Development and testing of detachable waterproof feed-through for a CAT5/CAT6 cable of multi-PMT module in Water Cherenkov Test Experiment

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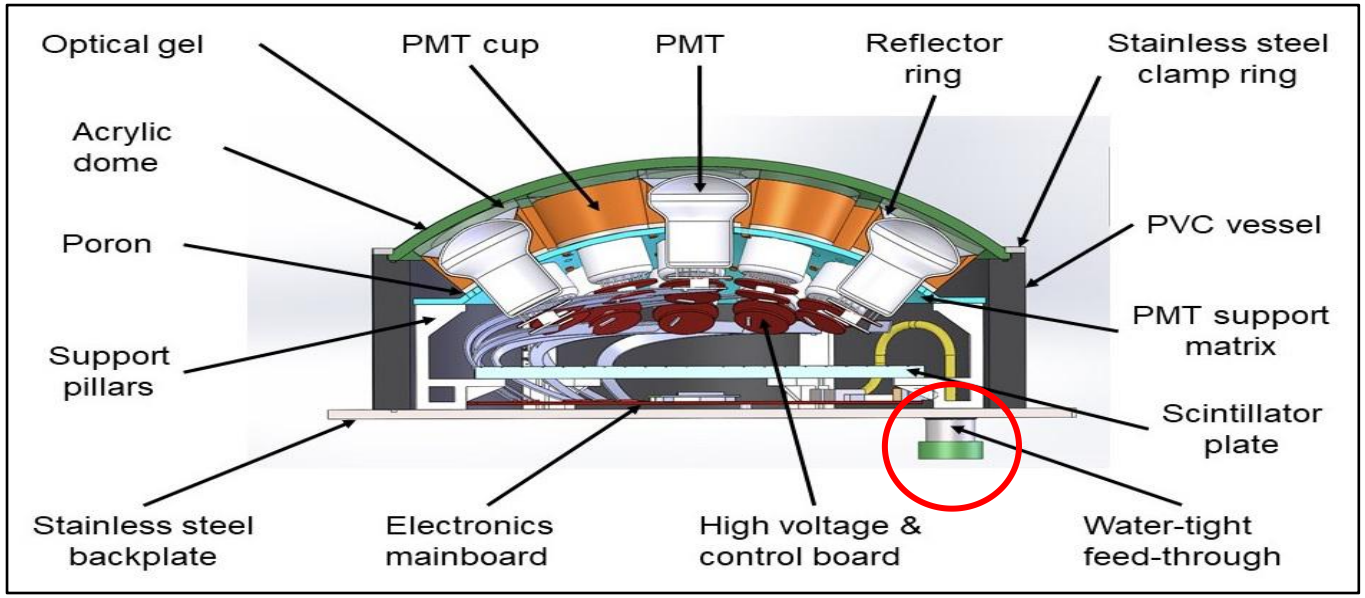
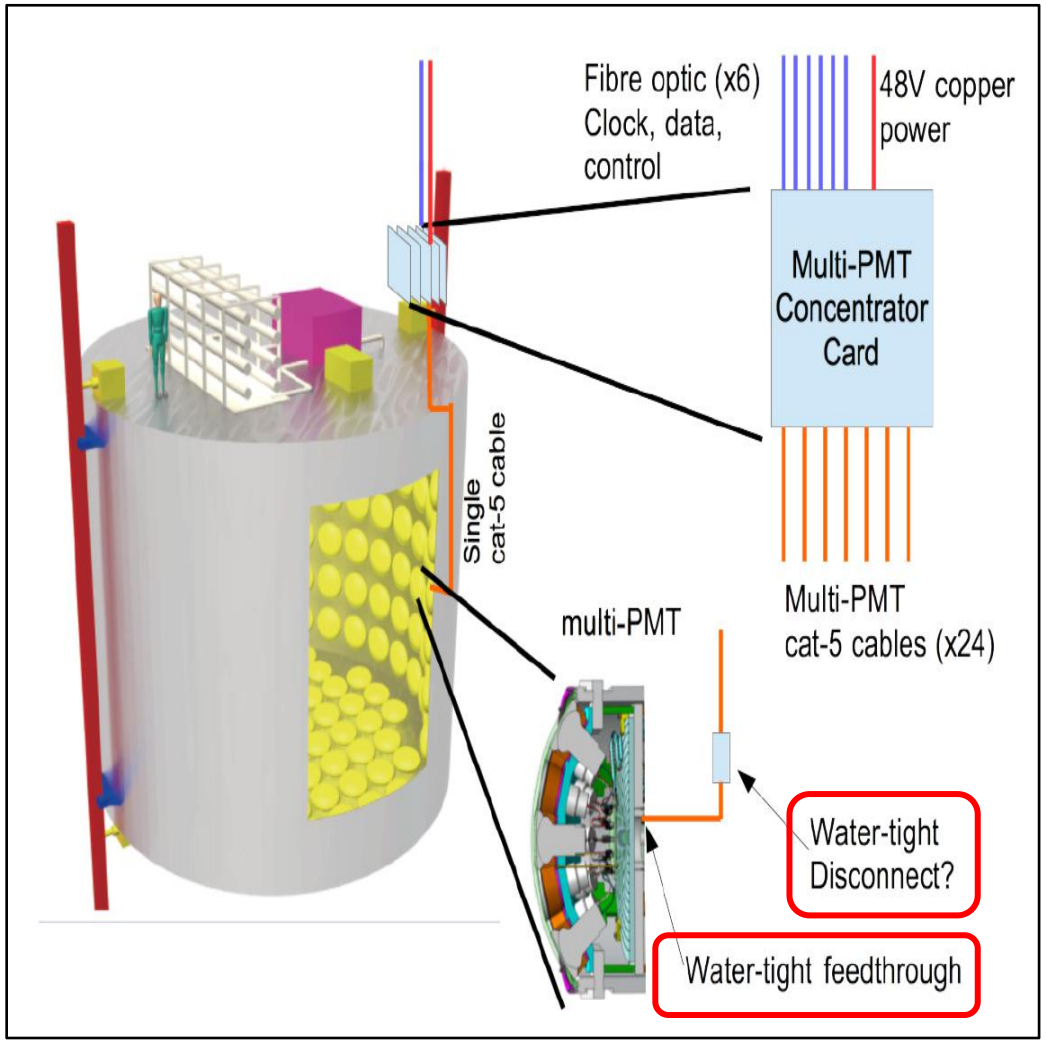
Purpose of Waterproof feed-through connector

Requirements:

1. The cable, water-tight feed-through and water-tight disconnect should
   a. be chemically inert with ultra-pure water and Gadolinium-doped water.
   b. be water-tight to 20m water depth
   c. have 20-year lifetime
2. It must be possible to connect or disconnect the mPMT from the long ethernet cable. Disconnect can either happen right at the steel baseplate or at a cable-to-cable disconnect ~50cm from the baseplate.





In-house Connector Development

Observations from market survey:

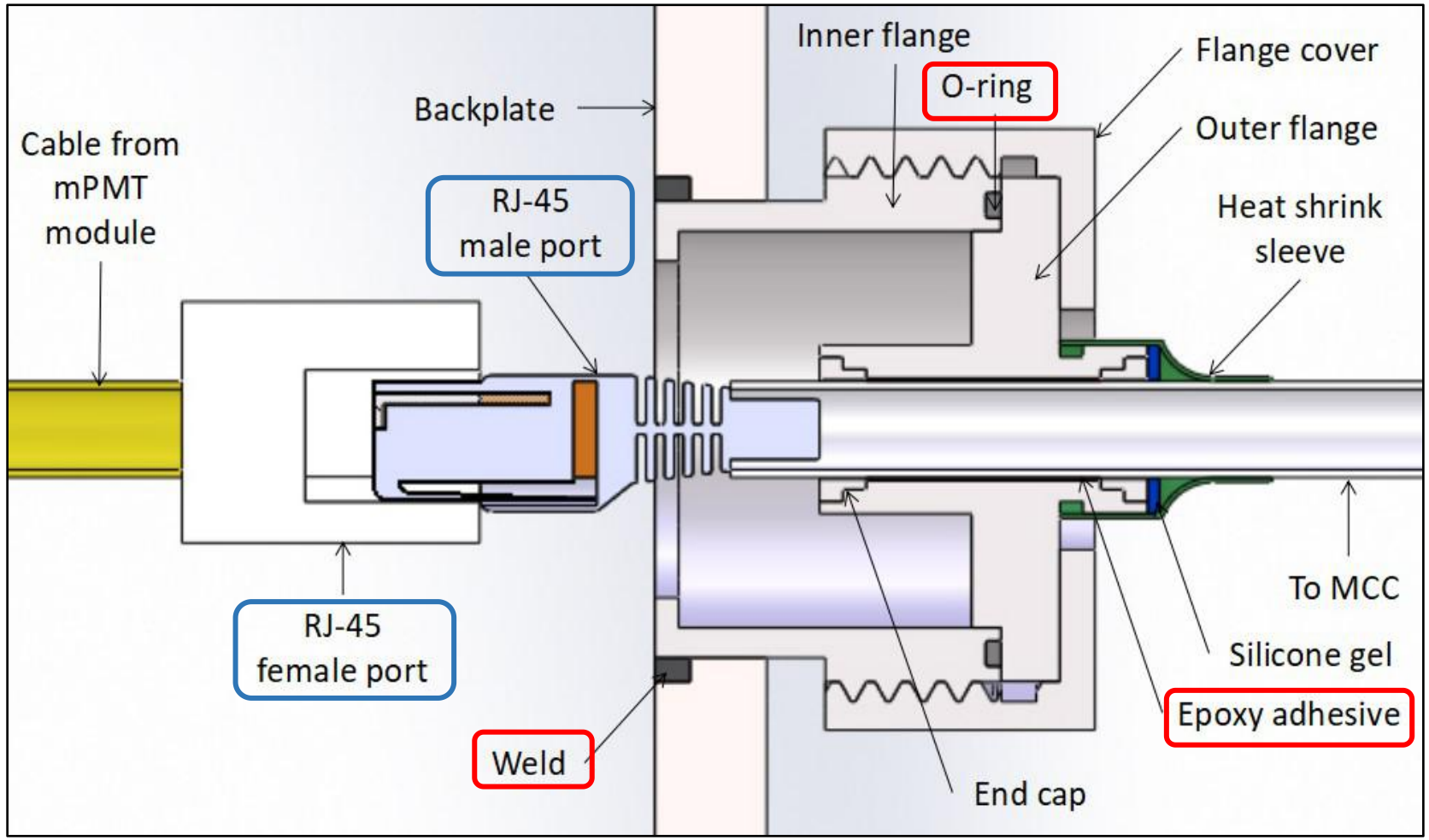
- Commercially available solutions are expensive
- Unable to fulfil all the requirements of the experiment

Consumables

- Araldite standard 2 component epoxy adhesive
- Anabond RTV 666 silicone gel
- Polyolefin Ø16mm heat shrink sleeve

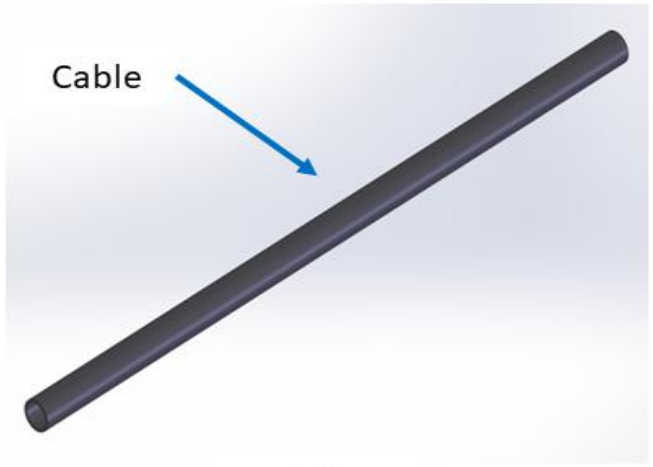
Components	Material	Quantity
Inner Flange	SS 304	1
Outer Flange	SS 304	1
Flange Cover	SS 304	1
End Cap	SS 304	2
O-ring	Viton	1

Schematic of In-house connector



Assembly Procedure of feed-through connector

1. Sub-assembly of Outer Flange



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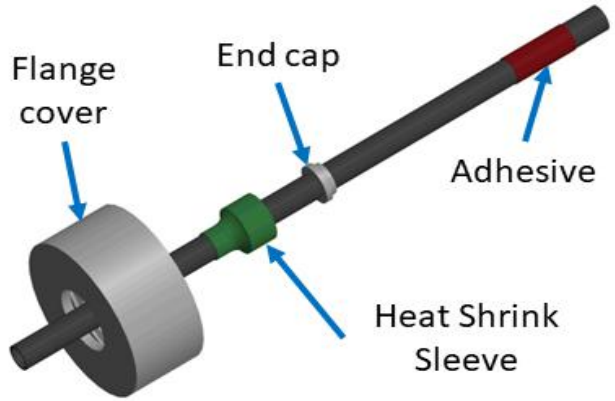

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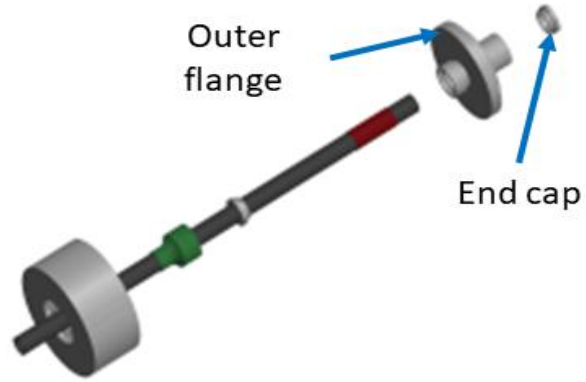

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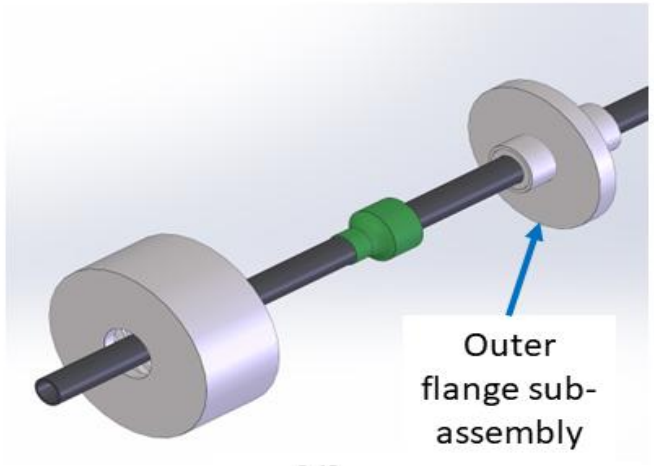

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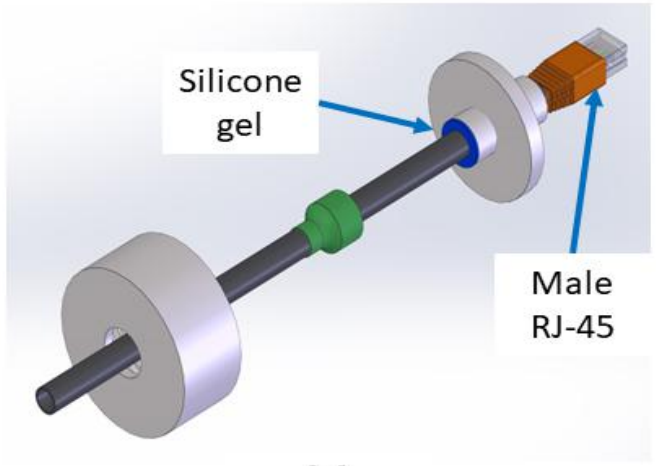

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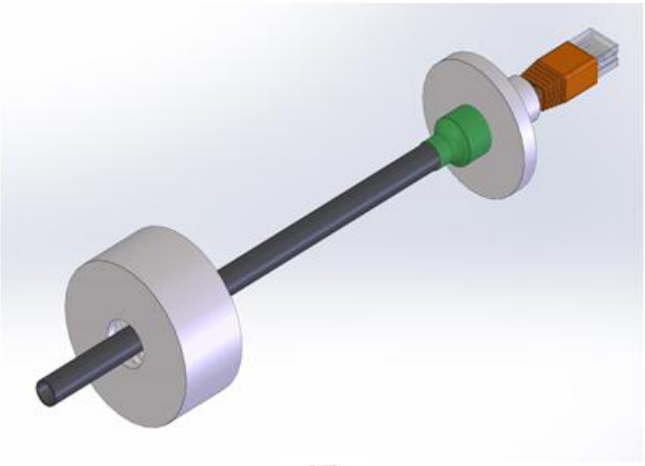
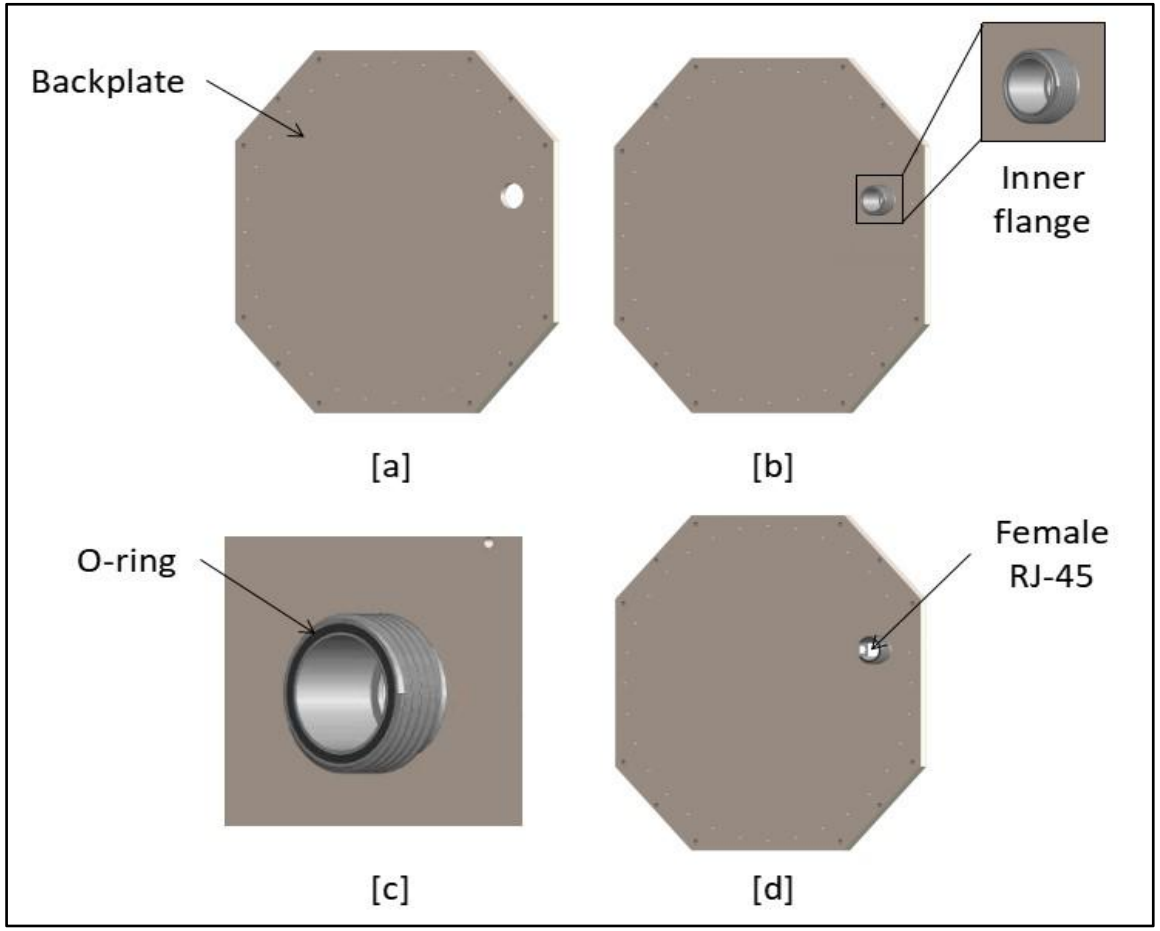


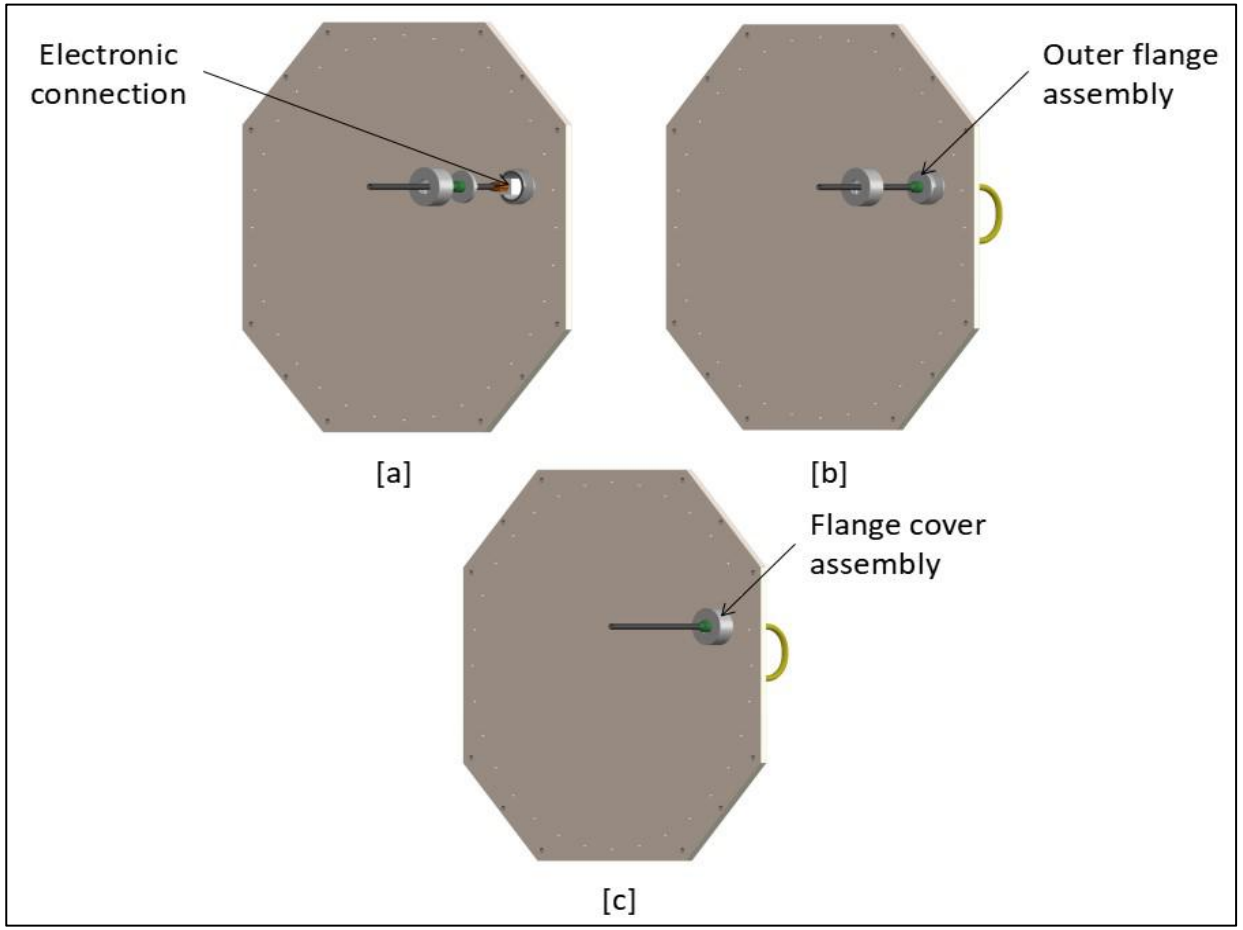
[f]

Assembly Procedure of feed-through connector

2. Assembly of Inner Flange



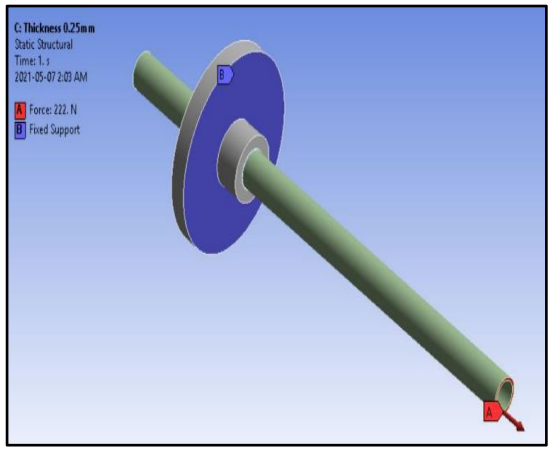
3. Complete Assembly of Feed-through Connector

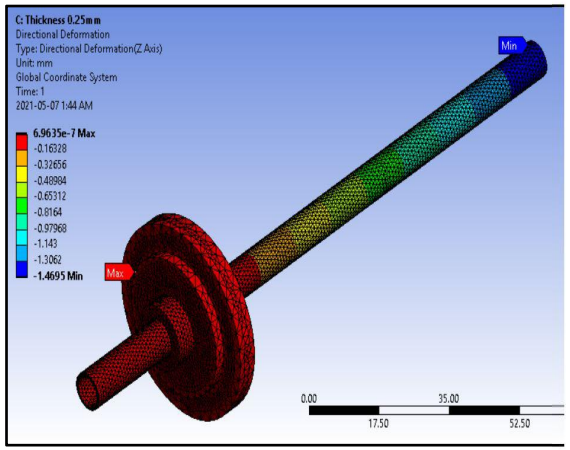


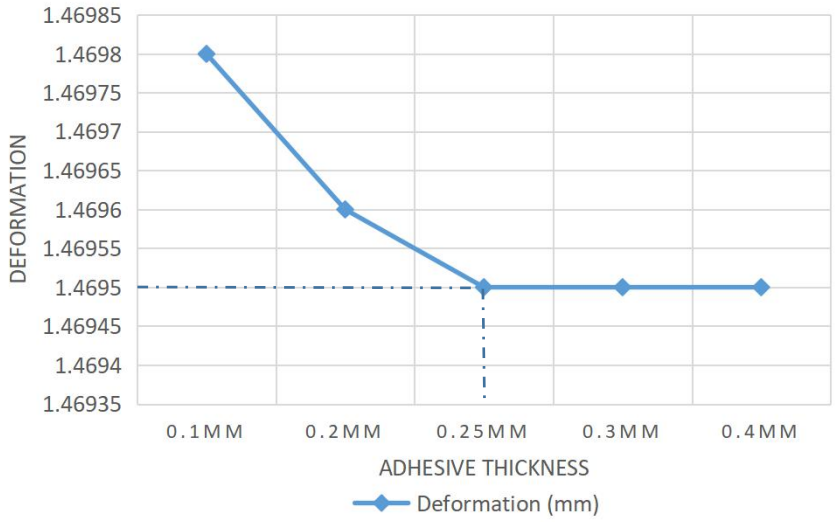
Design of In-house Connector

Simulation of Adhesive Failure under Tension

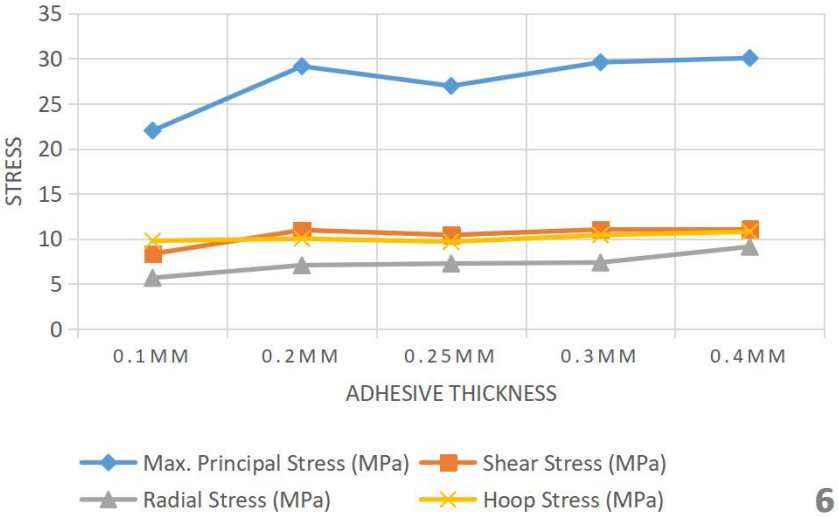
- Deformation reduces at 0.25mm
- Based on simulations and literature review, adhesive thickness considered: 0.25mm



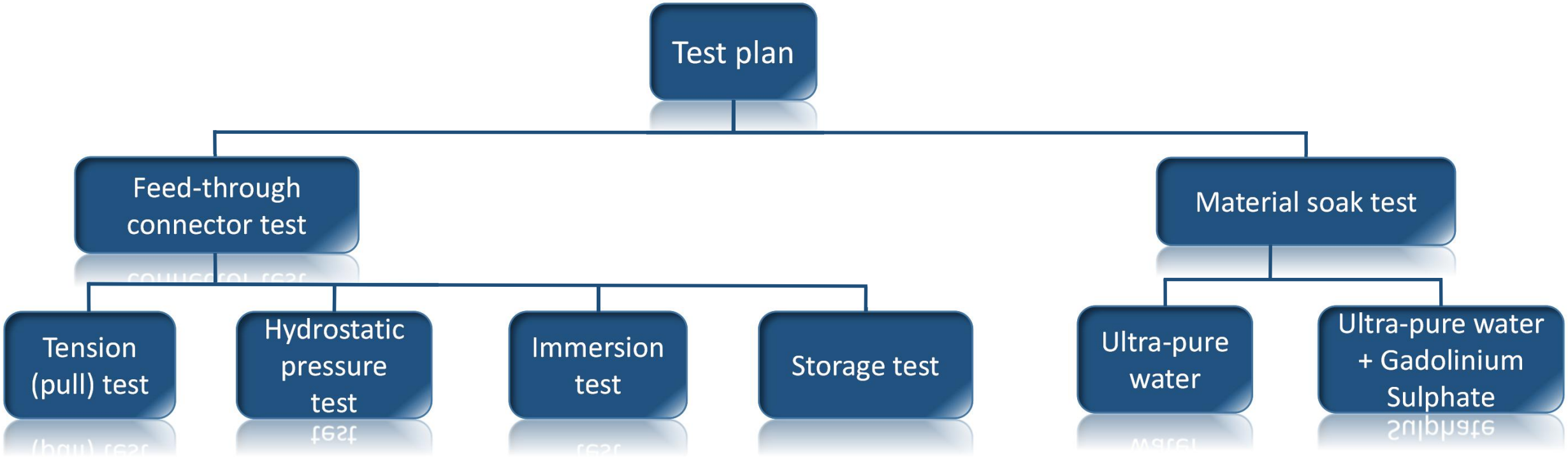




Adhesive Thickness (mm)	Deformation (mm)	Max. Principal Stress (MPa)	Shear Stress (MPa)	Radial Stress (MPa)	Hoop Stress (MPa)
0.1	1.4698	22.007	8.339	5.6752	9.7851
0.2	1.4696	29.151	10.976	7.0728	10.022
0.25	**1.4695**	**26.965**	**10.431**	**7.2598**	**9.6842**
0.3	1.4695	29.591	11.038	7.3744	10.415
0.4	1.4695	30.061	11.079	9.1276	10.797



Test Plan



Test Purpose

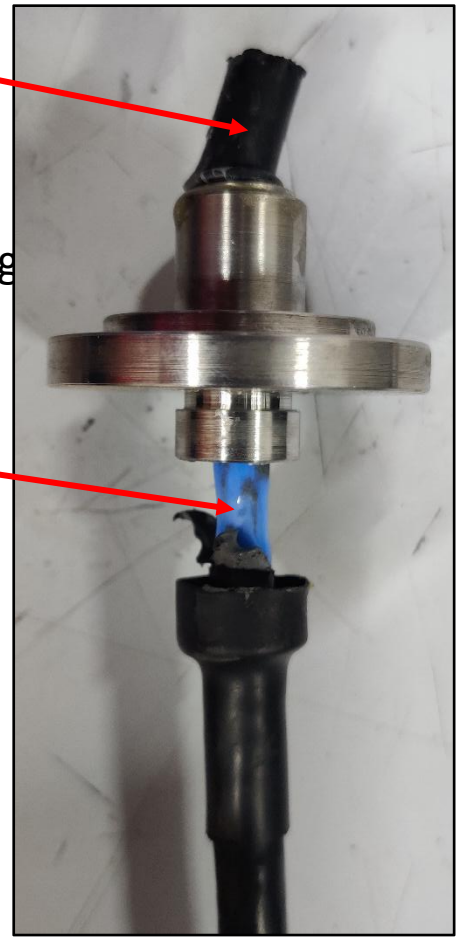
- Connector sustainability
  - ✓ Check for safe operation of feed-through connector under all work phases
- Material compatibility
  - ✓ Check for materials degrading the quality of ultra-pure water

Feed-through Connector: Tension (pull) test

Cable slipping

Fixture for gripping feed-through connector

Failure region



Test parameters-

As per the document “Human performance capabilities” by NASA, maximum pull force exerted by human with one hand is considered as 222N.

Sample	Failure Load	Remark
MS Connector	137.6 N	Non-marine cable resulted in reduced strength
SS304 Connector 1	348 N	Marine cable with 1.58 Factor of Safety
SS304 Connector 2	380 N	Marine cable with 1.72 Factor of Safety

Result-

Adhesive was intact, failure was observed at cable outer sheath

Feed-through Connector: Hydrostatic Pressure Test

Test parameters-

a. Test type: Hydrostatic pressure test
b. Work medium: Potable water
c. Operating temperature: Room temperature
d. Operating pressure: 10 bar (1MPa)
e. Test duration: 1 hour

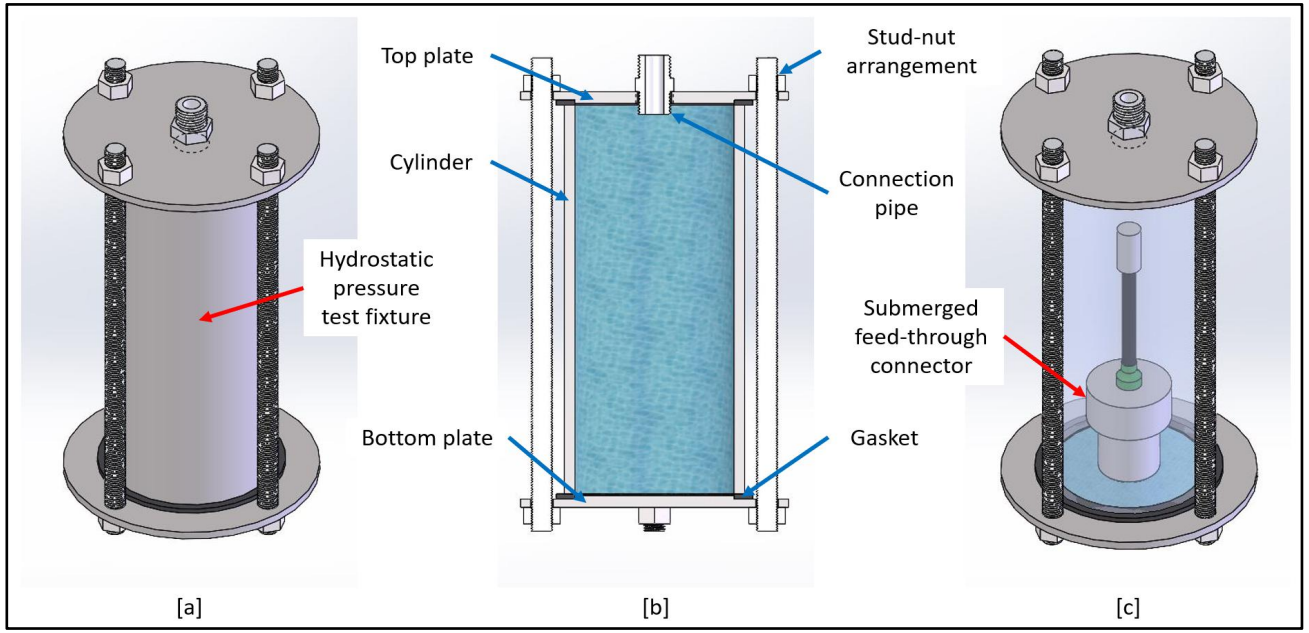
Maximum hydrostatic pressure for HyperK: 8 bar

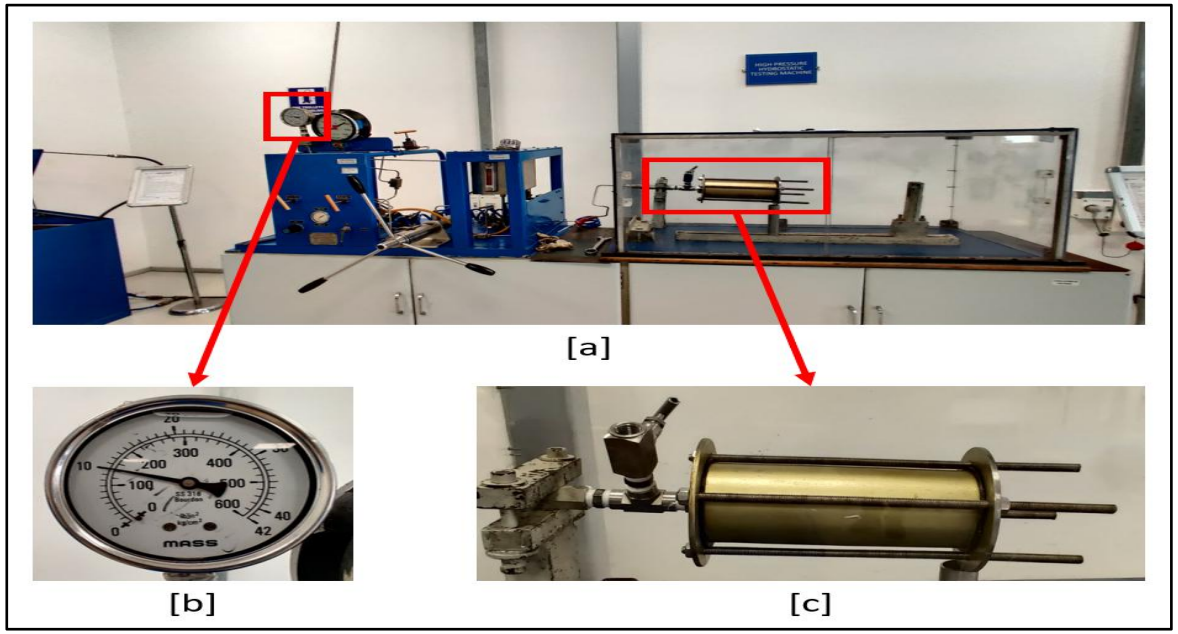
Observations-

No physical leaks observed inside the connector.

Results-

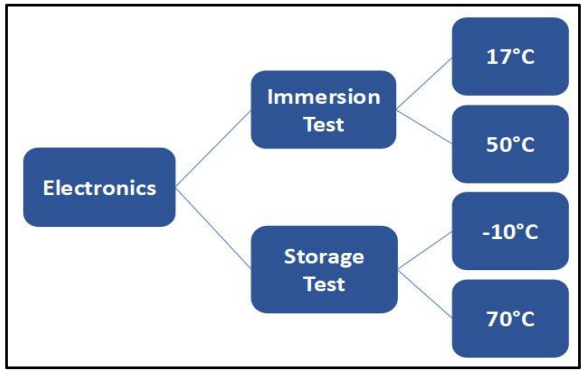
Adhesive was intact under 10 bar water pressure



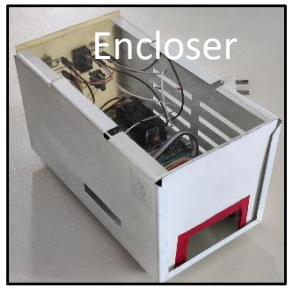


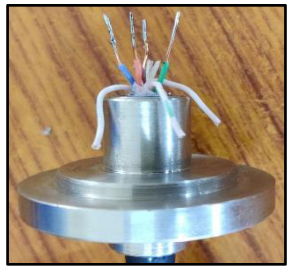
Feed-through Connector: Immersion Test and Storage Test

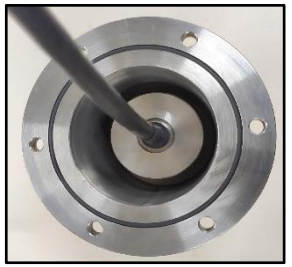
- Temperature and humidity measurement
- Multi-channel interfacing with flexible data acquisition interval

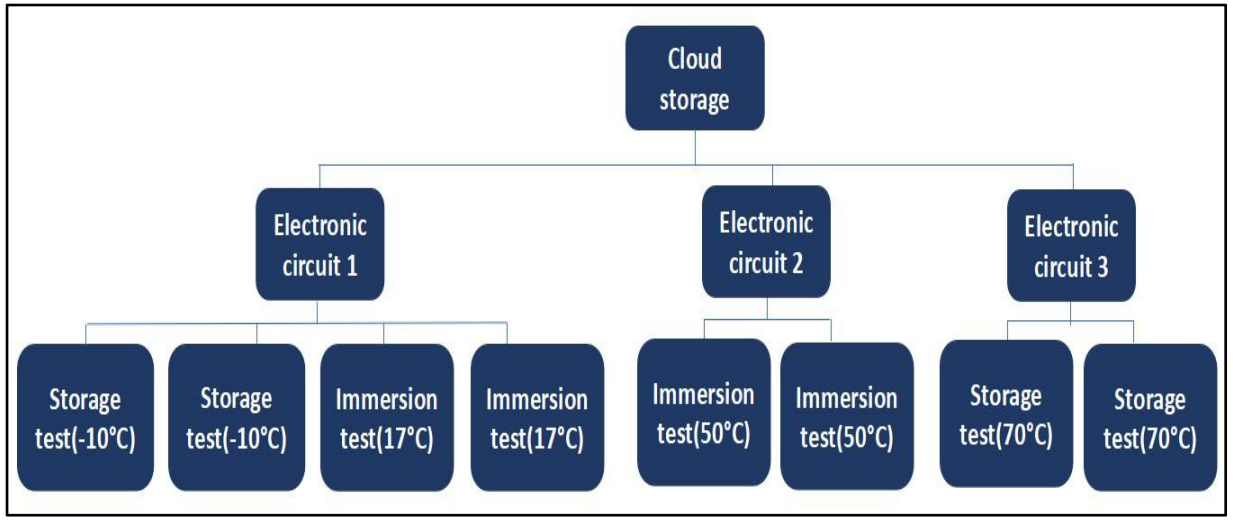


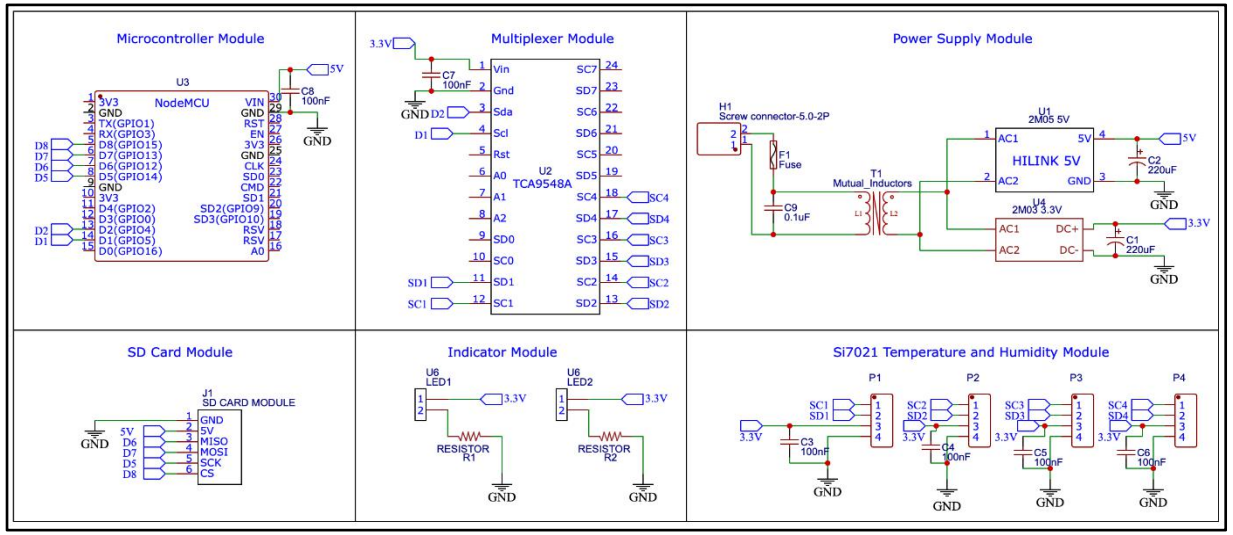
- Local memory storage provision
- Wi-Fi enabled system for global storage on cloud











Electronics

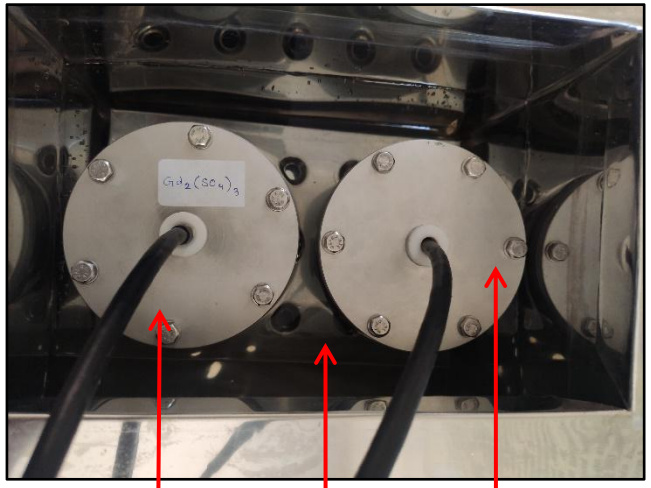
Schematic Design

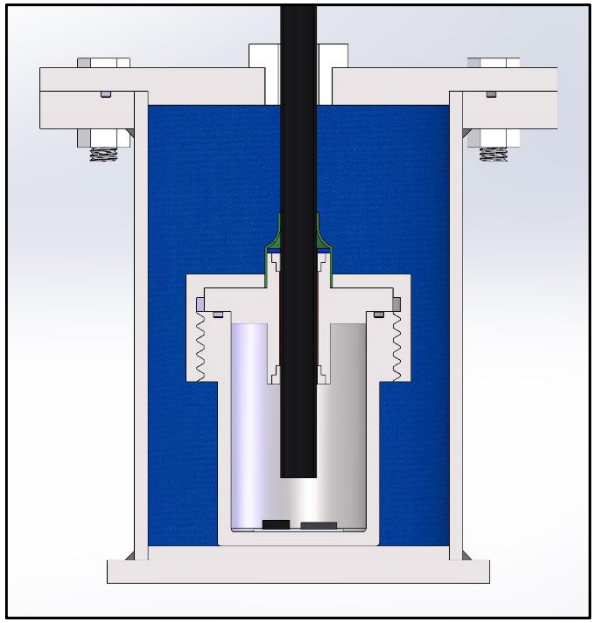
Feed-through Connector: Immersion Test

Test parameters-

a. Test type: Immersion test
b. Work medium: Ultra-pure water, Gd loaded water
c. Test duration: 3 months
d. Parameters to measure: Temperature & humidity (throughout the test), Adhesive strength (pull test afterwards)

Setup: Water Bath
Test temperature: 50℃
Test Medium:
Ultra Pure-water (1 sample)
Gd loaded water (1 sample)



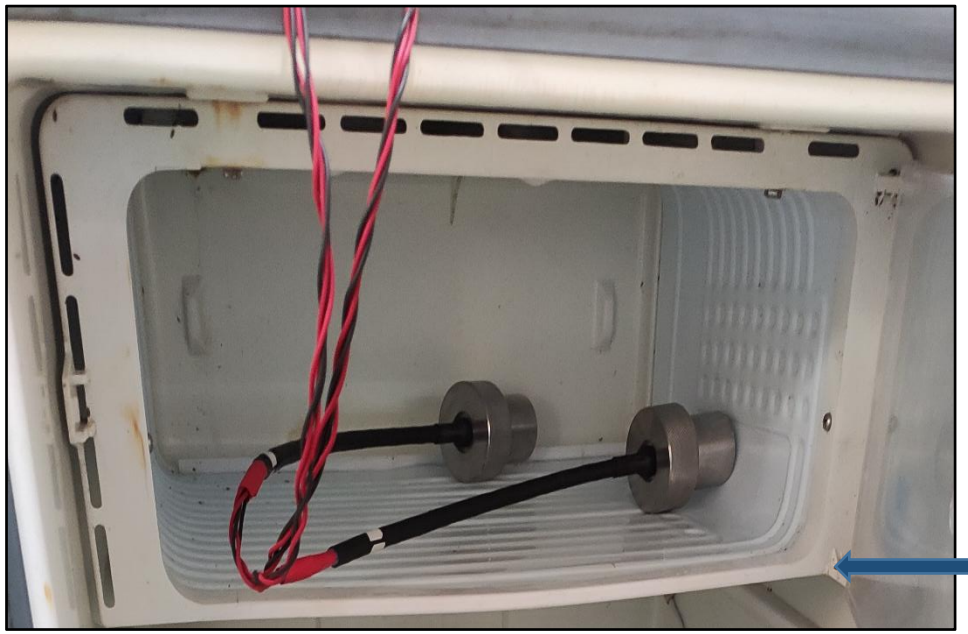


Setup: Refrigrator
Test temperature: 10℃ (Close to 17℃)
Test Medium:
Ultra Pure-water (1 sample)
Gd loaded water (1 sample)

Feed-through Connector: Storage Test

Test parameters-

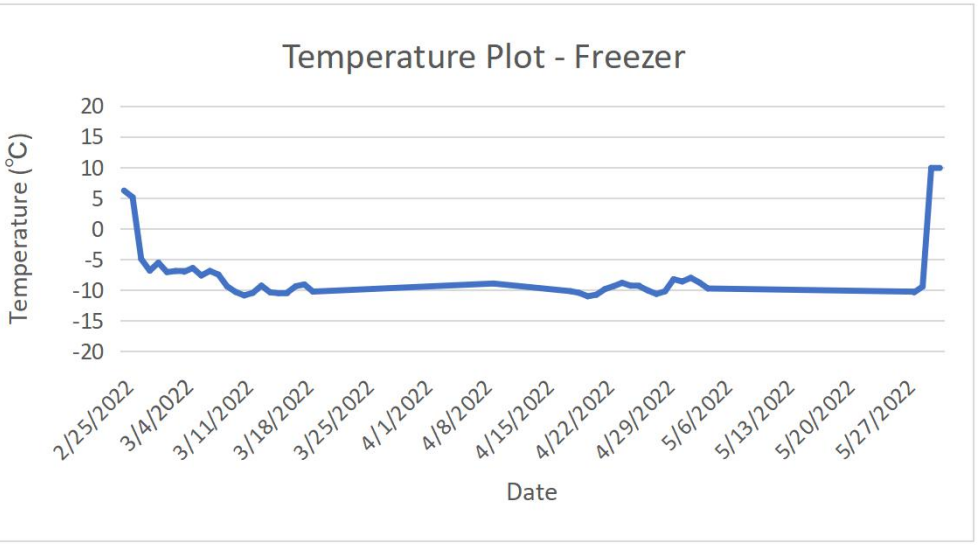
a. Test type: Storage test
b. Work medium: Air
c. Test duration: 3 months
d. Parameters to measure: Temperature & humidity (throughout the test), Adhesive strength (pull test afterwards)

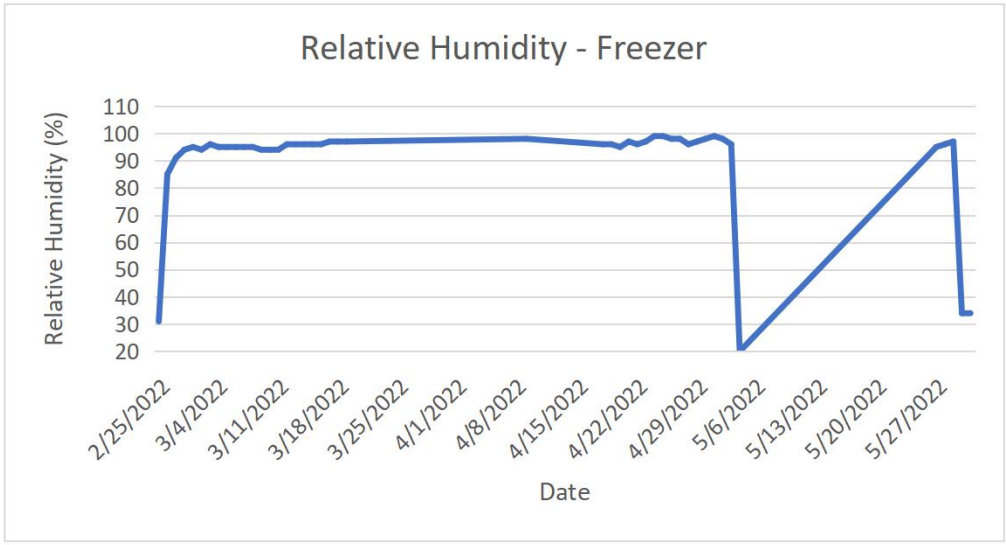


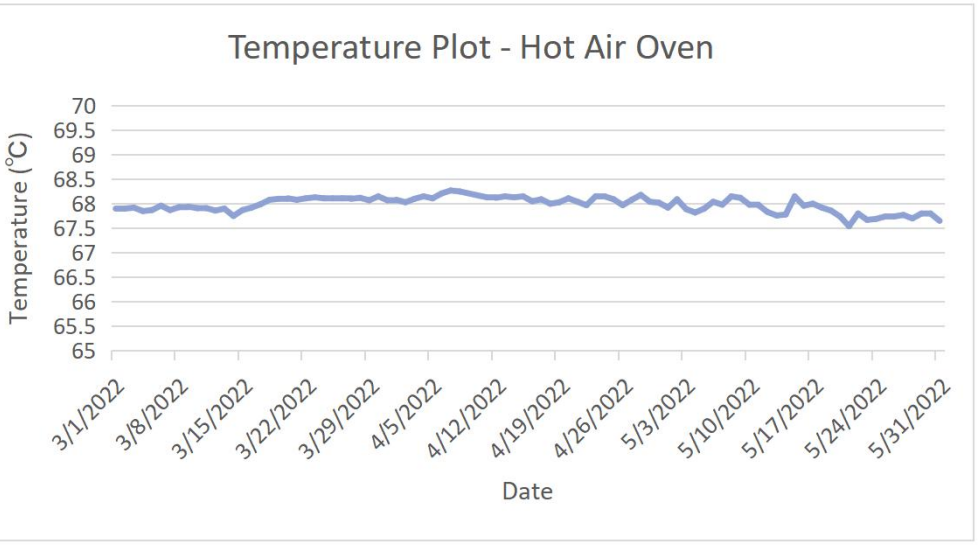
Setup: Refrigrator
Test temperature: -10℃
Test Medium: Air
Total Samples: 2

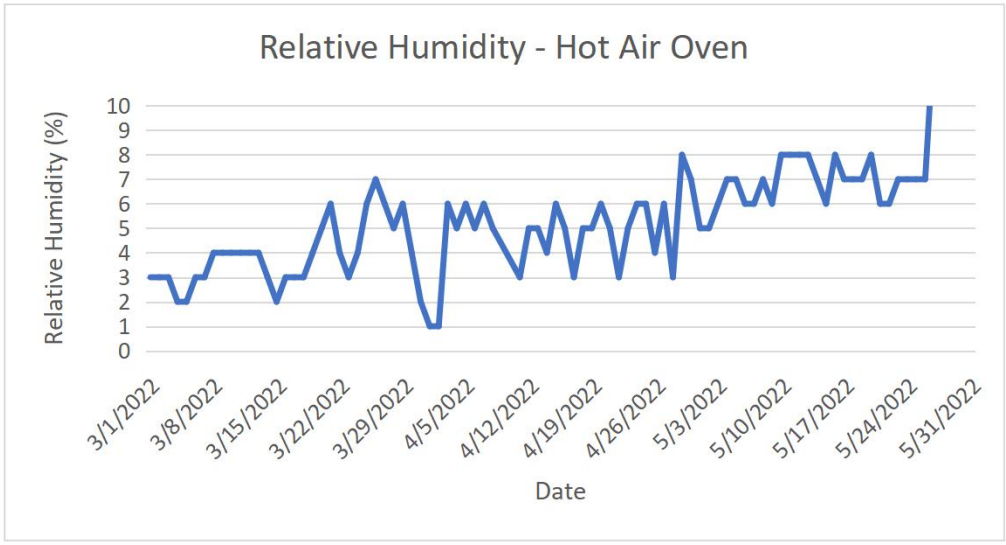
Setup: Hot Air Oven
Test temperature: 70℃
Test Medium: Air
Total Samples: 2

Feed-through Connector: Immersion Test and Storage Test







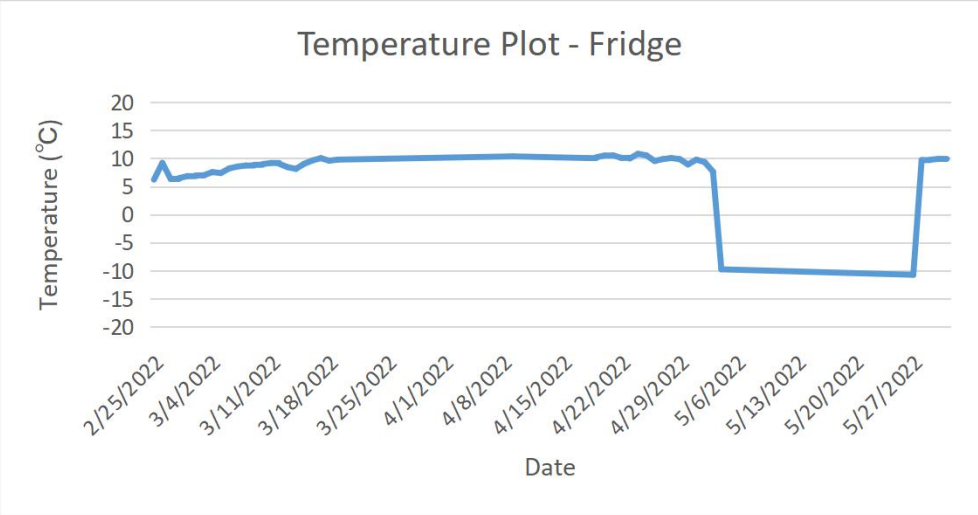


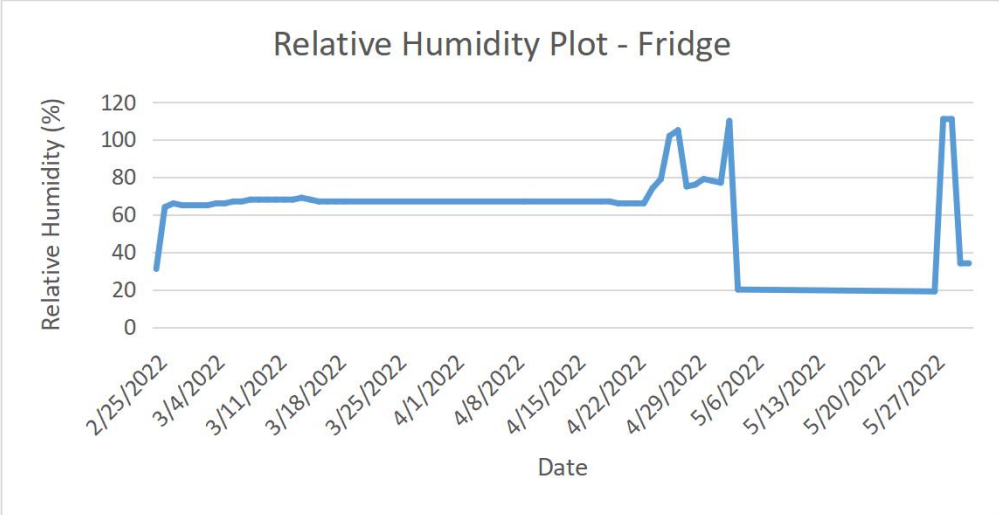
Possible reasons for leakage:

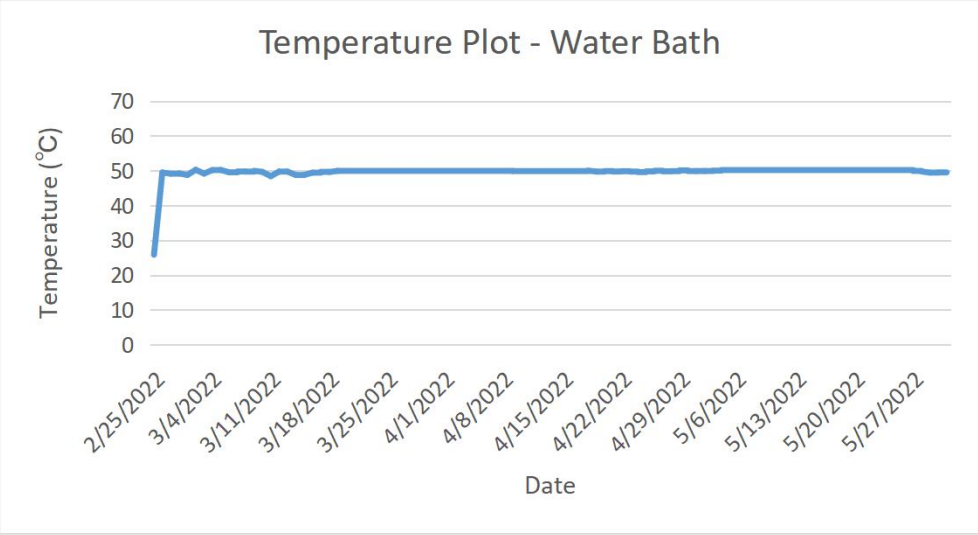
1. The end point of CAT 5 cable was inside the fridge. There may be capillary action.

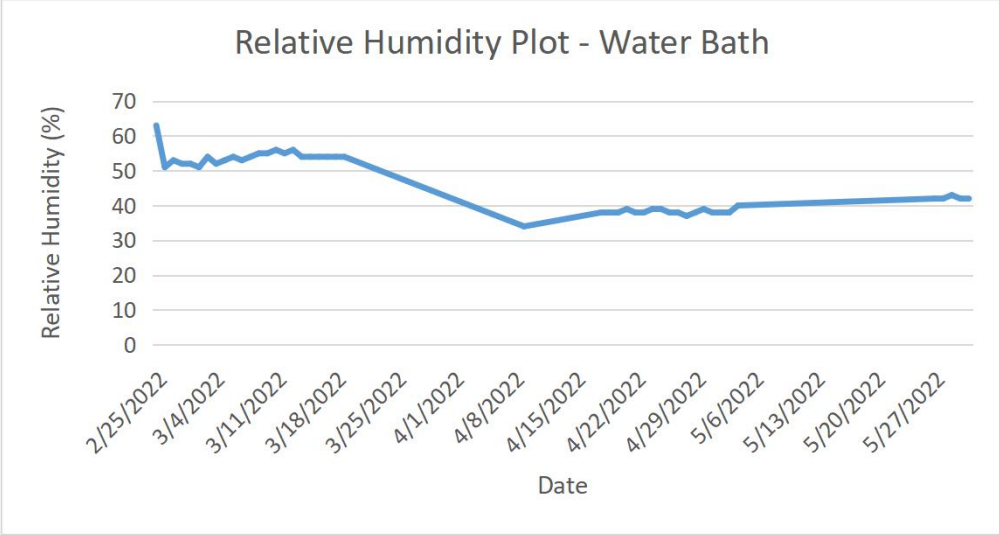
2. Thermal expansion of o-ring and SS304 feed-through connector.

Feed-through Connector: Immersion Test and Storage Test









Solutions:

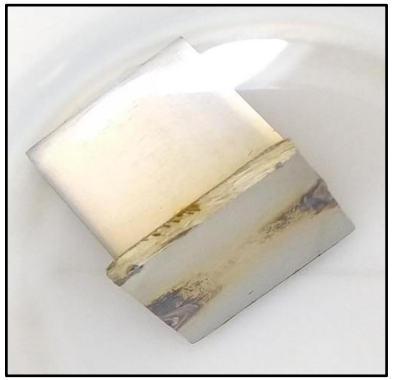
1. The cable can be taken out completely without any joints.

2. Changing the dimensions of O-ring by increasing it's width.

3. Uniform surface smoothness for flat face and groove of inner flange.

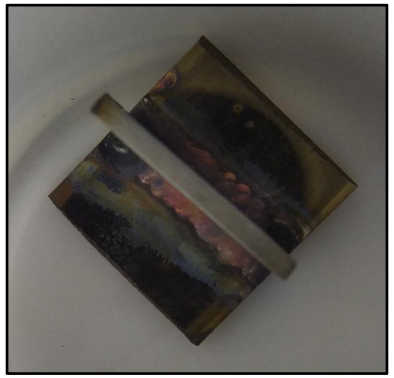
Corrosion of welds and machined surfaces in Ultra-Pure Water

No Pickling and Passivation



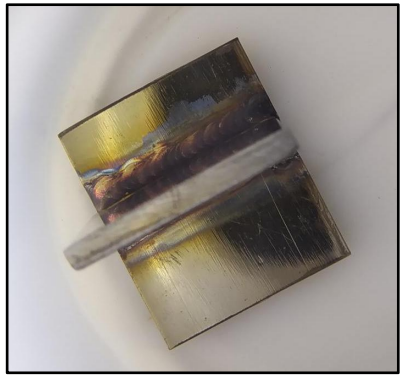
SS304 Plates With SS304L Filler Material Welding

No corrosion



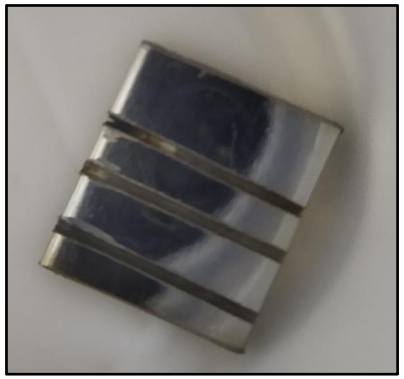
SS304 Plates With SS316L Filler Material Welding

Corrosion



SS304 Plates With SS308L Filler Material Welding

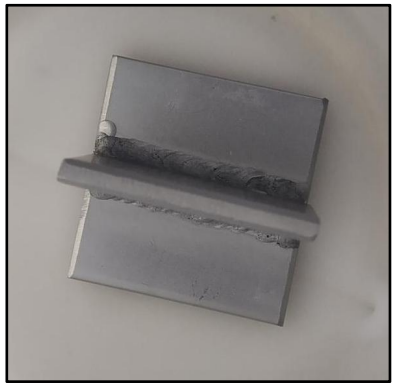
Corrosion



SS304 Plates With Machined Surface

No corrosion

Pickling and Passivation

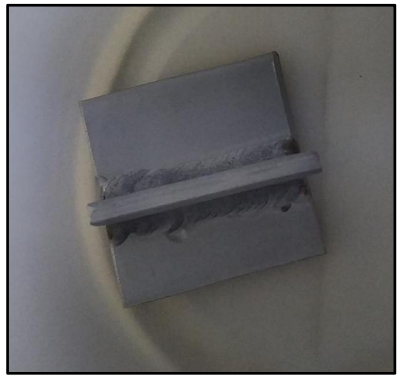


SS304 Plates With SS304L Filler Material Welding + Pickling & Passivation

No corrosion

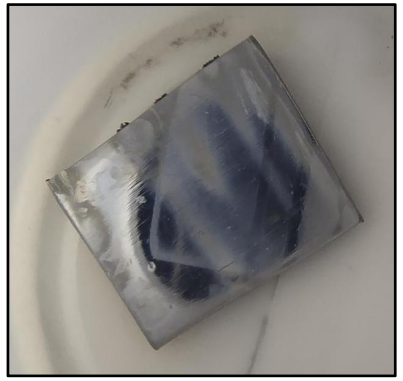
SS304 Plates With SS316L Filler Material Welding + Pickling & Passivation

No corrosion



SS304 Plates With SS308L Filler Material Welding + Pickling & Passivation

No corrosion

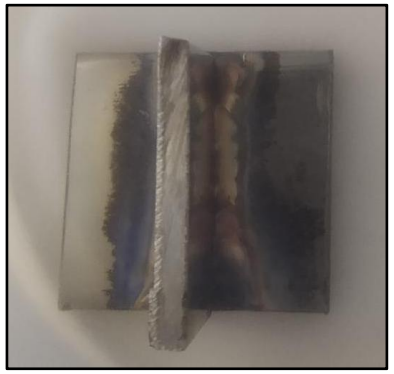


SS304 Plates With Machined Surface + Pickling & Passivation

No corrosion

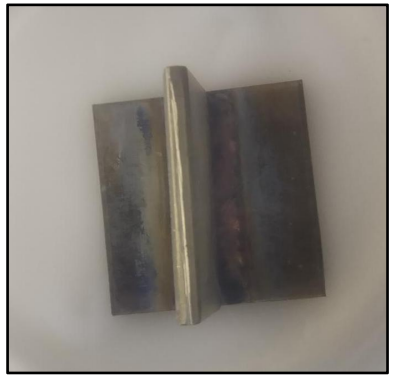
Corrosion of welds and machined surfaces in Gd-Loaded Water

No Pickling and Passivation



SS304 Plates With SS304L Filler Material Welding

Corrosion

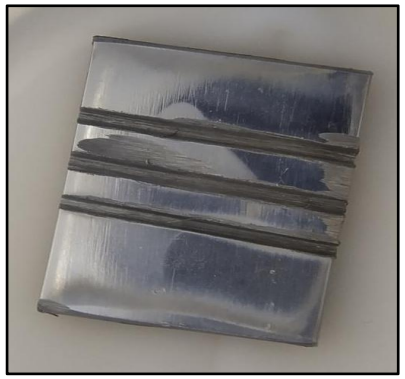


SS304 Plates With SS316L Filler Material Welding

Corrosion

SS304 Plates With SS308L Filler Material Welding

Corrosion



SS304 Plates With Machined Surface

No corrosion

Pickling and Passivation

SS304 Plates With SS304L Filler Material Welding + Pickling & Passivation

No corrosion

SS304 Plates With SS316L Filler Material Welding + Pickling & Passivation

No corrosion

SS304 Plates With SS308L Filler Material Welding + Pickling & Passivation

No corrosion

SS304 Plates With Machined Surface + Pickling & Passivation

No corrosion

Corrosion of welds and machined surfaces in Gd-Loaded Water

- As-welded SS304 plates with different filler material corrode in Ultra-pure water as well as Gd-Loaded water.
- As welded SS304 plates with SS304 filler material corrode in Gd-Loaded water but not Ultra-pure water
- Machined SS plates do not react with Ultra-pure water as well as Gd-Loaded water.
- Pickling and passivation seems to be inevitable for protecting welds from corrosion.

Material Soak Test

Sr. No.	Sample Material
1.	SS304 Plates With SS304L Filler Material Welding
2.	SS304 Plates With SS304L Filler Material Welding + Pickling & Passivation
3.	SS304 Plates With SS308L Filler Material Welding
4.	SS304 Plates With SS308L Filler Material Welding + Pickling & Passivation
5.	SS304 Plates With SS316L Filler Material Welding
6.	SS304 Plates With SS316L Filler Material Welding + Pickling & Passivation
7.	SS304 Plates With Machined Surface
8.	SS304 Plates With Machined Surface + Pickling & Passivation

Test Duration: 3 months

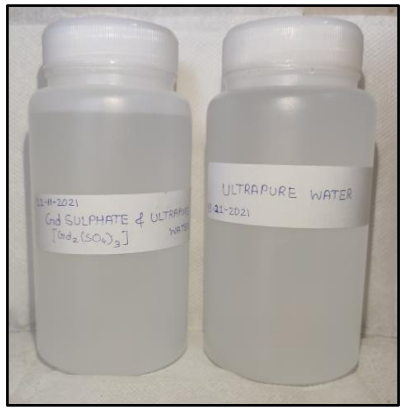
Soak Medium:
1. Ultra Pure-Water
2. Ultra Pure-Water + Gadolinium Sulphate

$Gd_2(SO_4)_3$:
99.99% Pure

Gadolinium Sulphate

Gd Loading:
0.2% by weight

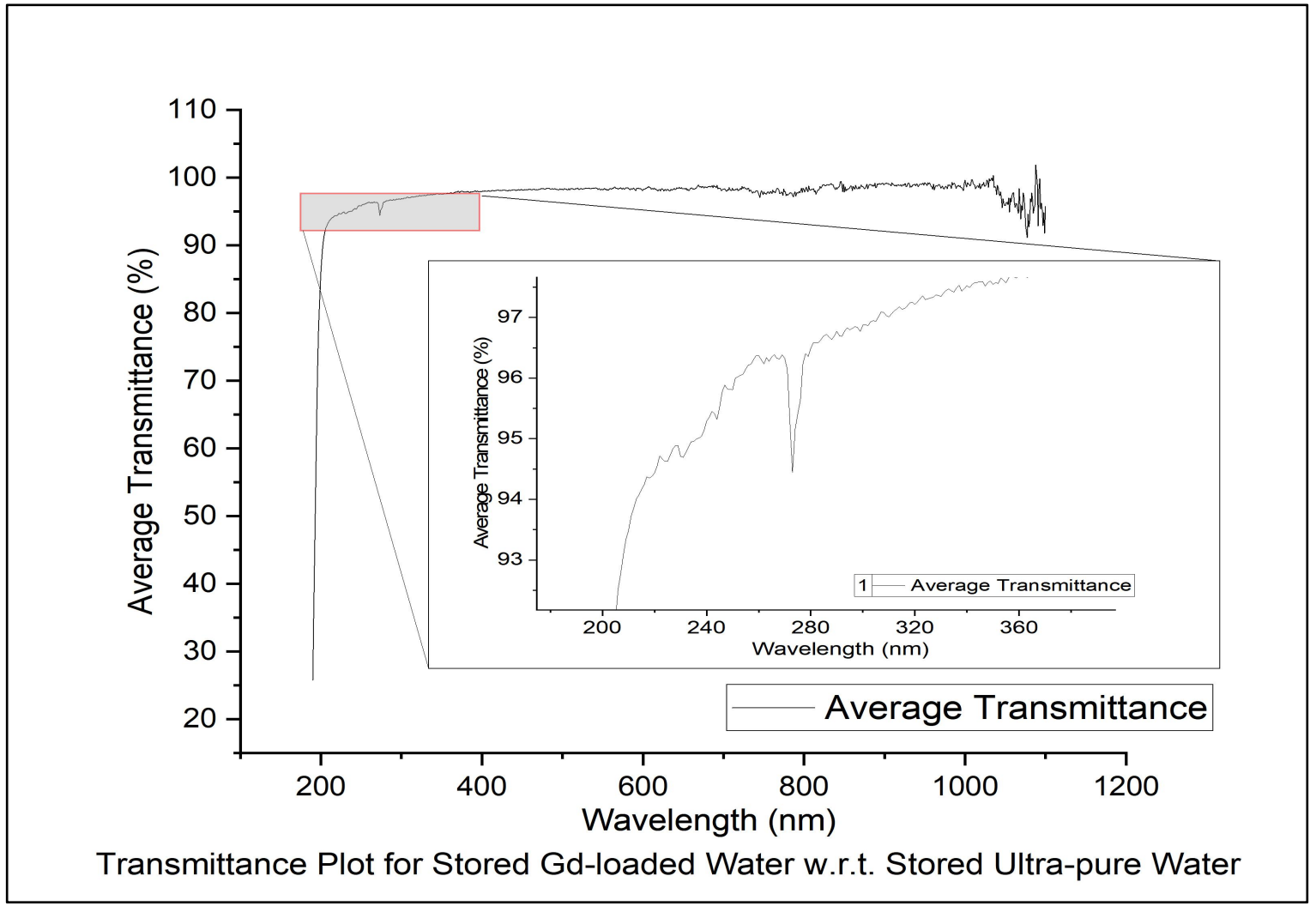

500 ml
Polypropylene Bottle



Reference samples

Material Soak Test

Characteristic absorption peak at 278nm

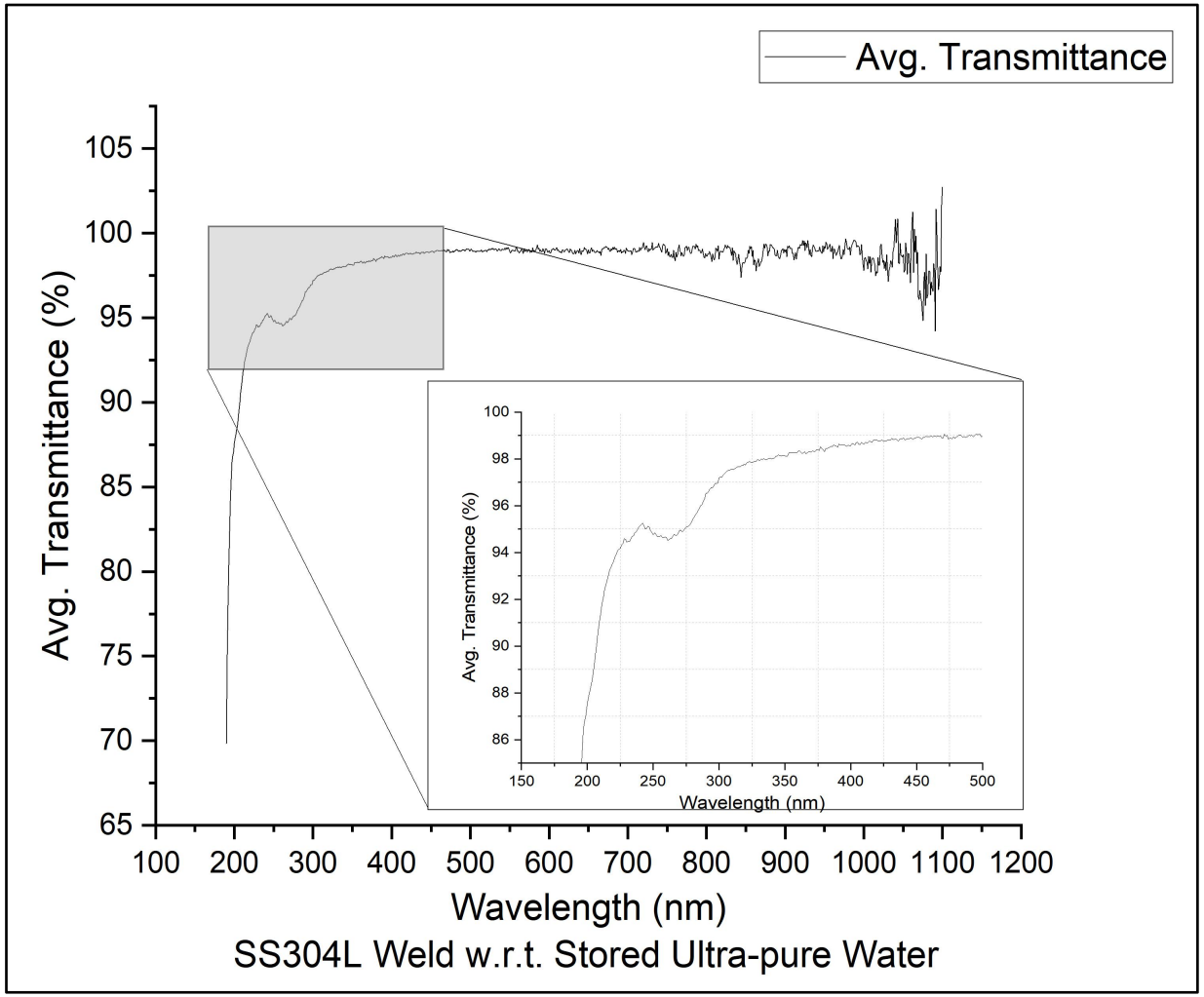


Transmittance Plot for Stored Gd-loaded Water w.r.t. Stored Ultra-pure Water

Material Soak Test - Transmission Plots

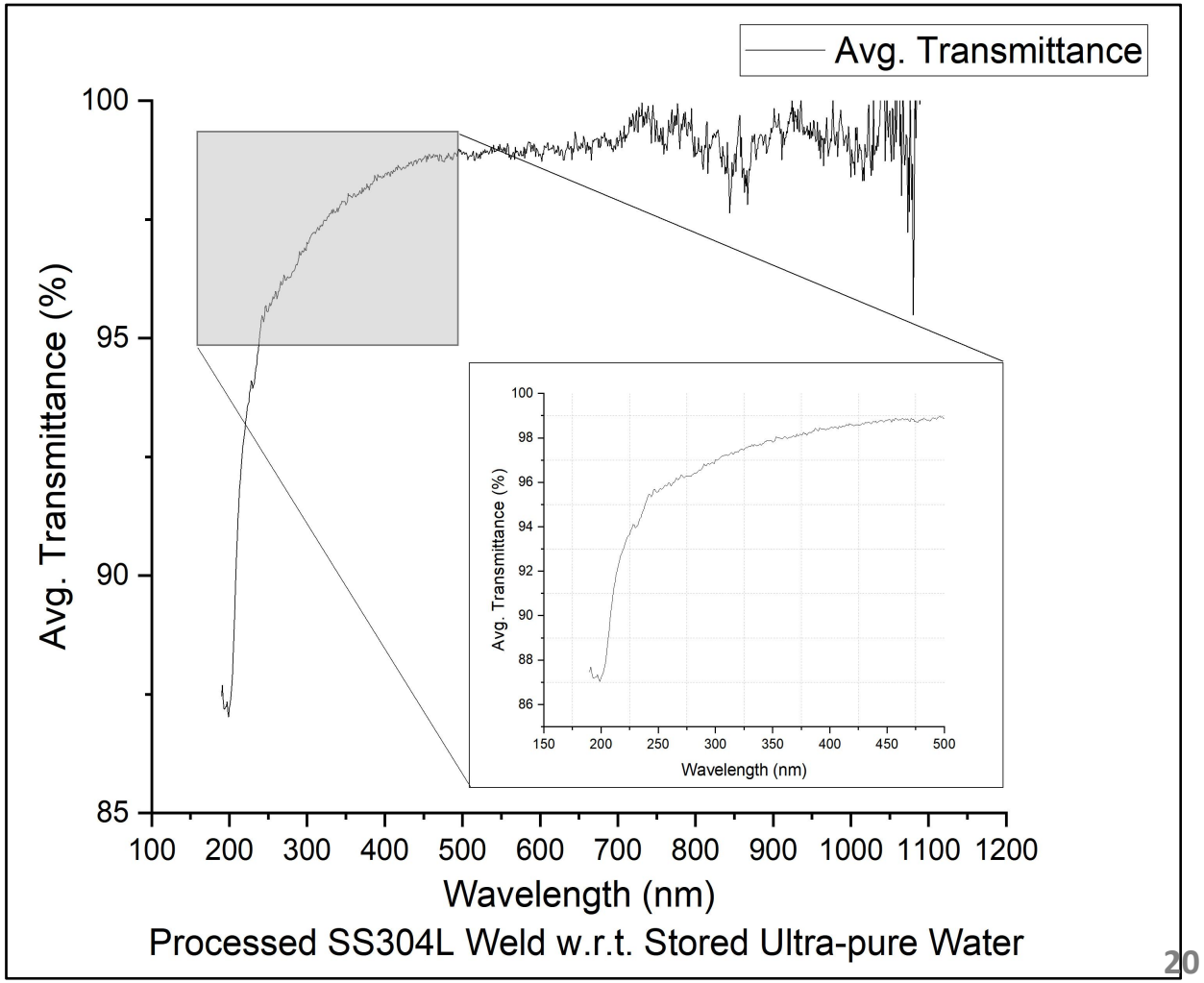
Medium: Ultra-Pure Water

SS304 Plates With SS304L Filler Material



SS304L Weld w.r.t. Stored Ultra-pure Water

Picked and passivated SS304 Plates With SS304L Filler Material

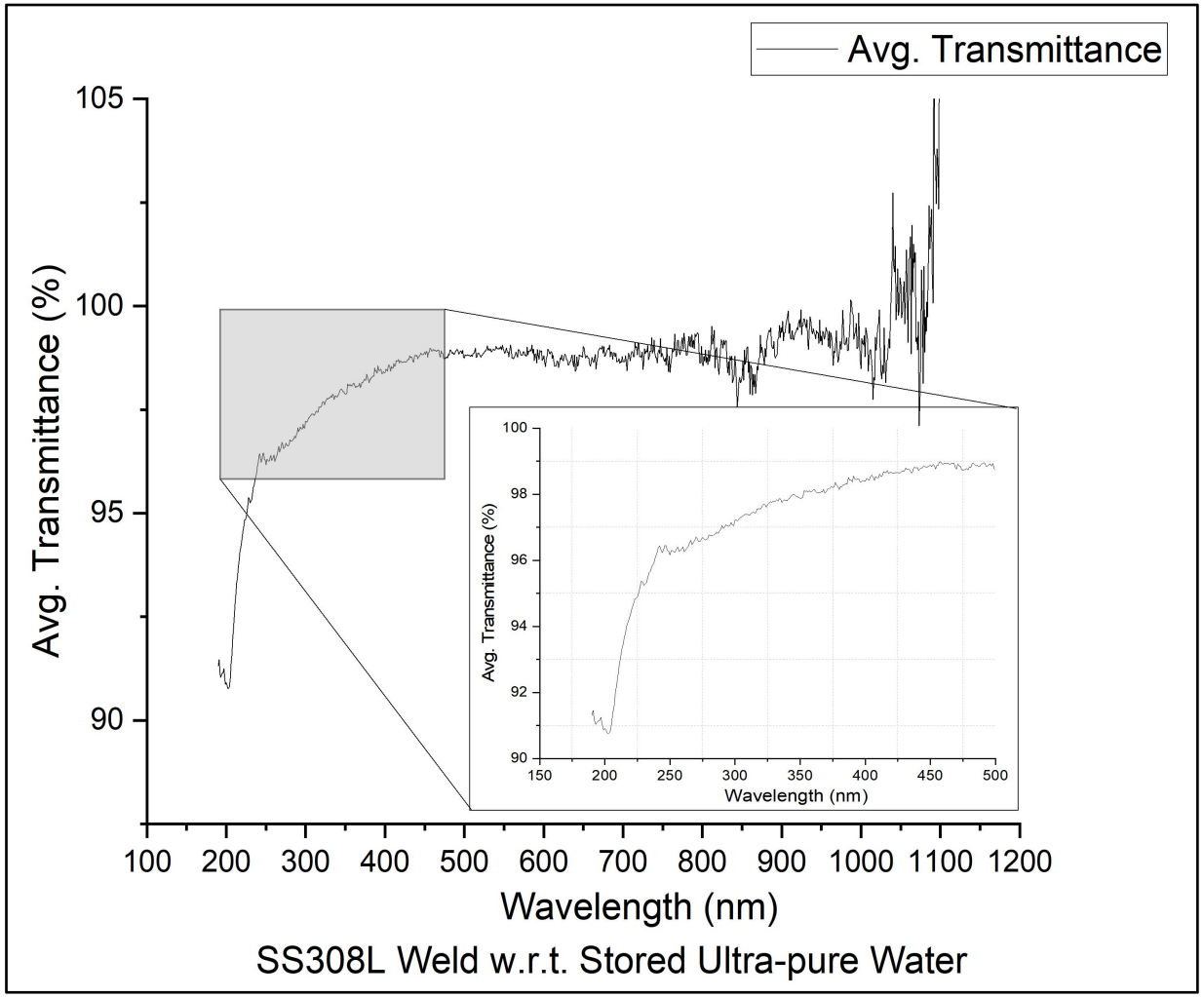


Processed SS304L Weld w.r.t. Stored Ultra-pure Water

Material Soak Test - Transmission Plots

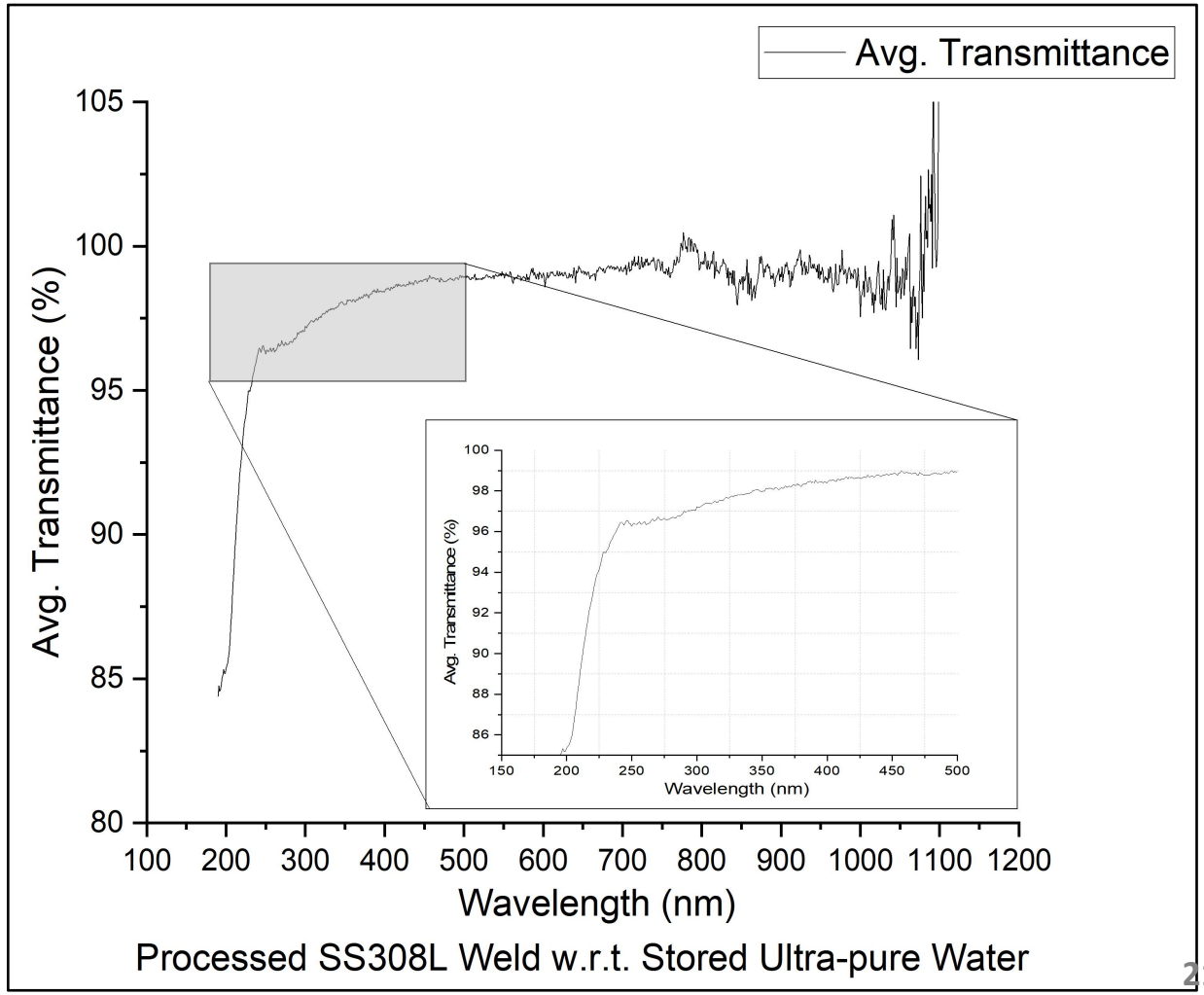
Medium: Ultra-Pure Water

SS304 Plates With SS308L Filler Material



SS308L Weld w.r.t. Stored Ultra-pure Water

Picked and passivated SS304 Plates With SS308L Filler Material

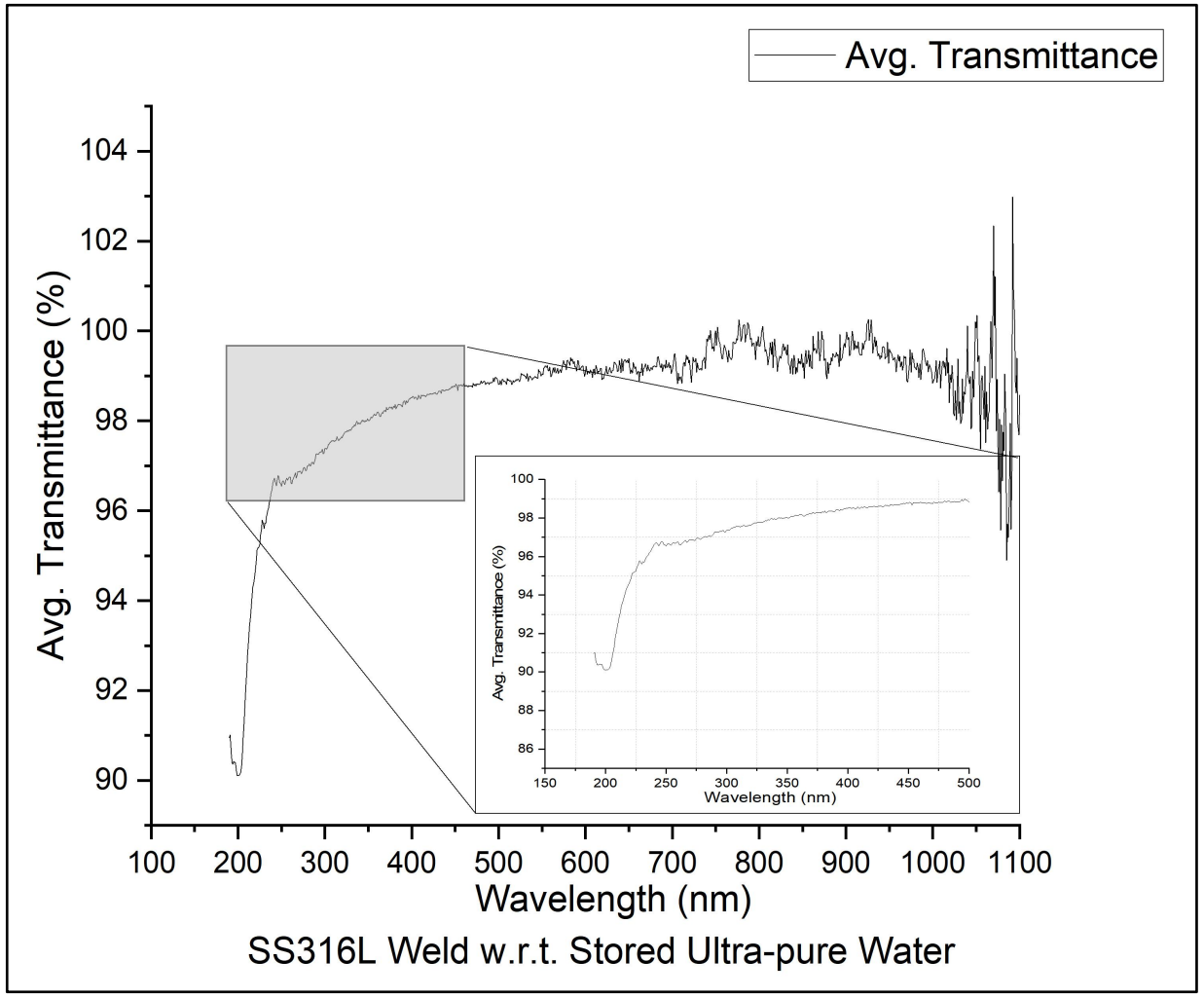


Processed SS308L Weld w.r.t. Stored Ultra-pure Water

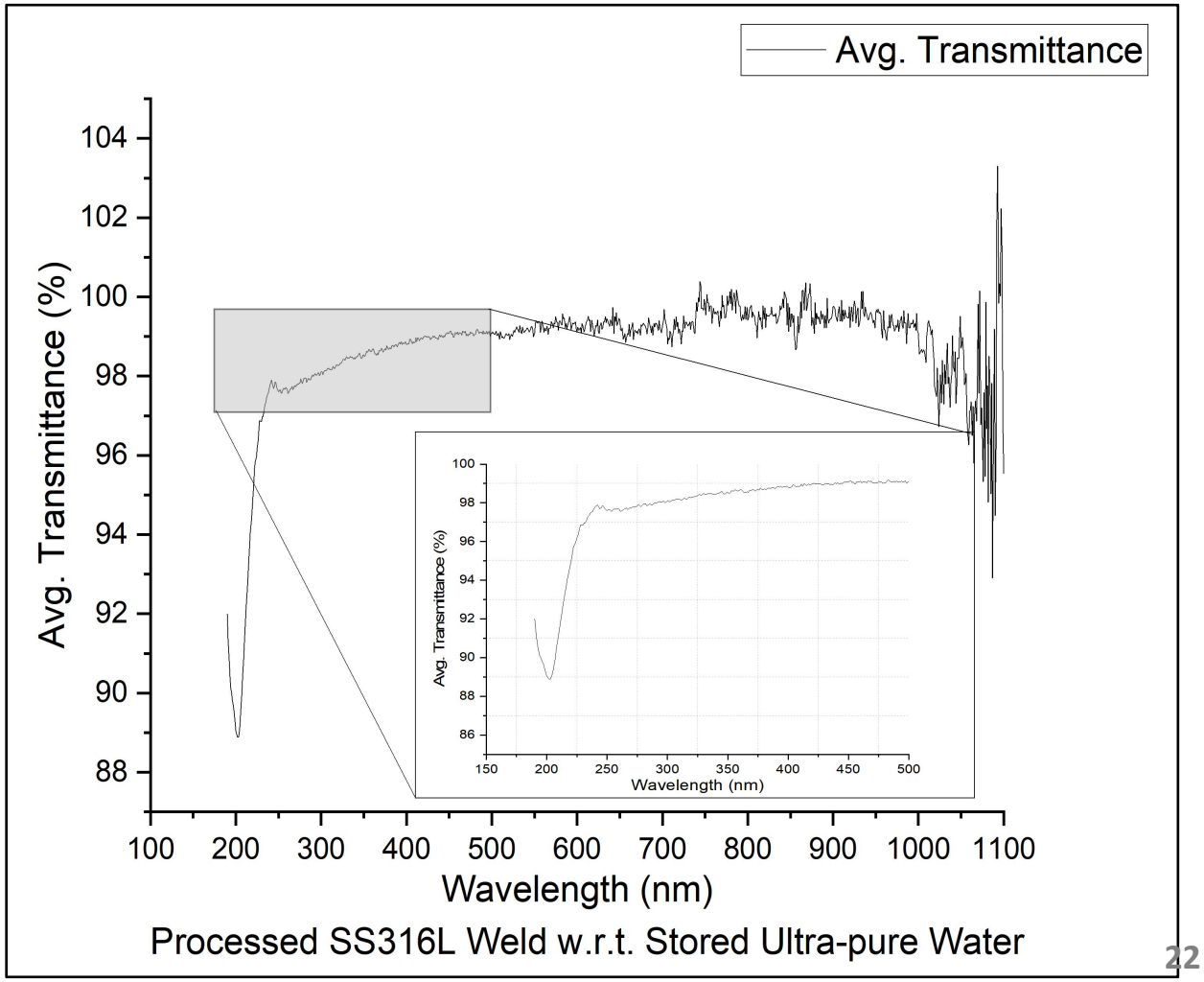
Material Soak Test - Transmission Plots

Medium: Ultra-Pure Water

SS304 Plates With SS316L Filler Material



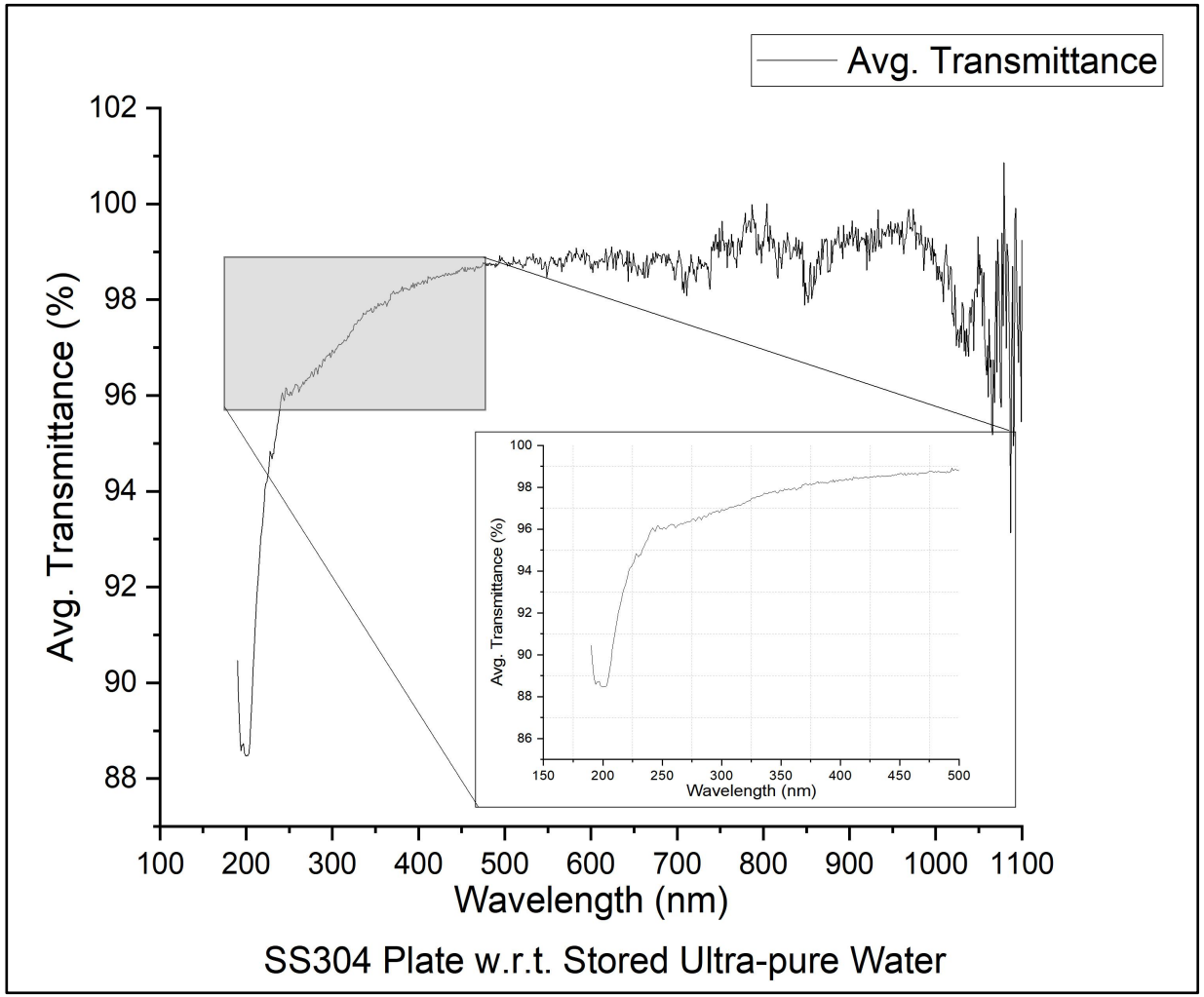
Picked and passivated SS304 Plates With SS316L Filler Material



Material Soak Test - Transmission Plots

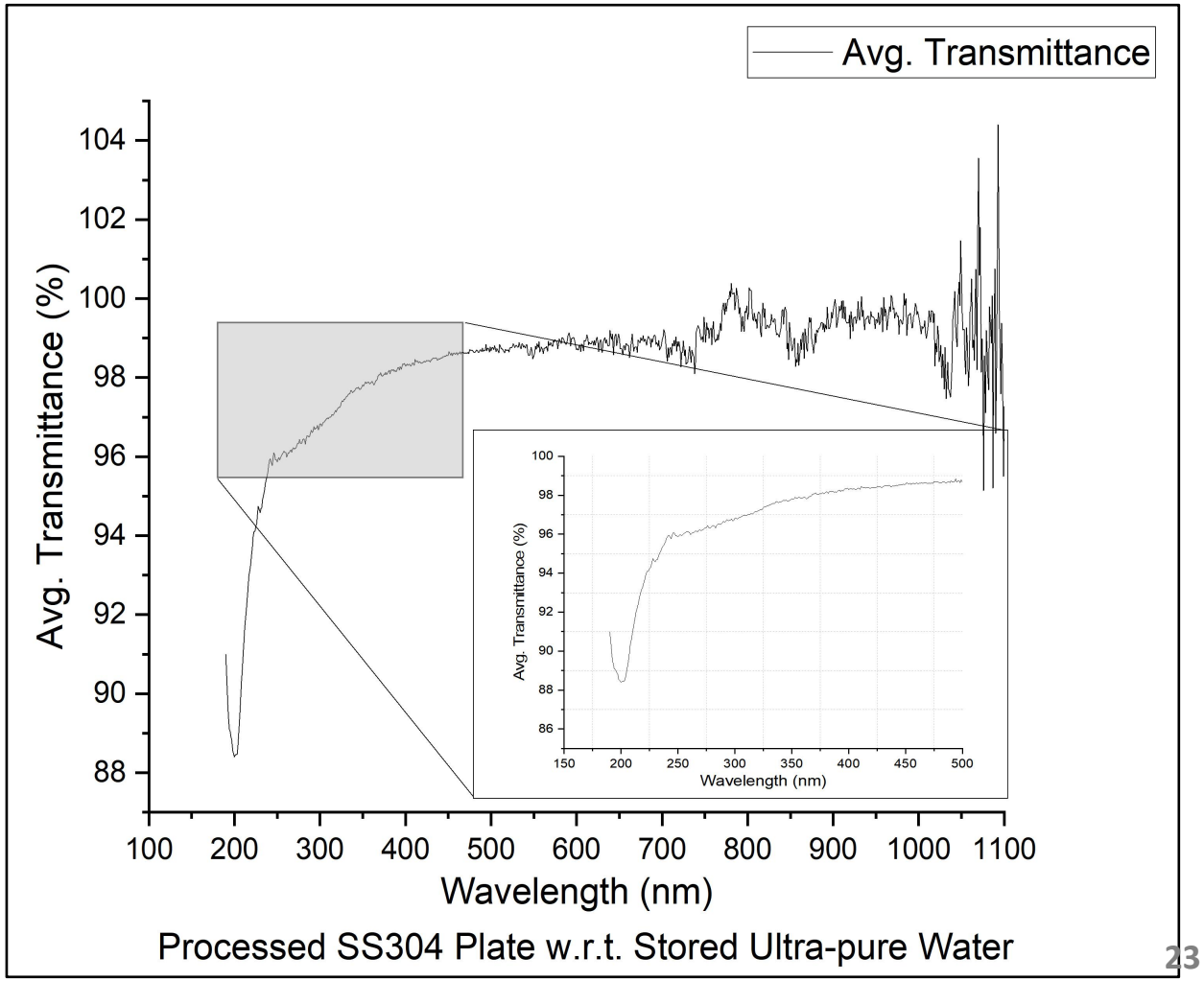
Medium: Ultra-Pure Water

Machined SS304 Plates



SS304 Plate w.r.t. Stored Ultra-pure Water

Picked and passivated machined SS304 Plates

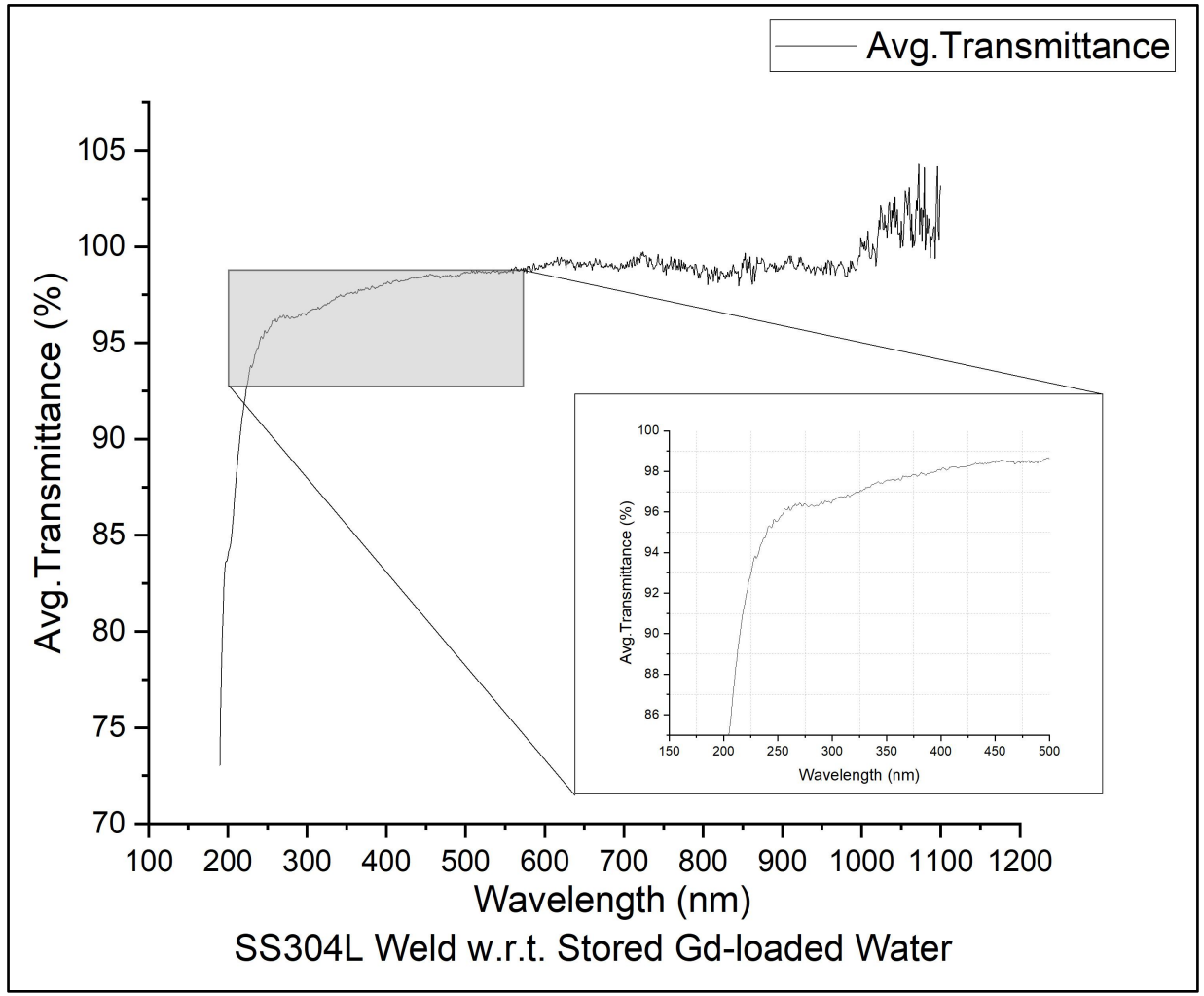


Processed SS304 Plate w.r.t. Stored Ultra-pure Water

Material Soak Test - Transmission Plots

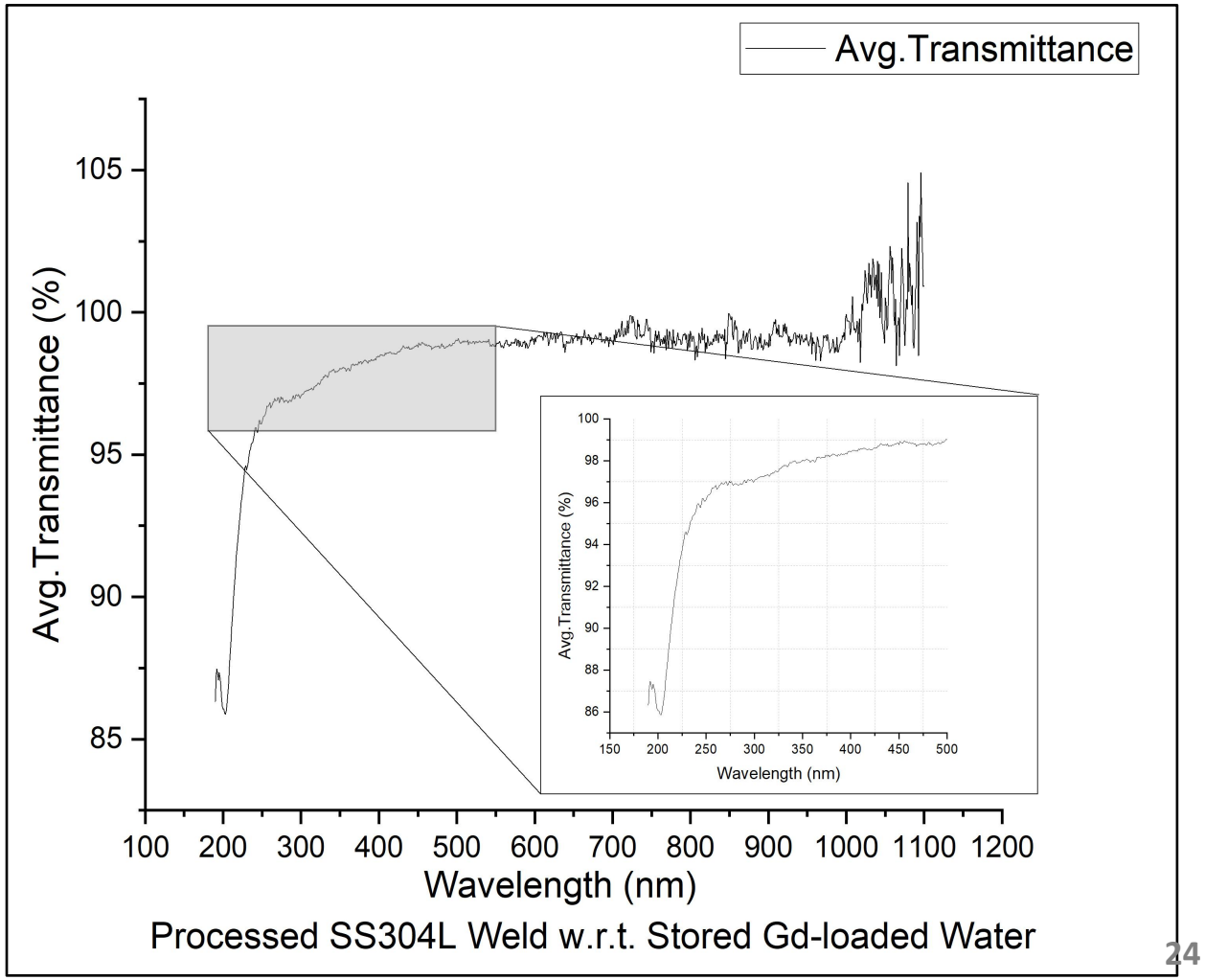
Medium: Gd-Loaded Water

SS304 Plates With SS304L Filler Material



SS304L Weld w.r.t. Stored Gd-loaded Water

Picked and passivated SS304 Plates With SS304L Filler Material

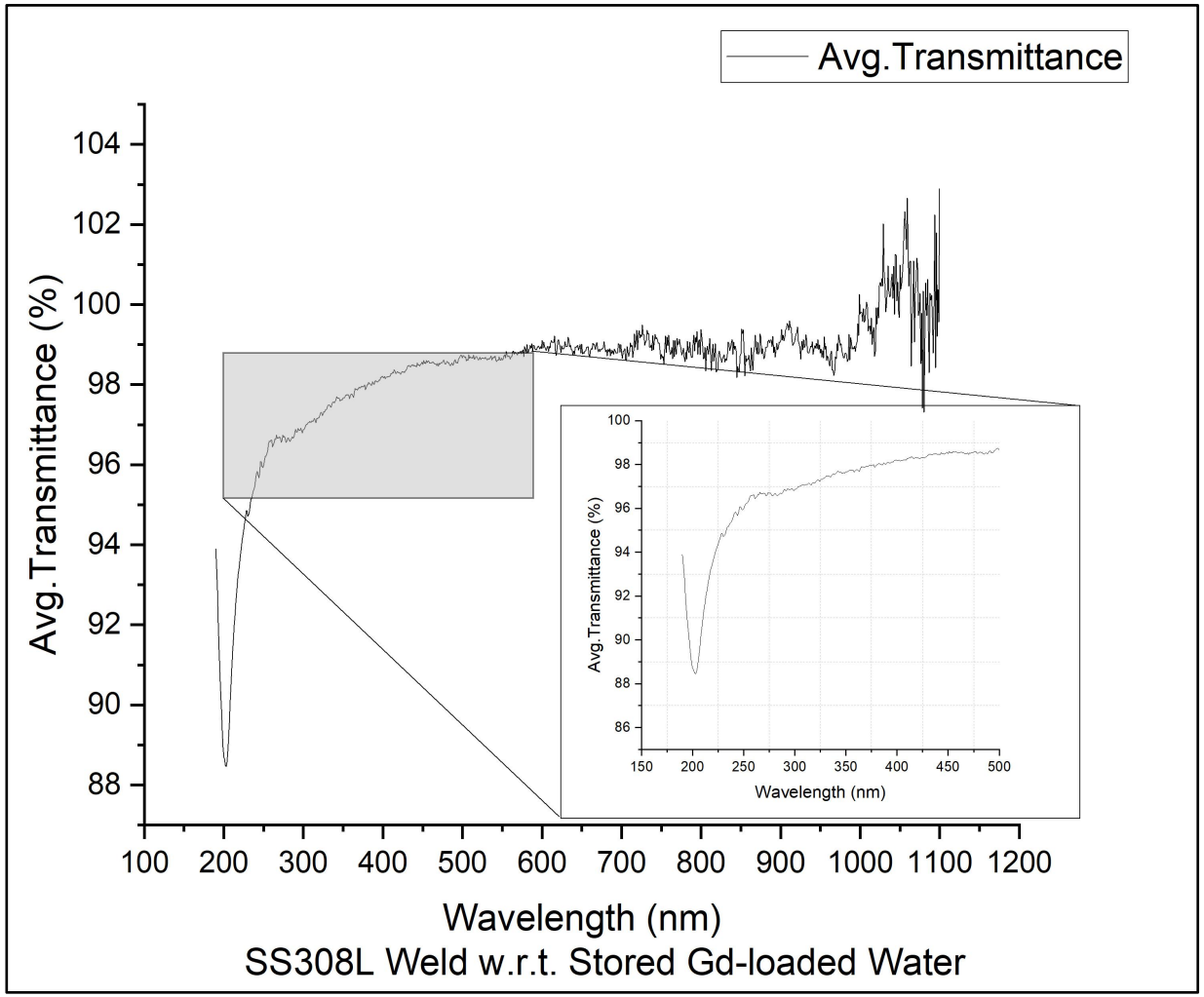


Processed SS304L Weld w.r.t. Stored Gd-loaded Water

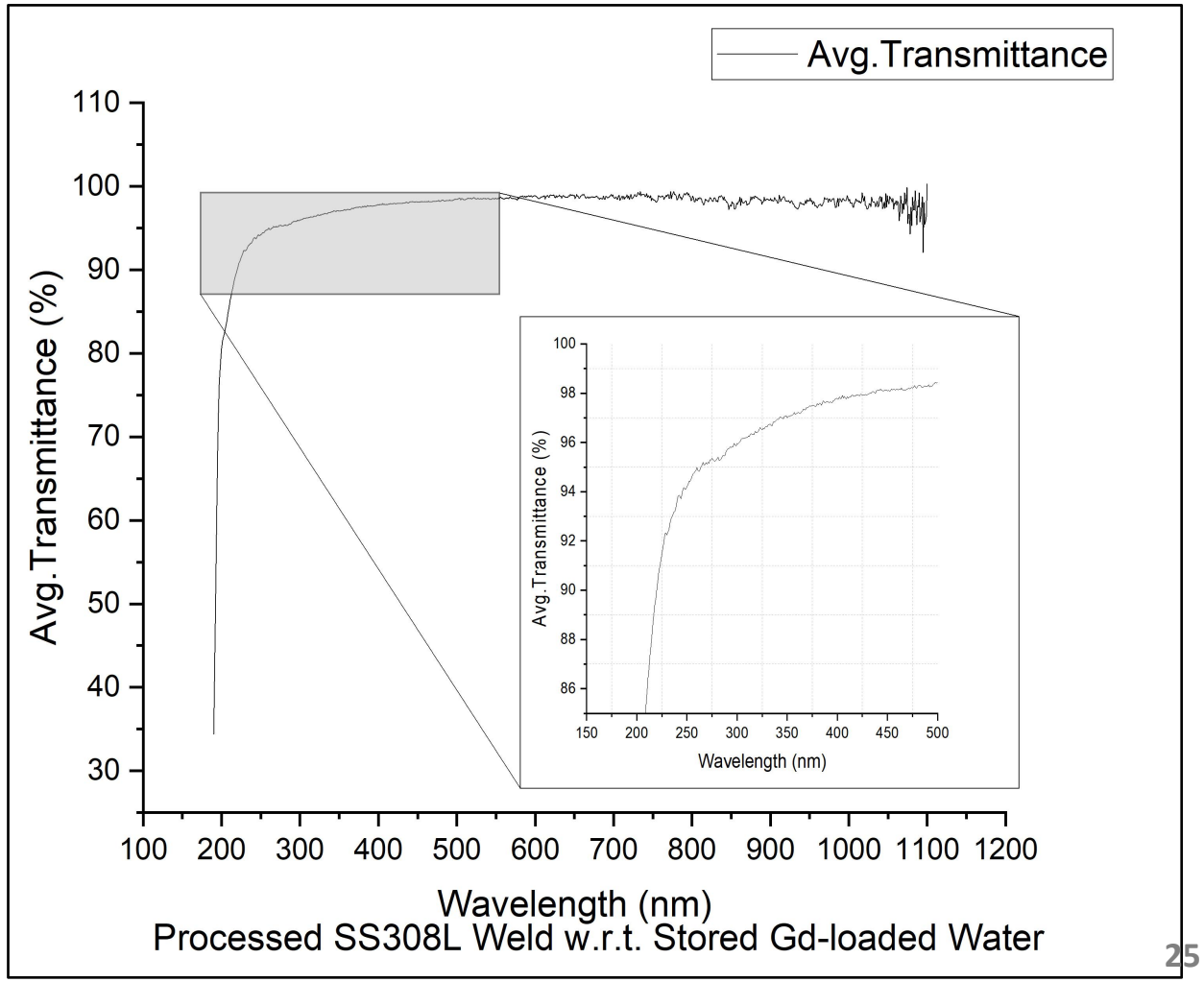
Material Soak Test - Transmission Plots

Medium: Gd-Loaded Water

SS304 Plates With SS308L Filler Material



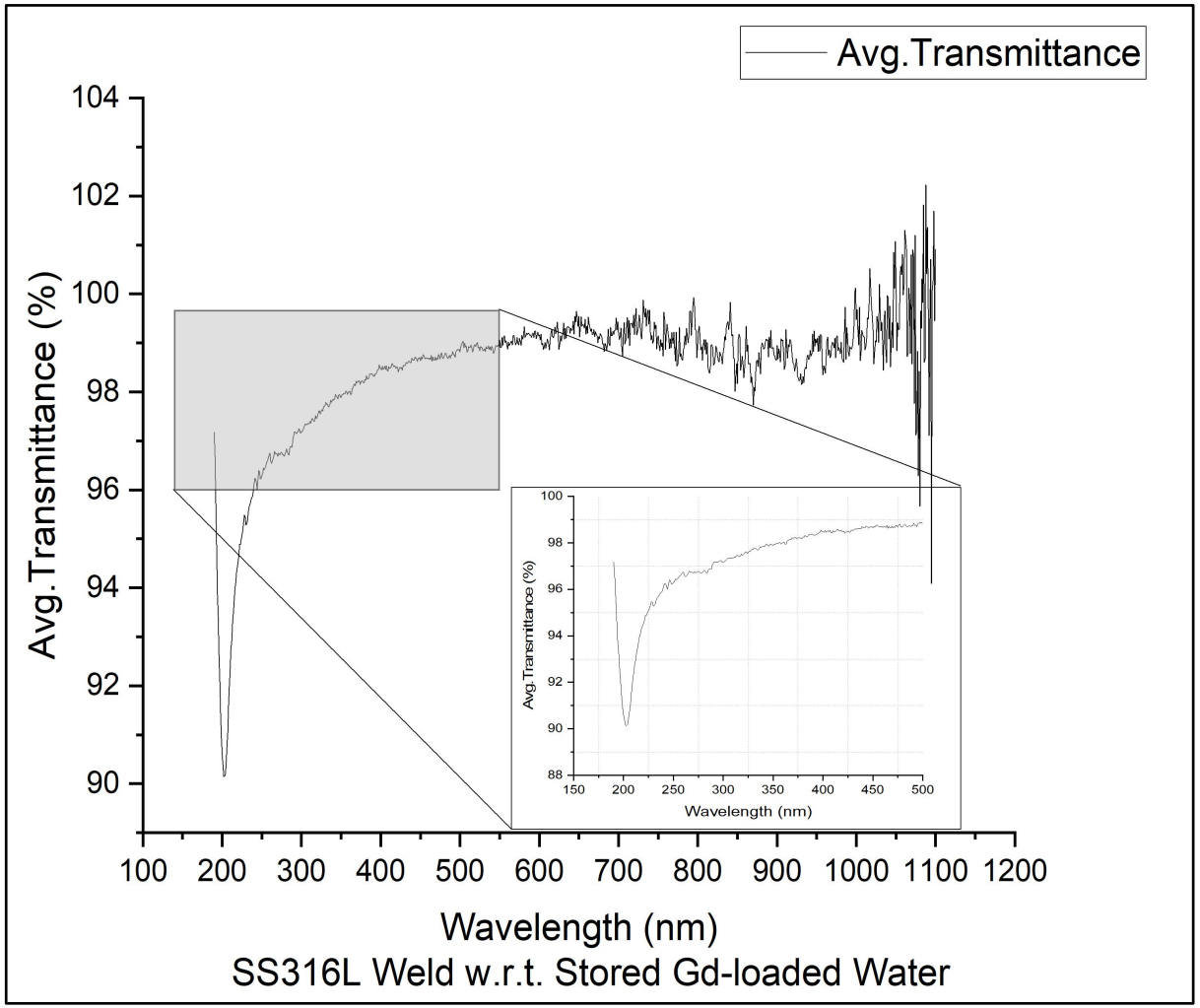
Picked and passivated SS304 Plates With SS308L Filler Material



Material Soak Test - Transmission Plots

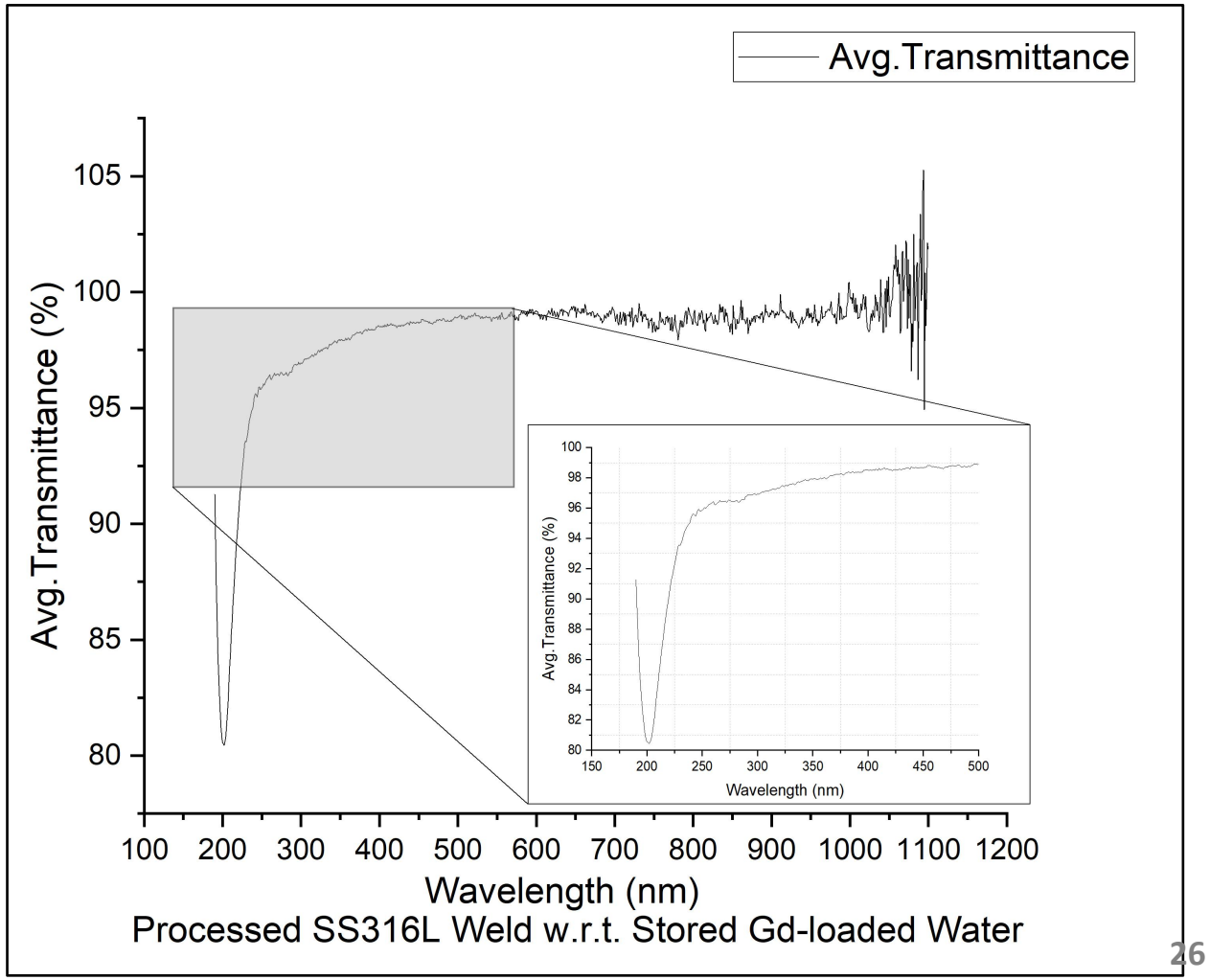
Medium: Gd-Loaded Water

SS304 Plates With SS316L Filler Material



SS316L Weld w.r.t. Stored Gd-loaded Water

Picked and passivated SS304 Plates With SS316L Filler Material

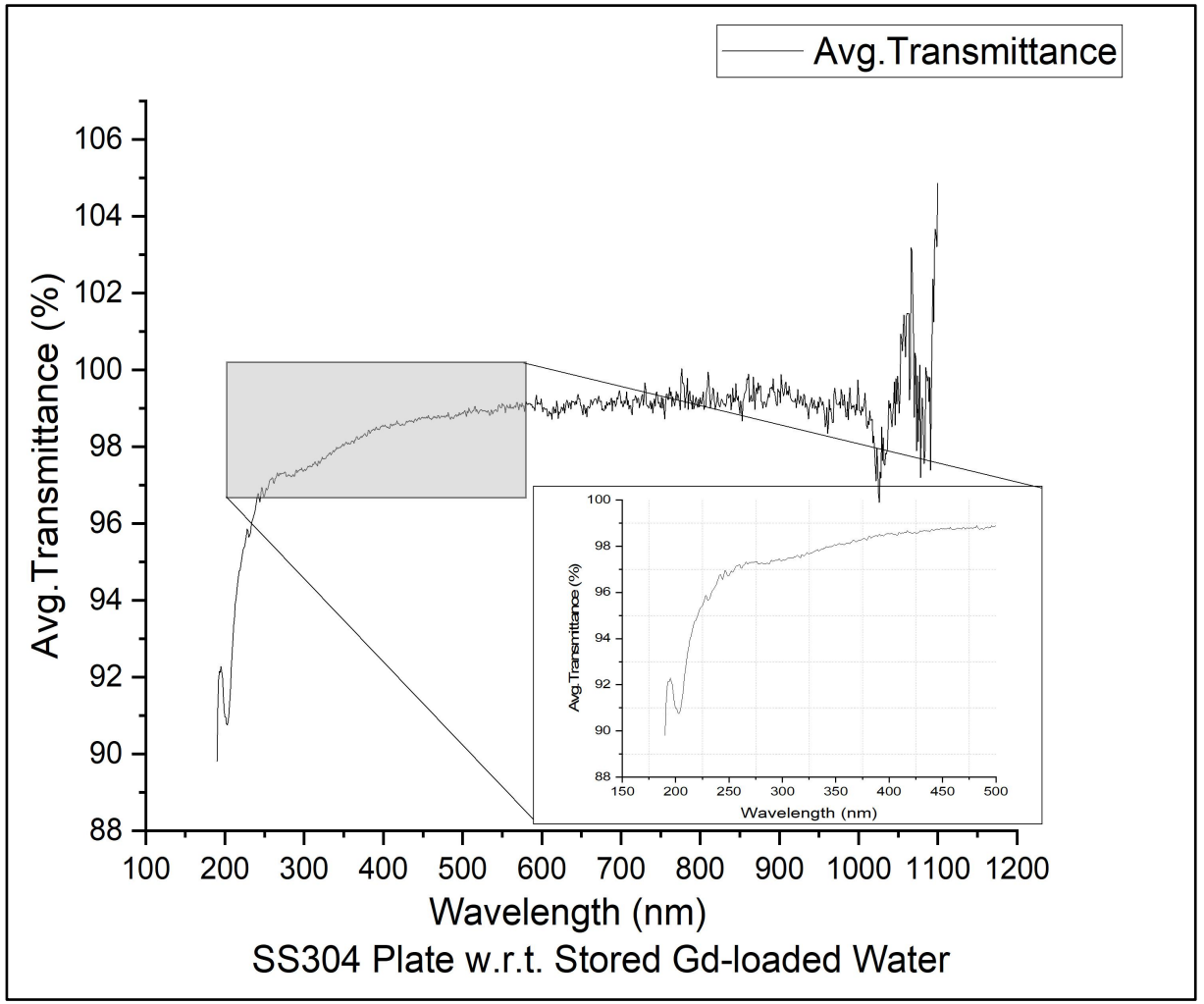


Processed SS316L Weld w.r.t. Stored Gd-loaded Water

Material Soak Test - Transmission Plots

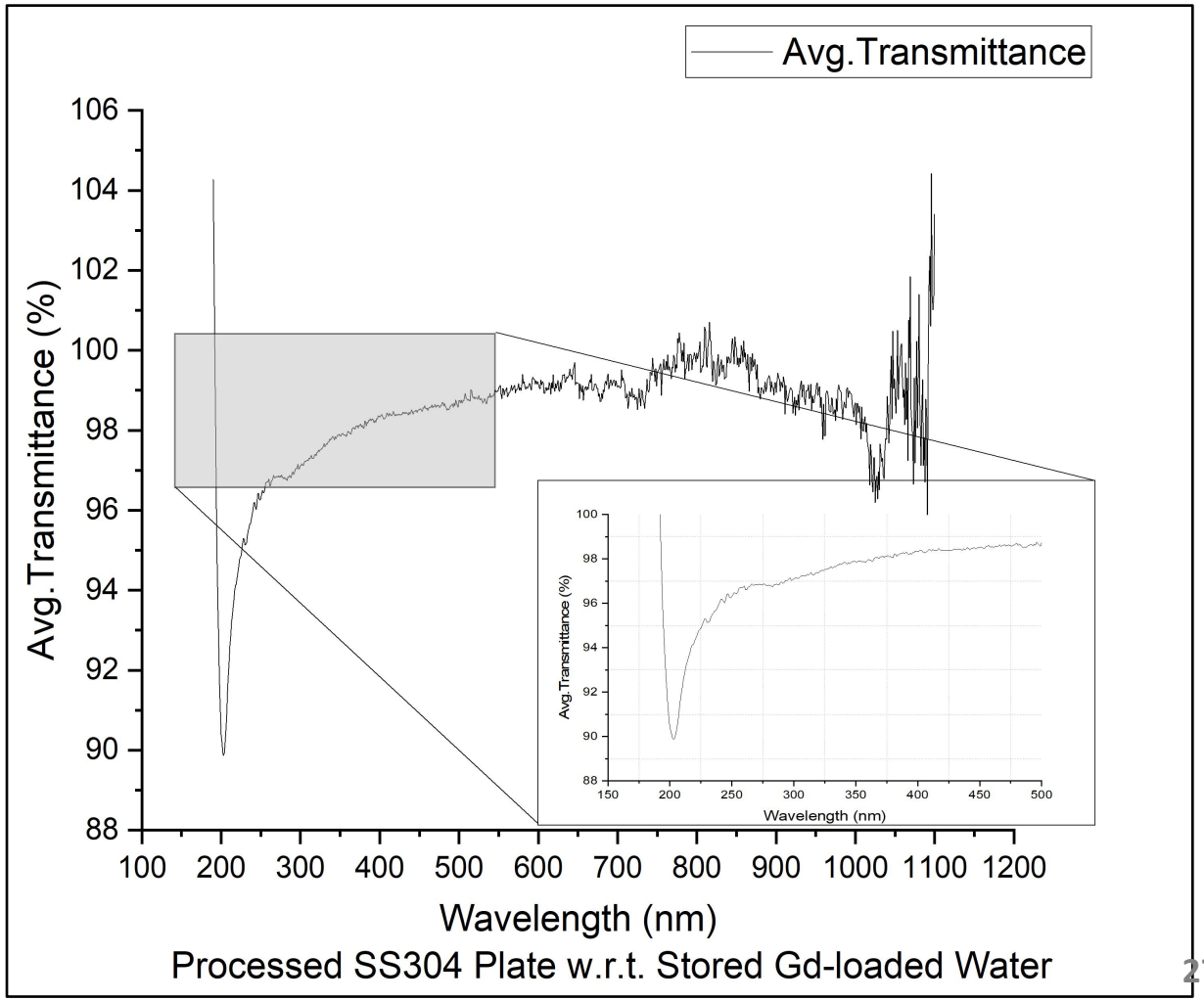
Medium: Gd-Loaded Water

Machined SS304 Plates



SS304 Plate w.r.t. Stored Gd-loaded Water

Picked and passivated machined SS304 Plates



Processed SS304 Plate w.r.t. Stored Gd-loaded Water

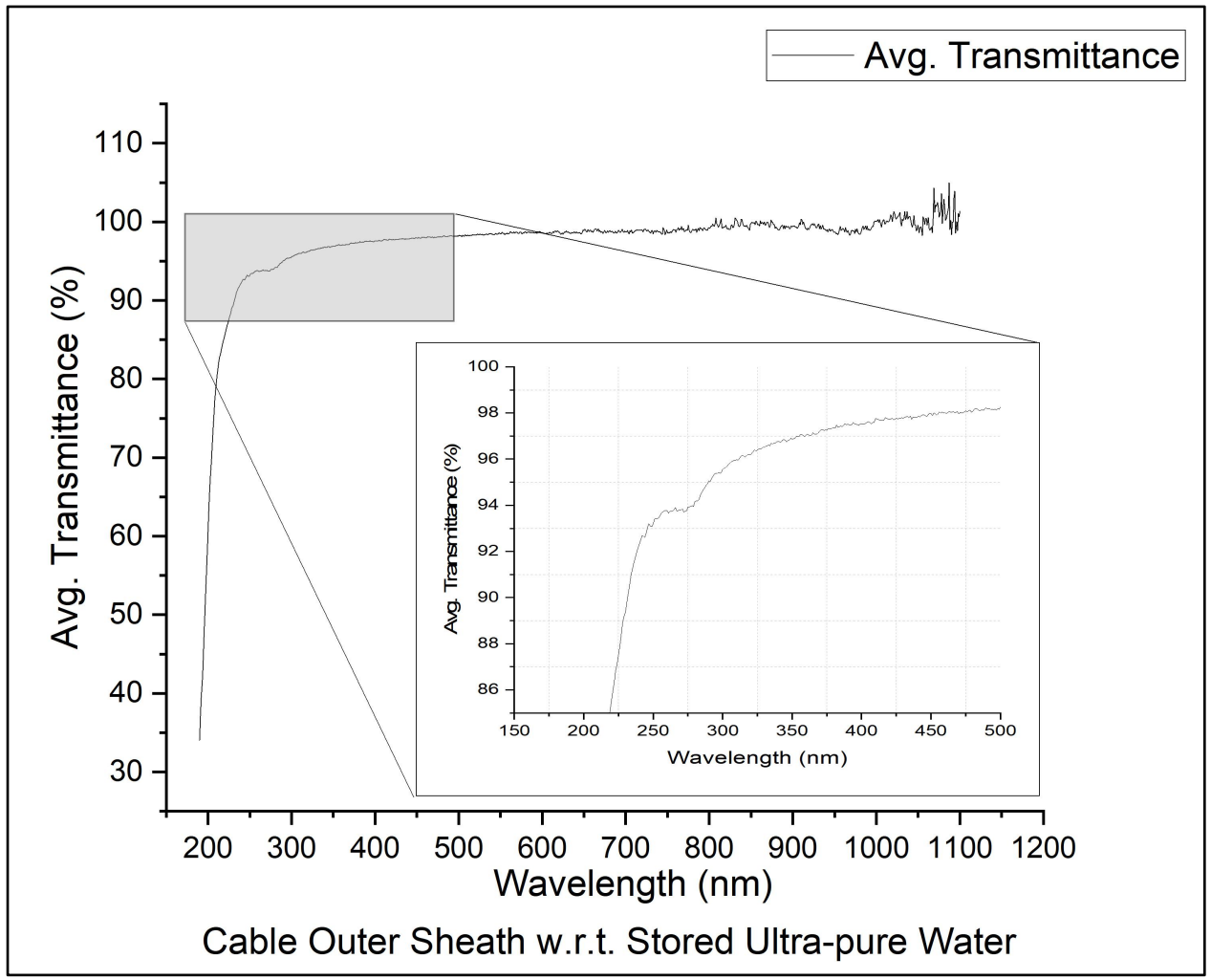
Material Soak Test

Sr. No.	Sample Material
9.	Cable Outer Sheath (Marine grade CAT 5e)
10.	Araldite
11.	Silicone Gel
12.	Heat Shrink Sleeve (Polyolefin)
13.	Silicone Grease
14.	O-Ring
15.	Teflon Bush
16.	Teflon Tape

Material Soak Test - Transmission Plots

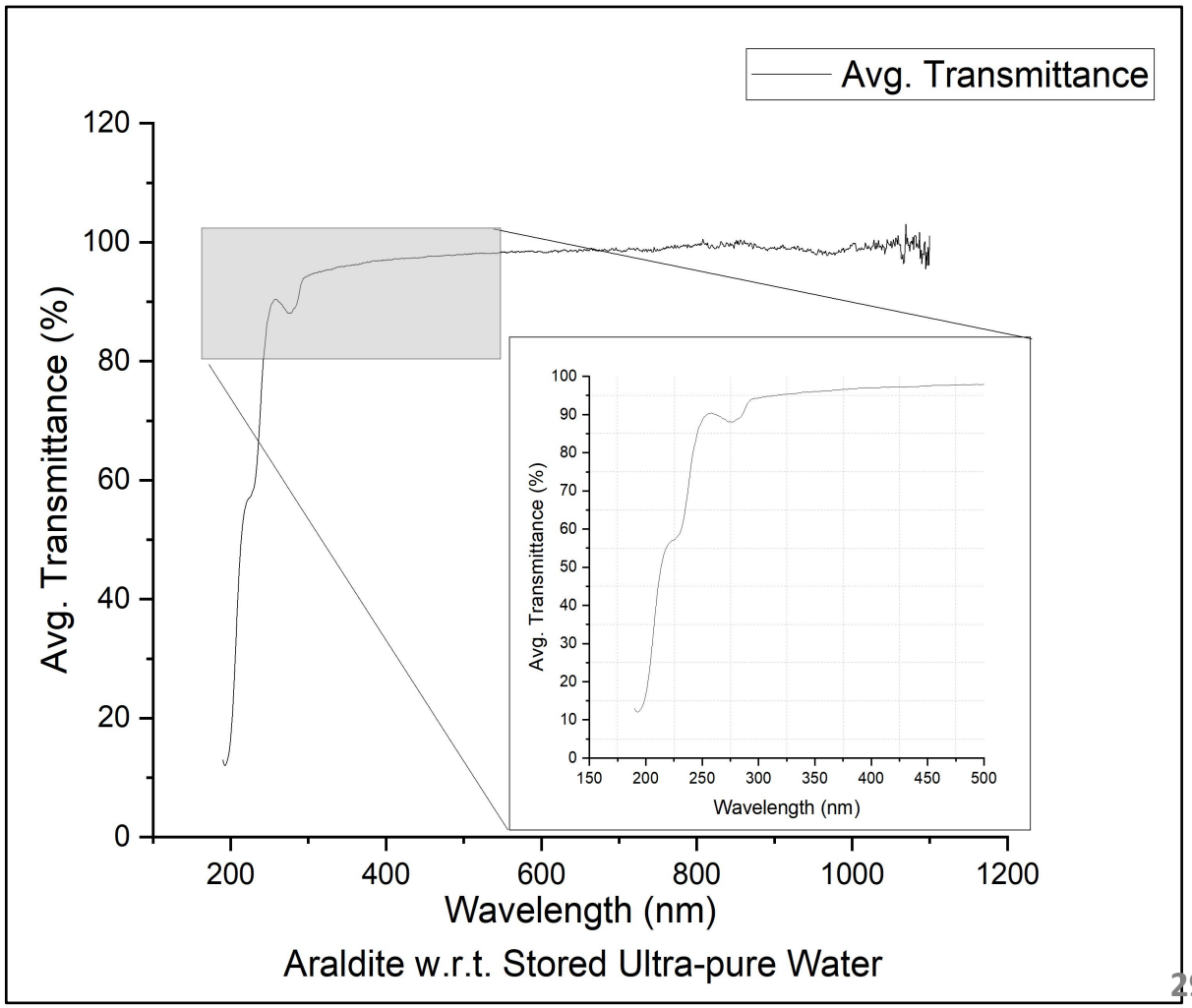
Medium: Ultra-Pure Water

Cable Outer Sheath



Cable Outer Sheath w.r.t. Stored Ultra-pure Water

Araldite

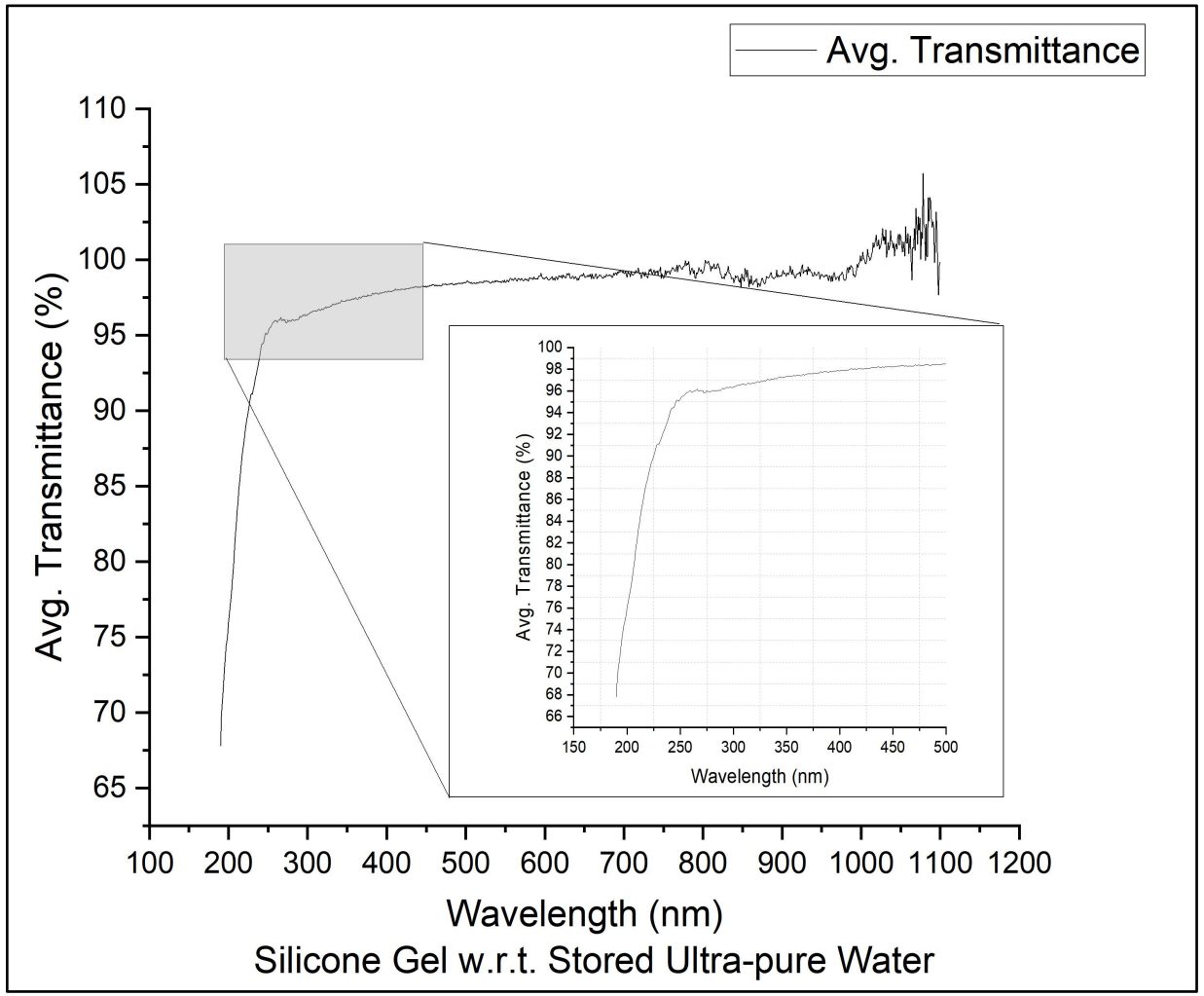


Araldite w.r.t. Stored Ultra-pure Water

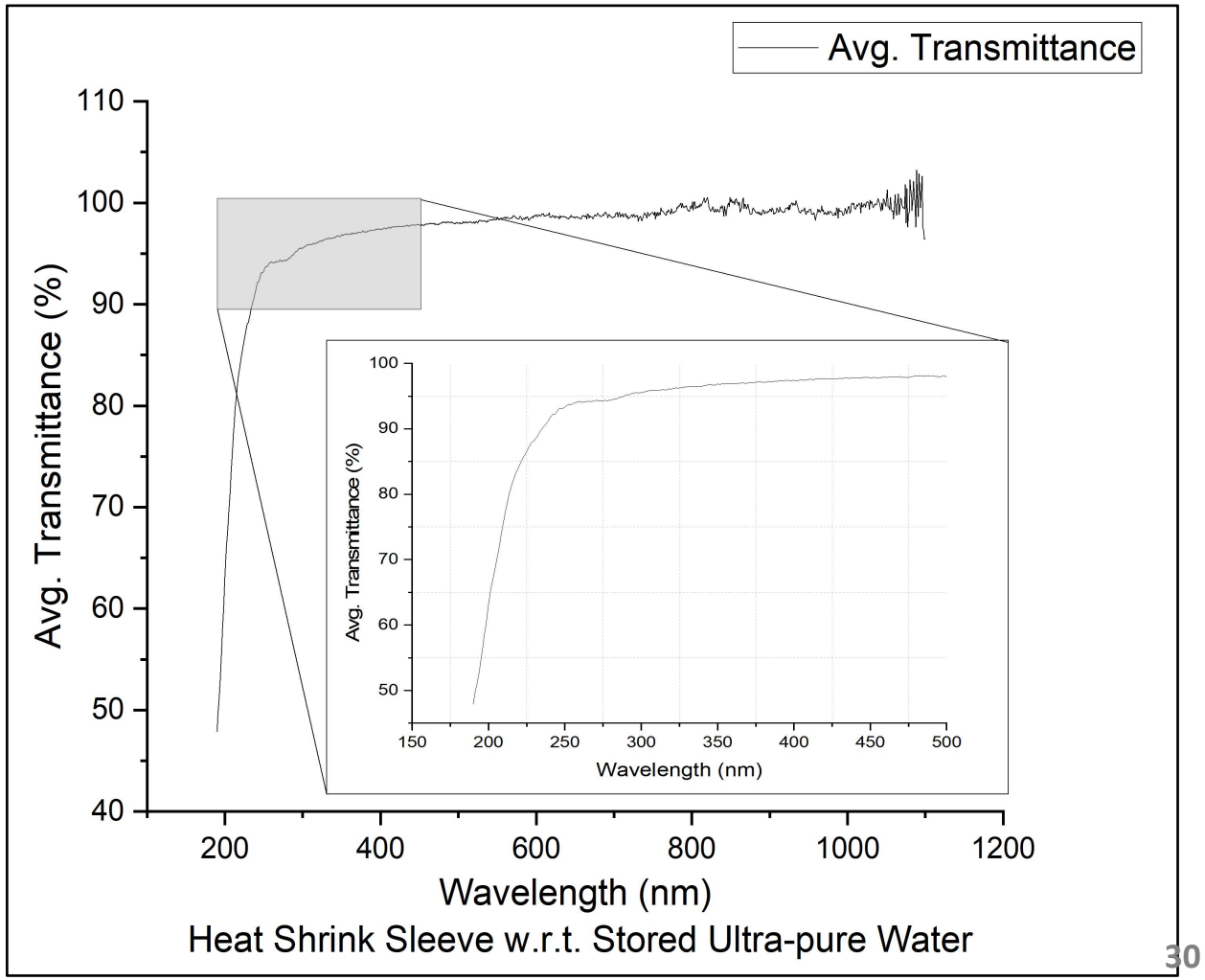
Material Soak Test - Transmission Plots

Medium: Ultra-Pure Water

Silicone Gel



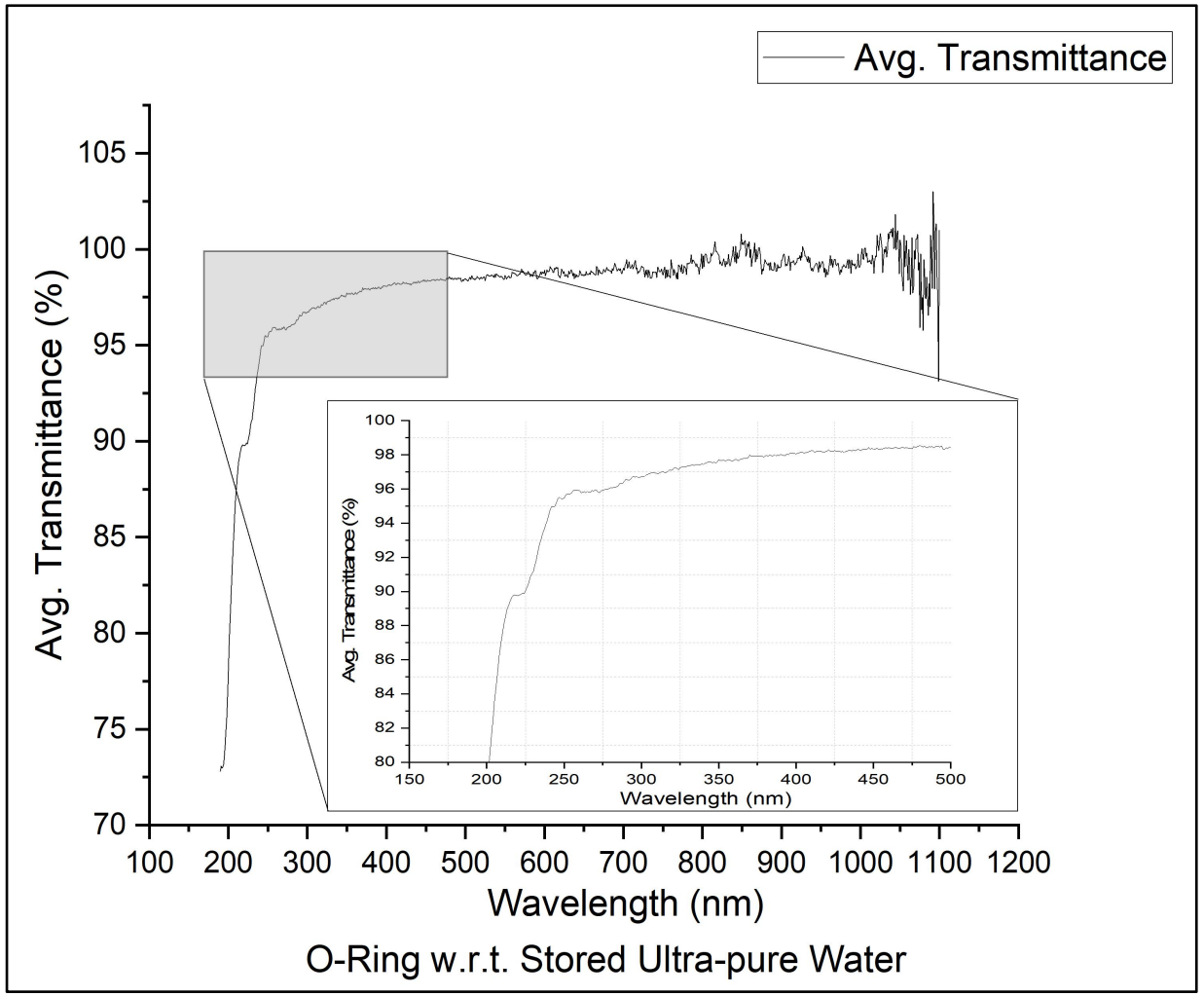
Heat Shrink Sleeve



Material Soak Test - Transmission Plots

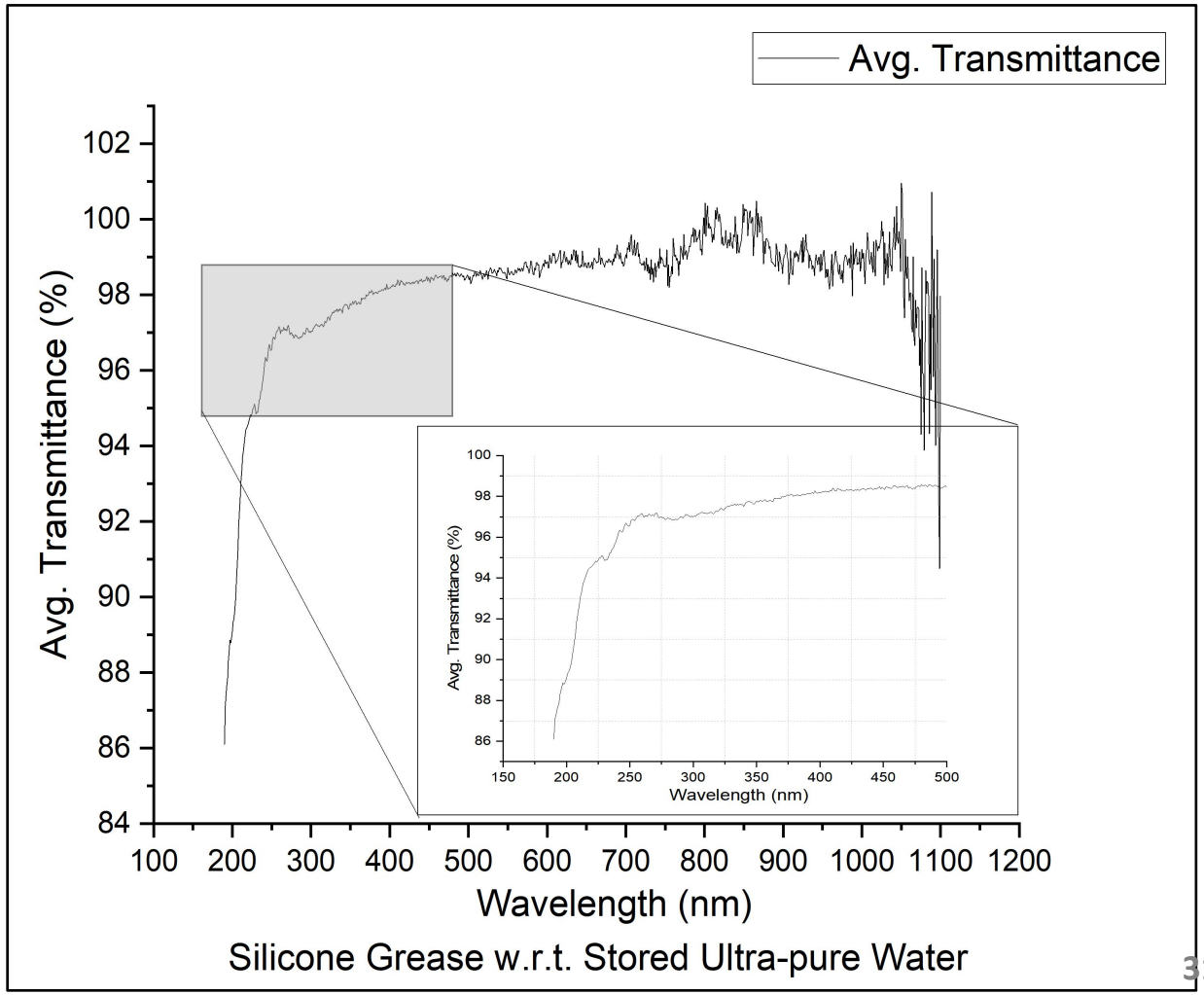
Medium: Ultra-Pure Water

O-Ring



O-Ring w.r.t. Stored Ultra-pure Water

Silicone Grease

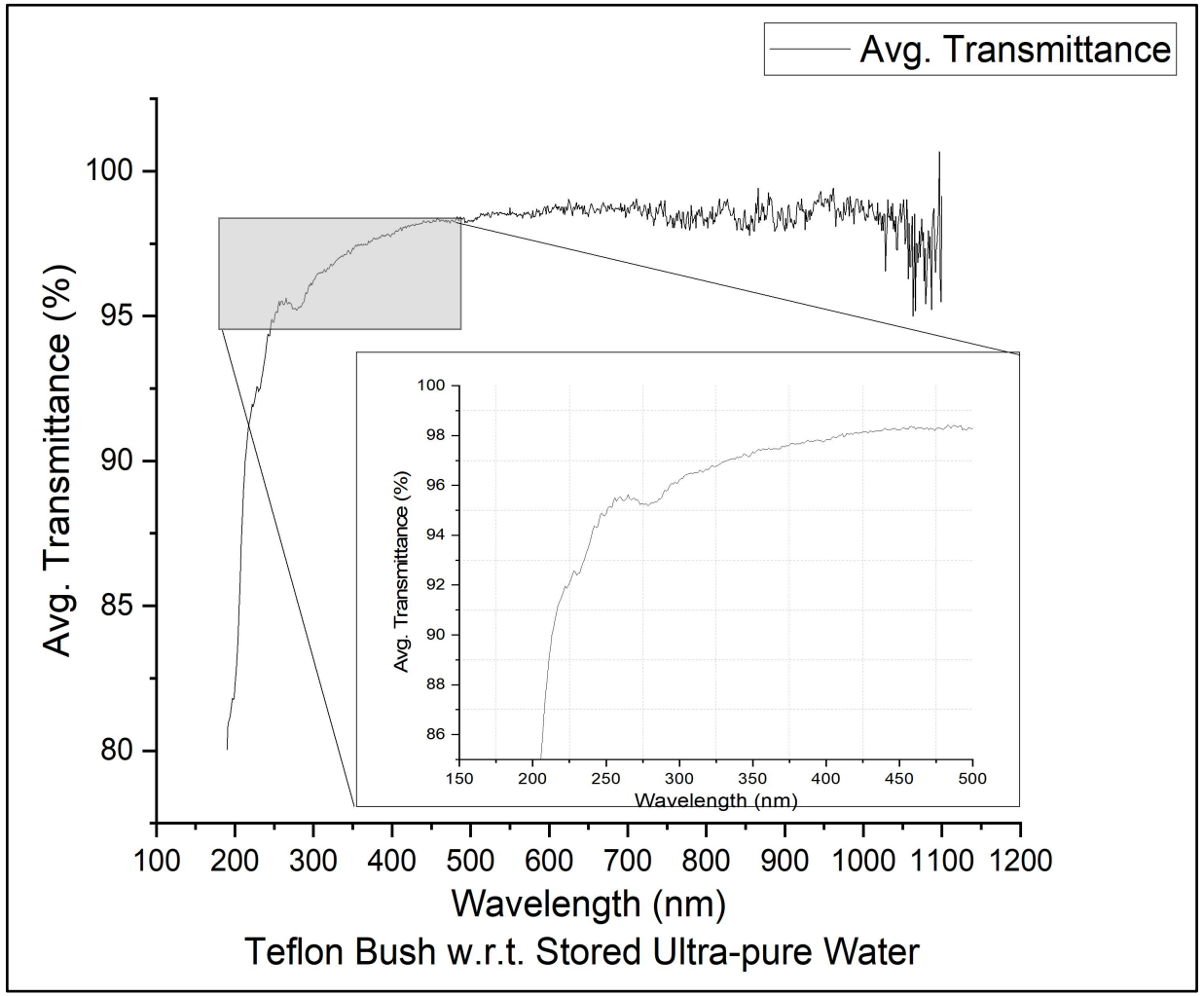


Silicone Grease w.r.t. Stored Ultra-pure Water

Material Soak Test - Transmission Plots

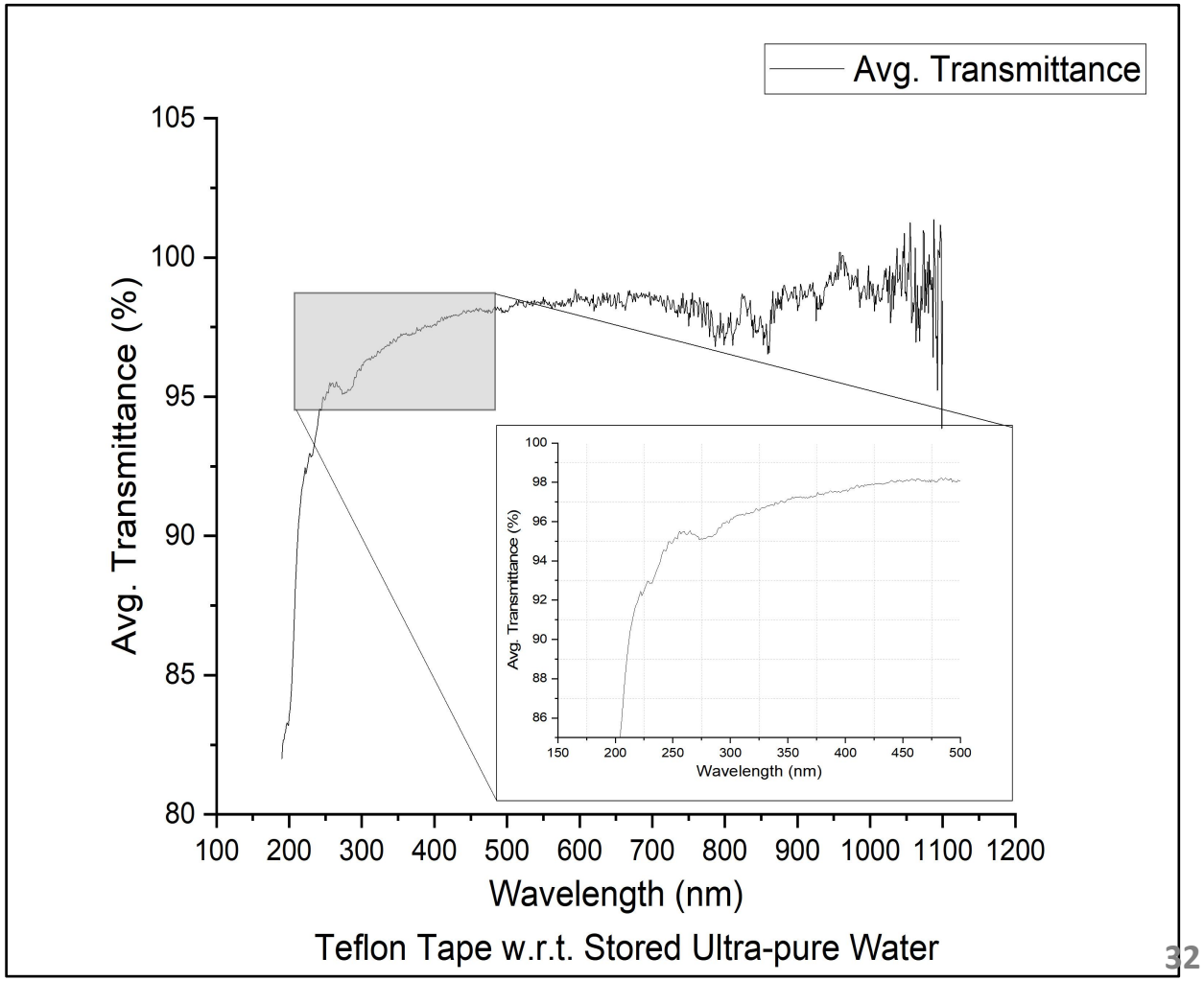
Medium: Ultra-Pure Water

Teflon Bush



Teflon Bush w.r.t. Stored Ultra-pure Water

Teflon Tape

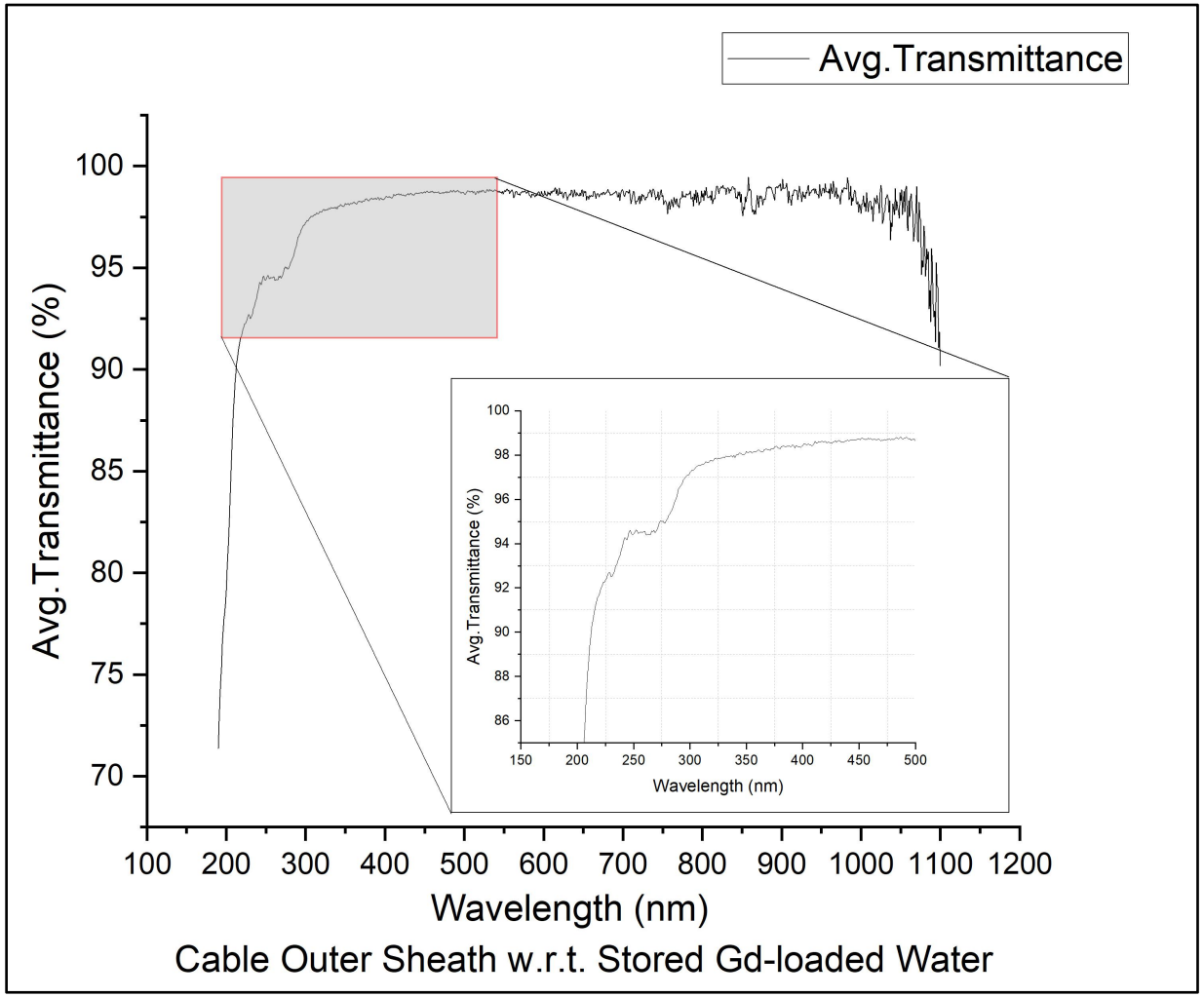


Teflon Tape w.r.t. Stored Ultra-pure Water

Material Soak Test - Transmission Plots

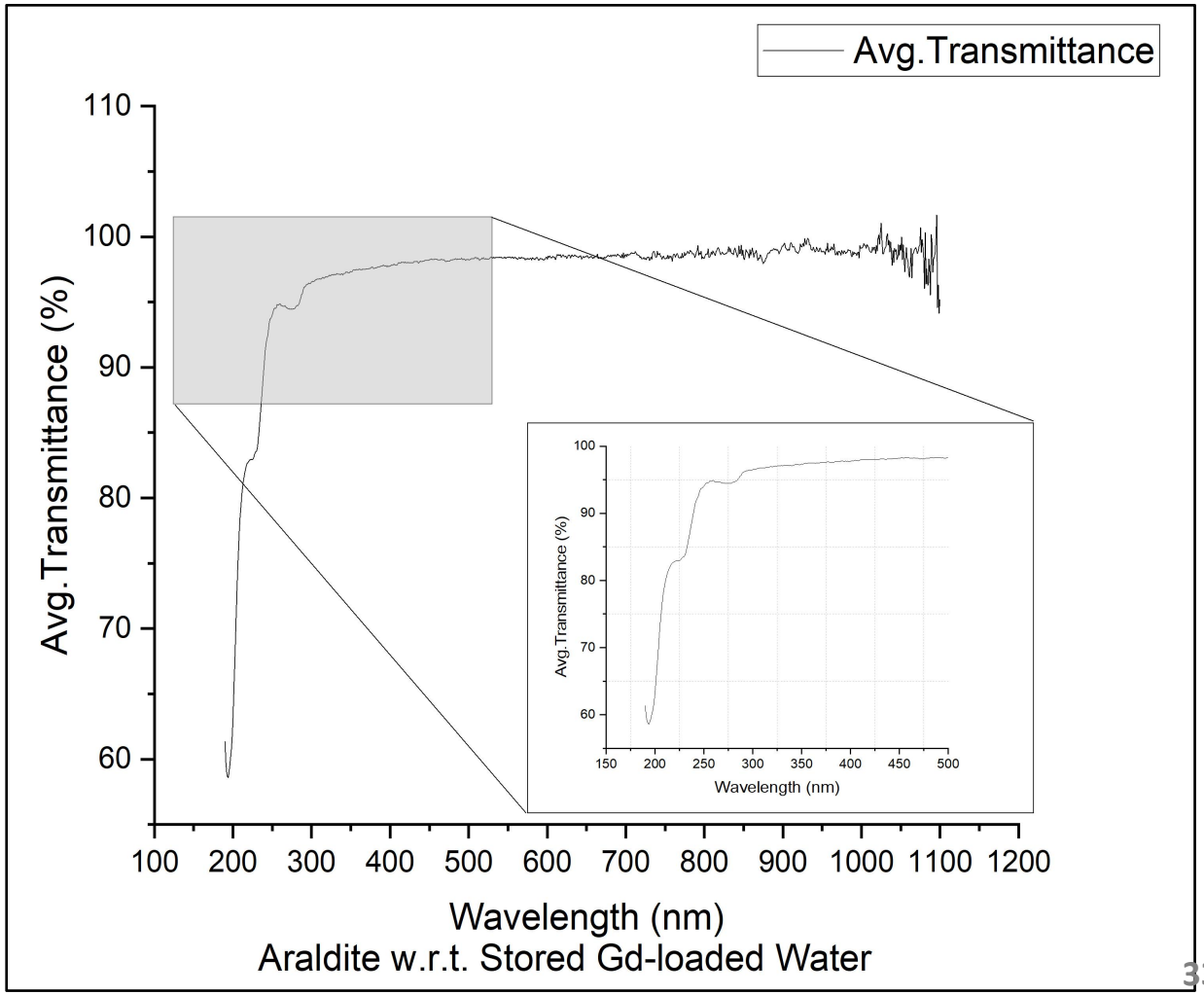
Medium: Gd-Loaded Water

Cable Outer Sheath



Cable Outer Sheath w.r.t. Stored Gd-loaded Water

Araldite

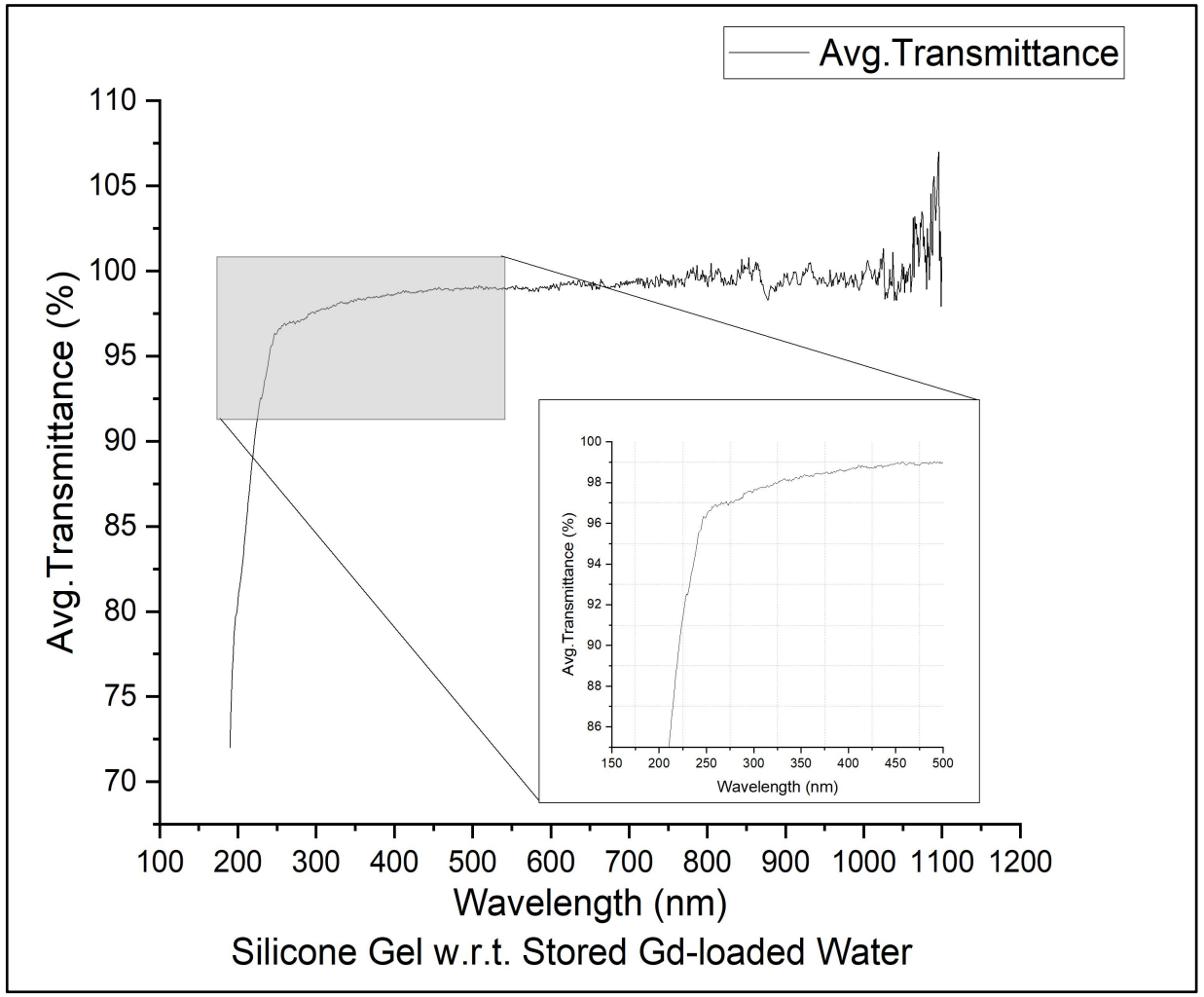


Araldite w.r.t. Stored Gd-loaded Water

Material Soak Test - Transmission Plots

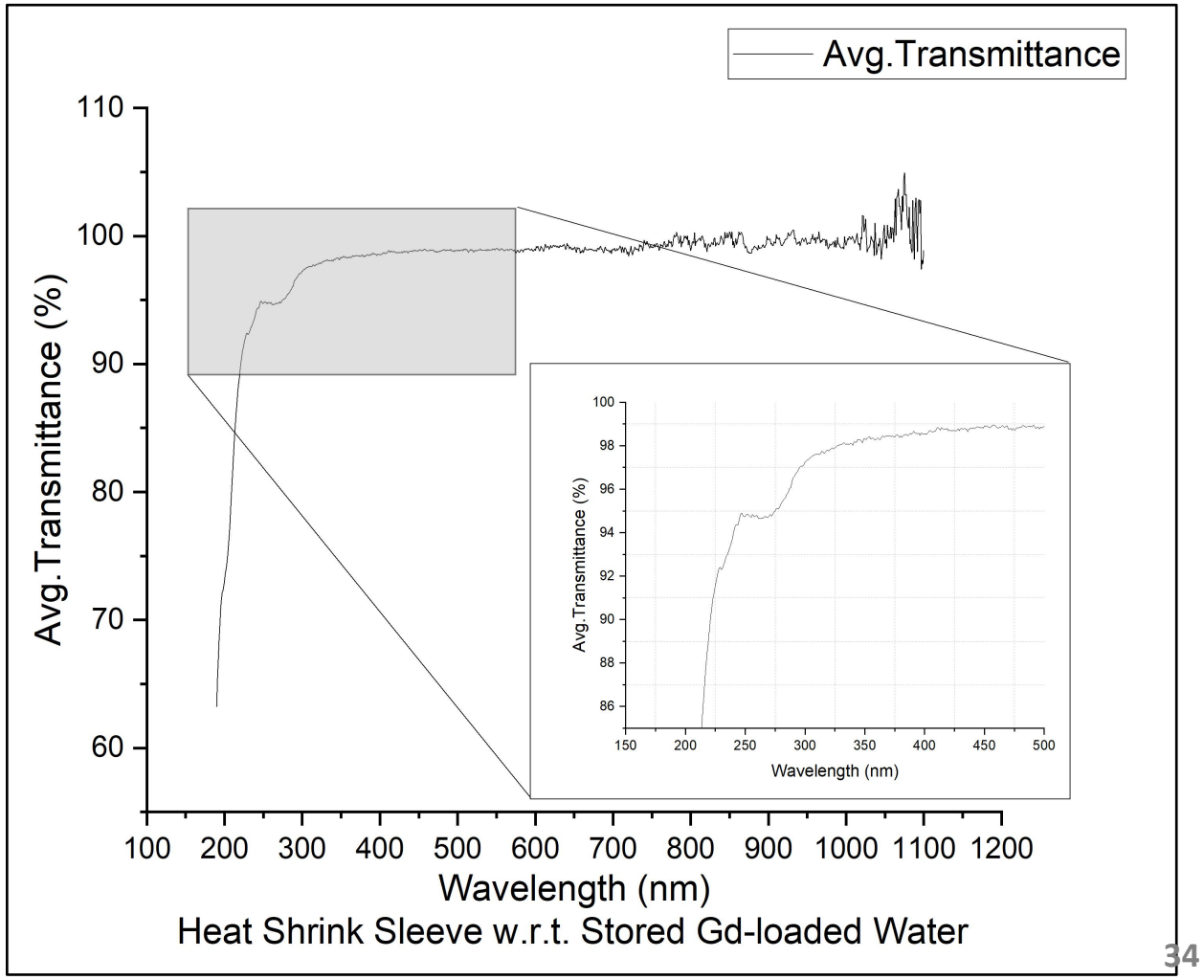
Medium: Gd-Loaded Water

Silicone Gel



Silicone Gel w.r.t. Stored Gd-loaded Water

Heat Shrink Sleeve

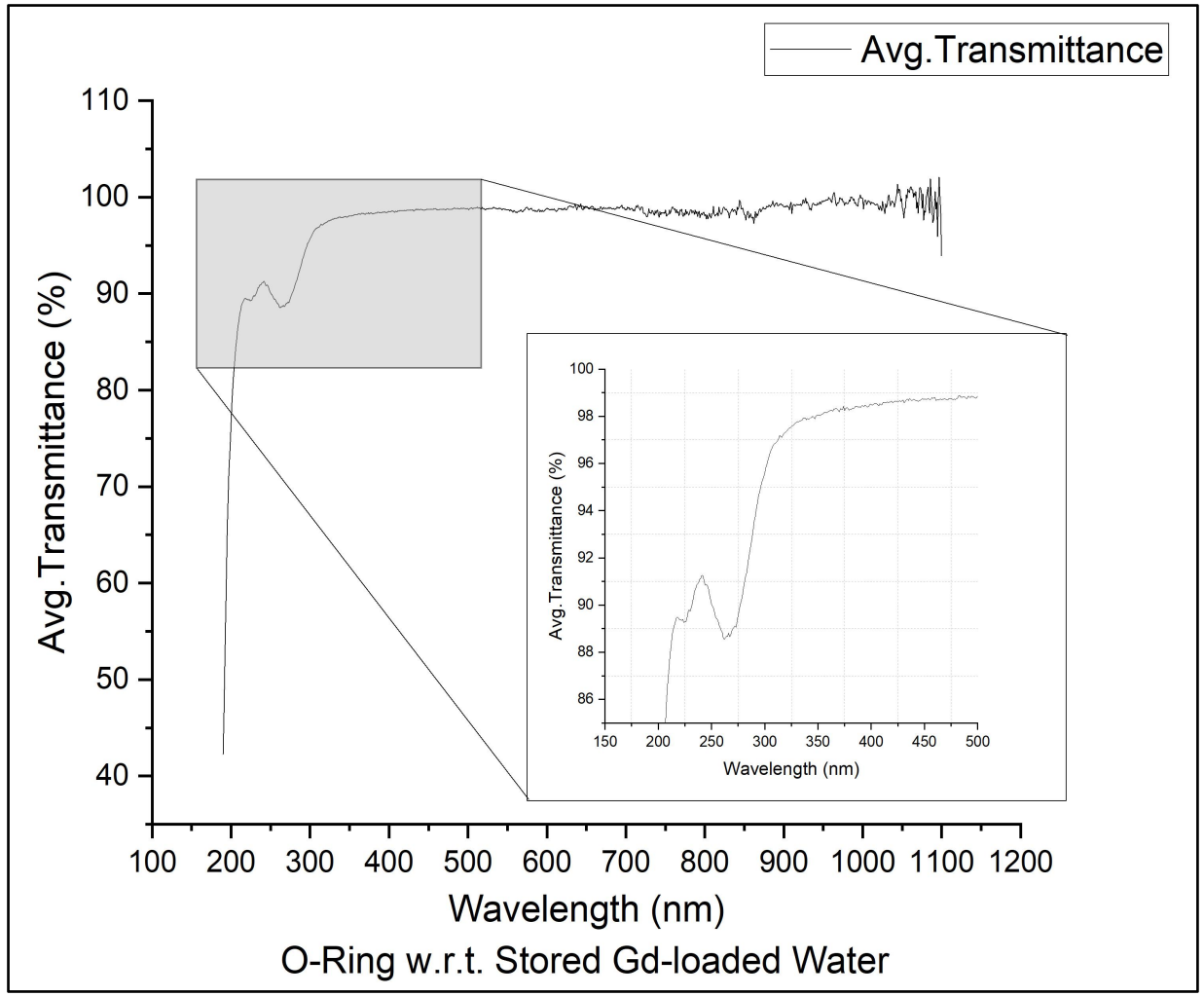


Heat Shrink Sleeve w.r.t. Stored Gd-loaded Water

Material Soak Test - Transmission Plots

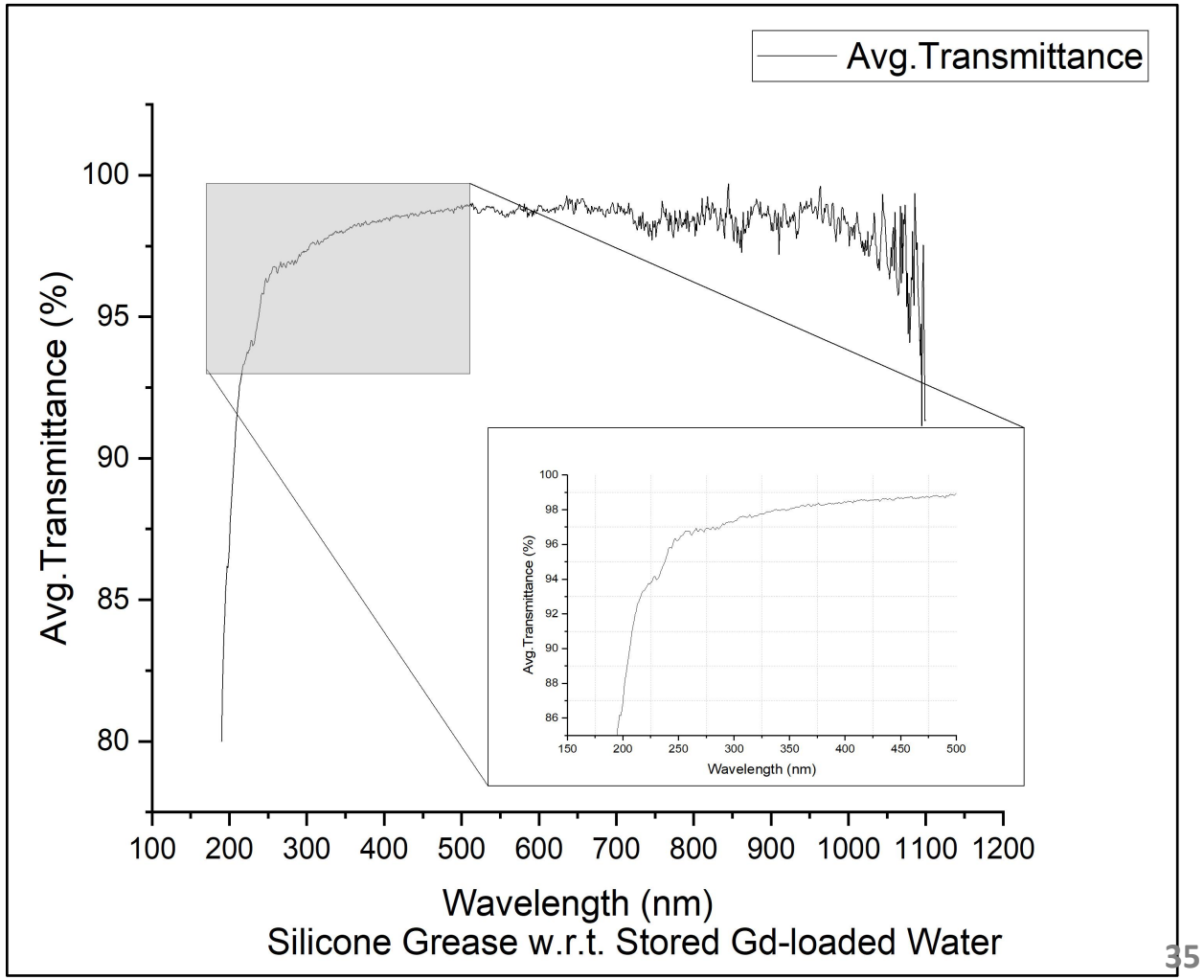
Medium: Gd-Loaded Water

O-Ring



O-Ring w.r.t. Stored Gd-loaded Water

Silicone Grease

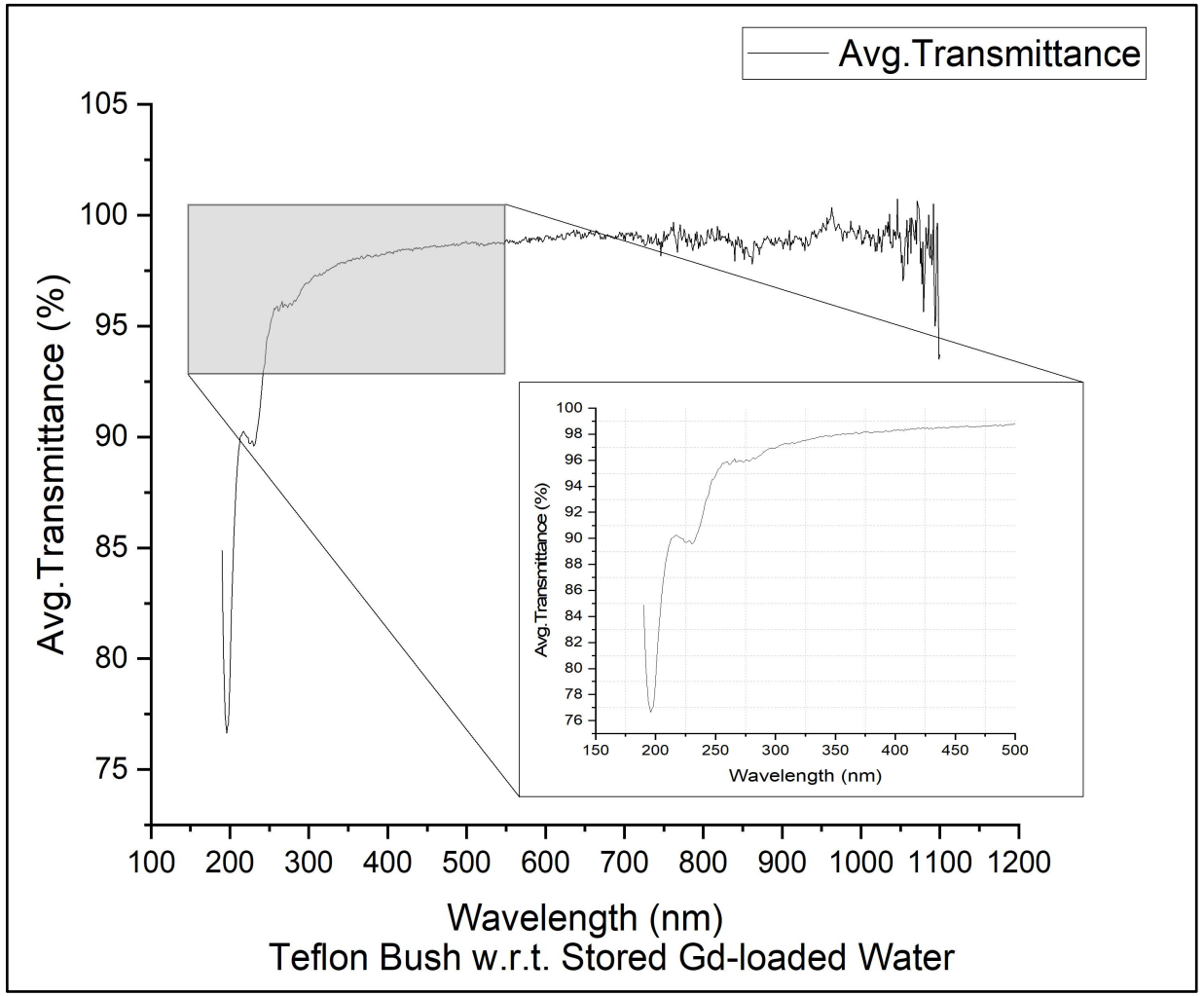


Silicone Grease w.r.t. Stored Gd-loaded Water

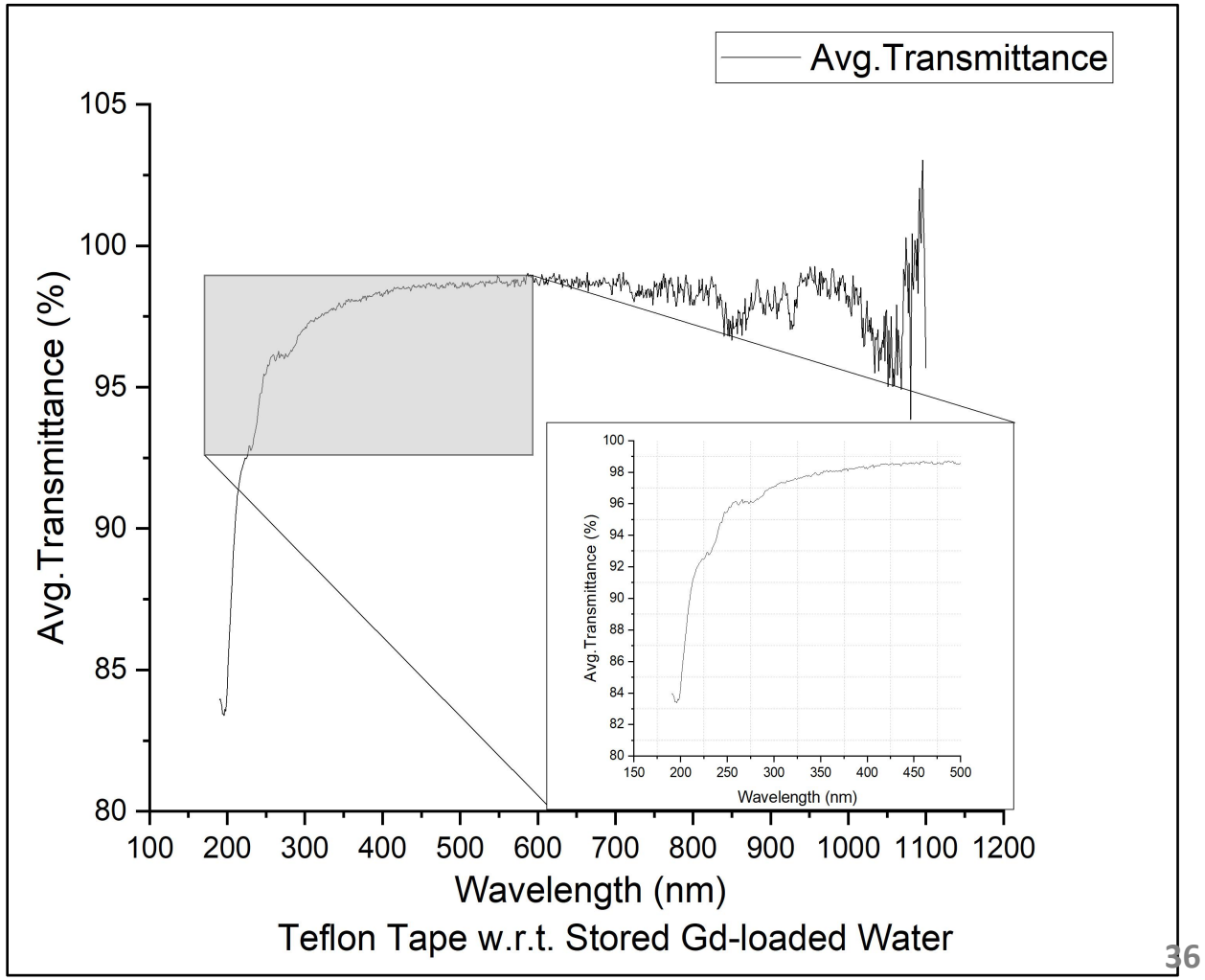
Material Soak Test - Transmission Plots

Medium: Gd-Loaded Water

Teflon Bush



Teflon Tape



Material Soak Test – Inference from Transmission Plots

UV-Visible Transmission spectroscopy

- Transmittance spectrum may not be very reliable for 200 - 250nm.
- There is possibility of leaching from polyproplene bottles. Will be verified by storing solution in Stainless steel container.
- Araldite leaches in the solution. In WCTE, exposure of Araldite to solution will be very less and is covered by Silicone gel and Heat shrink sleeve.

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Kshitija Satao

Prajwal Lale

Thank You