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Detection of beta-emitters in gas with YAG:Ce highly porous aerogels

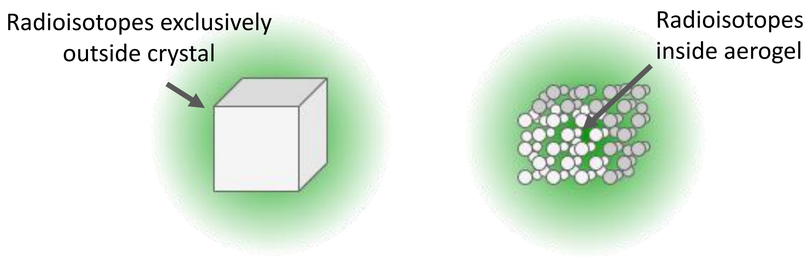
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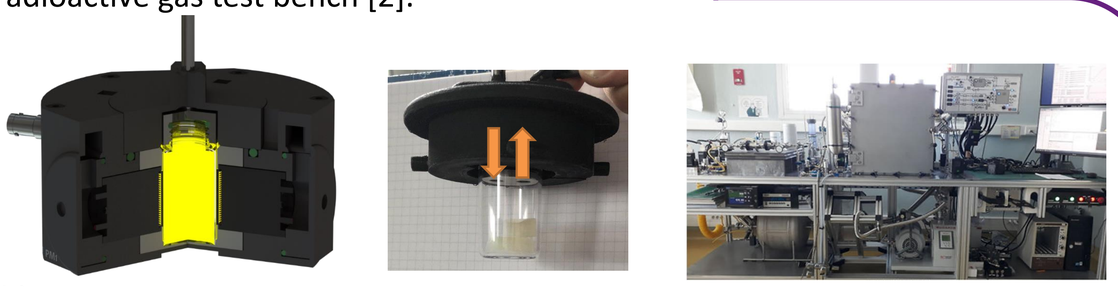
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Beta emitting radioisotopes are challenging to detect and differentiate due to rather short mean free path of electrons in air at low kinetic energies (up to tens of keV). In concert with importance of certain isotopes to nuclear security and their potential use for metrology, it is of special interest to research a detection method of beta ray emitters such as ^{85}Kr, ^{133}Xe, ^{3}H and even ^{37}Ar. Our aim is to develop a full solid-state scintillating detector where the radioactive gas is penetrating the scintillator. Our strategy is based on highly porous scintillating materials made of scintillating inorganic nanoparticles. In this frame we have developed dedicated highly concentrated colloidal solution of YAG:Ce nanoparticles to create aerogels via process of supercritical drying. By optimizing subsequent thermal treatment, initial nanoparticle size and final aerogel shape, we aim to achieve reliable and reusable radioactive gas detector with a scintillating aerogel.

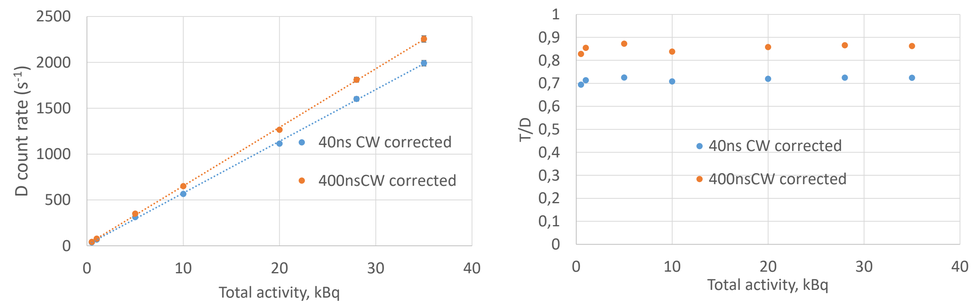


^{85}Kr and ^{3}H detection

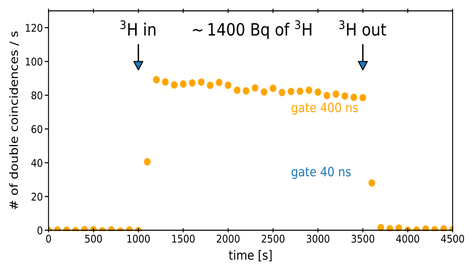
(a) Modified µ-TDCR device [1], a 3 PMTs device for metrology with scintillators. A specific cap is used for gas circulation that is connected to a radioactive gas test bench [2].



(b)



(c)



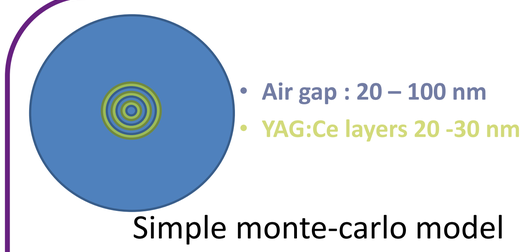
As can be seen on the data to the left, ^{3}H has been detected at significant counts above the detection limit; comparable to the ^{85}Kr detections, even if lower.

(b) – Triple/Double (right) and Double (left) coincidences of PMT detections in TDCR device at different ^{85}Kr concentrations to show linear response.
(c) – example of ^{3}H detection with the aerogel.

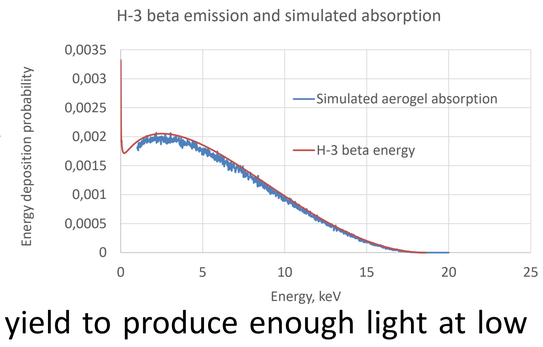
CW = Coincidence Window, TDCR = Triple to Double Coincidence Ratio

Modelling, optimisation

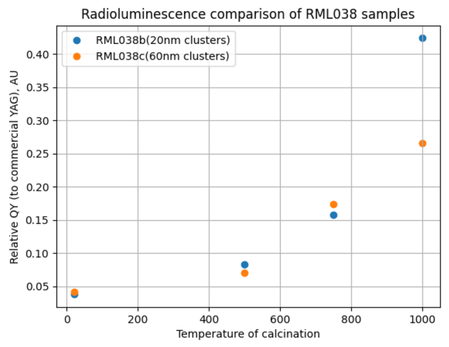
Monte-carlo model using emission beta spectra from the radionuclide (^{85}Kr, ^{133}Xe, ^{3}H) and the size of YAG:Ce nanoparticles : study of the deformation of the absorbed spectrum in the scintillator.

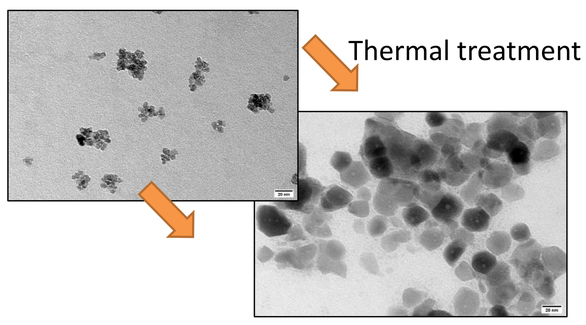


Simple monte-carlo model (PENELOPE)



Quantum yield optimization: increase the yield to produce enough light at low absorbed energy.

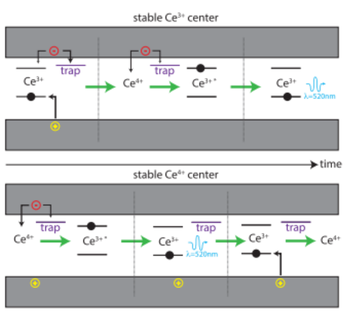


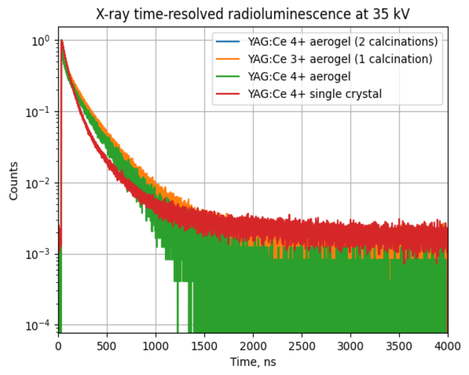


Transparency of an aerogel is inversely proportional to the size of its consistent nanoparticles due to scattering. On the other hand, the bigger volume of the absorbing nanoparticles positively impacts total luminescence. This and the impact of the calcination temperature on both the defects and the size of NPs in the aerogel bears investigation. In this regard, optimization of aerogel for metrological purposes is currently being implemented based on both empirical data from the physical results and on ongoing simulation data from PENELOPE/GEANT4 simulations.

Ce^{3+} and Ce^{4+} transitions in aerogels

[3]





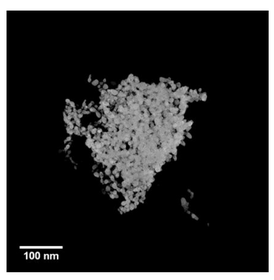


YAG:Ce may contain two species of Ce: Ce^{3+} and Ce^{4+}. The former is a viable source of photoluminescence, but is a slower emitter during radioluminescence events. The effect is shown to be even more pronounced in materials with many confined spaces such as aerogels.

Conclusions

YAG:Ce aerogels show a lot of promise as porous solid state scintillators by manifesting beneficial higher volume-to-luminosity ratio than single crystals and having fast decay times. The fully scintillating aerogels are a newer breed of materials that could be used for a multitude of applications in radiation detection and have already presented a faster and more ergonomic way of detection of low energy beta decays in air. Of particular note is that this is the first evidence of on-line detection of tritium gas with a porous scintillator.





References

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