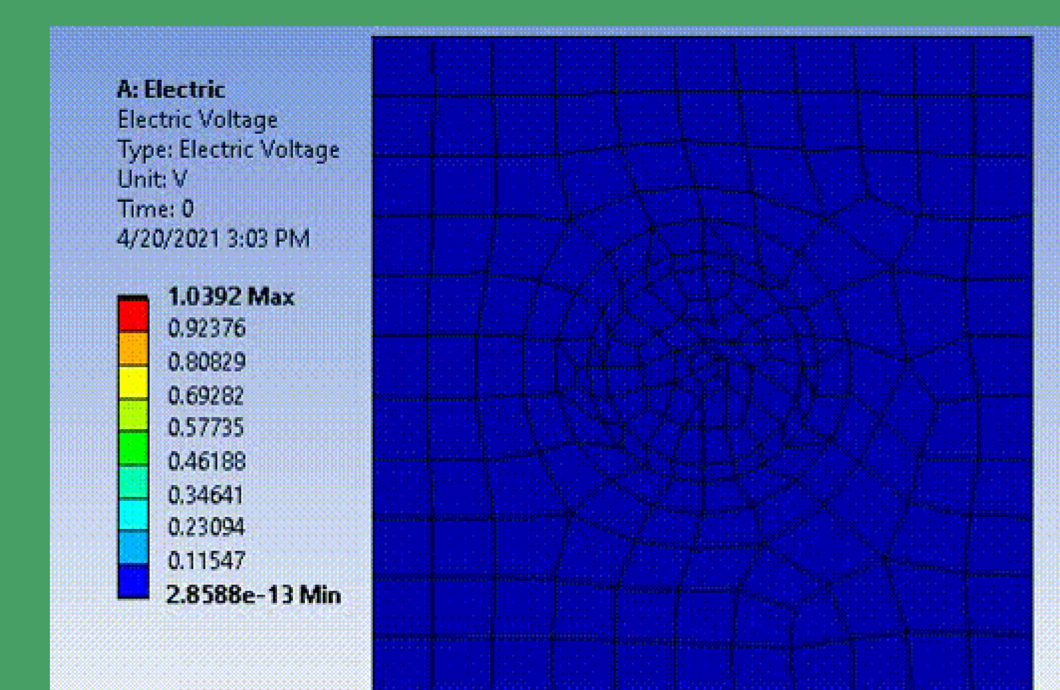
RMD Sensor Wire Design



X-Wave Sensor Wire Design



RMD Sensor Wire Simulation



X-Wave Sensor Wire Simulation

Wire Simulations

- RMD Sensor:
  - 400 V Power Supply
  - 3.5 - 5 V Data Signal
- X-Wave Sensor:
  - 1 Vpp @ 20-30 MHz pulse signal.
- XLPE fully insulates both wires.
- Woven Copper shielding protects against EMF interference
- Outer PEEK Plastic adds extra environmental protection while insulating against any possible exterior electric contact.

UNC CHARLOTTE

Optimization Study for Off-Loading the Shearon Harris Spent Nuclear Fuel Pool using Transportable Aging and Disposal (TAD) Canisters Phase II

Senior Design 2 - Spring 2021

Team Members: Mikayla Harkey (mharkey7@uncc.edu), John Gasson (jgasson@uncc.edu), Bhargav Gajjar (bgajjar1@uncc.edu), Albert Shank (ashank3@uncc.edu), Andriy Bilovol (abilovol@uncc.edu), Nathan Pearce (npearce@uncc.edu), Victoria Kuntz (vkuntz@uncc.edu), Sydney Rowan (srowan2@uncc.edu).
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FMEA and Manufacturing Analysis

FAILURE MODE AND EFFECTS ANALYSIS

Item: TAD Canister Lid **Responsibility:** V.Kuntz & S.Rowan **FMEA number:** 2
Model: Current **Prepared by:** V.Kuntz **Page:** 1 of 1
Core Team: ORANO_TAD2 **FMEA Date (Orig):** 11/18/2020 **Rev:** 2

Part Design	Potential Failure Mode	Potential Effect(s)	Sev	Potential Cause(s)	Occ	Current Process Controls	Det	RPN	Recommended Action(s)	Responsibility	Action Results				
											Actions Taken	Sev	Occ	Det	RPN
TAD Canister Lid	Cracking	Scrap part	8	Stress when printing or temperature expansion	6	None	5	240	Use UAM	Lid Design Team	Use UAM	4	2	5	40
	Warping	Potential to affect signal transmission	5	Stress when printing or temperature expansion	8	None	2	80	Use UAM	Lid Design Team	Use UAM	4	3	2	24
	Print failure	Scrap part	9	Machine error	6	None	1	54	Consult Fabrisonic experts	Manufacturer: Fabrisonics	Use UAM	9	3	1	27
TAD Canister Lid Wiring	Wire shorting	No signal	7	Wire fracture	3	None	1	21	Anodized wire	Lid Design Team	Anodized wire	4	2	1	8
	Inability to transmit signal through wall	No signal	7	Insulation failure	5	None	1	35	Insulate with titanium or ceramic	Lid Design Team	Insulate with titanium or ceramic	6	2	1	12
	Voltage leak	electrocution effect	5	Melted Insulator	2	None	5	50	Choose insulator with high melting temperature. Perform tests.	Lid Design Team	Choose insulator with high melting temperature. Perform tests.	5	1	5	25
	Fraying of insulator/ conductor	No Signal	5	Lid placed on or removed from cask	4	None	1	20	Use embedded wires and use protective metal layer over them.	Lid Design Team	Use embedded wires and use protective metal layer over them.	5	1	1	5
	Electromagnetic Field Interference	Interrupt data signals and break sensors	9	Alternating current	8	None	2	144	add electromagnetic shielding	Lid Design Team	add electromagnetic shielding	9	1	2	18
	Loss of Confinement	Gas and radiation leakage	8	confinement seal; leak where gas can get through	6	None	3	144	Use fabrasonic manufacturing process	Lid Design Team	Use fabrasonic manufacturing process	8	2	3	48
	Insufficient Shielding	Radiation Exposure	9	Insulation breaking down	5	None	3	135	Use ceramic insulators instead of polymers and minimize the size of cross sectional insulator area	Lid Design Team	Use ceramic insulators instead of polymers and minimize the size of cross sectional insulator area	9	2	2	36
	Contraction and Expansion	Break in seal, loss of confinement, pressure on insulators	9	High temperatures affecting resistivity, melting, expansion, and contraction	5	None	3	135	Use ceramics and polymenrs that provide better thermal properties	Lid Design Team	Use ceramics and polymenrs that provide better thermal properties	9	2	3	54

- S=Severity (A number 1-10, 10 is the highest severity)
- O=Occurrence (A number 1-10, 10 is the highest occurrence)
- D=Detection (1-10, 10 is the hardest to detect)

FAILURE MODE AND EFFECTS ANALYSIS

Item: Impact Limiter **Responsibility:** V. Kuntz & S.Rowan FMEA number: 3
Model: Current **Prepared by:** V.Kuntz Page : 1 of 1
Core Team: ORANO_TAD2 FMEA Date (Orig): 11/21/2020 **Rev:** 1

Part Design	Potential Failure Mode	Potential Effect(s)	Sev	Potential Cause(s)	Occ	Current Process Controls	Det	RPN	Recommended Action(s)	Responsibility	Action Results				
											Actions Taken	Sev	Occ	Det	RPN
Impact Limiter honeycomb structure	Cracking	Decrease in performance	8	Stress when printing	6	None	8	384	Thicker walls, NDT internal testing	Impact Limiter Design Team, Manufacturer	Thicker walls	8	3	8	192
	Warping	Decrease in performance	5	Stress when printing	8	None	8	320	Thicker walls, NDT internal testing	Impact Limiter Design Team, Manufacturer	Thicker walls	5	3	8	120
	Print failure	Scrap part	9	Machine error	6	None	1	54	Consult ARC Specialties experts	Manufacturer: ARC Specialties	N/A	9	6	1	54
Impact Limiter walls	Warping	Decrease in performance	7	Stress when printing	8	None	3	168	Add supports, NDT internal testing	Impact Limiter Design Team, Manufacturer	Add supports	7	3	3	63
	Cracking	Scrap part	8	Stress when printing	6	None	5	240	Add supports, NDT internal testing	Impact Limiter Design Team, Manufacturer	Add supports	8	3	5	120
	Print failure	Scrap part	9	Machine error	6	None	1	54	Consult ARC Specialties experts	Manufacturer: ARC Specialties	N/A	9	6	1	54

FAILURE MODE AND EFFECTS ANALYSIS

Item: Manufacturing Phase 1 Prints **Responsibility:** V.Kuntz & S. Rowan FMEA number: 4
Model: Current **Prepared by:** V.Kuntz Page : 1 of 1
Core Team: ORANO_TAD2 FMEA Date (Orig): 11/21/2020 **Rev:** 2

Part Design	Potential Failure Mode	Potential Effect(s)	Sev	Potential Cause(s)	Occ	Current Process Controls	Det	RPN	Recommended Action(s)	Responsibility	Action Results				
											Actions Taken	Sev	Occ	Det	RPN
TAD Canister Shell Wall	Cracking	Scrap part	8	Stress when printing	5	None	5	200	Add internal and external supports	TAD Canister Design Team	Add internal and external supports	5	2	5	50
	Warping	Affect shape of interior canister	5	Stress when printing	8	None	3	120	Add internal and external print supports	TAD Canister Design Team	Add internal and external supports	4	3	3	36
	Print Failure	Scrap part	7	Post print processes	8	None	1	56	Minimize size of print	TAD Canister Design Team	Minimize size of print	7	4	1	28
TAD Canister Basket Walls	Cracking	Scrap part	8	Stress when printing	5	None	5	200	Add internal and external supports	TAD Canister Design Team	Add internal and external supports	5	2	5	50
	Warping	Affect shape of interior canister	5	Stress when printing	8	None	4	160	Add internal and external print supports	TAD Canister Design Team	Add internal and external supports	4	3	4	48
	Print Failure	Scrap part	7	Post print processes	8	None	1	56	Minimize size of print	TAD Canister Design Team	Minimize size of print	7	4	1	28

Note: All ratings generated from design review meetings with Fabrisonic, Oerlikon, Aerosint, and ARC specialties as well as case study research and journal publications.

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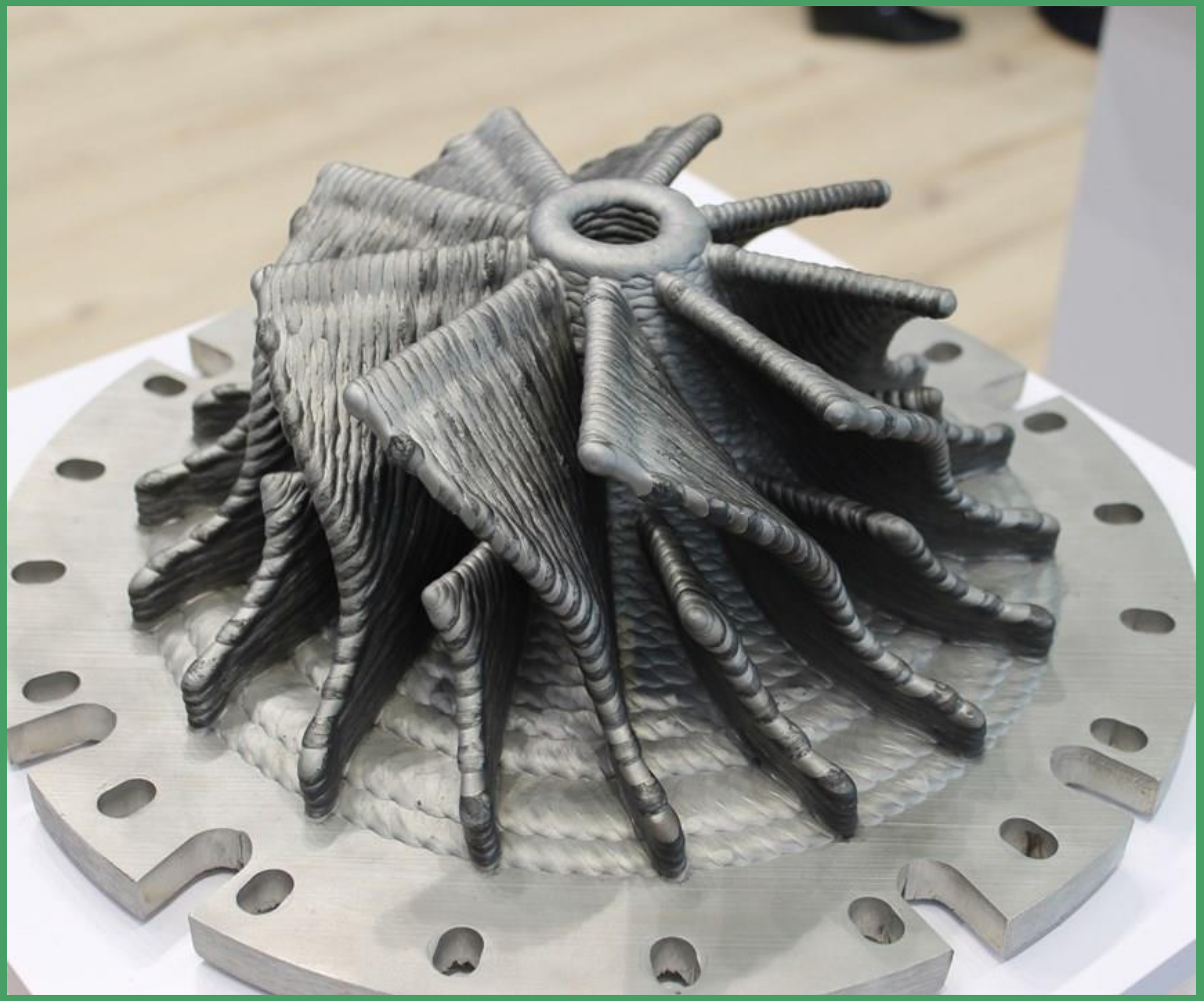
Full Scale Applications

- **UAM (Ultrasonic Additive Manufacturing)**
  Most viable process for full scale manufacturing of the lid due to superior hermetic seal

Source:https://www.lboro.ac.uk/research/amrg/about/the7categories ofadditivemanufacturing/sheetlamination/

- **WAAM (Wire Arc Additive Manufacturing)**
  Most viable process for full scale manufacturing of the impact limiter. Easy to scale up



Source:https://www.additivemanufacturing.media/articles/wire-arc-additive-manufacturing-delivers-low-buy-to-fly-ratios

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Lessons Learned

- 3D printing methods for large scale industry purposes are still relatively new and can be extremely expensive depending on the complexity and size of the product required.
- Certain 3D printing methods are incapable of printing certain combinations of materials and as a result this limits manufacturing and cost options.
- Focus groups are important for compiling information from relevant professionals and running project related ideas by other engineers to gather input about design and project improvements.
- When planning projects, more time needs to be given to contact manufacturers and start production earlier in the project timeframe to account for lengthy leadtimes.

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Phase III Considerations

Research
-Electroplating with WAAM
-Reducing cost of AM

Fabrication
-Complete printing of phase 2 TN44
-Complete printing of impact limiter honeycomb

Testing
-Crush test honeycomb structure
-Materials testing with FDM
-Materials testing with 17-4 stainless steel
-Continue WAAM materials testing
-Test for anisotropic properties in AM materials