Efficient production of $^{129m,131m,133m}Xe$ for a novel medical imaging technique, gamma-MRI

Mateusz Chojnacki

17th International Symposium on Capture Gamma-Ray Spectroscopy and Related Topics - CGS17
18/07/2023

UNIVERSITÉ DE GENÈVE

CERN

ISOLDE

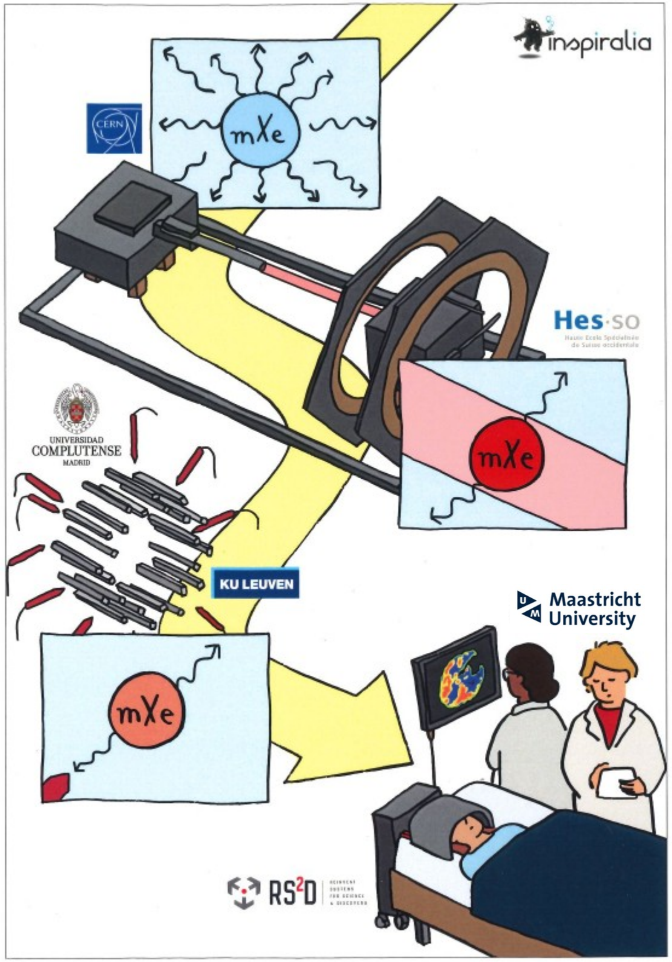
Gamma MRI - motivation

Increased MRI sensitivity + Improved SPECT resolution

FET-OPEN project (H2020-EU.1.2.,H2020-EU.1.2.1),
European Union’s Horizon 2022, grant agreement No 964644

Gamma MRI - principles

- Use of polarised unstable tracers
- Positioning given by MRI sequences
- Tracer amount given by degree of asymmetry of gamma emission



proof of principle
Y. Zheng, et al., Nature (537), 652 (2016)

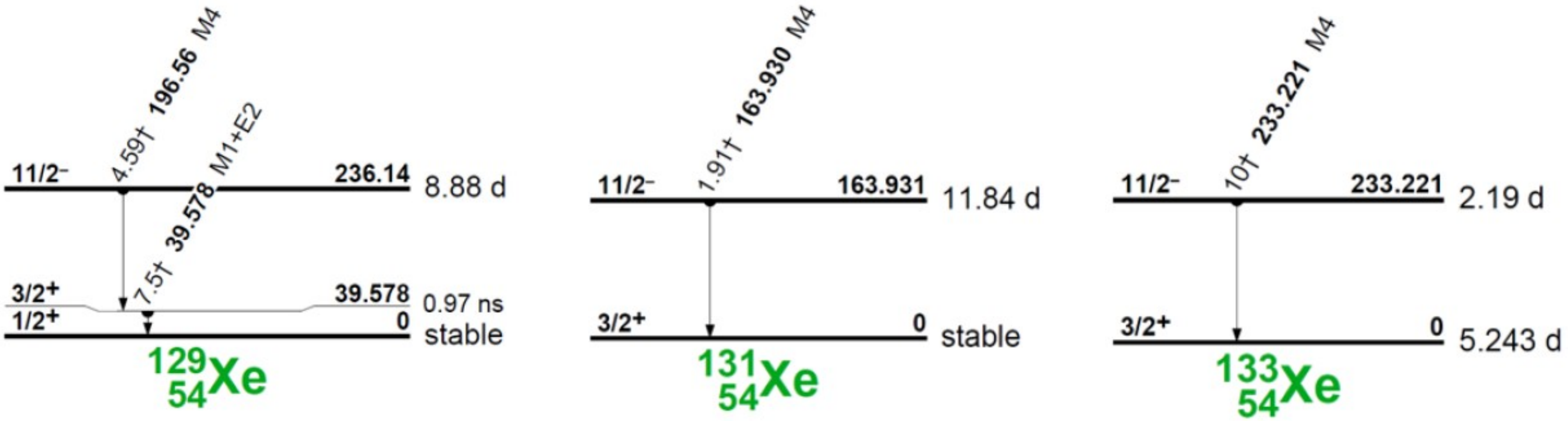
Gamma MRI - principles

- Use
- Posit
- Trac
  asym

MANIPULATION LIKE IN MRI
(HIGHER SPATIAL RESOLUTION)
DETECTION LIKE IN SPECT
(HIGHER SENSITIVITY)

proof of principle
Y. Zheng, et al., Nature (537), 652 (2016)

Gamma MRI – ^{m}Xe nuclei



- **Why mXe nuclei?**
  - hyperpolarization of ^{129}Xe well established
  - isomers with spin 11/2 - high degree of gamma emission asymmetry
  - Xe – nobel gas (neutral to human body)
  - ^{129}Xe is already used in MRI studies of the lungs and brain

Gamma MRI – ᵐXe nuclei

MAIN ROUTES OF PRODUCTION

PROTON INDUCED NUCLEAR FISSION

^{129m}Xe
^{131m}Xe
^{133m}Xe

NEUTRON IRRADIATION IN RESEARCH NUCLEAR REACTOR

^{129m}Xe
^{131m}Xe
^{133m}Xe

NEUTRONS FOR SOCIETY

NATIONAL CENTRE FOR NUCLEAR RESEARCH ŚWIERK

Gamma MRI – ^{m}Xe nuclei

MAIN ROUTES OF PRODUCTION

PROTON INDUCED NUCLEAR FISSION

^{129m}Xe

^{131m}Xe

^{133m}Xe

NEUTRON IRRADIATION IN RESEARCH NUCLEAR REACTOR

^{129m}Xe

^{131m}Xe

^{133m}Xe

NEUTRONS FOR SOCIETY

NATIONAL CENTRE FOR NUCLEAR RESEARCH ŚWIERK

^{m}Xe production – reactors

- Thermal neutron irradiation of highly enriched ^{128}Xe/^{130}Xe in the reactor core

NEUTRONS FOR SOCIETY

NATIONAL CENTRE FOR NUCLEAR RESEARCH ŚWIERK

^{128}Xe(n,γ) ^{129m}Xe

^{128}Xe(n,γ) ^{129}Xe

^{130}Xe(n,γ) ^{131m}Xe

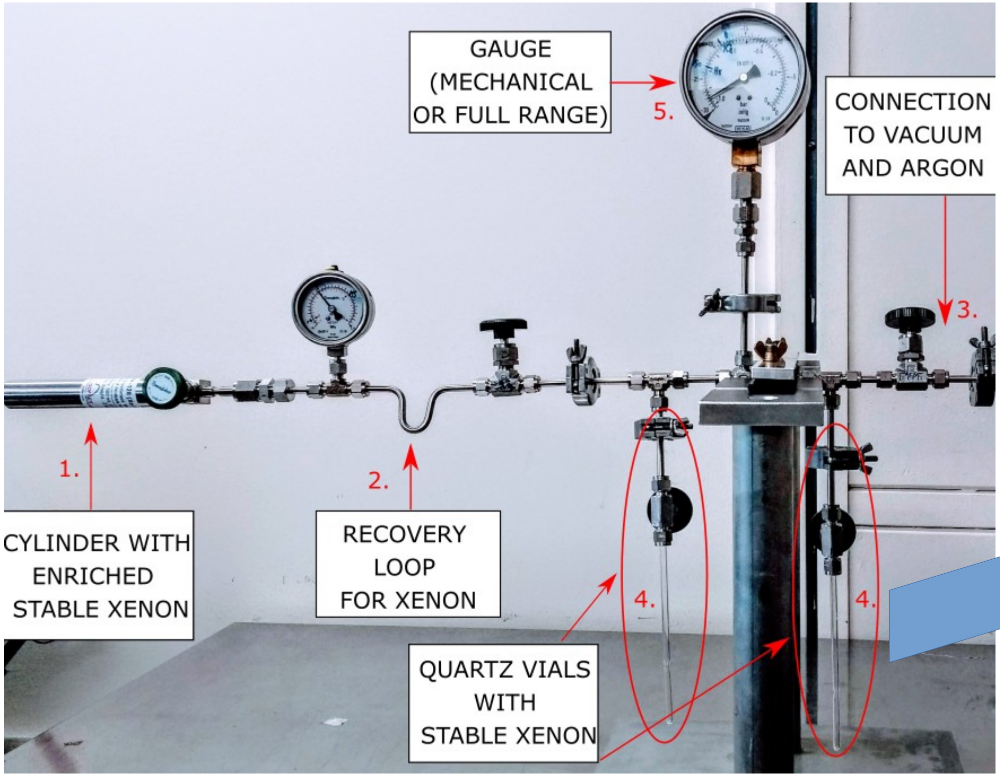
^{130}Xe(n,γ) ^{131}Xe

CERN

M.Chojnacki,K.Kulesz et al, in preparation

^{m}Xe production – reactors

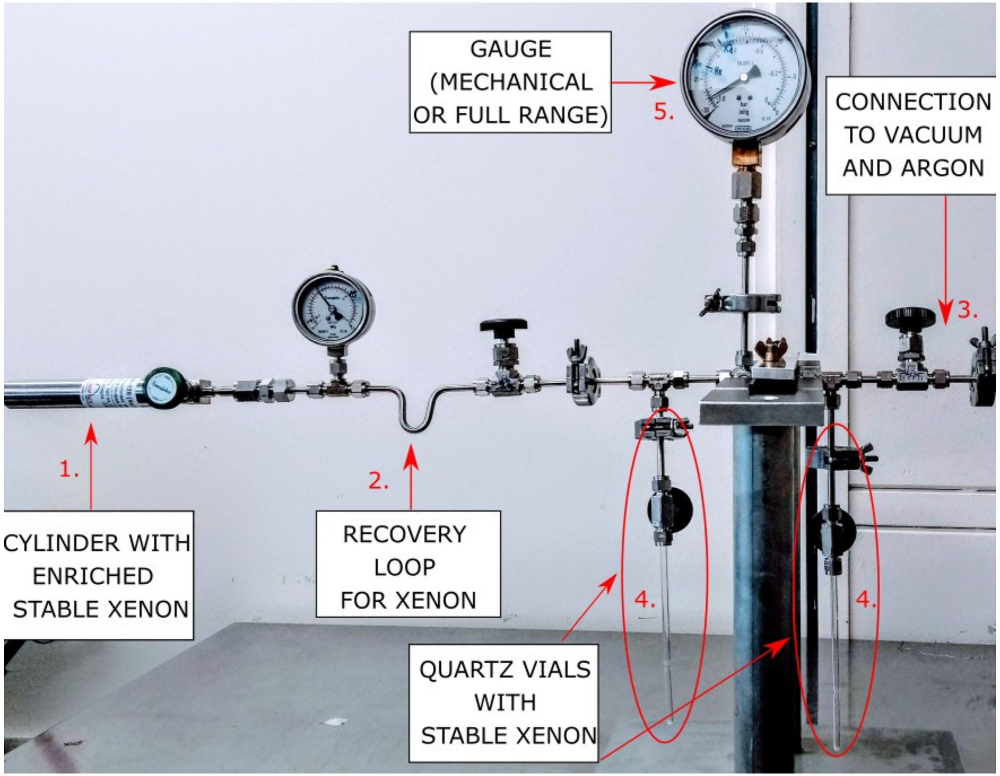
- Stable xenon samples preparation



M.Chojnacki,K.Kulesz et al, in preparation

^{m}Xe production – reactors

- Stable xenon samples preparation



QUARTZ TUBE WITH STABLE Xe

p_{Xe}=300mbar
H=46-50 mm,
V≈0.8cm^3
d_{inner}=4mm,
d_{outter}=6mm

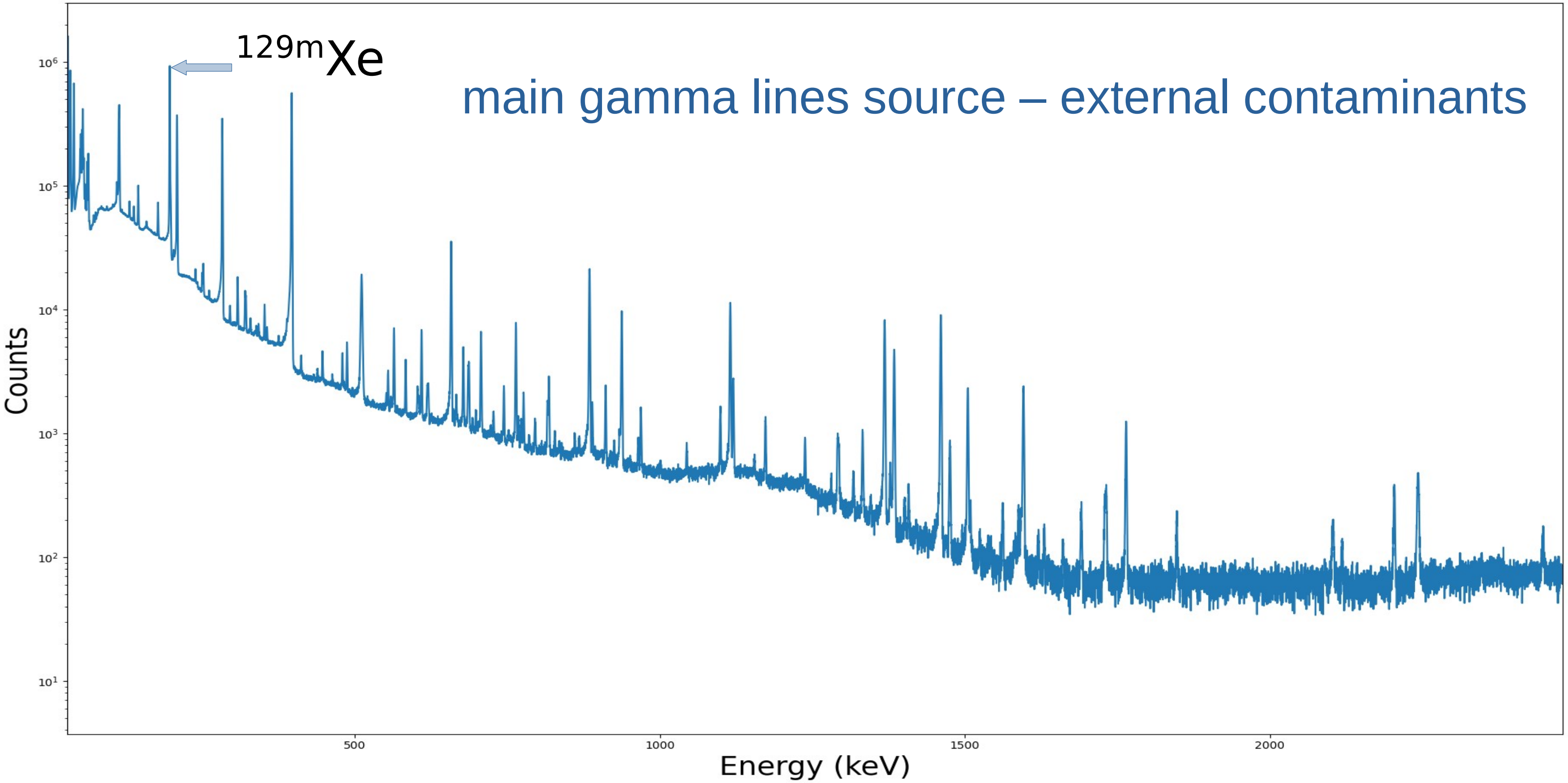
^{128}Xe (99.931%) + ^{124,126,129,130,131,132,134,136}Xe

^{130}Xe (99.947%) + ^{124,126,128,129,131,132,134,136}Xe

M.Chojnacki,K.Kulesz et al, in preparation

^{m}Xe production – reactors

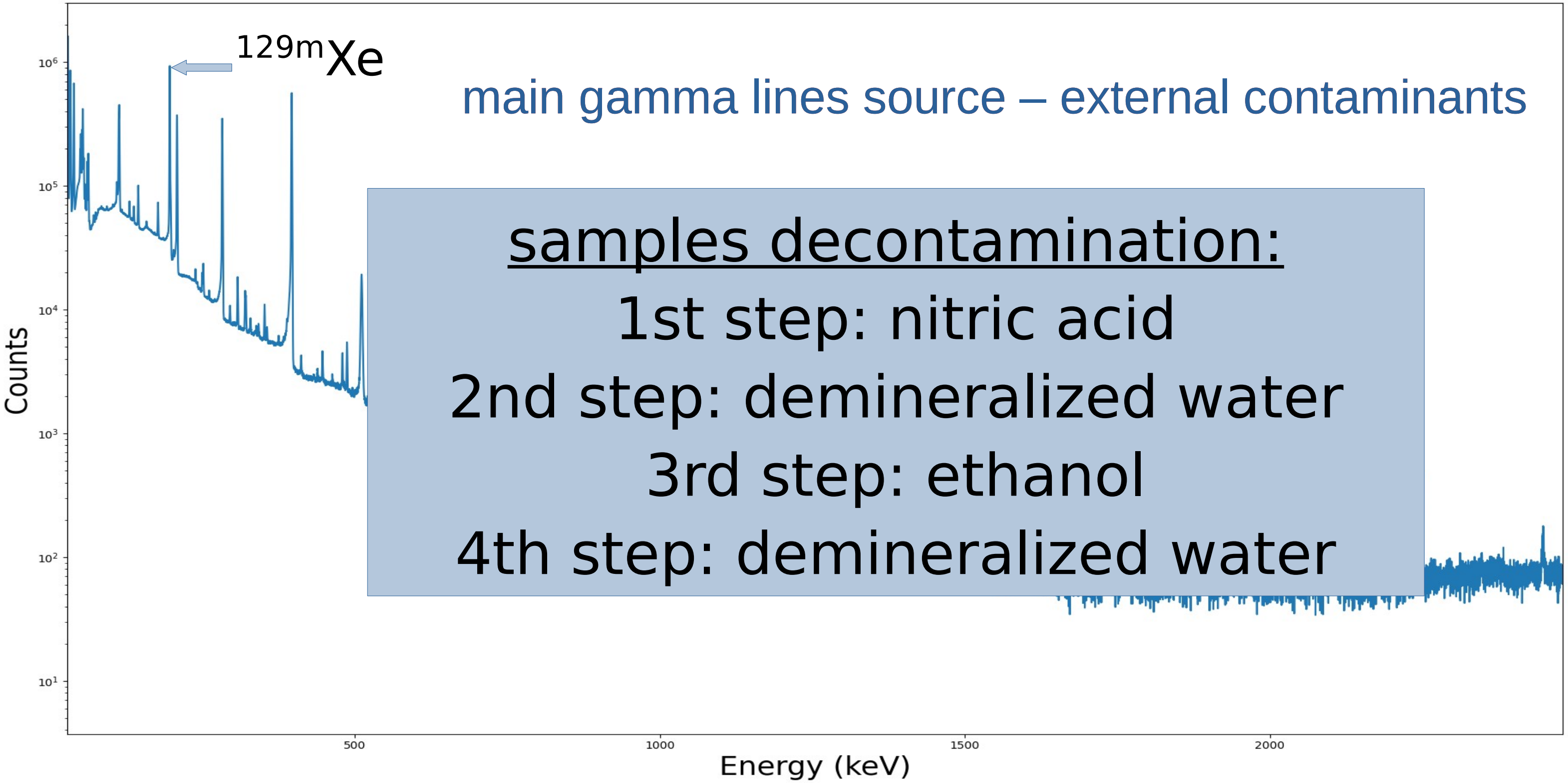
- Gamma spectroscopy of Xe irradiated samples



M.Chojnacki,K.Kulesz et al, in preparation

^{m}Xe production – reactors

- Gamma spectroscopy of Xe irradiated samples



<u>samples decontamination:</u>

1st step: nitric acid

2nd step: demineralized water

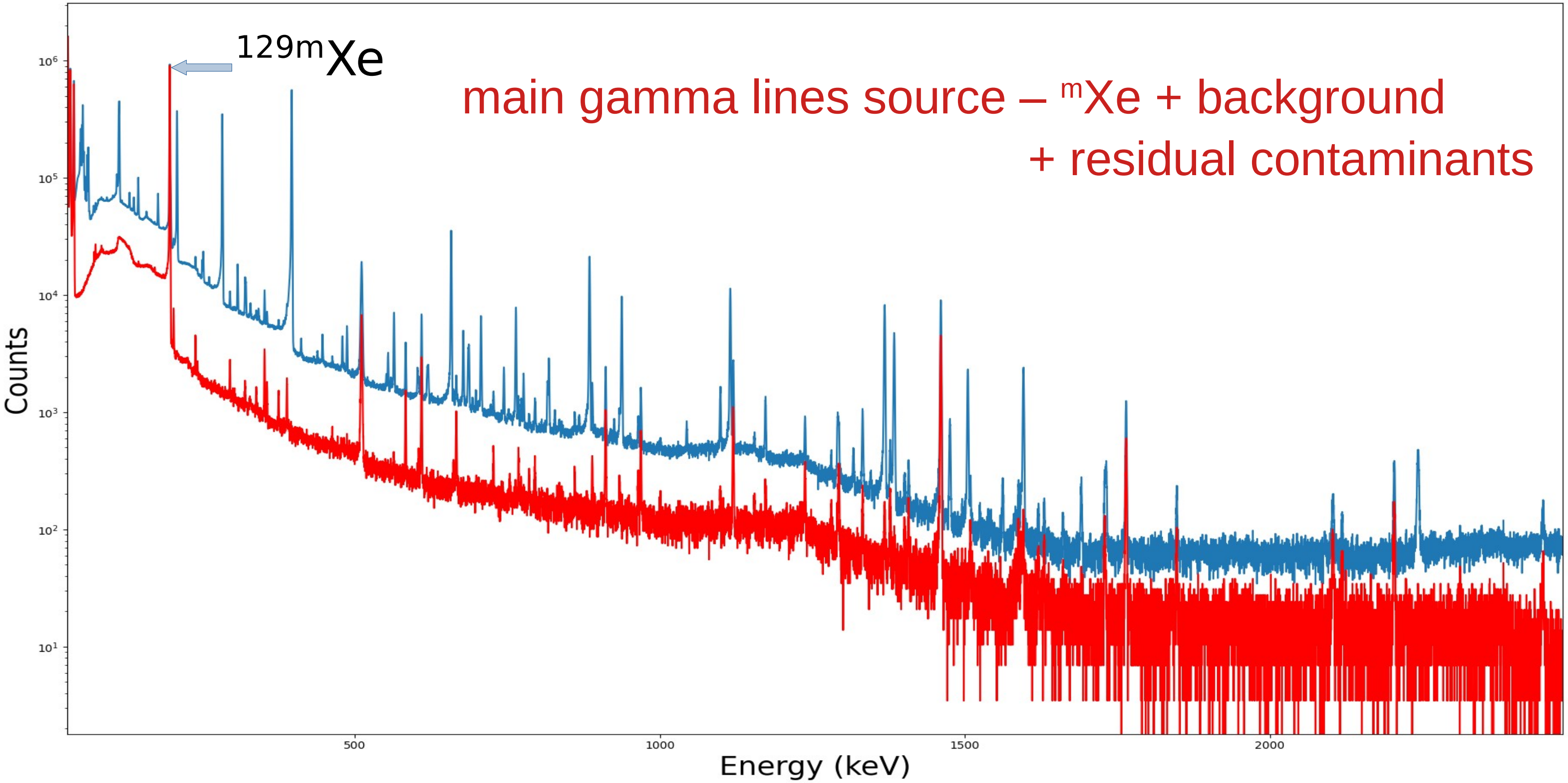
3rd step: ethanol

4th step: demineralized water

M.Chojnacki,K.Kulesz et al, in preparation

^{m}Xe production – reactors

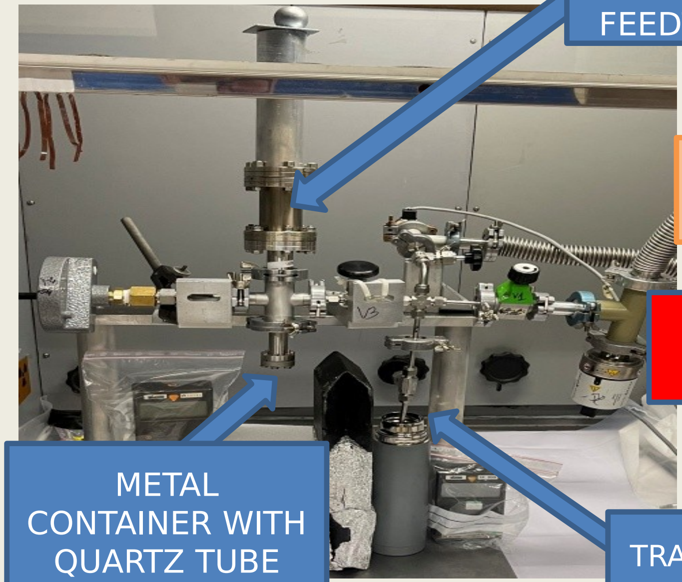
- Gamma spectroscopy of Xe irradiated samples (after decontamination)



M.Chojnacki,K.Kulesz et al, in preparation

^{m}Xe production – reactors

- Opening of irradiated Xe samples (after decontamination)



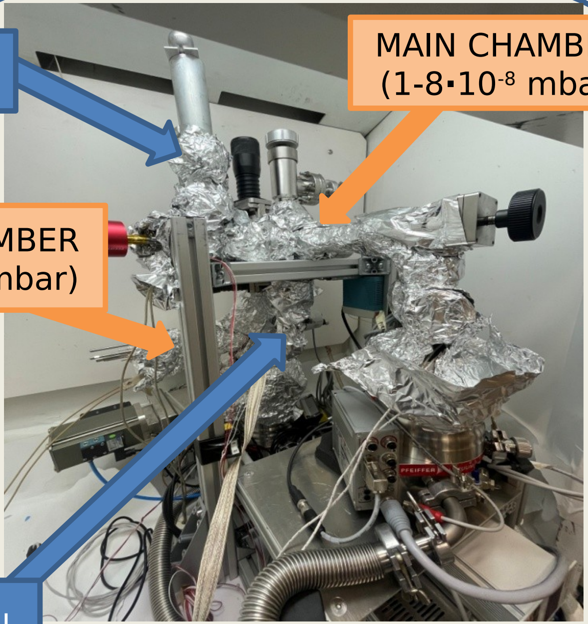
MECHANICAL FEEDTHROUGH

METAL CONTAINER WITH QUARTZ TUBE

TRANSPORT VIAL

HV SETUP (10^{-3}-10^{-6} mbar) – 2021/22

TRANSFER EFFICIENCY: **76(2)%**



MAIN CHAMBER ($1\text{-}8 \cdot 10^{-8}$ mbar)

RGA CHAMBER ($<5 \cdot 10^{-9}$ mbar)

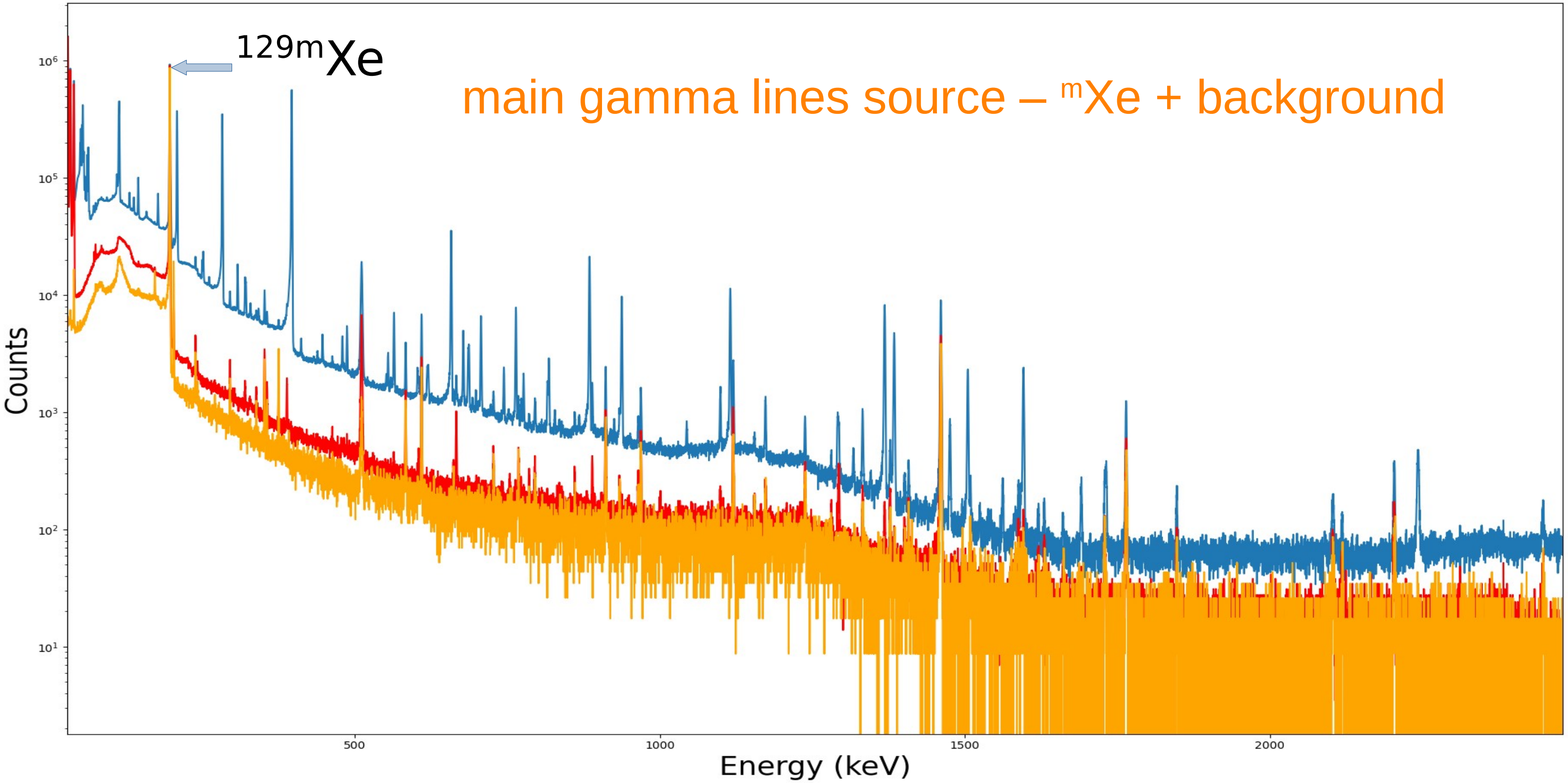
UHV SETUP ($<10^{-7}$ mbar) – 2022/23

TRANSFER EFFICIENCY: **92(2)%**

M.Chojnacki,K.Kulesz et al, in preparation

^{m}Xe production – reactors

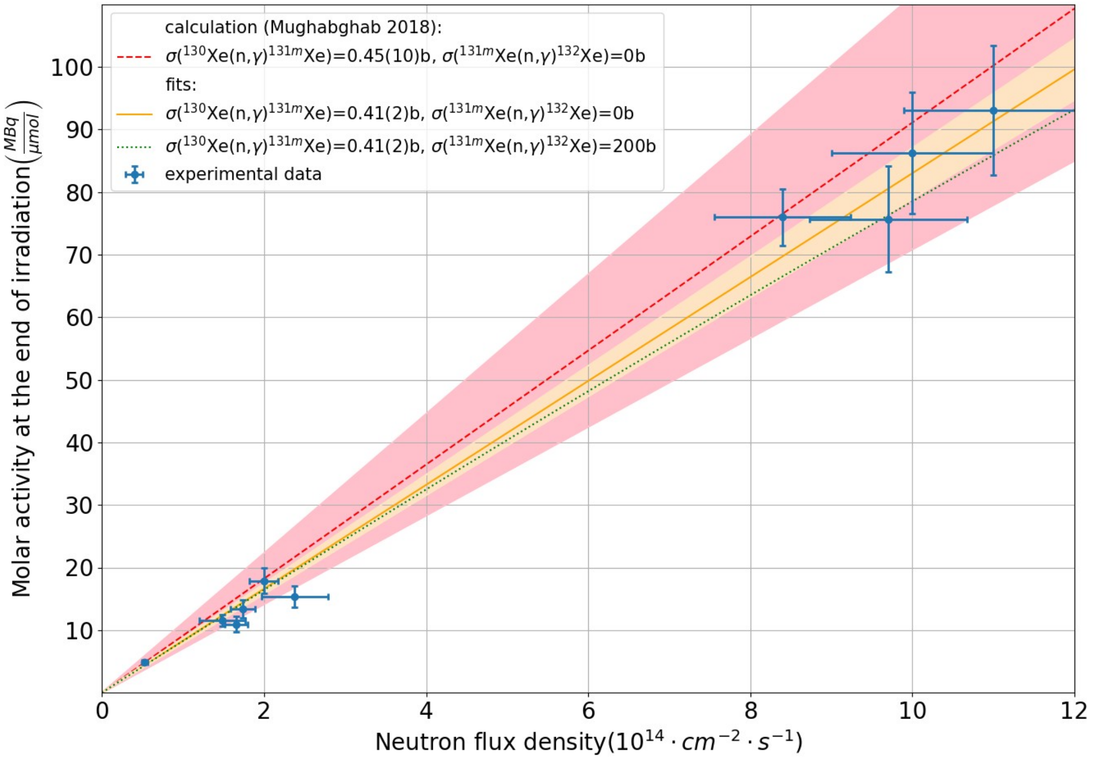
- Gamma spectroscopy of Xe irradiated samples (after opening)



M.Chojnacki,K.Kulesz et al, in preparation

^{m}Xe production – reactors

- ^{130}Xe samples irradiation results (7days, 17samples) - ^{131m}Xe

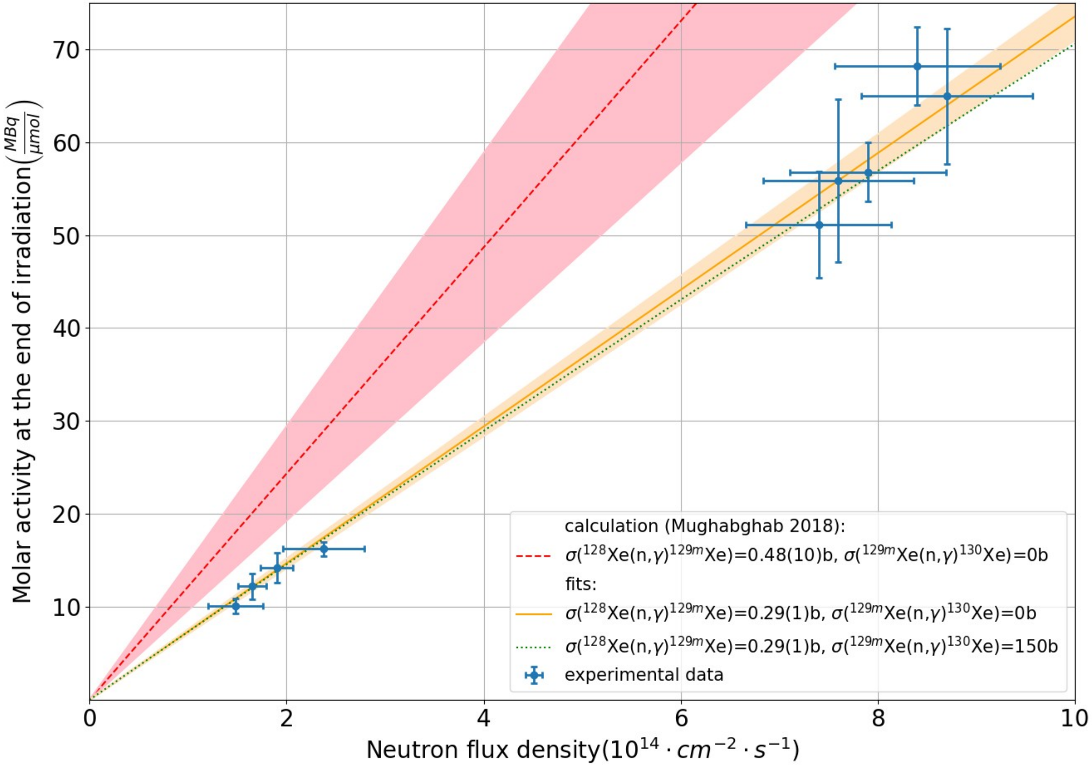


No unstable contaminants detected in the samples

M.Chojnacki,K.Kulesz et al, in preparation

^{m}Xe production – reactors

- ^{128}Xe samples irradiation results (7days, 19samples) - ^{129m}Xe

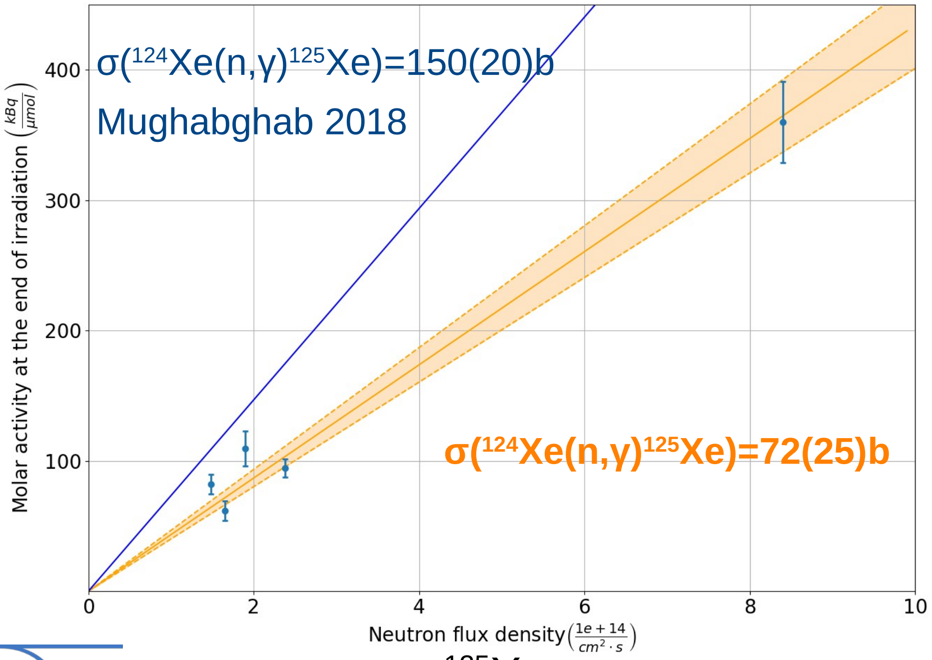


two unstable contaminants detected in the samples

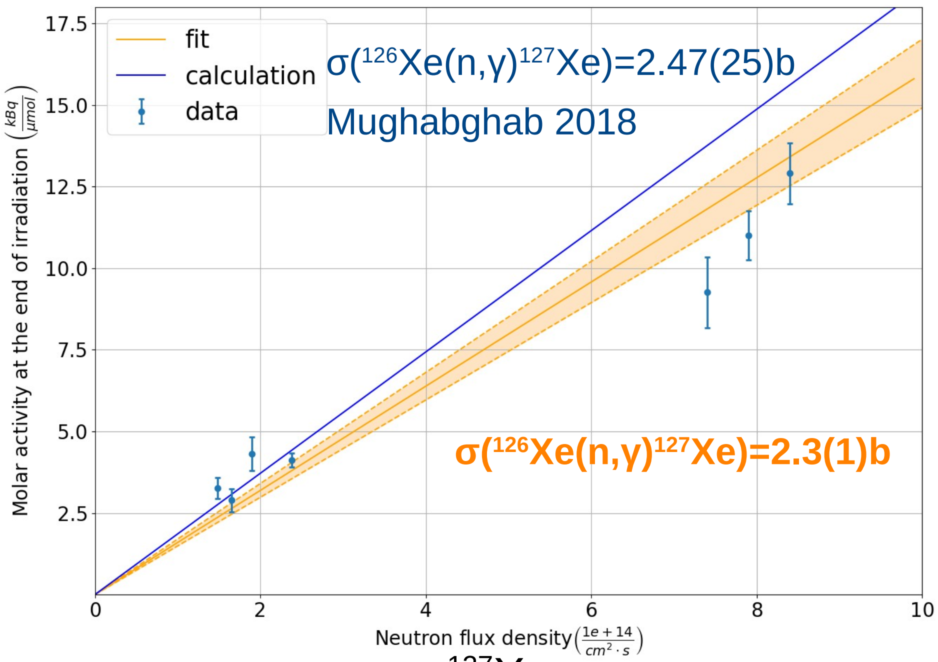
M.Chojnacki,K.Kulesz et al, in preparation

^{m}Xe production – reactors

➔ ^{128}Xe samples irradiation results (7days, 19samples) – contaminants



^{125}Xe



^{127}Xe

M.Chojnacki,K.Kulesz et al, in preparation

^{m}Xe production – reactors

- Gamma-MRI project activity requirements

A_{min} = 10MBq (10 days after the end of irradiation)

$A_{EOI}(^{129m}Xe)$ = 29MBq and $A_{EOI}(^{131m}Xe)$ = 24MBq

$$\Phi\left(^{129m}Xe\right) > 5.9\cdot 10^{13}\, cm^{-2}\cdot s^{-1}$$

$$\Phi\left(^{131m}Xe\right) > 4.4\cdot 10^{13}\, cm^{-2}\cdot s^{-1}$$

reactors with thermal neutron flux greater than $6\cdot 10^{13}\, cm^{-2}\cdot s^{-1}$ suitable for the project

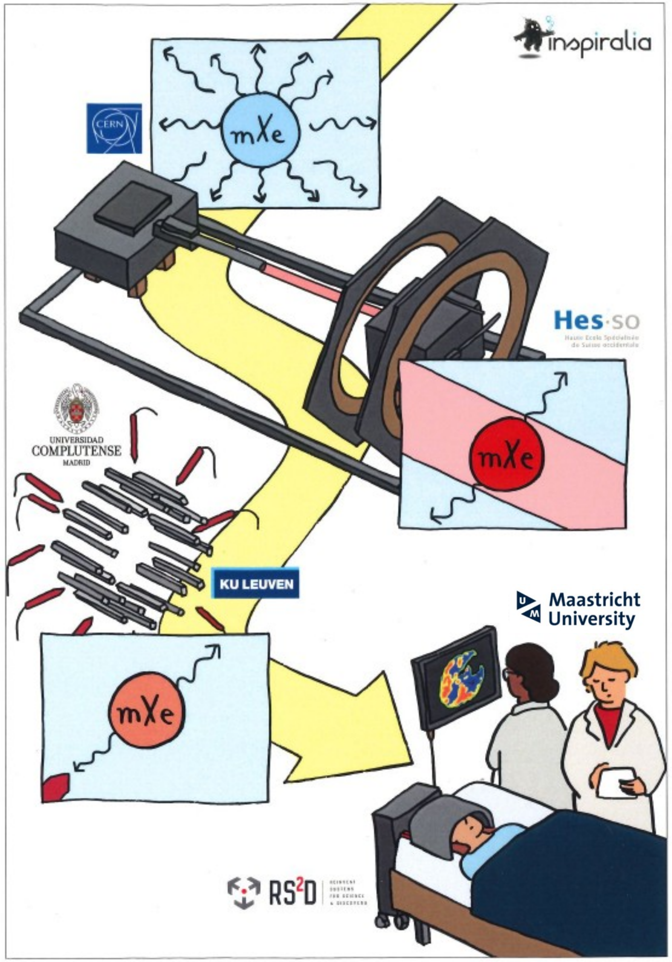
M.Chojnacki,K.Kulesz et al, in preparation

SUMMARY

- gamma-MRI – novel medical imagining modality

- two methods of mXe production were developed

- $^{129m,131m}Xe$ production established with ILL and MARIA reactors



gamma-MRI project website:
http://gamma-mri.eu

ACKNOWLEDGMENTS

CERN: M.Kowalska[1,2], K.Kulesz[1,2], I.Michelon[3], J.Schell[1,4], R.Lica[1,5], N.Azaryan[1,6], T.T.Dang[4], A.M.Gerami[7], S.Pascu[5], M.Piersa-Siłkowska[1,], M.Jankowski[1,14], M.Bissell[1], T.Treczoks[1,15], K.Vitulova[1,16], A.Dorsival[1], E.Aubert[1], L.Lambert[1]

HES-SO: S.Pallada[8], T.Kanellakopoulos[8], V.Sanchez-Tembleque[8]

UCM: L.Fraile[9], J.M.Udias Moinelo[9]

MAASTRICHT UNIVERSITY: R.Jolivet[10], K.M.Dziubińska-Kühn[10]

NCBJ(MARIA REACTOR): R.Prokopowicz[11], Ł.Murawski[11], Ł.Bąk[11], W.Kubiński[11], A.Korgul[12]

ILL(RHF REACTOR): U.Köster[13]

[1]CERN, Meyrin, Switzerland
[2]University of Geneva, Geneva, Switzerland
[3]University of Padova, Padova, Italy
[4]University of Duisburg-Essen, Duisburg-Essen, Germany
[5]Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest, Romania
[6]Adam Mickiewicz University, Poznań, Poland
[7]School of Particles and Accelerators, Institute for Research in Fundamental Sciences (IPM), Teheran, Iran
[8]University of Applied Sciences and Arts of Western Switzerland, Geneva, Switzerland
[9]Universidad Complutense de Madrid, Madrid, Spain
[10]Maastricht University, Maastricht, Netherlands
[11]National Centre for Nuclear Research, Świerk, Poland
[12]University of Warsaw, Warsaw, Poland;
[13]Institut Laue-Langevin, Grenoble, France
[14]Technische Universitaet Darmstadt, Germany
[15]University of Oldenburg, Germany
[16]Palacky University Olomouc, Olomouc, Czech Republic

FET-OPEN project (H2020-EU.1.2.,H2020-EU.1.2.1),
European Union’s Horizon 2022, grant agreement No 964644

BACK-UP SLIDES

Xe samples composition

Table 1: Relative molar concentration (in %) of Xe isotopes in natural and enriched $^{128,130}Xe$ samples used in irradiations (according to distributor).

Xe sample	^{124}Xe	^{126}Xe	^{128}Xe	^{129}Xe	^{130}Xe	^{131}Xe	^{132}Xe	^{134}Xe	^{136}Xe
Xe natural abundance	0.1	0.1	1.9	26.4	4.1	21.2	26.9	10.4	8.9
enriched ^{128}Xe	0.001	0.010	99.931	0.052	0.001	0.001	0.002	0.001	0.001
enriched ^{130}Xe	0.003	0.003	0.003	0.023	99.947	0.012	0.003	0.003	0.003

Table 2: Relative molar concentration (in %) of other gases in enriched $^{128,130}Xe$ samples used in irradiations (according to distributor).

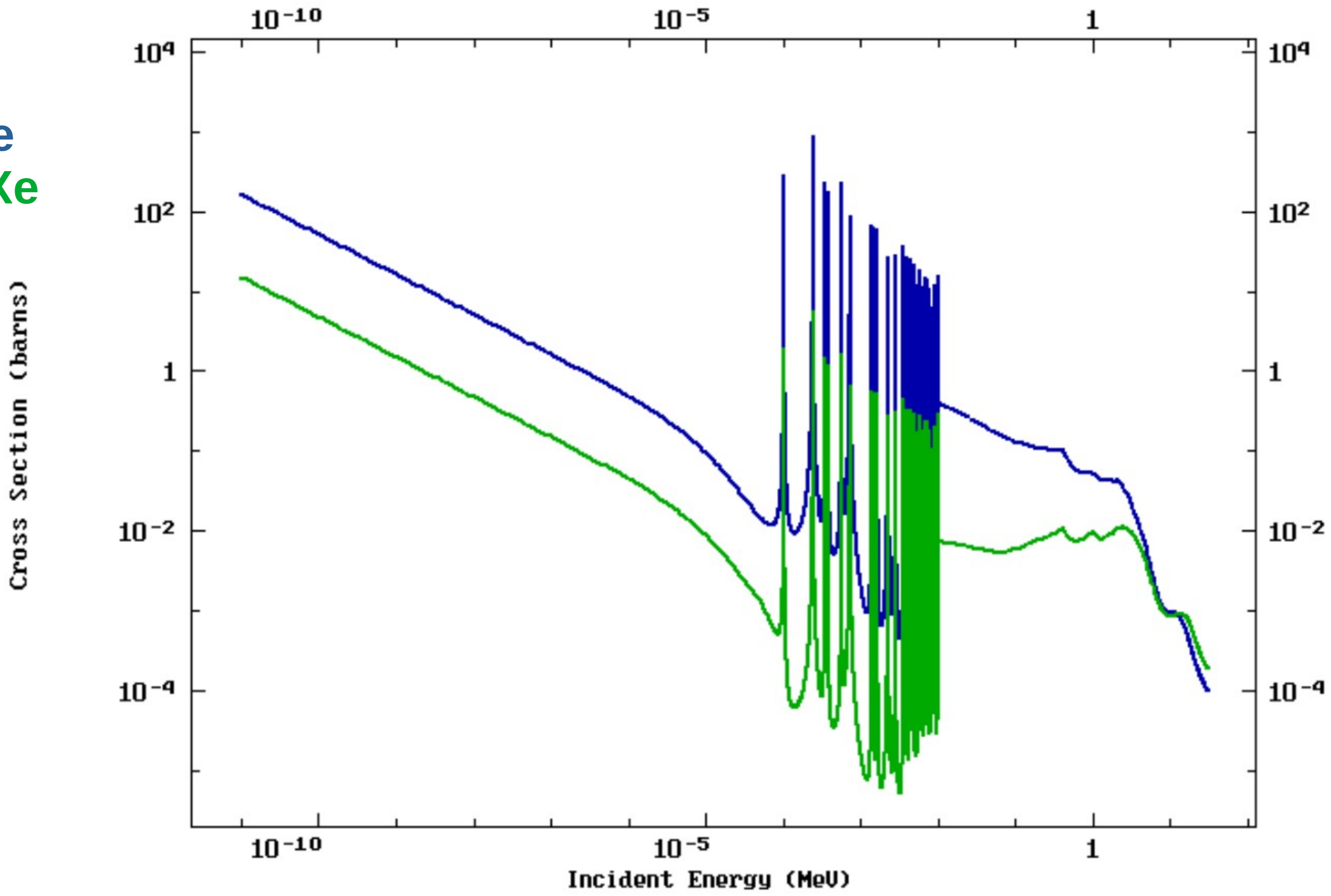
Xe sample	$CO+N_2$	CO_2	Ar	CH_4	H_2O	O_2	Kr	C_7H_8
enriched ^{128}Xe	0.004	0.008	<0.002	<0.001	<0.001	0.002	<0.004	<0.002
enriched ^{130}Xe	0.003	0.011	<0.006	<0.001	<0.009	<0.005	<0.006	<0.005

CERN

${}^{m}Xe$ cross section - ${}^{128}Xe$

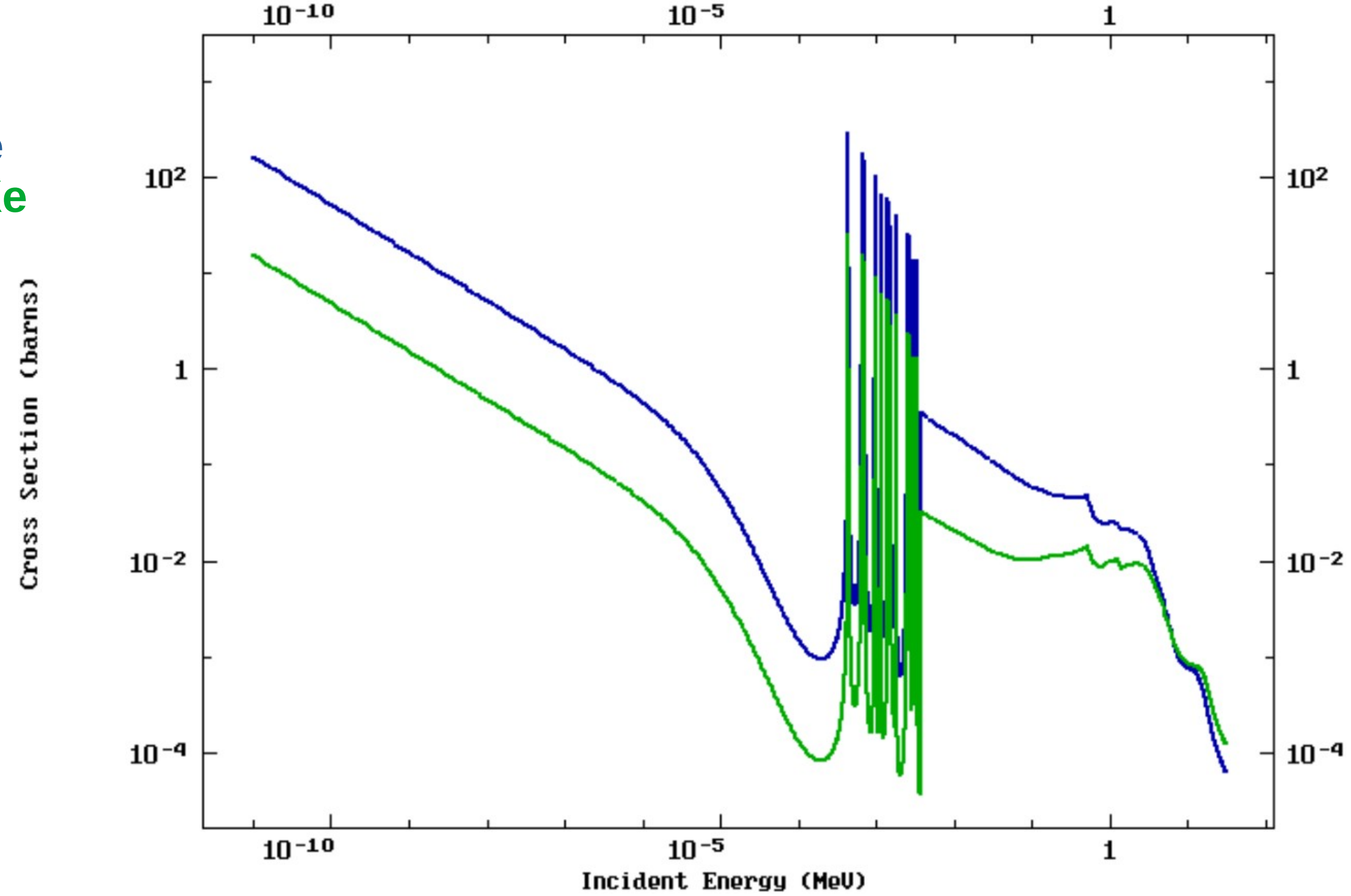
${}^{128}Xe(n,g){}^{129}Xe$

${}^{128}Xe(n,g){}^{129m}Xe$



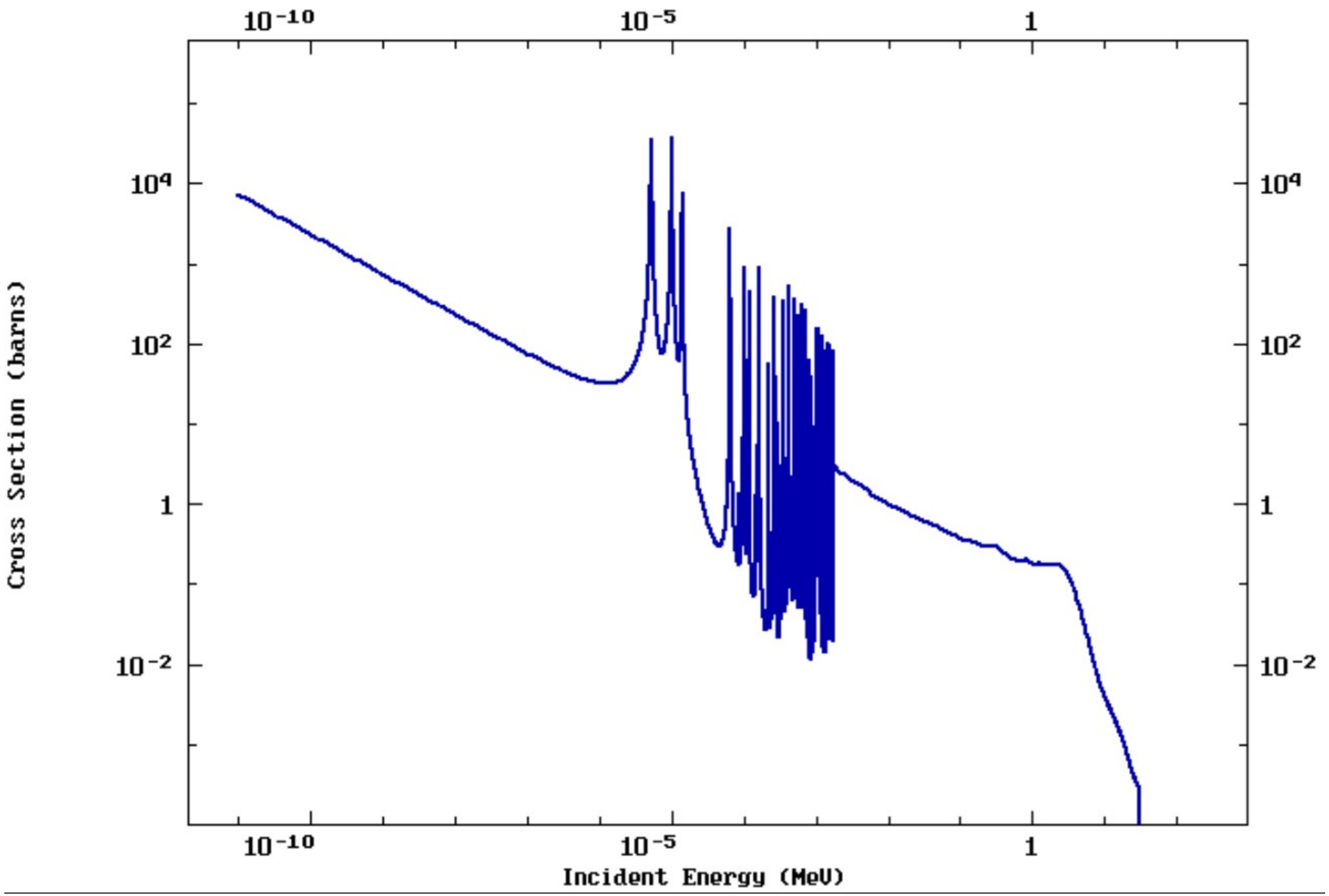
^{m}Xe cross section - ^{130}Xe

$^{130}Xe(n,g)^{131}Xe$
$^{130}Xe(n,g)^{131m}Xe$



Xe cross section - ^{124}Xe

$^{124}Xe(n,g)^{125}Xe$



Xe cross section - ^{126}Xe

$^{126}Xe(n,g)^{127}Xe$