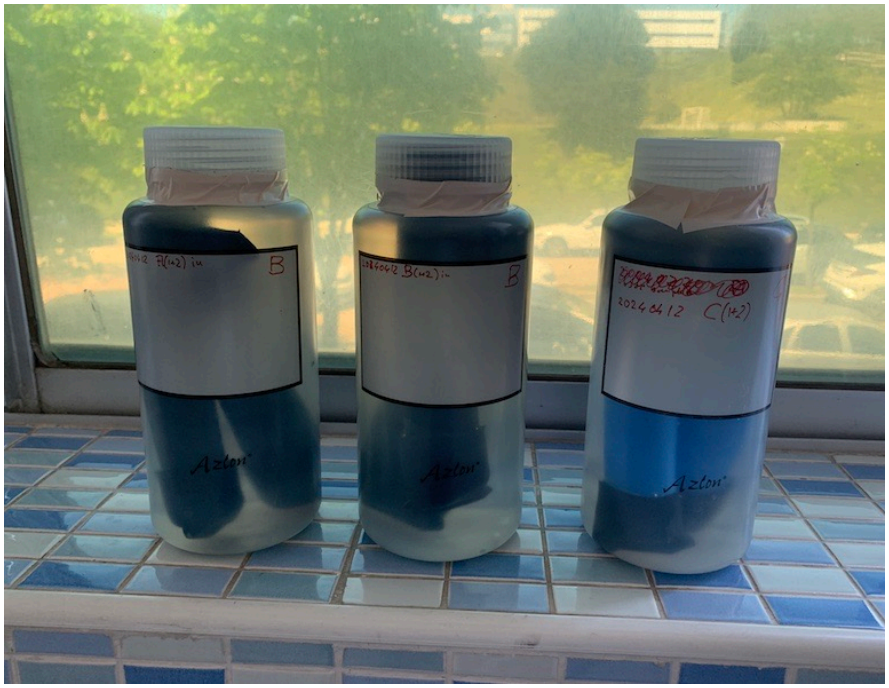
vACA's Local Workshop on Hyper-Kamiokande Physics

IFAE, Barcelona, September 30th – October 1st, 2024

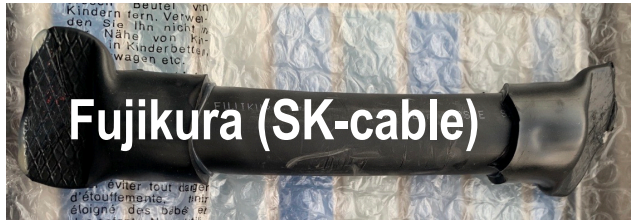
test program for candidate cables
"final" soaking and TOC measurement results

L. Labarga, U.A.M.



- We measure:
  - ✓ ***Degradation of light transmittance in the water*** because of the cable*:* Soaking measurements both, in pure water & 0.2% $Gd_2(SO_4)_3$ water
  - ✓ ***Total Organic Carbon*** (TOC) induced in the water by the cable (There is concern that the very large absorption at very low wave lengths in some of the cables, might be related to this)

- For the following cables



Note: transmittance measurements have been carried out at those cables several times, at different conditions and with different experimental apparatus. Here we report our “final” and most accurate and sensitive measurements/results.

requirement on degradation of Light transmission:

[as stablished in TN0061 (HK-note related to 50-cm PMT Covers)]

the maximum loss of the light transparency in a range of 300nm to 600nm should be less than 5% after traveling 100m in Hyper-K, by considering the ratio of the total water volume to the total surface area facing with water.

$$L(\lambda) = 1 / [- \ln(T_{X\text{-}S} / T_0)] \cdot X_S \cdot [P_S / P_{HK}] \cdot [(A / V)_S / (A / V)_{HK}]$$

requirement: $L(\lambda) > 2000$ m

X_S: path of light at sampling (cuvette length)

$T_{X\text{-}S} / T_0$: ratio of measured transmittance of sample ($T_{X\text{-}S}$) and blank (T_0)

P_S : time of soaking (in weeks)

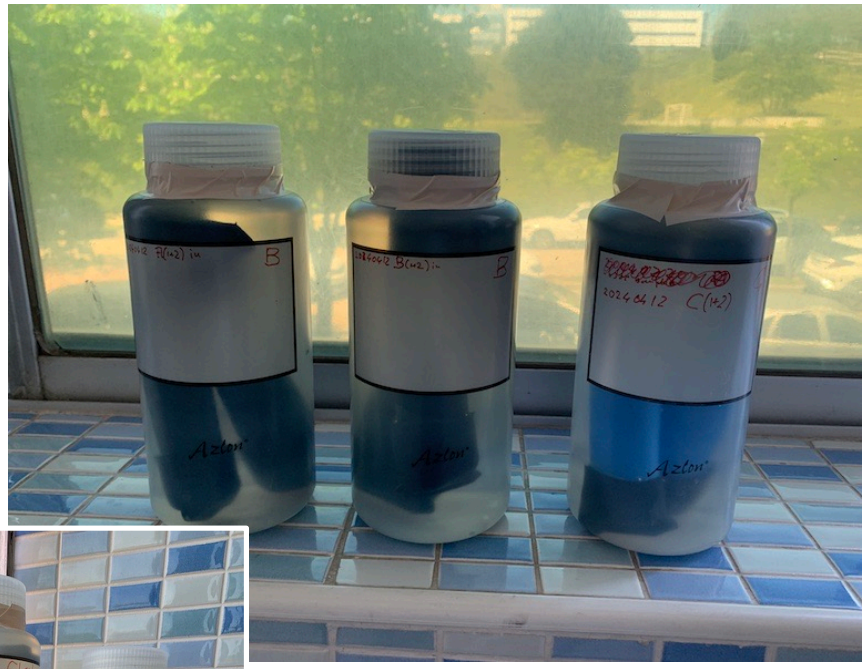
P_{HK} : relevant time to compare to [taken 12 weeks – 3 months]

$(A / V)_S$: surface of sample / volume of water in bottle *estimated by J. Menéndez*

$(A / V)_{HK}$: surface of cable in HK / volume of water in HK

requirement on TOC:

Less than the equivalent to, surface-volume-corrected, 20 μ-gram/L of water in HK (20 ppb) [as it is the maximum amount of TOC from the point of view of the water system] → TOC $\lesssim$ 100 ppm

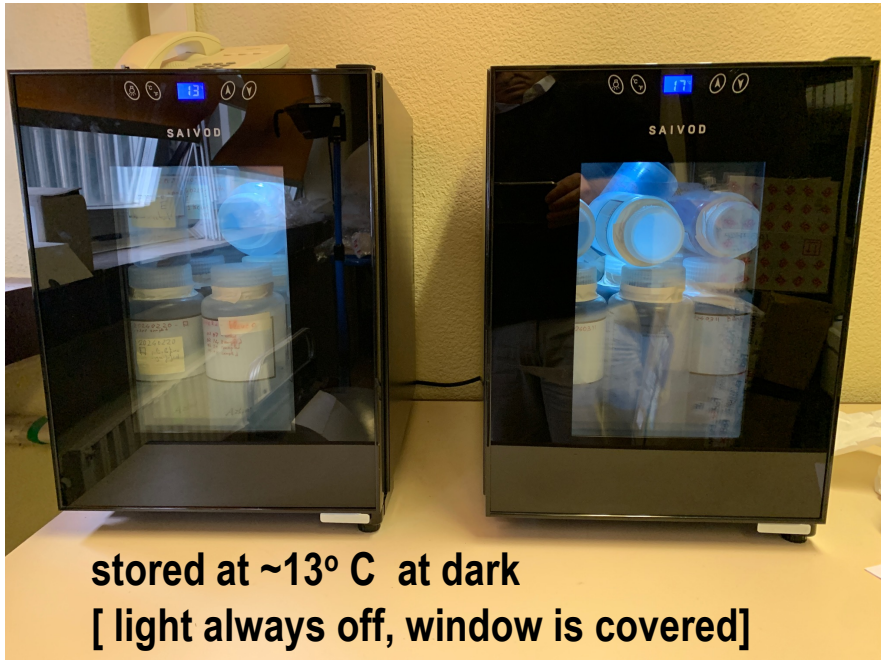


$(AV)_{soak}/(AV)_{HK}$ *from JMM*

Fujikura(SK)	4193
4G35 H07RN-F –neoprene-	4451
4G35 SumFlex R Clear -Xlink polyethy-	4294

- Soaking on pure-water since 20240412

- Soaking on pure-water + 0.2 % $Gd_2(SO_4)_3$ since 20240416



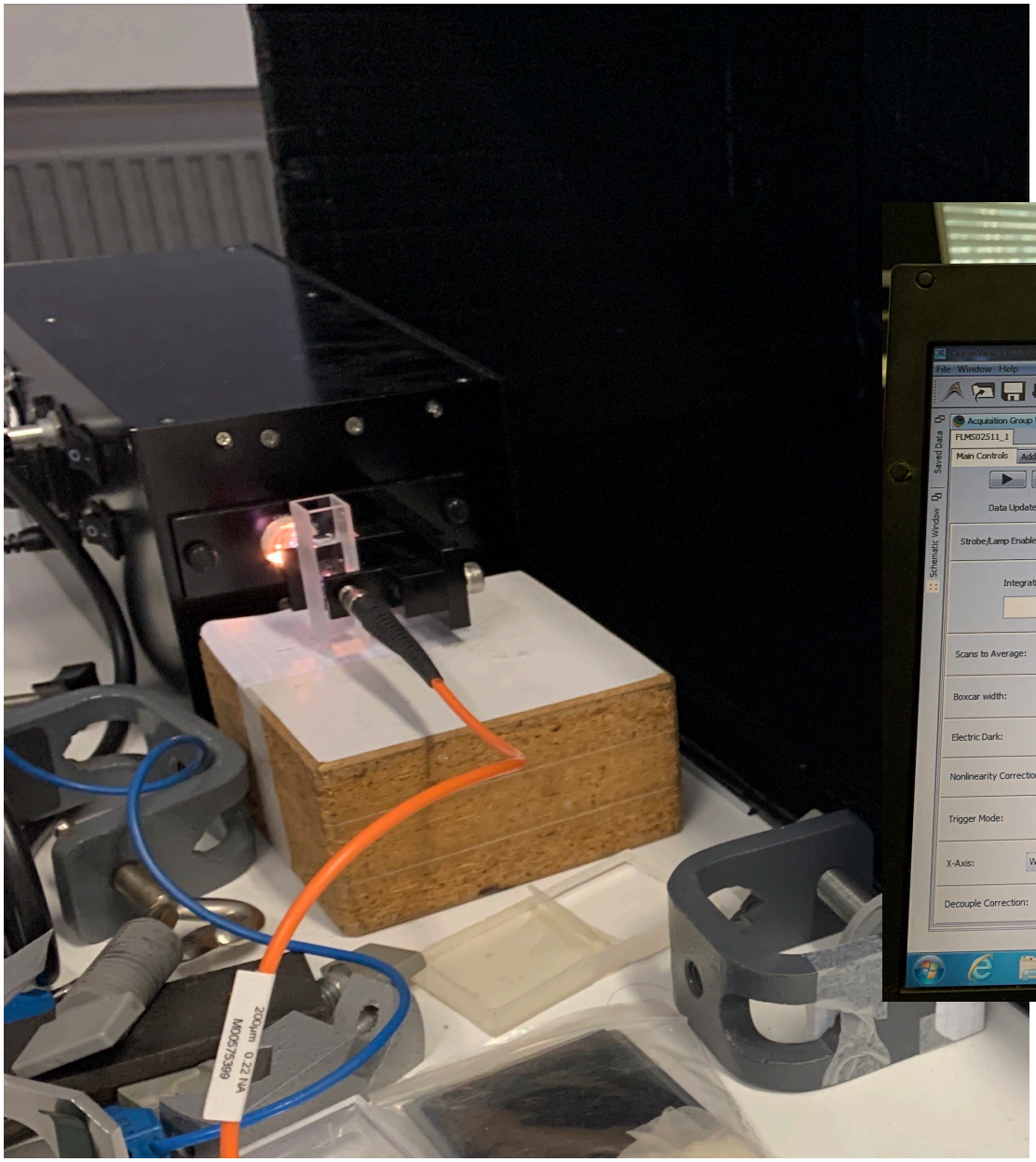
stored at ~13° C at dark
[light always off, window is covered]

- *HITACHI U-3501* spectrophotometer [UAM's Material Science Dep., *Prof. A. García*] with 4 cm light path cuvettes *HELLMA 100-40-40* is used
- ~36 measurements, ~10 minutes each: ~20 to understand reproducibilities and determine measurement errors, the rest were the measurement themselves.
- baseline was set as transmittance through an empty cuvette
- i.e. measurements (blanks & samples) were w.r.t. empty cuvette

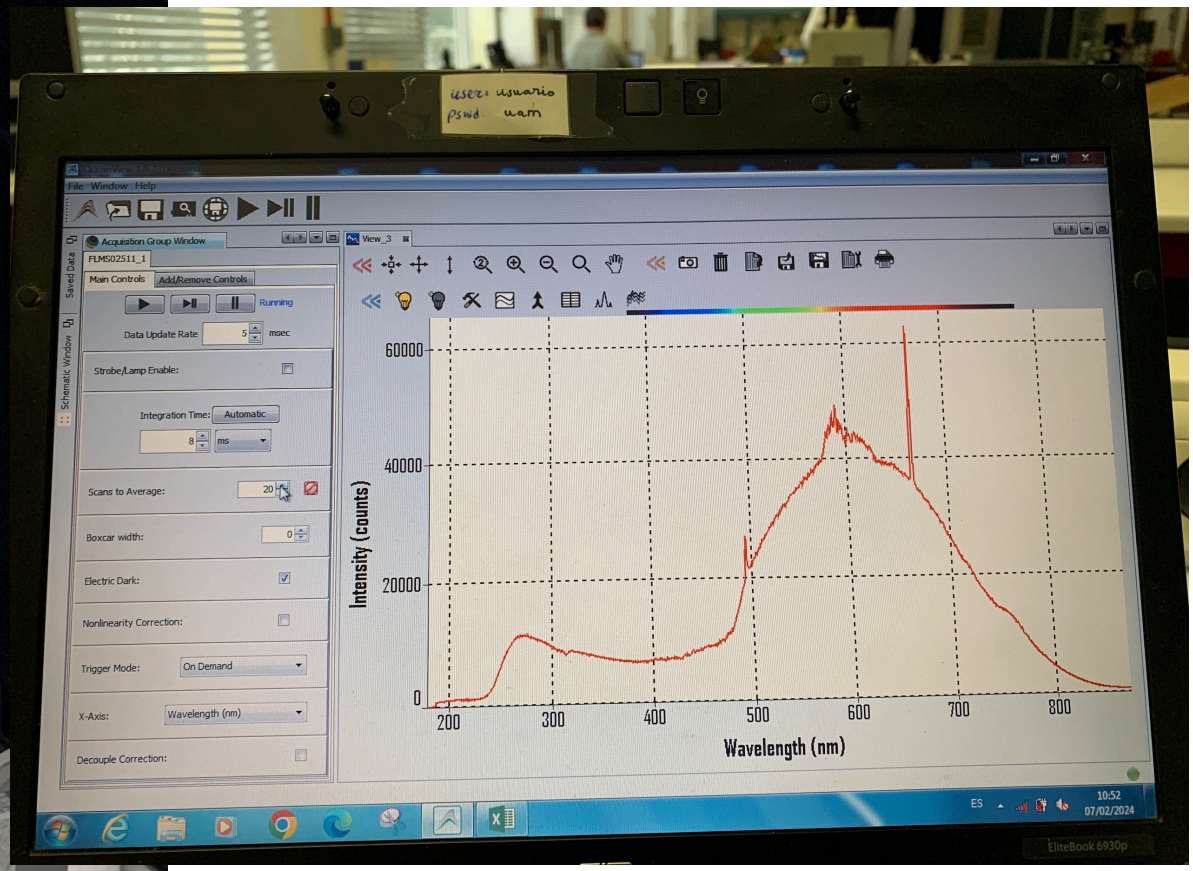
- *Fujikura(SK)* cable was measured 10 times, also its blank-sample
- the "one-measurement error" ΔT, ΔT_0, $\Delta(T/T_0)$ (as a function of λ) is taken as the RMS of those 10 results (see slide)

- Measured samples: *Fujikura(SK)* cable (pure water & 0.2% $Gd_2(SO_4)_3$ water), Heat-Shrinkable tube *TTAM-075 75mm* (pw), *4G35 H07RN-F Top-Cable –neoprene-* (pw & Gd-w), *4G25 H07RN-F Top-Cable –neoprene-* at its 3rd iteration (pw), *4G35 SumFlex R Clear -Xlink polyethy-* (pw & Gd-w)

- TOC (total organic carbon) was measured for all the above samples using a *Shimadzu TOC-VCSH* [UAM's Chemical Engineering Dep., *Prof. L. Calvo, Dr. J. Baeza*]



Started with a hand-made (LL+FL) spectrophotometer system



final results with a professional Spectro-photometer; full consistency among both

Few-words-summary:

- Transmittance Measurements:
  - ✓ Measurement errors from reproducibility ≤ 1%
  - ✓ *–neoprene-* and *–Xlink polyethylene-* have bad transmittance in the lower part of the spectrum (λ ~ 300 nm). However, *–Xlink polyethylene-* is clearly better. For λ > 350 nm they both are OK.
  - ✓ However, the degradation of the *–neoprene-* cable in its third measurement, after two periods of soaking with water changed afterwards, show important significant reductions in the degradation
  - ✓ transmittance in Gd-soaked samples is always slightly better than when soaking in pure water.
  - ✓ *–Fujikura(SK)-* satisfies our requirements
- TOC measurements
  - ✓ The results in every sample ~follow behavior of transmittance in the lower part of the spectrum i.e.
    - ✓ TOC(*–neoprene-*) > TOC(*–Xlink polyeth-*) > TOC(*-Fujikura-*)
    - ✓ TOC(*–neoprene-**2**-*) > TOC(*–neoprene-**3**-*) [**2**- , **3**- refer to the measurement after the corresponding soaking period]

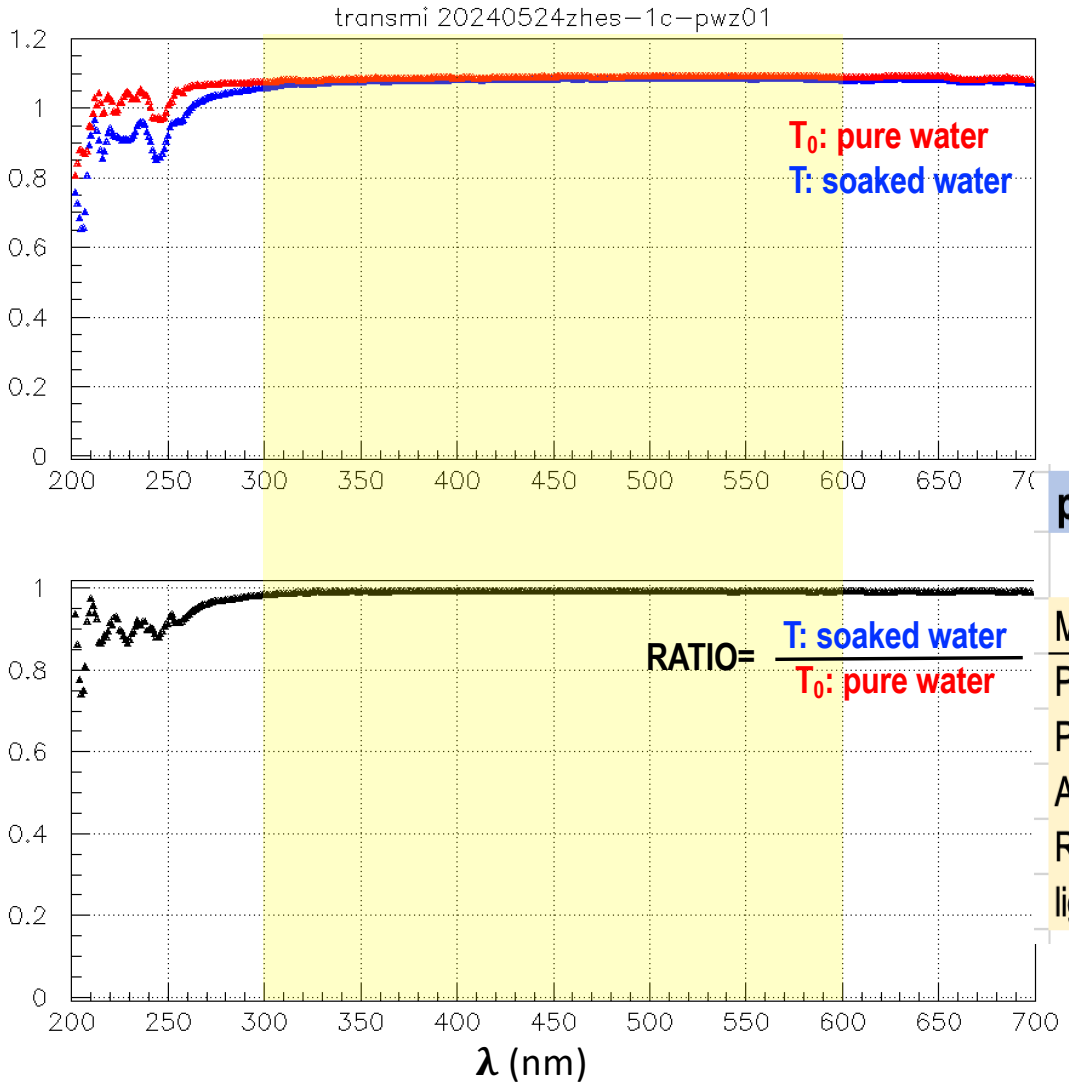
Few-words Grand-Summary:

- in terms of light transmission and TOC the Fujikura/polyethylene cable satisfy well all our requirements and recommendations.

→ Next slide shows a summary of results

→ The following slides show some of the details of the error estimates and measurements

Heat-Shrinkable tube; TTAM-075 75 mm

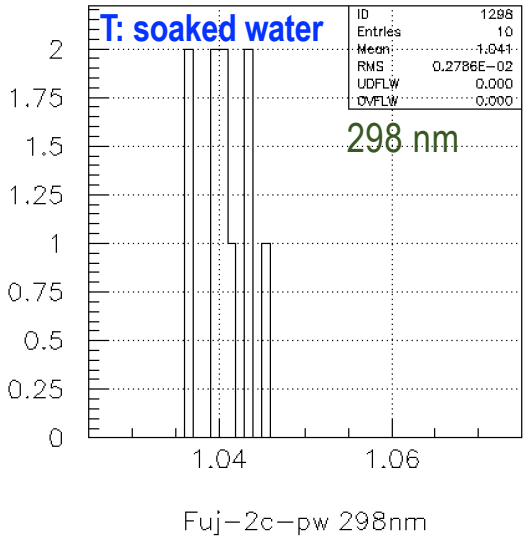


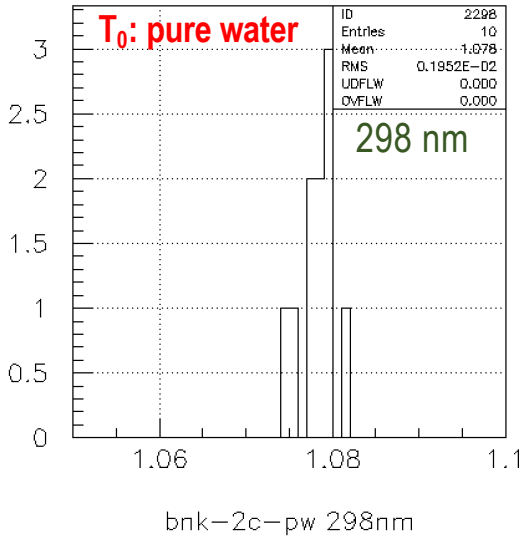
20240311 → 0524 (10 w)

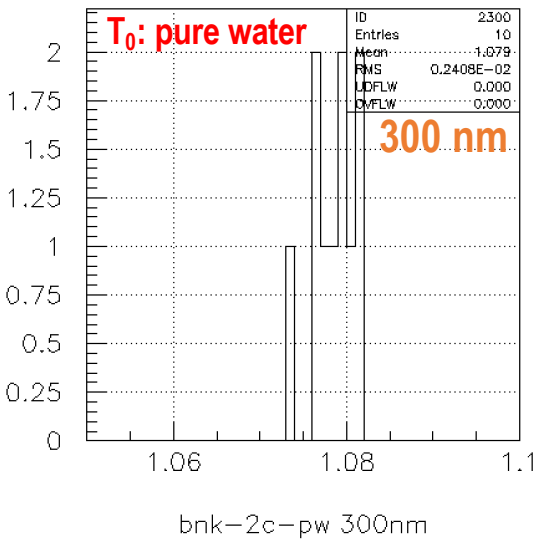
pure water soak			TOC :		2.2 ppm	
			Blank pure-water		0,04 ppm	
Measurement conditions:		HITACHI			|L(m)|	T/T0 |100 m
Psoak (w)	10,0	Lambda	T/T0	ΔT/T0	*[> 2000]*	*[> 0.951]*
Preal (w)	12	300 nm	0,985	0,003	788169	1,000
Avsoak / Avreal	357363,0	350 nm	0,993	0,005	1695766	1,000
R	297802,5	450 nm	0,993	0,009	1695766	1,000
light path (m)	0,04	550 nm	0,993	0,011	1695766	1,000

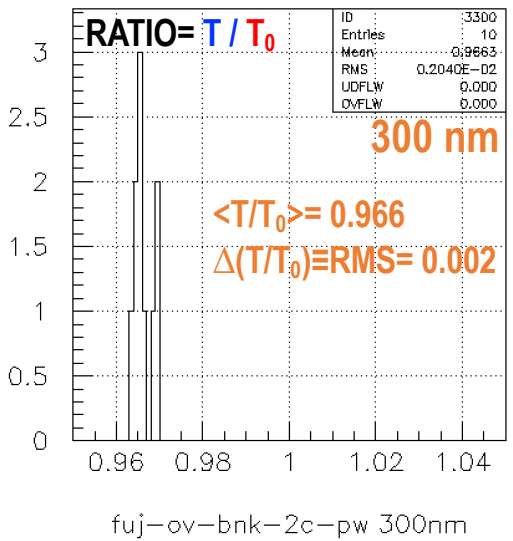
1 measurement sample & 1 measurement blank

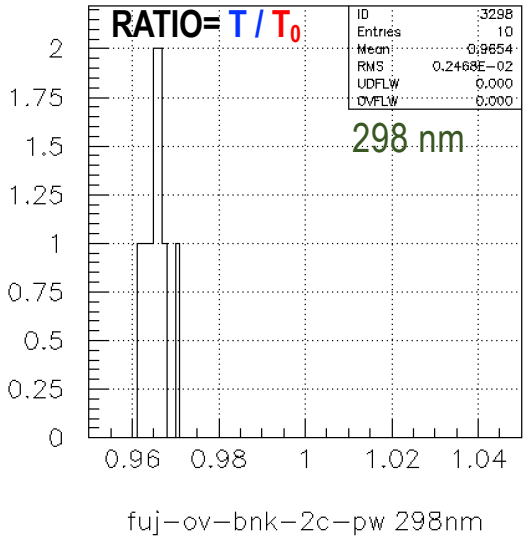
Histograms with some results (some wavelengths) for the *-Fujikura(SK)-* cable;

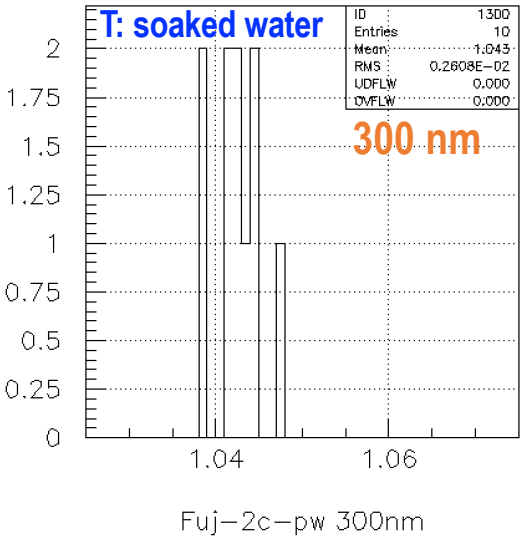


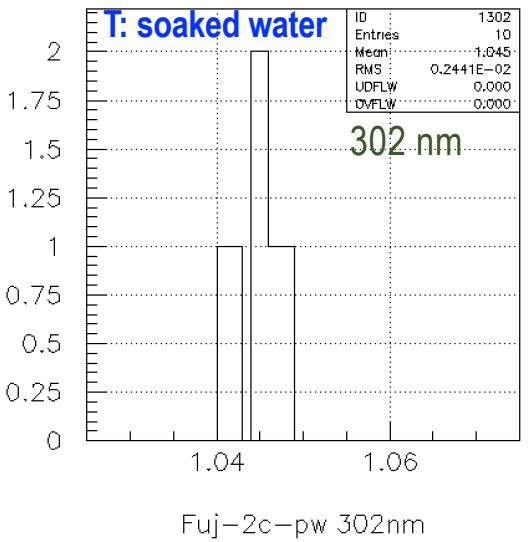


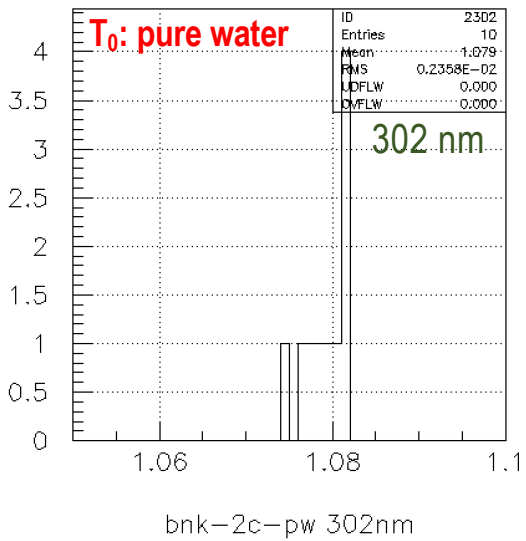






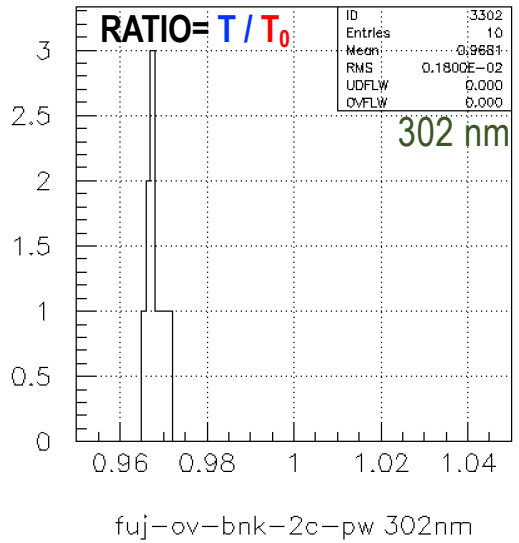


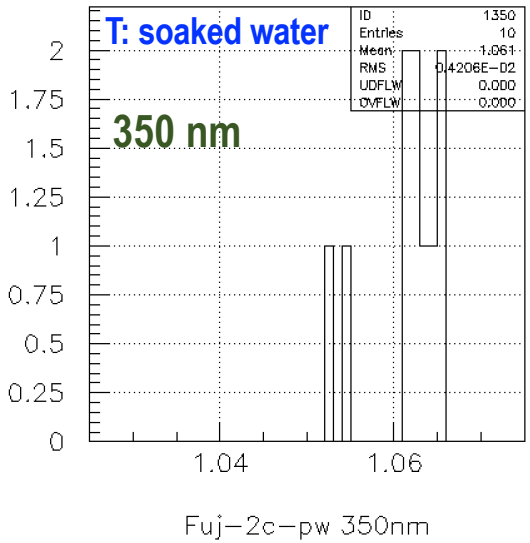


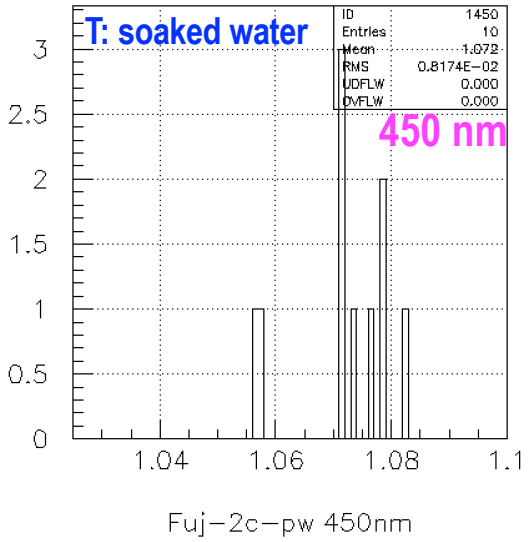


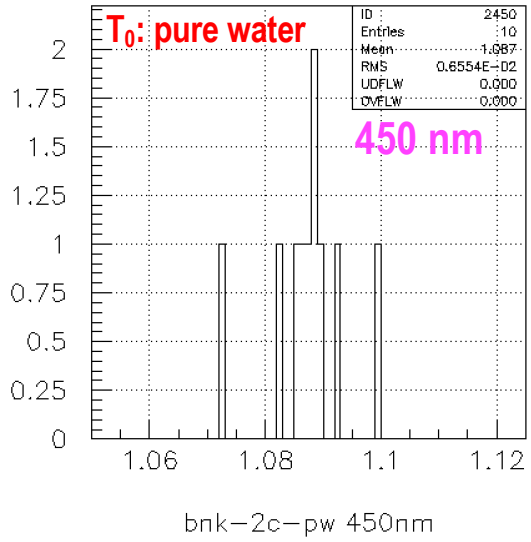
Fujikura (SK-cable);

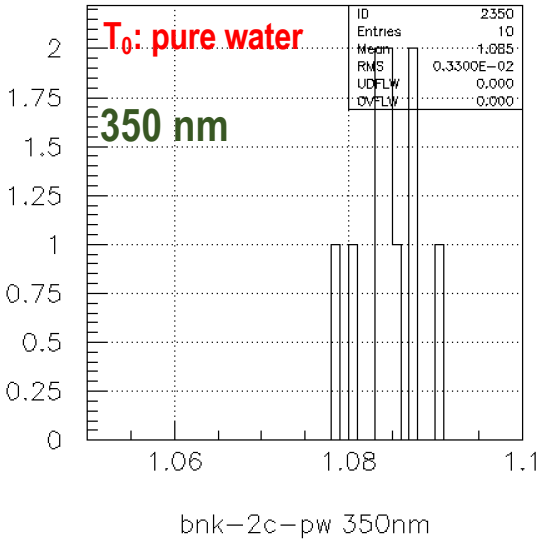
450 nm

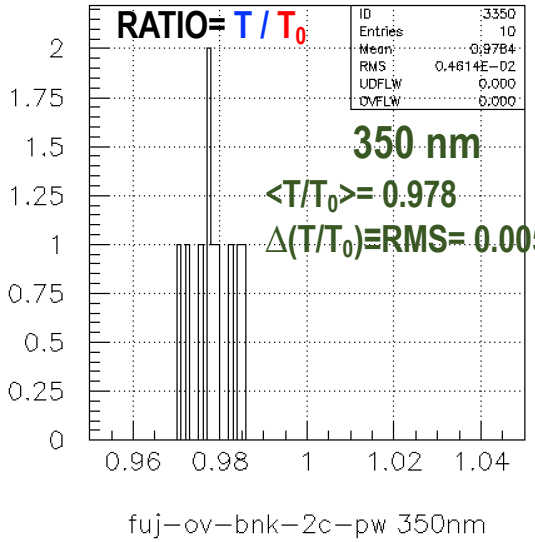


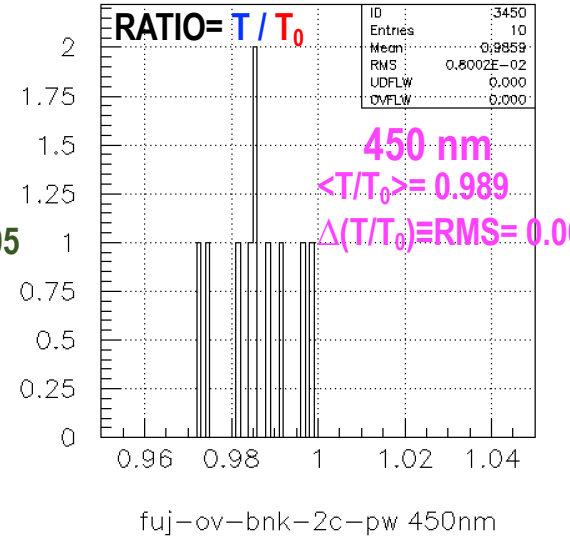


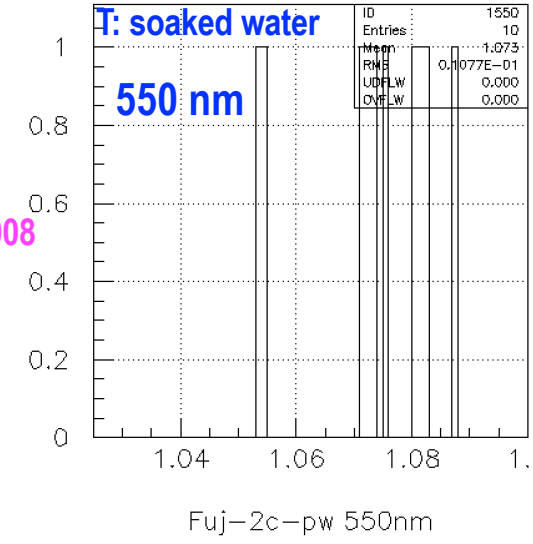




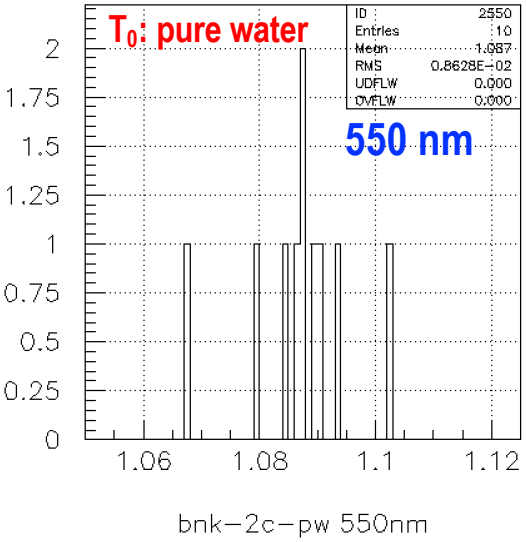


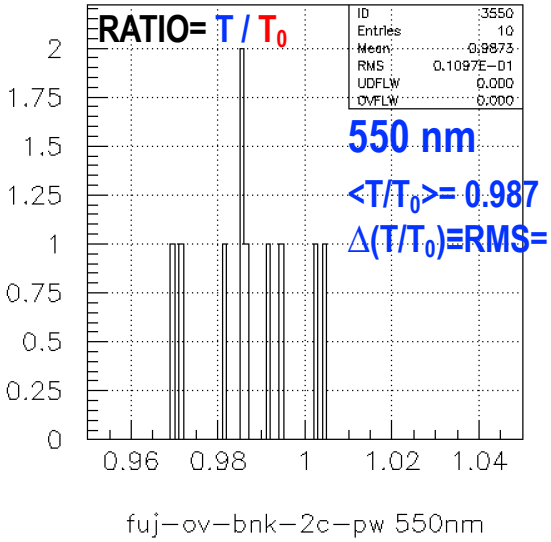






Fujikura (SK-cable);



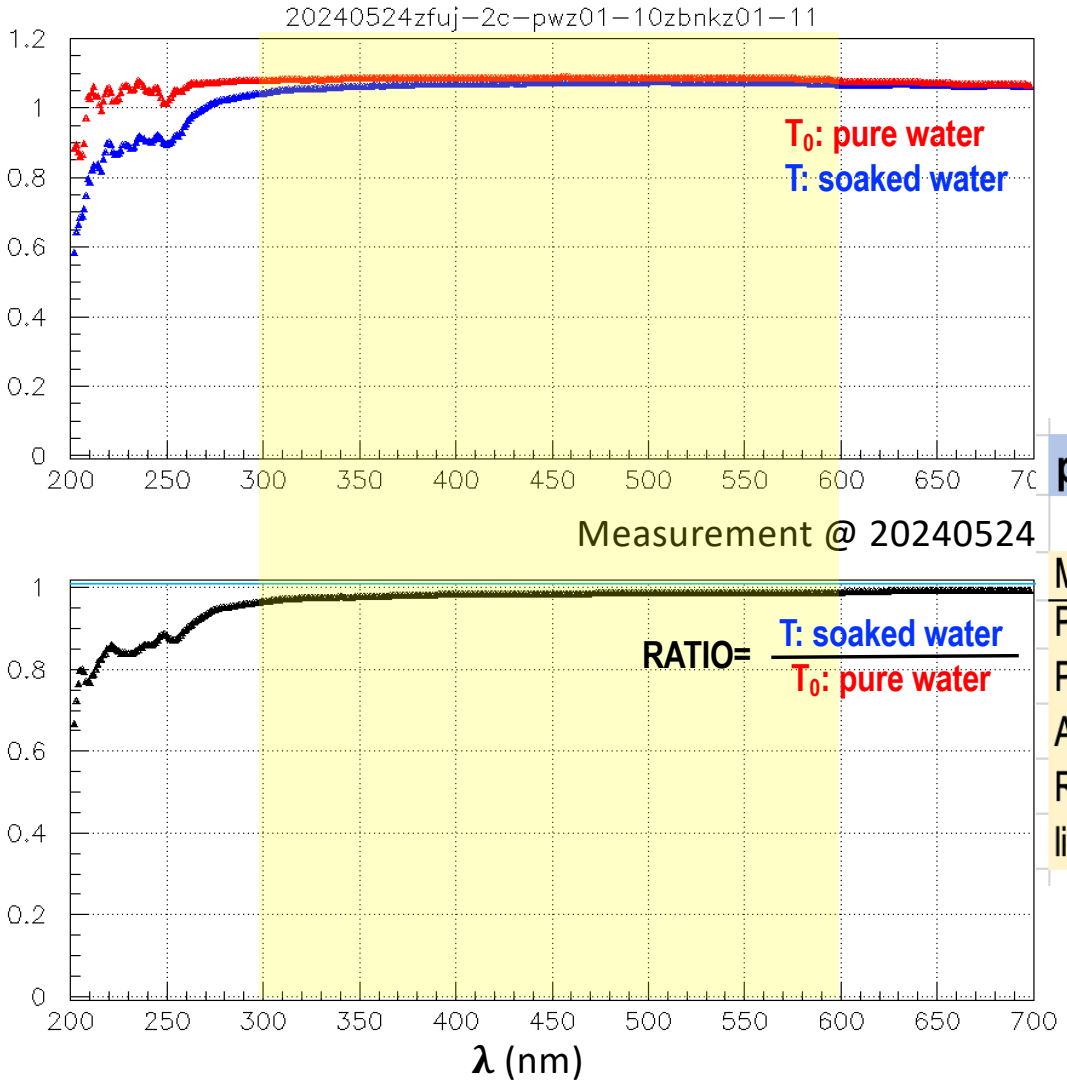


550 nm

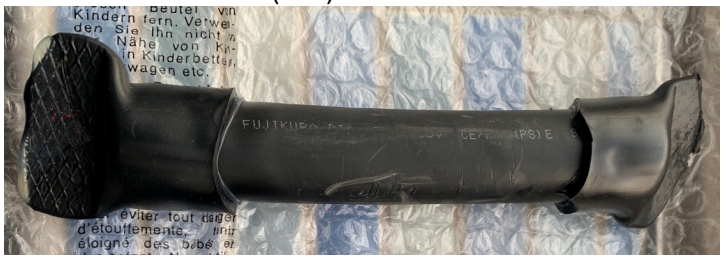
$\langle T/T_0 \rangle = 0.987$

$\Delta(T/T_0) \equiv RMS = 0.011$

Fujikura (SK-cable);



20240412 → 0524 (6 w)

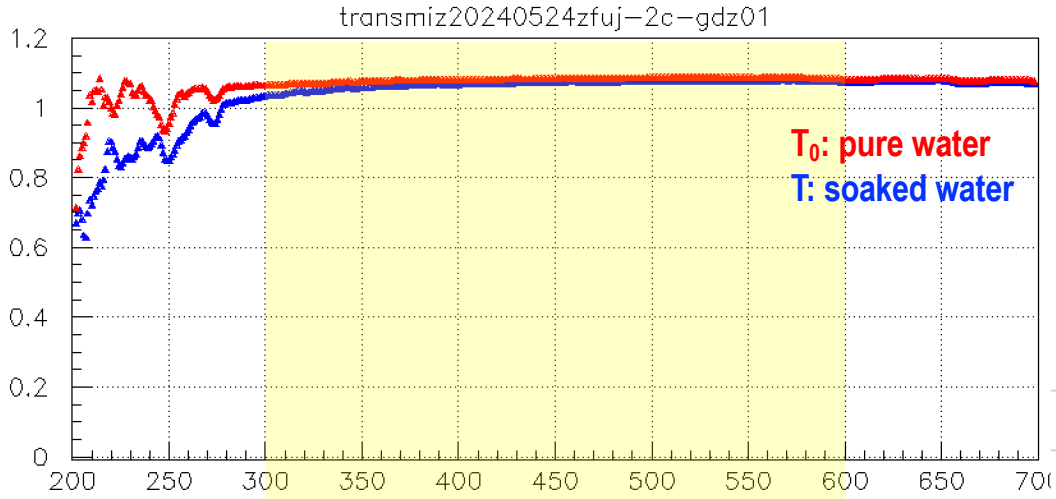


pure water soak				TOC:	2.0 ppm	
				Blank pure-water	0,7 ppm	
Measurement conditions:		HITACHI			|L(m)|	T/T0 |100 m
Psoak (w)	6,0	Lambda	T/T0	ΔT/T0	[> 2000]	[> 0.951]
Preal (w)	12	300 nm	0,966	0,001	2446	0,960
Avsoak / Avreal	4193,0	350 nm	0,979	0,002	3951	0,975
R	2096,5	450 nm	0,986	0,003	5905	0,983
light path (m)	0,04	550 nm	0,987	0,004	6409	0,985

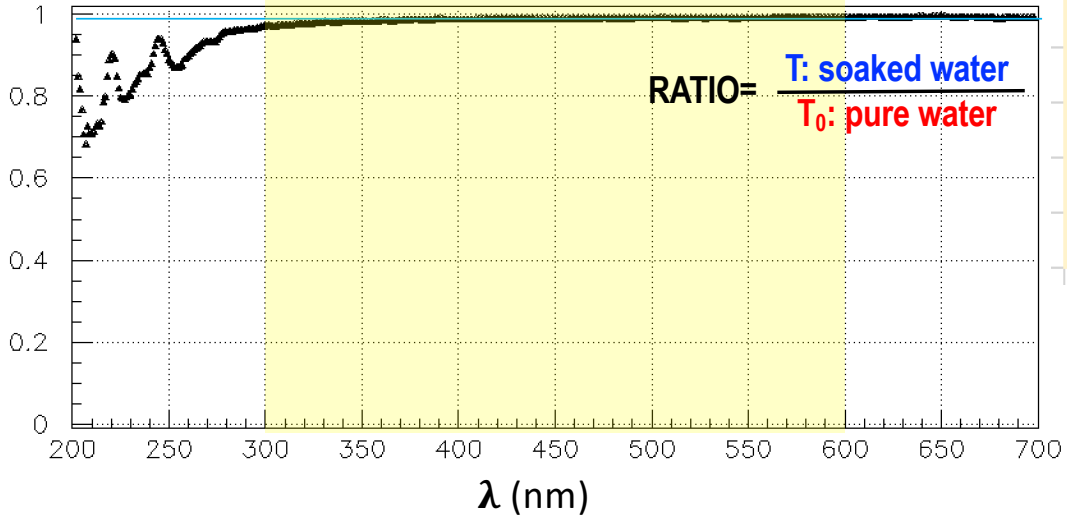
10 measurements sample & 10 measurements blank,
see histograms for 300, 350, 450, 550 nm

Note: some of the small degradation seen comes from the HS tube. It ought to be estimate t.b.d.

Fujikura (SK-cable);



Measurement @ 20240524



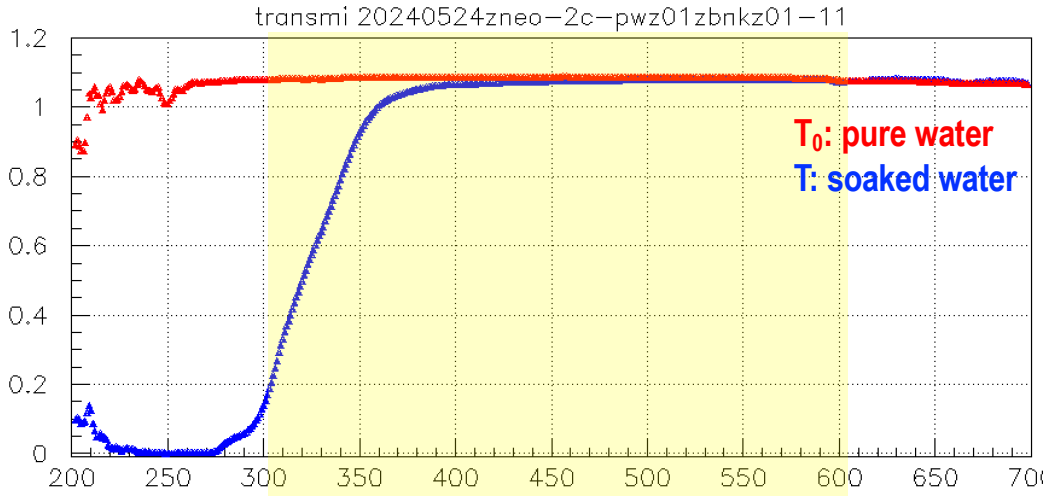
20240412 → 0524 (6 w)

Gd soak			TOC:		1.6 ppm	
			Blank Gd-water		1.2 ppm	
Measurement conditions:		HITACHI			|L(m)|	T/T0 |100 m
Psoak (w)	6,0	Lambda	T/T0	ΔT/T0	[> 2000]	[> 0.951]
Preal (w)	12	300 nm	0,973	0,003	3064	0,968
Avsoak / Avreal	4193,0	350 nm	0,984	0,005	5199	0,981
R	2096,5	450 nm	0,990	0,009	8344	0,988
light path (m)	0,04	550 nm	0,991	0,011	9276	0,989

1 measurement sample & 1 measurements blank

Note: some of the small degradation seen comes from the HS tube. It ought to be estimate t.b.d.

4G35 H07RN-F Top-Cable (neoprene)

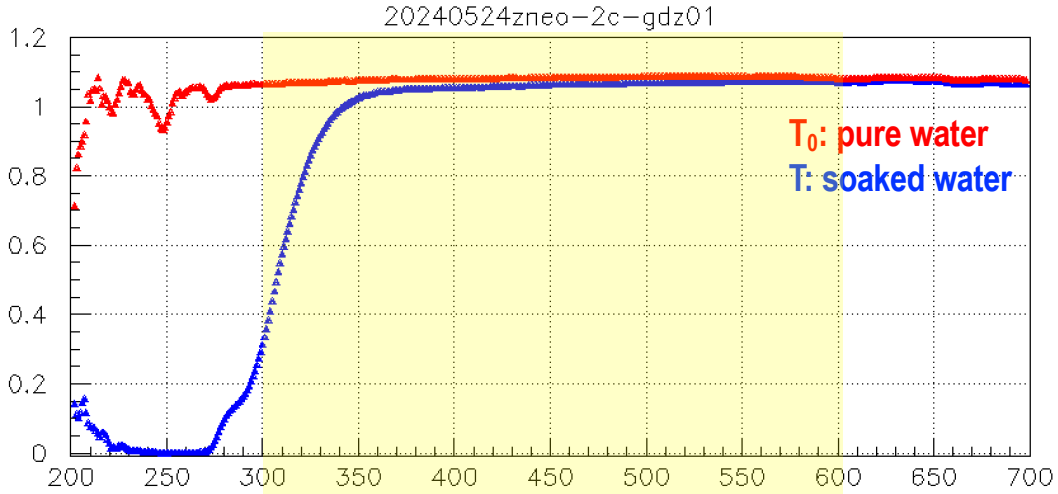


20240412 → 0524 (6 w)

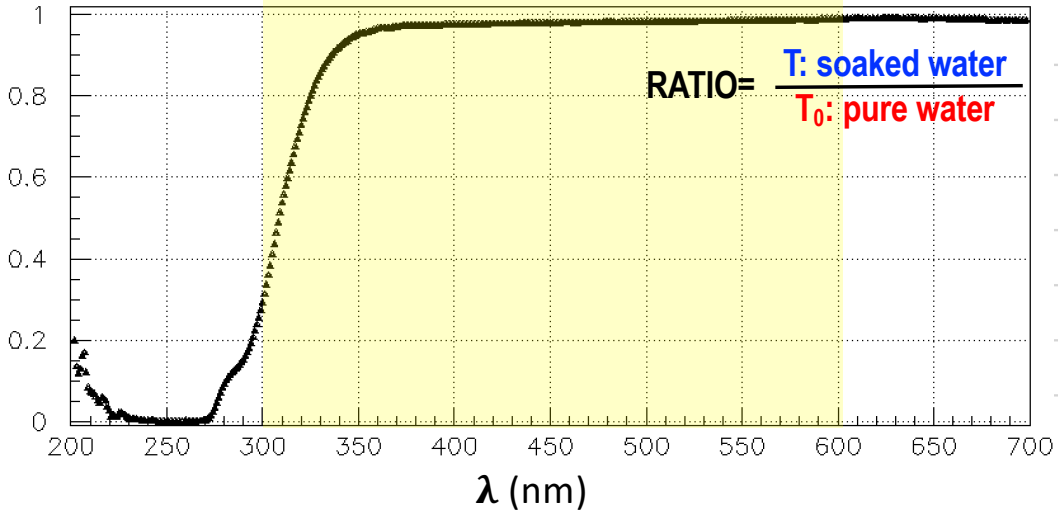
pure water soak			TOC :		37 ppm	
			Blank pure-water		0.7 ppm	
Measurement conditions:		HITACHI			|L(m)|	T/T0 |100 m
Psoak (w)	6,0	Lambda	T/T0	ΔT/T0	[> 2000]	[> 0.951]
Preal (w)	12	300 nm	0,130	0,000	44	0,101
Avsoak / Avreal	4451,0	350 nm	0,854	0,001	564	0,838
R	2225,5	450 nm	0,978	0,002	4002	0,975
light path (m)	0,04	550 nm	0,993	0,003	12673	0,992

1 measurement sample & 10 measurements blank

4G35 H07RN-F Top-Cable (neoprene)



Measurement @ 20240524



20240412 → 0524 (6 w)

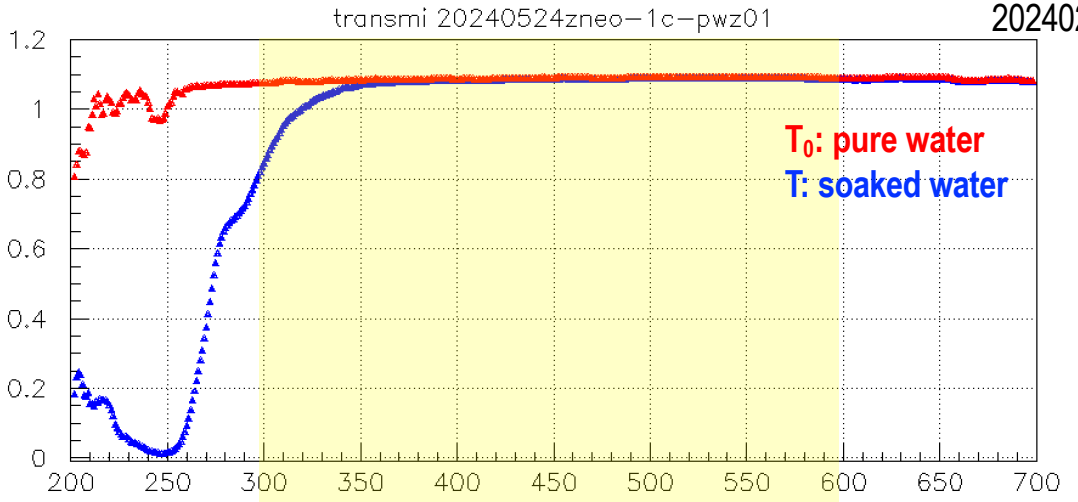
Gd soak			TOC [<100]:	**25 ppm**	
			Blank Gd-water	1.2 ppm	
Measurement conditions:		HITACHI		**|L(m)|**	T/T0 $\|_{100\ m}$
Psoak (w)	6,0	Lambda	T/T0	ΔT/T0	*[> 2000]*	*[> 0.951]*
Preal (w)	12	300 nm	0,294	0,001	73	0,253
Avsoak / Avreal	4451,0	350 nm	0,953	0,005	1849	0,947
R	2225,5	450 nm	0,981	0,009	4641	0,979
light path (m)	0,04	550 nm	0,986	0,011	6314	0,984

1 measurement sample & 1 measurement blank

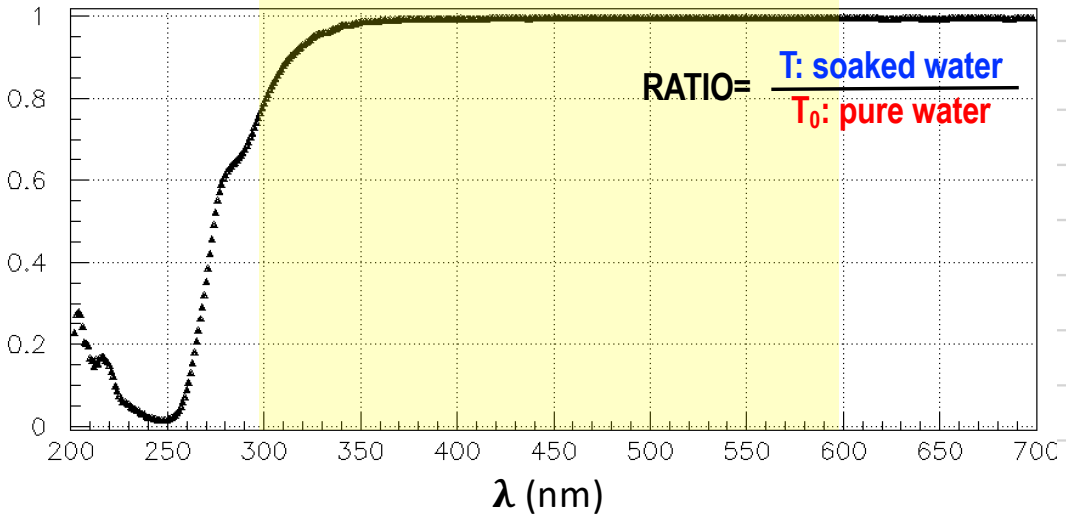
4G25 H07RN-F Top-Cable (neoprene); 2 x water changed after ~1 month soaking

measured after 1.5 months soaking

20240215 → 0313 → 0410 – 0524 (6.3 w)



Measurement @ 20240524

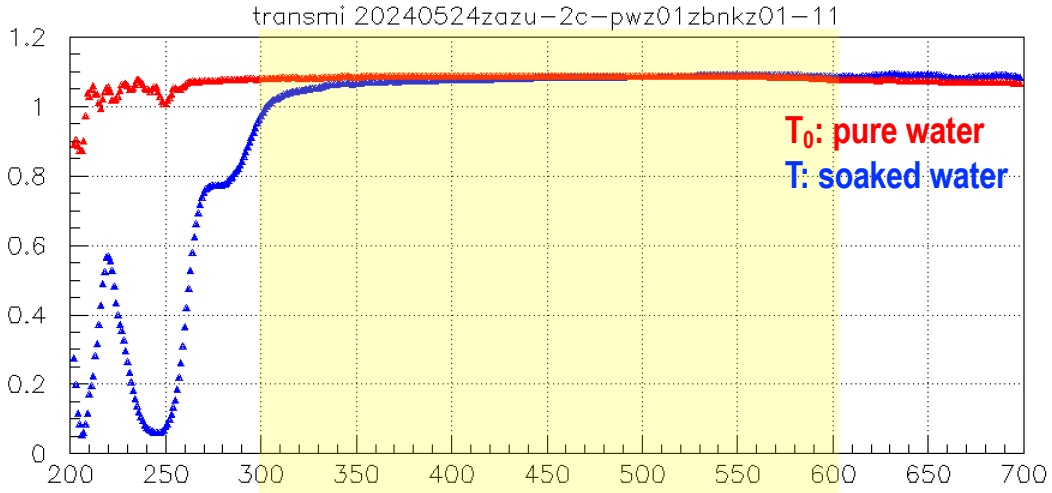


water was changed **2 times**, each after ~1 month previous soak

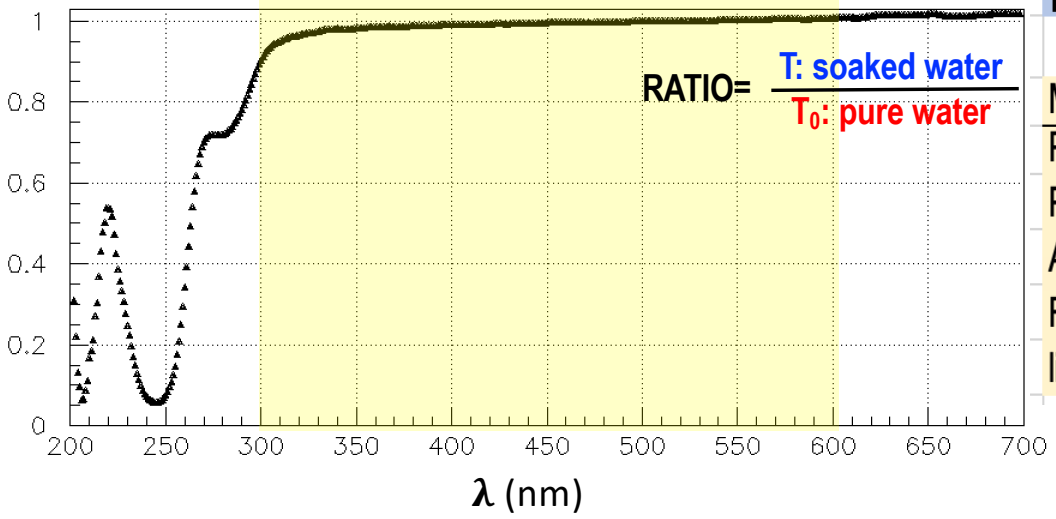
pure water soak			TOC:		**6.7 ppm**	
			Blank pure-water		**0.9 ppm**	
Measurement conditions:		HITACHI			|L(m)|	T/T0 |100 m
Psoak (w)	6,3	Lambda	T/T0	ΔT/T0	*[> 2000]*	*[> 0.951]*
Preal (w)	12	300 nm	0,788	0,002	274	0,694
Avsoak / Avreal	3106,0	350 nm	0,986	0,005	4626	0,979
R	1630,7	450 nm	0,996	0,009	16274	0,994
light path (m)	0,04	550 nm	0,997	0,011	21709	0,995

1 measurement sample & 1 measurement blank

4G35 SumFlex R Clear (cross-link polyethylene)



Measurement @ 20240524

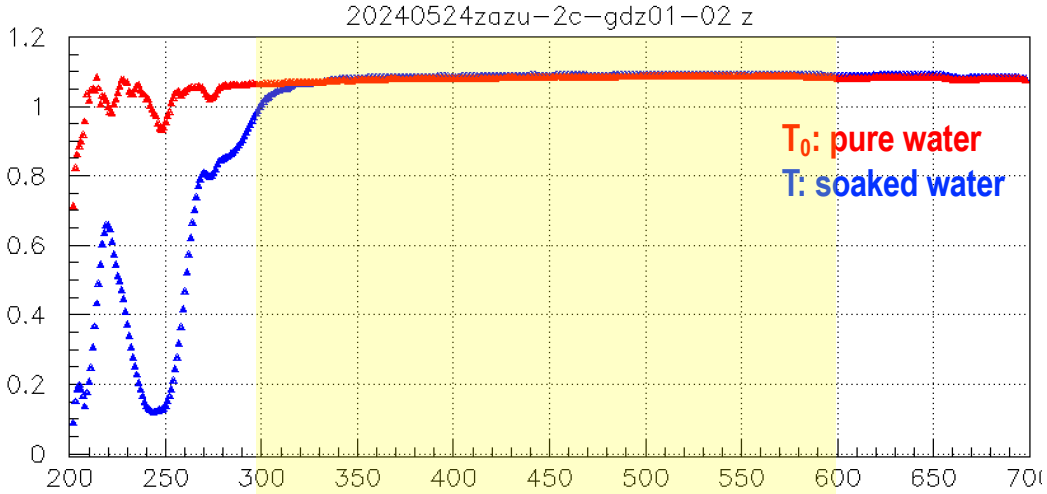


20240412 → 0524 (6 w)

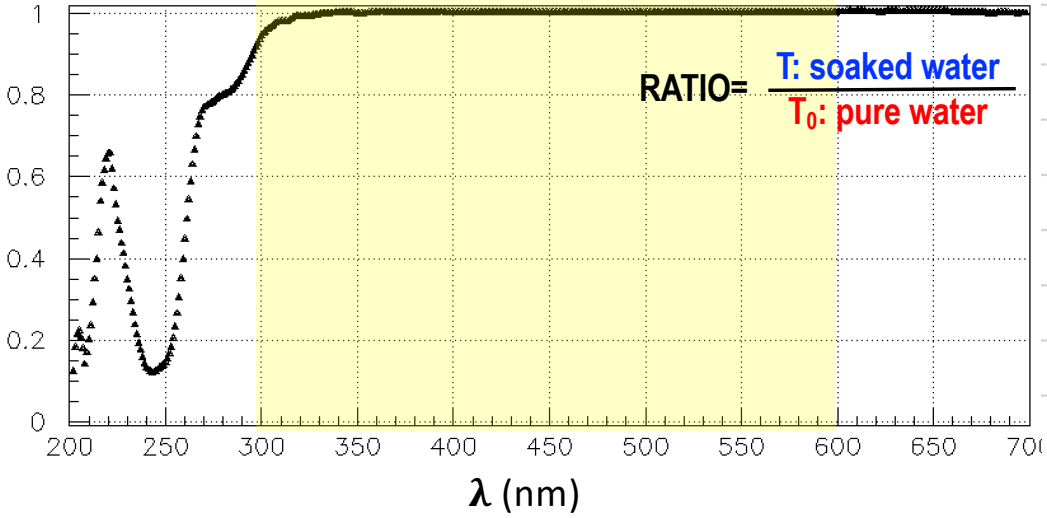
pure water soak			TOC :		25 ppm	
			Blank pure-water		0.7 ppm	
Measurement conditions:		HITACHI			|L(m)|	T/T0 |100 m
Psoak (w)	6,0	Lambda	T/T0	ΔT/T0	[> 2000]	[> 0.951]
Preal (w)	12	300 nm	0,904	0,001	851	0,889
Avsoak / Avreal	4294,0	350 nm	0,983	0,001	4921	0,980
R	2147,0	450 nm	0,996	0,002	21427	0,995
light path (m)	0,04	550 nm	1,003	0,003	28670	0,997

1 measurement sample & 10 measurements blank

4G35 SumFlex R Clear (cross-link polyethylene)



Measurement @ 20240524



20240412 → 0524 (6 w)

Gd soak			TOC :		15 ppm	
			Blank Gd-water		1.2 ppm	
Measurement conditions:		HITACHI			|L(m)|	T/T0 |100 m
Psoak (w)	6,0	Lambda	T/T0	ΔT/T0	[> 2000]	[> 0.951]
Preal (w)	12	300 nm	0,948	0,003	1608	0,940
Avsoak / Avreal	4294,0	350 nm	1,003	0,005	28670	0,997
R	2147,0	450 nm	1,005	0,009	17219	0,994
light path (m)	0,04	550 nm	1,005	0,011	17219	0,994

1 measurement sample & 1 measurement blank

ADDITIONAL MATERIALS

summary of light transmission and TOC results

4G35 SumFlex R Clear (cross-link polyethylene)

pure water soak — TOC : **25 ppm** — Blank pure-water 0.7 ppm

Measurement conditions:		HITACHI			|L(m)|	T/T0 |100 m	|L [T/T0 ± ΔT/T0](m)|	
Psoak (w)	6,0	Lambda	T/T0	ΔT/T0	[> 2000]	[> 0.951]		
Preal (w)	12	300 nm	0,904	0,001	851	0,889	845	857
Avsoak / Avreal	4294,0	350 nm	0,983	0,001	4921	0,980	4653	5221
R	2147,0	450 nm	0,996	0,002	21427	0,995	14136	44149
light path (m)	0,04	550 nm	1,003	0,003	28670	0,997	294489	15088

Gd soak — TOC : **15 ppm** — Blank Gd-water 1.2 ppm

Measurement conditions:		HITACHI			|L(m)|	T/T0 |100 m	|L [T/T0 ± ΔT/T0](m)|	
Psoak (w)	6,0	Lambda	T/T0	ΔT/T0	[> 2000]	[> 0.951]		
Preal (w)	12	300 nm	0,948	0,003	1608	0,940	1523	1704
Avsoak / Avreal	4294,0	350 nm	1,003	0,005	28670	0,997	42577	10758
R	2147,0	450 nm	1,005	0,009	17219	0,994	21188	6157
light path (m)	0,04	550 nm	1,005	0,011	17219	0,994	14140	5392

4G35 H07RN-F TopCable (neoprene)

pure water soak — TOC : **37 ppm** — Blank pure-water 0.7 ppm

Measurement conditions:		HITACHI			|L(m)|	T/T0 |100 m	|L [T/T0 ± ΔT/T0](m)|	
Psoak (w)	6,0	Lambda	T/T0	ΔT/T0	[> 2000]	[> 0.951]		
Preal (w)	12	300 nm	0,130	0,000	44	0,101	44	44
Avsoak / Avreal	4451,0	350 nm	0,854	0,001	564	0,838	560	568
R	2225,5	450 nm	0,978	0,002	4002	0,975	3656	4419
light path (m)	0,04	550 nm	0,993	0,003	12673	0,992	9209	20280

Gd soak — TOC [<100] : **25 ppm** — Blank Gd-water 1.2 ppm

Measurement conditions:		HITACHI			|L(m)|	T/T0 |100 m	|L [T/T0 ± ΔT/T0](m)|	
Psoak (w)	6,0	Lambda	T/T0	ΔT/T0	[> 2000]	[> 0.951]		
Preal (w)	12	300 nm	0,294	0,001	73	0,253	73	73
Avsoak / Avreal	4451,0	350 nm	0,953	0,005	1849	0,947	1675	2063
R	2225,5	450 nm	0,981	0,009	4641	0,979	3154	8708
light path (m)	0,04	550 nm	0,986	0,011	6314	0,984	3538	28180

water was changed 2 times, each after ~1 month previous soak

4G25 H07RN-F TopCable (neoprene)

pure water soak — TOC: **6.7 ppm** — Blank pure-water **0.9 ppm**

Measurement conditions:		HITACHI			|L(m)|	T/T0 |100 m	|L [T/T0 ± ΔT/T0](m)|	
Psoak (w)	6,3	Lambda	T/T0	ΔT/T0	[> 2000]	[> 0.951]		
Preal (w)	12	300 nm	0,788	0,002	274	0,694	270	277
Avsoak / Avreal	3106,0	350 nm	0,986	0,005	4626	0,979	3413	7159
R	1630,7	450 nm	0,996	0,009	16274	0,994	4999	13172
light path (m)	0,04	550 nm	0,997	0,011	21709	0,995	4637	8220

Fujikura (SK cable)

pure water soak — TOC: **2.0 ppm** — Blank pure-water 0,7 ppm

Measurement conditions:		HITACHI			|L(m)|	T/T0 |100 m	|L [T/T0 ± ΔT/T0](m)|	
Psoak (w)	6,0	Lambda	T/T0	ΔT/T0	[> 2000]	[> 0.951]		
Preal (w)	12	300 nm	0,966	0,001	2446	0,960	2397	2498
Avsoak / Avreal	4193,0	350 nm	0,979	0,002	3951	0,975	3679	4267
R	2096,5	450 nm	0,986	0,003	5905	0,983	4898	7429
light path (m)	0,04	550 nm	0,987	0,004	6409	0,985	5000	8911

Gd soak — TOC: **1.6 ppm** — Blank Gd-water 1.2 ppm

Measurement conditions:		HITACHI			|L(m)|	T/T0 |100 m	|L [T/T0 ± ΔT/T0](m)|	
Psoak (w)	6,0	Lambda	T/T0	ΔT/T0	[> 2000]	[> 0.951]		
Preal (w)	12	300 nm	0,973	0,003	3064	0,968	2753	3452
Avsoak / Avreal	4193,0	350 nm	0,984	0,005	5199	0,981	3951	7582
R	2096,5	450 nm	0,990	0,009	8344	0,988	4372	83818
light path (m)	0,04	550 nm	0,991	0,011	9276	0,989	4151	41972

Heat-shrinkable tube TTAM-075 75mm

pure water soak — TOC : **2.2 ppm** — Blank pure-water 0,04 ppm

Measurement conditions:		HITACHI			|L(m)|	T/T0 |100 m	|L [T/T0 ± ΔT/T0](m)|	
Psoak (w)	10,0	Lambda	T/T0	ΔT/T0	[> 2000]	[> 0.951]		
Preal (w)	12	300 nm	0,985	0,003	788169	1,000	657468	982998
Avsoak / Avreal	357363,0	350 nm	0,993	0,005	1695766	1,000	989611	5847654
R	297802,5	450 nm	0,993	0,009	1695766	1,000	741477	6155722
ot path (m)	0,04	550 nm	0,993	0,011	1695766	1,000	658652	3042429

A. Takeda 20240603

Requirement for soak test

- Attenuation length in HK: >2km (considering 3 months for HK water cycle)

- Requirement in SK is "attenuation length in SK > 1km" = "10% attenuation at 100 m" $\left(e^{-\frac{100\,m}{1000\,m}} = 0.90\right)$
  - Attenuation length in SK was calculated from the attenuation length of water after soak multiplied by
    - Ratio of "surface area/volume" of in the sample and in the SK
    - Ratio of "time" of soak test and 1 month for SK water cycle (→ 3 months in HK)
- Considering a factor 2 difference in the dimensions of SK ID (H: 36.2 m, D: 33.8 m) and HK ID (H: 65.8 m, D: 64.8 m), requirement is scaled by a factor 2.
  - For 30 m flight length of photons in HK, attenuation will be $e^{-\frac{30\,m}{2000\,m}} = 0.985$
  - Attenuation length will be shortened by the accumulation of contaminations from various materials
- Note: Control of reliability and stability of water quality (systematic uncertainties) are important in HK
  - Simulation study (TN0021) indicates 10% bias of attenuation length causes 1% shift of momentum scale, which causes sizable impact on δ_{CP} and Δm^2 measurement.
  - Time variation and reproducibility should be accounted in soak test