Instituto Universitario de Ciencias y Tecnologías Espaciales de Asturias
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ICTEA

moma
GRUPO DE MODELIZACIÓN MATEMÁTICA APLICADA

GEOMAGNETIC FIELD COMPENSATION SYSTEM

1. System of coils
2. Connections and materials
3. Power
4. Conclusions

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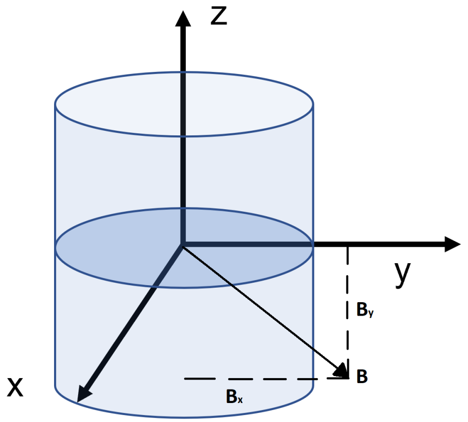
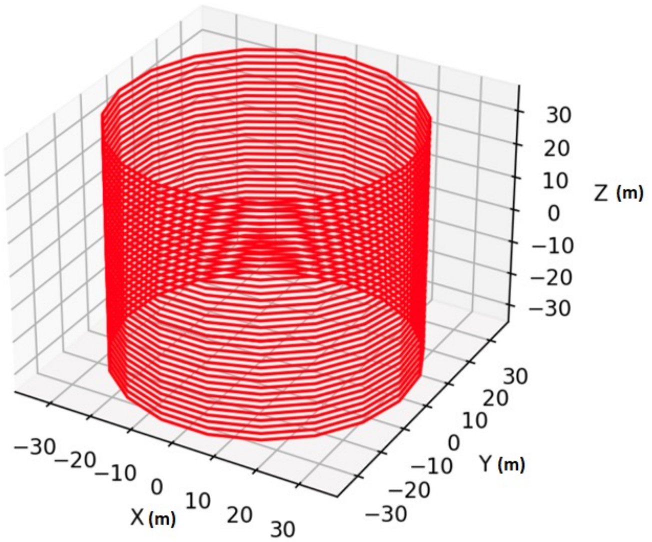
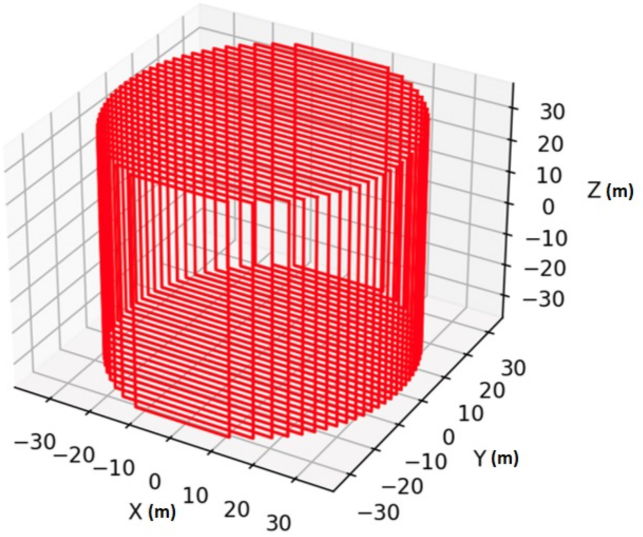
1. System of coils

B = (0, 303, -366) mG







Reference system:

y axis in the direction of horizontal component of geomagnetic field
circular horizontal coils
rectangular vertical coils

Goals:

- maximum number of PMTs under 100 mG
- average magnetic field under 50 mG
- minimum efficiency loss
- low asymmetry

Calculation of **B perpendicular** to the PMTs

Detection efficiency as a function of magnetic field applied to PMTs

Experimental correlation function (by Y. Nishimura, Keio University)

Effect of asymmetry

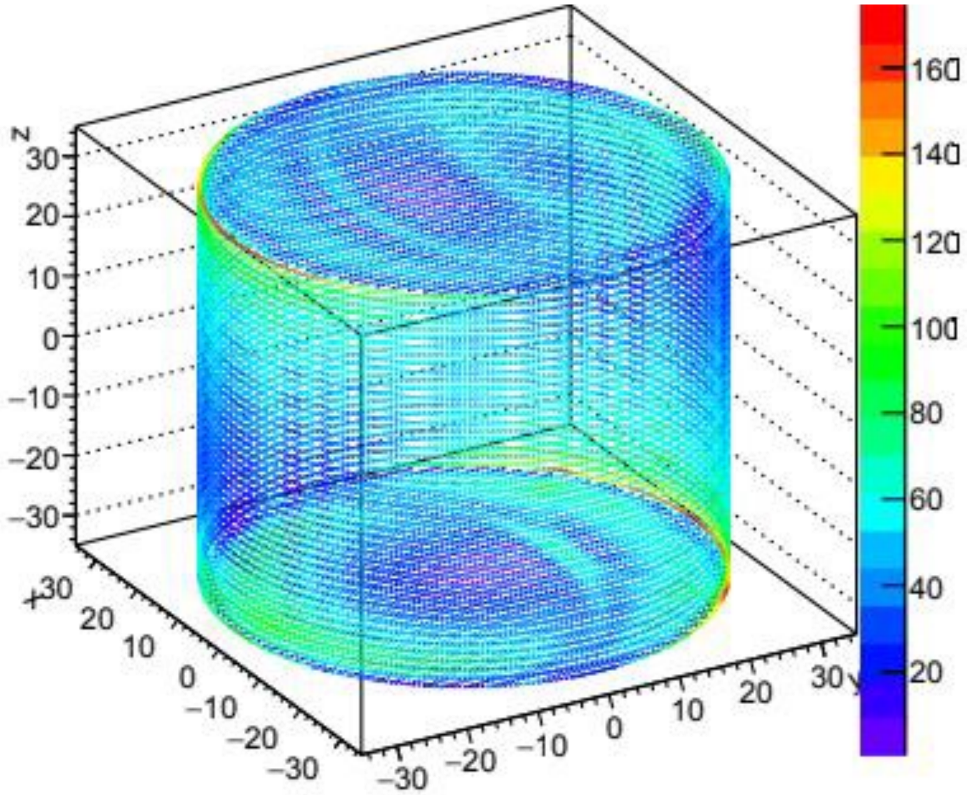
Difference in the loss of efficiency between PMTs of top and bottom and of the upper and lower half of the detector

Optimization algorithm:

Optimization of the intensity of current of all circular coils and all rectangular coils

Increasing the number of turns of the upper and lower circular coils until a minimum is reached for B_{perp}

Addition of circular coils at both top and bottom ends of smaller radius



Difficulty in compensating for the geomagnetic field at the top and bottom of walls

Different designs proposed for HK:

Configuration	PMTs with excess (%)	Average Magnetic field (mG)	Average loss of Efficiency (%)	Maximum current (A)	Cable lenght (km)
2m v1	3.06	49.35±21.39	0.33±0.72	71	18.31
2m v2	3.20	47.79±21.50	0.32±0.71	71	18.51
2m v3	2.71	48.76±22.18	0.34±0.76	70	18.73
2m+elliptical	1.85	50.34±19.90	0.33±0.72	130	17.99
2.35m v1	3.88	43.85±24.58	0.30±0.75	82	17.35
2.35m v2	3.62	43.54±23.70	0.29±0.73	81	17.23
2.35m v3	3.89	43.44±26.57	0.30±0.81	81	17.46
2.4m v1	**4.05**	**42.33±25.68**	**0.28±0.77**	**82**	**17.02**
2.4m v2	3.38	43.55±24.63	0.29±0.76	82	17.22
2.4m v3	3.76	45.48±25.95	0.32±0.80	83	17.44
1m	4.65	49.59±27.17	0.38±0.81	34	33.33
2m -1m	5.74	57.24±23.10	0.44±0.81	61	25.16
1m - 2m	4.17	44.25±25.55	0.31±0.78	70	26.27
3m	5.90	49.03±30.90	0.42±1.01	101	12.09
4m	9.78	55.10±34.03	0.51±0.98	135	9.86

PMTs above 100 mG
Average magnetic field < 50 mG

Best case: 2.4 m v1

- Low average perpendicular magnetic field
- low efficiency loss
- feasible for construction

highest current is 82A
above 17 km of cable needed

Circular coils: I=82A

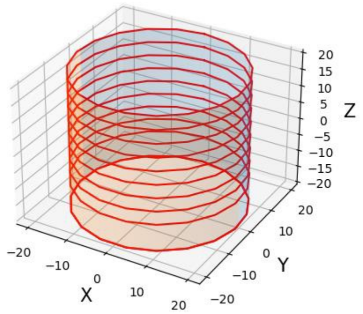
At top (z = 36.5 m):

- n = 1 coil with R = 26 m
- n = 5 coils with R = 34 m

At bottom (z = −35.5 m):

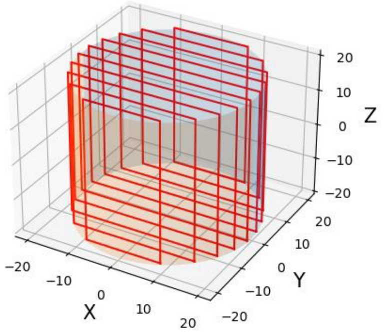
- n = 1 coils with R = 25 m
- n = 5 coils with R = 34 m

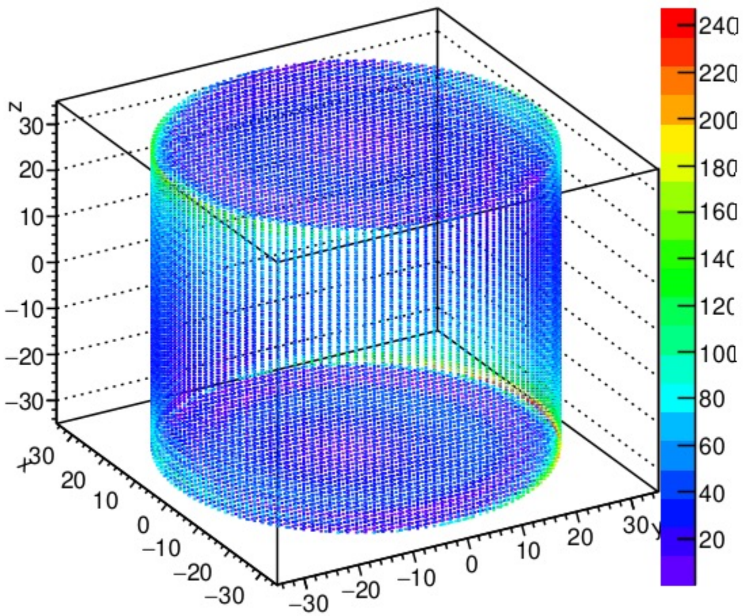
Coils from z = 34.1 m to z = −33.1 m
separated 2.4 m

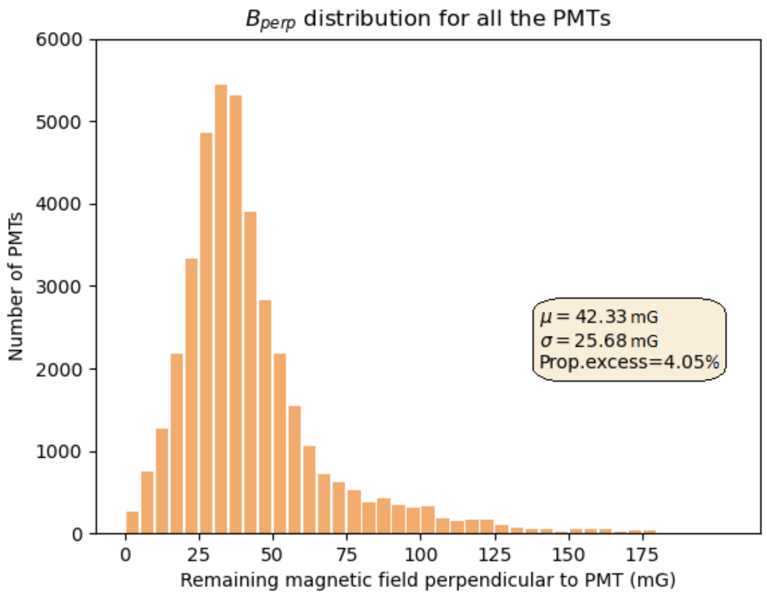


Rectangular vertical coils: I=69A

Coils from y = −32 m to y = 32 m
separated 2 m





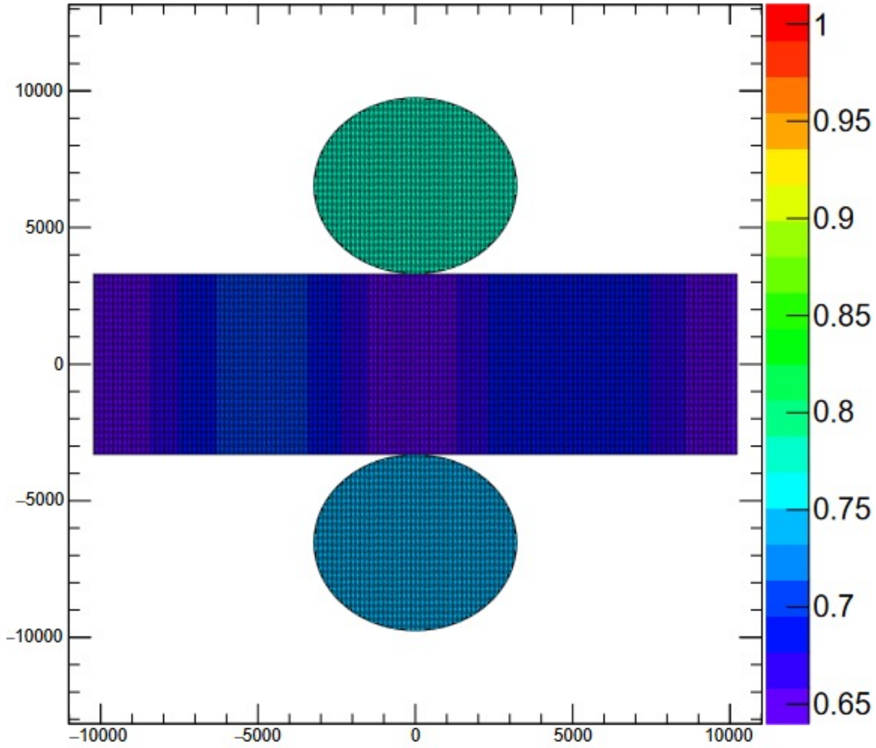


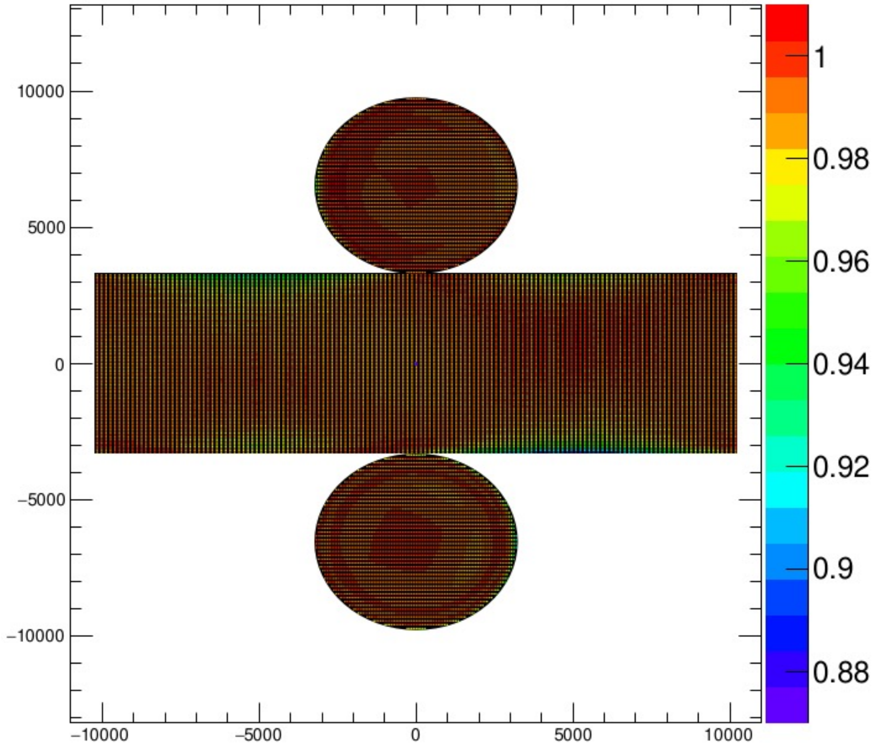
Efficiency: comparison with no compensation case

No compensation: B=(0, 303, -366) mG

2.4m v1 case

Efficiency





26% **0.28%** **Efficiency loss**

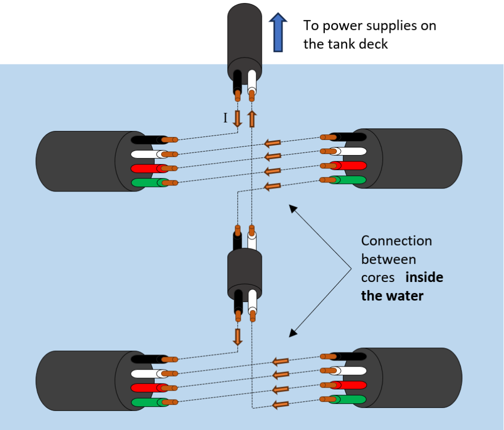
top/bottom: 2.36%
up/down: 0.66%

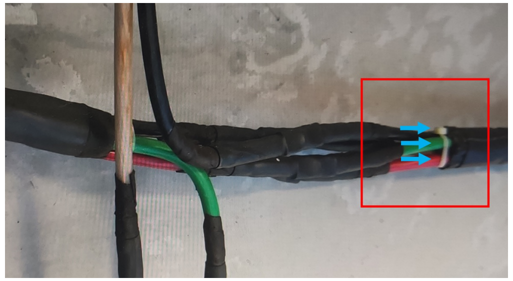
top/bottom: 0.02%
up/down: 0.07%

Asymmetry

2. Connections and materials

connections in SK:

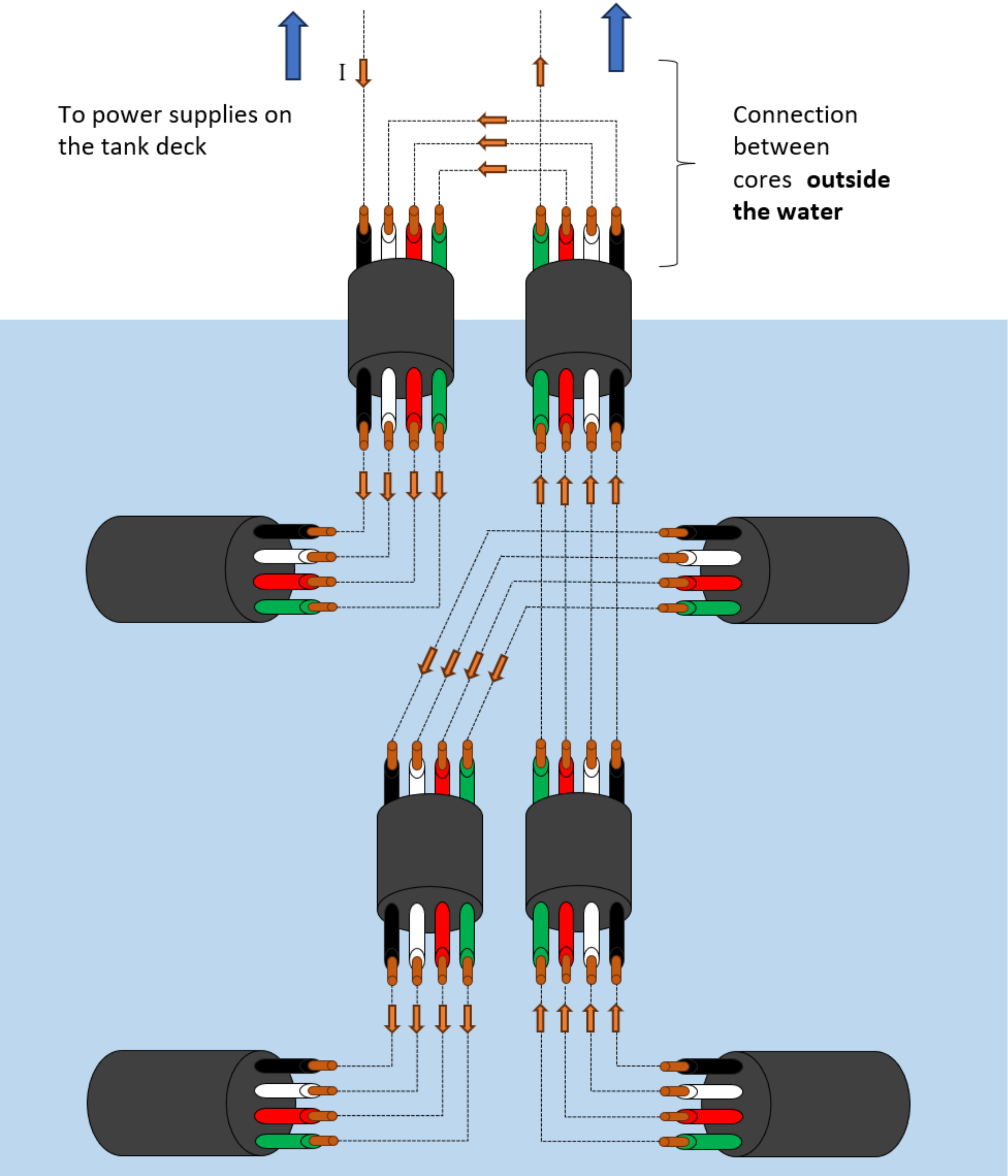




connections in HK:

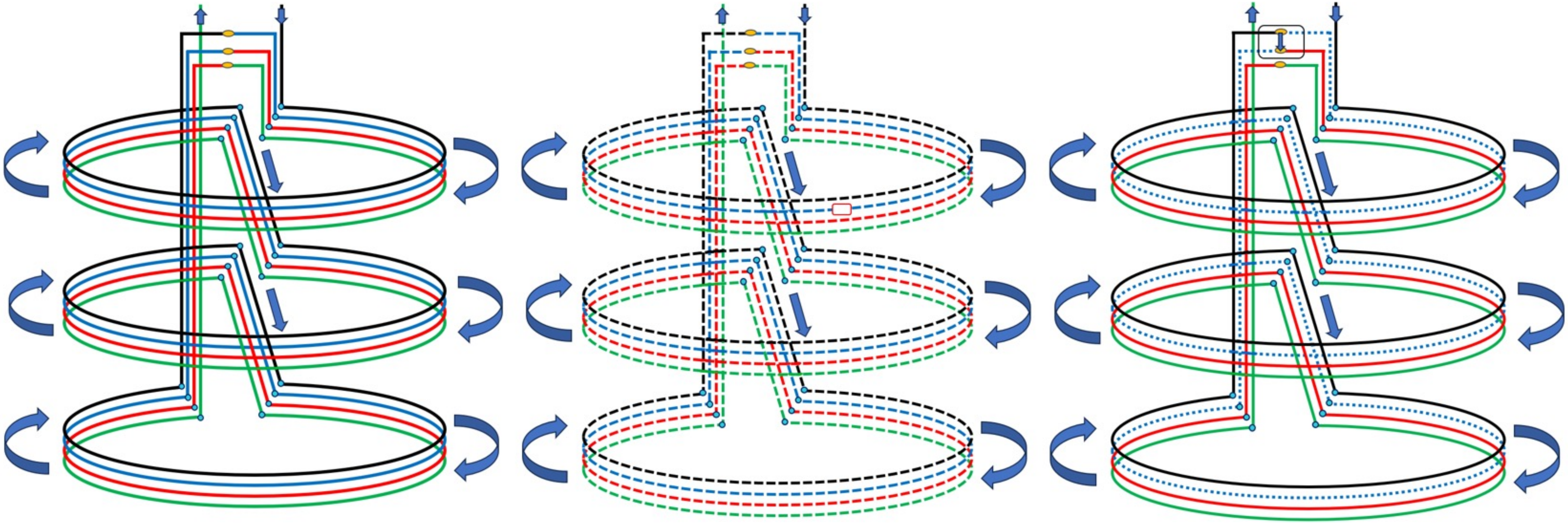
closed cable connections
(prevents entry of water between the cores)

Possibility of repair in case of failure
(next slide)

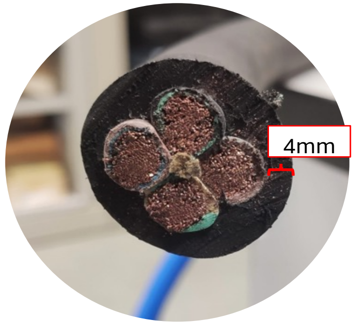


in case of failure

4 core cables allows to reconnect the remaining 3 cores and adjust the current value

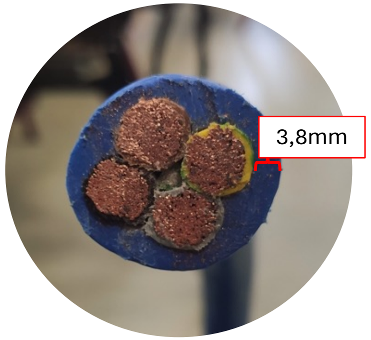


commercial cables: 3 types found



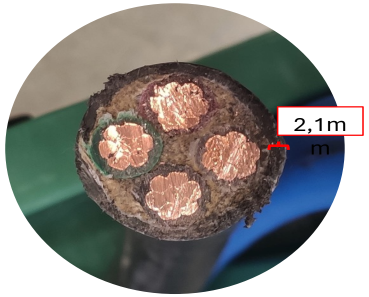
Neoprene
32.7mm diameter
130.8 mm bending radius
1.28 Ω/km resistance

19,62 €/m



polyethylene
30.2 mm diameter
181.2 mm bending radius
1.28 Ω/km resistance

41,00 €/m



polyethylene
28 mm diameter
186.0 mm bending radius
0.491 Ω/km resistance

25,00 €/m

Tests performed on cables:

(L.Labarga, UAM)

- soaking tests:

  Transparency, T/T_o measured in the range within 300nm-600nm

  (**transparency loss < 5%**)

  Attenuation length, **L (m) > 2000 m**

- TOC (Total Organic Carbon) **< 100 ppm**

samples soaked in **pure water** and in 2% **Gd water**

(G.Pronost, Kamioka)

- Rn emanation tests **(< 200 Bq)**

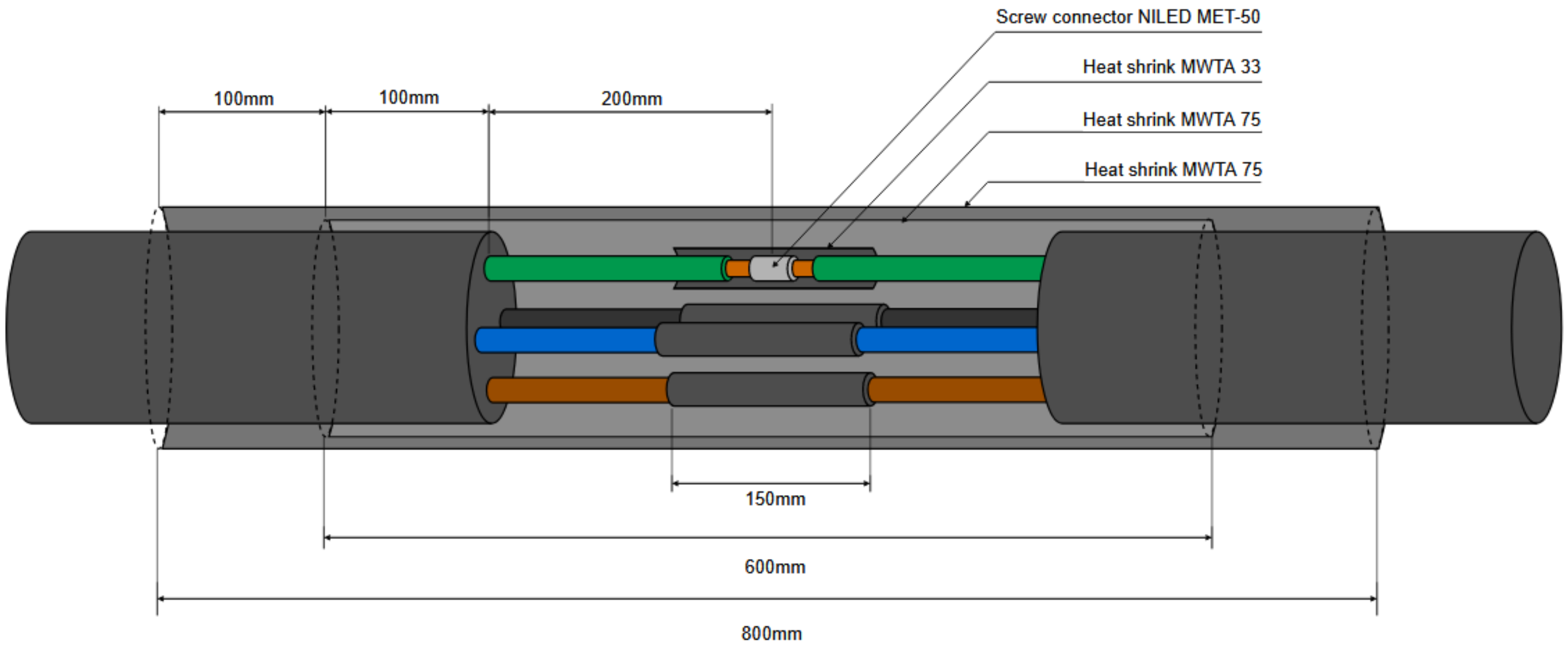
(LSC, Canfranc)

- pressure tests **(no leaking of water)** transparency loss <5% --- L(λ) > 2000m --- TOC <100ppm --- Rn emanation < 200Bq

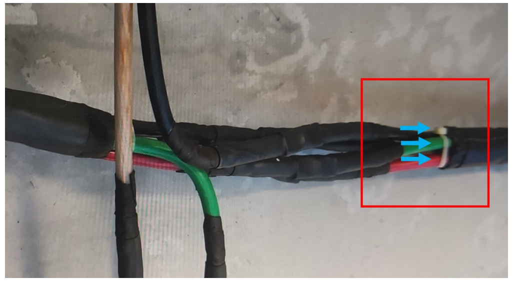
Cable (material)	λ (nm)	pure water			Gd water			Rn emanation (Bq)
		T/To	L(λ)(m)	TOC (ppm)	T/To	L(λ)(m)	TOC (ppm)	
TopCable (Neoprene)	300	0,130	44	37	0,294	73	25	2000
	350	0,854	564		0,953	1849		
	450	0,978	4002		0,981	4641		
	550	0,993	12673		0,986	6314		
SumCab (Polyethylene)	300	0,904	851	25	0,948	1608	15	77
	350	0,983	4921		1,003	28670		
	450	0,996	21427		1,005	17219		
	550	1,003	28670		1,005	17219		
Fujikura (Polyethylene)	300	0,966	2446	2	0,973	3064	1,6	37
	350	0,979	3951		0,984	5109		
	450	0,986	5905		0,990	8344		
	550	0,987	6409		0,991	9276		

Soaking test results for the heat shrinkable tube in **pure water**

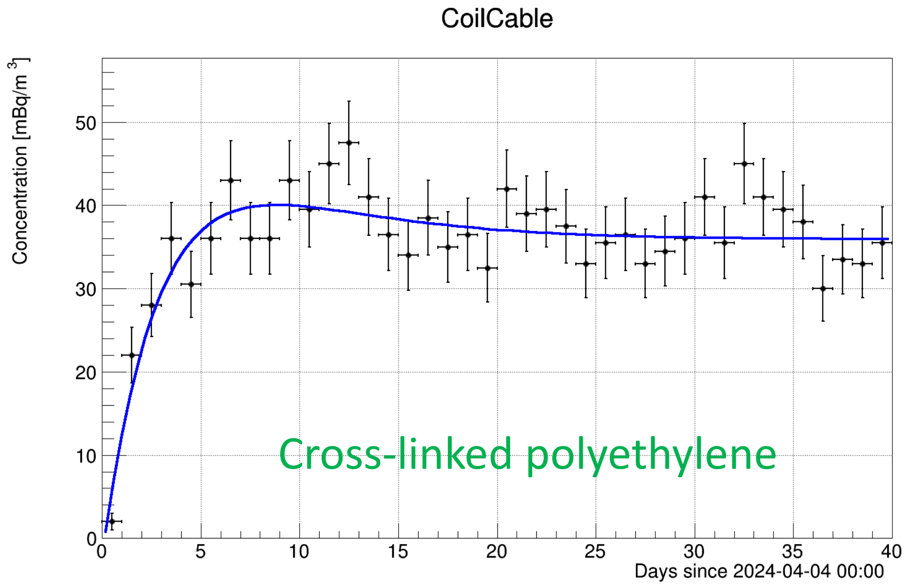
λ (nm)	T/To	L(λ)(m)	TOC (ppm)
300	0,985	788169	2,2
350	0,993	1695766	
450	0,993	1695766	
550	0,993	1695766	

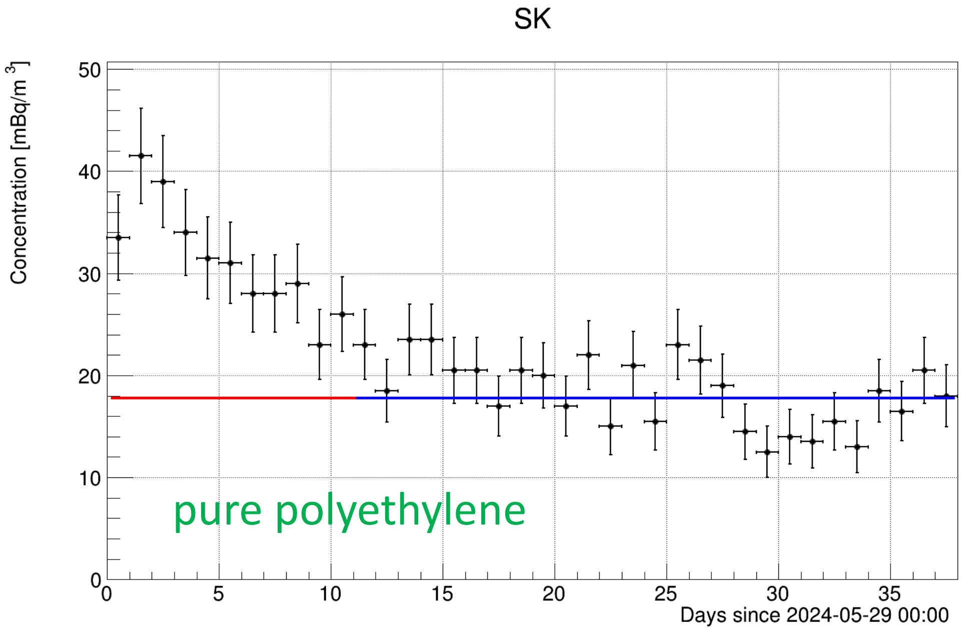


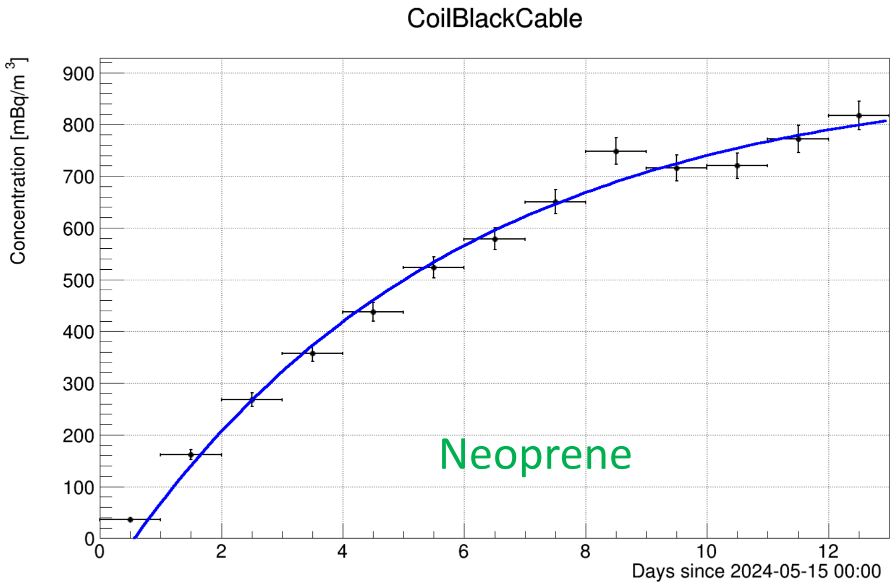
without outer shrinkable tube in SK:



Rn emanation test results **(< 200 Bq)**

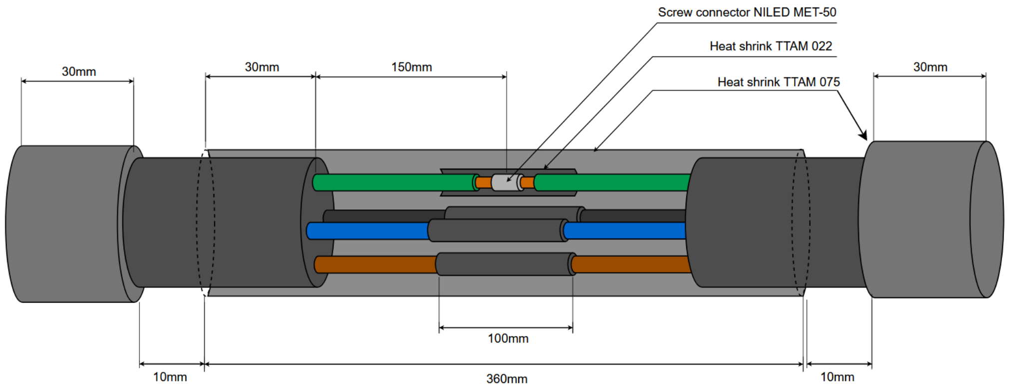






Cable	Material	time (days)	mBq/m	Total (Bq)
SumFlex	Cross-linked polyethylene	40	4.5±0.2	77
H07RN-F	Neoprene	14	>100	**2000**
Fujikura	Pure polyethylene	38	2.15±0.10	**37**

Waterproof tests for the connections



Pressure vessel (25cm diameter x 50cm)

0.9 MPa

7days

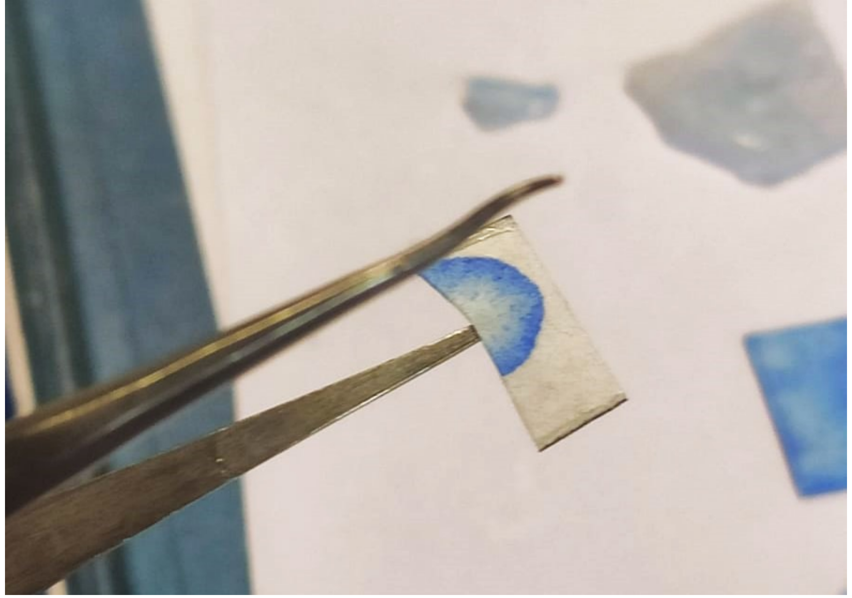
water detection:

visual inspection

change of weight

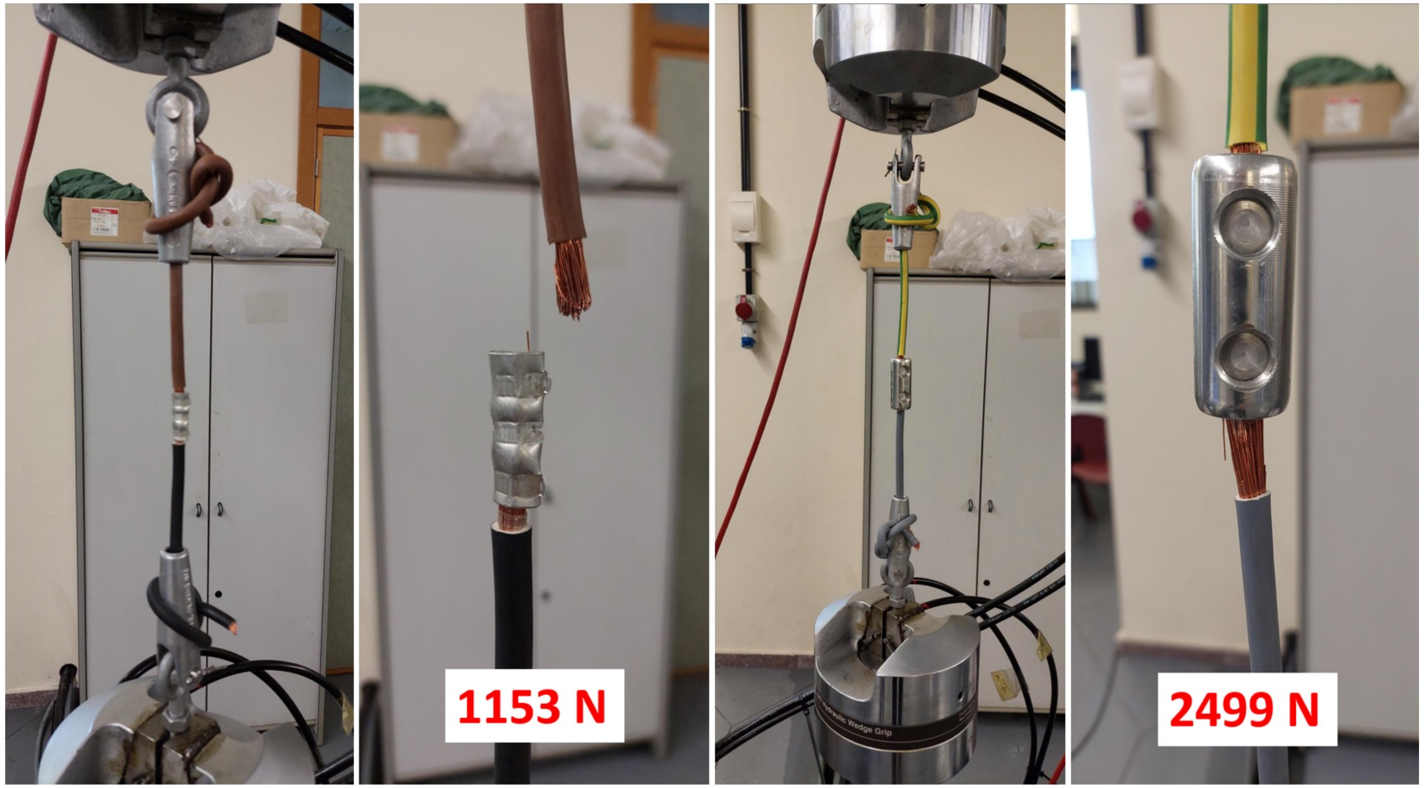
water indicator paper

Waterproof tests for the connections



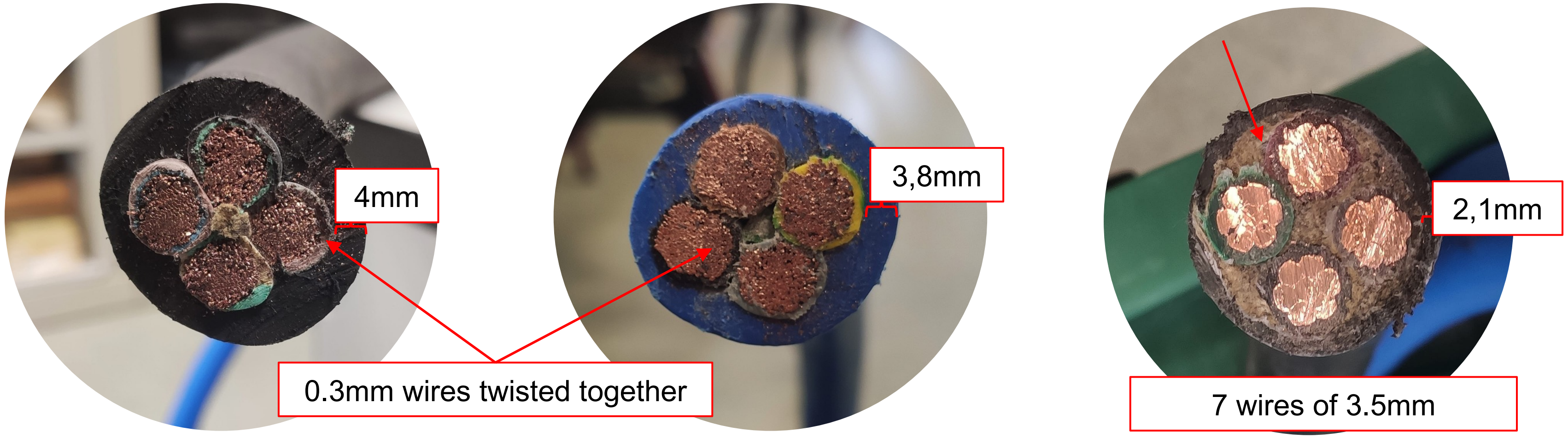
heat shrink connections meet requirements

Mechanical resistance of clamp connector- screw connector



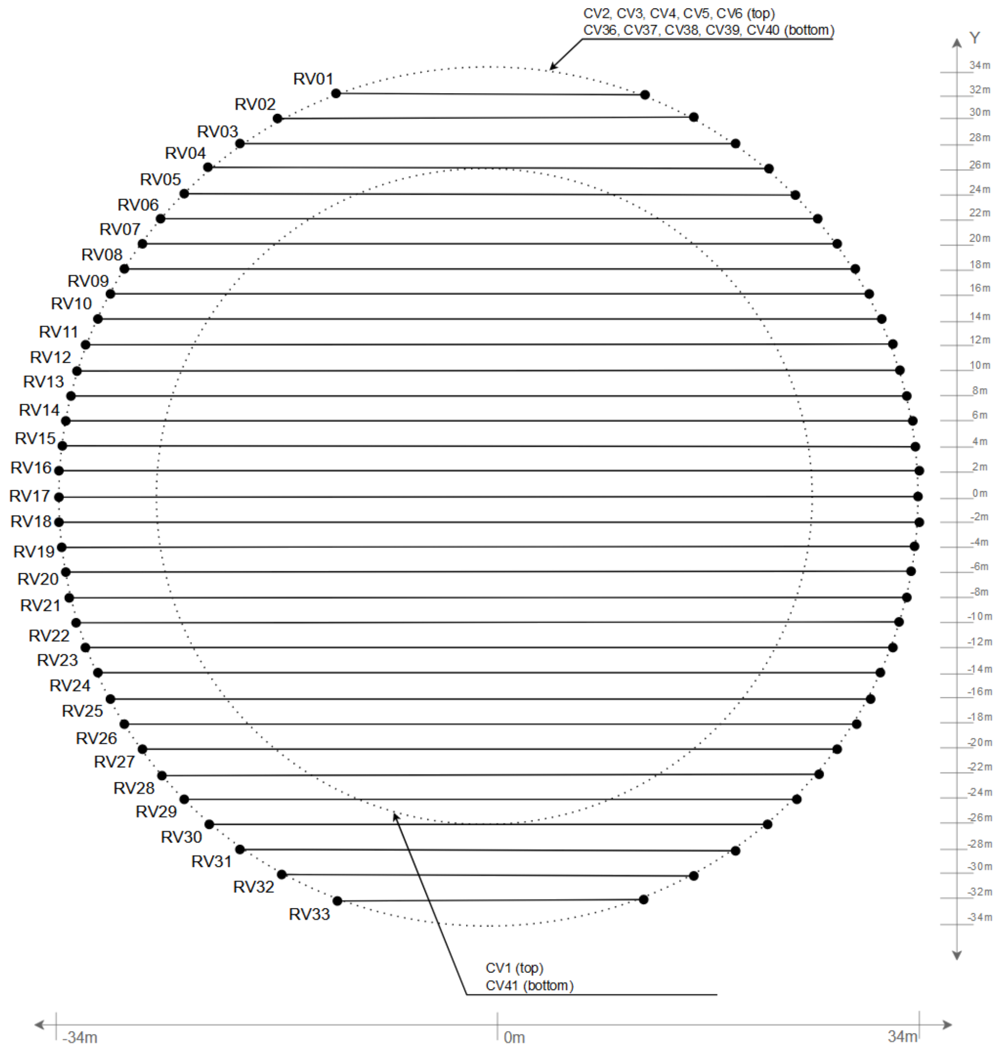
best solution is the bolt connector

Cable comparative



Cable (Manufacturer)	(1) H07RN-F (Top-Cable)	(2) SumFlex R Clean (SumCab)	(3) Model? (Fujikura Ltd.)
Cost (€/m)	19.62	41.00	25.00
Diameter (mm)	32.70	30.20	28.00
Bending radius (mm)	130.8	181.2	186.0
Resistance (Ω/km)	1.28	1.28	0.491
Sheath material	Neoprene	Crosslinked Polyethylene	Polyethylene
Sheath minimum thickness (mm)	4.00	3.80	2.10
Submerged work certification	AD8	AD8	-
Tested submerged in ultrapure water	No	No	~25 years in SK
Manipulability	Flexible	Flexible	Stiff
Soaking test result	Bad at 300nm and 350nm	Bad at 300nm	Good at all wavelengths [300nm-600nm]
Rn emanation test	2000 Bq	77 Bq	37 Bq

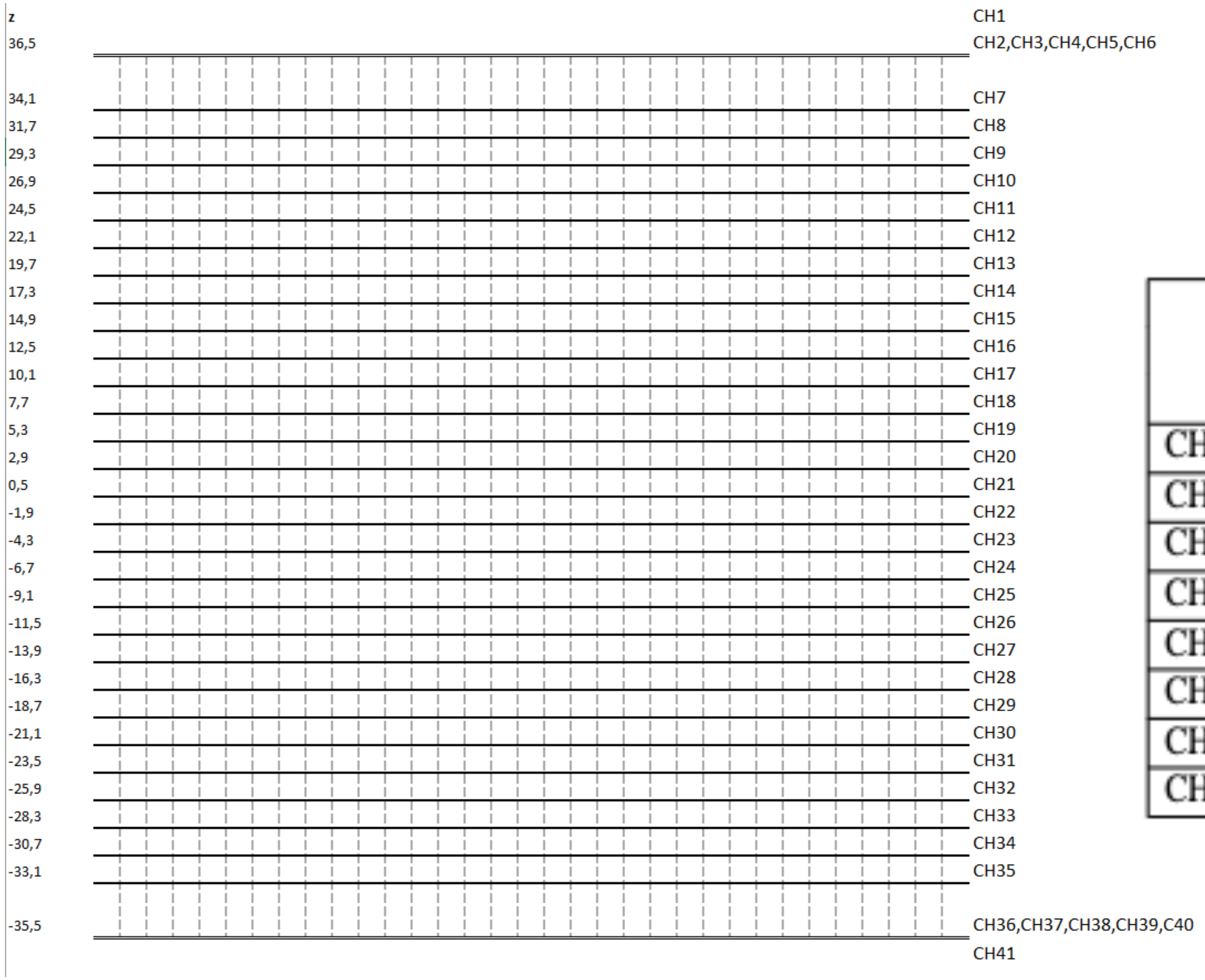
3. Power



Rectangular coils,
grouped in 7 power supplies with 150 V limit / 75 V limit

Coils	Current (A)	H07RN-F/SumFlex [1.28Ω/km]		Fujikura [0.491Ω/km]	
		Voltage (V)	Power (kW)	Voltage(V)	Power (kW)
RV01, RV02, RV03, RV04, RV05	17.25	94	1.67	37	0.64
RV06, RV07, RV08, RV09, RV10	17.25	115	1.97	44	0.76
RV11, RV12, RV13, RV14, RV15	17.25	122	2.10	45	0.81
RV16, RV17, RV18	17.25	75	1.28	29	0.5
RV19, RV20, RV21, RV22, RV23	17.25	122	2.10	45	0.81
RV24, RV25, RV26, RV27, RV28	17.25	115	1.97	44	0.76
RV29, RV30, RV31, RV32, RV33	17.25	94	1.67	37	0.64

Total power (kw): 13 kW / 6,5 kW



Circular coils,
8 power supplies with 150 V limit / 75 V limit

Coils	Current (A)	H07RN-F/SumFlex [1.28Ω/km]		Fujikura [0.491Ω/km]	
		Voltage (V)	Power (kW)	Voltage(V)	Power (kW)
CH01-CH06	20.5	130	2.65	50	1.016
CH07-CH11	20.5	113	2.30	43	1.613
CH12-CH16	20.5	113	2.30	43	1.613
CH17-CH21	20.5	113	2.30	43	1.613
CH22-CH26	20.5	113	2.30	43	1.613
CH27-CH31	20.5	113	2.30	43	1.613
CH32-CH36	20.5	113	2.30	43	1.613
CH37-CH41	20.5	129	2.18	49	1.012

Total power (kw): 19 kW / 12 kW

15 power supplies

Total power consumption: 32kW for Neoprene/polyethylene
16 kW for Fujikura SK cable

Item	Quantity	unit price (€)	subtotal (€)
Neoprene	17000	19,62	333518
Polyethylene	17000	41,00	697000
Fujikura SK	17000	25,00	425000
Power supplies	15	9000,00	135000

In the case of using a cable with lower resistance (Fujikura, for example), the number of power supplies could be reduced.

Estimation of prices, some other things (connectors, etc) have to be added. As well as taxes and installation costs

Summary:

Coil configuration:

- 2.4 v1
- wiring system
- connection protection method

Featuring:

17.02 km of cable
4.05% PMTs above 100 mG
42 mG average perpendicular magnetic field
average loss of efficiency: 0.28%
asymmetry top/bottom: 0.02%
up/down: 0.07%

Cable materials:

Transmitance:

- Neoprene and Xlink polyethylene have bad transmittance in the lower part of the spectrum ($\lambda \sim$300nm), however Xlink polyethylene is better.

-Fujikura - SK satisfies our requirements

TOC is non negligible for neoprene or Xlink polyethylene cables

Rn emanation

-Too high for the neoprene cable.

Waterproof tests:

-heat shrink connections meet requirements

Future works:

Calibration:

- measurement of real magnetic field!
- better optimization of currents with real magnetic field
- selection of power supplies!

Construction!

Thank you for your attention