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_RTM** 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 →

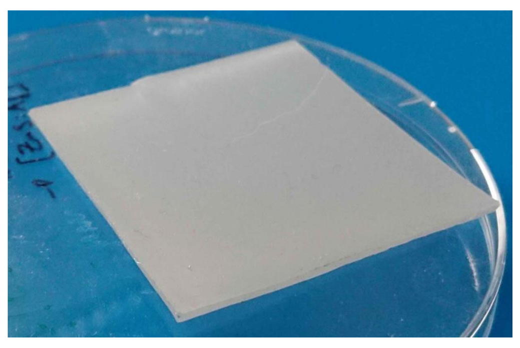
- Large area
- Very low intrinsic background
- Avoid window between water and detector active volume

Problem: **direct contact with water**

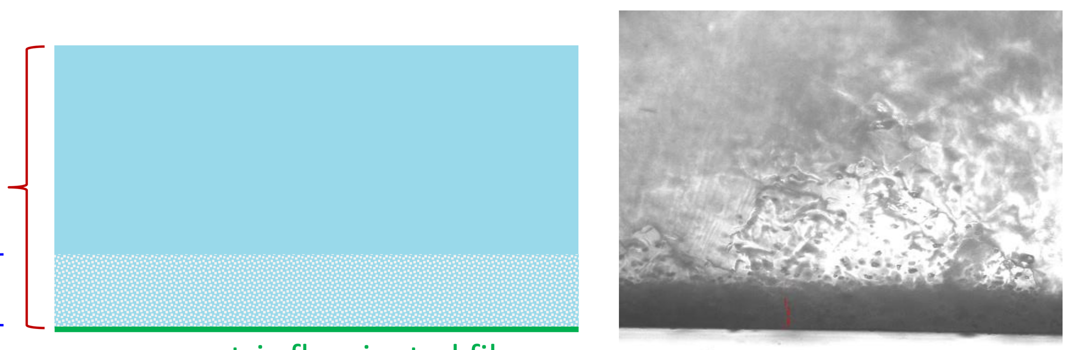
- If no protective layer → detector surface contamination
- If passive protective layer → efficiency reduction (especially for alpha) → passive layer contamination

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**

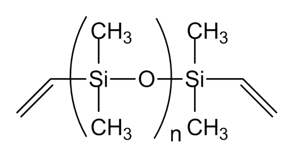


3. Materials



Cross-section at 40x optical transmission microscope

- **Passive silicone matrix:** polydimethylsiloxane *Gelest* DMS-V21

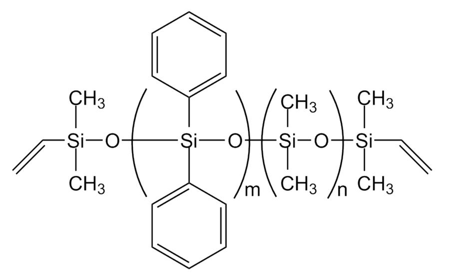


After cross-linking → elastomeric material
Hydrophobic
Transparent in the range 330-2200 nm
Wide range of temperature (-100 – 250°C)

or

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**



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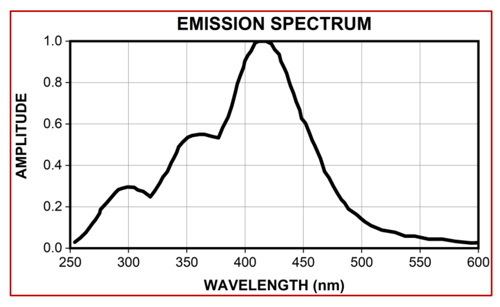
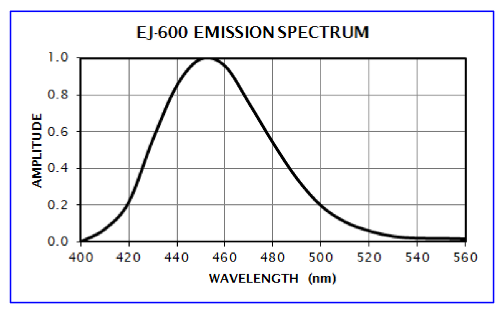
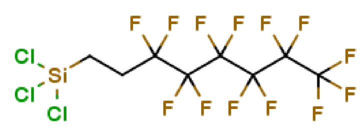


- **Inorganic alpha scintillator**: ZnS:Ag powder *Eljen* EJ-600 (5.5 mg/cm²)

Silver activated ZnS crystals
Typical particle size 8 μm



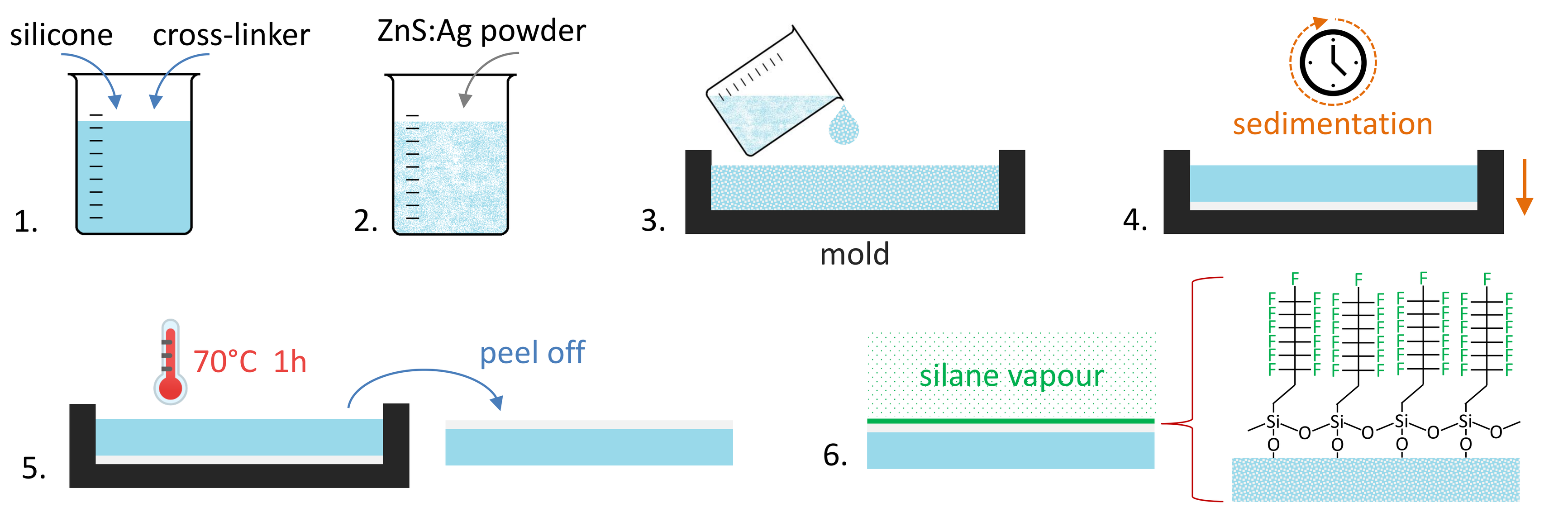
- **Fluorinated protective film:** nanometric trichloro(1H,1H,2H,2H-perfluorooctyl)silane film



Fluorinated organic chain → omniphobic layer
reduce surface contamination

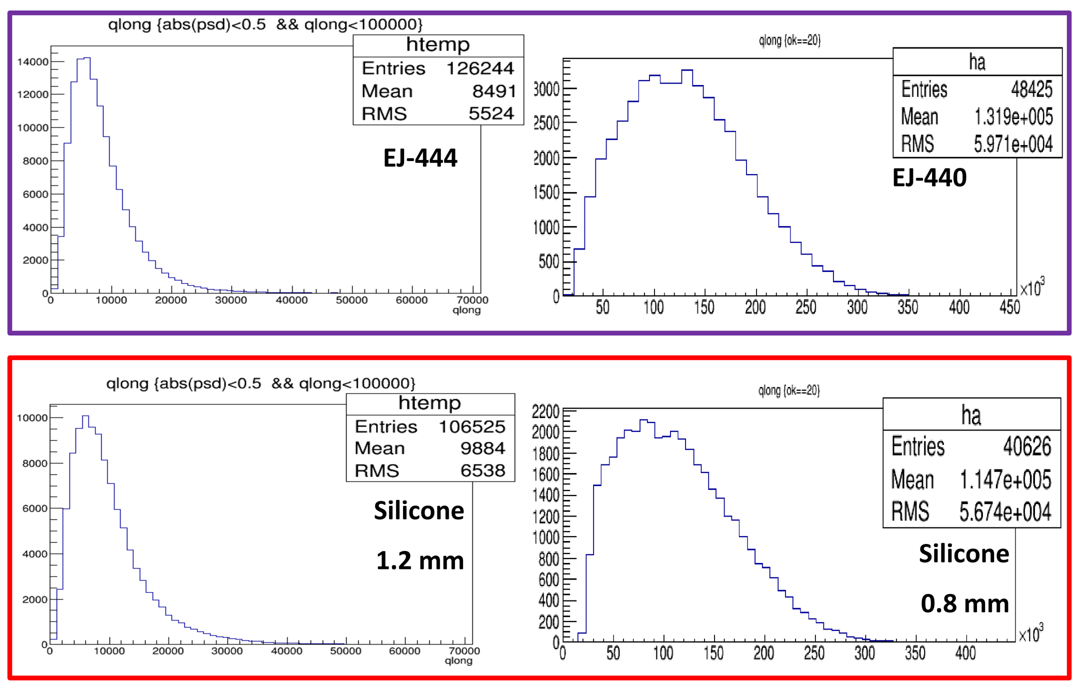
4. Production @University of Padova

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



5. Detection performance @University of Padova

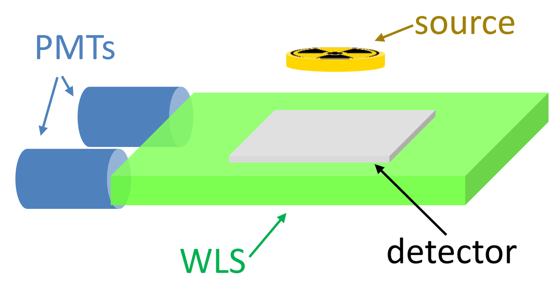
Light output spectra of standard commercial *Eljen* samples and silicone-based samples



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

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

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

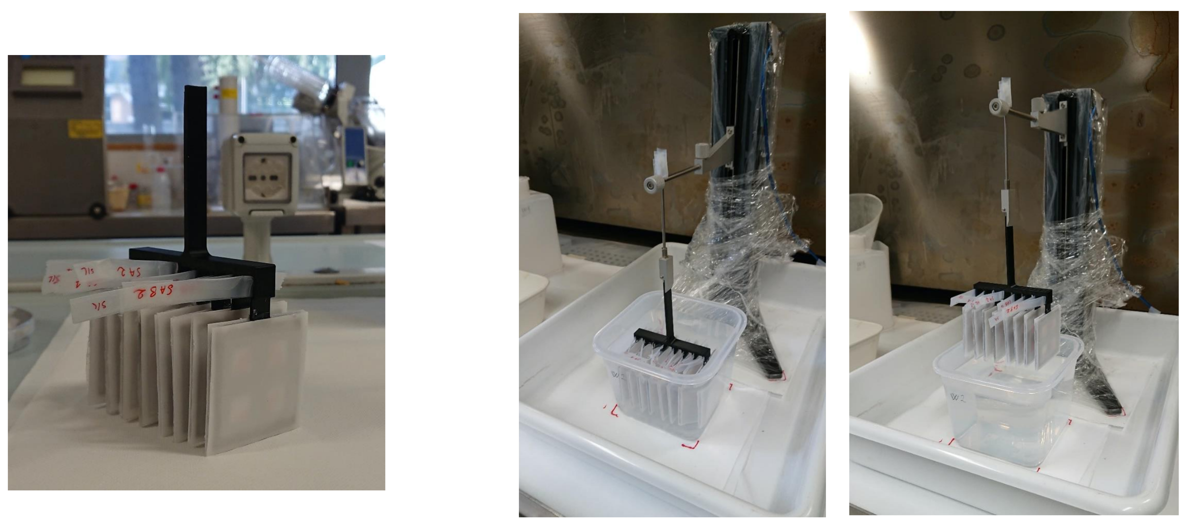


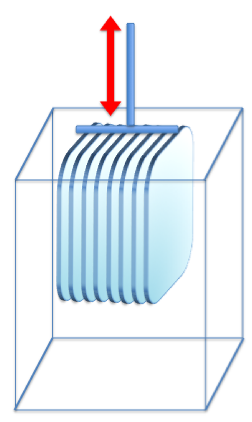
6. Contamination tests @ ENEA

Samples 5 x 5 cm² square detectors:

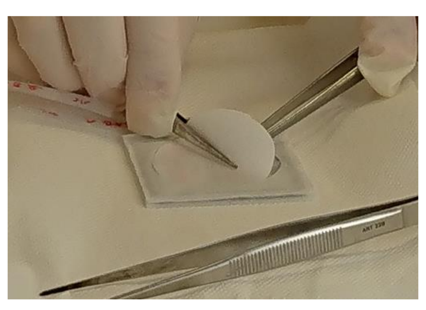
1.	passive silicone + ZnS:Ag	alpha detector	(SA)
2.	passive silicone + ZnS:Ag + fluorosilane	alpha detector	(SA-S)
3.	active silicone + ZnS:Ag	alpha/beta detector	(SAB)
4.	active silicone + ZnS:Ag + fluorosilane	alpha/beta detector	(SAB-S)
5.	Eljen EJ-440 discs	reference	

- 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





- Contamination by immersion and motion inside an **aqueous solution of Cs-137 or Co-60**
  - varying **concentration** (specific activity ~1, ~10, ~100 kBq/L)
  - varying bath **time** (30', 5h, 15h)
- After contamination, samples are **rinsed with D.I.** water and discs are cut out



Decontamination tests:

- A sub-set of samples is **washed** after contamination following different procedures
  - immersion in a solution of CONTRAD 2000 for 30'
  - immersion in a solution of HCl 0.5M for 30'

  } «soft» wash

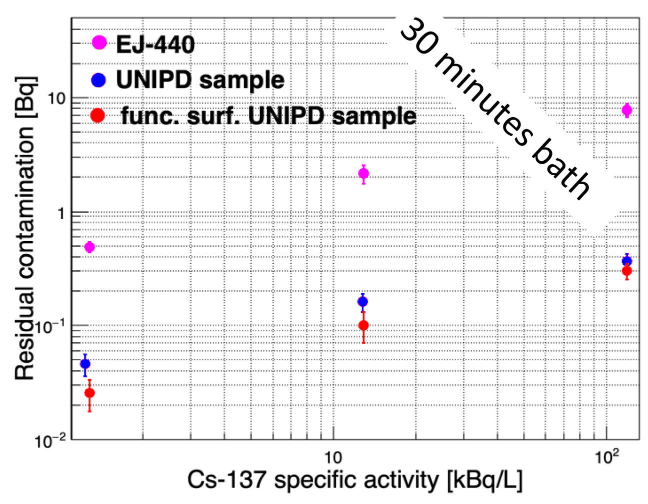
  - immersion in a solution of CONTRAD 2000 for 30' + **rubbing** with a soft towel
  - immersion in a solution of HCl 1.5M for 30'

  } «strong» wash

*Detector performances are not affected by the decontamination procedures

7. Contamination measurements @ ENEA

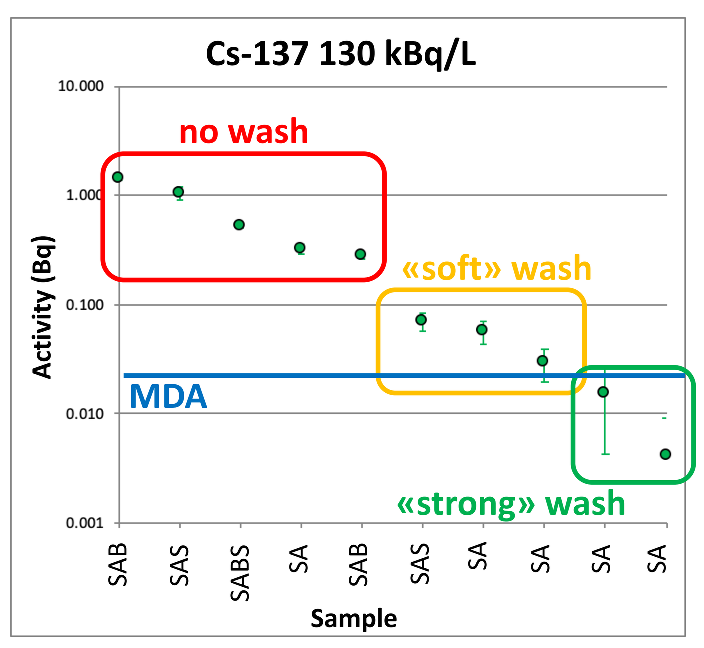
Residual contamination measured using a **very low-background and calibrated gamma detection** system

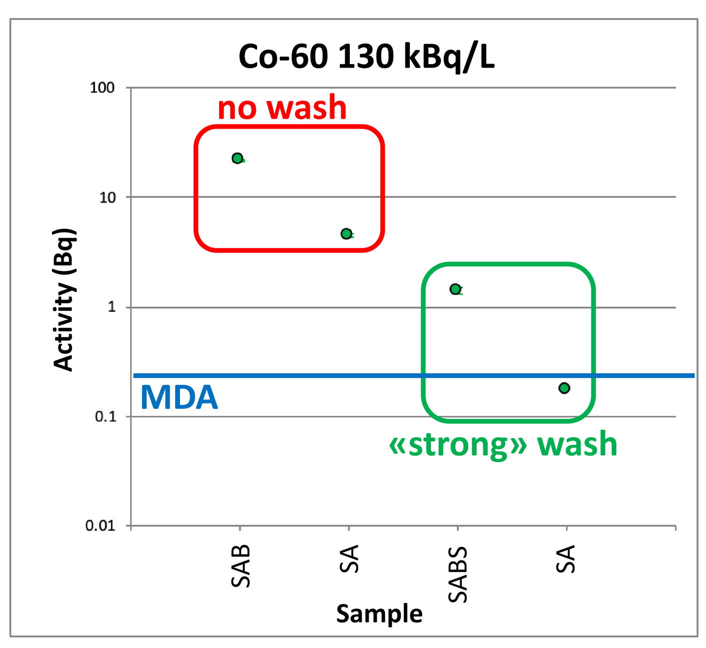


Results:

- 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**

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)