Toward a radiopure optical readout

Studies for low radioactivity cameras and optics

Francesco Renga, INFN Roma CYGNO Collaboration Meeting, Dec. 2022

Background contributions

- Photo camera and optics are among the dominant contributions to the expected electron recoil background in CYGNO
- Background from camera and optics cannot be reduced with a passive shielding
 - dedicated R&D is needed

• ER rate [1-20] keV = 2.3x10⁶ cts/yr



G. D'Imperio, CYGNO Collaboration Meeting 2021

Photo camera radioactivity

- The components of a Teledyne BS Prime camera have been singularly analyzed
 - Dominant contributions from some mechanics (easy to replace) but, mostly, from the CMOS sensor

piece #	description	weight [kg]	Ra228 from Th232 [Bq]	Th228 from Th232 [Bq]	Ra226 from U238 [Bq]	Th234 from U238 [Bq]	Pa234m from U238 [Bq]	K40 [Bq]	U235 [Bq]	Cs 137 [Bq]
1	CMOS sensor	1	0.0052	0.0053	0.0068	0.011	0.007	3.5	0.00091	0.00042
2	sensor frame	1	0.113	0.111	0.08	0.29	0.14	0.08	0.006	0.00086
3	sensor frame holder	1	0.007	0.016	0.0046	0.5	0.26	0.08	0.015	0.001
4	peltier cooler	1	0.00036	0.00024	0.00017	0.012	0.021	0.0026	0.0002	0.000054
5	electronic board	1	0.208	0.202	0.187	0.16	0.25	0.24	0.009	0.002
6	electronic board	1	0.248	0.229	0.335	0.12	0.2	0.19	0.0075	0.0025
7	electronic board	1	0.0679	0.0639	0.0552	0.053	0.1	0.053	0.0017	0.00047
8	electronic board	1	0.104	0.1	0.072	0.12	0.266	0.07	0.002	0.0011
9	cooling fan	1	0.07	0.0687	0.0558	0.1	0.2	1.4	0.0013	0.0011
10	metal supports	1	0.0012	0.0007	0.00031	0.024	0.036	0.0052	0.00074	0.0004
11	plastic support	1	0.0048	0.002	0.0024	0.08	0.16	0.1	0.004	0.00085
12	metal support	1	0.01	0.0067	0.003	0.8	1.1	0.015	0.039	0.0015
13	plastic objective support	1	0.006	0.0073	0.003	1.6	1.2	0.02	0.052	0.00093
14	camera case	1	0.0028	0.013	0.001	0.24	0.2	0.01	0.008	0.00031
15	camera objective case	1	0.0025	0.028	0.001	0.36	0.33	0.012	0.013	0.00029
16	sensor plastic frame	1	0.0004	0.00025	0.00011	0.0011	0.0081	0.0025	0.0004	0.00008
17	glass window	1	0.00033	0.00022	0.0002	0.0023	0.0016	0.006	0.0002	0.00024
18	plastic o-ring	1	0.001	0.001	0.00043	0.027	0.06	0.0032	0.001	0.00013
19	plastic o-rings	1	0.0011	0.00041	0.00049	0.0059	0.02	0.0043	0.00027	0.00009
20	salt dehumidifier	1								

Photo camera radioactivity

- Further investigations indicate that all cooled CMOS sensors show a 3-4 Bq from ⁴⁰K, but it comes from the protective glass avoiding water condensation due to the sensor cooling
 - a possible solution by providing the manufacturer a low-radioactivity protection window to be mounted on the sensor (at least Teledyne seems collaborative on this idea)

1		C11440-52U, board only	PRIME-BSI EXPRESS, Teledyne	orca-flash4.0, model C11440-22CU	Thorlabs Quantalux	PRIME-BSI EXPRESS, Teledyne - CMOS from unassembled camera	PRIME-BSI EXPRESS, Teledyne - CMOS without glass
2	Th-232						
3	Ra-228	1.03	1.3	2.1	0.26	5.20E-03	2.00E-03
4	Th-228	1.06	1.8	2.1	0.63	5.30E-03	1.80E-03
5							
6	U-238						
7	Ra-226	1.15	1	1.8	0.21	6.80E-03	2.83E-03
8	Pa-234m	1.1	6	7	3	0.007	<15 mBq
9							
10	U235	0.06	0.27	0.4	0.12	0.00091	<0.29 mBq
11	K-40	4.3	3.6	1.9	1.2	3.50E+00	9.00E-03
12	Cs-137	7	<32 mBq	0.09	<2.3 mBq	0.00042	<0.24 mBq
13	Co-60	<1.2 mBq	<17 mBq	<0.012 mBq	<5.5 mBq		

Optics radioactivity

- Radioactivity in the optics come from the glasses used to produce the lenses
- High purity glasses by Heraeus (Suprasil, etc.) have been proved to be suitable for building radiopure optical windows for lowbackground experiments (e.g. CUORE)
- Unfortunately, all Heraeus glasses share the same optical properties, while suppressing achromaticity and other distortions require many materials with different properties to be used together
 - the LOBRE S.r.I. company (Brescia, Italy) agreed to perform some feasibility study, considering PMMA and polycarbonate as additional materials

Optics specifications

Tabella riassuntiva requisiti

WD	600 mm
Apertura	0.95
Materiali	Suprasil, PMMA, Policarbonato
EFL	25 mm
Sensore utilizzato	Hamamatsu Orca-Fusion Gen III

The Lobre report

- A report was produced by LOBRE, proposing an optical scheme with 12 lenses and a total length of 390 mm
- On paper, all specs can be met with an acceptable optical performance



Next steps

- The LOBRE report (costed 6.1 k€ in 2022) is not conclusive concerning the technical feasibility of the optics (possibility to meet the required mechanical tolerances, etc.)
- A second study (15 k€ + VAT) has been commissioned, for an executive design including the analysis of the mechanical tolerances
- Total cost can be an issue:
 - a first estimate was discouraging (up to 72 k€ + VAT for a single prototype, 30-40 k€ +VAT per unit in the final production)
 - the company investigated alternative machining techniques that could reduce significantly the costs -> 2 single-lens prototypes have been commissioned (6 k€ + VAT) to check if the required tolerances can be met on PMMA and PC