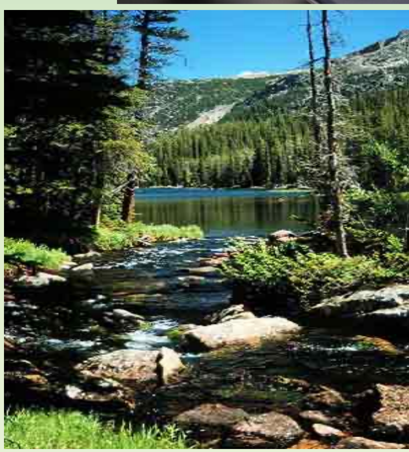
NUCLEAR DATA PRIORITIES FOR NON-ENERGY APPLICATIONS

Roberto Capote, Deputy Section Head
NAPC-Nuclear Data Section, IAEA

Nuclear Sciences and Applications:
Serving Basic Human Needs



IAEA

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Atoms for Health: Disease Prevention and Control

- ✓ Nutrition
- ✓ Nuclear Medicine
- ✓ Radiobiology and Radiotherapy
- ✓ Dosimetry and Medical Physics
- ✓ Fighting Global Cancer

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NON-ENERGY APPLICATIONS

Non-energy ? Anything? A fuzzy definition…

- Medical applications: radionuclide production
- Astrophysics
- Planetary defence
- Space exploration
- Space safety
- Geological applications
- …

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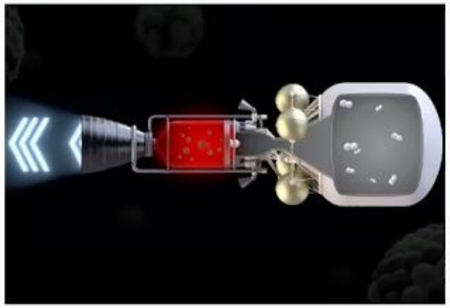
ND needs in space propulsion

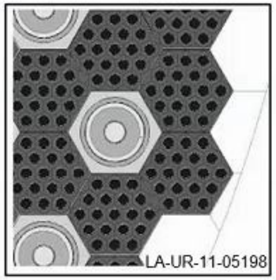
Viewing Kelsa Palomares's sc...

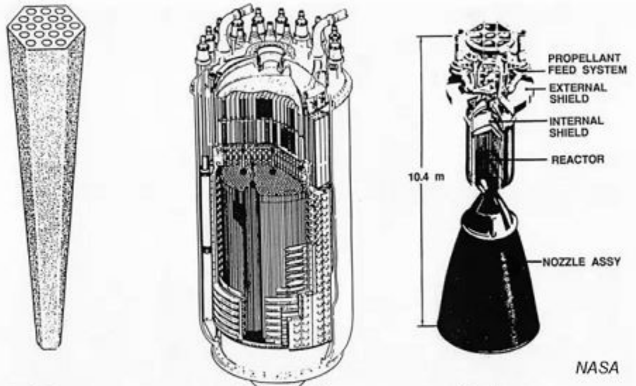
Nuclear thermal pro tor technologies are being developed for in-space propulsion

Nuclear thermal propulsion is an in-space propulsion technology being evaluated for crewed Mars Missions

- **Major components:**
  - **Moderators:** metallic hydrides (ZrH_x, YH_x), beryllium compounds (Be, BeO, Be_2C) or combinations there-of
  - **Control:** Be, B_4C
  - **Fuel forms:** refractory U-ceramics (UO_2, UC_2, UC, UN, UC-ZrC), coated fuel particles
  - **Structural materials:** Refractory ceramics (carbides, graphite), refractory metals (W, Mo)
- **Unique design features:**
  - Reactor design requires unique materials to enable operation at extremely high temperature
  - Wide temperature range needed for cross sections to inform the reactor design
    - Coldest regions of the reactor are cooled by liquid hydrogen
    - Hottest regions operate as a heat exchanger above 2700 K
  - High Assay Low Enriched Uranium (HALEU)
    - Synergies with ongoing advanced, small, or microreactors?
  - Use environment: in-space background radiation and impacts to overall system design
  - Nuclear data needed for both reactor and shielding design
    - Reactor design requires accurate prediction of reactivity over a range of operational modes
    - Shielding design must ensure that critical components, systems and crew are not exposed to neutron and gamma sources above design limits







Workshop on Applied Nuclear Data Activities (WANDA) 2021

5

Taken from WANDA 2021 presentation by K. Palomares

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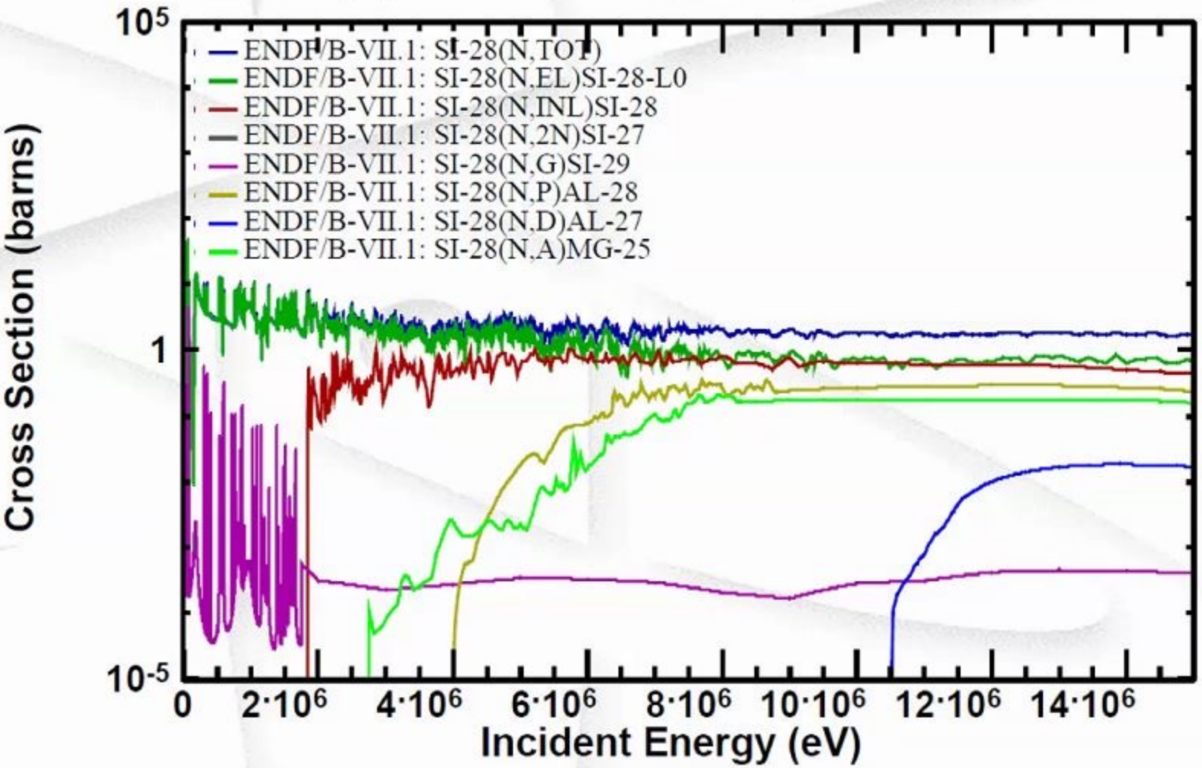
ND needs for planetary defense

Nuclear data is the … Viewing Lansing Horan's appl… on of this work.

AFIT
AIR FORCE INSTITUTE OF TECHNOLOGY

- For a given problem geometry and material composition, **nuclear cross sections are how bulk neutron interactions are mapped to energy deposition profiles.**



changing the neutron energy changes:

1. cross section magnitude
2. mean-free-path
3. spatial extent/distribution
4. energy deposition profiles

changing the neutron energy changes:

1. open/closed reaction channels
2. endothermic/exothermic reactions
3. energy coupling efficiencies

Nuclear data *ultimately determines the end results of asteroid deflection.*

8

Taken from WANDA 2021 presentation by Lansing Horan

NUCLEAR DATA FOR MEDICAL APPLICATIONS

- The utilization of radiation in medicine for diagnosis and treatment dates from the 19th century, almost from the time x-rays (atomic data) and radioactivity (nuclear data) were discovered

- Now its use is deeply embedded in medical practice. For many purposes, it is indispensable – both for diagnosis and for treatment

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IAEA
International Atomic Energy Agency

INDC(NDS)-0776
Distr. G+NM+SD

INDC International Nuclear Data Committee

Summary Report

Technical Meeting on

Nuclear Data for Medical Applications

IAEA Headquarters
Vienna, Austria
10-13 December 2018

Prepared by

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Vienna, Austria

May 2019

IAEA Nuclear Data Section

NUCLEAR DATA NEEDS FOR MEDICAL APPLICATIONS

IAEA meeting in 2018

THREE DISTINCT MEDICAL FIELDS

- Diagnostic radiology
  - 100% diagnostic
- Radiotherapy
  - 100% treatment
- Nuclear medicine
  - 80% diagnostic
  - 10% treatment

Multidisciplinary team: physicians, physicists, radiographers,..

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Radionuclide	Clinical use	Application	Decay mode (used emission)	$T_{\frac{1}{2}}$
^{99m}Tc	~80%	Imaging	IT (γ 140keV)	6.0h
^{133}Xe	~1%	Imaging	β^- (γ 81keV)	5.3d
^{111}In	~1%	Imaging	EC (γ 171, 245keV)	2.8d
^{123}I	~0.5%	Imaging	EC (γ 159keV)	13h
^{201}Tl	~0.1% (↓)	Imaging	EC (γ 135, 167keV)	3.0d
^{51}Cr	~5%	Blood tests	EC (γ 320keV)	28d
^{18}F	~2% (↑)	PET imaging	β^+ (γ 511keV)	110min
^{11}C	~0.6%	PET imaging	β^+ (γ 511keV)	20min
^{15}O	~0.3%	PET imaging	β^+ (γ 511keV)	2.1min
^{124}I	Research	PET imaging	β^+ (γ 511keV)	4.2d
^{131}I	~5%	Therapy	β^- (806keV; γ 364keV)	8.1d
^{32}P	~0.2%	Therapy	β^- (1706keV)	14d
^{153}Sm	~0.2%	Therapy	β^- (810keV; γ 103keV)	47h
^{89}Sr	~0.1%	Therapy	β^- (1480keV)	51d
^{177}Lu	Research	Therapy	β^- (497keV; γ 208keV)	6.6d
^{211}At	Research	Therapy	α (5870, 7450keV)	7.2h

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NUCLEAR DATA FOR RADIOISOTOPE PRODUCTION

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IAEA projects on radioisotopes: Overview

Radioisotopes for medical applications: accelerator and reactor production

I. CRP on "Charged Particle Cross-Section Database for Medical Radioisotope Production: Diagnostic Radioisotopes and Monitor Reactions"-completed in 2002 (updated in 2007)

IAEA-TECDOC-1211

II. CRP on "Nuclear Data for the Production of Therapeutic Radionuclides" 2003-2007

IAEA TRS 473 (2011)

CRP on "CP monitor reactions and nuclear data for non-standard positron emitters", 2012-2017

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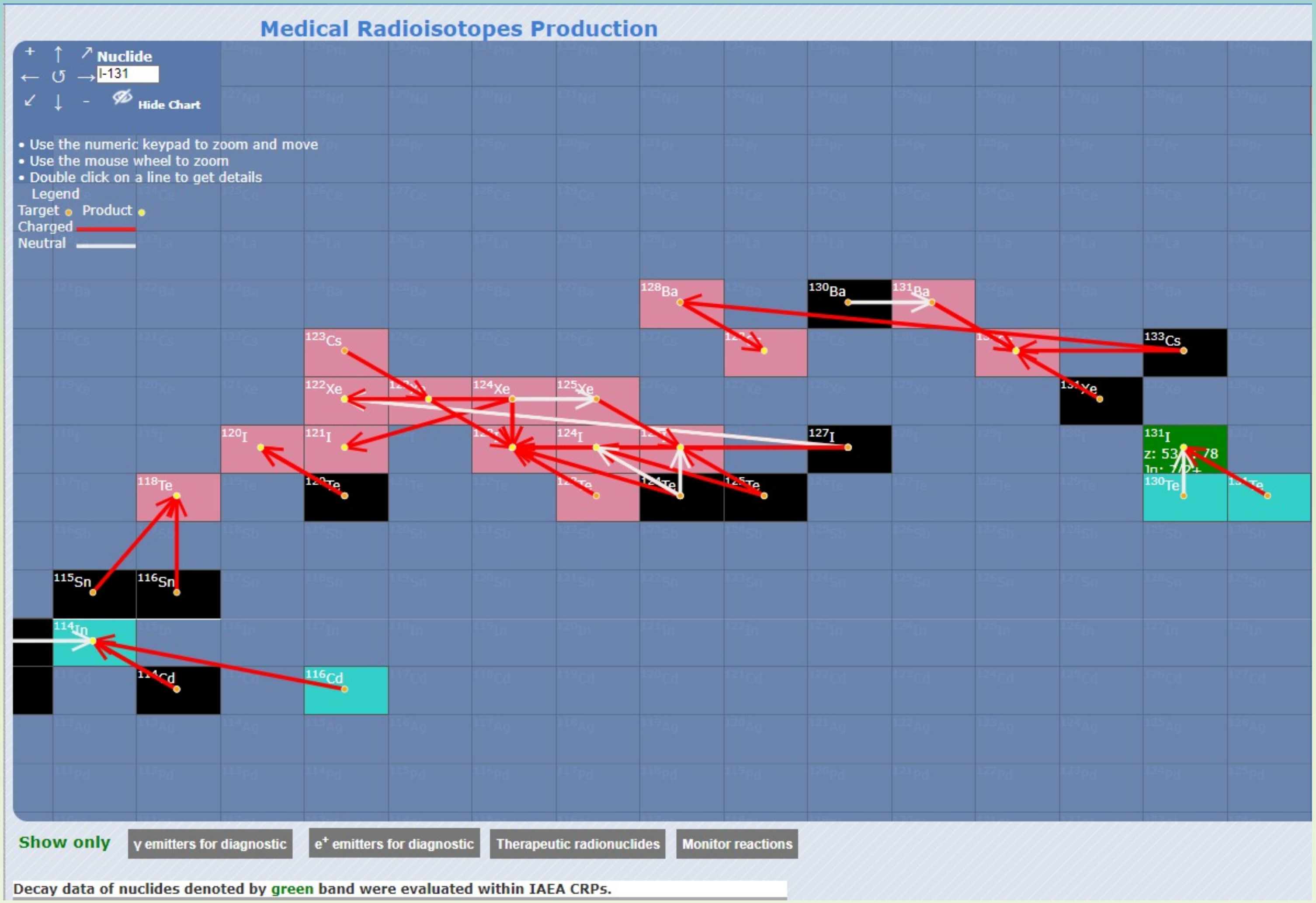
Diagnostic radioisotope production

https://nds.iaea.org/medportal/



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Radioisotope production data

https://nds.iaea.org/relnsd/isotopia/isotopia.html

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Beam monitor reactions (reference XS)

Monitor Reactions 2017

A. Hermanne et al., Nucl. Data Sheets 148 (2018) 338-382

Protons	Deuterons	^{3}He-particles	Alpha-particles
^{27}Al(p,x)^{22}Na	^{27}Al(d,x)^{22}Na	^{27}Al(^{3}He,x)^{22}Na	^{27}Al(α,x)^{22}Na
^{27}Al(p,x)^{24}Na	^{27}Al(d,x)^{24}Na	^{27}Al(^{3}He,x)^{24}Na	^{27}Al(α,x)^{24}Na
^{nat}Ti(p,x)^{48}V	^{nat}Ti(d,x)^{48}V	^{nat}Ti(^{3}He,x)^{48}V	^{nat}Ti(α,x)^{51}Cr
^{nat}Ti(p,x)^{46}Sc	^{nat}Ti(d,x)^{46}Sc	^{nat}Cu(^{3}He,x)^{66}Ga	^{nat}Cu(α,x)^{66}Ga
^{nat}Ni(p,x)^{57}Ni	^{nat}Fe(d,x)^{56}Co	^{nat}Cu(^{3}He,x)^{63}Zn	^{nat}Cu(α,x)^{67}Ga
^{nat}Cu(p,x)^{62}Zn	^{nat}Ni(d,x)^{61}Cu	^{nat}Cu(^{3}He,x)^{65}Zn	^{nat}Cu(α,x)^{65}Zn
^{nat}Cu(p,x)^{63}Zn	^{nat}Ni(d,x)^{56}Co		
^{nat}Cu(p,x)^{65}Zn	^{nat}Ni(d,x)^{58}Co		
^{nat}Cu(p,x)^{56}Co	^{nat}Cu(d,x)^{62}Zn		
^{nat}Cu(p,x)^{58}Co	^{nat}Cu(d,x)^{63}Zn		
^{nat}Mo(p,x)$^{96m+g}$Tc	^{nat}Cu(d,x)^{65}Zn		

Main	Monitor Reactions 2007	Gamma Emitters	Positron Emitters	Therapeutic Isotopes

Last edited by: S. Takacs: Aug. 2019.

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Gamma Emitters

K. Gul et al., IAEA TECDOC 1211, Vienna, 2001
F. T. Tarkanyi et al., J. Radioanal. Nucl. Chem. 319 (2018) 487-531

^{51}Cr

^{51}V(p,n)^{51}Cr
^{51}V(d,2n)^{51}Cr
^{55}Mn(p,x)^{51}Cr
^{55}Mn(d,x)^{51}Cr
^{nat}Fe(p,x)^{51}Cr
^{nat}Ti(α,x)^{51}Cr

^{99m}Tc

^{100}Mo(p,x)^{99}Mo
^{100}Mo(d,x)^{99}Mo
^{100}Mo(p,2n)^{99m}Tc
^{100}Mo(d,3n)^{99m}Tc
^{100}Mo(γ,n)^{99}Mo
^{98}Mo(n,γ)^{99}Mo
^{100}Mo(n,2n)^{99}Mo
^{238}U(γ,f)^{99}Mo

^{123}I

^{123}Te(p,n)^{123}I
^{124}Te(p,2n)^{123}I
^{124}Te(p,n)^{124}I
^{127}I(p,5n)^{123}Xe
^{127}I(p,3n)^{125}Xe
^{124}Xe(p,2n)^{123}Cs
^{124}Xe(p,pn)^{123}Xe
^{124}Xe(p,x)^{123}Xe
^{124}Xe(p,x)^{121}I

^{201}Pb

^{203}Tl(p,3n)^{201}Pb
^{203}Tl(p,4n)^{200}Pb
^{203}Tl(p,2n)^{202m}Pb

^{67}Ga

^{67}Zn(p,n)^{67}Ga
^{68}Zn(p,2n)^{67}Ga

^{81}Rb

^{82}Kr(p,2n)^{81}Rb
^{nat}Kr(p,x)^{81}Rb

^{111}In

^{111}Cd(p,n)^{111}In
^{112}Cd(p,2n)^{111}In

^{178}W

^{181}Ta(p,4n)^{178}W
^{181}Ta(p,4n)^{178}W
^{181}Ta(p,4n)^{178}W

Main	Monitor Reactions 2017	Monitor Reactions 2007	Positron Emitters	Therapeutic Isotopes

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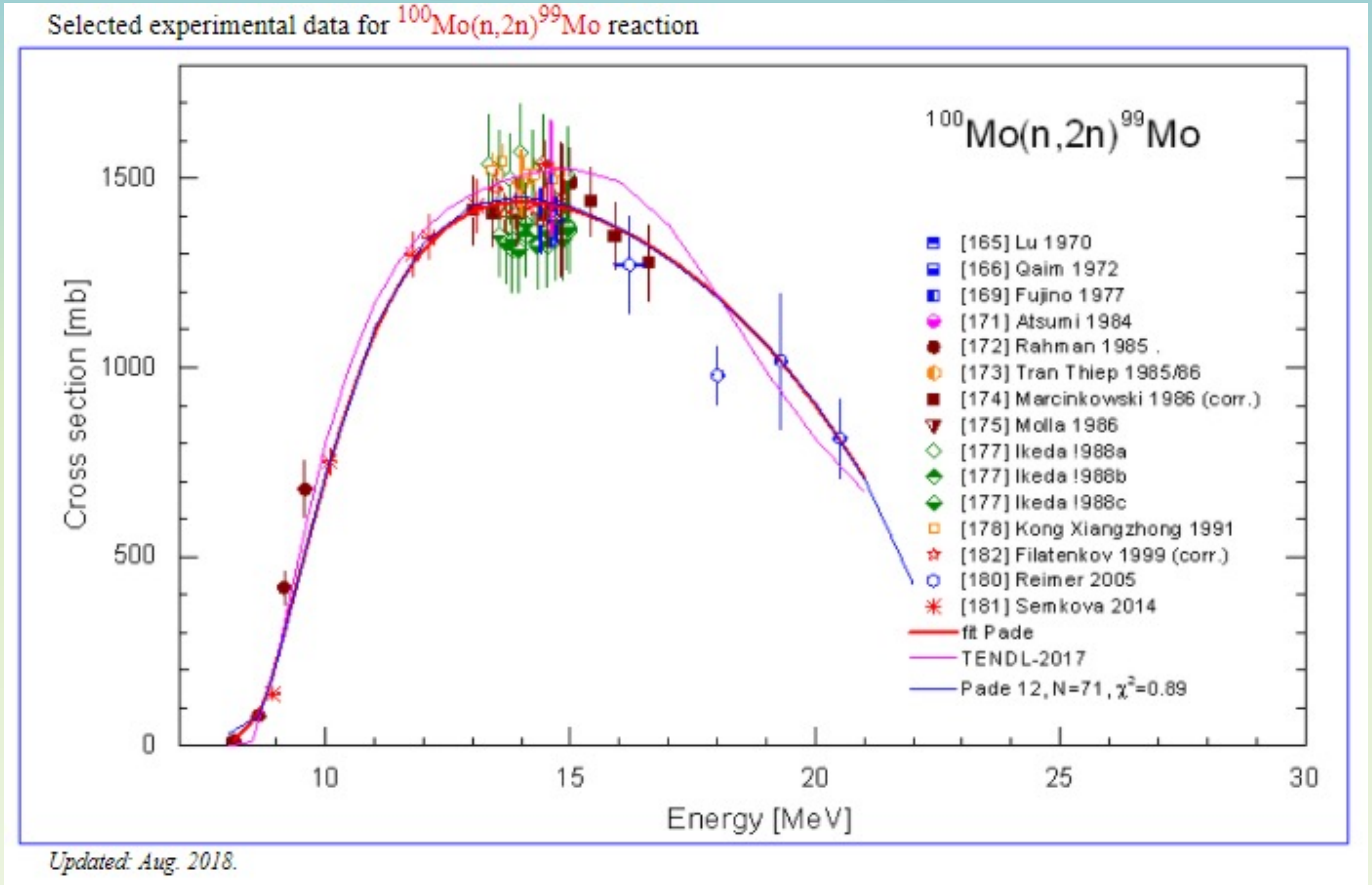
Mo-99 production via (n,2n) reaction (deployed in Japan)



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Positron Emitters

K. Gul et al., IAEA TECDOC 1211, Vienna, 2001
F.T. Tarkanyi et al., J. Radioanalytical and Nucl. Chem. (2019) 319. 533-666

^{11}C
^{14}N(p,α)^{11}C

^{13}N
^{16}O(p,α)^{13}N

^{15}O
^{15}N(p,n)^{15}O
^{14}N(d,n)^{15}O

^{18}F
^{18}O(p,n)^{18}F
^{nat}Ne(d,x)^{18}F

^{44}Sc
^{44}Ca(p,n)^{44}Sc
^{44}Ca(d,2n)^{44}Sc
^{43}Ca(d,n)^{44}Sc
^{45}Sc(p,2n)^{44}Ti
^{45}Sc(d,3n)^{44}Ti

^{52m}Mn
^{nat}Ni(p,x)^{52}Fe
^{55}Mn(p,4n)^{52}Fe
^{50}Cr(α,2n)^{52}Fe
^{52}Cr(p,n)^{52m}Mn
^{52}Cr(d,2n)^{52m}Mn

^{52}Mn
^{52}Cr(p,n)^{52}Mn
^{52}Cr(d,2n)^{52}Mn

^{55}Co
^{58}Ni(p,α)^{55}Co
^{54}Fe(d,n)^{55}Co
^{56}Fe(p,2n)^{55}Co

^{61}Cu
^{61}Ni(p,n)^{61}Cu
^{60}Ni(d,n)^{61}Cu
^{64}Zn(p,α)^{61}Cu

^{62}Cu
^{63}Cu(p,2n)^{62}Zn
^{63}Cu(d,3n)^{62}Zn
^{nat}Ni(α,x)^{62}Zn
^{62}Ni(p,n)^{62}Cu
^{62}Ni(d,2n)^{62}Cu

^{66}Ga
^{66}Zn(p,n)^{66}Ga
^{63}Cu(α,n)^{66}Ga

^{68}Ga
^{68}Zn(p,n)^{68}Ga
^{65}Cu(α,n)^{68}Ga
^{nat}Ga(p,x)^{68}Ge
^{69}Ga(p,2n)^{68}Ge

^{72}As
^{75}As(p,4n)^{72}Se
^{nat}Br(p,x)^{72}Se
^{nat}Ge(p,x)^{72}As
^{nat}Ge(d,x)^{72}As

^{73}Se
^{75}As(p,3n)^{73}Se
^{72}Ge(α,3n)^{73}Se

^{76}Br
^{76}Se(p,n)^{76}Br
^{77}Se(p,2n)^{76}Br
^{75}As(α,3n)^{76}Br

^{82m}Rb
^{82}Kr(p,n)^{82m}Rb
^{82}Kr(d,2n)^{82m}Rb

^{82}Rb
^{nat}Rb(p,x)^{82}Sr
^{85}Rb(p,4n)^{82}Sr

^{86}Y
^{86}Sr(p,n)^{86}Y
^{88}Sr(p,3n)^{86}Y
^{85}Rb(α,3n)^{86}Y

^{89}Zr
^{89}Y(p,n)^{89}Zr
^{89}Y(d,2n)^{89}Zr

^{90}Nb
^{93}Nb(p,x)^{90}Nb
^{89}Y(α,3n)^{90}Nb

^{94m}Tc
^{92}Mo(α,x)^{94m}Tc
^{94}Mo(p,n)^{94m}Tc

^{110m}In
^{nat}In(p,x)^{110}Sn
^{108}Cd(α,2n)^{110}Sn
^{110}Cd(p,n)^{110m}In
^{110}Cd(d,2n)^{110m}In
^{107}Ag(α,n)^{110m}In

^{118}Sb
^{115}Sn(α,n)^{118}Te
^{116}Sn(α,2n)^{118}Te
^{nat}Sb(p,x)^{118}Te
^{nat}Sb(d,x)^{118}Te

^{120}I
^{120}Te(p,n)^{120}I
^{122}Te(p,3n)^{120}I

^{122}I
^{124}Xe(p,x)^{122}Xe
^{127}I(p,6n)^{122}Xe
^{127}I(d,7n)^{122}Xe

^{128}Cs
^{133}Cs(p,6n)^{128}Ba

^{140}Pr
^{141}Pr(p,2n)^{140}Nd
^{141}Pr(d,3n)^{140}Nd
^{nat}Ce(^{3}He,x)^{140}Nd

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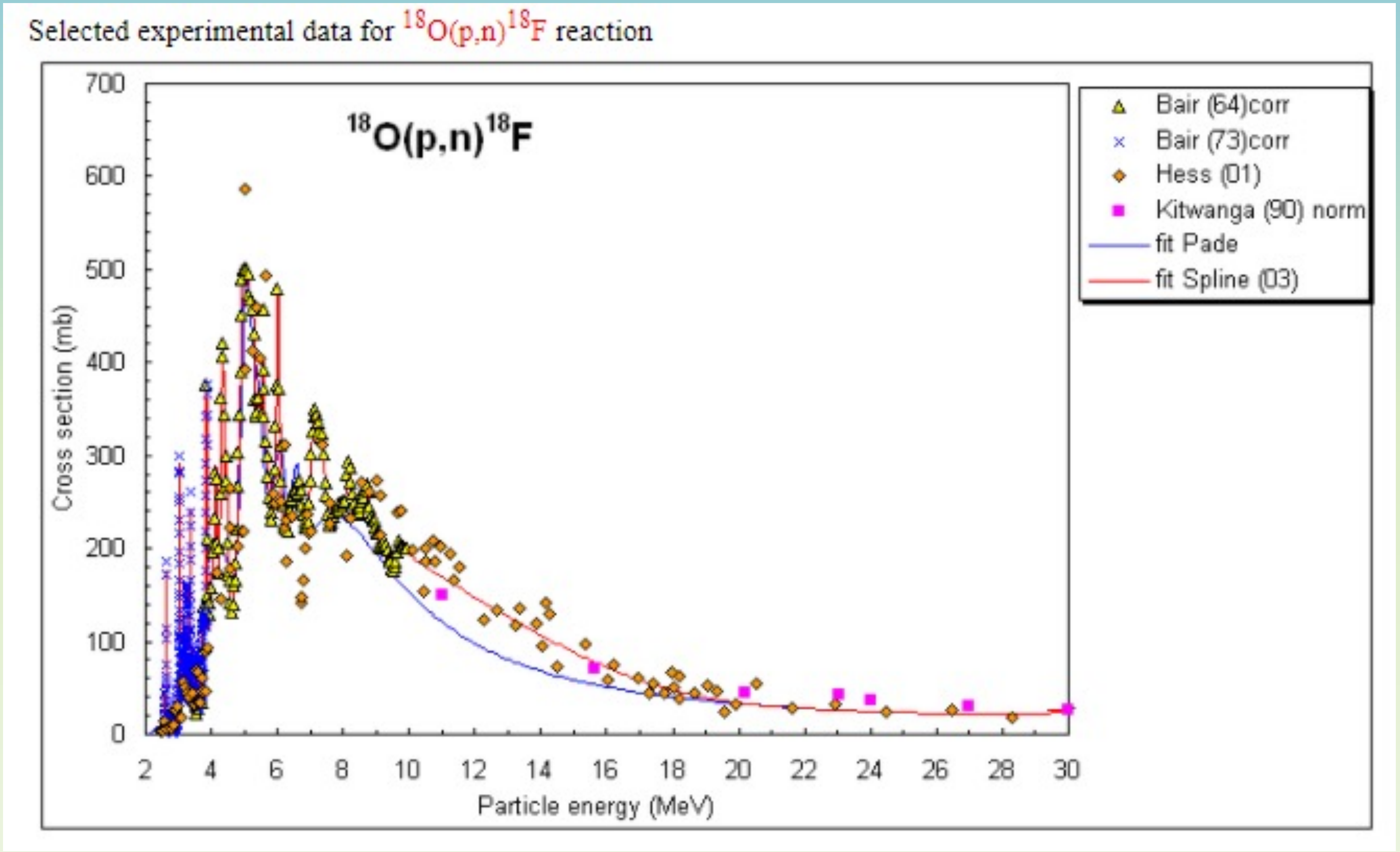
F-18 production in small cyclotrons



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Therapeutic Radionuclides

E. Betak et al., IAEA Technical Reports Series no. 473, Vienna, 2011
J.W. Engle et al., Nuclear Data Sheets 155 (2019) 56-74

^{64}Cu
^{64}Ni(p,n)^{64}Cu
^{64}Ni(d,2n)^{64}Cu
^{68}Zn(p,x)^{64}Cu
^{nat}Zn(d,x)^{64}Cu

^{67}Cu
^{68}Zn(p,2p)^{67}Cu
^{70}Zn(p,x)^{67}Cu

^{67}Ga
^{67}Zn(p,n)^{67}Ga
^{68}Zn(p,2n)^{67}Ga

^{86}Y
^{86}Sr(p,n)^{86}Y

^{103}Pd
^{103}Rh(p,n)^{103}Pd
^{103}Rh(p,x)^{102}Rh
^{103}Rh(d,2n)^{103}Pd
^{103}Rh(d,x)^{102}Rh

^{111}In
^{111}Cd(p,n)^{111}In
^{112}Cd(p,2n)^{111}In

^{114m}In
^{114}Cd(p,n)^{114m}In
^{114}Cd(d,2n)^{114m}In
^{116}Cd(p,3n)^{114m}In

^{124}I
^{124}Te(p,n)^{124}I
^{125}Te(p,2n)^{124}I
^{124}Te(d,2n)^{124}I

^{125}I
^{125}Te(p,n)^{125}I
^{124}Te(d,n)^{125}I

^{169}Yb
^{169}Tm(p,n)^{169}Yb
^{169}Tm(d,2n)^{169}Yb

^{177}Lu
^{176}Yb(d,n)^{177g}Lu
^{176}Yb(d,p)^{177}Yb
^{176}Yb(d,x)^{177g}Lu

^{186}Re
^{186}W(p,n)^{186}Re
^{186}W(d,2n)^{186}Re

^{192}Ir
^{192}Os(p,n)^{192}Ir
^{192}Os(d,2n)^{192}Ir

^{211}At
^{209}Bi(α,2n)^{211}At
^{209}Bi(α,3n)^{210}At

^{131}Cs
^{131}Xe(p,n)^{131}Cs
^{133}Cs(p,3n)^{131}Ba

^{225}Ac
^{232}Th(p,x)^{225}Ac
^{226}Ra(p,2n)^{225}Ac
^{232}Th(p,x)^{225}Ra

^{227}Th
^{232}Th(p,x)^{227}Th
^{232}Th(p,x)^{227}Ac

^{230}U
^{231}Pa(p,2n)^{230}U
^{231}Pa(d,3n)^{230}U
^{232}Th(p,3n)^{230}Pa

Main	Monitor Reactions 2017	Monitor Reactions 2007	Gamma Emitters	Positron Emitters

Last edited by: S. Takacs: Aug. 2019.

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(n,γ)		Neutron data for production in a nuclear reactor
(n,f)	–	production of neutron excess radionuclides
(n,p)	–	experimental data and comparison with theory
(p,xn)		Charged-particle data for production at a cyclotron
(d,xn)	–	production of neutron deficient radionuclides
(α,xn)	–	crucial role of nuclear data to check impurities
(^{3}He,xn)	–	experimental data and comparison with theory

ESTABLISHED: ^{89}Sr, ^{90}Y, ^{131}I, ^{153}Sm, ^{186}Re, ^{188}Re
^{32}P, ^{125}I, ^{103}Pd, ^{137}Cs, ^{192}Ir (brachytherapy)

EMERGING: ^{64}Cu, ^{67}Cu, ^{67}Ga, ^{86}Y, ^{105}Rh, ^{111}In, ^{114m}In,
^{124}I, ^{149}Pm, ^{166}Ho, ^{169}Y, ^{177}Lu
^{211}At, ^{213}Bi, ^{225}Ac (α emitters)

Nuclear Data for the Production of Therapeutic Radionuclides

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REACTORS

Neutron-induced reactions

(n,γ)

(n,p)

(n,f)

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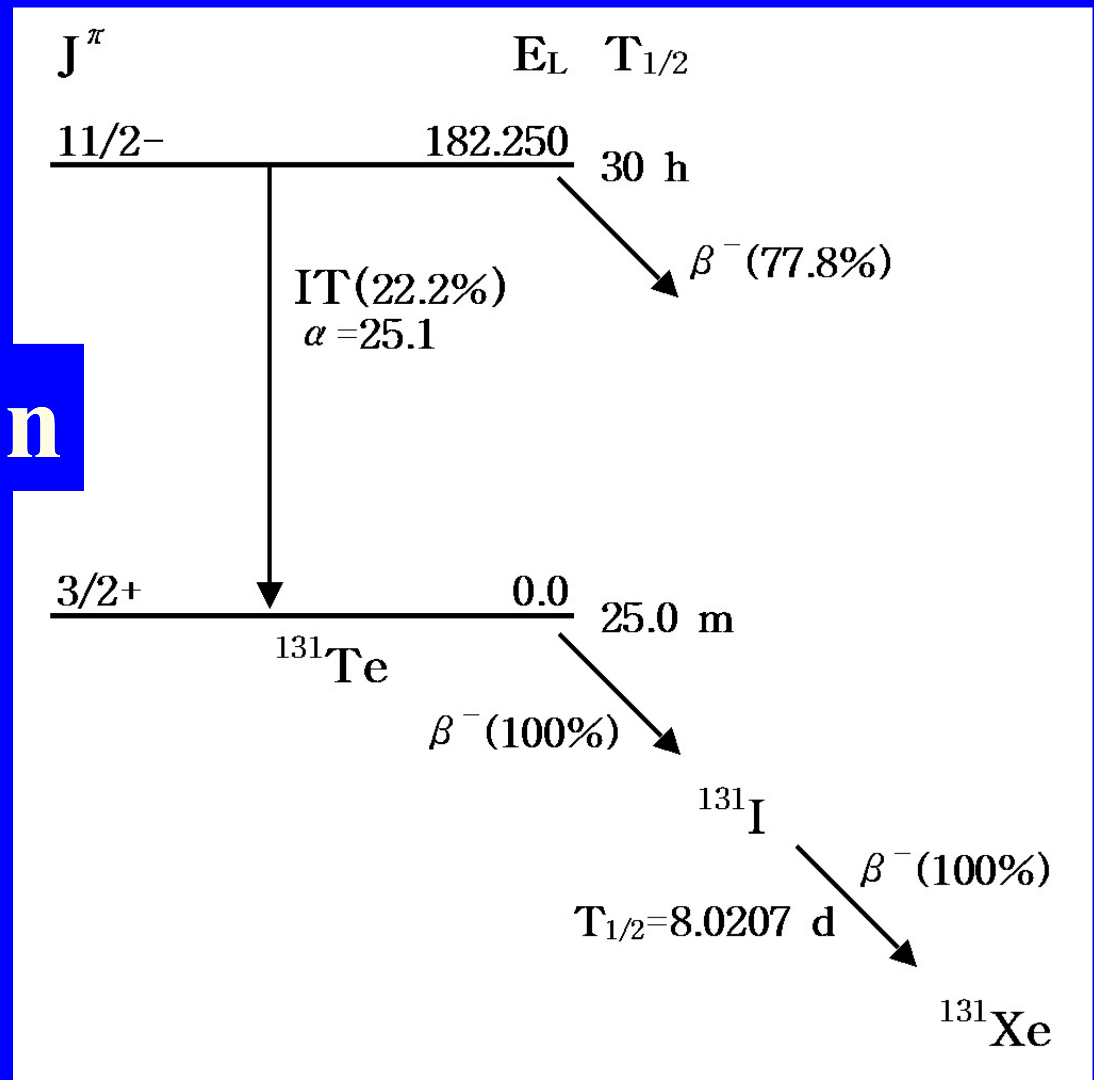
$^{130}Te(n,\gamma)^{131}Te \longrightarrow {}^{131}I$ reaction



^{131}I production

ENSDF data

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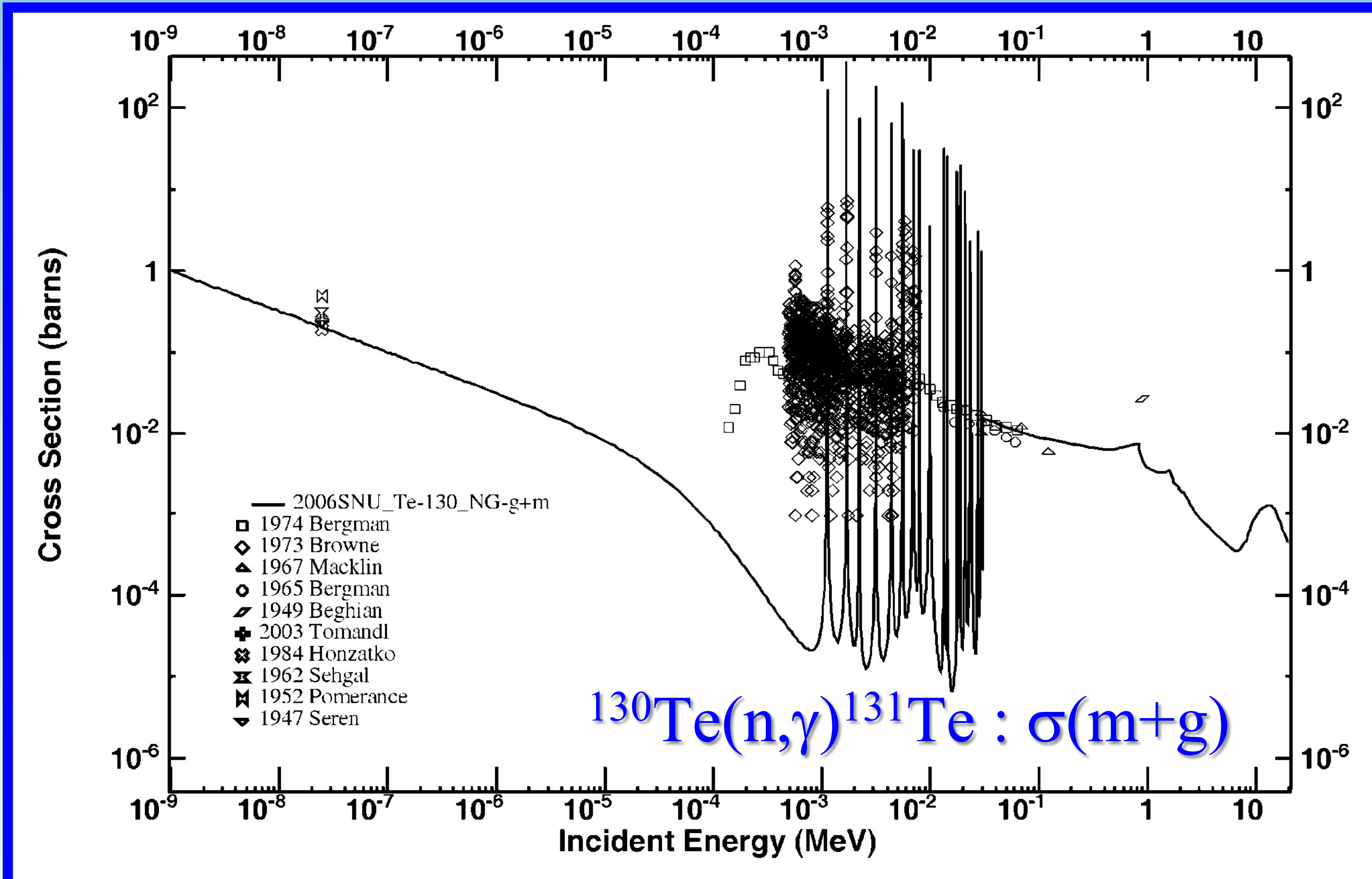
$^{130}Te(n,\gamma)^{131}Te \longrightarrow {}^{131}I$ reaction



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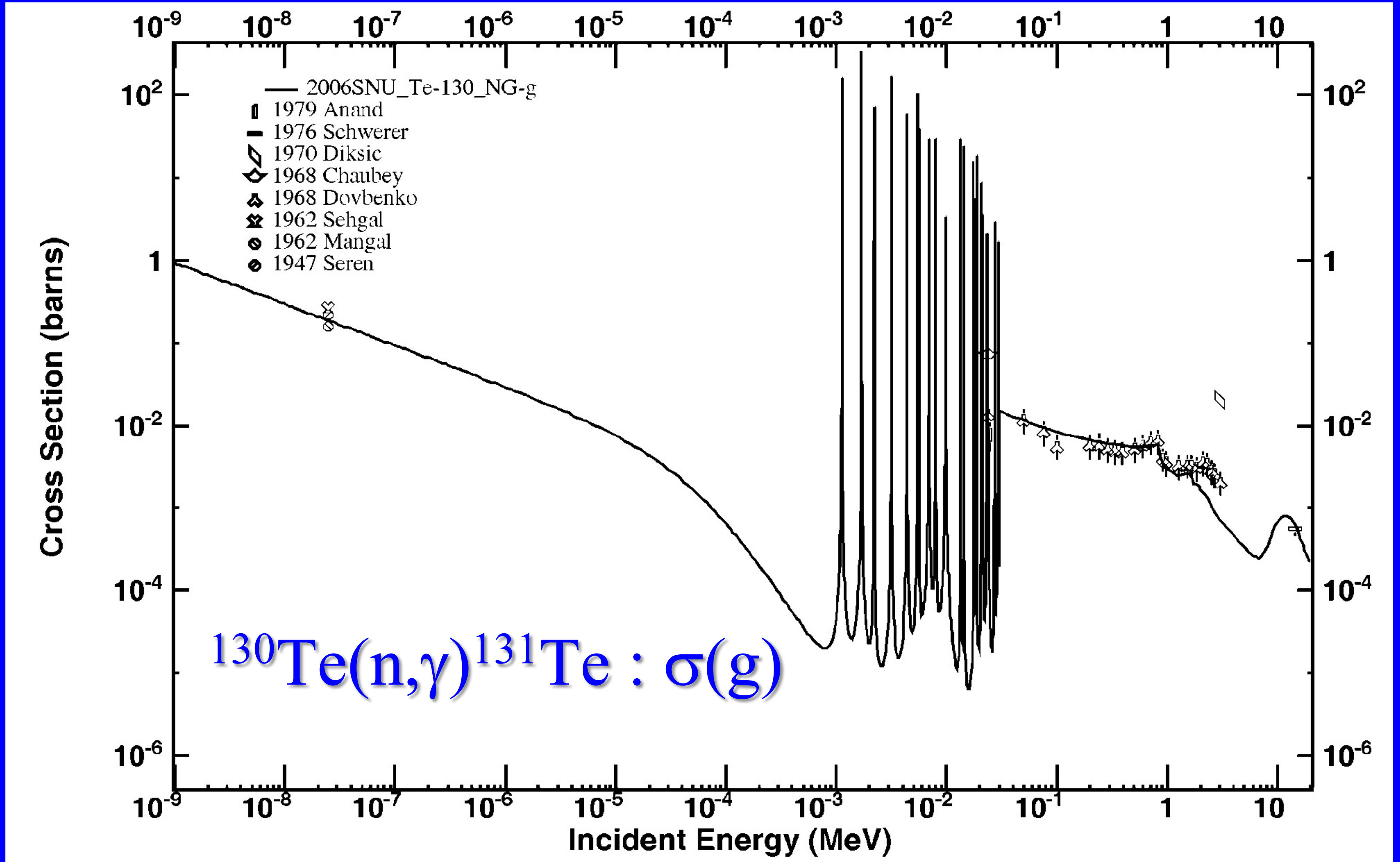
$^{130}Te(n,\gamma)^{131}Te \longrightarrow {}^{131}I$ reaction



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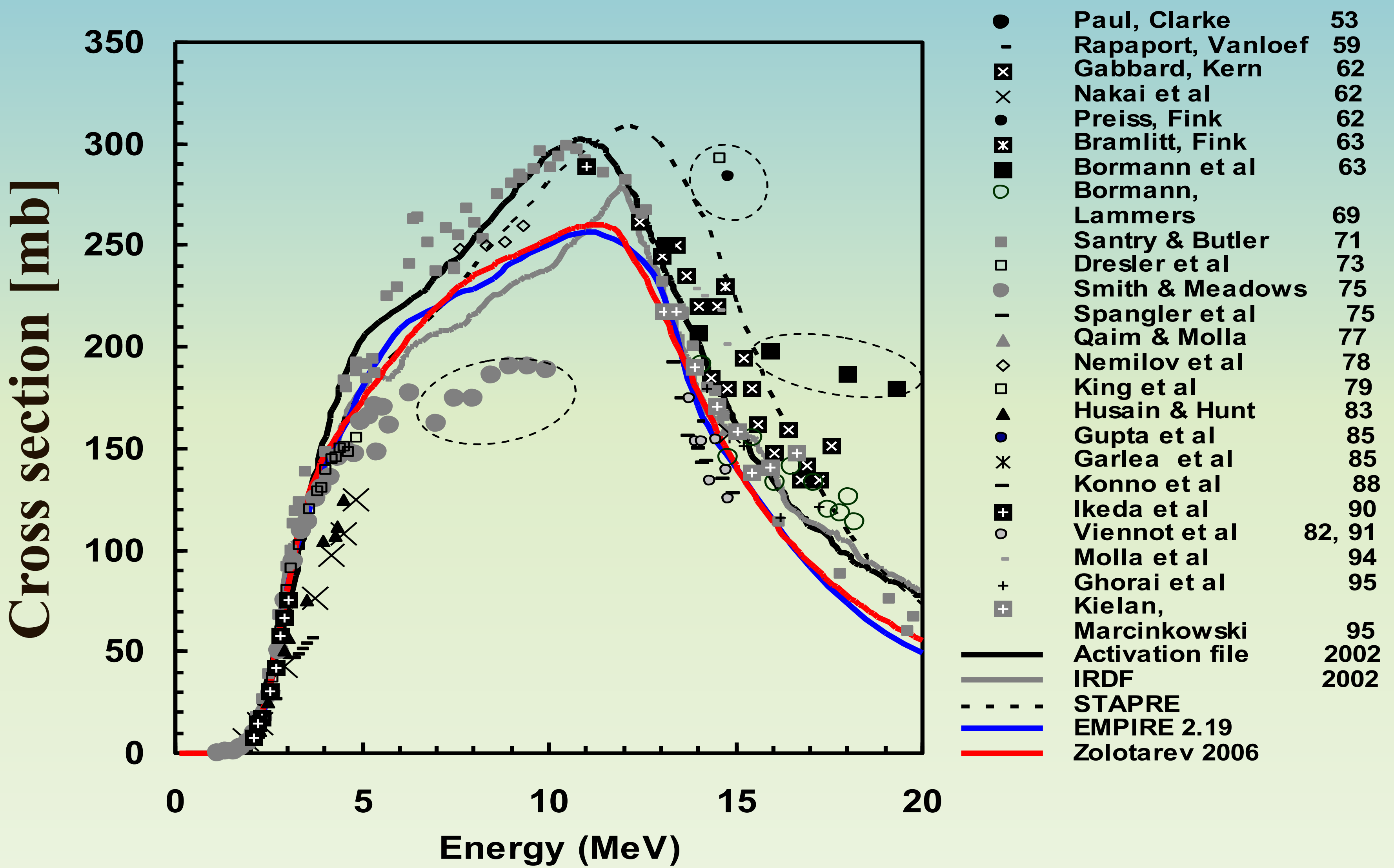
$^{64}Zn(n,p)^{64}Cu$ (raw EXFOR data)



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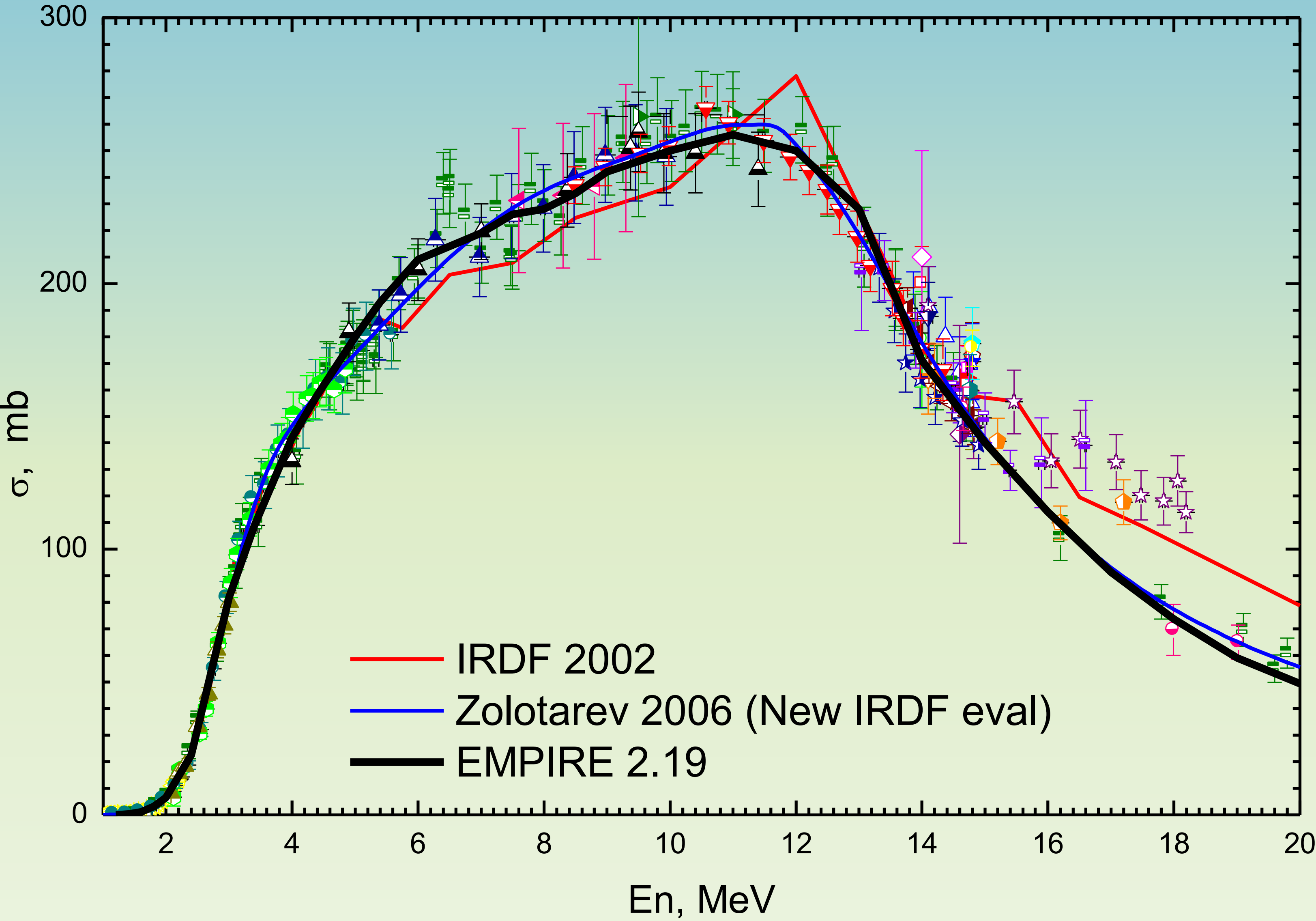
Zn(n,p) Cu reaction (evaluation)



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^{64}Zn(n,p)^{64}Cu reaction

Integral Validation

Neutron fields	Average cross section, mb		C/E
	Calculated [A]	Measured [*]	
^{235}U thermal fission neutron spectrum	38.9 ± 0.7 (1.7%)	38.9 ± 2.8	1.000
^{252}Cf spontaneous fission neutron spectrum	42.7 ± 0.80 (1.9%)	42.3 ± 0.9	1.009

[A] – Zolotarev, INDC(NDS)-0526, Vienna, Austria

[*] – evaluated experimental cross section

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summary on RN production

- Experimental **data compilations** and **data selection**, **theoretical calculations** and the **final evaluations** for each of the reactions producing therapeutic radionuclides, have been undertaken
- Data will help to define **strategies for the production of radioisotopes** both at cyclotrons and reactors
- The resulting **completeness** and **accuracy** of the **cross-section data** for the production of these nuclides, along with a re-definition of their **decay data**, should be extremely beneficial in ensuring their **safe and efficient application** both in nuclear medicine and cancer therapy.

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HEAVY CHARGED PARTICLE INTERACTIONS FOR RADIOTHERAPY

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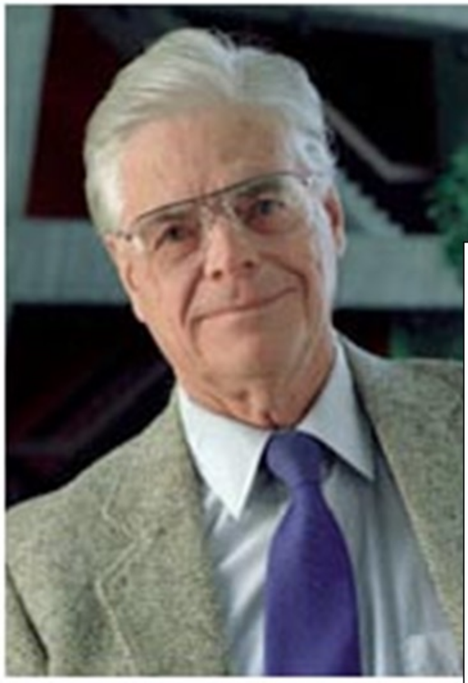
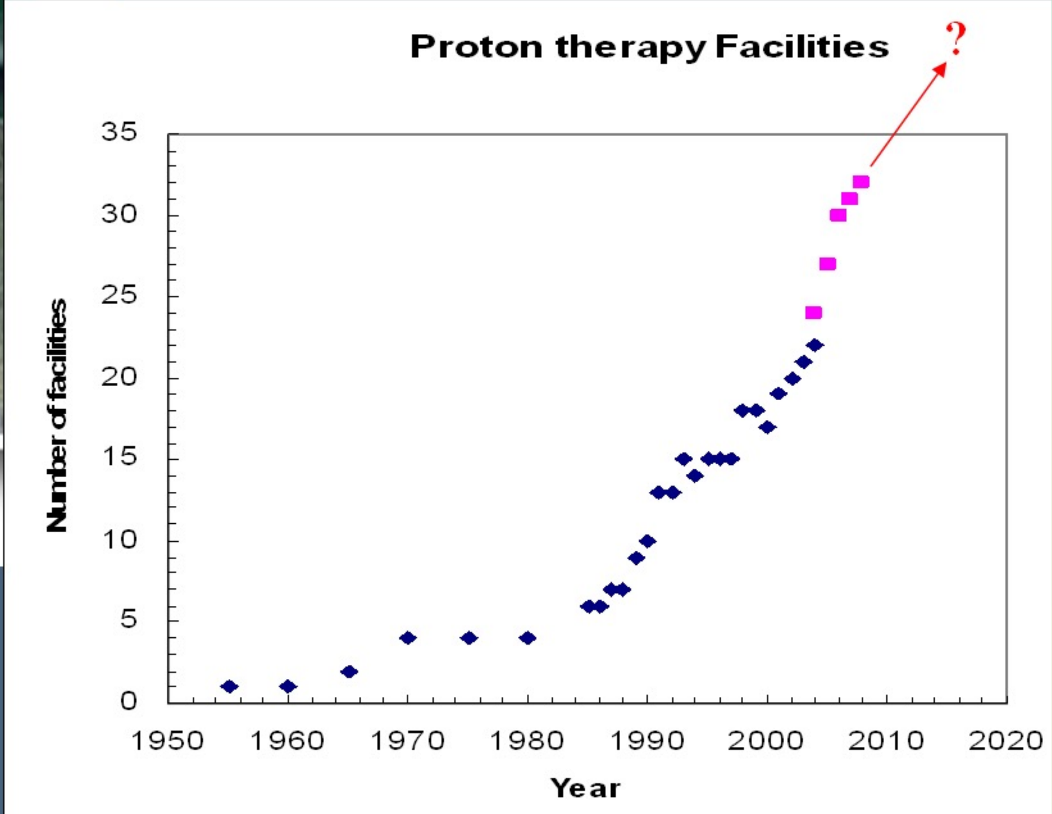
In 1946 Harvard physicist Robert Wilson (1914-2000) suggested that protons can be used clinically



Robert Wilson



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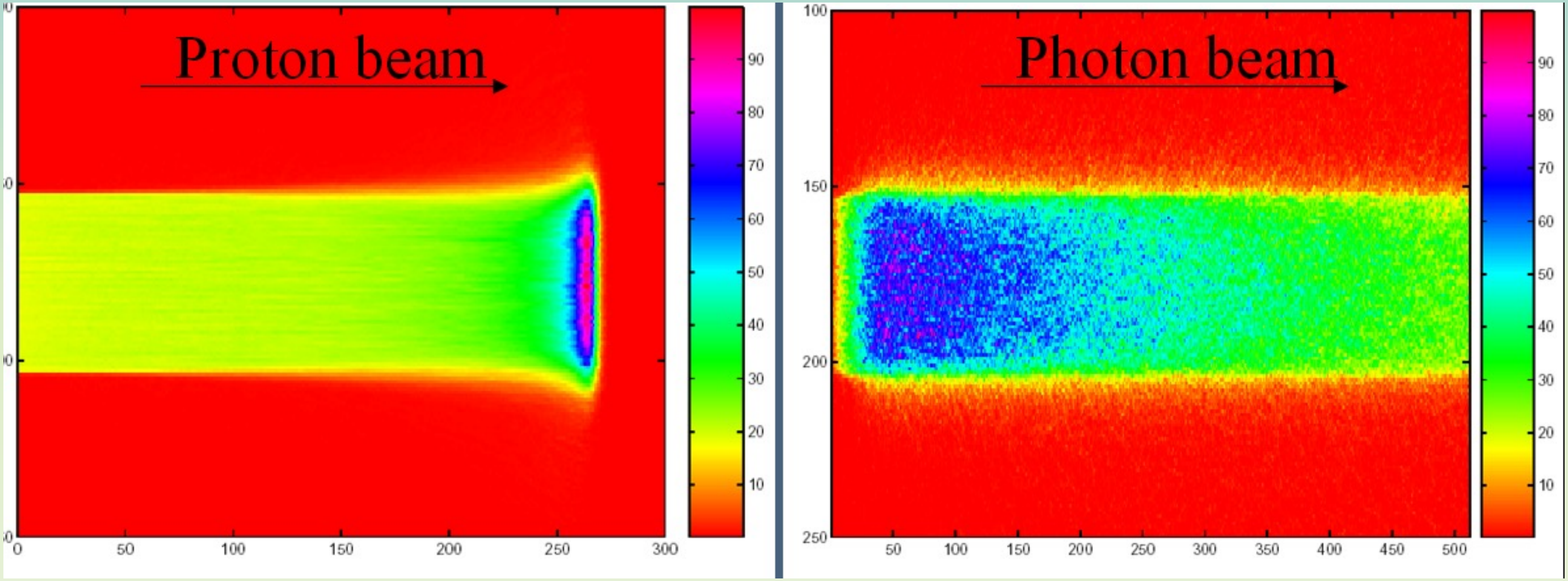
Protons vs Photons



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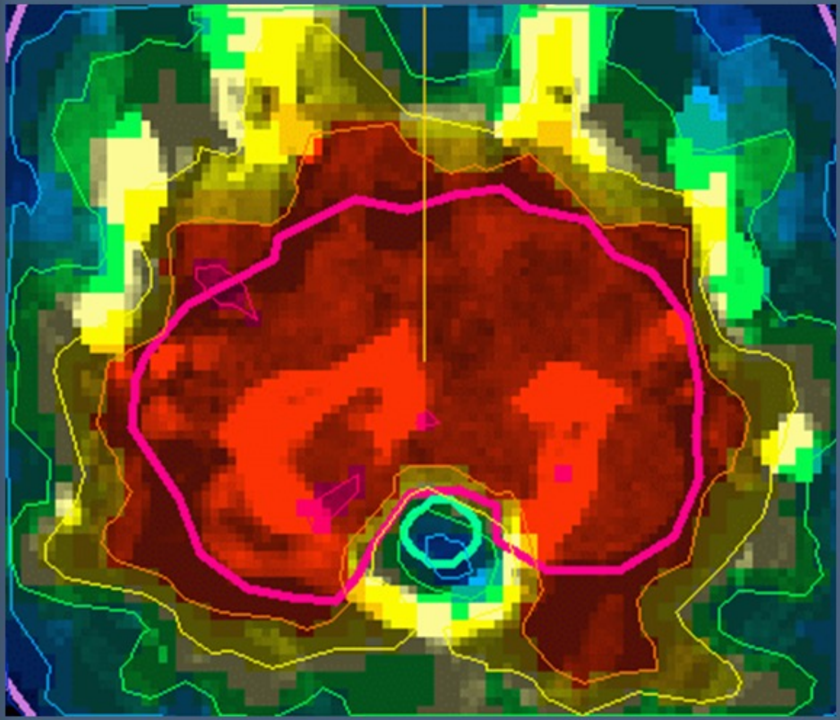
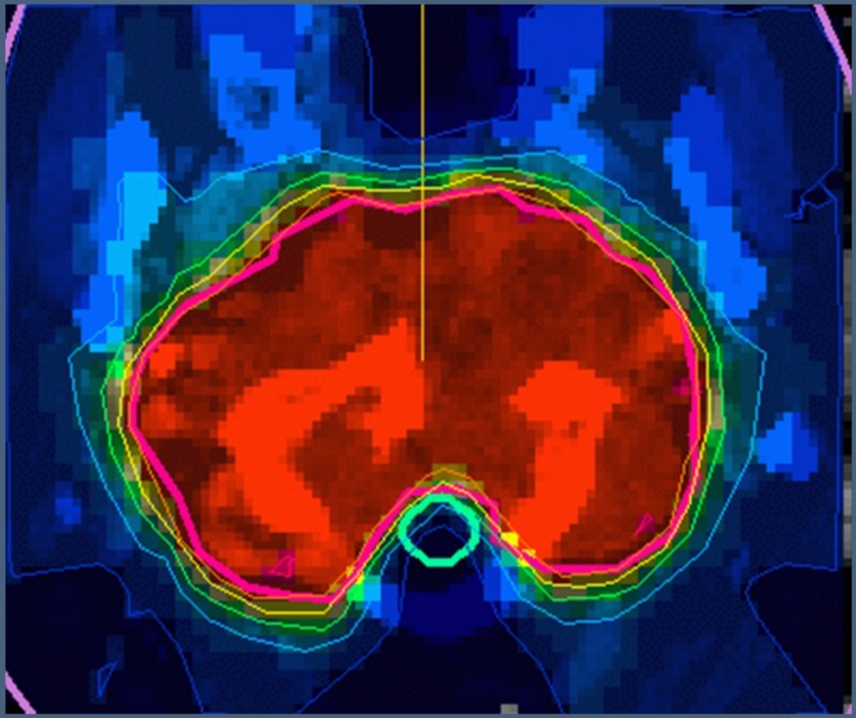
Special case: Paediatric patients





Photon integral dose is higher by a factor of 2-3 !

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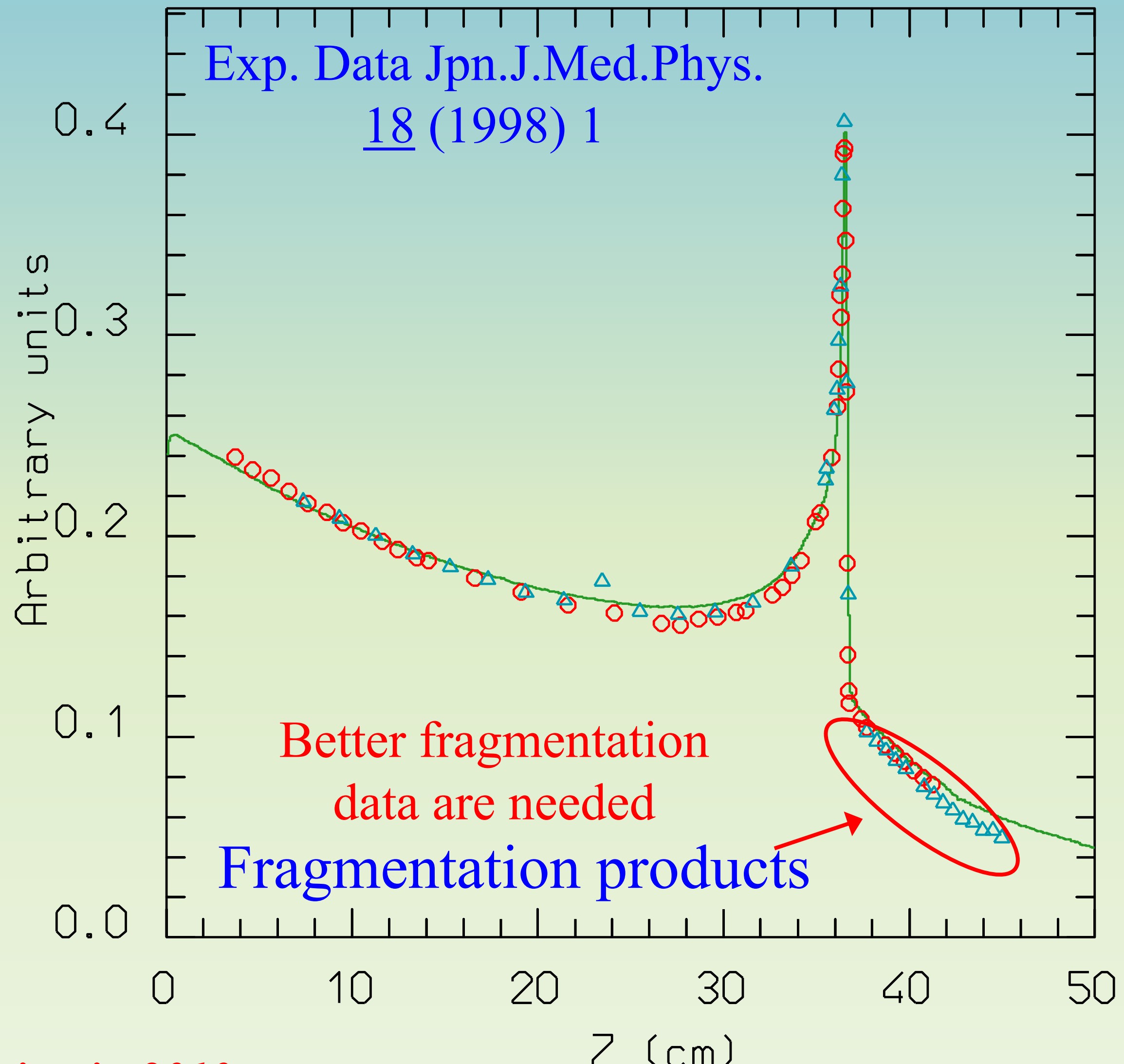
Bragg peaks vs exp. : ^{20}Ne @ 670 MeV/n

Dose vs depth distribution for 670 MeV/n ^{20}Ne ions on a water phantom.
The green line is the FLUKA prediction
The symbols are exp data from LBL and GSI



Taken from A. Ferrari presentation in 2010

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PROBLEMS IN EVALUATED GAMMA SPECTRA

Nuclear data needs of gamma spectra (D. Lawrence & P. Peplowski)

- Carbon sequestration ()
- Active neutron interrogation (C. Romano et al)
- Non-proliferation applications (D. Matters)
- Planetary science (T. Prettyman et al)
- Subsurface exploration (M.-L.Mauborgne et al)
- Shielding and criticality safety (Miller et al.)

see WANDA 2021 presentations at:

https://conferences.lbl.gov/event/504/

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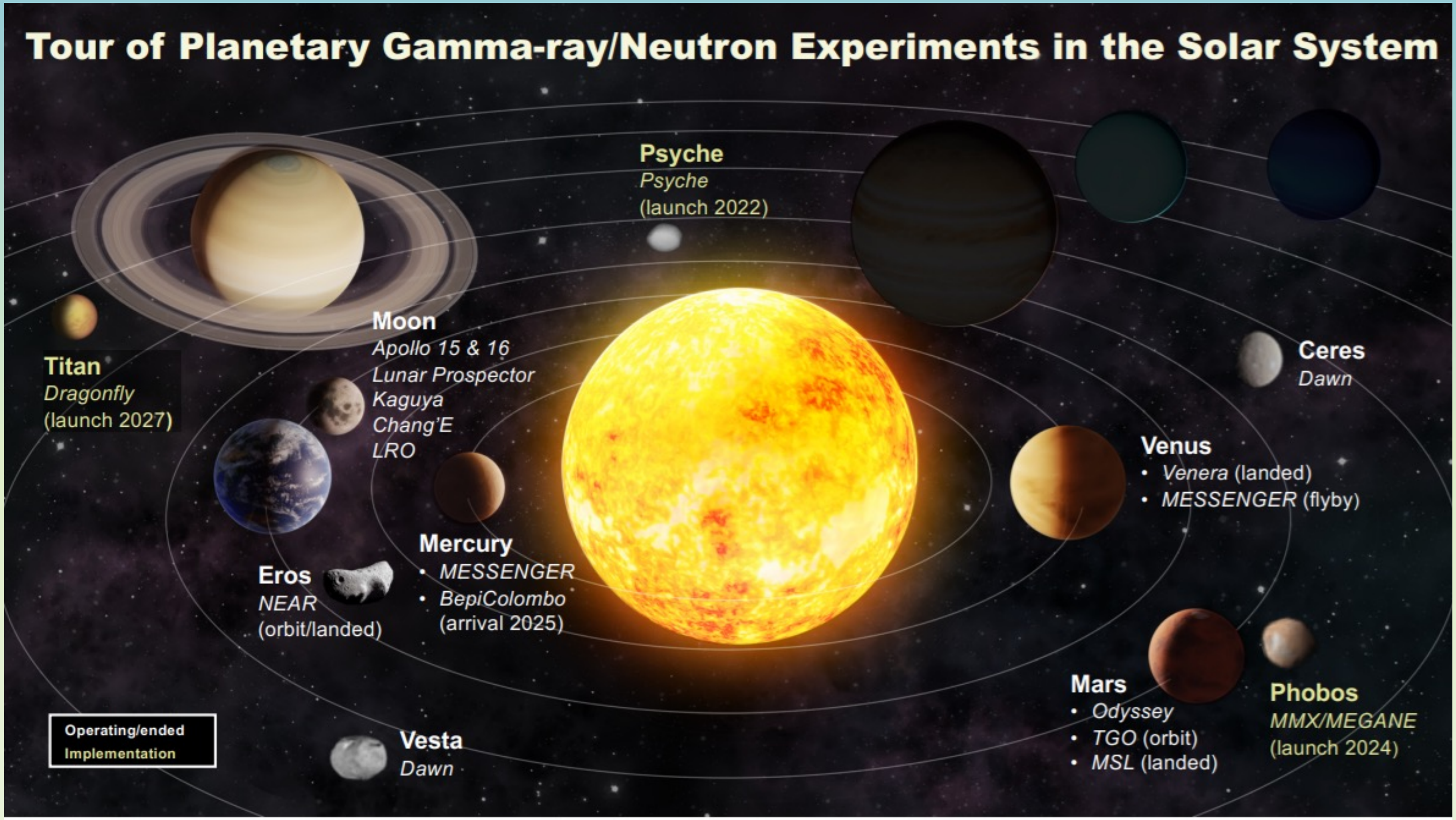
ND needs in planetary gamma spectroscopy



Taken from WANDA 2021 presentation by D. Lawrence and P. Peplowski

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ND needs in planetary gamma spectroscopy

Elements of Interest

- The needs of the planetary nuclear spectroscopy community are:
  - (n,n'γ) and (n,γ) gamma-ray production cross sections,
  - on natural targets of major and minor elements,
  - for each gamma-ray emission of interest,
  - over a wide range of neutron energies.
- This information needs to be accurately provided for use in radiation transport codes (Geant4, MCNP6) via appropriate libraries.
  - To date, no one library works for all gamma-ray lines.
  - New does not mean better – benchmarks show that ENDF VI is better than ENDF VIII!
- The list to the right shows the required element measurements for the three APL-led gamma-ray spectroscopy investigations currently in development.
  - It is complete in terms of elements, but it is not exhaustive in terms of gamma rays.
  - It also doesn't cover the needs of prior missions.
  - The list is not meant to imply that we do or don't have the data we need for these elements.

	Typical Gamma Rays (non-inclusive list)	Psyche GRS (Asteroid 16 Psyche)	MEGANE (Mars' Moon Phobos)	DraGNS (Saturn's Moon Titan)
H	(n,γ): 2223 keV		Y	Y
C	(n,n' γ): 4438 keV			Y
N	(n,n' γ): 2312 keV			Y
O	(n,n' γ): 6129 keV (n,n' αγ): 4438 keV		Y	Y
Na	(n,n' γ): 440 keV		Y	Y
Mg	(n,n' γ): 1369 keV		Y	Y
Al	(n,n' γ): 843, 1014, 2211 keV	Y		
Si	(n,n' γ): 1778 keV (n,γ): 3539, 4934 keV	Y	Y	
P	(n,n' γ) 2233 keV			Y
S	(n,n' γ) 2232 keV	Y		Y
Cl	(n,γ) 1951, 1960, 6111 keV			Y
K	(n,n' γ) 2814 keV		Y	Y
Ca	(n,n' γ) 1940 keV (n,γ) 3736 keV	Y	Y	
Fe	(n,n' γ): 846, 1238, 1408, 1809 keV (n,γ): 7631, 7646, keV	Y	Y	
Ni	(n,n' γ): 1332, 1454 keV	Y		

Taken from WANDA 2021 presentation by D. Lawrence and P. Peplowski

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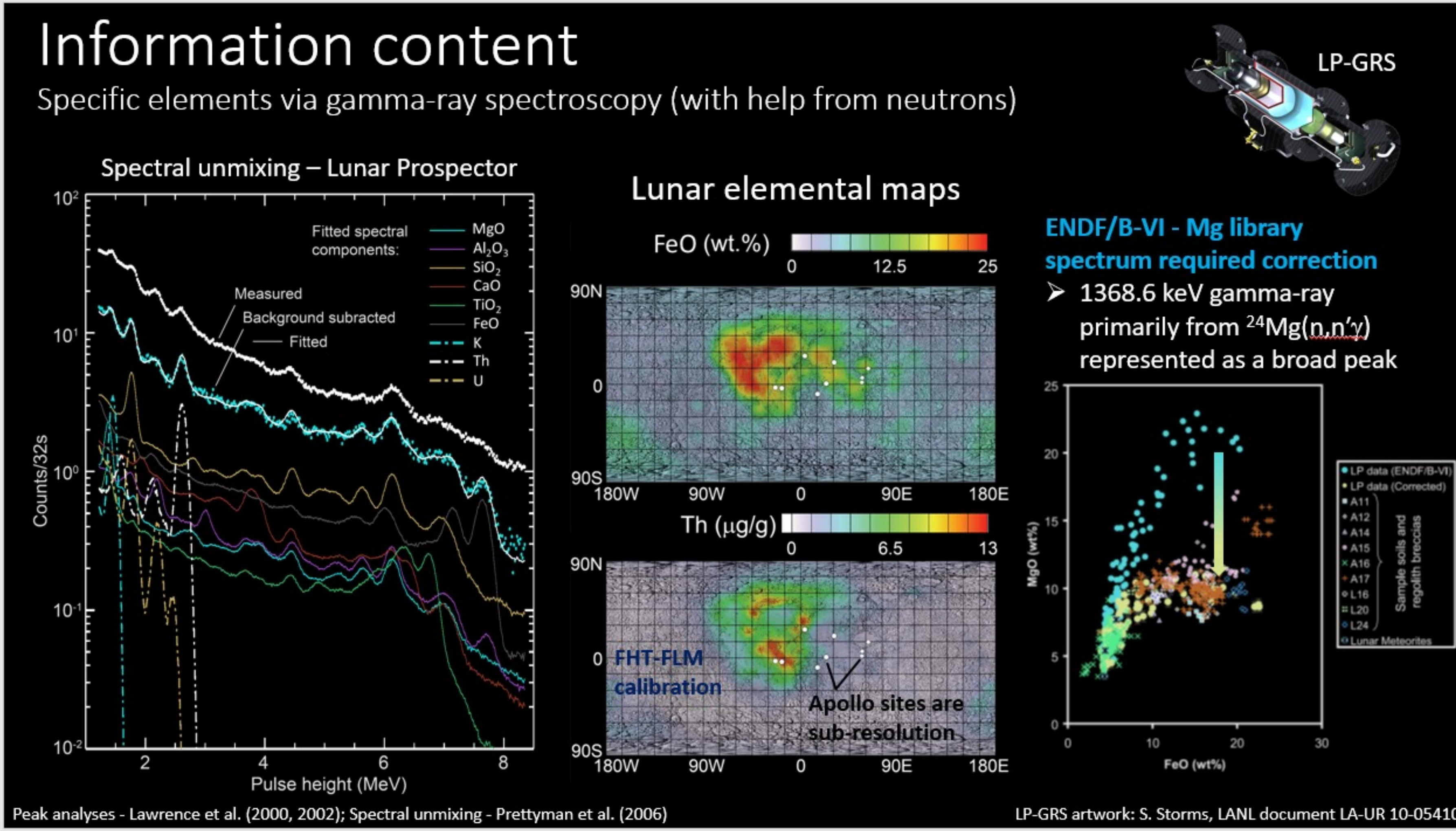
ND needs in planetary gamma spectroscopy



Taken from WANDA 2021 presentation by T. Prettyman

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ND needs in planetary gamma spectroscopy

U.S. DEPARTMENT OF ENERGY

Benchmark Data Needs

NNSA National Nuclear Security Administration

NA-22 has needs for improved benchmark data on a variety of elements that comprise structural and shielding materials, controlled or dangerous substances, and detector materials

- Active neutron interrogation techniques are employed in a variety of nonproliferation applications
- Modeling of secondary γ-ray emission from active neutron interrogation would benefit greatly from quality assurance checks with benchmark datasets
- Improved γ-production cross sections are needed on priority elements
- Benchmark data are primarily required from radiative capture (n,γ) and inelastic scattering (n,n'γ), depending on which cross sections dominate γ-ray production

First Priority	Follow-up	Remaining	
H	He	F	Gd
C	Li	Mg	Bi
N	Be	P	Np
O	B	S	Am
Na	Cl	Ar	
Al	Cr	K	
Si	Mn	Ca	
Fe	Ni	Ti	
Cu	Ge	As	
Pb	Br	Kr	
W	Cd	Mo	
U	I	Sn	
Pu	Cs	Sb	
	La	Xe	

6

Taken from WANDA 2021 presentation by D. Matters

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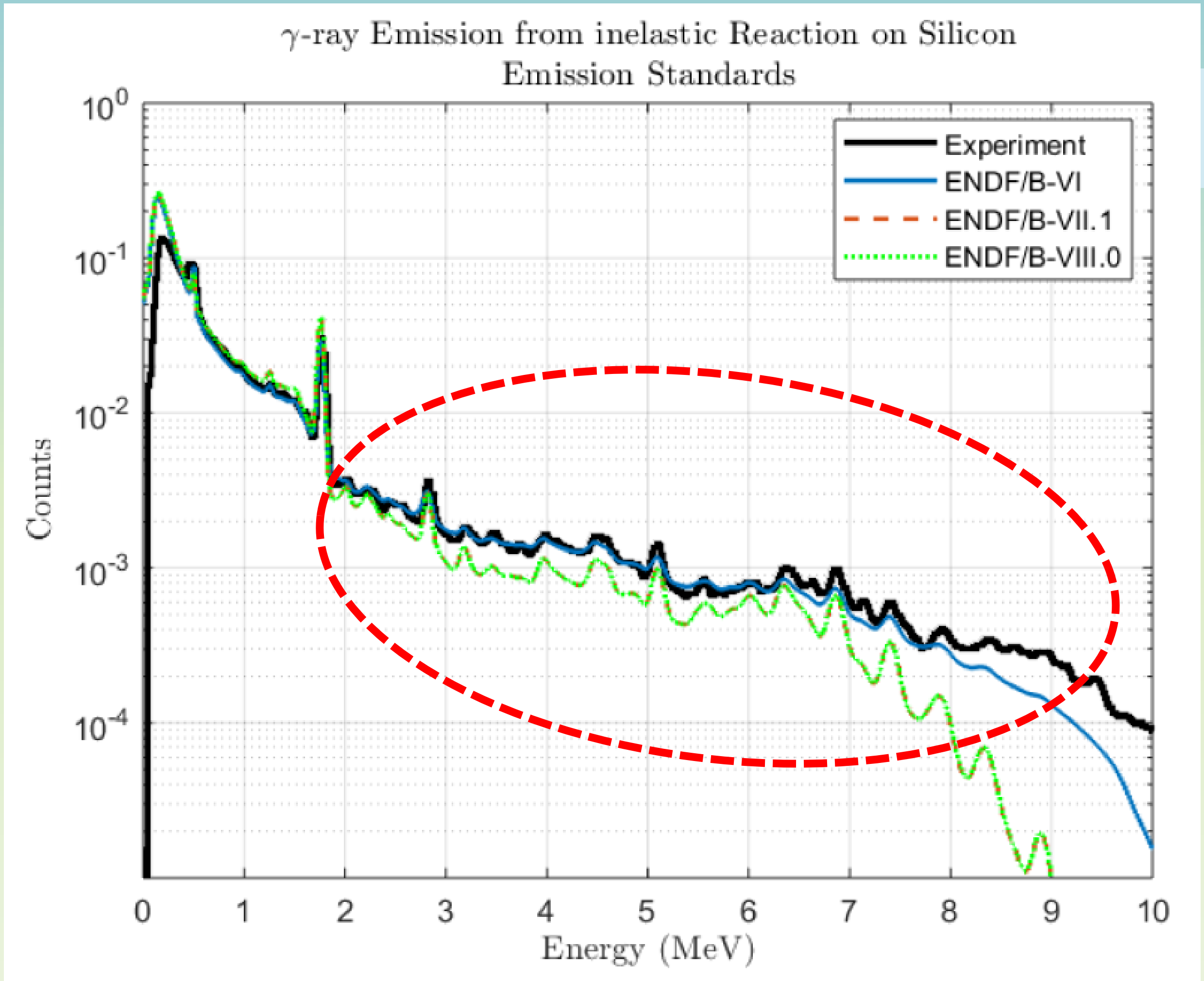
Problems identified in inelastic/capture gammas of many ENDF/B-VIII.0 evaluations



Si(n,n'γ)

Hint:
ENDF/B-VI.8
was better for gammas

Marie-Laure Mauborgne et al, CSWEG 2019 & EPJ WoC **239** (2020) 20007 (ND2019)

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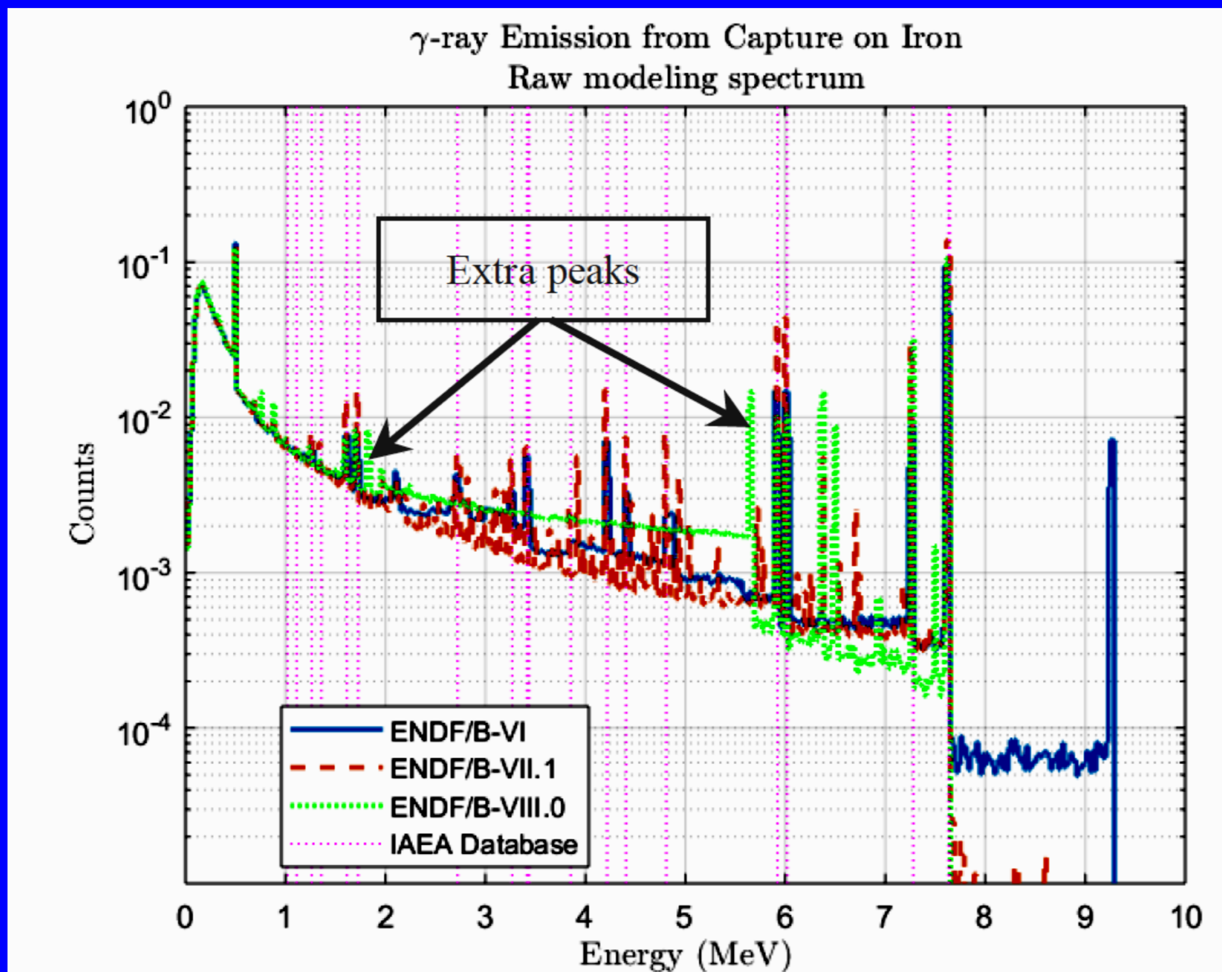
Problems identified in inelastic/capture gammas of many ENDF/B-VIII.0 evaluations



^{56}Fe(n,γ)

Hint:
ENDF/B-VI.8
was better for gammas

Marie-Laure Mauborgne et al, CSWEG 2019 & EPJ WoC **239** (2020) 20007 (ND2019)

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Problems identified in inelastic/capture gammas of many ENDF/B-VIII.0 evaluations

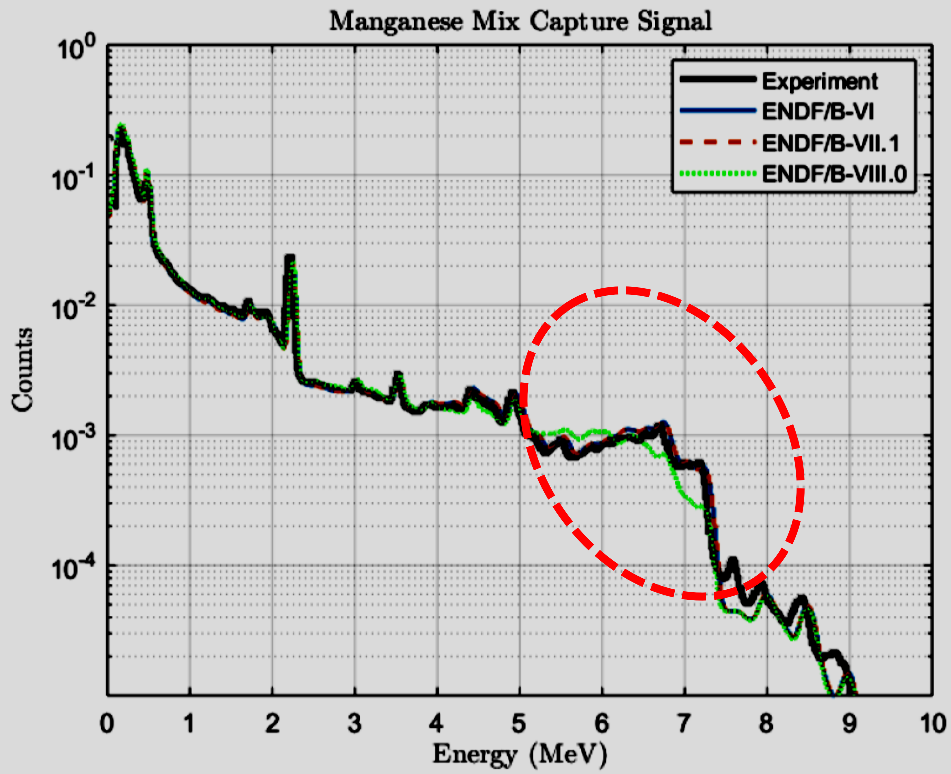

Fig. 9: Comparison of capture γ-ray spectra from the manganese mix from experiment and modeled with various libraries

Similar problems: Mn(n,γ), (Si(n,n'γ), Fe(n,γ), Fe(n,n'γ), Mg(n,γ), Mg(n,n'γ), Ti(n,γ), Ti(n,n'γ)

Hint: ENDF/B-VI.8 was better for gammas

Marie-Laure Mauborgne et al, CSWEG 2019 & EPJ WoC **239** (2020) 20007 (ND2019)

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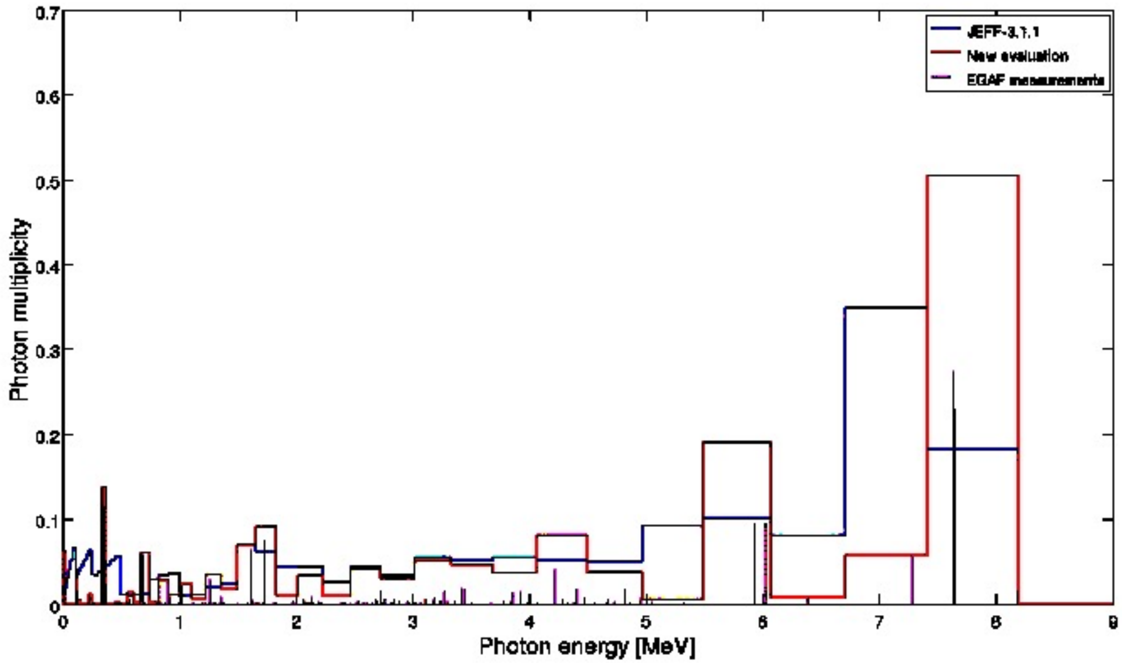
Problems discussed, but not solved

GAMMA PRODUCTION LINES

With the help of IAEA/EGAF mesured values, MF6 for gamma production lines for $^{56}Fe+n_{th}$ (≥JEFF-3.2)



CADARACHE

D. Bernard - 10/29/2018 | PAGE 11

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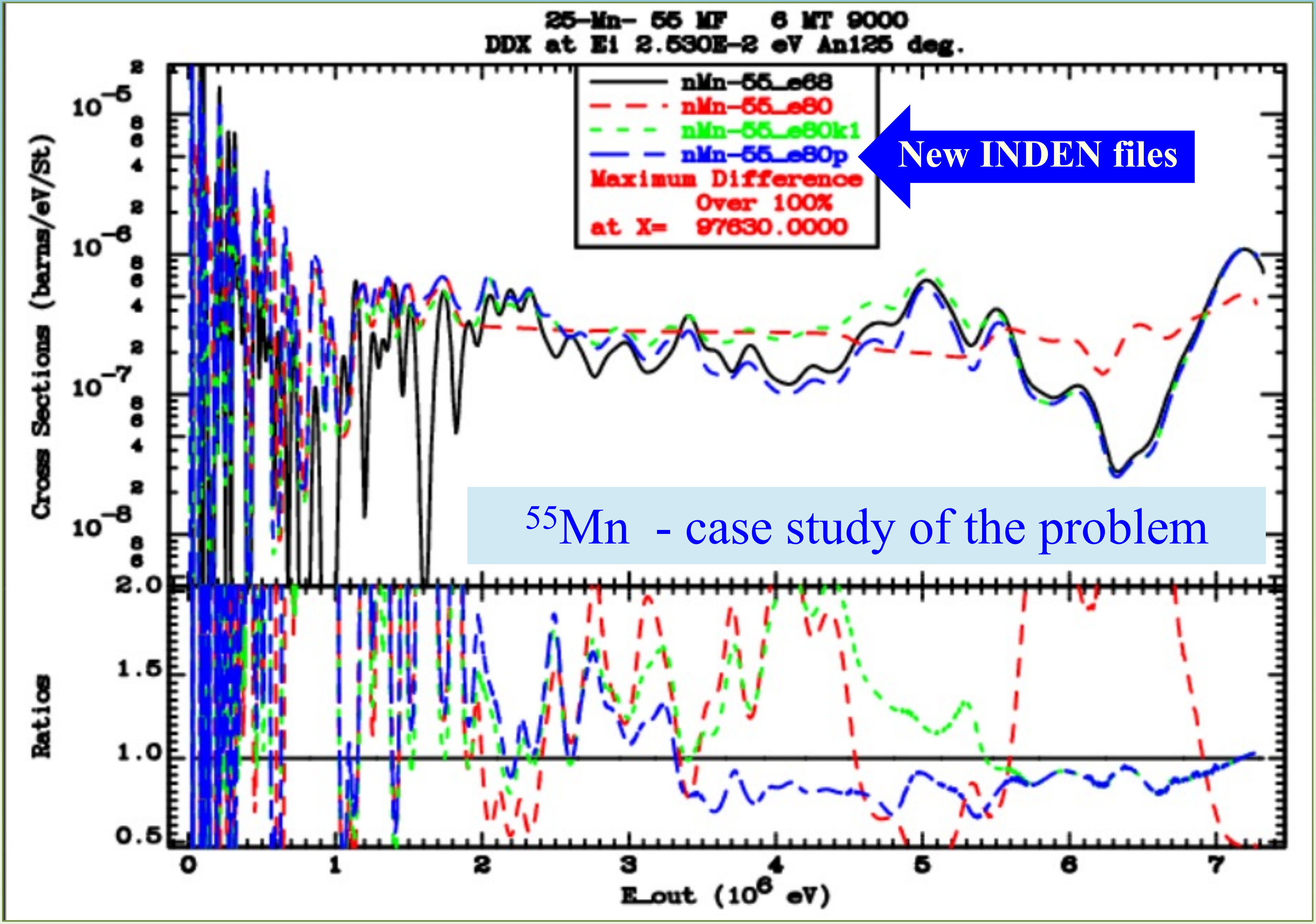
^{55}Mn update of thermal (n,γ) gammas



^{55}Mn - case study of the problem

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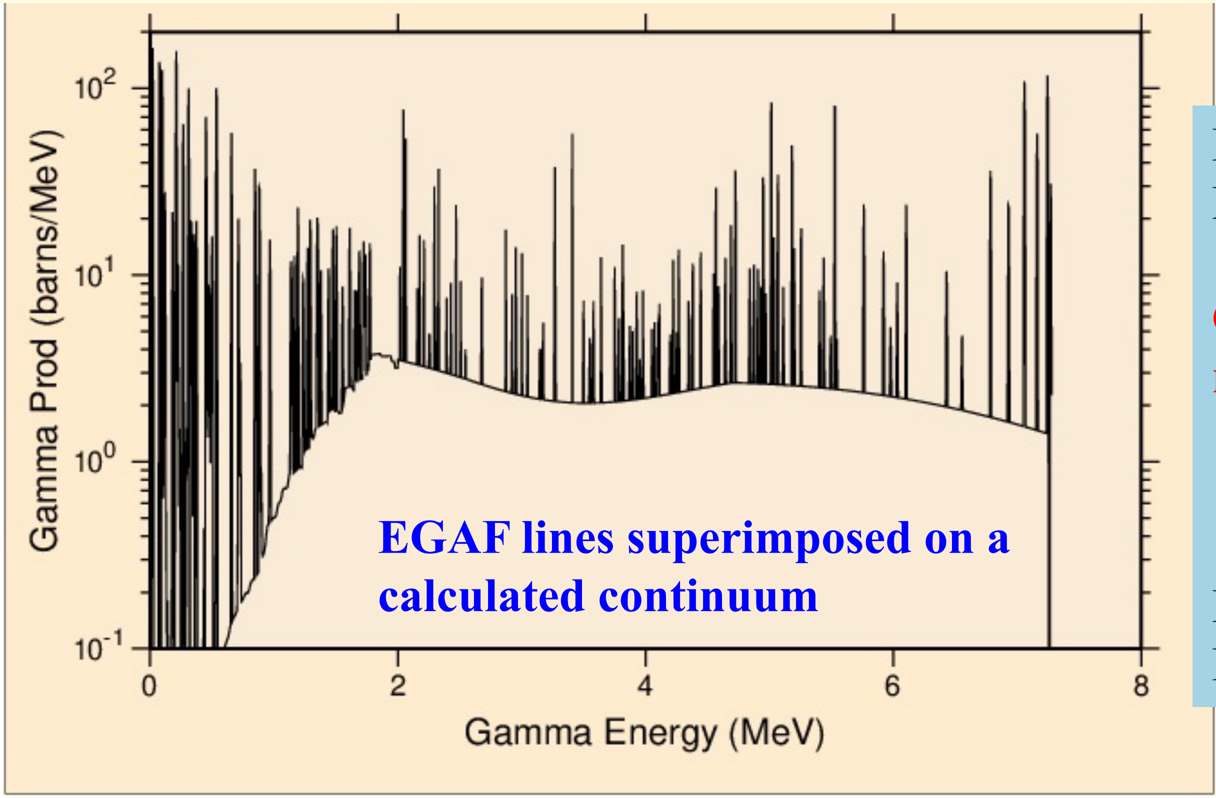
^{55}Mn update of thermal (n,γ) gammas

Thermal capture photon spectrum updated



EGAF IAEA database: Measured thermal capture γ

Quite challenging to reproduce via modelling

But very well measured ☺, Let's use it.

See description in INDC(NDS)-0810, performance restored

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^{55}Mn update of thermal (n,g) gammas

- Mn-55 evaluation in ENDF/B-VIII.0 was criticized for poor prediction of capture and inelastic gamma spectra (Marie-Laure Mauborgne, CSEWG-2019, EPJ WoC **239**, 20007 (2020).
- The data are important for oil-well exploration.
- Using the information in the EGAF library and EMPIRE nuclear model calculations the gamma production data were improved. High resolution energy bins (~5 keV/bin)
- Good performance of updated file **mn55e80p** on **proprietary benchmark** was confirmed by Marie-Laure Mauborgne (file **mn55e80p** available at https://nds.iaea.org/INDEN/data/mn55e80p_ENDF.zip)
- Documented in INDC(NDS)-0810 on "Evaluation of thermal capture gamma spectra"
- Updated methodology tested to be applied to other evaluations, but:

PUBLIC EXPERIMENTAL BENCHMARKS NEEDED

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Summary

- A non-comprehensive (and biased) selection of nuclear data priorities have been presented as a motivation for nuclear data research
- Applications like radionuclide production of medical radioisotopes, planetary exploration, space nuclear propulsion, planetary defense, and geological applications have been discussed to highlight associated nuclear data needs
- Workshop for Applied Nuclear Data Activities (WANDA 2021) is an excellent resource of information: https://conferences.lbl.gov/event/504/

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