Update on dRICH gas system

dRICH Office

September 10th, 2025

Silvia Dalla Torre and Fulvio Tessarotto

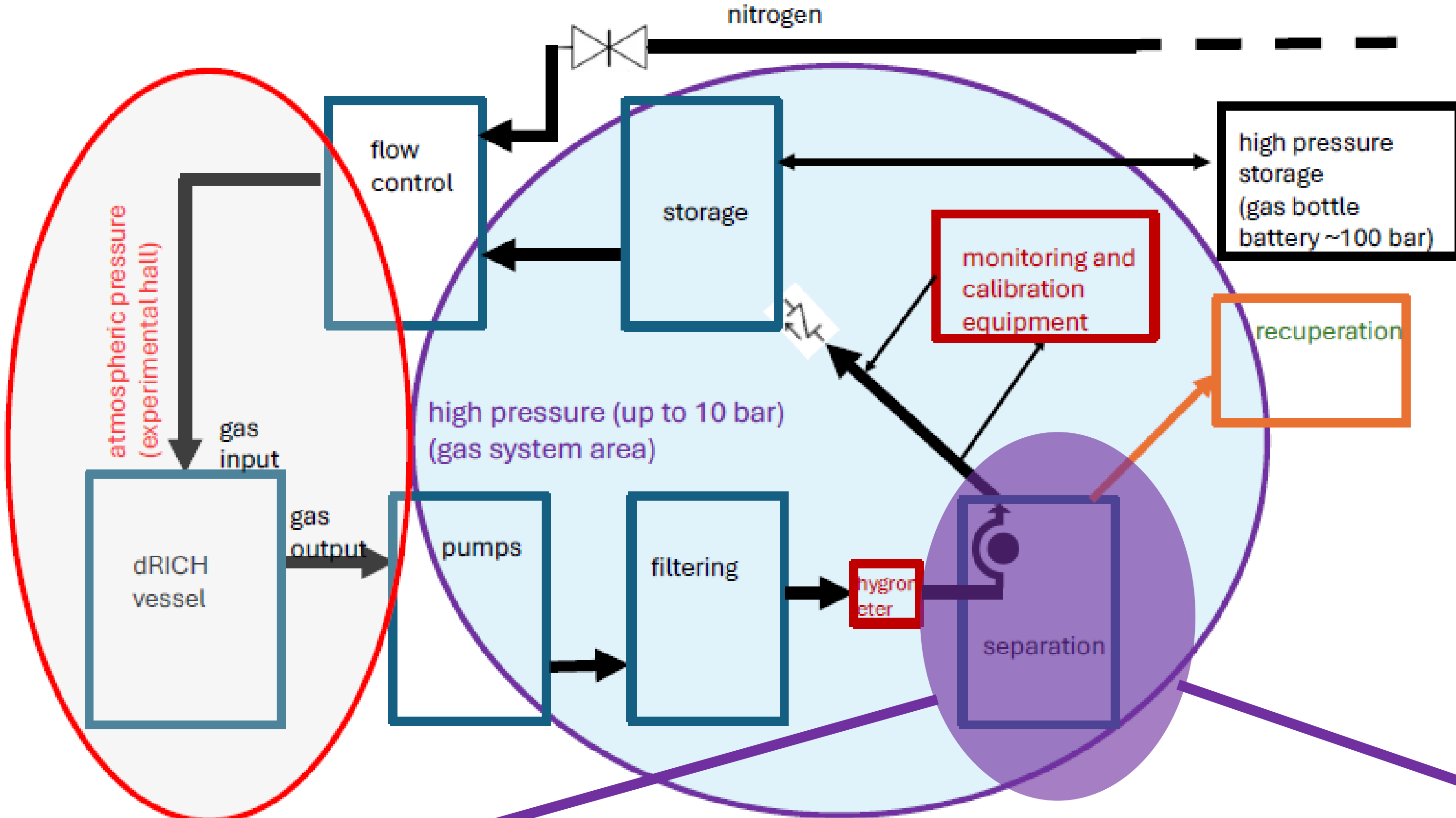
Update on dRICH gas system

Studies of C_2F_6 – CO_2 separation via membranes

Studies of C_2F_6 scintillation and chemical properties

Studies of C_2F_6 – CO_2 separation via membranes

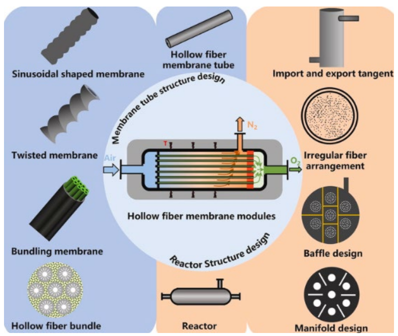
Block diagram of the dRICH gas system

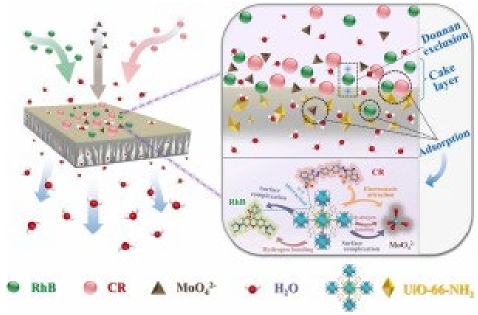


Studies for a possible separation system

Selective permeability

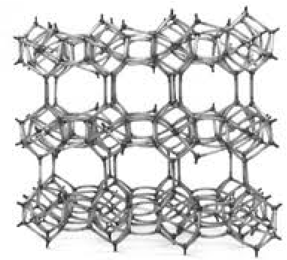
Polymeric Membranes
Polyimides, Polysulfones,
Polyethylene or Polypropylene

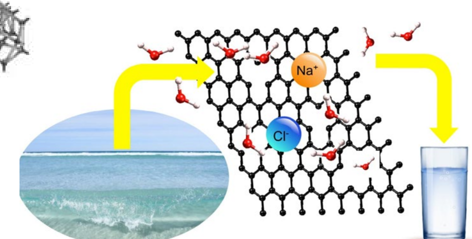




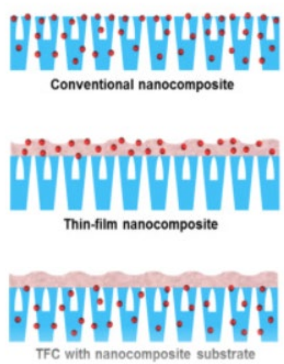
Inorganic Membranes
Zeolites , 4A & 5A, CMS

Mixed Matrix Membrane
Composite Membranes
Polymer & inorganic



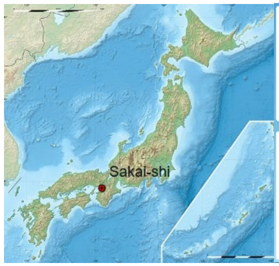


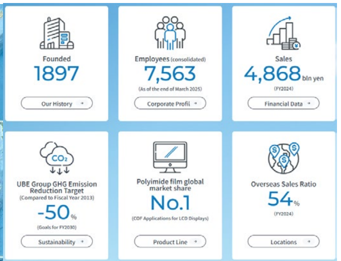
Nanocomposite Membranes



Graphene-based membranes
1. Monolayer Graphene Membranes
2. Graphene Oxide (GO)
3. Graphene-Based Composite Membranes
4. Graphene Nanopore Membranes

UBE membranes





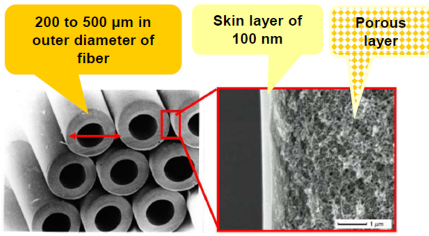
History of UBE's Membrane Business

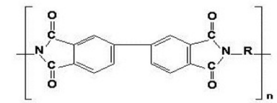
UBE Corporation
CS-001E_REV.K_250717
As a reference

- 1978 Started R&D Work
- 1981 Jointed MITI's C1 Project (National Project)
- 1983 First Membrane for H_2
  Field Tests at Ammonia Plant for H_2 Recovery
- 1985 Organized Membrane Dept.
- 1986 Supply First H_2 Recovery Unit
- 1989 First Membranes for CO_2 & Dryer
- 1989 First Membrane for Dehydration
- 1992 First Membrane for N_2/O_2 Separation
- \- Improving Membranes and Modules
- 2007 2nd Hollow Fiber Line in Ube City facility
  Module Assembly Line in Sakai.
- 2008 3rd Hollow Fiber Line in Ube.
- 2025 4th Hollow Fiber Line in Ube.
  Expansion in the Module Assembly facility in Sakai.

Polyimide Hollow Fiber Membranes

UBE Corporation
CS-001E_REV.K_250717
As a reference





BPDA-based polyimide

Permeation rate to gases in polyimide membrane

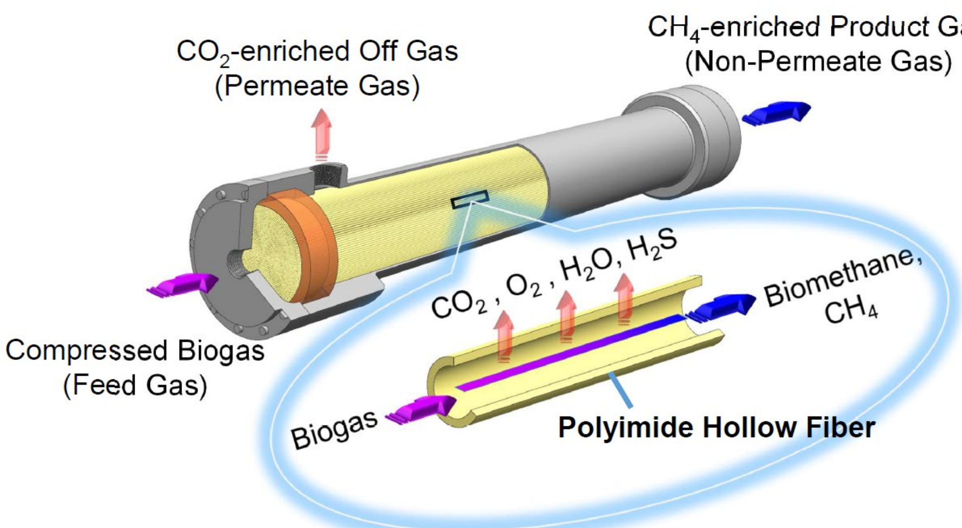
High permeation	↑	H_2O
		H_2 He
dependent on solubility and molecule size		CO_2 H_2S
		O_2
		CO Ar
Equilibrium + Kinetic Separ.		N_2 CH_4 C_2H_5OH
		C_2H_6
Low		C_3+ Hydrocarbons

Benefits of BPDA-based polyimide as material for hollow fiber membrane

1) Good balance for permeability and selectivity
2) Good mechanical property
3) Excellent heat resistance
4) Good chemical resistance
5) Excellent lifetime
6) Easy to make fiber and thin skin layer

Module Structure - CO_2 Separator

UBE Corporation
CS-001E_REV.K_250717
As a reference



- Product Specification and Features

Hollow Fiber	Polyimide Resin
Housing	Aluminum
Operating Pressure	Housing type - Max. 1.4 MPaG Cartridge type - Max. 2.4 MPaG
Operation Temperature	up to 60°C
H_2S resistance up to 3 vol %	

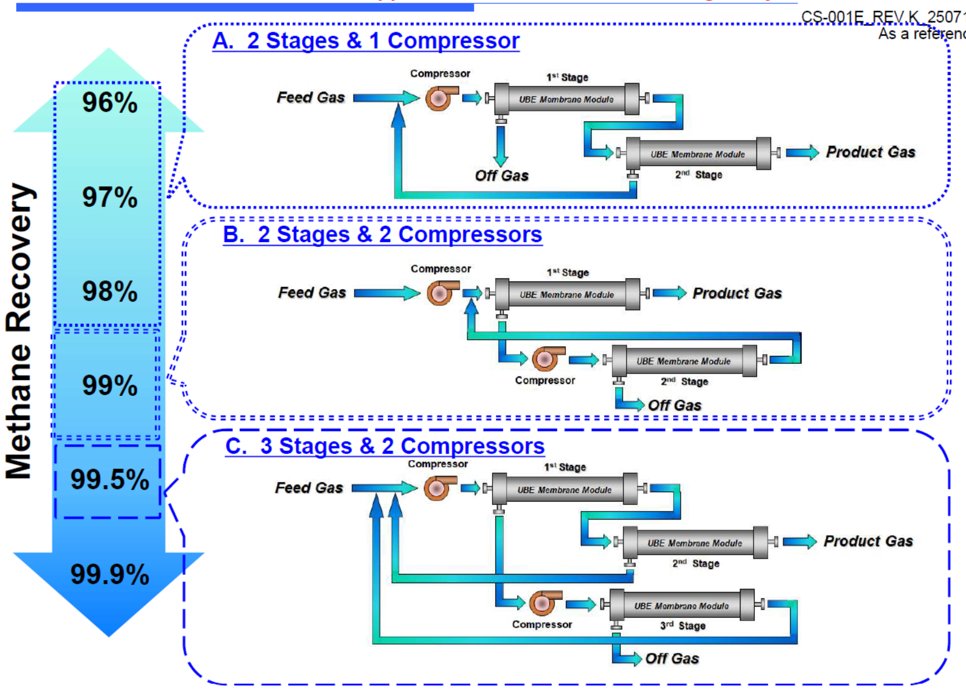
Biogas applications

System Configuration of Membranes **

**UBE supplies membrane module/cartridge only.

UBE Corporation

CS-001E_REV.K_250717
As a reference

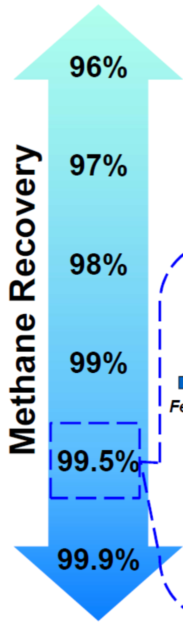


New System Configuration of Membranes **

**UBE supplies membrane module/cartridge only.

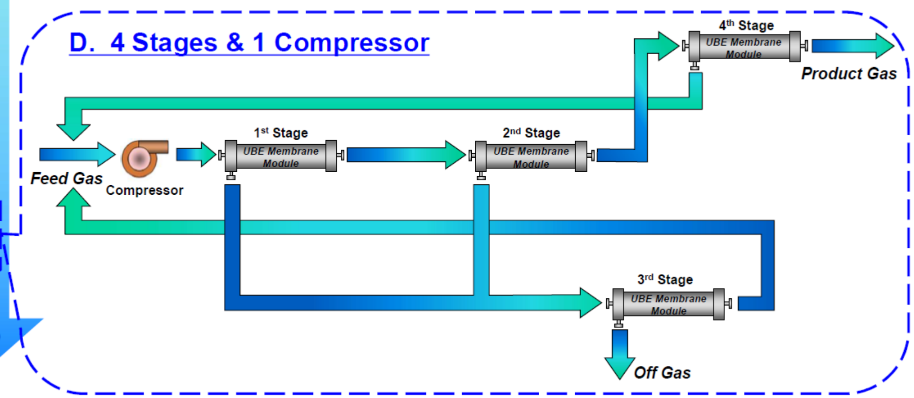
UBE Corporation

CS-001E_REV.K_250717
As a reference



Competitive Advantages

- 99.5 % recovery & 99.0 % purity CH_4, all in one go.
- Save energy with just one compressor.
- Big savings especially for small scale plants.



Feed Gas Flow Rate : 600 Nm^3/h (at 0 °C, 1013 mbara)

Feed Gas Composition : CO_2 40 %, CH_4 60 %

Product Gas Purity : CO_2 < 1 %

Operating Temperature : 25 °C (77 °F)*

*Maximum allowable temperature is 60 °C (140 °F).

UBE membranes

UBE CO_2 Separator Lineup

UBE Corporation

CS-001E_REV.K_250717
As a reference

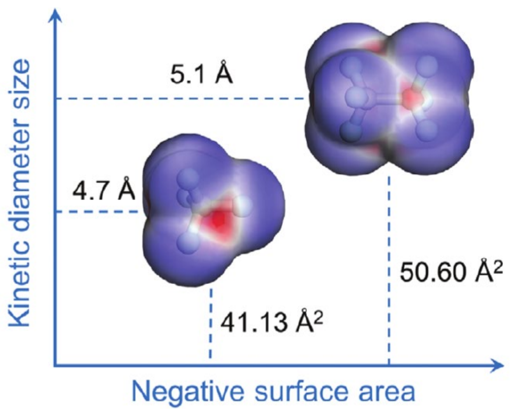
	Model: High Permeability Membrane	Model: High Selectivity Membrane	PED Classification	Max. Operating Conditions	Weight (kg)	Dimensions (mm)
with housing type	CO-0302NFS (1)	CO-0302SES (1)	Art. 4 par. 3	60 °C 24 barg	1.7	Φ 47mm; L 380mm
with housing type	CO-C07F	CO-C07FS	Art. 4 par. 3	60 °C 16 barg	4.2	Φ 109mm; L 800mm
with housing type	CO-510F	CO-510FS	Category I (CE Mark)	60 °C 16 barg	16	Φ 180mm; L 1,080mm
with housing type	CO-710F	CO-710FS	Category I (CE Mark)	60 °C 10.4 barg(CO-710F) 9.6 barg(CO-710FS)	33	Φ 244mm; L 1,080mm
without housing type (2) (cartridge type)	CC-1610NFH	CC-1610SEH	N/A (w/o housing)	60 °C 24 barg	19	Φ 175mm; L 1,030mm; Φ 175mm
without housing type (2) (cartridge type)	CO-810FC	CO-810FSC	N/A (w/o housing)	60 °C 24 barg	23	Φ 239mm; L 1,026mm; Φ 249mm
without housing type (2) (cartridge type)	CC-2015NFH	-	N/A (w/o housing)	60 °C 24 barg	30	Φ 239mm; L 1,526mm; Φ 239mm

(1) Mainly for testing purpose
(2) Customer needs to procure the housing. UBE supports a design of the housing.

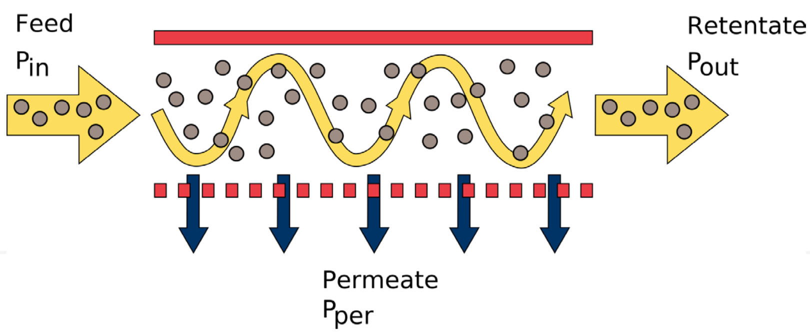
7

C_2F_6 - CO_2 permeability separation

CF4 and C2F6 Kinetic diameters



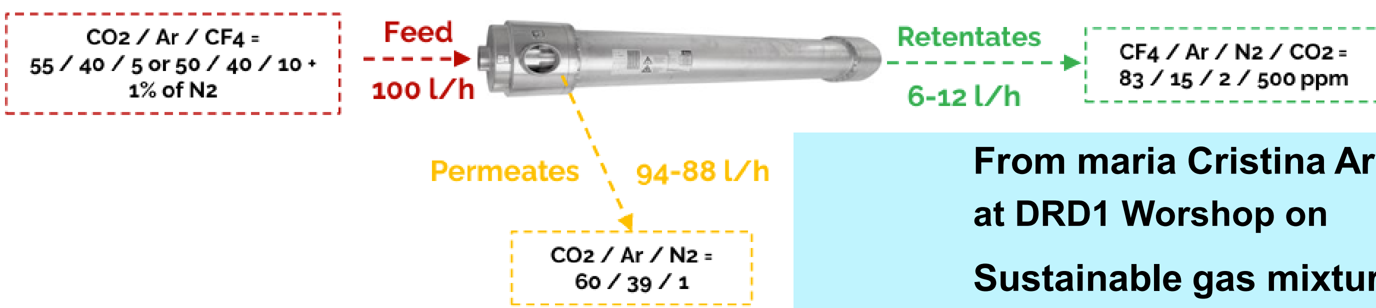
use of membranes optimized for CO_2



EP-DT
Detector Technologies

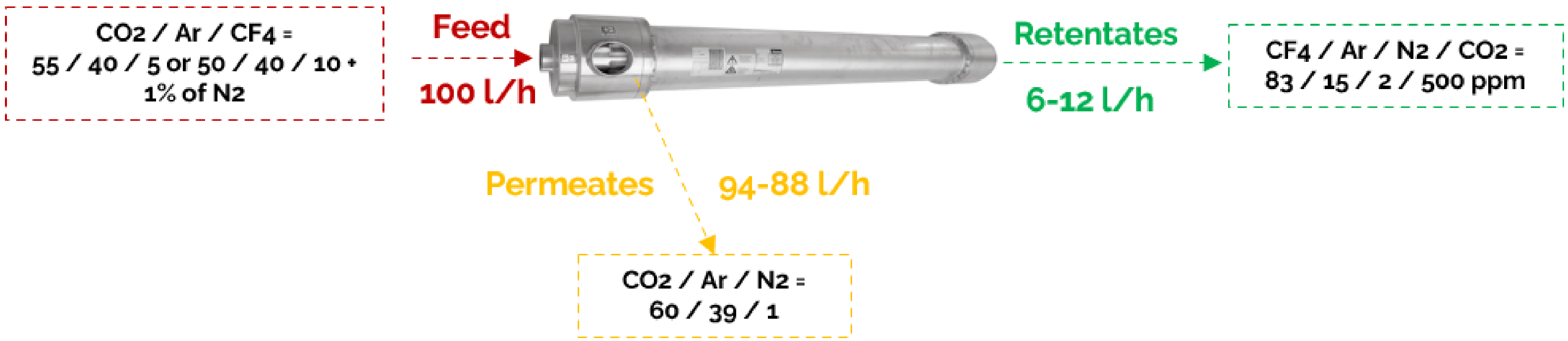
CMS CSC recovery system for CF4

Phase 1 → CO_2 separation



From maria Cristina Arena presentation at DRD1 Worshop on Sustainable gas mixtures for future detectors

Tests with C_2F_6



Example from Cristina Arena measurement using an UBE membrane also available for our tests:

Composition input flow l/h				
CF4	CO2	Ar	O2	N2
21	214	157	0.6	7.920

Compositon retentates flow l/h				
CF4	CO2	Ar	O2	N2
15	0.06	1	0.000	0.1

We plan a first test in October-November at CERN with C_2F_6 (and then purchasing new membranes for ePIC)

Studies of C_2F_6 scintillation and chemical properties

Collaboration with Belgrade

Letter of Agreement

for the study of C_2F_6 and C_4F_{10} molecular properties

BETWEEN

the "Trieste Section of INFN"

AND

the "Institute of General and Physical Chemistry, Belgrade University",

1. Scope of the agreement

On request of the Trieste team participating in the ePIC experiment at BNL (USA), the Trieste Section of INFN and the Institute of General and Physical Chemistry, Belgrade University, will perform a joint investigation of the properties of hexafluoro-ethane and perfluoro-butane molecules to determine their:

- excitation states, light emission and absorption probabilities, in particular the scintillation probability in the visible range,

- kinetic diameter of the molecules, and other chemical properties relevant for the selective permeability of membranes,

- the refractive index for the wavelength range between 200 nm and 900 nm,

- the properties of gas mixtures of hexafluoroethane and nitrogen.

- the properties of gas mixtures of hexafluoroethane and carbon dioxide.

Molecule chemical simulation study

Jelena Jovanovic and Nebojsa Begovic have performed dedicated calculations for C_2F_6

Photon interaction with C_2F_6 calculate by XCOM program
(National Institute of Standards and Technology)

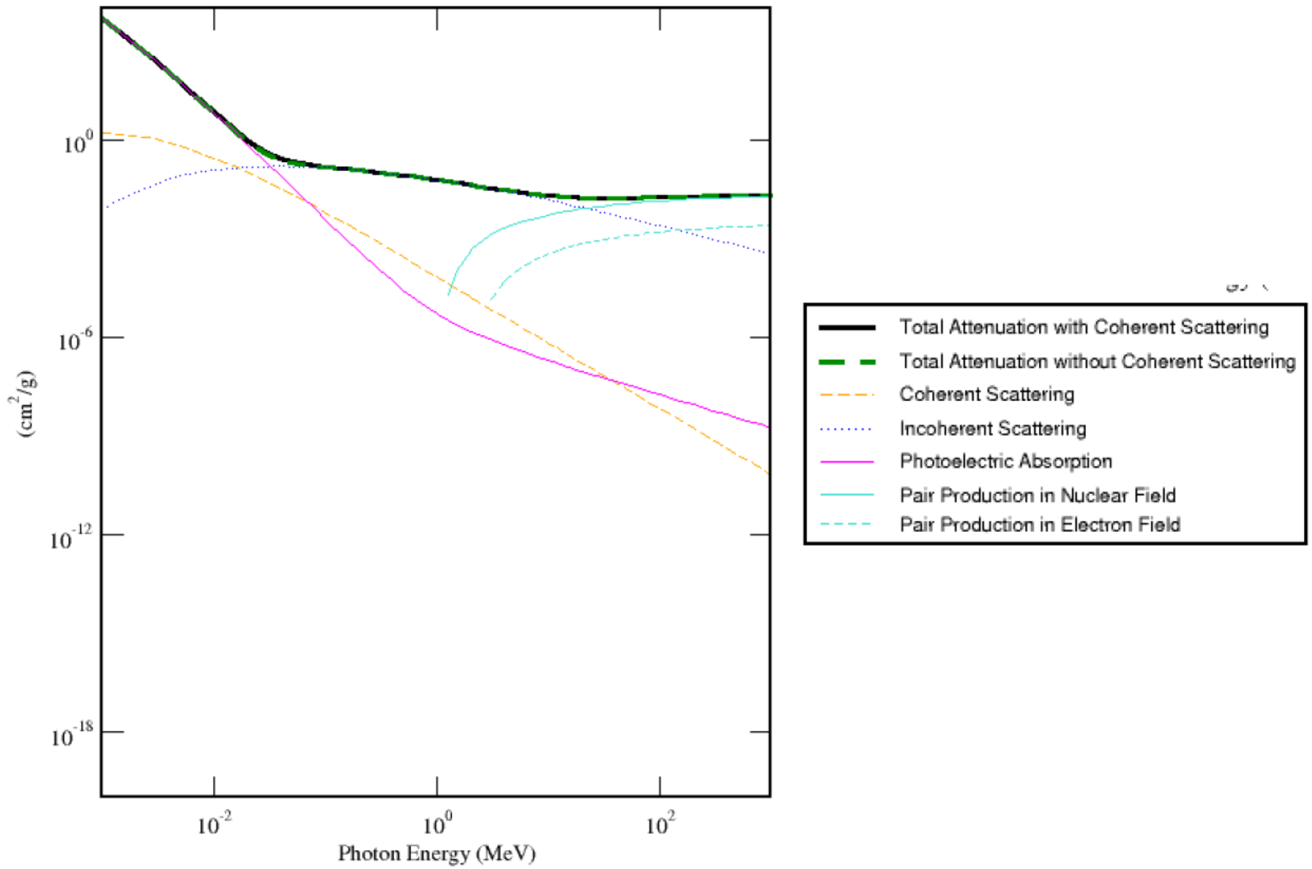
J.J. & N.B.
IOFH (GIPC)

A computer program and data base can be used to calculate, on a personal computer, photon cross sections for scattering, photoelectric absorption and pair production, as well as total attenuation coefficients, in any element, compound, or mixture, at energies from 1 keV to 100 GeV.

Cross sections: photons

Cross-section for photons on C_2F_6

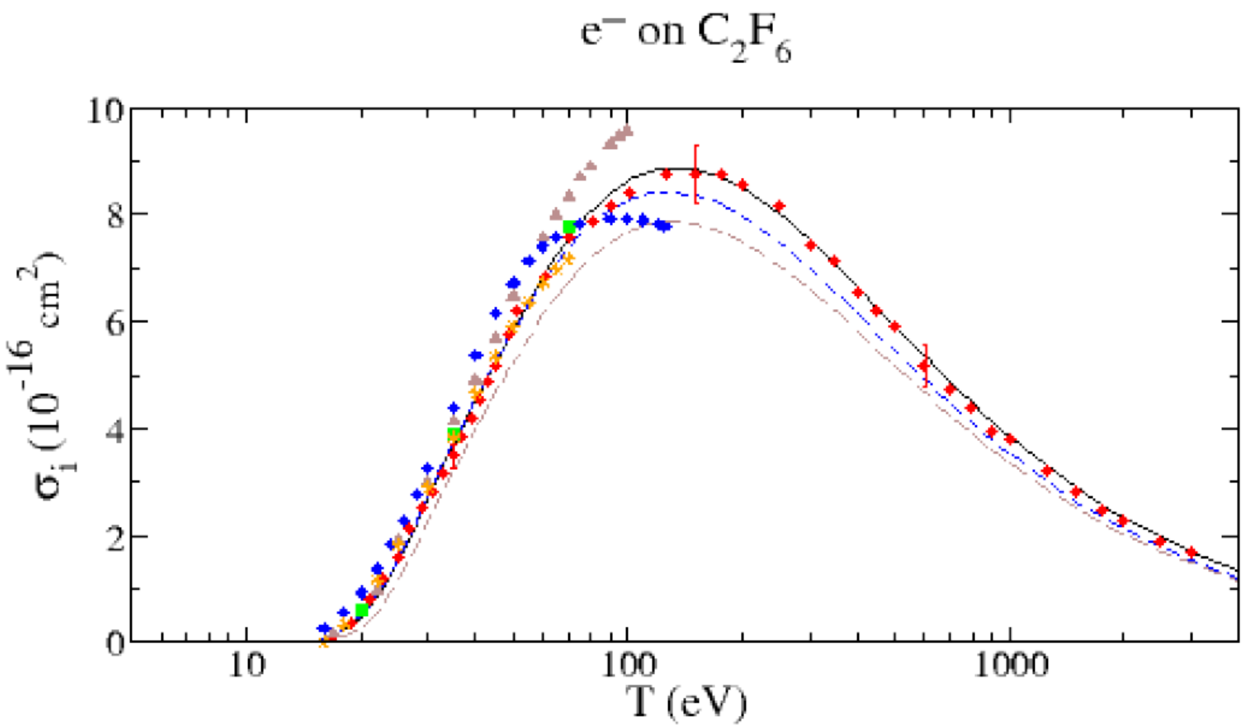
Result from XCOM calculation for C_2F_6



Cross sections: electrons

Cross-section for low-energy electrons on C_2F_6

Data from NIST data base for cross section for ionization end **excitation**

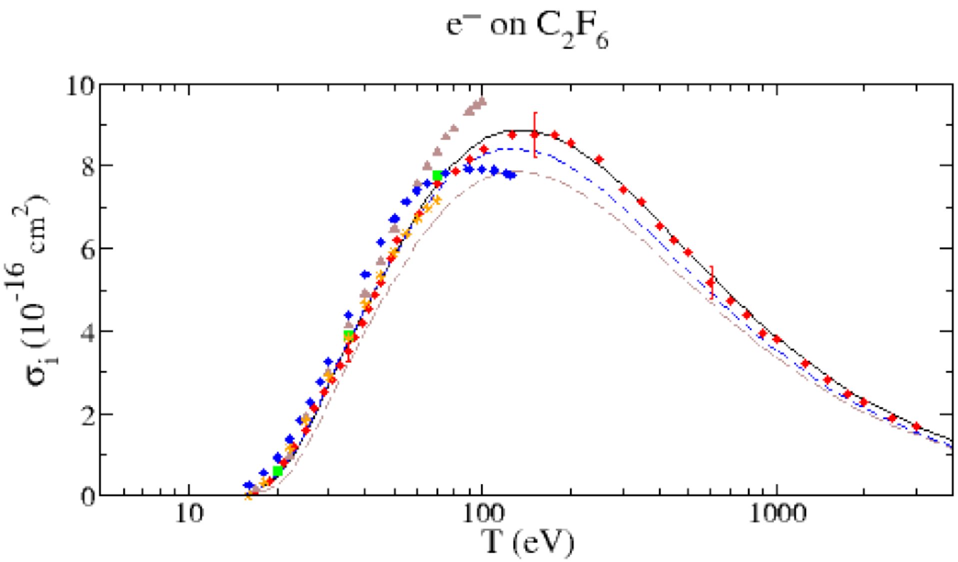


* Black curve could be calculated by **QC**

Cross sections: electrons

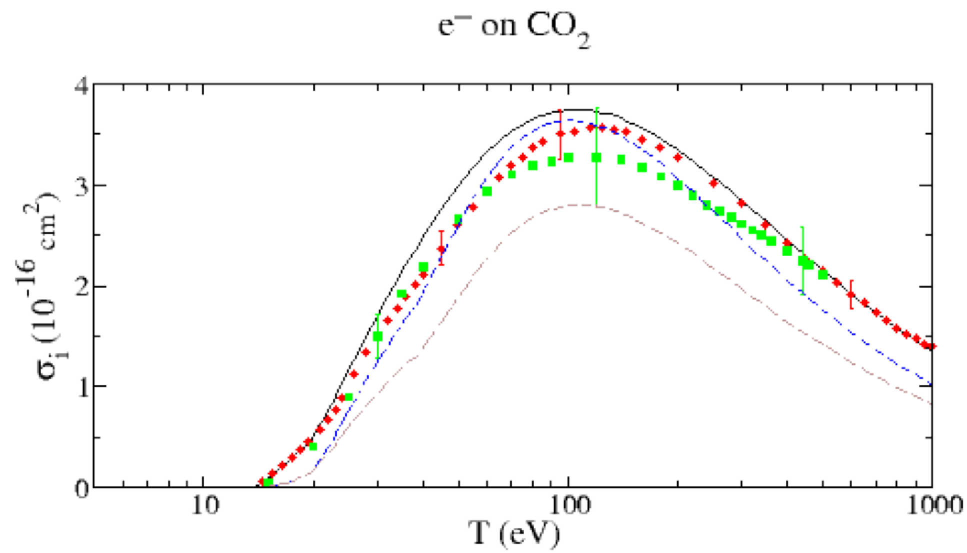
Cross-section for low-energy electrons on C_2F_6 and CO_2

Data from NIST data base for cross section for ionization end **excitation**



* Black curve could be calculated by **QC**

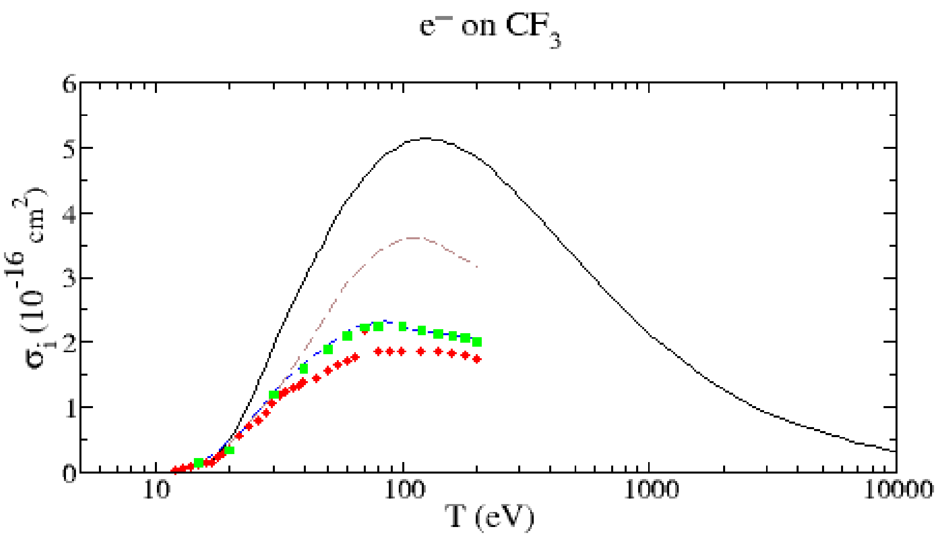
Comparison of experimental (points)and calculated (curve) values

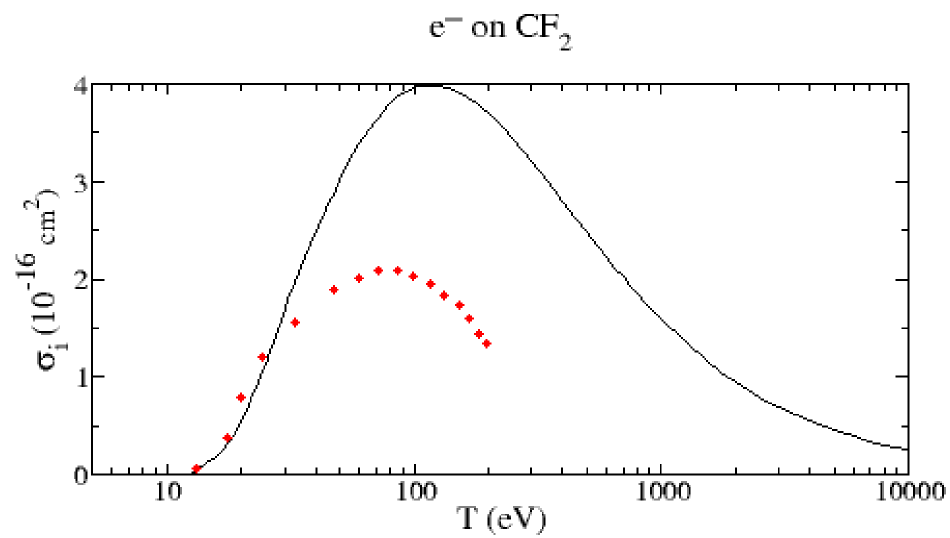


* Black curve could be calculated by **QC**

Cross sections: electrons on fragments

Cross-section for low-energy electrons on CF_3 and CF_2





Evaluation of C2F6 degradation applying QC calculations

NB & JJ ; IOFH

For all calculations used ***ORCA*** package, with ***aug-cc-pvdz*** basis set and perform calculation at ***B2PLYP*** double-hybrid theoretical level (combination of ***DFT*** and ***MP2*** methods)

We recheck all calculations presented in previous presentation:
Three main processes :

IP *ionization*
EA electron abstraction
EXC *excitation*

C_2F_6 excitation and ionization

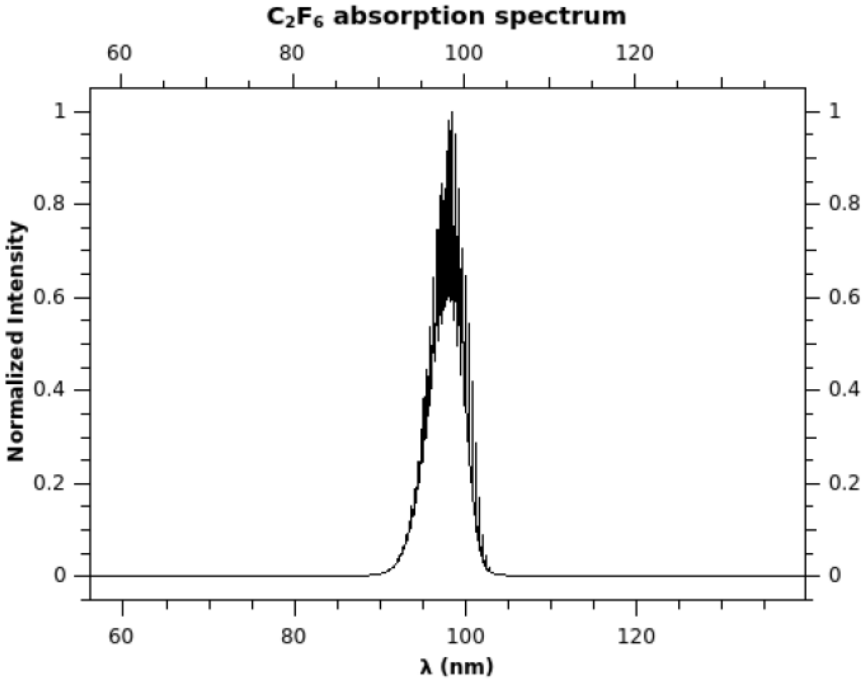
Reaction schema for C_2F_6 molecule degradation

$[C_2F_6] \rightarrow$ *IP* $\rightarrow CF_3^{½} + CF_3^{1/2}$ => $CF_3^{+} + \cdot CF_3$

$[C_2F_6] \rightarrow$ *EA* $\rightarrow \cdot C_2F_5 + F^{-}$

$[C_2F_6] \rightarrow$ *EXC* $\rightarrow \cdot CF_3 + \cdot CF_3$

$[C_2F_6]$ absorption spectra



C_2F_5 excitation and emission

Reaction schema for $\cdot C_2F_5$ molecule degradation

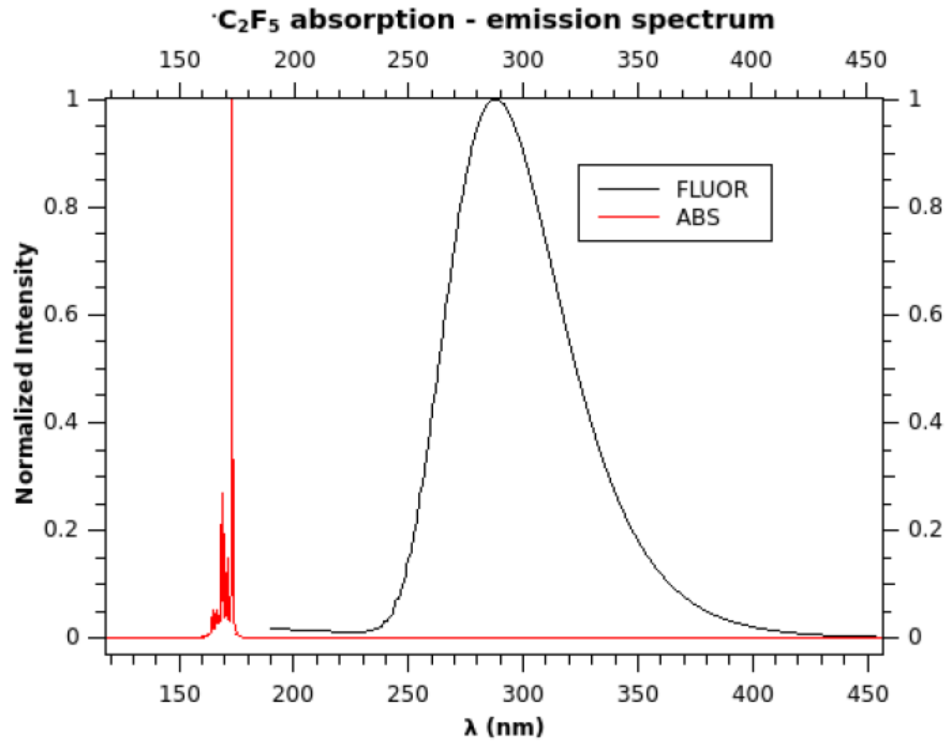
$$[\cdot C_2F_5] \rightarrow IP \rightarrow [C_2F_5]^+$$

$$[\cdot C_2F_5] \rightarrow EA \rightarrow [C_2F_5]^-$$

$$[\cdot C_2F_5] \rightarrow EXC \rightarrow [\cdot C_2F_5]^*$$

The calculated fluorescence rate constant is 3.926436e+07 s-1 with 24.73% from FC and 75.27% from HT

Tau=2.55E-08 s



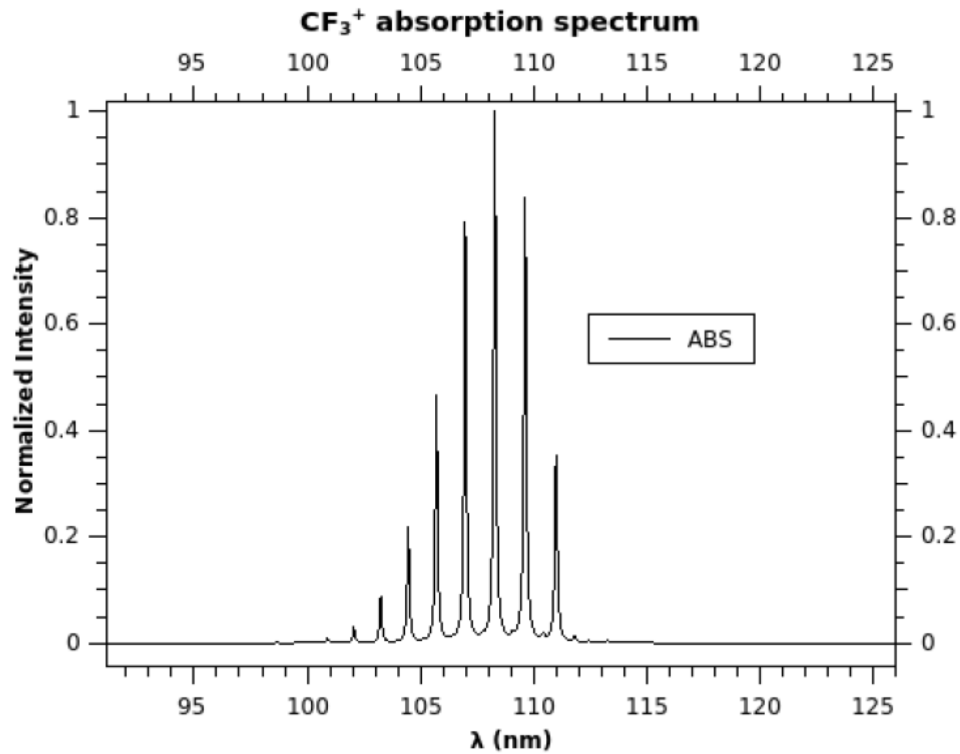
CF_3^+ excitation and emission

Reaction schema for CF_3^+ molecule degradation

$[\ CF_3^+\ ] \rightarrow\ IP \rightarrow\ [\ \cdot CF_3\ ]^{2+}$

$[\ CF_3^+\ ] \rightarrow\ EA \rightarrow [\ \cdot CF_3\ ]$

$[\ CF_3^+\ ] \rightarrow EXC \rightarrow \cdot CF_2^+\ +\ \cdot F$



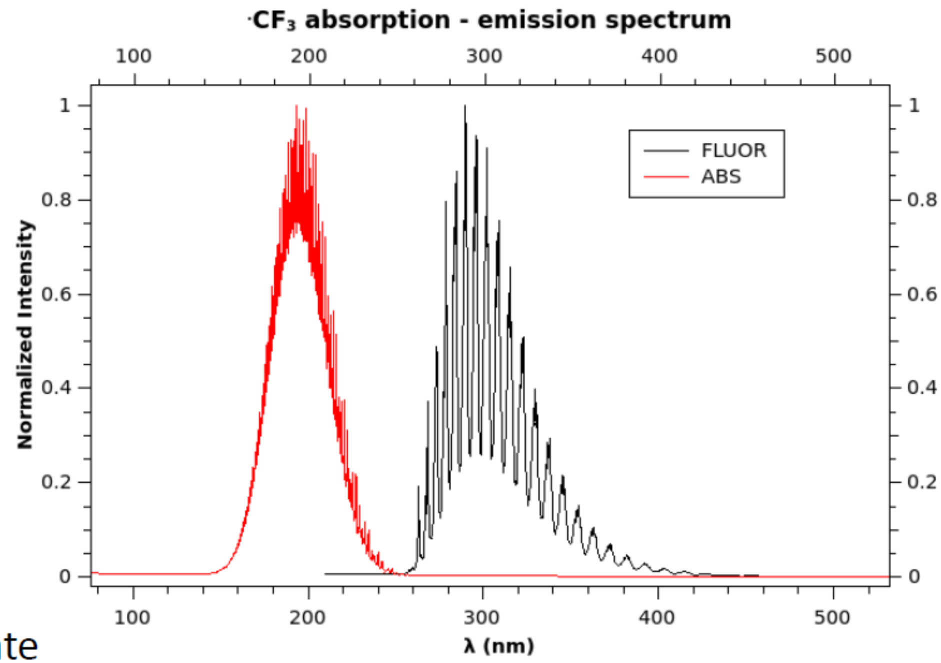
$\cdot CF_3$ excitation and emission

Reaction schema for $\cdot CF_3$ molecule degradation

$[\cdot CF_3] \rightarrow IP \rightarrow [CF_3]^+$

$[\cdot CF_3] \rightarrow EA \rightarrow [CF_3]^-$

$[\cdot CF_3] \rightarrow EXC \rightarrow [\cdot CF_3]^*$



The calculated fluorescence rate constant is 1.097213e+07 s-1 with 66.77% from FC and 33.23% from HT

Tau= 9.11E-08 s

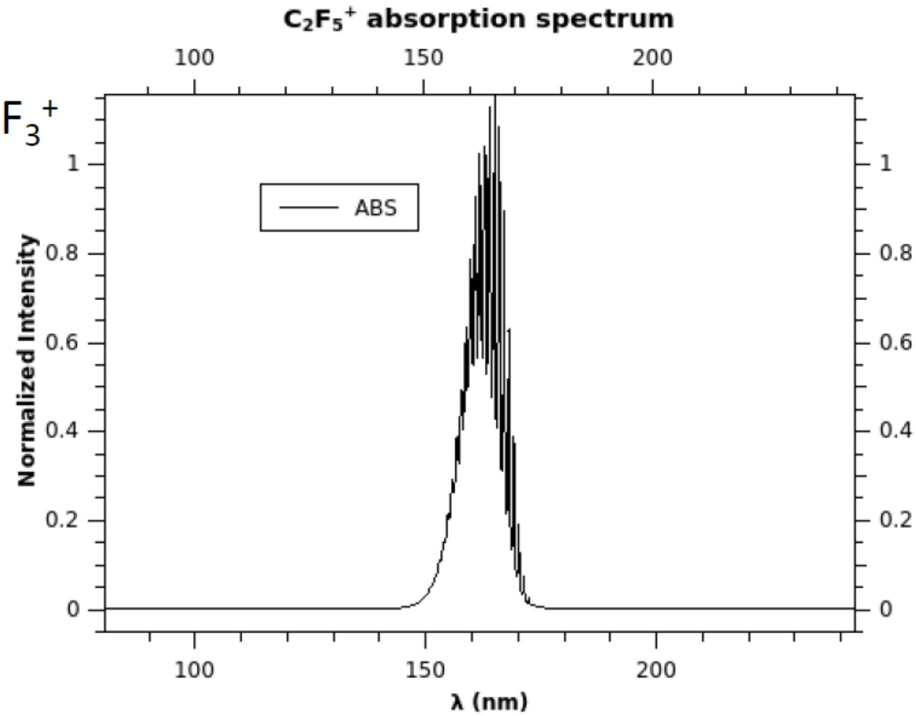
$C_2F_5^+$ excitation

Reaction schema for $[C_2F_5]^+$ molecule degradation

$[C_2F_5^+] \rightarrow IP \rightarrow [\cdot C_2F_5]^{2+} \rightarrow \cdot F + C_2F_4^{2+}$

$[C_2F_5^+] \rightarrow EA \rightarrow [\cdot C_2F_5]$

$[C_2F_5^+] \rightarrow EXC \rightarrow CF_2 + CF_3^+$



$C_2F_5^-$ excitation and emission

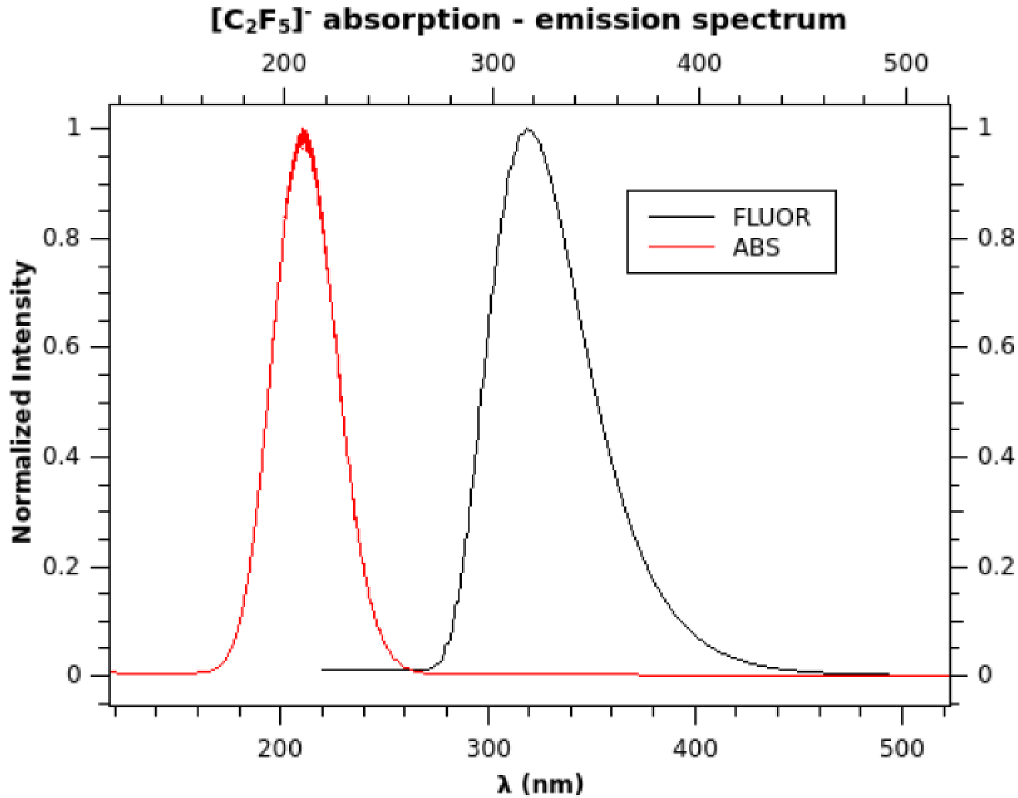
Reaction schema for $[C_2F_5]^-$ molecule degradation

$[C_2F_5^-] \rightarrow$ *IP* $\rightarrow [\cdot C_2F_5]$

$[C_2F_5^-] \rightarrow$ *EA* $\rightarrow \cdot F + C_2F_4^{2-}$

$[C_2F_5^-] \rightarrow$ *EXC* $\rightarrow [C_2F_5^-]^*$

The calculated fluorescence rate constant is 3.064903e+07 s^{-1} with 98.10% from FC and 1.90% from HT



Tau = 3.26E-08 s

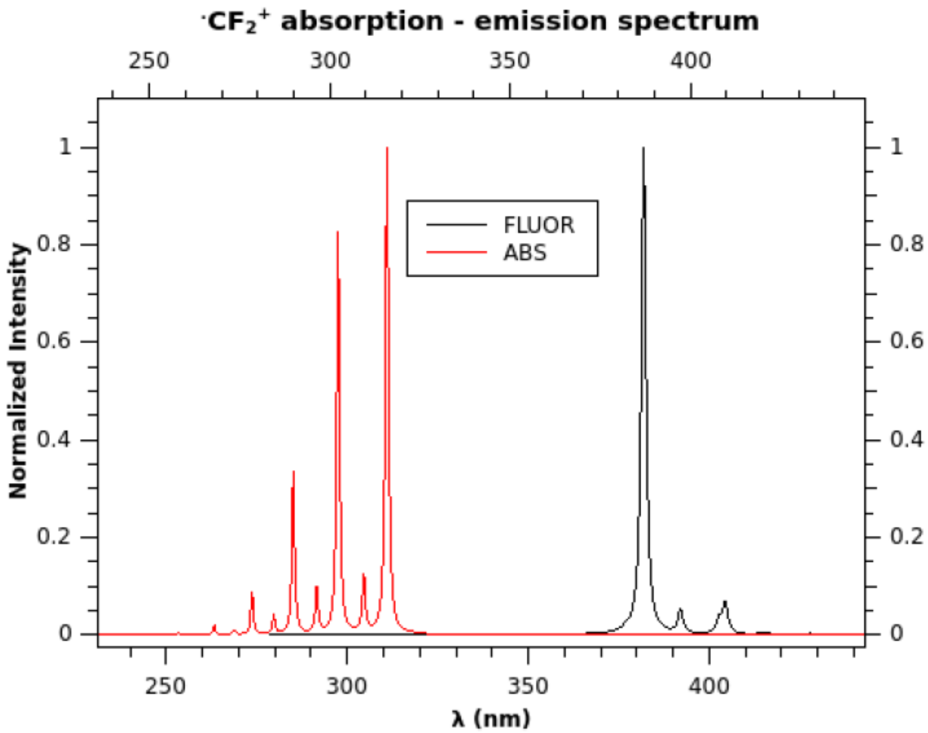
$\cdot CF2^{+}$ excitation and emission

Reaction schema for $[\cdot CF_2^{+}]$ molecule degradation

$[\cdot CF_2^{+}] \rightarrow IP \rightarrow [CF_2]^{2+}$

$[\cdot CF_2^{+}] \rightarrow EA \rightarrow [CF_2]$

$[\cdot CF_2^{+}] \rightarrow EXC \rightarrow [\cdot CF_2^{+}]^*$

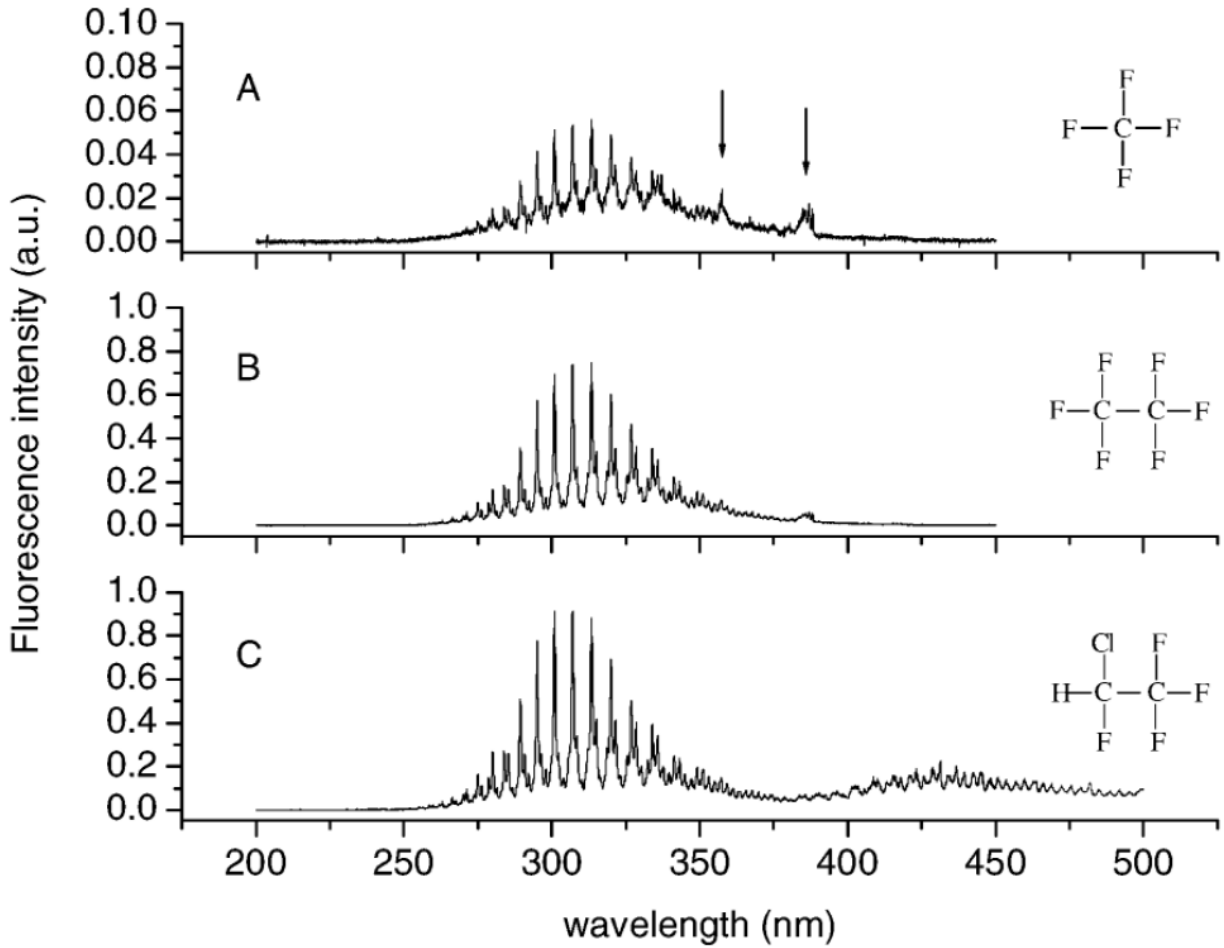


The calculated fluorescence rate constant is 4.043094e+06 s-1 with 98.65% from FC and 1.35% from HT

Tau = 2.47E-07 s

Very large fluorescence! (10×CF_4)

Experimentally obtained spectra



LHCb quenching of CF_4 scintillation

Nuclear Instruments and Methods in Physics Research A 791 (2015) 27–31

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

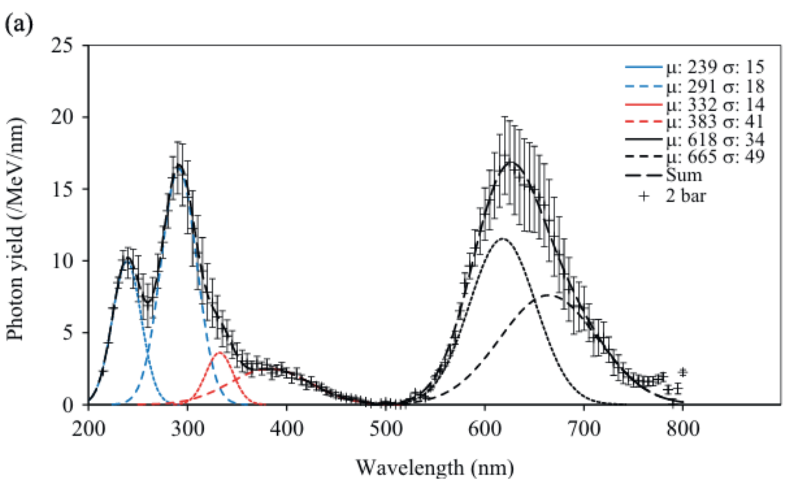
journal homepage: www.elsevier.com/locate/nima

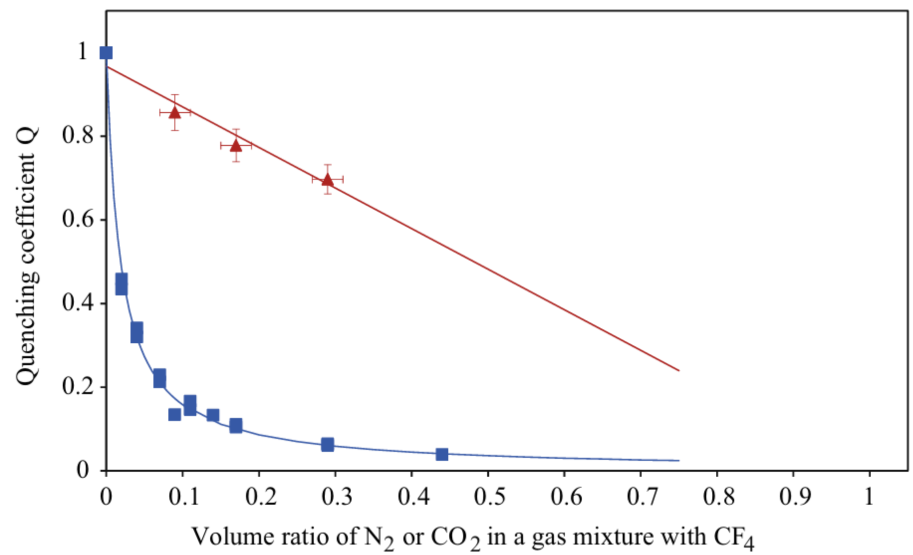
Quenching the scintillation in CF_4 Cherenkov gas radiator

T. Blake[f], C. D'Ambrosio[b], S. Easo[g,b], S. Eisenhardt[h], C. Fitzpatrick[c], R. Forty[b], C. Frei[b], V. Gibson[e], T. Gys[b], N. Harnew[j], P. Hunt[j], C.R. Jones[e], R.W. Lambert[d], C. Matteuzzi[a], F. Muheim[h], A. Papanestis[g,b,*], D.L. Perego[a,k,1], D. Piedigrossi[b], R. Plackett[i], A. Powell[j], S. Topp-Joergensen[j], O. Ullaland[b,k], D. Websdale[i], S.A. Wotton[e], K. Wyllie[b]

similar results [5]. The estimated total scintillation photon yield per MeV of energy deposited in CF_4 was about 1200 photons/MeV $\times 4\pi$ [4]. About 75% of these photons were estimated to be emitted at wavelengths in the range 220–600 nm. The scintillation in C_4F_{10} is, in comparison to CF_4, only a minor effect [5]. Our

... in 2010 the charged particle rate was higher than expected and the background became unsustainable for data taking ...





LHCb decided to add few% of CO_2 to CF_4

Conclusions

Membranes for C_2F_6 – CO_2 separation expected to be very effective

Test at CERN with UBE membrane on Oct-Nov. foreseen

Studies of C_2F_6 scintillation and chemical properties ongoing

Scintillation expected to be a potentially serious problem!

Scintillation measurement to be organized.