Innovative alpha-detection system based on radiochromic diacetylenic monomer

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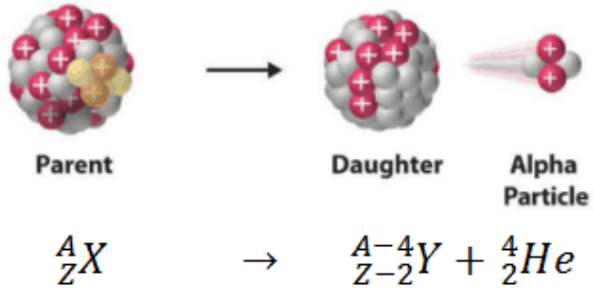
Introduction

α particle

- Nucleus of ^{4}He ;
- Monoenergetic : 3.5 to 9 MeV ;
- Highly ionising, not very penetrating particle ;
- Low range in matter (< 60 μm in Si).



Protection from contamination by alpha-particle-emitting radionuclides is crucial because alpha particles are harmful to the tissues in which they accumulate if inhaled or ingested

PPE

CPE

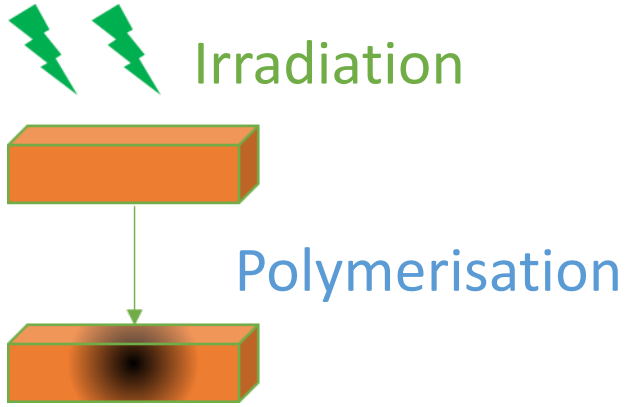
This work

- ❑ **Aim.** To develop a tool for alpha visualisation in worksites
- ❑ **Technology.** Radiochromic films made of diacetylene compounds : radiation-sensitive material

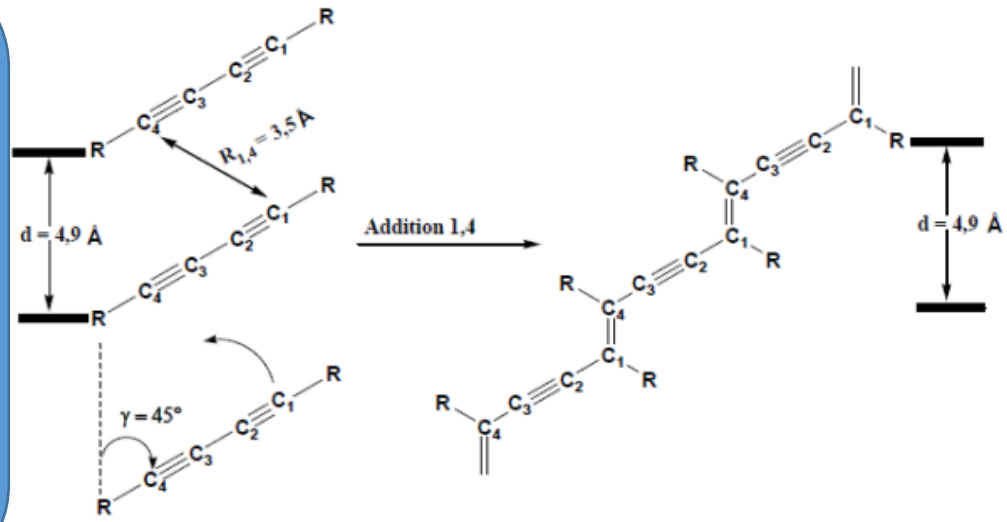
Measures

Diacetylene polymerisation

- Diacetylene (DA) monomers polymerise topochemically in the solid state upon UV and γ irradiation, resulting in coloured polymers ;
- Polymerisation occurs within the monomer crystal.



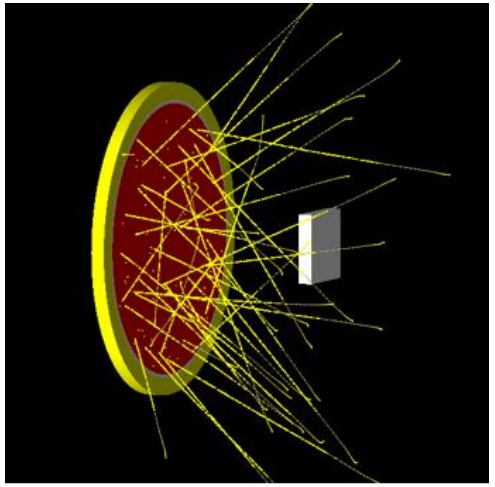
- The polymerisation 1,4 occurs by a molecular rotation along the axis C1-C4 carbon atoms
- C1 and C4 of two close monomers must obey, simultaneously :
  - The distance between two dynes units (2 triples C-C bounds) is less than 4.9 Å ;
  - The distance ($R_{1,4}$) between the C1 of a dyne and the C4 of the close dyne is 3.5 Å .

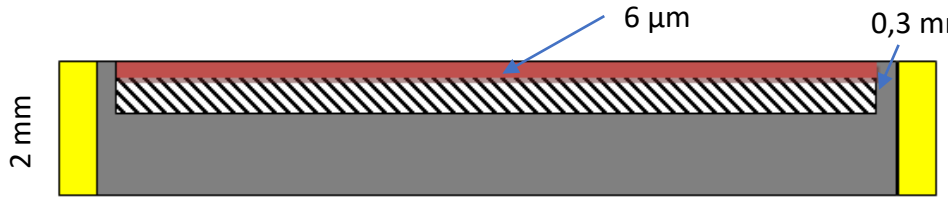


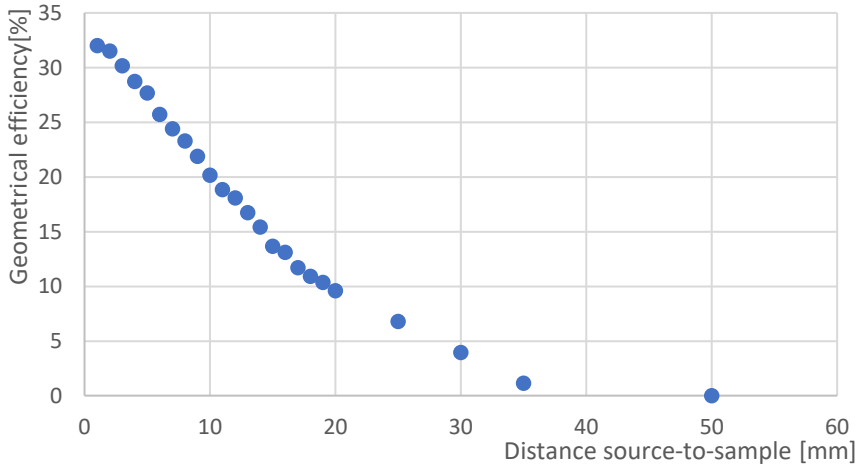
Geant4 Simulations

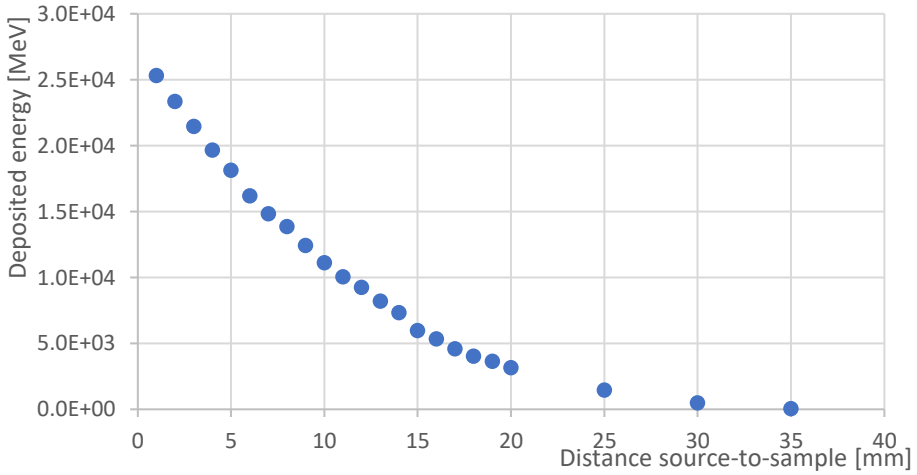
GEANT 4 simulations of sources and 6-BU sample to determine :

1. alpha flux at the sample and the geometrical efficiency as a function of the sample-to-source distance;
2. deposited energy in the sample ;
3. alpha particles range in the sample ;
4. the impact of a glass slide on these quantities.

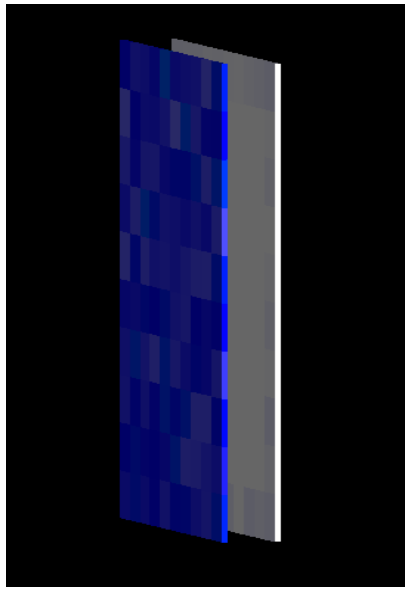


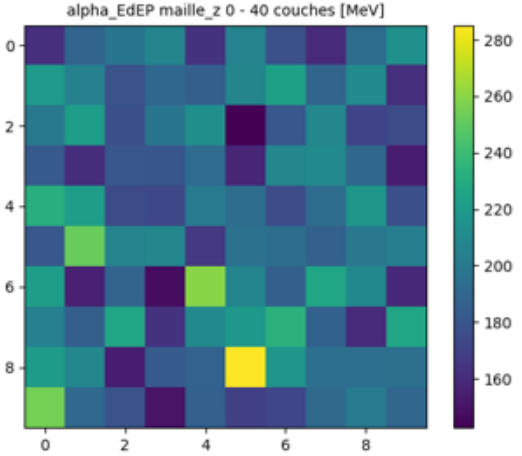


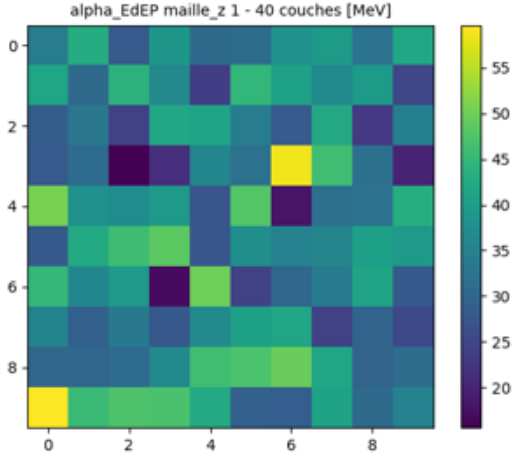


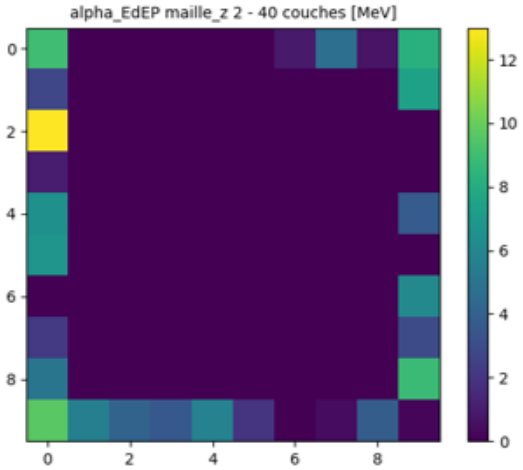


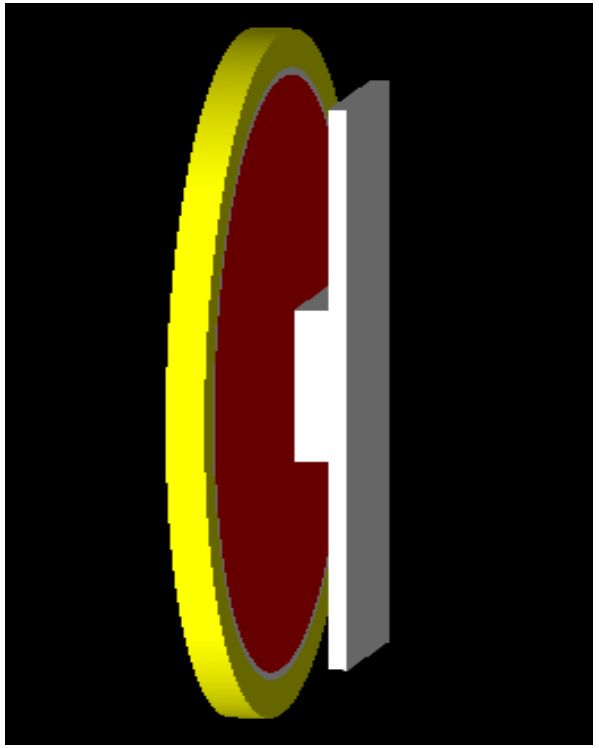
Geant4 Simulations





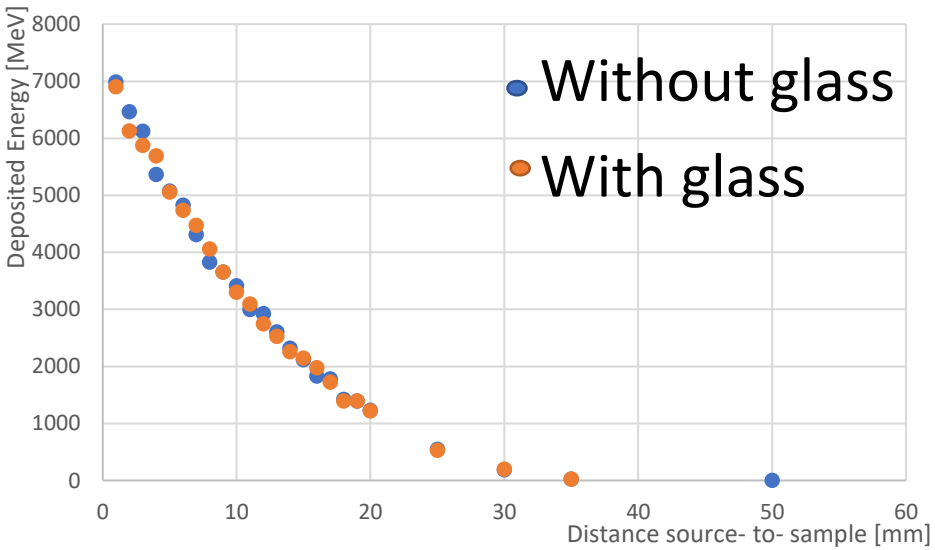






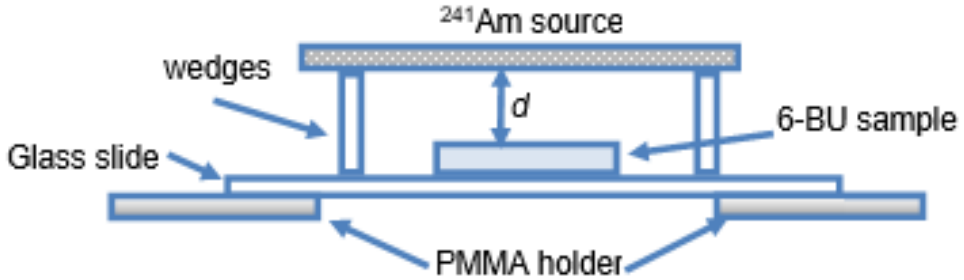
The sample thickness is divided into 40 meshes (25 µm).

Distance source – to- sample of 1 mm



Experimental campaign

- Two ^{241}Am sources are used to irradiate the 6-BU samples.
- Activities : 3.82 kBq and 1.93 kBq.
- Fluxes : 1700 α.s-1 and 772 α.s-1.



Experimental configuration as a function of :

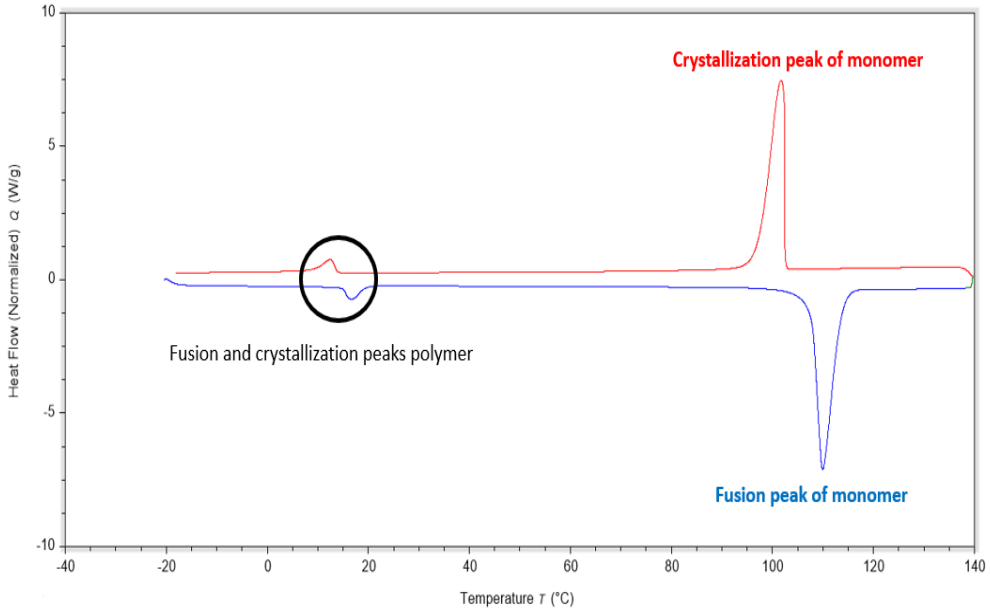
1. Exposure time : 1 minute to 2 weeks;
2. Distance source-to-sample : 1 mm and 20 mm.

Totally, 40 samples have been tested in 2023.

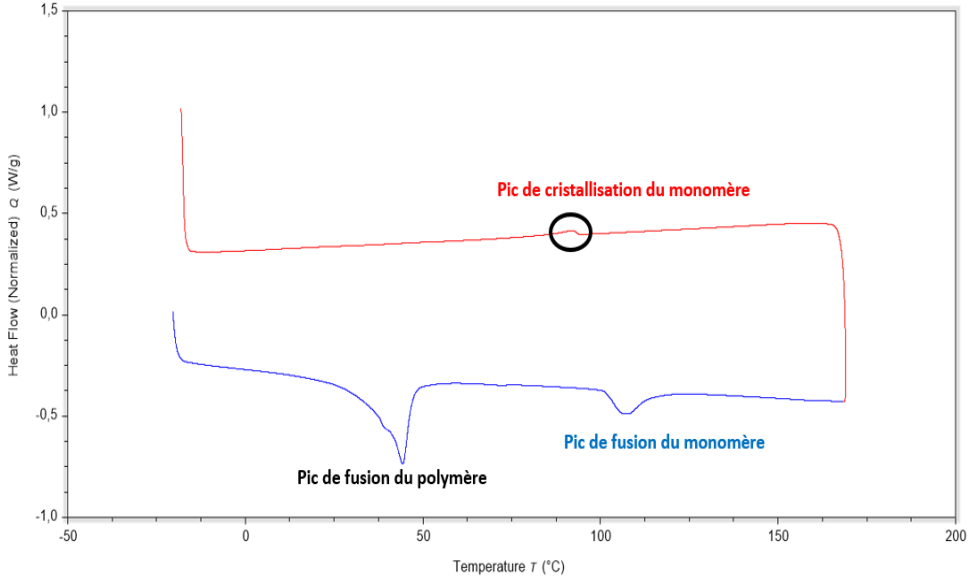
To estimate the polymerisation rate :
Characterization of the sample before and after the alpha irradiation by Differential Scanning Calorimetry (DSC)

Differential Scanning Calorimetry

Before Irradiation

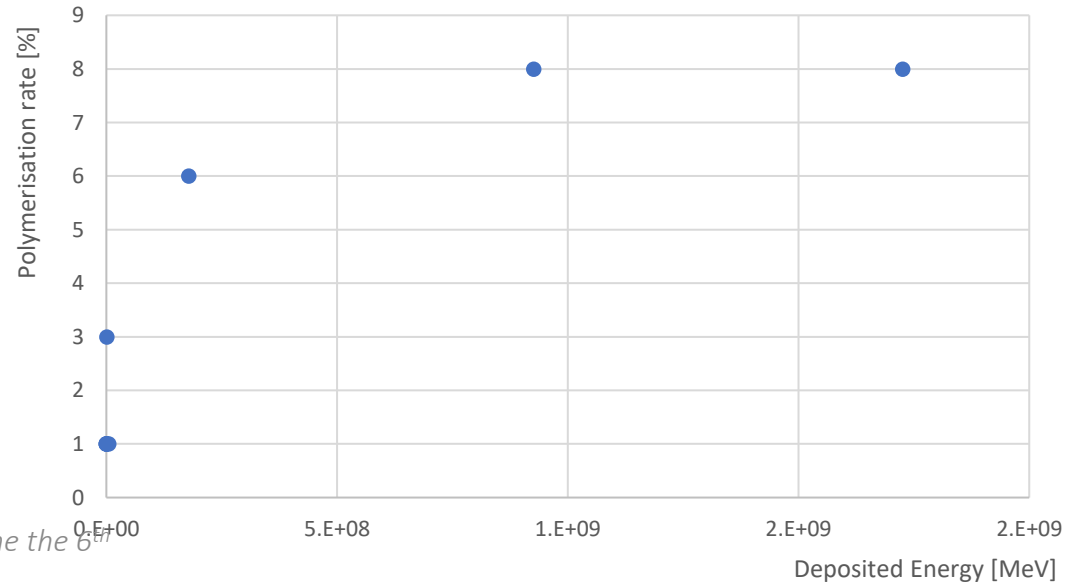


After irradiation

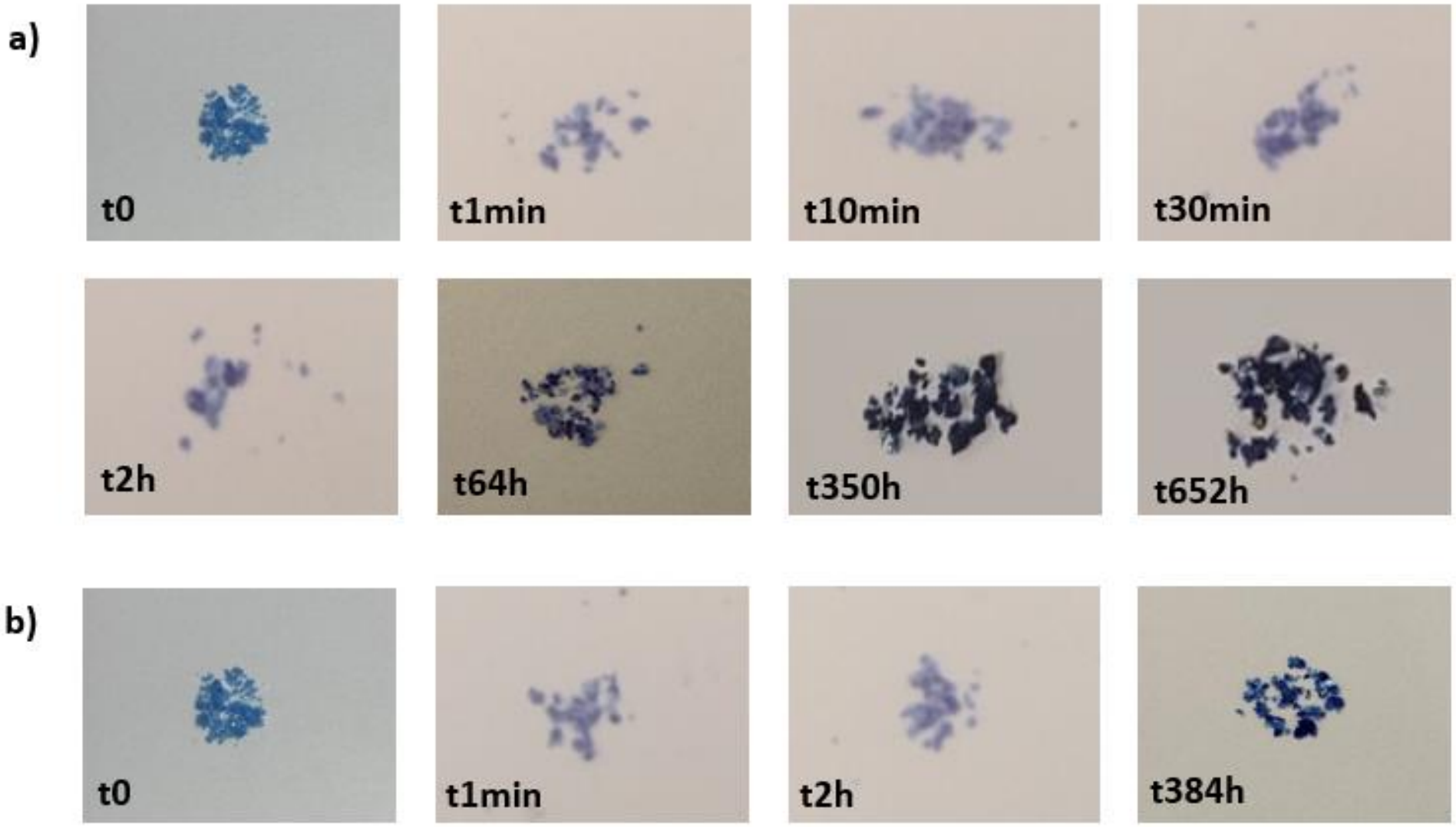


DSC : thermal analysis technique. It measures the difference of heat exchange between the sample and a reference => enthalpy.
The area of the monomer melting peak is linked to the amount of monomer present in the sample.

$$Polymerisation\ rate = \left(\frac{\Delta_{fus}H_0 - \Delta_{fus}H_t}{\Delta_{fus}H_0}\right) X\ 100$$

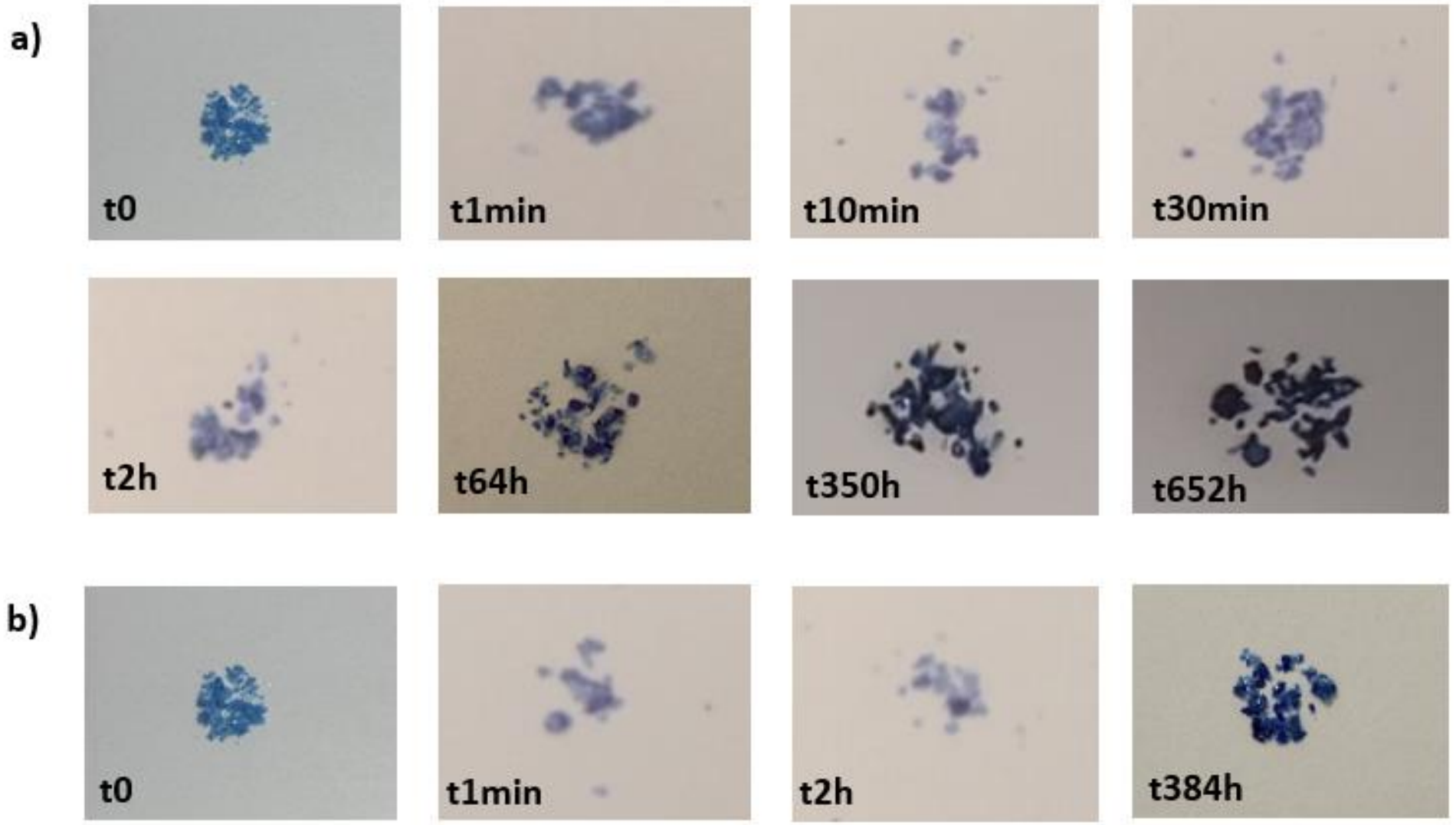


Preliminary Results – source # 1



a) source-to-sample distance of 1 mm; b) source-to-sample distance of 20 mm

Preliminary Results – source # 2



a) source-to-sample distance of 1 mm ; b) source-to-sample distance of 20 mm

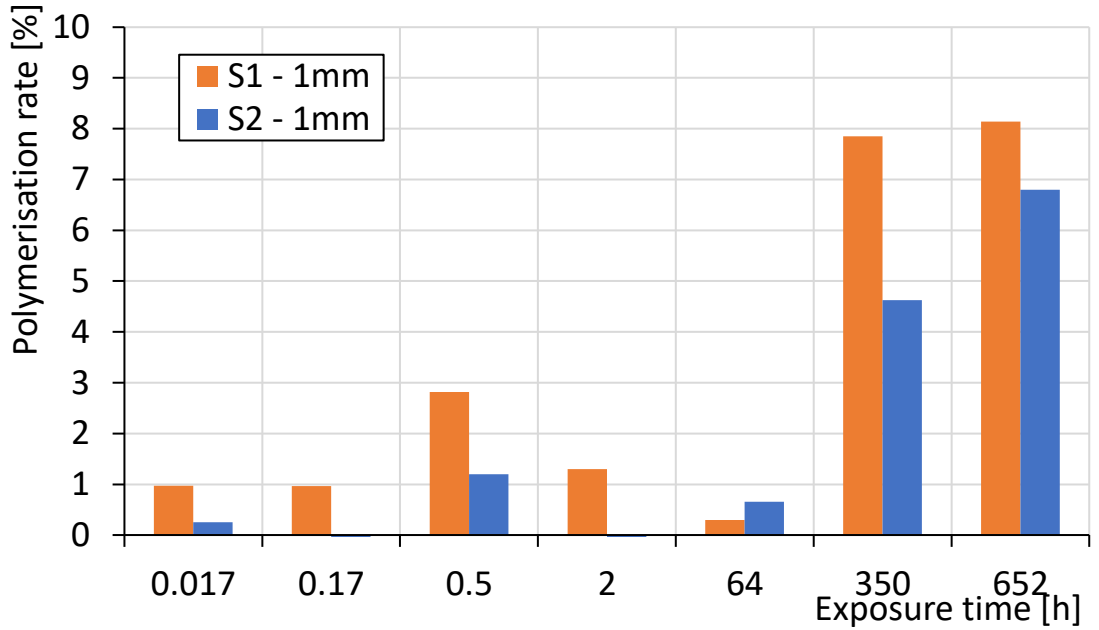
Preliminary results

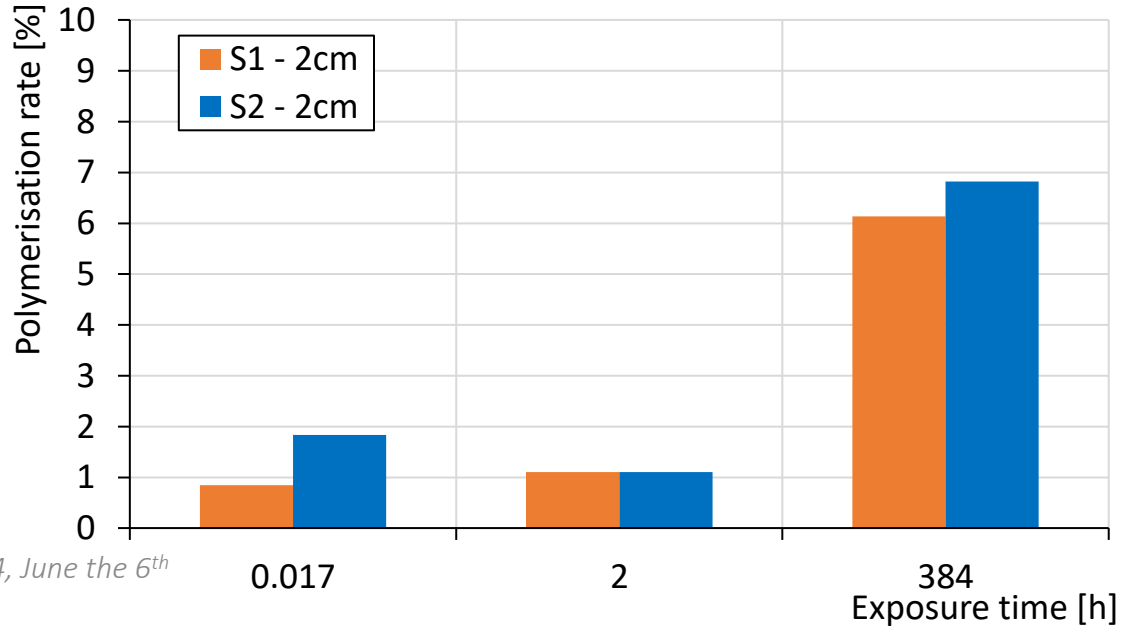
Source	Polymerisation rate [%]	Exposure time [h]
Alpha « S1 »	**8**	350 (~14 j)
Alpha « S2 »	**5**	350 (~14 j)

The polymerisation of 6-BU monomers is confirmed but slow :

- **Colour change : from bluish to dark violet ;**
- **Slow** : rate < 10 % ;
- Best result for S1 at 1 mm distance.

Need to speed up the polymerisation reaction to be able to observe the colour change in real-time

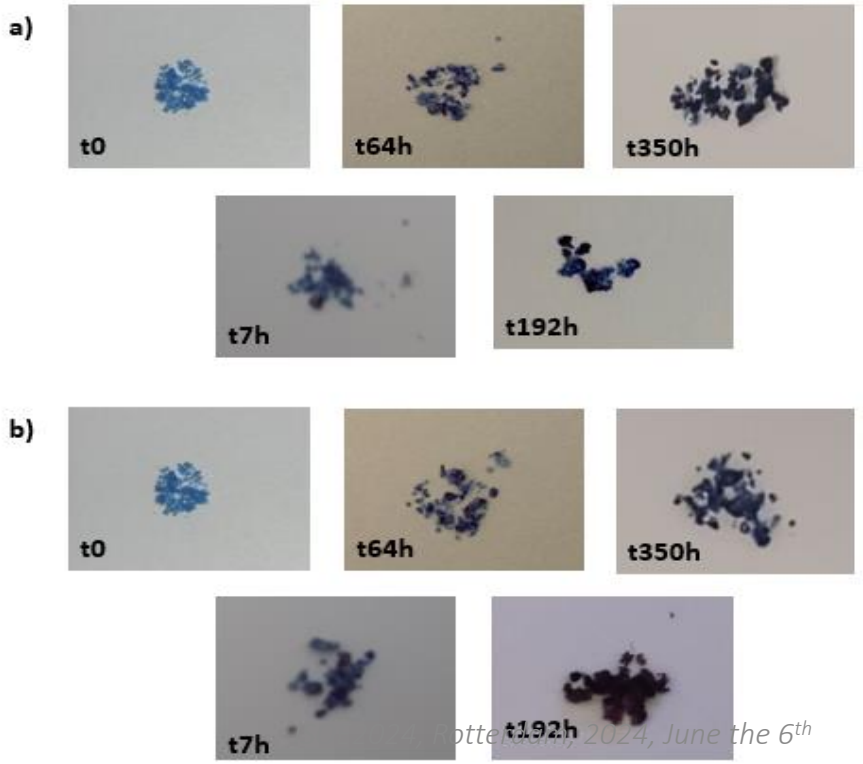




Catalyst

Distance source-to-sample of 1 mm

Source	Polymerisation rate [%]	Exposure time [h]
Alpha « S1 » without catalyst	8	350 (~14 j)
Alpha « S1 » **with** catalyst	**7**	**7**
Alpha « S2 » without catalyst	5	350 (~14 j)
Alpha « S2 » **with** catalyst	**8**	**7**



w/t catalyst

with catalyst

w/t catalyst

with catalyst

Gain in polymerisation rate : 50-fold

Conclusions

- ❑ **Polymerisation of 6-Bu monomers upon alpha irradiation is demonstrated**
- ❑ **The reaction is slow (< 10 % after 2 weeks)**

- ❑ **Catalyst** : the preliminary essays show a 50-fold gain in the polymerisation rate with the catalyst

Perspectives

Fine characterisation of the polymerisation reaction as a function of :

- ❑ Source : other than 241Am; other distances, behaviour upon beta and gamma irradiation (background)
- ❑ Catalyst: type and method of incorporation;
- ❑ Development of a POC embarking the 6-BU;
- ❑ …

Thank you for your attention