


#07-40

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Contamination Tests of New Silicone-Based Detectors for Beta-Alpha Radiation in Water

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1. Abstract

We present the results of radioactivity contamination tests on a novel contamination-safe scintillation detector for alpha and beta radiation detection in water, as follow-up of the TAWARA_RTМ project. This detectors are large-area silicone-based scintillators with functionalized surface, representing an improvement in the realization of radioactivity monitors for water with high sensitivity and reasonable costs.

2. Intro

- Short path-length of alpha and beta in water
- Low detection limit (international legislations)

require → Large area, Very low intrinsic background, Avoid window between water and detector active volume

Problem: direct contact with water → detector surface contamination, If no protective layer → efficiency reduction (especially for alpha), If passive protective layer → passive layer contamination

Our solution: large area silicone-based scintillator with functionalized surface

- no need of passive protection layer/window
- low surface contamination
- can be easily decontaminated
- flexible



3. Materials

Silicone matrix (≈ 1 mm), ZnS:Ag powder (≈ 50 μm), nanometric fluorinated film

Cross-section at 40x optical transmission microscope

- Passive silicone matrix:** polydimethylsiloxane Gelest DMS-V21. After cross-linking → elastomeric material. Hydrophobic. Transparent in the range 330-2200 nm. Wide range of temperature (-100 - 250°C).
- Active silicone matrix:** polydiphenyl-co-dimethylsiloxane Gelest PDV-2331 + primary dopant: 2,5-diphenyl oxazole (1.0%wt) - secondary dopant: Lumogen F Violet 570 (0.05%wt) → organic beta scintillator. After cross-linking → elastomeric material. Hydrophobic. Wide range of temperature (-100 - 250°C).
- Inorganic alpha scintillator:** ZnS:Ag powder Ejen EJ-600 (5.5 mg/cm²). Silver activated ZnS crystals. Typical particle size 8 μm.
- Fluorinated protective film:** nanometric trichloro(1H,1H,2H,2H-perfluoroalkyl)silane film. Fluorinated organic chain → omniphobic layer reduce surface contamination.

4. Production @University of Padua

- Mixing liquid silicone and cross-linking agent
- Add ZnS:Ag powder
- Pour the liquid mixture in a mold → 1 mm thick layer
- Powder sedimentation overnight (ρ_{ZnS:Ag} ≈ 1 g/cm³, ρ_{Silicone} ≈ 4 g/cm³) → ≈ 50 μm layer with 60wt% of ZnS:Ag
- Silicone cross-linking in oven @70°C, 1h → solid elastomeric slab can be peeled off
- Surface functionalization with fluorinated silane film by vapour phase deposition



5. Detection performance @University of Padua

Light output spectra of standard commercial Ejen samples and silicone-based samples

	Efficiency	Light output
Beta	80-85%	100-120%
Alpha	85-90%	90%



Performance with respect to EJ-440/EJ-444 reference detectors

BETA (Sr-90 source) ALPHA (Po-210 source)

6. Contamination tests @ ENEA

Samples 5 x 5 cm² square detectors:

- passive silicone + ZnS:Ag alpha detector (SA)
- passive silicone + ZnS:Ag + fluorosilane alpha detector (SA-S)
- active silicone + ZnS:Ag alpha/beta detector (SAB)
- active silicone + ZnS:Ag + fluorosilane alpha/beta detector (SAB-S)
- Ejen EJ-440 discs reference

- Couples of samples mounted back-to-back on plastic supports and sealed at the edges
- Sets of 8 couples are mounted on a rack attached to the moving arm of a dip-coater



7. Contamination measurements @ ENEA

Residual contamination measured using a very low-background and calibrated gamma detection system

Results:

- Contamination level saturates after just some minutes
- Approx. linear growth of contamination with increasing specific activity
- Silicone-based detector less contaminate by a factor 10-20 with respect to commercial EJ-440
- Fluorinated film further decrease residual contamination

Effect of Decontamination procedures:



8. Conclusions

- good detection efficiency for alpha and beta radiation
- high hydrophobicity, chemical resistance and long-term stability of the surface
- negligible contamination level after exposition to radioactive aqueous solutions
- possibility to cleanup the surface from possible residual contaminations using chemical cleaning agents without damaging the detector
- low production cost

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Radioactivity contamination tests on a novel contamination-safe scintillation detector for alpha and beta radiation detection in water, as follow-up of the TAWARA_RTМ project.

Detectors are large-area silicone-based scintillators with functionalized surface, representing an improvement in the realization of radioactivity monitors for water with high sensitivity and reasonable costs.



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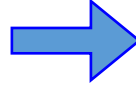
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References
 • Quaranta A. et al., "Doping of polysiloxane rubbers for the production of organic scintillators", Opt. Mat. 32 (2010)
 • Dalla Palma M et al., "Non-toxic liquid scintillators with high light output based on phenyl-substituted siloxanes" Opt. Mat. 42 (2015)

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- Short path-length of alpha and beta in water
- Low detection limit (international legislations)

require



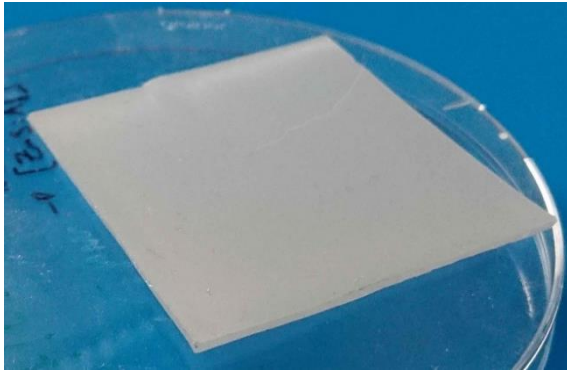
- Large area
- Very low intrinsic background
- Avoid window between water and detector active volume

Problem: **direct contact with water**

- If no protective layer/window
- If passive protective layer/window

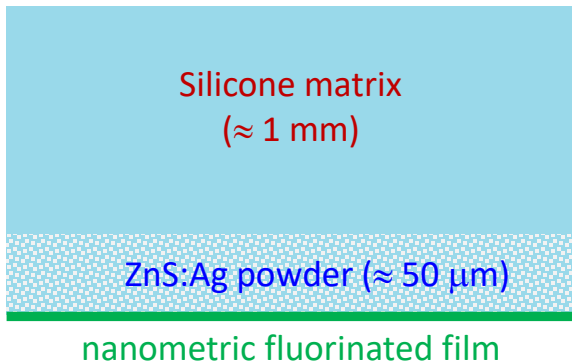


detector surface contamination
efficiency reduction (especially for alpha)
passive layer contamination



Our solution: **silicone-based scintillator with functionalized surface**

- no need of passive protection layer/window
- low surface contamination
- can be easily decontaminated
- flexible elastomeric material
- good detection performances
- reasonable cost



Silicone rubber matrix:

Polydimethylsiloxane (passive)

Polydiphenil-dimethylsiloxane (beta scintillator)

ZnS:Ag powder:

50 μ m layer of alpha scintillator powder mixed with silicone (alpha scintillator)

Fluorosilane layer:

nanometric protective fluorinated layer - hydrophobic

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Silicone-based detectors **performance** with respect to **EJ-440/EJ-444 reference detectors** →

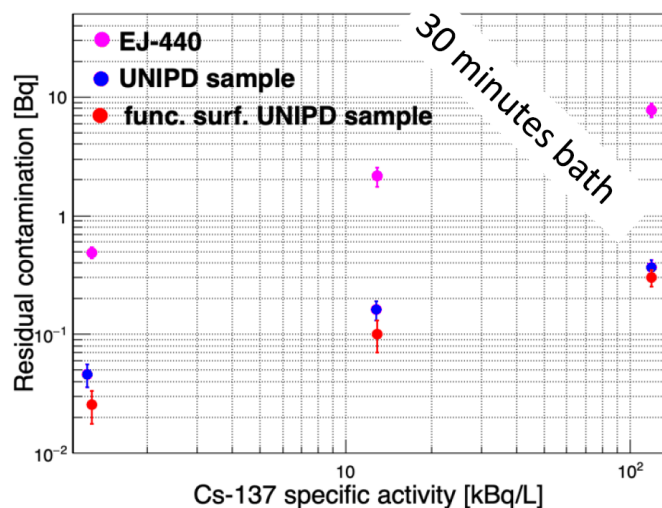
	Efficiency	Light output
Beta	80-85%	100-120%
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Contamination tests

immersion in aqueous solution of Cs-137 or Co-60

- varying concentration
- varying immersion time

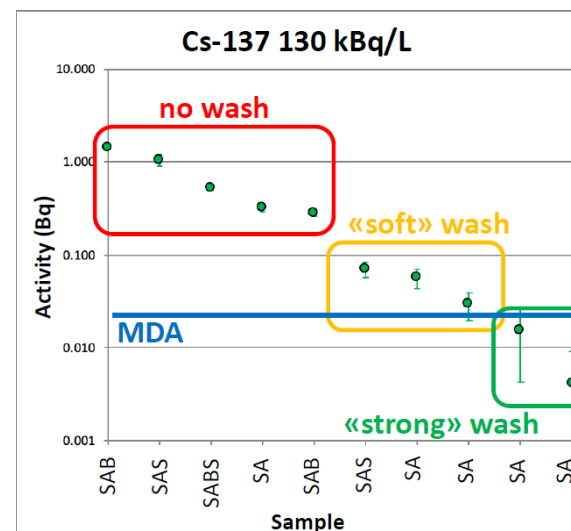
Silicone-based detectors are ~10 times **less contaminated**
Surf. functionalization **further reduces contamination**



Decontamination tests

washing after contamination following different procedures:

- solution of **CONTRAD 2000** for 30'
- solution of **HCl 0.5M** for 30'
- solution of **CONTRAD 2000** for 30' + **rubbing**
- immersion in a solution of **HCl 1.5M** for 30'



Residual activity can be **reduced** by **washing** procedure with **no loss in performance**