The Abdus Salam
International Centre
for Theoretical Physics

2484-20

ICTP-IAEA Joint Workshop on Nuclear Data for Science and Technology: Medical Applications

30 September - 4 October, 2013

α, β+, γ and Auger-electron Decay Data in Nuclear Medicine − Experimental Determination, Status and Deficiencies Part II

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α, β^+, γ and Auger-electron Decay Data in Nuclear Medicine – Experimental Determination, Status and Deficiencies Part II

Alan Nichols

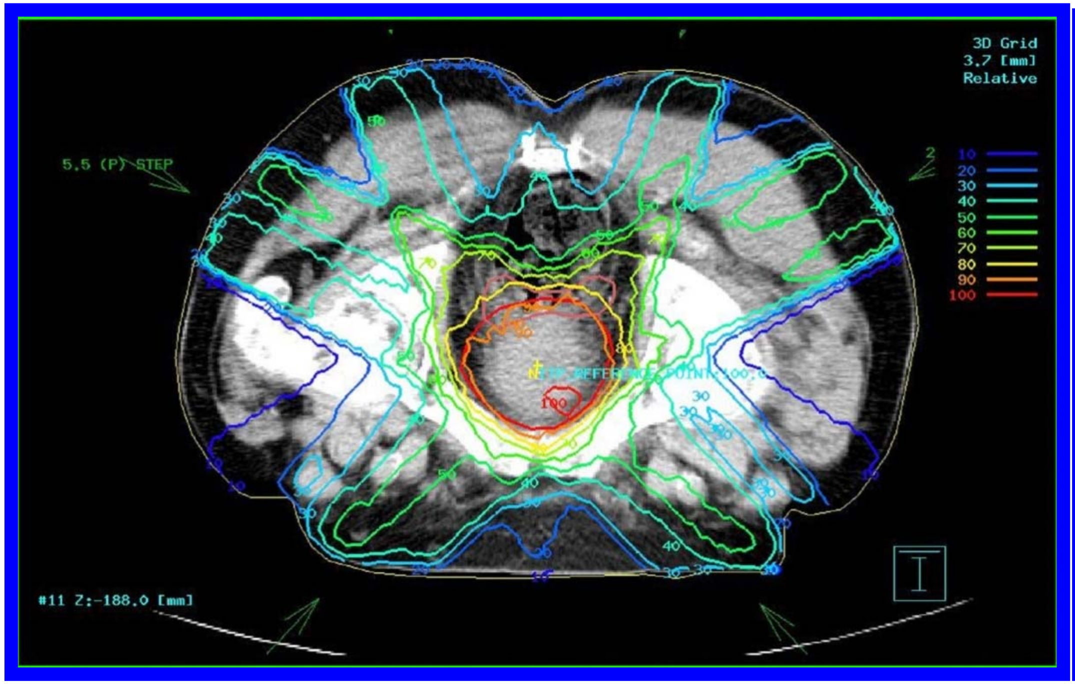
Department of Physics, University of Surrey, Guildford, UK
Manipal University, Madhav Nagar, Karnataka, India

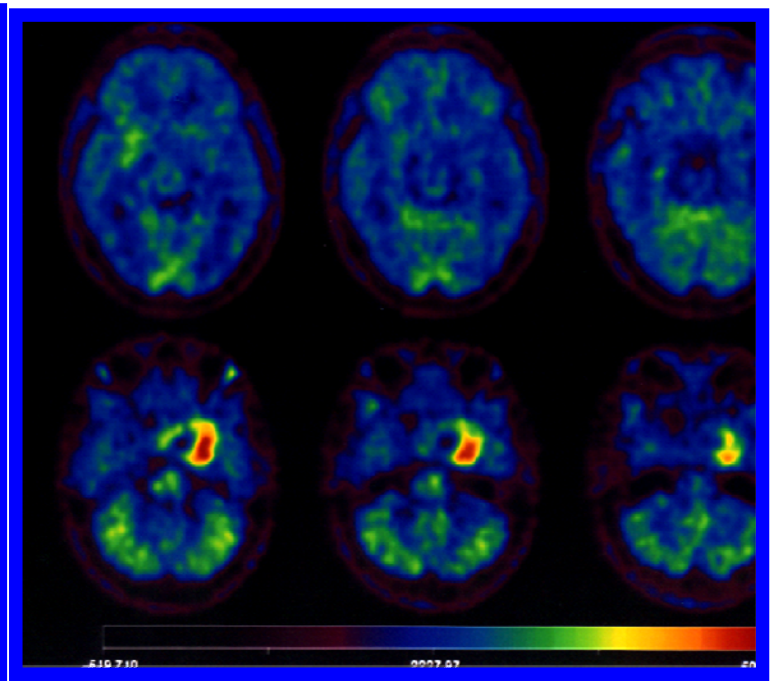
1 October 2013

Workshop on Nuclear Data for Science and Technology: Medical Applications
ICTP, Trieste, Italy, 30 September – 4 October 2013

Nuclear Data for Medical Applications

Rationale: **Cancer therapy** **Diagnosis**



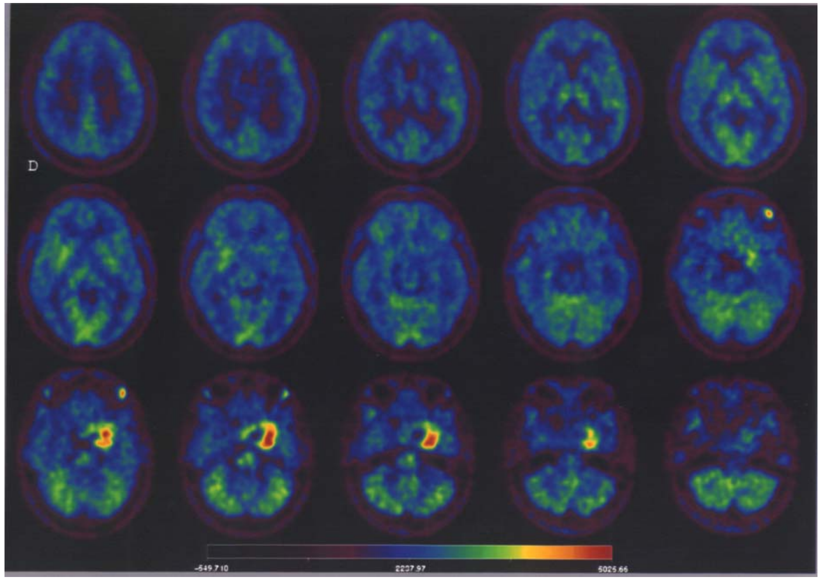


Beneficiaries: **medical physicists, radioisotope producers, researchers …**

Objectives: **improve data for medical radioisotope production and patient dose delivery calculations in radiotherapy**

ATOMIC AND NUCLEAR DATA

SUPPORT FOR MEDICAL APPLICATIONS



- Production of radioisotopes for medical diagnosis and therapy
- Radiotherapy: photons, electrons, protons and heavy ions
- Brachytherapy combines radiotherapy with monoclonal antibodies
- Dosimetry and radiation safety
- Radiation transport data

Atomic and Nuclear Data

Nuclear structure and decay data

→ nuclear energy levels, half-lives and radioactive decay (α, β, γ)

ENSDF

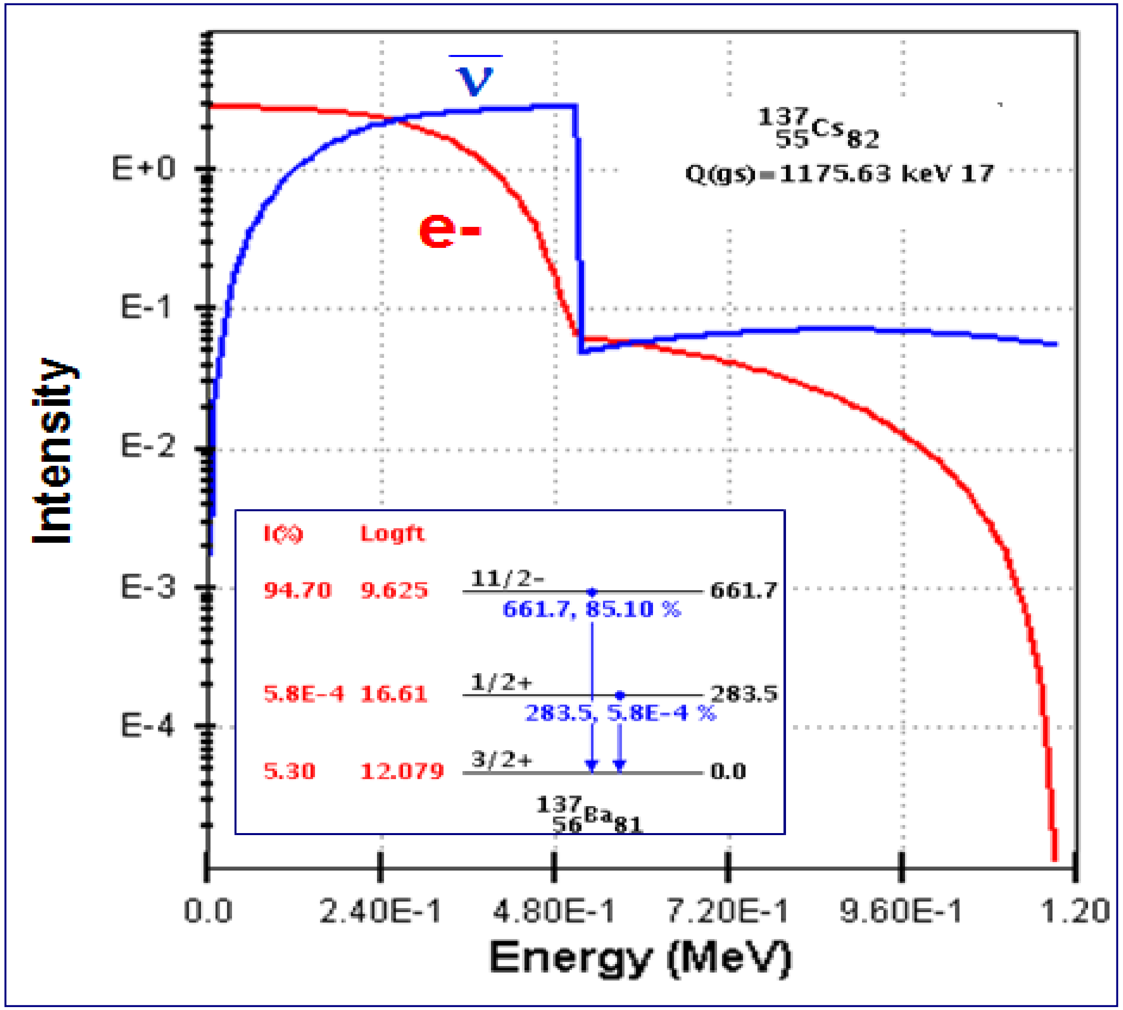
MIRD

DDEP

Atomic decay data

→ X-rays, Auger electrons

β^- decay of ^{137}Cs



β^- and β^+ decay

β^- and β^+ spectra:

- **β emissions are NOT discrete** – even reasonably simple β spectra can be difficult if not impossible to analyse so as to quantify individual β transitions
- therefore, proposed decay schemes are commonly derived from measured γ and conversion-electron energies and emission probabilities
- **balance population-depopulation of nuclear levels by total (γ + ce) transitions** to provide the means of calculating β^- emission probabilities and (EC + β^+) transition probabilities by difference

β^- and β^+ decay

β^- and β^+ spectra:

- (EC + β^+) transitions manipulated further to determine EC and β^+ components of their total (EC + β^+) transition probability to each specific nuclear level
- EC-to-positron ratios adopted from relevant tabulations, e.g.

  N.B. Gove, M.J. Martin, *Nuclear Data Tables*, **10** (1971) 205-317
- would benefit from direct (and accurate) $P_{\beta+}$ measurements, despite inherent difficulties

Auger emitters and related ND needs

Auger, Coster-Kronig and super-Coster-Kronig

- ✓ low-energy (10 eV–10 keV) electrons – short range (few nm to 1 μm)
- ✓ commonly emitted by radionuclides that decay by EC, CE or IT

INVITED COMMENTARY

Cancer Therapy with Auger Electrons: Are We Almost There?

Amin I. Kassis, PhD
Harvard Medical School
Boston, Massachusetts
J. Nucl. Med. 44 (2003)

- ✓ high toxicity – highly localized energy deposition in a small volume
- ✓ availability of many radionuclides with a wide range of physical half-lives
- ✓ emission of gamma rays - useful for imaging

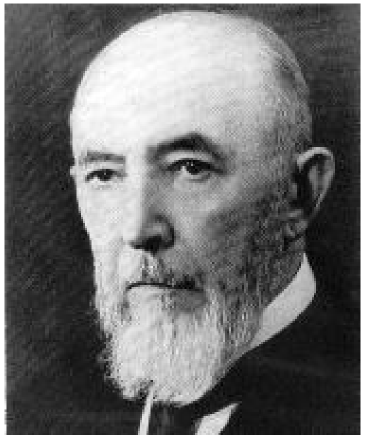
more than 100 Auger emitters

most popular: **$^{99}Tc^{m}$, ^{111}In, $^{123,125}I$, ^{67}Ga, $^{193}Pt^{m}$**

new and emerging: **$^{117,119}Sb$, ^{165}Er**

Medical applications - Auger electrons

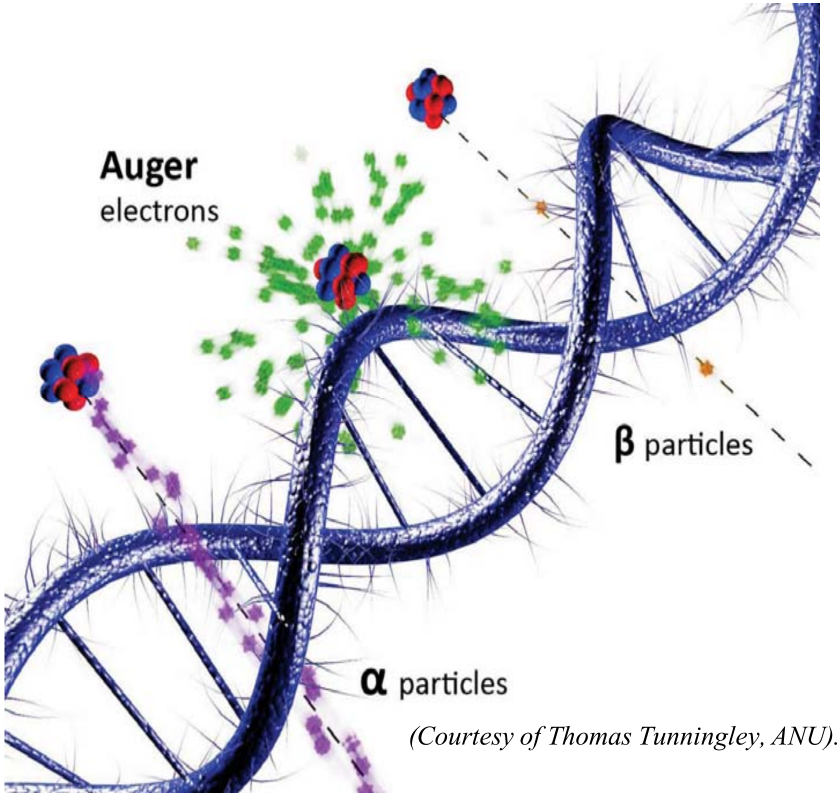
Regaud and Lacassagne (1927)
"The ideal agent for cancer therapy would consist of heavy elements capable of emitting radiations of molecular dimensions, which could be administered to the organism and selectively fixed in the protoplasm of cells one seeks to destroy."



Claudius Regaud (1870-1940)

Antoine Lacassagne (1884-1971)

Targeted tumor therapy



(Courtesy of Thomas Tunningley, ANU).

Medical applications - Auger electrons

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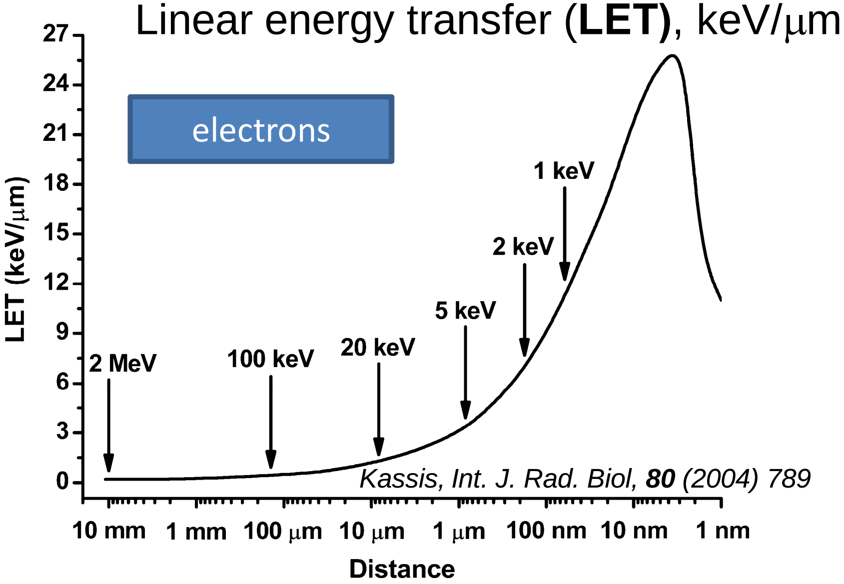
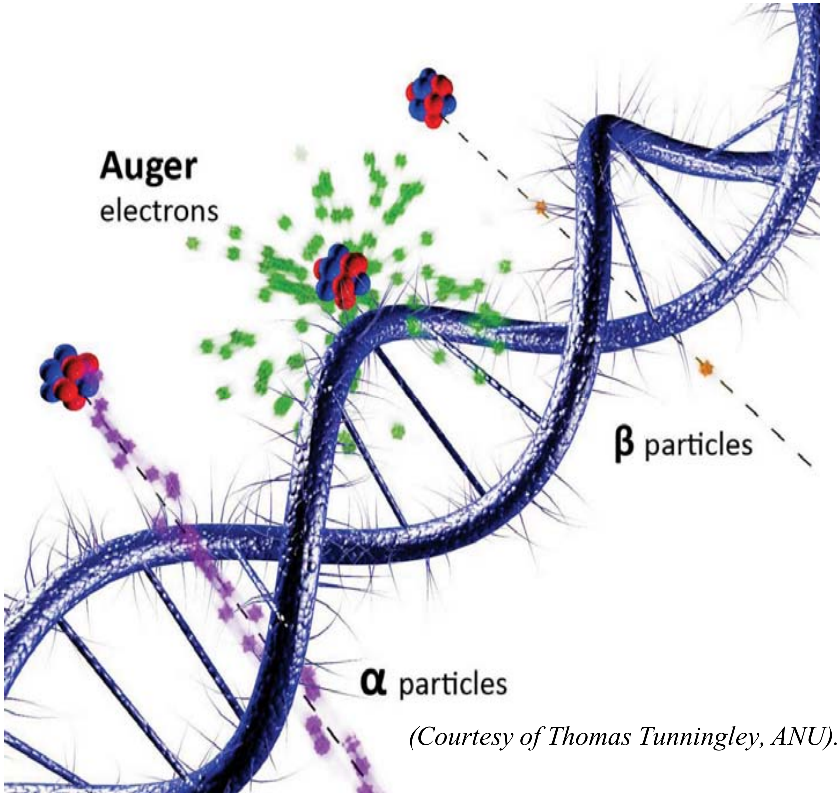
Biological effect:
Linear energy transfer (**LET**), keV/μm



Kassis, Int. J. Rad. Biol, ***80*** *(2004) 789*

Targeted tumor therapy



(Courtesy of Thomas Tunningley, ANU).

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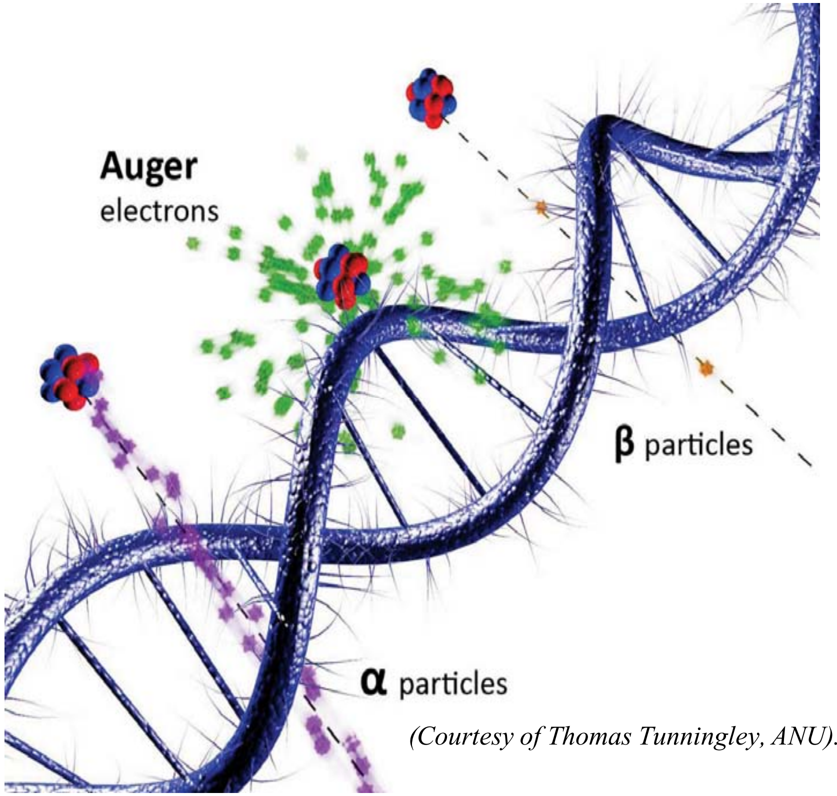
Targeted tumor therapy



(Courtesy of Thomas Tunningley, ANU).

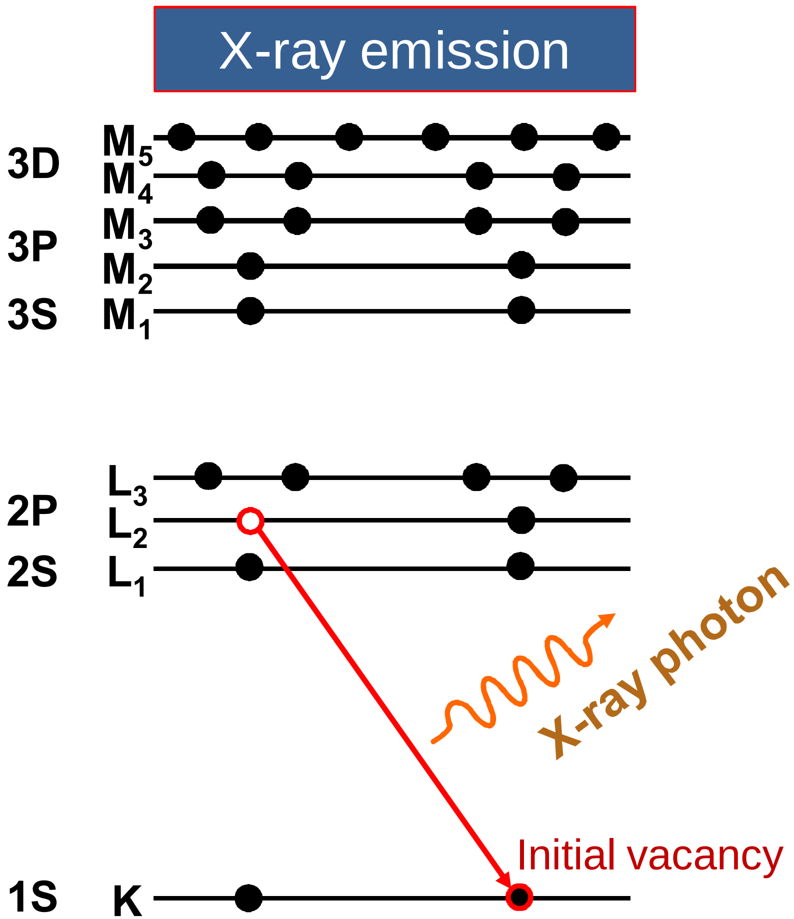
22-26 August 2011

Technical Meeting on Intermediate-term Nuclear Data Needs for Medical Applications: Cross Sections and Decay Data

A.L. Nichols, et al., IAEA report INDC(NDS)-0596, September 2011

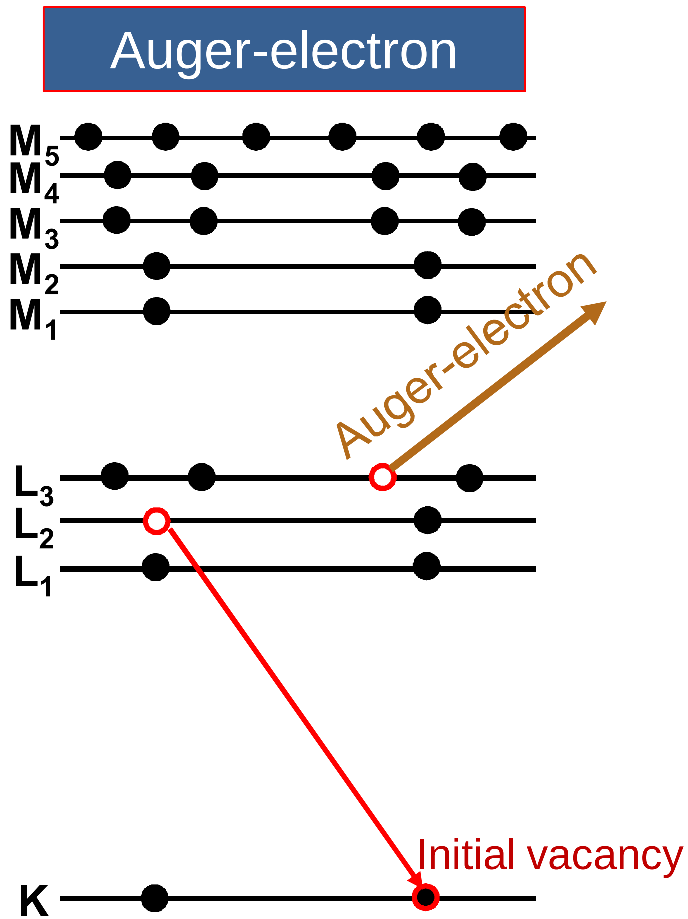
Auger emitters: ^{67}Ga , ^{71}Ge, ^{77}Br, ^{99m}Tc, ^{103}Pd, ^{111}In, ^{123}I, **^{125}I**, ^{140}Nd, ^{178}Ta, ^{193}Pt, ^{195m}Pt, ^{197}Hg

Atomic radiations - Basic concepts



$$E_{X_{K\alpha 2}} = E_K - E_{L2}$$

Kα2 X-ray
1 secondary vacancy

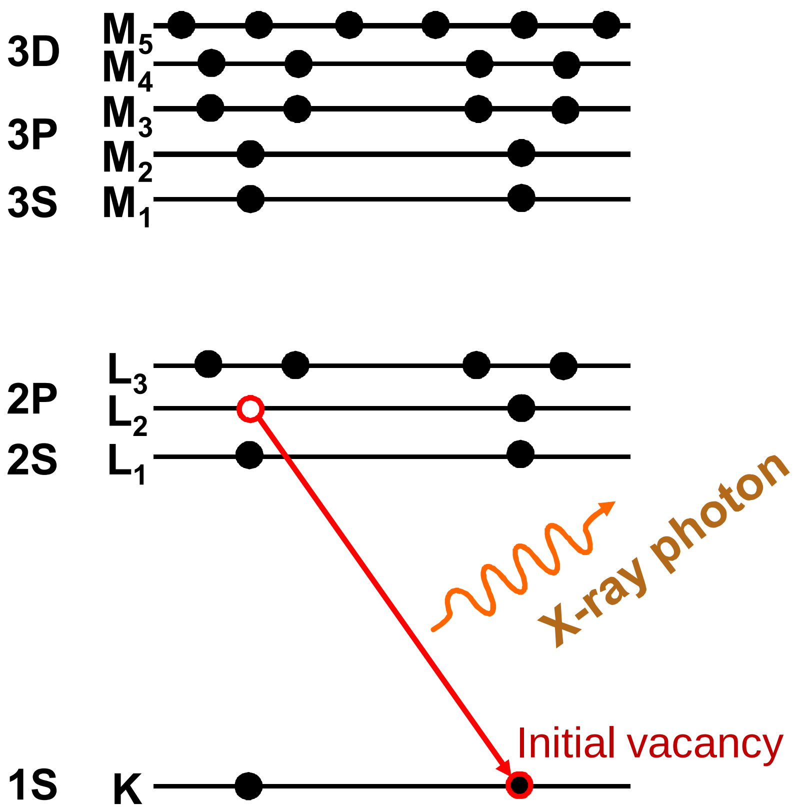


$$E_{K\,L2\,L3} = E_K - E_{L2} - E_{L3}^{L2}$$

K L2 L3 Auger-electron
2 new secondary vacancies

Atomic radiations - Basic concepts

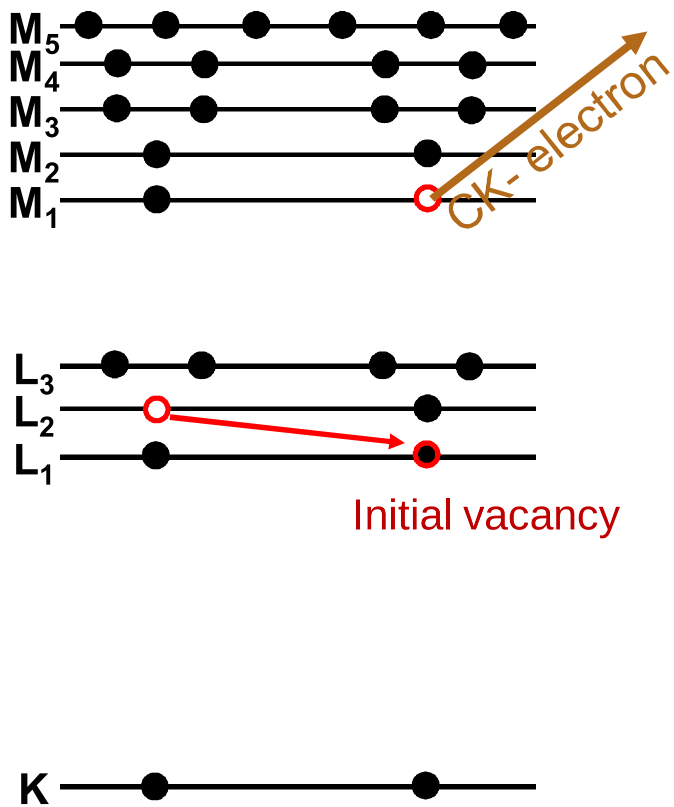
X-ray emission



$$E_{X_{K\alpha 2}} = E_K - E_{L2}$$

Kα2 X-ray
1 secondary vacancy

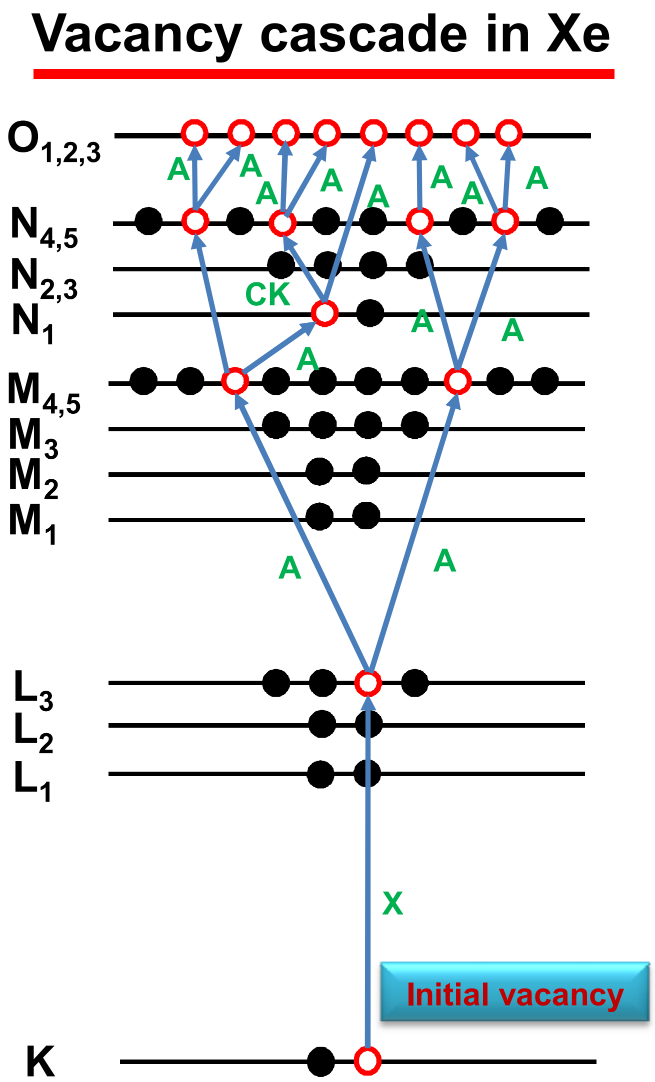
Coster-Kronig electron



$$E_{L1L2M1} = E_{L1} - E_{L2} - E_{M1}^{L2}$$

L1 L2 M1 Coster-Kronig transition
2 new secondary vacancies

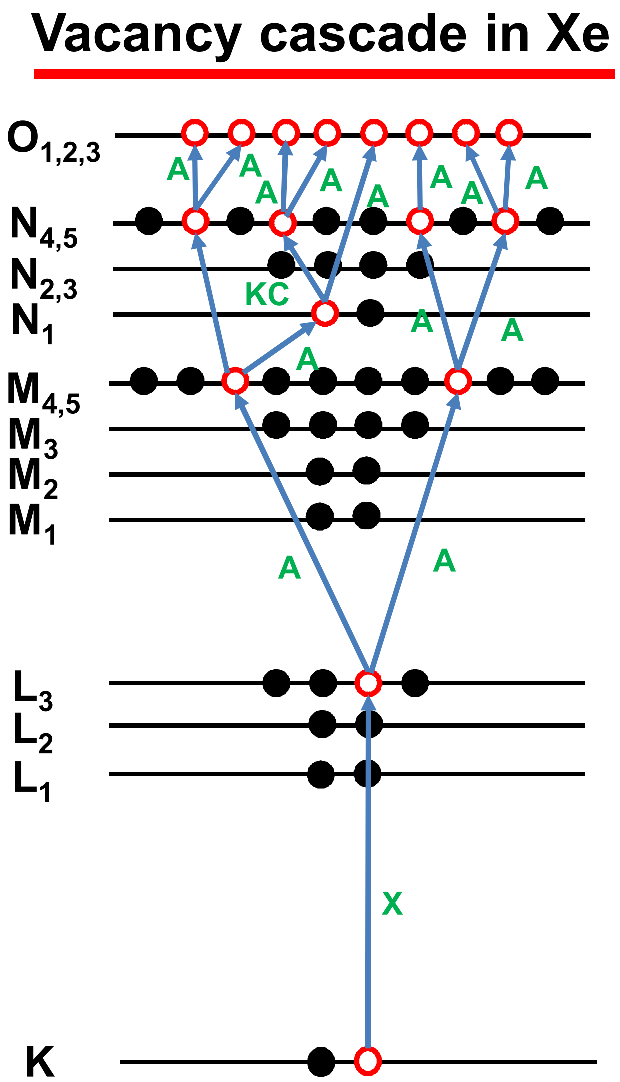
Atomic relaxation and vacancy transfer



M.O. Krause, J. Phys. Colloques, 32 (1971) C4-67

- Full relaxation of an initial inner shell vacancy creates vacancy cascade involving **X**-ray (radiative) and **A**uger as well as **C**oster-**K**ronig (non-radiative) transitions
- Many possible cascades for a single initial vacancy
- Typical relaxation time ~10^{-15} seconds
- Many vacancy cascades following a single ionisation event

Atomic radiations - Basic concepts



M.O. Krause, J. Phys. Colloques, 32 (1971) C4-67

Vacancies on the inner-shell can be produced by

- **electron impact**
- **photo ionization**
- **ion-atom collision**
- **internal conversion**
- **electron capture**
- **secondary processes accompanying β-decay or electron capture**

- **X-rays and Auger electrons are an integral part of the radiations emitted in nuclear decay**

- **Atomic radiations are important for radioisotope applications (medical physics, nuclear astrophysics, nuclear engineering)**

- **ENSDF: atomic radiations are not included in ENSDF**

Existing calculations
Auger electron yield per nuclear decay

	RADAR	DDEP	Eckerman & Endo (2007)	Howell (1992)	Stepanek (2000)	Pomplun (2012)
$^{99}Tc^{m}$ (6.007 h)	0.122	0.13	4.363	4.0		2.5
^{111}In (2.805 d)	1.136	1.16	7.215	14.7	6.05	
^{123}I (13.22 h)	1.064	1.08	13.71	14.9		6.4
^{125}I (59.4 d)	1.77	1.78	23.0	24.9	15.3	12.2
^{201}Tl (3.04 d)	0.773	0.614	20.9	36.9		
Vacancy propagation	**Deterministic**	**Deterministic**	**Deterministic** (+++)	**Monte Carlo** with charge neutralization	**Monte Carlo**	**Monte Carlo**

Existing programs

Common problems/limitations:

- Neutral atom binding energies are sometimes used for atoms with vacancies, i.e. for ions
- Single initial vacancy is considered. Secondary vacancies are ignored
- Atomic radiations only from primary vacancies on the K and L shell
- Limited information on sub-shell rates
- Auger electrons below ~ 1 keV are often omitted

BrIccEmis – Monte Carlo approach for vacancy creation and propagation

- **<u>Initial state:</u>** neutral isolated atom
- **<u>Nuclear structure data:</u>** from nuclear decay scheme evaluation (e.g. ENSDF)
- **<u>Electron capture (EC) rates:</u>** Schönfeld (1998Sc28)
- **<u>Internal conversion coefficients (ICC):</u>** BrIcc (2008Ki07)
- **<u>Auger and X-ray transition rates:</u>** EADL (1991 Perkins)

  Calculated for single vacancies!
- **<u>Auger and X-ray transition energies:</u>** RAINE (2002Ba85)

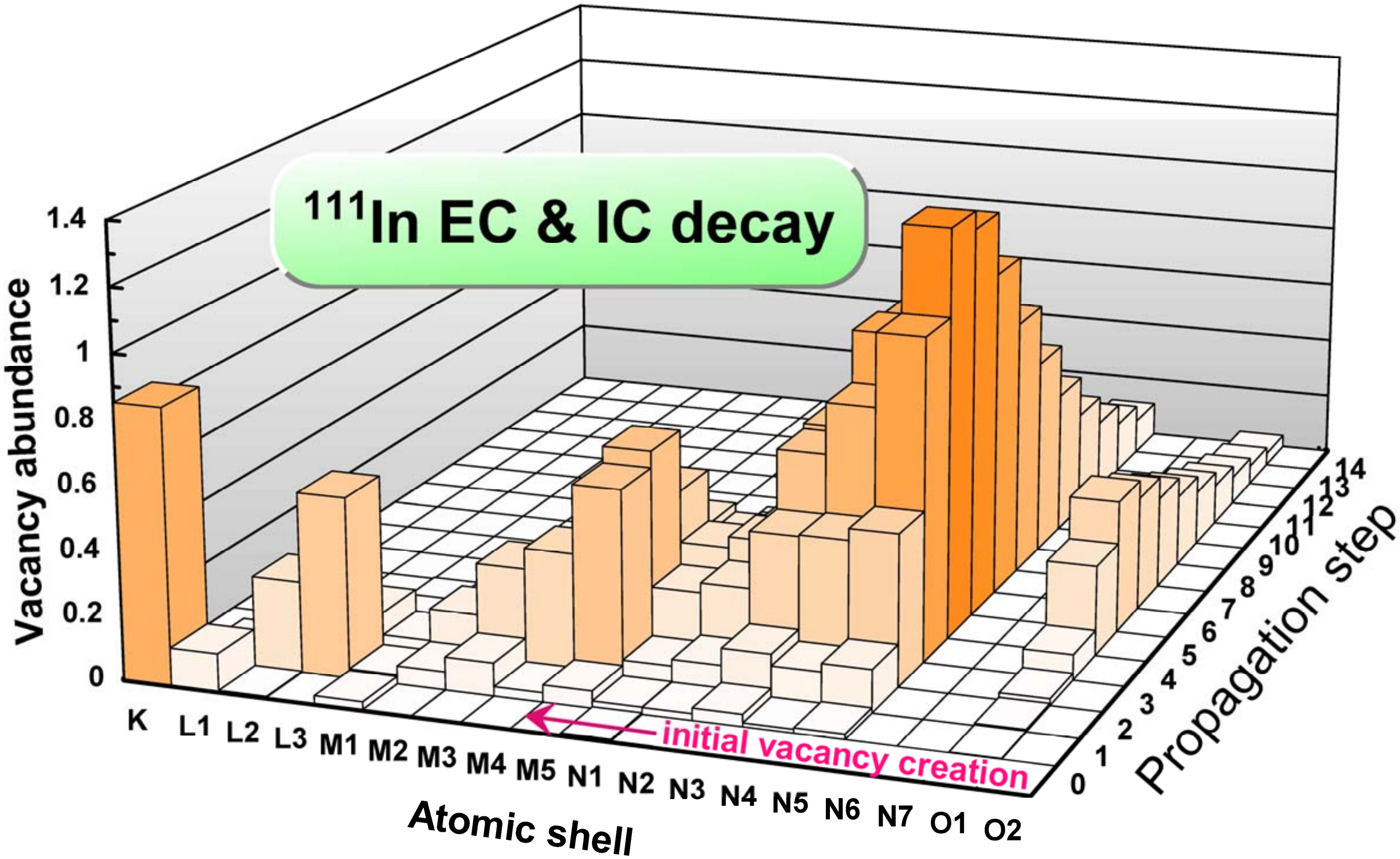
  Calculated for actual electronic configuration!
- **<u>Vacancy creation and relaxation from EC and IC:</u>** treated independently
- **<u>*Ab initio* treatment of the vacancy propagation:</u>**
  - Transition energies and rates evaluated on the spot
  - Propagation terminated once the vacancy reaches the valence shell

BrIccEmis

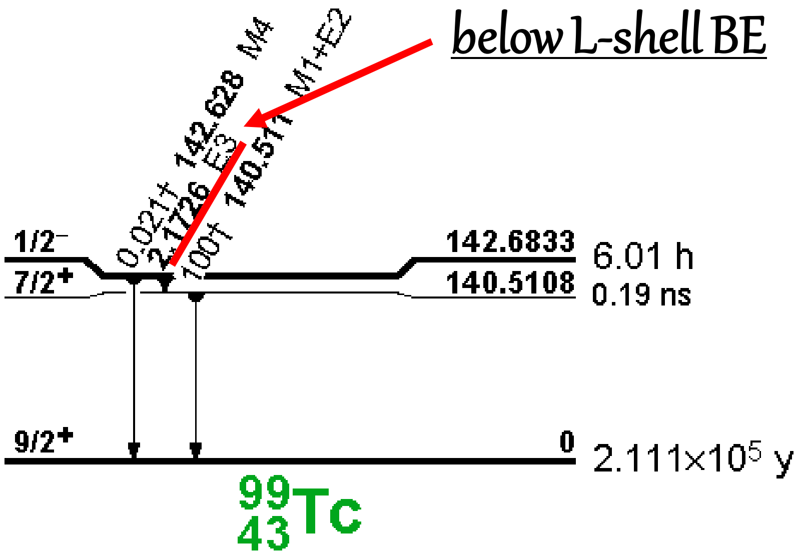
- **Reads the ENSDF file, evaluates absolute decay intensities** of EC, GAMMA, CE and PAIR transitions
- **Simulates a large number events:** 100k-10M radioactive decays followed by atomic relaxation
- Electron configurations and binding energies stored in memory (and saved on disk). **New configurations only calculated if needed**

  (^{55}Fe: 15 k, ^{201}Tl: 1300 k)
- Emitted atomic radiations stored on disk (Gb files)
- Separate files for X-rays and Auger electrons
- Smaller programs to sort/project energy spectra, and produce detailed reports

^{111}In EC decay – vacancy propagation



$^{99}Tc^{m}$ atomic radiations



BrIccS v2.3 (9-Dec-2011)
Z=43 (Tc, Technetium)
γ-energy: 2.1726 keV
Data Sets: BrIccFO

Shell	E(ce)	E3
Tot		1.370E10 (20)
M1	1.63	2.26E6 (4)
M2	1.73	3.37E9 (5)
M3	1.75	5.98E9 (9)
M4	1.92	1.100E9 (16)
M5	1.92	1.655E9 (24)
M-tot	1.78	1.211E10 (17)
N1	2.10	5.00E5 (7)
N2	2.13	4.92E8 (7)
N3	2.14	8.77E8 (13)
N4	2.17	9.11E7 (13)
N5	2.17	1.350E8 (19)
N-tot	2.14	1.596E9 (23)
O1	2.17	3.49E4 (5)
O-tot	2.17	3.49E4 (5)

$^{99}Tc^{m}$ atomic radiations – X-rays

	DDEP	BrIccEmis
$K\alpha_1$	18.3672 ***4.21E-2***	18.421 ***4.05E-2***
$K\alpha_2$	18.251 ***2.22E-2***	18.302 ***2.13E-2***
$K\beta$	20.677 ***1.30E-2***	20.729 ***1.18E-2***
L	[2.134 - 3.002] ***4.82E-3***	2.466 ***4.72E-3***
M		0.263 ***7.83E-4***
N		0.047 ***8.73E-1***

$^{99}Tc^{m}$ atomic radiations – Auger electrons

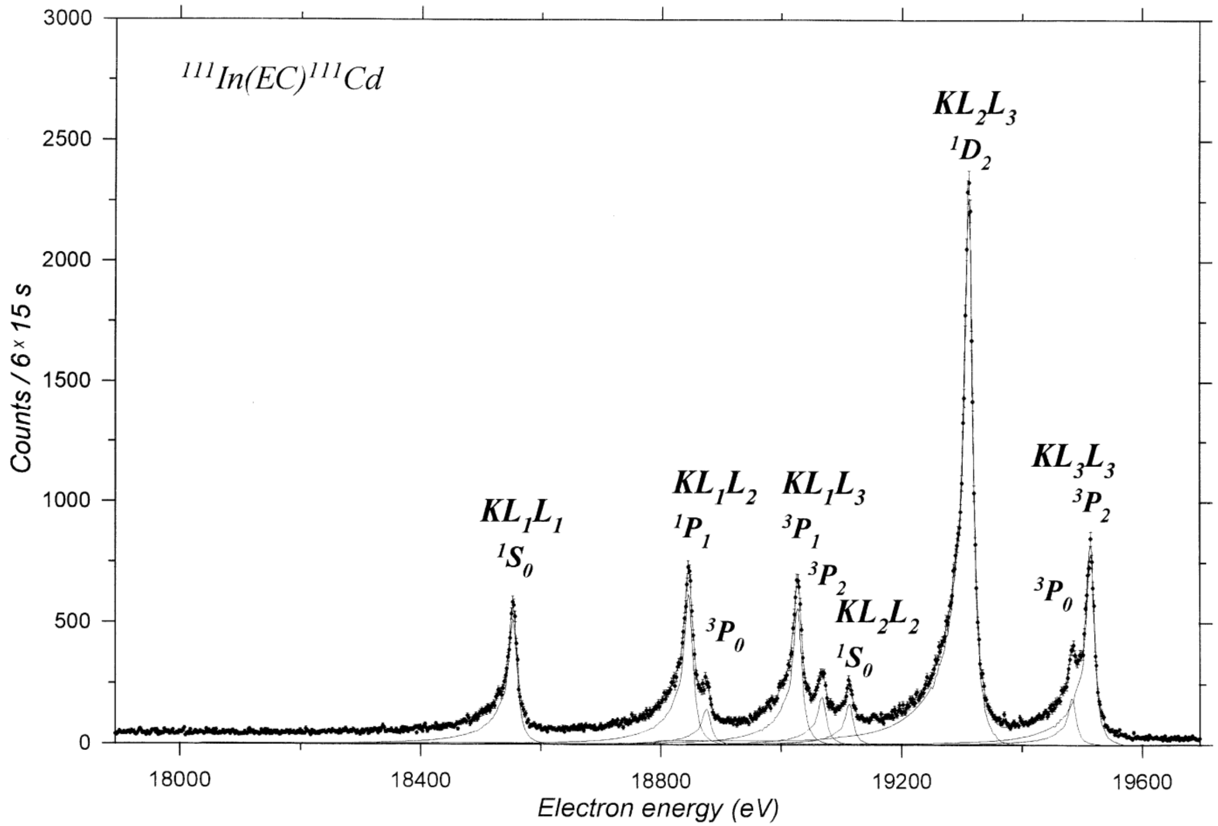
	DDEP	BrIccEmis
KLL	[14.86:15.58] ***1.49E-2***	15.37 ***1.48E-2***
KLX	[17.43:18.33] ***2.79E-3***	17.85 ***5.58E-3***
KXY	[19.93:21.00] ***2.8E-4***	20.27 ***5.07E-4***
K-total	***2.15E-2***	16.15 ***2.08E-2***
CK LLM		***2.08E-2*** 0.054
CK LLX		0.144 ***9.48E-3***
LMM		2.016 ***9.02E-2***
LMX		2.328 ***1.41E-2***
LXY		2.654 ***6.07E-4***
L-total	[1.6:2.9] ***1.089E-1***	1.765 ***1.24E-1***

$^{99}Tc^{m}$ atomic radiations – Auger electrons

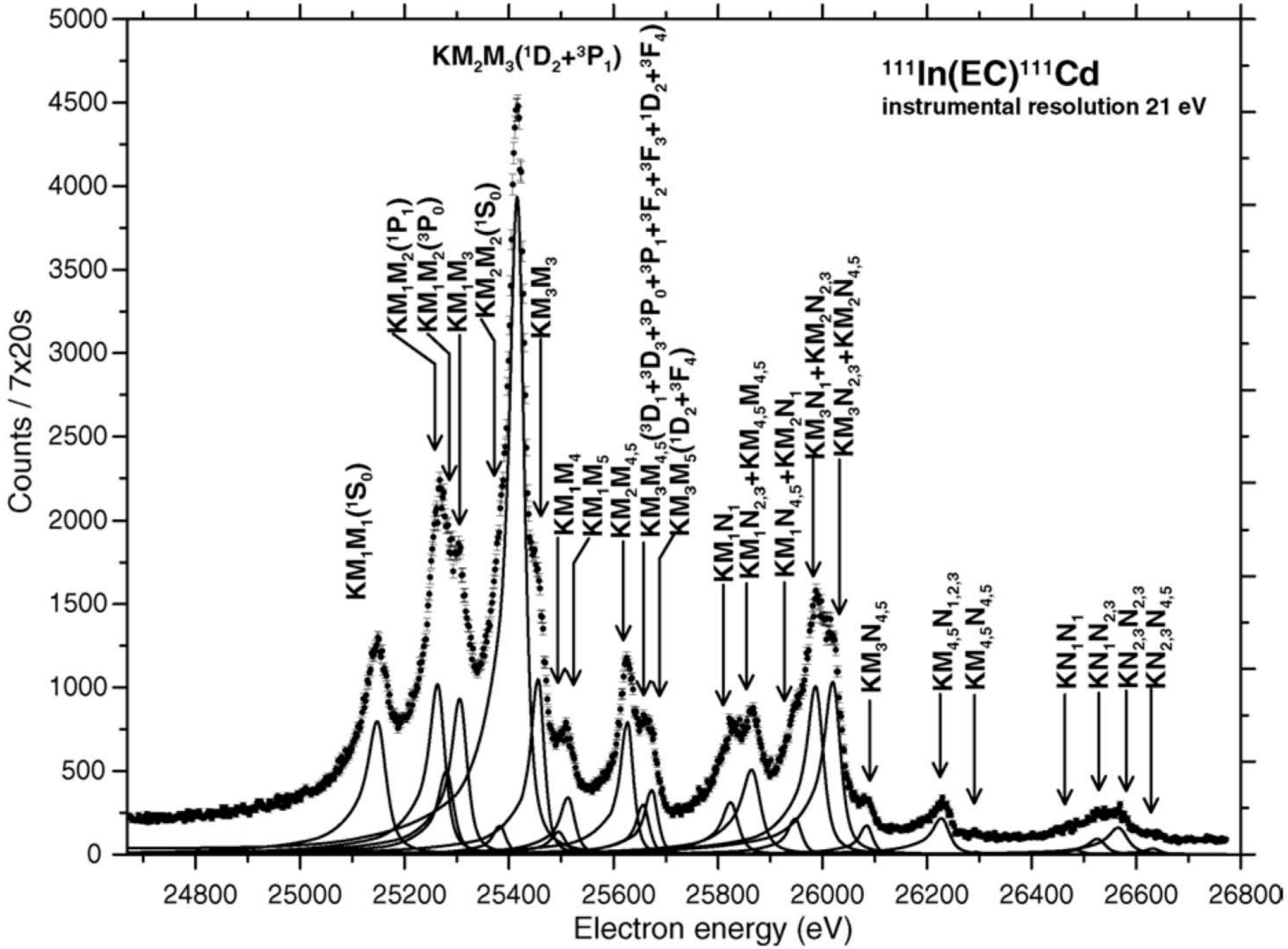
	DDEP	BrIccEmis
CK MMX		0.104 ***7.10E-1***
MXY		0.170 ***1.10E+0***
Super CK NNN		0.014 ***5.36E-1***
CK NNX		0.012 ***8.45E-1***
Total yield Auger electron per nuclear decay	***0.13***	***3.37***

~95%
below 500 eV

KLL-Auger spectrum of ^{111}Cd from EC decay of ^{111}In

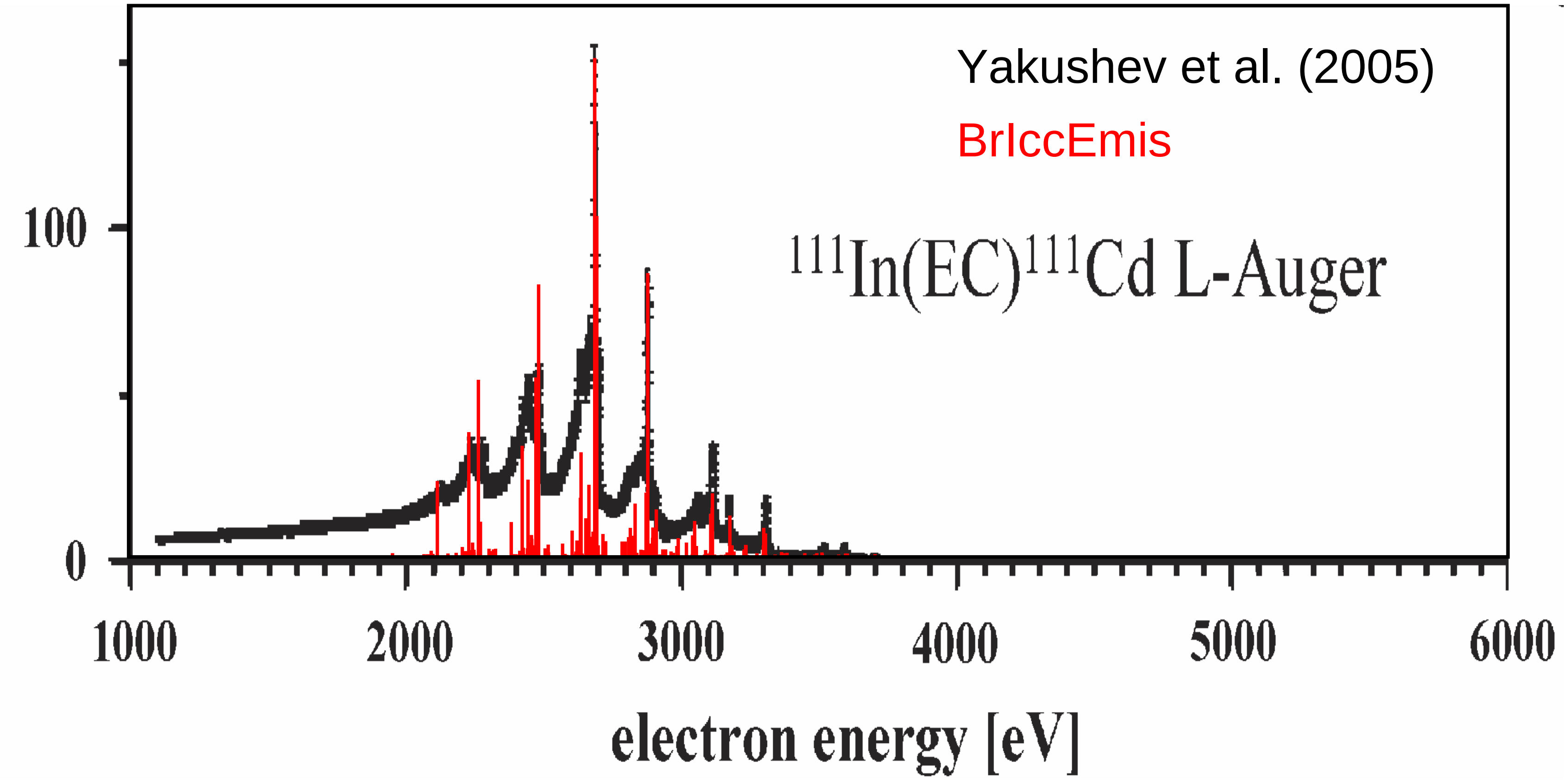


KMM-, KMN- and KNN-Auger spectrum of ^{111}Cd from EC decay of ^{111}In



^{111}In EC decay – experiment vs calculation

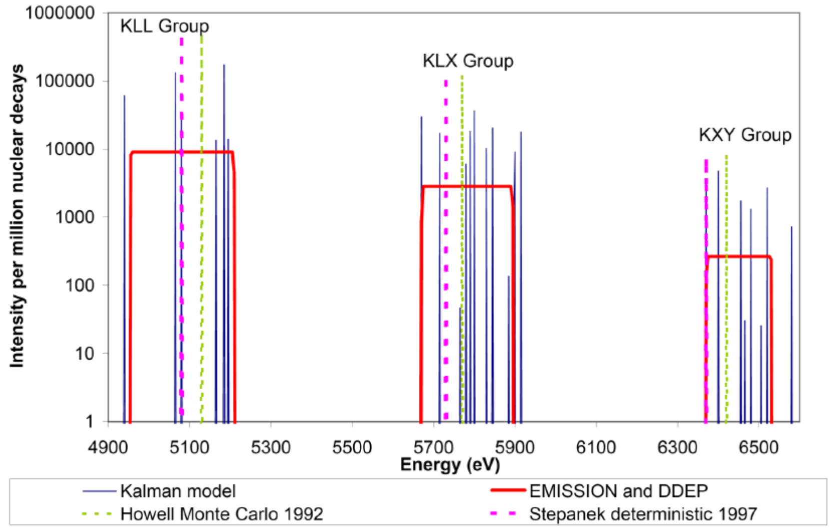
E.A. Yakushev, et al., Appl. Radiat. Isot. **62** (2005) 451



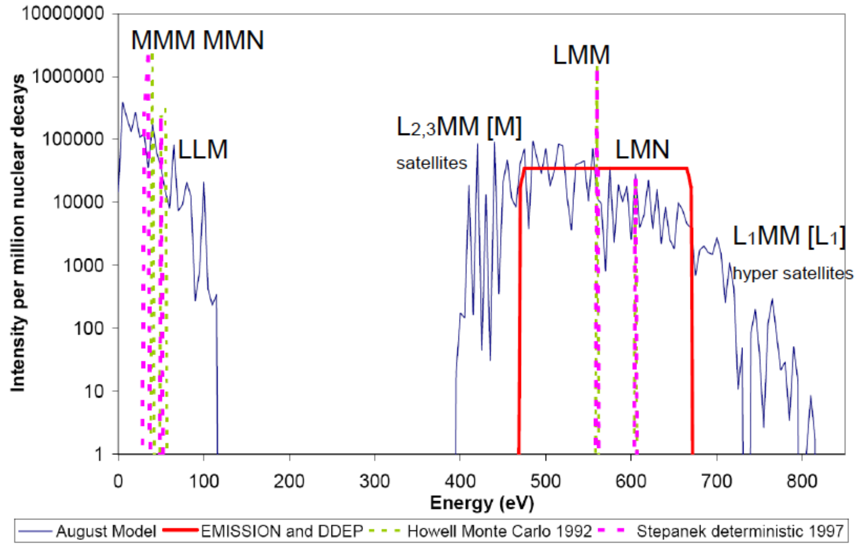
- ESCA; FWHM = 4 eV
- Calculations normalized to the strongest experimental line

New model: ^{55}Fe EC decay

- primary vacancies from BrIcc (for CE) and EC (for electron capture)
- Binding energies calculated using RAINE code for electron configurations of a neutral atom or an ion with single or multiple vacancies
- Auger and CK transition rates calculated using non-relativistic perturbation theory with screened hydrogen wave functions (simple general formalism for all shells and transitions)
- Partially Defrosted Orbitals: calculations for all electronic configurations (complete treatment), but with single-vacancy transition rates



Slide courtesy of Kalman Robertson



Slide courtesy of Kalman Robertson

Medical Internal Radiation Dose (MIRD)

1. "**The Program RADLST**" - documentation of the calculational methods and auxiliary data to quantify dose rates: **T.W. Burrows, Brookhaven National Laboratory Report BNL-NCS-52142, February 1988**
2. Access software at:

   www.nndc.bnl.gov/mird/

   www-nds.iaea.org/medportal/

Medical Internal Radiation Dose (MIRD)

MIRD dose rate data for ^{18}F as determined from ENSDF decay data

Half-life of 109.77 min			November 1996
β^+/EC decay mode		^{18}O daughter is stable	
Radiation	**P_i (Bq-s)$^{-1}$**	**Energy (MeV)**	**$P_i \times E_i$**
β^+_1	9.67×10^{-01}	2.498×10^{-01} *	**2.42×10^{-01}**
$\gamma^{\pm}$	1.93	5.110×10^{-01}	**9.89×10^{-01}**
K X-ray	1.80×10^{-04}	5.249×10^{-04} *	**9.42×10^{-08}**
K X-ray	4.74×10^{-12}	5.000×10^{-04} *	**2.37×10^{-15}**
Auger-K	3.07×10^{-02}	5.200×10^{-04} *	**1.60×10^{-05}**
Listed X, γ and $\gamma^{\pm}$ radiations			9.89×10^{-01}
Listed β, ce and Auger radiations			2.42×10^{-01}
Listed radiations			**1.23**

* Average energy (MeV).

Medical Internal Radiation Dose (MIRD)

MIRD dose rate data for ^{213}Bi as determined from ENSDF decay data

Half-life of 45.59 min		^{209}Tl daughter is radioactive	α November 1991
α and β^- decay modes		^{213}Po daughter is radioactive	β^- April 2007

Radiation	P_i (Bq-s)$^{-1}$	Energy (MeV)	$P_i \times E_i$
α_1	1.55×10^{-03}	5.549	**8.58×10^{-03}**
α recoil	1.55×10^{-03}	1.053×10^{-01}	**1.63×10^{-04}**
α_2	1.94×10^{-02}	5.869	**1.14×10^{-01}**
α recoil	1.94×10^{-02}	1.114×10^{-01}	**2.16×10^{-03}**
γ_1	1.27×10^{-04}	8.680×10^{-01}	**1.11×10^{-04}**
β^-_3	5.86×10^{-03}	9.080×10^{-02} *	**5.32×10^{-04}**
β^-_8	3.07×10^{-01}	3.204×10^{-01} *	**9.85×10^{-02}**
β^-_9	2.29×10^{-03}	3.768×10^{-01} *	**8.62×10^{-04}**
β^-_{10}	6.58×10^{-01}	4.922×10^{-01} *	**3.24×10^{-01}**
γ_1	4.29×10^{-03}	2.928×10^{-01}	**1.26×10^{-03}**
....	....	....	....
....	....	....	....
γ_{17}	5.20×10^{-04}	1.119	**5.82×10^{-04}**
$K_{\alpha1}$ X-ray	1.83×10^{-02}	7.929×10^{-02}	**1.45×10^{-03}**
$K_{\alpha2}$ X-ray	1.10×10^{-02}	7.686×10^{-02}	**8.45×10^{-04}**
K_{β} X-ray	8.27×10^{-03}	8.980×10^{-02} *	**7.43×10^{-04}**
L X-ray	1.55×10^{-02}	1.110×10^{-02} *	**1.72×10^{-04}**

Listed X, γ and $\gamma^{\pm}$ radiations	**1.22×10^{-02}**
Omitted X, γ, and $\gamma^{\pm}$ radiations**	1.48×10^{-05}
Listed β, ce and Auger radiations	**4.24×10^{-01}**
Omitted β, ce, and Auger radiations**	7.74×10^{-04}
Listed α radiations	**1.22×10^{-01}**
Listed radiations	**5.58×10^{-01}**
Omitted radiations**	7.89×10^{-04}

* Average energy (MeV).

** Each omitted transition contributes < 0.100% to $\Sigma(P_i \times E_i)$.

Nuclear Data Needs for Medical Applications: Cross Sections and Decay Data

Relevant recent past:

1. Cross sections – IAEA-NDS CRP 1995–2000: **Charged Particle Cross-Section Database for Medical Radioisotope Production: Diagnostic Radioisotopes and Monitor Reactions**, IAEA-TECDOC-1211, May 2001
2. Cross sections – IAEA-NDS CRP 2003–2010: **Nuclear Data for the Production of Therapeutic Radionuclides**, IAEA Technical Reports Series No. 473, IAEA, Vienna, Austria, December 2011
3. Decay data – IAEA-NDS CRP 1998-2005: **Update of X Ray and Gamma Ray Decay Data Standards for Detector Calibration and Other Applications**, IAEA-STI/PUB/1287, published as 2 volumes, May 2007
4. Decay data – IAEA-NDS CRP 2005-2010: **Updated Decay Data Library for Actinides**, prepared in draft, IAEA, Vienna, Austria, to be published

Immediate past and future:

Cross sections and decay data – one further IAEA-NDS CRP launched in late 2012 on the basis of

- **High-Precision Beta-Intensity Measurements and Evaluations for Specific PET Radioisotopes** (see IAEA report INDC(NDS)-0535, 2008)
- **Improvements in Charged-Particle Monitor Reactions and Nuclear Data for Medical Isotope Production** (see IAEA report INDC(NDS)-0591, 2011)

High-precision β^+-intensity Measurements and Evaluations for Specific PET Radioisotopes

Consultants' Meeting, IAEA Headquarters, Vienna, Austria
3-5 September 2008, IAEA report INDC(NDS)-0535

Tadashi Nozaki	ex-RIKEN, Japan
Syed Qaim	Forschungszentrum Jülich, Germany [Chairman]
Deon Steyn	iThemba Laboratory, South Africa
Stephen Waters	ex-Cyclotron Unit, Hammersmith Hospital, UK
Roberto Capote	IAEA Nuclear Data Section [Scientific Secretary]
Alan Nichols	IAEA Nuclear Data Section [Rapporteur]

High-precision β^+-intensity Measurements and Evaluations for Specific PET Radioisotopes

Consultants' Meeting, IAEA Headquarters, Vienna, Austria

3-5 September 2008, IAEA report INDC(NDS)-0535

Radionuclides – standard β^+ emitters	Requirements				
	$t_{1/2}$	P_{β^+}	P_X	P_γ	evaluate
^{11}C, ^{13}N, ^{15}O, ^{18}F	none - well-defined decay data				
^{68}Ge/^{68}Ga, ^{82}Sr/^{82}Rb	none - well-defined ^{68}Ga and ^{82}Rb decay data				
Radionuclides – hadron therapy					
^{10}C, ^{14}O, ^{17}F, ^{18}Ne, ^{19}Ne	none – adequate decay data				

High-precision β^+-intensity Measurements and Evaluations for Specific PET Radioisotopes

Consultants' Meeting, IAEA Headquarters, Vienna, Austria

3-5 September 2008, IAEA report INDC(NDS)-0535

Radionuclides – non-standard β^+ emitters	Requirements				
	$t_{1/2}$	P_{β^+}	P_X	P_γ	evaluate
^{57}Ni	√	√	√		√
^{66}Ga, ^{72}As, ^{73}Se, ^{86}Y, ^{94}Tc^m		√	√		√
^{75}Br, ^{77}Kr		√			(√)
^{64}Cu				√ 1345.8-keV γ	(√)
^{76}Br, ^{120}I					√
^{81}Rb, ^{82}Rb^m, ^{83}Sr	inaccurately defined decay data				√
^{22}Na, ^{30}P, ^{34}Cl^m, ^{38}K, ^{45}Ti, ^{48}V, ^{49}Cr, ^{51}Mn, ^{52}Mn, ^{52}Mn^m, ^{52}Fe, ^{55}Co, ^{61}Cu, ^{90}Nb, ^{110}In^m, ^{124}I, ^{152}Tb, ^{44}Ti/^{44}Sc, ^{62}Zn/^{62}Cu, ^{140}Nd/^{140}Pr	reasonably well-defined decay data				

- most important non-standard radionuclides for PET (2008).
- increasingly important for PET (2008).
- merit further work for potential PET applications (2008).

NUCLEAR DATA FOR CHARGED-PARTICLE MONITOR REACTIONS AND MEDICAL ISOTOPE PRODUCTION

First Research Coordination Meeting, 3-7 December 2012

IAEA Report INDC(NDS)-0630

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First Research Coordination Meeting on Nuclear Data for Charged-particle Monitor Reactions and Medical Isotope Production

3-7 December 2012, IAEA report INDC(NDS)-0630

Cross sections	Decay data	Additional comments
monitor reactions		
$^{27}Al(p,x)^{22,24}Na$	–	re-evaluate up to 800 MeV
$^{27}Al(d,x)^{22,24}Na$		re-evaluate
$^{27}Al(^{3}He,x)^{22,24}Na$		re-evaluate
$^{27}Al(\alpha,x)^{22,24}Na$		measure and re-evaluate
$^{nat}Ti(d,x)^{46}Sc$	–	re-evaluate
$^{nat}Ti(^{3}He,x)^{48}V$		measure and re-evaluate up to 46 MeV
$^{nat}Ni(d,x)^{56,58}Co$	–	measure and re-evaluate
$^{nat}Cu(p,x)^{58}Co$	–	measure and evaluate up to 100 MeV
$^{nat}Cu(p,x)^{62,63,65}Zn$	**$^{62,63}Zn$**	inconsistencies – measure and re-evaluate; **evaluate $^{62,63}Zn$ decay schemes**
$^{nat}Cu(d,x)^{62,63,65}Zn$		measure and evaluate
$^{nat}Cu(\alpha,x)^{66,67}Ga$, ^{65}Zn		measure and re-evaluate
$^{nat}Mo(p,x)^{96}Tc^{g+m}$	–	evaluate
–	**^{61}Cu**	**evaluate ^{61}Cu decay scheme**

First Research Coordination Meeting on Nuclear Data for Charged-particle Monitor Reactions and Medical Isotope Production

3-7 December 2012, IAEA report INDC(NDS)-0630

Cross sections	Decay data	Additional comments
diagnostic γ emitters		
$^{90}Zr(n,p)^{90}Y^{g+m}$	–	re-evaluate
$^{100}Mo(n,2n)^{99}Mo$	**$^{99}Tc^{m}$**	evaluate; **decay data - focus on Auger electrons**
$^{100}Mo(p,2n)^{99}Tc^{g+m}$		measure and evaluate
$^{100}Mo(p,pn)^{99}Mo$		measure and evaluate
$^{100}Mo(d,3n)^{99}Tc^{g+m}$		evaluate
$^{100}Mo(d,p2n)^{99}Mo$		evaluate
$^{100}Mo(\gamma,n)^{99}Mo$		measure
$^{100}Mo(\gamma,f)^{99}Mo$		measure
$^{64}Zn(n,p)^{67}Cu$	**^{67}Cu**	measure and evaluate; **evaluate ^{67}Cu decay scheme**
$^{67}Zn(n,p)^{64}Cu$		measure and evaluate; ^{64}Cu impurity from $^{nat}Zn(n,p)$ reaction
$^{68}Zn(n,x)^{67}Cu$		measure and evaluate
$^{68}Zn(\gamma,p)^{67}Cu$		measure
$^{112}Cd(p,2n)^{111}In$	**^{111}In**	re-evaluate; **decay data - focus on Auger electrons**

Cross sections	Decay data	Additional comments
<u>**diagnostic γ emitters**</u> **(cont.)**		
$^{124}Xe(p,2n)^{123}Cs$	–	re-evaluate – ^{123}I production
$^{124}Xe(p,pn)^{123}Xe$		re-evaluate – ^{123}I production
$^{124}Xe(p,x)^{121}I$		evaluate – ^{123}I production: ^{121}I impurity from $^{124}Xe(p,x)$ reaction
$^{51}V(p,n)^{51}Cr$	–	evaluate all noteworthy production routes of ^{51}Cr
$^{nat}Fe(p,x)^{51}Cr$		measure and evaluate
$^{203}Tl(p,2n)^{202}Pb^{m}(EC)^{202}Tl$	–	re-evaluate
$^{203}Tl(p,3n)^{201}Pb(EC)^{201}Tl$		re-evaluate
$^{203}Tl(p,4n)^{200}Pb(EC)^{200}Tl$		re-evaluate
$^{nat}W(\alpha,x)^{186,188}Re$	–	measure

First Research Coordination Meeting on Nuclear Data for Charged-particle Monitor Reactions and Medical Isotope Production

3-7 December 2012, IAEA report INDC(NDS)-0630

Cross sections	Decay data	Additional comments
β^+ emitters		
^{55}Mn(p,4n)^{52}Fe	**^{52}Fe**	evaluate; **evaluate ^{52}Fe decay scheme**
^{nat}Ni(p,x)^{52}Fe		evaluate
^{52}Cr(^{3}He,3n)^{52}Fe		evaluate
^{58}Ni(p,α)^{55}Co	–	evaluate
^{54}Fe(d,n)^{55}Co		evaluate
^{56}Fe(p,2n)^{55}Co		evaluate
^{nat}Fe(p,x)^{55}Co		measure and evaluate
^{61}Ni(p,n)^{61}Cu	–	measure and evaluate
^{64}Zn(p,α)^{61}Cu		measure and evaluate
^{66}Zn(p,n)^{66}Ga	**^{66}Ga**	evaluate; **decay data - positron intensities: measurements, and ^{66}Ga evaluate decay scheme**
^{63}Cu(α,n)^{66}Ga		evaluate
^{68}Zn(p,n)^{68}Ga	–	measure and evaluate
^{65}Cu(α,n)^{68}Ga		evaluate

First Research Coordination Meeting on Nuclear Data for Charged-particle Monitor Reactions and Medical Isotope Production

3-7 December 2012, IAEA report INDC(NDS)-0630

Cross sections	Decay data	Additional comments
β^+ emitters (cont.)		
$^{nat}Ge(p,xn)^{72}As$	**^{72}As**	measure and evaluate; **decay data - positron intensities: measurements, and evaluate ^{72}As decay scheme**
$^{75}As(p,3n)^{73}Se$	**^{73}Se**	measure and evaluate; **decay data - positron intensities: measurements, and evaluate ^{73}Se decay scheme**
$^{72}Ge(\alpha,3n)^{73}Se$		evaluate
$^{76}Se(p,n)^{76}Br$	**^{76}Br**	measure and evaluate; **decay data - positron intensities: measurements, and evaluate ^{76}Br decay scheme**
$^{77}Se(p,2n)^{76}Br$		measure and evaluate
$^{75}As(\alpha,3n)^{76}Br$		evaluate
$^{86}Sr(p,n)^{86}Y$	**^{86}Y**	re-evaluate; **decay data - positron intensities: measurements, and evaluate ^{86}Y decay scheme**
$^{88}Sr(p,3n)^{86}Y$		evaluate
$^{85}Rb(\alpha,3n)^{86}Y$		evaluate
$^{89}Y(p,n)^{89}Zr$	**^{89}Zr**	evaluate; **measure and evaluate ^{89}Zr decay scheme**
$^{89}Y(d,2n)^{89}Zr$		measure and evaluate
$^{nat}Y(\alpha,x)^{89}Zr$		measure and evaluate

Cross sections	Decay data	Additional comments
β^+ emitters (cont.)		
$^{93}Nb(p,x)^{90}Nb$	–	measure and evaluate
$^{89}Y(\alpha,x)^{90}Nb$		measure and evaluate
$^{94}Mo(p,n)^{94}Tc^m$	**$^{94}Tc^m$**	evaluate; **measure and evaluate $^{94}Tc^m$ decay scheme**
$^{92}Mo(\alpha,x)^{94}Tc^m$		evaluate
$^{111}Cd(p,2n)^{110}In^m$	–	evaluate
$^{120}Te(p,n)^{120}I$	**^{120}I**	evaluate; **measure and evaluate ^{120}I decay scheme**
$^{122}Te(p,3n)^{120}I$		
–	**^{64}Cu**	**evaluate decay scheme – discrepant weak gamma emission**

First Research Coordination Meeting on Nuclear Data for Charged-particle Monitor Reactions and Medical Isotope Production

3-7 December 2012, IAEA report INDC(NDS)-0630

Cross sections	Decay data	Additional comments
β^+ emitters: generators		
$^{62}Zn/^{62}Cu$ generator:		PET analogue of therapeutic ^{67}Cu
$^{63}Cu(p,2n)^{62}Zn$	–	measure and evaluate
$^{68}Ge/^{68}Ga$ generator:		PET analogue of new/proposed therapeutic ^{67}Ga
$^{nat}Ga(p,xn)^{68}Ge$	–	measure and evaluate
$^{69}Ga(p,2n)^{68}Ge$		measure and evaluate
$^{71}Ga(p,4n)^{68}Ge$		measure and evaluate
$^{72}Se/^{72}As$ generator:		
$^{75}As(p,4n)^{72}Se$	–	evaluate
$^{nat}Br(p,x)^{72}Se$		evaluate
$^{82}Sr/^{82}Rb$ generator:		
$^{nat}Rb(p,xn)^{82}Sr$	–	evaluate

First Research Coordination Meeting on Nuclear Data for Charged-particle Monitor Reactions and Medical Isotope Production

3-7 December 2012, IAEA report INDC(NDS)-0630

Cross sections	Decay data	Additional comments
β^+ emitters: generators		
$^{44}Ti/^{44}Sc$	**^{44}Ti $t_{1/2}$**	**evaluate ^{44}Ti half-life**
$^{52}Fe/^{52}Mn^m$	–	evaluate
$^{110}Sn/^{110}In^m$	–	evaluate; PET analogue of therapeutic ^{111}In and $^{114}In^m$
$^{118}Te/^{118}Sb$	–	evaluate; PET analogue of new/proposed therapeutic ^{117}Sb and ^{119}Sb
$^{122}Xe/^{122}I$	–	evaluate; PET analogue of therapeutic ^{123}I, ^{125}I and ^{131}I
$^{128}Ba/^{128}Cs$	–	evaluate; PET analogue of new/proposed therapeutic ^{131}Cs
$^{140}Nd/^{140}Pr$	–	evaluate

Cross sections	Decay data	Additional comments
<u>**α emitters**</u>		
$^{229}Th(\alpha)^{225}Ra(\beta^-)^{225}Ac(\alpha)$ decay chain to ^{213}Bi:	–	
$^{232}Th(p,x)^{225}Ra$		measurements up to 200 MeV, and evaluate
$^{232}Th(p,x)^{225}Ac$		measurements up to 200 MeV, and evaluate
$^{226}Ra(p,2n)^{225}Ac$		measure and re-evaluate
$^{232}Th(p,x)^{227}Ac$		evaluate; ^{227}Ac ($t_{½}$ 21.8 y) long-lived contaminant of ^{225}Ac ($t_{½}$ 10.0 d)
$^{230}U(\alpha)^{226}Th(\alpha)$ decay chain:	**^{230}U decay chain**	**evaluate all decay schemes in decay chain: $^{230}U(\alpha)^{226}Th(\alpha)^{222}Ra(\alpha)^{218}Rn(\alpha)^{214}Po(\alpha)^{210}Pb(\beta^-)$ $^{210}Bi(\beta^-)^{210}Po(\alpha)^{206}Pb$(stable)**
$^{231}Pa(d,3n)^{230}U$		evaluate
$^{231}Pa(p,2n)^{230}U$		evaluate
$^{232}Th(p,3n)^{230}Pa(\beta^-)^{230}U$		^{230}Pa β^- branch of only 7.8% – evaluate
$^{227}Th(\alpha)^{223}Ra(\alpha)$ decay chain: $^{232}Th(p,x)^{227Th}$	–	

First Research Coordination Meeting on Nuclear Data for Charged-particle Monitor Reactions and Medical Isotope Production

3-7 December 2012, IAEA report INDC(NDS)-0630

Cross sections	Decay data	Additional comments
electron and X-ray emitters		
$^{130}Ba(n,\gamma)^{131}Ba(EC)^{131}Cs$	–	evaluate
$^{131}Xe(p,n)^{131}Cs$		evaluate
$^{133}Cs(p,3n)^{131}Ba(EC)^{131}Cs$		evaluate
$^{176}Hf(\alpha,2n)^{178}W(EC)^{178}Ta$	**^{178}Ta**	measure and evaluate; **decay data - focus on Auger electrons**
$^{nat}Hf(p,x)^{178}Ta$		measure and evaluate
–	**^{103}Pd**	**evaluate ^{103}Pd decay scheme (including Auger electrons)**

Intermediate-term Nuclear Data Needs for Medical Applications: Cross Sections and Decay Data

Technical Meeting
IAEA Headquarters, Vienna, Austria
22-26 August 2011

Nuclear Medicine: Nuclear Data Considerations

Future applications in nuclear medicine?

- diagnostic

  new developments over next 20 years?

- therapeutic

  new developments over next 20 years?

If we answer the above question for nuclear medicine, we define our needs for nuclear data measurements and evaluations over both the intermediate- and longer-term timescales

Intermediate-term Nuclear Data Needs for Medical Applications: Cross Sections and Decay Data

Technical Meeting
IAEA Headquarters, Vienna, Austria
22-26 August 2011

Radionuclides:

Diagnostic γ-ray emitters

β^+ emitters

Therapeutic β^-, X-ray and γ-ray emitters

Therapeutic Auger-electron emitters

Therapeutic α emitters

Proton and heavy-ion beam therapy

Intermediate-term Nuclear Data Needs for Medical Applications: Cross Sections and Decay Data

Technical Meeting
IAEA Headquarters, Vienna, Austria
22-26 August 2011

Nuclear Data:

Cross–section production data

Decay data

Modelling?

Intermediate Term:

5 to 15 years → up to 2025

Intermediate-term Nuclear Data Needs for Medical Applications: Cross Sections and Decay Data

Technical Meeting
IAEA Headquarters, Vienna, Austria
22-26 August 2011

Marie-Martine Bé	Laboratoire National Henri Becquerel, France
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Ondrej Lebeda	Czech Academy of Sciences, Czech Republic
Alan Nichols	University of Surrey, UK [Rapporteur]
Syed Qaim	Forschungszentrum Jülich, Germany [Chairman]
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Sandor Takács	Hungarian Academy of Sciences, Hungary
Roberto Capote:	IAEA Nuclear Data Section [Scientific Secretary]

Intermediate-term Nuclear Data Needs for Medical Applications: Cross Sections and Decay Data

Immediate past and future:

22-26 August 2011, IAEA Headquarters, Vienna, Austria

Intermediate-term Nuclear Data Needs for Medical Applications: Cross Sections and Decay Data

A.L. Nichols, S.M. Qaim and R. Capote Noy

IAEA report INDC(NDS)-0596, September 2011

Intermediate-term Nuclear Data Needs for Medical Applications: Cross Sections and Decay Data

Technical Meeting
IAEA Headquarters, Vienna, Austria
22-26 August 2011

Diagnostic γ-ray emitters

Radionuclide	Requirements	Comments
$^{99}Tc^{m}$	**^{100}Mo(p,xn), (p,α), (d,xn); (γ,n), (γ,f); nuclear decay data evaluated in previous CRP (IAEA-STI/PUB/1287); Auger electrons**	**Accelerator production; highly-enriched ^{100}Mo (> 99%) should be investigated; Auger-electron studies planned in CRP (2012)**
^{97}Ru	^{3}He and ^{4}He on Mo	Limited application
^{123}I	See IAEA-TECDOC-1211 and IAEA-STI/PUB/1287; **Auger electrons**	Several production reactions and discrepancies to be studied in planned CRP
^{147}Gd	**^{4}He on Sm; proton on Eu**	Special application in MRI + SPECT
^{203}Pb		Special application in tracer studies

β^+ emitters

Radionuclide	Requirements	Comments
^{11}C, ^{13}N, $^{14,15}O$, ^{30}P, ^{38}K	Activation cross sections for proton-induced reactions with energies up to 250 MeV	Cross sections well defined for $E_p < 20$ MeV → **higher energies of interest up to 250 MeV for proton therapy**
$^{34}Cl^m$	Cross-section measurements and evaluations	Low priority
^{43}Sc	**Cross-section measurements and evaluations**	Good positron-decay characteristics, but difficult to produce
^{45}Ti, ^{48}V, ^{49}Cr, ^{90}Nb	**Cross-section measurements and evaluations**	Potentially important for radioimmunotherapy
$^{51,52}Mn$	**Cross-section measurements and evaluations**	Special application in MRI + PET
^{52}Fe, ^{55}Co, ^{61}Cu, $^{110}In^m$	**Cross-section evaluations**	Several novel applications; **^{52}Fe and ^{61}Cu decay-data evaluations planned in CRP (2012)**
^{57}Ni, ^{72}As, ^{73}Se, $^{94}Tc^m$	**Cross-section measurements and evaluations; β^+ and X-ray emission probabilities**	**^{72}As, ^{73}Se and $^{94}Tc^m$ decay-data evaluations planned in CRP (2012)**

β^+ emitters (continued)

Radionuclide	Requirements	Comments
^{64}Cu	Cross sections - see previous CRP (IAEA Technical Reports Series No. 473)	Important β^+ emitter, especially for radioimmunotherapy; **decay-data evaluation planned in CRP (2012)**
^{66}Ga	**Cross-section measurements and evaluations; β^+ and X-ray emission probabilities**	**Decay-data evaluation planned in CRP (2012)**
^{68}Ga	**Cross-section measurements and evaluations**	Direct production, as well as $^{68}Ge/^{68}Ga$ generator route
^{75}Br, ^{77}Kr	Cross-section measurements and evaluations; **β^+ and X-ray emission probabilities**	Limited application
^{76}Br, ^{89}Zr	**Cross-section measurements and evaluations; β^+ and X-ray emission probabilities**	**Decay-data evaluations planned in CRP (2012)**
^{81}Rb, $^{82}Rb^m$, ^{83}Sr,	Cross-section measurements and evaluations; **β^+ and X-ray emission probabilities**	Limited application
^{86}Y	**Cross-section evaluations; β^+ and X-ray emission probabilities**	**Important positron emitter for quantification of dosimetry calculations; decay-data evaluation planned in CRP (2012)**

β^+ emitters (continued)

Radionuclide	Requirements	Comments
^{95}Ru	^{3}He and ^{4}He beam cross-section measurements and evaluations	Limited application; many gamma rays, together with ~ 14% β^+ emission
^{120}I	**Cross-section evaluations; β^+ and X-ray emission probabilities**	**Decay-data evaluation planned in CRP (2012)**
^{121}I	Cross-section measurements and evaluations	Borderline – longer-term consideration (easier to produce than ^{120}I); many gamma rays, together with ~ 11% β^+ emission
^{124}I	Cross sections - see previous CRP (IAEA Technical Reports Series No. 473)	Important positron emitter for quantification of dosimetry calculations
^{152}Tb	**Cross-section measurements and evaluations**	Potentially useful as lanthanide-based positron emitter

β^+ emitters (continued): generators

Radionuclide	Requirements	Comments
$^{44}Ti/^{44}Sc$	**Cross-section measurements and evaluations; evaluation of parent $T_{1/2}$**	Long-lived parent ($T_{1/2}$ of 60 y); difficult to produce; **evaluation of ^{44}Ti $T_{1/2}$ planned in CRP (2012)**
$^{52}Fe/^{52}Mn^{m}$	**Cross-section and decay-data measurements and evaluations**	Special application in MRI + PET
$^{62}Zn/^{62}Cu$	**Cross-section measurements and evaluations; β^+ and X-ray emission probabilities**	**^{62}Zn decay-data evaluation planned in CRP (2012)**
$^{68}Ge/^{68}Ga$, $^{82}Sr/^{82}Rb$	**Cross-section measurements and evaluations**	**Well-established systems, but inadequate databases**
$^{72}Se/^{72}As$	**Cross-section measurements and evaluations; β^+ and X-ray emission probabilities**	**^{72}As decay-data evaluation planned in CRP (2012)**
$^{140}Nd/^{140}Pr$	**Cross-section measurements and evaluations; Auger-electron and other low-energy electron data for ^{140}Nd microdosimetry**	Radiotherapy + PET; parent ^{140}Nd(EC) to operate as therapeutic radionuclide, while ^{140}Pr is positron emitter (*in-vivo* generator)

Therapeutic β^-, X-ray and γ-ray emitters

Radionuclide	Requirements	Comments
^{47}Sc	Cross-section measurements and evaluations	Low-energy β^- emitter
^{67}Cu	Cross sections - see previous CRP (IAEA Technical Reports Series No. 473); decay-data measurements and evaluation, particularly g.s. to g.s. transition	Important radionuclide – emission of low-energy β^- particles, and preparation of organometallic complexes; decay-data evaluation planned in CRP (2012)
^{103}Pd	Cross sections - see previous CRP (IAEA Technical Reports Series No. 473); decay-data discrepancies – measurements and evaluation; Auger electrons	Decay-data evaluation and Auger-electron studies planned in CRP (2012)
^{131}Cs	Cross-section measurements and evaluations	X-ray emitter
^{131}Ba	Cross-section measurements and evaluations; decay-data evaluation	X-ray emitter
^{161}Tb	$^{160}Gd(n,\gamma)^{161}Gd(\beta^-)^{161}Tb$; decay-data measurements and evaluation	Low-energy β^- emitter

Therapeutic β⁻, X-ray and γ-ray emitters (continued)

Radionuclide	Requirements	Comments
^{166}Ho	Cross sections and **decay data – see previous CRP** **(IAEA Technical Reports Series No. 473 and IAEA-STI/PUB/1287)**; **require cross-section measurements and evaluation for $^{164}Dy(2n,\gamma)^{166}Dy(\beta^-)^{166}Ho$**	High-flux reactor required for double-neutron capture
^{169}Er	**Cross-section measurements and evaluations, including spallation beam cross sections; decay-data measurements and evaluation**	Low-energy β^- emitter
^{175}Yb	**Cross-section measurements and evaluations for charged-particle reactions; decay-data measurements and evaluation**	Low-energy β^- emitter
^{191}Os / $^{191}Ir^m$	**Cross-section measurements and evaluations**	Low-energy β^- emitter for radiotherapy + SPECT; potential *in-vivo* generator
^{191}Pt / $^{191}Ir^m$	**Cross-section and decay-data measurements and evaluations**	X-ray emitter; potential *in-vivo* generator

Therapeutic Auger-electron emitters

Radionuclide	Requirements	Comments
^{67}Ga, ^{111}In	Cross sections evaluated in two previous CRPs (IAEA-TECDOC-1211 (^{67}Ga and ^{111}In), and IAEA Technical Reports Series No. 473 (^{67}Ga)); **Auger electrons may become an issue**	^{67}Ga and ^{111}In of increased application in internal radiotherapy; **^{111}In Auger-electron studies planned in CRP (2012)**
^{71}Ge	**Cross-section measurements and evaluations;** **Auger electrons may become an issue**	Half-life is rather long at 11.4 d
^{77}Br	Cross-section evaluations; **Auger electrons may become an issue**	
$^{99}Tc^m$	**Auger-electron (E_e < 25 keV) and other low-energy electron (E_e < 1 keV) data for microdosimetry; nuclear decay data evaluated in previous CRP (IAEA-STI/PUB/1287); further needs for cross-section data will arise if produced by charged-particle reactions**	Regularly used for diagnosis, but also increased application in therapeutics; **Auger-electron studies planned in CRP (2012)**
^{103}Pd	Cross sections evaluated in previous CRP (IAEA-TECDOC-1211); **decay-data measurements and evaluation**	**Decay-data evaluation and Auger-electron studies planned in CRP (2012)**

Therapeutic Auger-electron emitters (continued)

Radionuclide	Requirements	Comments
^{123}I	See IAEA-TECDOC-1211 and IAEA-STI/PUB/1287; **Auger electrons**	Regularly used for diagnosis, but also increased application in therapeutics; several production reactions and discrepancies to be studied in planned CRP
^{140}Nd	**Cross-section evaluations of several reactions; Auger electrons may become an issue**	Auger and EC decay; *in-vivo* generator (^{140}Pr) – see previous table (β^+ emitters: generators)
^{178}Ta	$^{176}Hf(\alpha,2n)^{178}W(EC)^{178}Ta$; **Auger electrons may become an issue**	Auger and EC decay; *in-vivo* generator (^{178}W); **Auger-electron studies planned in CRP (2012)**
$^{193}Pt^m$, $^{195}Pt^m$	**Cross-section measurements and evaluations; Auger electrons may become an issue**	Large number of Auger electrons emitted
^{197}Hg	**Cross-section and decay-data measurements and evaluations; Auger electrons may become an issue**	

Therapeutic α emitters

Radionuclide	Requirements	Comments
^{149}Tb	**Cross-section measurements and evaluations of spallation and heavy-ion beam reactions**	**Emission of low-energy alpha particles (< 4 MeV) – potentially useful for special applications**
$^{211}At/^{211}Po$	**Cross sections and decay data evaluated in previous CRPs** **(IAEA Technical Reports Series No. 473, and "Updated Actinide Decay Data Library (to be published))**	Well-established therapeutic radionuclide
$^{225}Ac/^{213}Bi$	**Lack of cross-section data at higher energies for spallation reaction on ^{232}Th; nuclear decay chain evaluated in previous CRP** **("Updated Actinide Decay Data Library" (to be published))**	**Potentially important therapeutic radionuclide**
$^{227}Ac/^{223}Ra$	**Inadequate cross-section data for $^{232}Th(p,x)$ production of ^{227}Ac – measurements and evaluation; ^{223}Ra nuclear decay data evaluated in previous CRP** **("Updated Actinide Decay Data Library" (to be published))**	Impurity in ^{225}Ac production
$^{230}U/^{226}Th$	Cross-section studies within planned CRP; **decay-data evaluations of complete α-decay chain**	New decay-data measurements presented at ICRM2011 conference; **decay-data evaluation planned for complete decay chain in CRP (2012)**

Intermediate-term Nuclear Data Needs for Medical Applications: Cross Sections and Decay Data

Technical Meeting
IAEA Headquarters, Vienna, Austria
22-26 August 2011

Proton beam therapy:

- non-elastic cross sections of C, N and O at E_p up to 250 MeV;
- activation cross sections of residual nuclei (^{11}C, ^{13}N, ^{15}O, ^{30}P and ^{38}K positron emitters)

Carbon beam therapy – complex fragmentation reactions → difficult to prepare data sets

Fragmentation and production of light particles and residues → require more precise models and validated parameter sets

Proton beam therapy → require more precise Monte-Carlo transport calculations for dose deposition of variations in morphology or in structure arising from bone or implants

Nuclear Data Needs

Immediate future:

IAEA-NDS CRP launched in late 2012 is dedicated to cross sections and decay data for medical applications based on:

High-Precision Beta-Intensity Measurements and Evaluations for Specific PET Radioisotopes (see IAEA report INDC(NDS)-0535, 2008)

Improvements in Charged-Particle Monitor Reactions and Nuclear Data for Medical Isotope Production (see IAEA report INDC(NDS)-0591, 2011)

Monitor reactions: ^{22,24}Na, ^{46}Sc, ^{56,58}Co, ^{62,63,65}Zn, ^{96}Tc^{m+g}

Reactions for diagnostic γ emitters: ^{99}Tc^{m}, ^{111}In, ^{123}I (^{123}Cs, ^{123}Xe, ^{121}I production)

Reactions for novel β⁺ emitters: ^{52}Fe, ^{55}Co, ^{61}Cu, ^{66,68}Ga, ^{72}As, ^{73}Se, ^{76}Br, ^{86}Y, ^{89}Zr, ^{94}Tc^{m}, ^{110}In^{m}, ^{120}I

Reactions for generators: ^{62}Zn/^{62}Cu, ^{68}Ge/^{68}Ga, ^{72}Se/^{72}As, ^{82}Sr/^{82}Rb

Reactions for therapeutic isotopes:

- α emitters – ^{225}Ra and ^{225}Ac production (→ ^{213}Bi); ^{227}Ac impurity
- electron and X-ray emitters – ^{131}Cs (also ^{131}Ba production)

Decay data evaluations: **^{52}Fe, ^{61,64,67}Cu, ^{62,63}Zn, ^{66}Ga, ^{72}As, ^{73}Se, ^{76}Br, ^{86}Y, ^{89}Zr, ^{94}Tc^{m}, ^{103}Pd, ^{120}I, ^{230}U decay chain**

^{44}Ti half-life, Auger electrons: ^{99}Tc^{m}, ^{103}Pd, ^{111}In, ^{178}Ta

Intermediate-term Nuclear Data Needs for Medical Applications: Cross Sections and Decay Data

Technical Meeting
IAEA Headquarters, Vienna, Austria
22-26 August 2011

Longer term:

Increased dynamic and quantitative positron tomography (PET) coupled with X-ray tomography (CT) and magnetic resonance imaging (MRI) for organ imaging

Assessment of improved internal radiotherapy:

- PET and therapy involving radioimmuno reactions
- Auger-electron and α-particle therapy at the cellular level

Positron emitters and therapeutic radionuclides – long-term possibilities:

- metallic-based positron emitters (e.g., Ti, Ga, Cu radionuclides) → developments in organometallic-complex chemistry
- improved microdosimetry → requirement to better characterise suitable low-energy Auger-electron emitters

Nuclear Data Needs

Intermediate- and longer-term considerations – 5 to 15/20 years?

Further need for future IAEA-NDS CRP(s) dedicated to cross sections and decay data for medical applications based on recommendations:

Intermediate-term Nuclear Data Needs for Medical Applications: Cross Sections and Decay Data

A.L. Nichols, S.M. Qaim and R. Capote Noy

22-26 August 2011, IAEA Headquarters, Vienna, Austria

IAEA Report INDC(NDS)-0596, September 2011

Previous tables refer

Where to get the data

NNDC National Nuclear Data Center
BROOKHAVEN NATIONAL LABORATORY

www.nndc.bnl.gov

NUCLEAR SCIENCE DIVISION
BERKELEY LAB
LBNL

ie.lbl.gov

TUNL

TUNL Nuclear Data Evaluation Project

www.tunl.duke.edu/nucldata

data for A < 20

Nuclear Data Services

www-nds.iaea.org

IAEA-NDS Medical Portal

Repository for and dissemination of nuclear data for medical applications:

IAEA-NDS Medical Portal must be the focal point

http://www-nds.iaea.org/medportal/

α, β^+, γ and Auger-electron Decay Data in Nuclear Medicine − Experimental Determination, Status and Deficiencies

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Workshop on Nuclear Data for Science and Technology: Medical Applications
ICTP, Trieste, Italy, 30 September – 4 October 2013