DE LA RECHERCHE À L'INDUSTRIE

C-BORD
EFFECTIVE **C**ONTAINER INSPECTION AT **BORD**ER CONTROL POINTS:
Development of an identification method of actinides in containers

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DE LA RECHERCHE À L'INDUSTRIE

A MULTI-DISCIPLINARY EUROPEAN CONSORTIUM*

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* http://www.cbord-h2020.eu/

OUTLINE

Project presentation

Principles & challenges

Need & availability of nuclear data

Theoretical & experimental efforts

Conclusion et perspectives

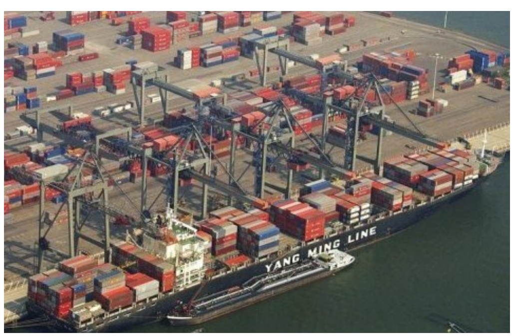
PROJECT PRESENTATION

Observation

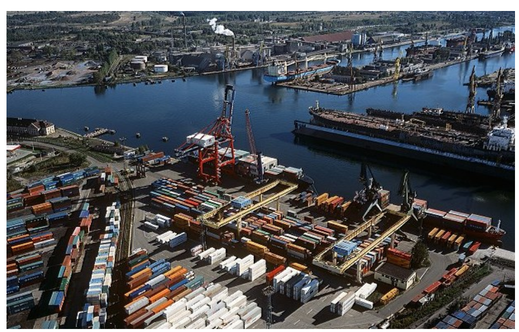
- Border security is a factor of most importance in the overall UE
- Main threats:

Objectives TRL 7

- Develop a reliable non-intrusive inspection solution
- « Inspect » container minimizing cost and time
- Reduce containers inspections by agents
- Not disrupt the current logistic flow
- Respect safety requirements



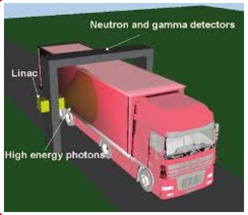
Rotterdam, Netherlands – Major Europeans harbors



Gdànsk, Poland – maritime boundaries

Hungary – land boundaries

PRINCIPLES & CHALLENGES(1)
Active photonic interrogation



Advanced photofission system

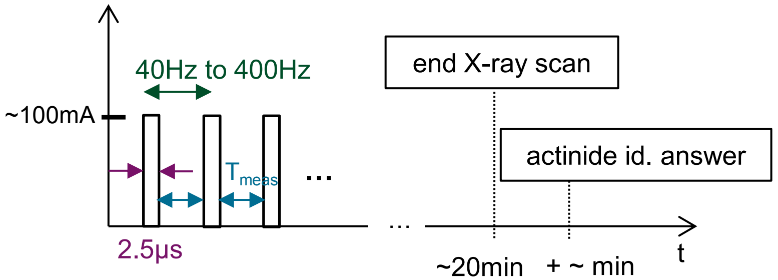
Objective

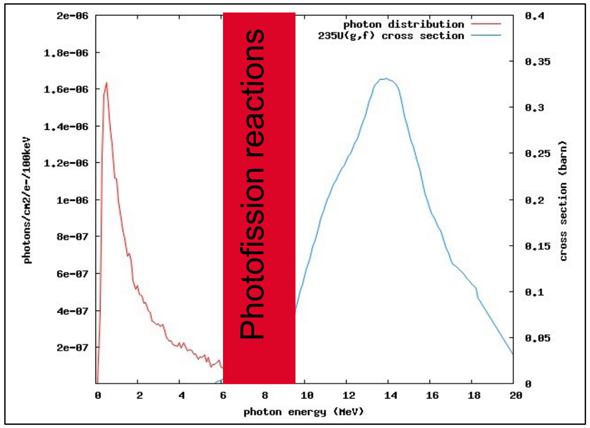
- Develop a detection and identification method of Special Nuclear Material (SNM) in containers
- targets: ^{235}U & ^{239}Pu / compared to ^{238}U

2 steps method

1. Irradiation

- Photofission reactions induced on the material
- 9 MeV X-ray generated by a linear accelerator





2. Detection

- Detection of prompt and **delayed** particles (n & **γ**) emitted by the photofission reaction (fission fragments and fission products[1])

[1]*M. Gmar et al., Proc. SPIE 6213, Non-Intrusive Inspection technologies, 62130F (30th May 2006)*

PRINCIPLES & CHALLENGES (3)
Identification method

Principle[1]

Detection of delayed γ (~150 ns<$T_{1/2}$<~3 μs) emitted by 3 fission fragments of interest → isomers ^{134m}Te, ^{135m}Te, ^{136m}Xe

- $T_{1/2}$ > 150 ns: limits the background due to the beam
- $T_{1/2}$ < 3 μs: more intense activity improves the signal-to-background ratio
- Eγ > 1 MeV : limits photon absorption by diverse materials
- Isomer production yields ratios allow the actinide discrimination ? (no γ-spectrum analysis)
- **+** : Get rid of geometrical corrections

prod. yie ratio	^{239}Pu V
^{134}Te/^{136}X	
^{135}Te/^{136}X	

Isotope	g.s. Spin	Isomer Spin	Level energy (keV)	Prod. Yield[2] (/fission) ^{235}U	^{239}Pu
^{134}Te	0^+	6^+	1691	6.0(2) x10^{-2}	4.5(5) x10^{-2}
^{135}Te	$7/2^-$	$19/2^-$	1555	2.5(6) x10^{-2}	2.1(7) x10^{-2}
^{136}Xe	0^+	6^+	1892	1.7(2)x10^{-2}	2.9(1)x10^{-2}

[1]*M. Jandel, J. Wlhelmy, Private communication, 2010*
[2]*NDC JENDL, Japan http://wwwndc.jaea.go.jp/cgi-bin/FPYfig?iso=nPu239&typ=g1*

NEED AND AVAILABILITY OF NUCLEAR DATA
Specific needs

What do we need ?

1. **Verification of the method feasibility (detection/analysis)**
   - Difference of isomer prod. Yield ratio between ^{235}U,^{239}Pu and ^{238}U ?
   - Good energy – time resolutions → $LaBr_3$ detector
   - Blocking function on a $LaBr_3$ detector using gating technique
   - Digital acquisition + Waveform/signal processing

2. **Get reliable nuclear data for application**

(γ,f) exp.

ELSA/SAPHIR
US program[1]

Models tested on alternative exp.

Spontaneous fission - ^{252}Cf
$^{235}U(n,f)$ - 4MV Van de Graaff (CEA DAM) exp.
Transfer reactions $^{238}U+^{3}He$ (Orsay Tandem)

ELSA, CEA DAM, Arpajon, France: linear electron accelerator that provides end-point Bremsstrahlung photons with energies from 4 MeV to 18 MeV

SAPHIR facility, CEA LIST, Saclay, France: Varian Linatron M9® LINAC 6 MeV or 9 MeV

3. **Guarantee a use in operational conditions**

From (γ,f) in research mode (ELSA) to on-site like measurements with a X-scanner (ELSA, SAPHIR)

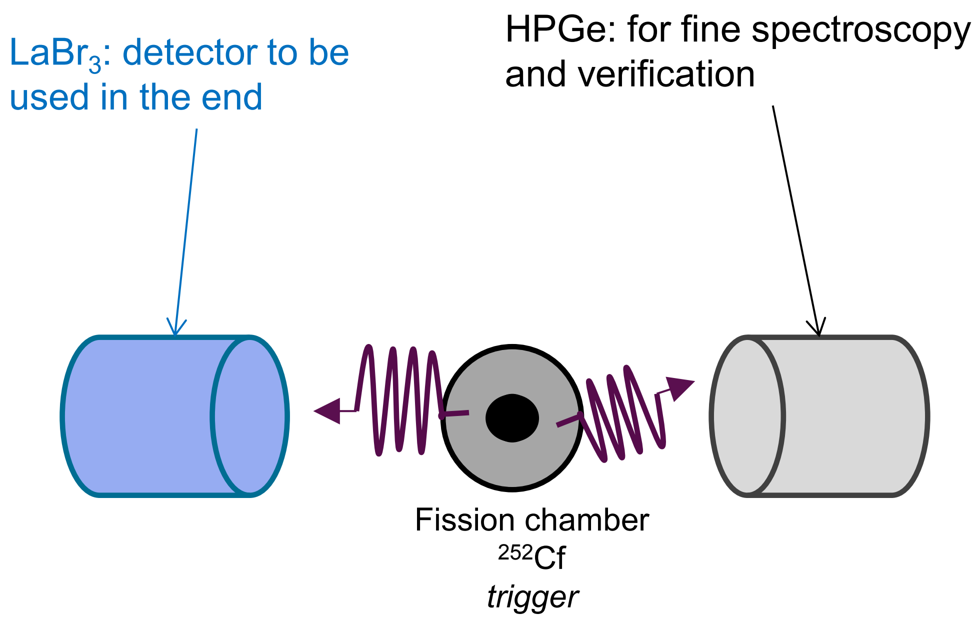
[1] *C.R. Howell et al., SSAP Symposium, Feb. 17-18 2016*

THEORETICAL AND EXPERIMENTAL EFFORTS (1)
Measurements of isomer production yields ratios

- Specific goal: getting $^{Y(134m-Te)}/_{Y(136m-Xe)}$ and $^{Y(135m-Te)}/_{Y(136m-Xe)}$ for different actinides

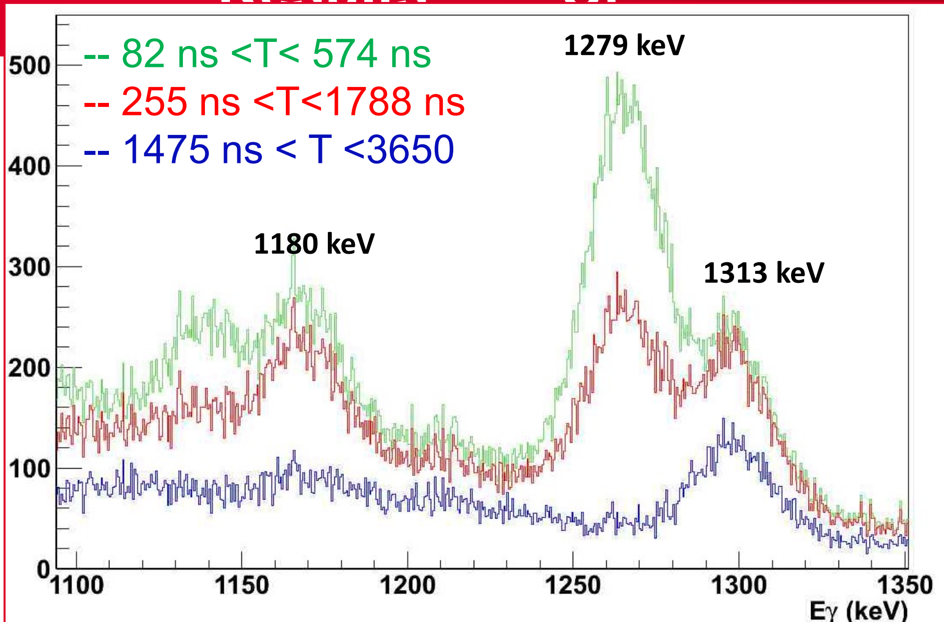
  - Determination of these ratios in ^{252}Cf spontaneous fission

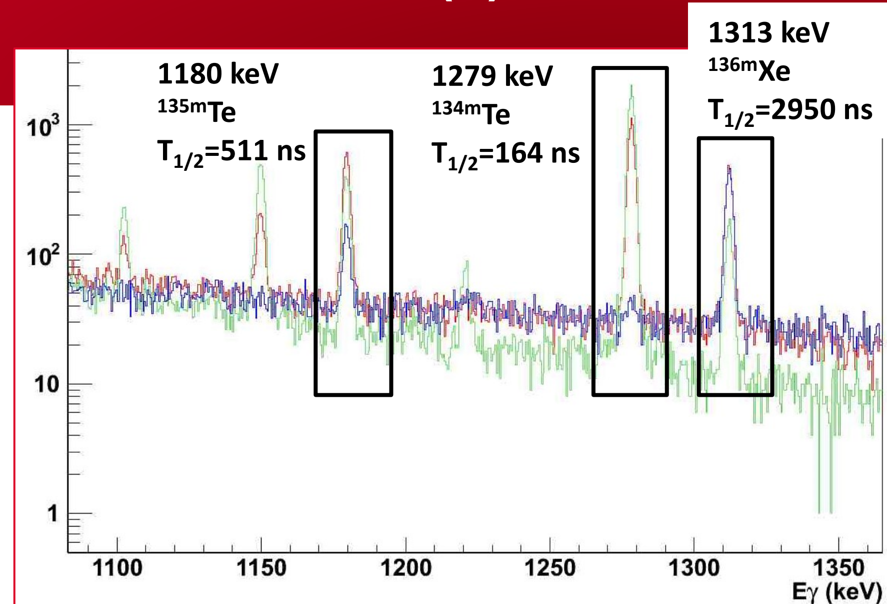
  - Is a LaBr detector adequate ?



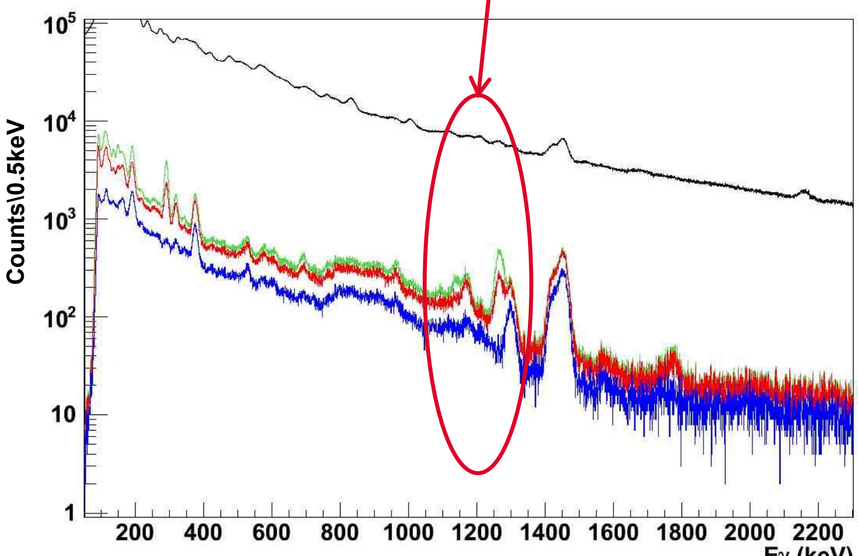
Theoretical and EXPERIMENTAL EFFORTS (2)

Results – ^{252}Cf

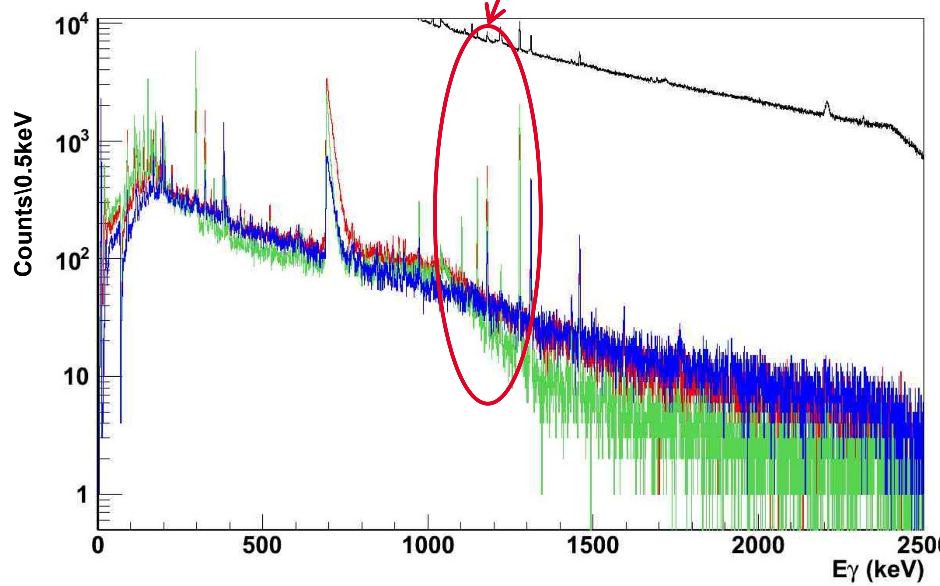




LaBr$_3$

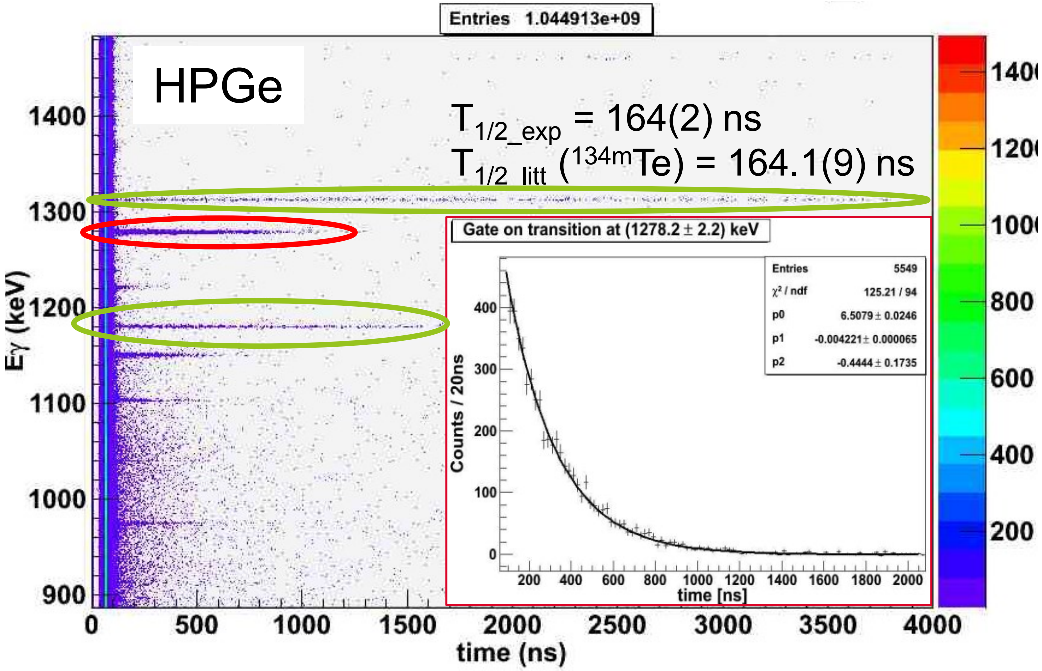


HPGe



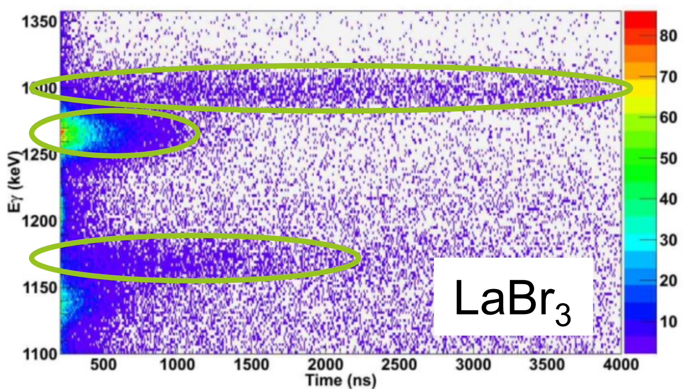
Theoretical and EXPERIMENTAL EFFORTS (3)
Results - ^{252}Cf

- Time and energy identification, ratio determination



Isomers	R_exp
^{134m}Te/^{136m}Xe	1.93(14)
^{135m}Te/^{136m}Xe	0.53(10)

Isotopes	R_eval JENDL
^{134}Te/^{136}Xe[1]	2.88±1,4
^{135}Te/^{136}Xe[1]	2.18±1,6



<u>Conclusion:</u> LaBr detector is OK
As expected isomers ratios measurements needed

[1]wwwndc.jaea.go.jp/cgi-bin/FPYfig?lib=11&mode=s&iso=sCf252&sub=Draw&typ=g1&ynuc=te-135&yld=i&zlog=set&ylow=12&xpar=a&eng=e1

Theoretical and EXPERIMENTAL EFFORTS (4)
Isomers $T_{1/2} < 3\mu s$ - ^{252}Cf

- Isomer production yields determination – experimental data

	Experimental results			
Isomer	Our work (γ/fission)	Sund, Hans Weber & Verbinski[1] (γ/fission)	John, Guy & Wesolowski[2]	Clarck, Glendenin & Talbert[3]
^{134m}Te (6^+)	0,0111(4)	0,0128(12)	0,0109(6)	0,0101(5)
^{135m}Te ($19/2^-$)	0,0031(3)	0,0033(11)	0,0031(3)	0,0027(2)
^{136m}Xe (6^+)	0,0057(6)	0,0086(24)	0,0070(6)	0,0047(31)

Isotope	Evaluated[4] (JENDL)
^{134}Te (0^+)	0,0237(38)
^{135}Te ($^-$)	0,0180(58)
^{136}Xe (0^+)	0,0082(37)

Can we reproduce this isomer prod. yield (ratio) in order to be predictive with (γ,f) data to overcome this lack of photofission data ?

1. R. R. Sund, Hans Weber & V.V. Verbinski, Phys. Rev. C **10**, 853 (1974)
2. W. John, F.W. Guy & J.J. Wesolowski, Phys. Rev. C **2**, 1451 (1970)
3. R.G. Clarck, L.E. Glendenin & W.L. Talbert., IAEA-SM-174/86 (1974).
4. http://wwwndc.jaea.go.jp/cgi-bin/FPYfig

THEORETICAL and experimental EFFORTS (5)

Models, a possible solution ?

- A Monte Carlo simulation of the fission fragment de-excitation process: **FIFRELIN**[1] developed by CEA Cadarache

  1. Sampling FF characteristics (mass, nuclear charge, kinetic energy, excitation energy, spin & parity)

  2. Decaying the completely characterized excited fragments

- CGMF[2], FREYA[3], GEF[4] …

Eur. Phys. J. A (2015) **51**: 177
DOI 10.1140/epja/i2015-15177-9

Regular Article – Theoretical Physics

Fission modelling with FIFRELIN*

Olivier Litaize[a], Olivier Serot, and Léonie Berge

CEA, DEN, DER, SPRC, F-13108 Saint Paul Lez Durance, France

Input/Output	Today
Mass and kinetic energy distributions	– Reconstructed from post-neutron data. – Calculated from fission mode parameters.
Charge distributions	– Modified Gaussian using Unchanged Charge Density (UCD) assumption, charge polarization function and even-odd factors.
Spin distributions	– Spin cut-off formula (mass and deformation dependent).
Excitation energy (sharing between fragments)	Temperature ratio law (mass, fission mode dependent).
De-excitation process	– Level Density model: CGCM/CTM/HFB. – Photon Strength Function: EGLO/SLO/HFB. – Optical Model Potential: KD/JLM.

[1] *O. Litaize , O.Sérot and L. Berge, Eur. Phys. J. A. **51**, 177 (2015)*
[2] *B. Becker et al., Phys. Rev. C **87**, 014617 (2013)*
[3] *R. Vogt and J. Randrup, Phys. Rev. C **87**, 044602 (2013)*
[4] *K. Schmidt and B. Jurado, in JEF/DOC 1423*

THEORETICAL and experimental EFFORTS (6)
Isomers $T_{1/2}$< 3µs - ^{252}Cf & FIFRELIN

- Isomer production yields determination – experimental data and FIFRELIN calculations (by O. Litaize, CEA Cadarache)

Isotope	Fifrelin	Evaluated[1] (JENDL)
^{134}Te	0,0270	0,0237(38)
^{135}Te	0,0192	0,0180(58)
^{136}Xe	0,0123	0,0082(37)

Isomer	Our work (γ/fission)	Fifrelin (γ/fission)
^{134m}Te (6$^+$)	0,0111(4)	0,0214
^{135m}Te (19/2$^-$)	0,0031(3)	0,0129
^{136m}Xe (6$^+$)	0,0057(6)	0,0085

PHYSICAL REVIEW C **88**, 044603 (2013)

Isomer production ratios and the angular momentum distribution of fission fragments

I. Stetcu,[1] P. Talou,[1] T. Kawano,[1] and M. Jandel[2]
[1]*Theoretical Division, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA*
[2]*C-NR, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA*

« quantity considered here. There are even cases when measured experimental isomer production ratio cannot be described in our formalism, even with the latest discrete level data [see »

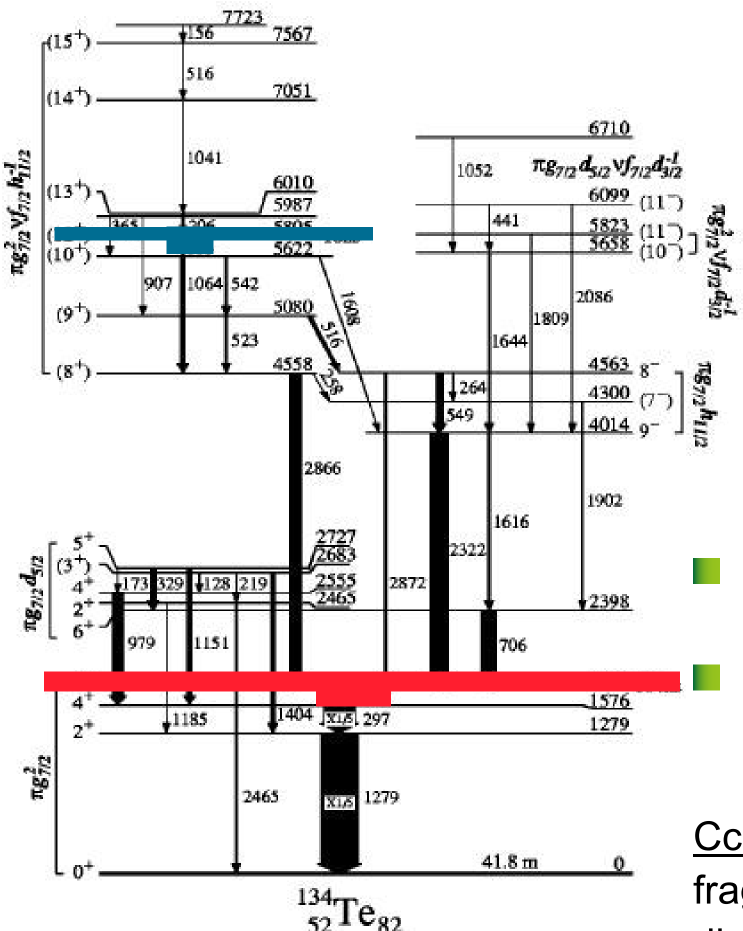
1. http://wwwndc.jaea.go.jp/cgi-bin/FPYfig

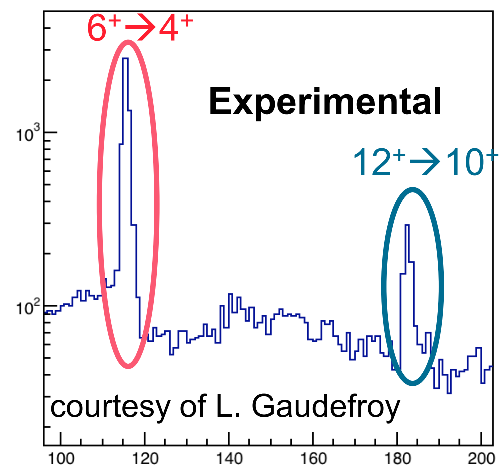
THEORETICAL and experimental EFFORTS (7)

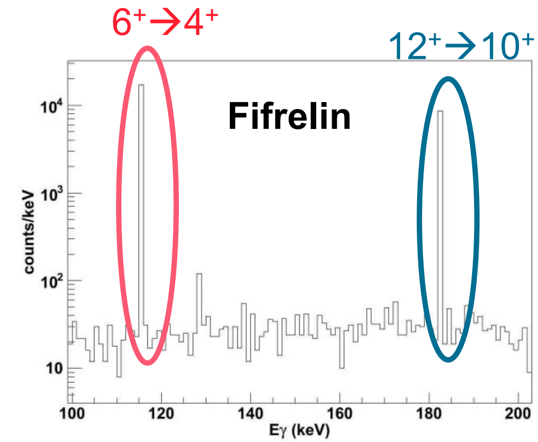
^{134}Te case - ^{252}Cf

Isomer feeding, spin issue ?

We observe an overfeeding of the isomeric levels (6$^+$ and 12$^+$) in Fifrelin compared to experimental results.







- RIPL-3 level scheme (used in FIFRELIN calculation) is correct
- Spin distribution when ^{134}Te is produced after neutron evaporation seems to be erroneous (spin too high)

Ccl: Isomeric ratios or isomers production yields in fission fragments are good means to test angular momentum distribution in fission models

*S.K. Saha *et al.*, Phys. Rev. C **65**, 017302, (2001)

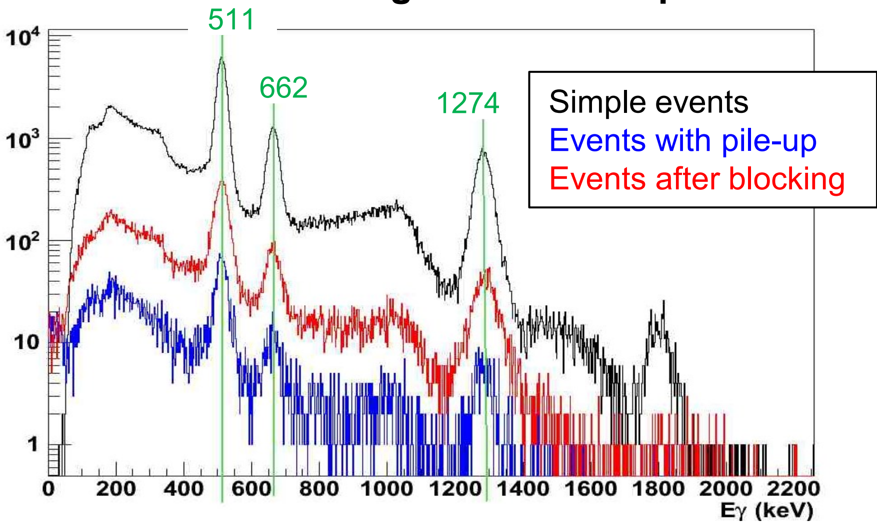
CONCLUSION & PERSPECTIVES

- Assessment : short-lived isomers production yields measurements in photofission experiments are **challenging**, even more below 15 MeV→ Many efforts must be done

- Data on ratios and isomers production yields in photofission for several actinides at 9 MeV to be provided
  - By experiment
  - By calculations code validation

- Test experiment of the detection set-up on real conditions at SAPHIR (CEA LIST, Saclay, France)

Reconstructed spectra of high intensity γ-sources – counting rate ~10^6-10^7 γ/s



THANK YOU FOR YOUR ATTENTION

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