Fast neutron reference fields above 20 MeV: challenges and opportunities.

Andy Buffler

DEPARTMENT OF PHYSICS
UNIVERSITY OF CAPE TOWN

MeASURe
Metrological and Applied Sciences University Research Unit

n lab

Webinar: Consultative Committee for Ionizing Radiation
26 January 2023 : 11:00 UTC

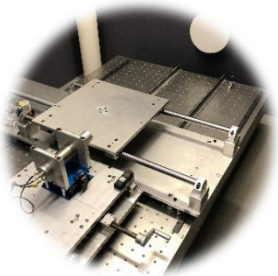
CCRI
CCRI webinars

Bureau International des Poids et Mesures

MeASURe

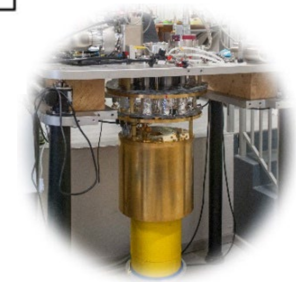
Metrological and Applied Sciences University Research Unit

www.measure.uct.ac.za



Radiation metrology

Neutron fields
and applications



Electrical metrology

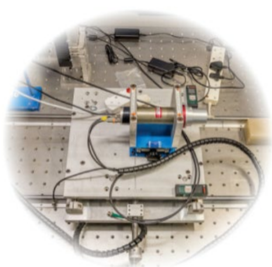
Applications of nanoelectronics
at ultralow temperatures

Metrology education

Science education
through metrology

Metrology services

Support and training
for industry



Physical metrology

Furthering research for
the Revised SI units

Industrial scale metrology

Positron emission
particle tracking

DEPARTMENT OF
PHYSICS
UNIVERSITY OF CAPE TOWN

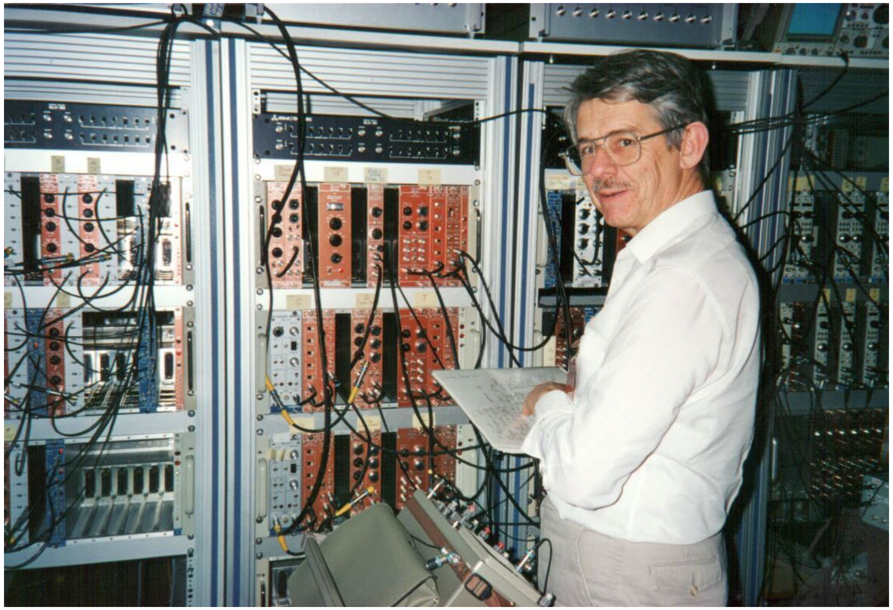
Acknowledgments

… with sincere debt to all the colleagues and students …

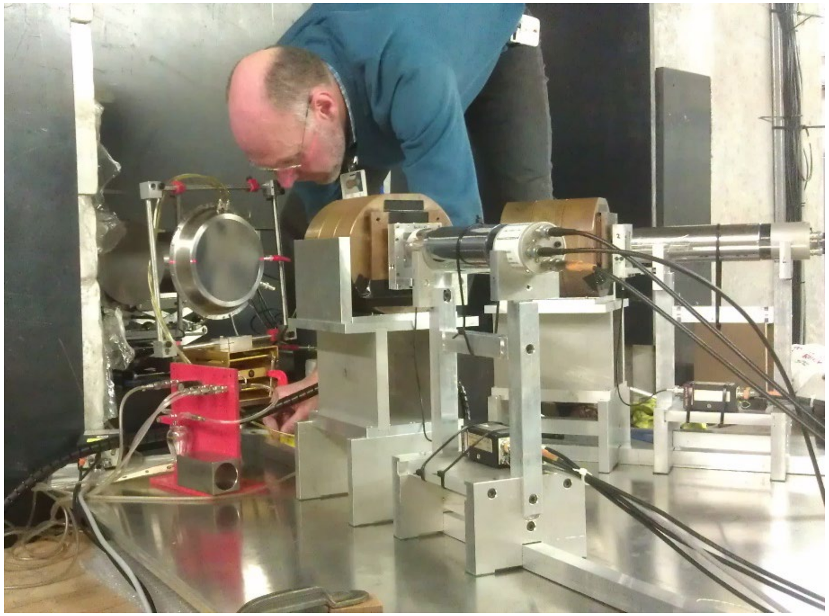
… past, present and future … South Africa and internationally …

… too many to mention … besides …

Frank Brooks



Ralf Nolte



Is counting a measurement?

So why measure?

… to update / improve our
state of knowledge about a **measurand**.

We assume that the quantity to be measured exists before the measurement …
… and it is regarded as the cause of specific effects …

… giving rise to data from measuring apparatus.

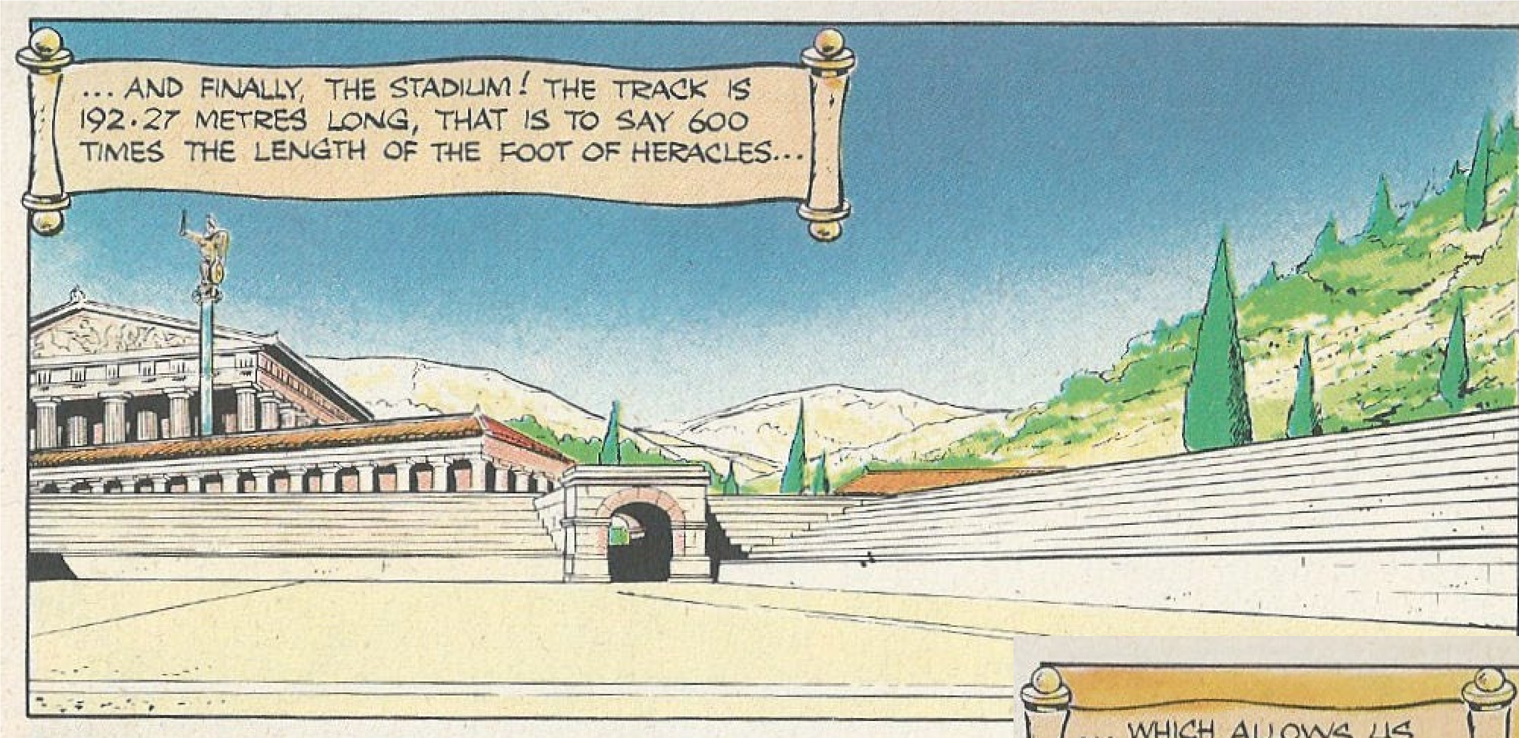
The assignment of the measurement value to the object measured is always achieved through a comparison with …

… the "**reference standard.**"

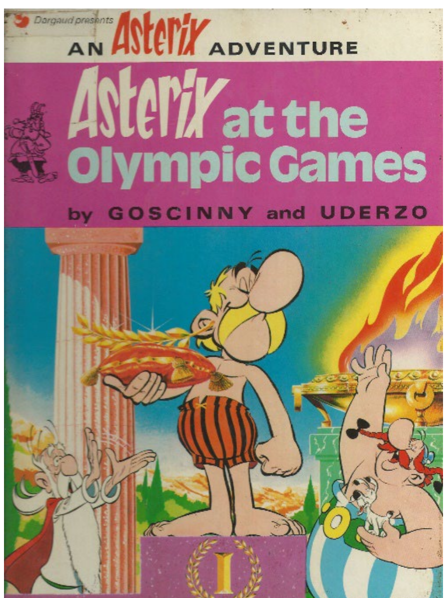
Two questions then arise:

1. How well do we know the reference standard?
2. How well can we estimate the measurand using the reference standard?

} leads to **uncertainty**

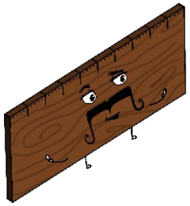

... AND FINALLY, THE STADIUM! THE TRACK IS 192·27 METRES LONG, THAT IS TO SAY 600 TIMES THE LENGTH OF THE FOOT OF HERACLES...

Ref:

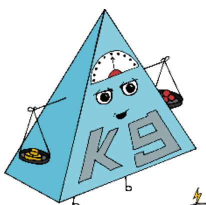

Dargaud presents
AN Asterix ADVENTURE
Asterix at the Olympic Games
by GOSCINNY and UDERZO


... WHICH ALLOWS US TO CALCULATE THAT THE DEMI-GOD TOOK ABOUT SIZE 11 IN SHOES

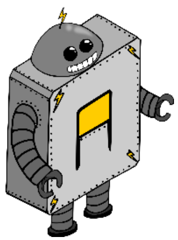
The second is defined by taking the fixed numerical value of the caesium frequency $\Delta\nu_{Cs}$, the unperturbed ground-state hyperfine transition frequency of the caesium-133 atom, to be 9192631770 s^{-1}



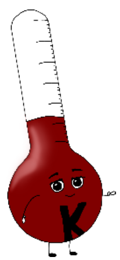
The metre is defined by taking the fixed numerical value of the speed of light in vacuum c to be 299792458 m s^{-1}



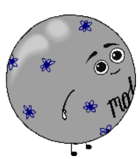
The kilogram defined by taking the fixed numerical value of the Planck constant h to be $6.62607015 \times 10^{-34}$ kg m^2 s



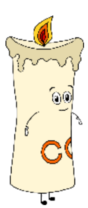
The ampere is defined by taking the fixed numerical value of the elementary charge e to be $1.602176634 \times 10^{-19}$ A s



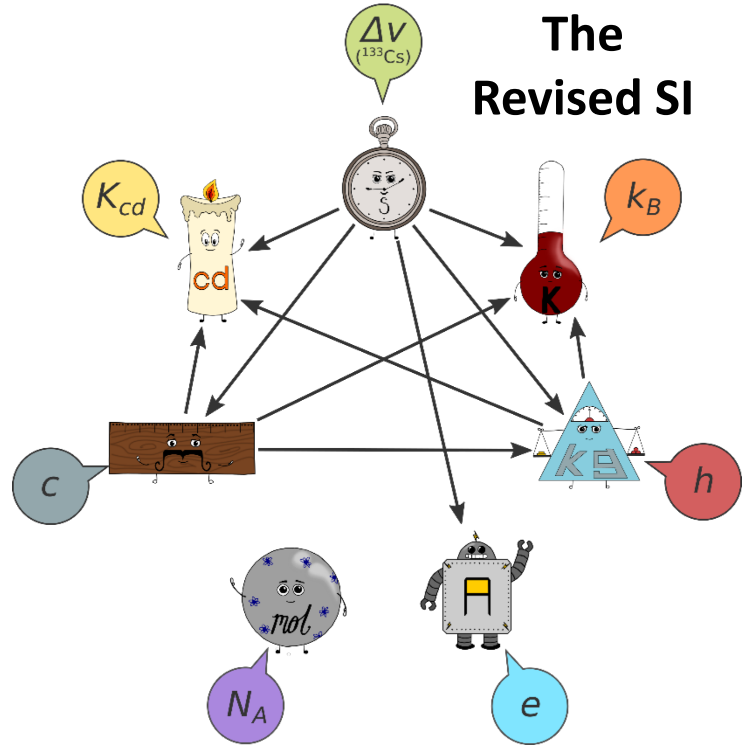
The kelvin is defined by taking the fixed numerical value of the Boltzmann constant k to be 1.380649×10^{-23} kg m^2 s^{-2} K^{-1}

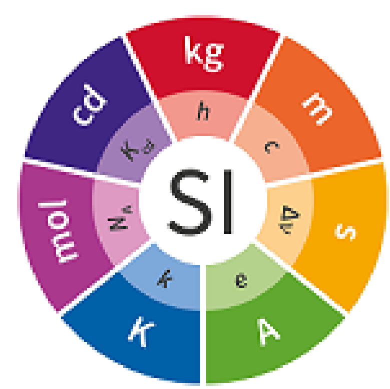


The mole is defined as an amount of substance containing exactly $6.02214076 \times 10^{23}$ elementary entities which is the fixed value of the Avogadro constant N_A



The candela defined by taking the fixed numerical value of the luminous efficacy of monochromatic radiation of frequency 540×10^{12} s^{-1}, K_{cd}, to be 683 cd sr kg^{-1} m^{-2} s^3





Therefore the question to consider is not …

“Is counting a measurement?”

… but rather …

“Are all measurements a form of counting?”

Metrologia 48 (2011)

IOP PUBLISHING METROLOGIA

Metrologia **48** (2011) doi:10.1088/0026-1394/48/6/E01

FOREWORD

Neutron metrology

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The International Committee for Weights and Measures (CIPM) has consultative committees covering various areas of metrology. The Consultative Committee for Ionizing Radiation (CCRI) differs from the others in having three sections: Section (I) deals with radiation dosimetry, Section (II) with radionuclide metrology and Section (III) with neutron metrology. In 2003 a proposal was made to publish special issues of *Metrologia* covering the work of the three Sections. Section (II) was the first to complete their task, and their special issue was published in 2007, volume **44**(4). This was followed in 2009 by the special issue on radiation dosimetry, volume **46**(2). The present issue, volume **48**(6), completes the trilogy and attempts to explain neutron metrology, the youngest of the three disciplines, the neutron only having been discovered in 1932, to a wider audience and to highlight the relevance and importance of this field.

When originally approached with the idea of this special issue, Section (III) immediately saw the value of a publication specifically on neutron metrology. It is a topic area where papers tend to be scattered throughout the literature in journals covering, for example, nuclear instrumentation, radiation protection or radiation measurements in general. Review articles tend to be few. People new to the field often ask for an introduction to the various topics. There are some excellent older textbooks, but these are now becoming obsolete. More experienced workers in specific areas of neutron metrology can find it difficult to know the latest position in related areas. The papers in this issue attempt, without presenting a purely historical outline, to describe the field in a sufficiently logical way to provide the novice with a clear introduction, while being sufficiently up-to-date to provide the more experienced reader with the latest scientific developments in the different topic areas.

WG11 - High energy radiation fields

Motivation Aim Task Groups

Chairperson

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CV

Secretary

Veronika Olšovcová
ELI Beamlines, Inst. of Physics, CAS (Czech Republic)
Email: Veronika.Olsovcova@eli-beams.eu

Membership

Working Group 11 has:

- 37 full members from 10 countries
- 50 corresponding members from 17 countries.

WG11 – High energy radiation fields

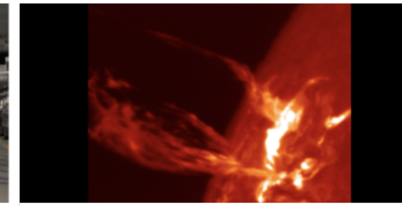
Task Groups

Task 1 - Comparison of Monte Carlo codes using ICRP 103 conversion factors for Radiation Exposure of Aircraft Crew

Task Group leader: Marcin Latocha (Seibersdorf Laboratories, Austria)

Task 2 - Dosimetry in pulsed radiation fields

Task Group leader: Marco Caresana (POLIMI, Italy)



Task 3 - Improvement of the models for dose assessment due to solar particle events and validation with experimental data

Task Group leader: Peter Beck (Seibersdorf Laboratories, Austria)

Task 4 - Solar particles events measurements

Task Group leader: Iva Ambrožová (Nuclear Physics Institute of the Czech Academy of Sciences, Czech Republic)

Task 7 - High energy reference field

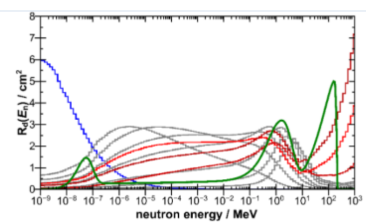
Task Group leader: Eike Hohmann (PSI, Switzerland)

Task 8 - Radiation dose induced by natural electric discharge in the atmosphere

Task Group leader: Ondrej Ploc (Nuclear Physics Institute of the Czech Academy of Sciences, Czech Republic)

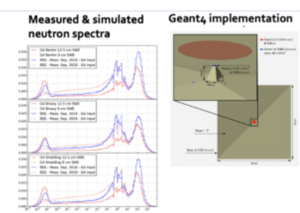
Task 10 - Operational Procedure for GLE Management

Task Group leader: Peter Beck (Seibersdorf Laboratories, Austria)



Task 11 - Course on unfolding neutron spectra

Task Group leader: Marcel Reginatto (PTB, Germany)



Task 12 - Benchmark of the MC models used for high energy neutrons

Task Group leader: Vladimir Mares (HMGU, Germany)

Neutron metrology

Quantity of interest is often a **fluence.**

Fluence $\Phi = \frac{dN}{da}$ neutrons m^{-2}

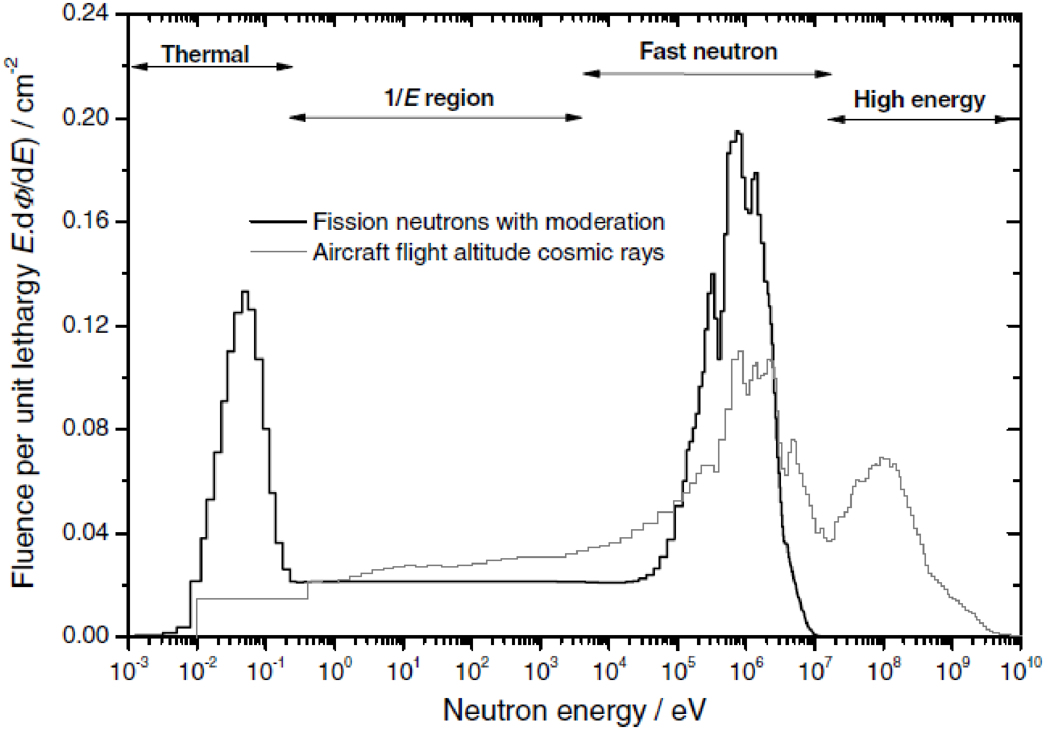
(Flux: $\frac{dN}{dt}$ neutrons s^{-1})

Sounds straightforward.

What can be simpler than counting free neutrons?

Neutron metrology has special challenges

… complicated by the very large range in both **energies** and **intensities** of interest …



Directional characteristics of the neutron field can also be of interest …

… but is typically difficult to achieve.

Also sometimes the spectral fluence is necessary …

… requires **spectrometry**.

Neutron detection has special challenges

Detecting a neutron is more challenging than charged particles since neutrons are

… well … neutrally charged …

… hence interact only with atomic nuclei.

Many interaction channels … [complicated to unravel]

Thermal region: neutron capture and fission
Higher energies: (n,p), (n,d), (n,α) reactions, and spallation
At all energies: scattering

Furthermore, it is seldom to have a neutron field which is free from gamma-rays …

… can complicate detector response.

High level measurement equation

Detector response per atom

Fluence

$$\Phi = \frac{R_\Phi}{\sigma}$$

Cross section

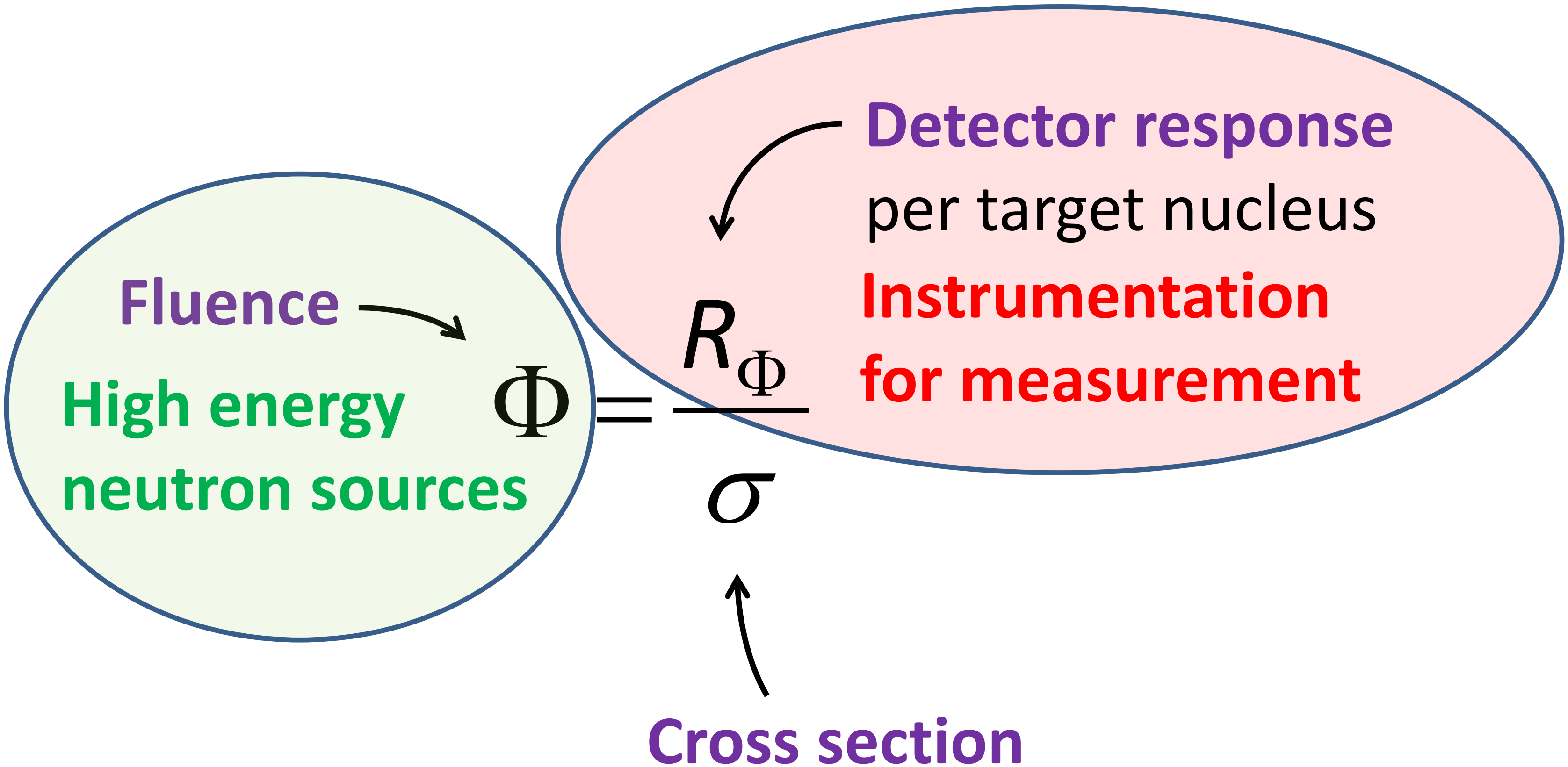
Detector response
per target nucleus

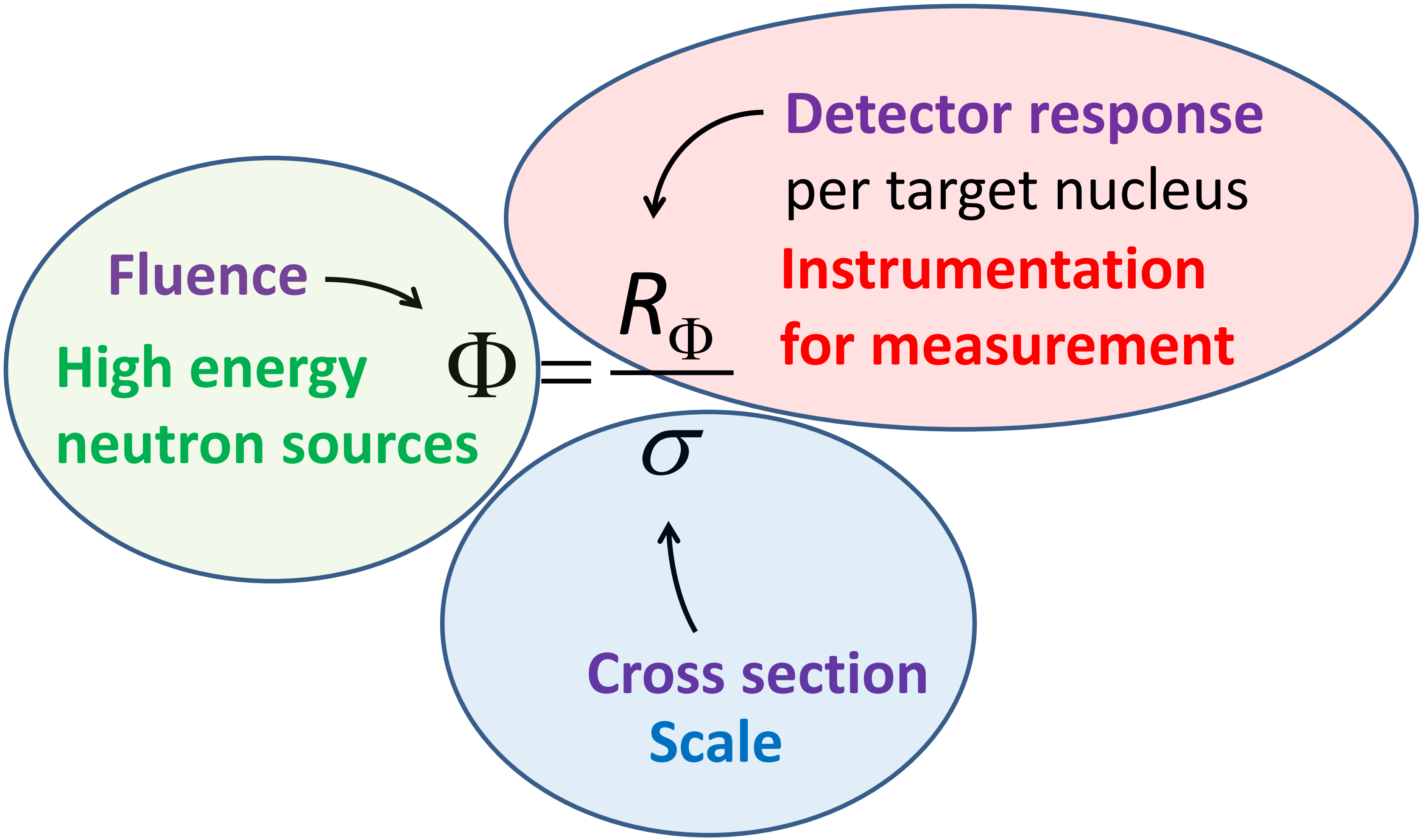
Fluence

High energy
neutron sources

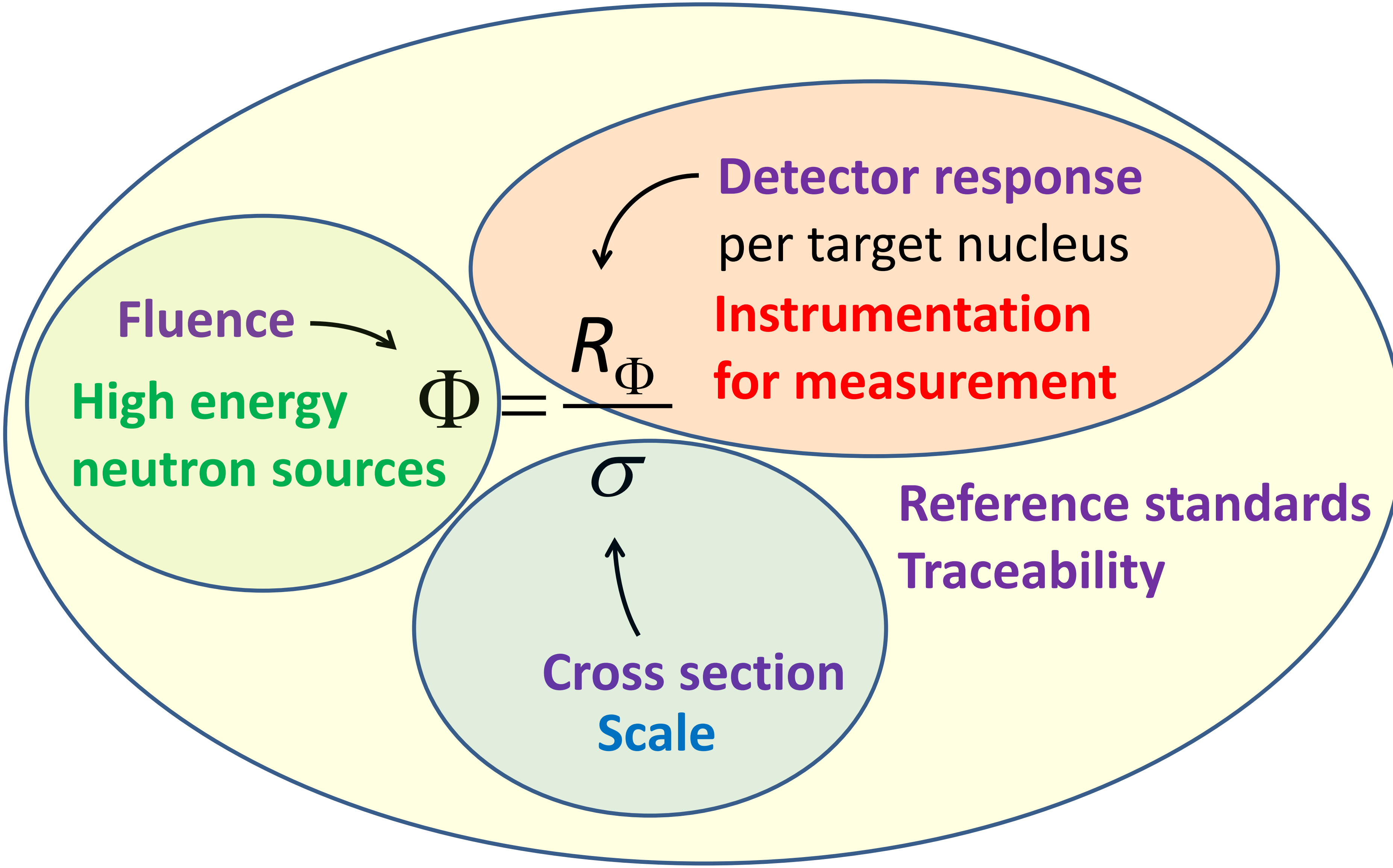
$$\Phi = \frac{R_{\Phi}}{\sigma}$$

Cross section

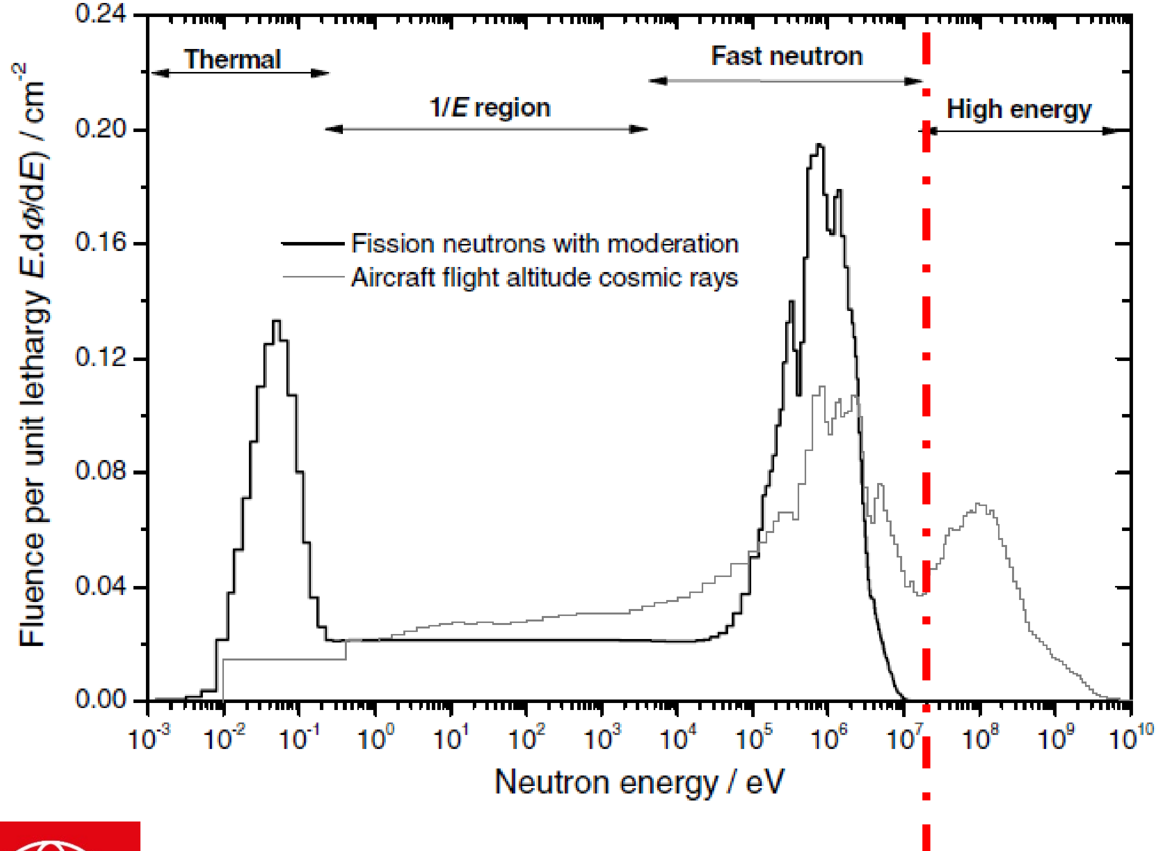

Detector response
per target nucleus
Instrumentation
for measurement
Fluence
High energy
neutron sources
$\Phi = \frac{R_\Phi}{\sigma}$
Cross section



Detector response
per target nucleus
Instrumentation
for measurement
Fluence
High energy
neutron sources
$\Phi = \frac{R_\Phi}{\sigma}$
Cross section
Scale


Detector response
per target nucleus
Instrumentation
for measurement
Fluence
High energy
neutron sources
$\Phi = \frac{R_\Phi}{\sigma}$
Reference standards
Traceability
Cross section
Scale

Why 20 MeV?



ISO

- 8529-1
- 8529-2
- 8529-3

$$\Phi = \frac{R_\Phi}{\sigma}$$

ISO-standards for neutron metrology: 8529

ISO 8529-1:2021

Neutron reference radiations fields — Part 1: Characteristics and methods of production

ISO 8529-2:2000

Reference neutron radiations — Part 2: Calibration fundamentals of radiation protection devices related to the basic quantities characterizing the radiation field

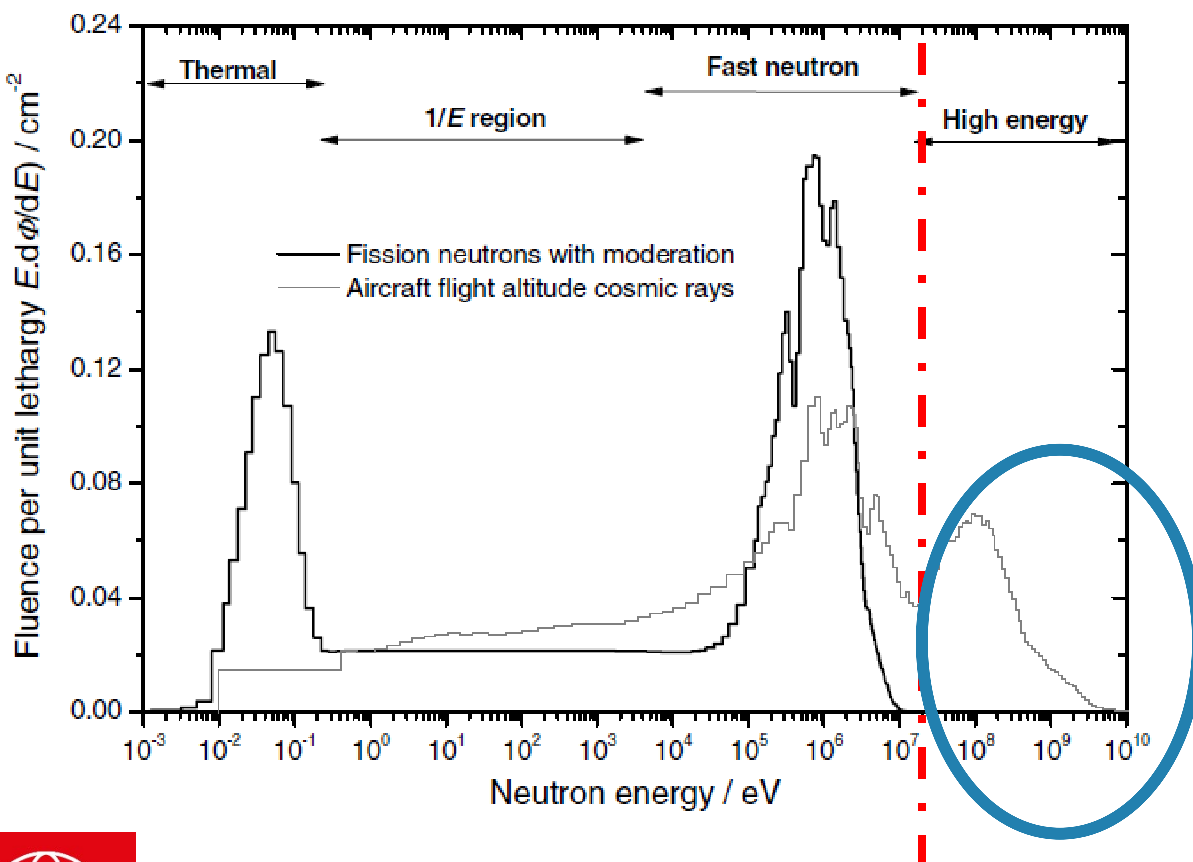
ISO 8529-3:1998

Reference neutron radiations — Part 3: Calibration of area and personal dosimeters and determination of response as a function of energy and angle of incidence

ISO

no standards for above 20 MeV

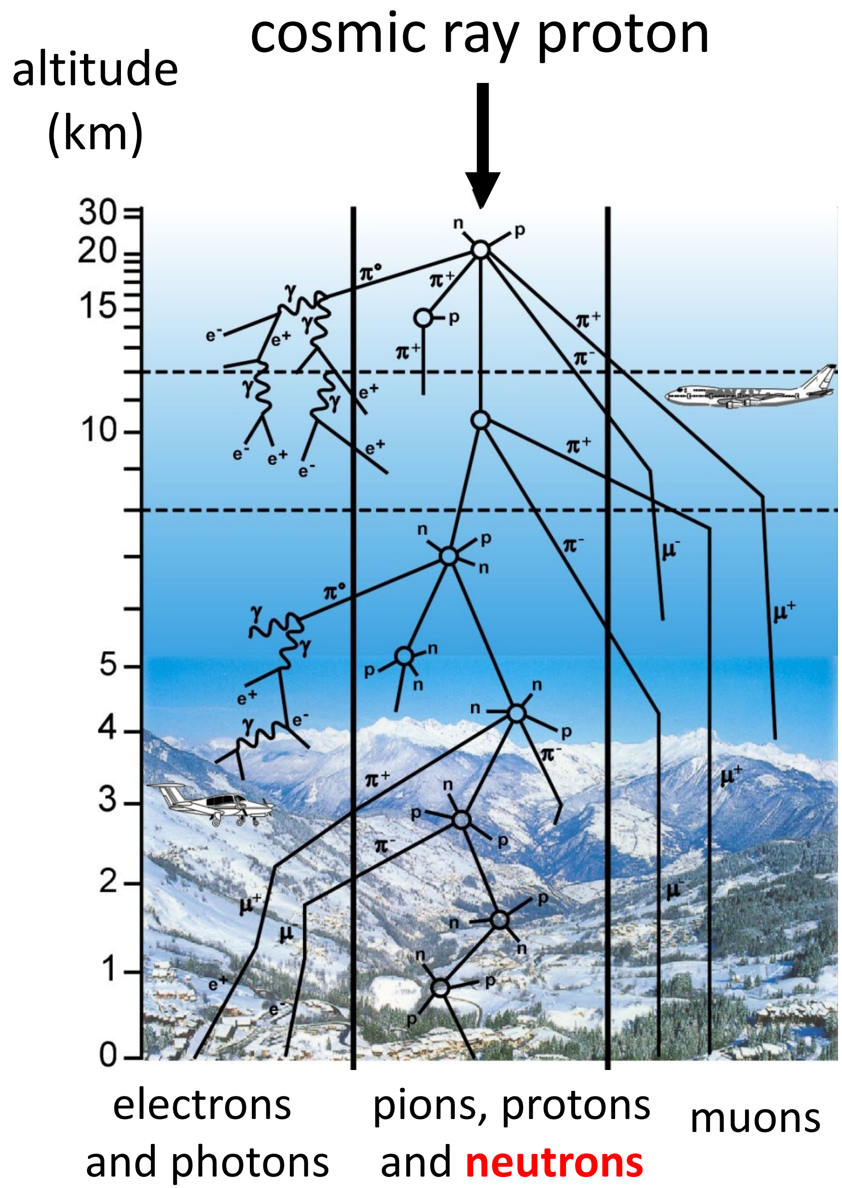
20 MeV



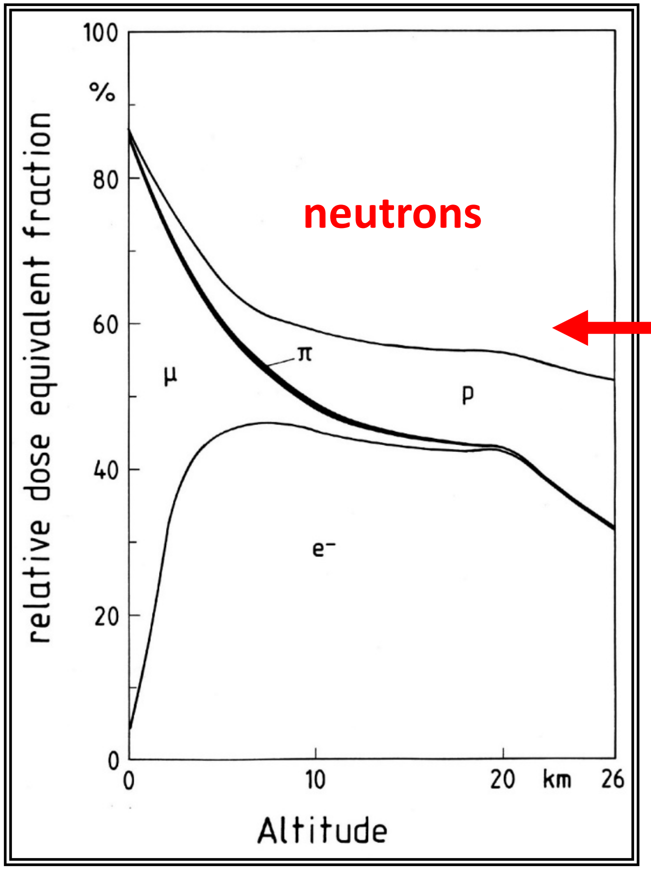
- 8529-1
- 8529-2
- 8529-3

$$\Phi = \frac{R_\Phi}{\sigma}$$

Neutron production from cosmic rays in the atmosphere

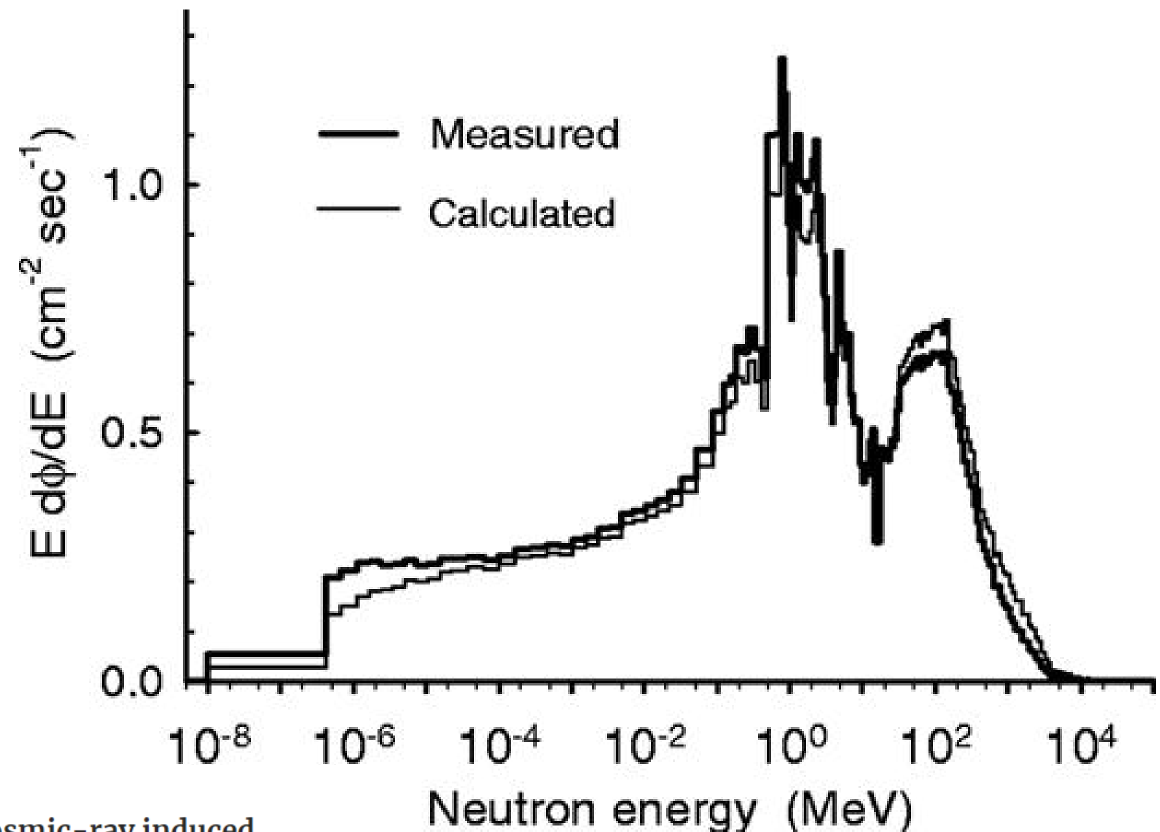


Secondary particles from spallation in earth's atmosphere



At flight altitudes **neutron** contribution is around 40 %.

Cosmic ray neutron spectrum in Earth's atmosphere: 20 km altitude at 54° N, 117° W



JOURNAL ARTICLE

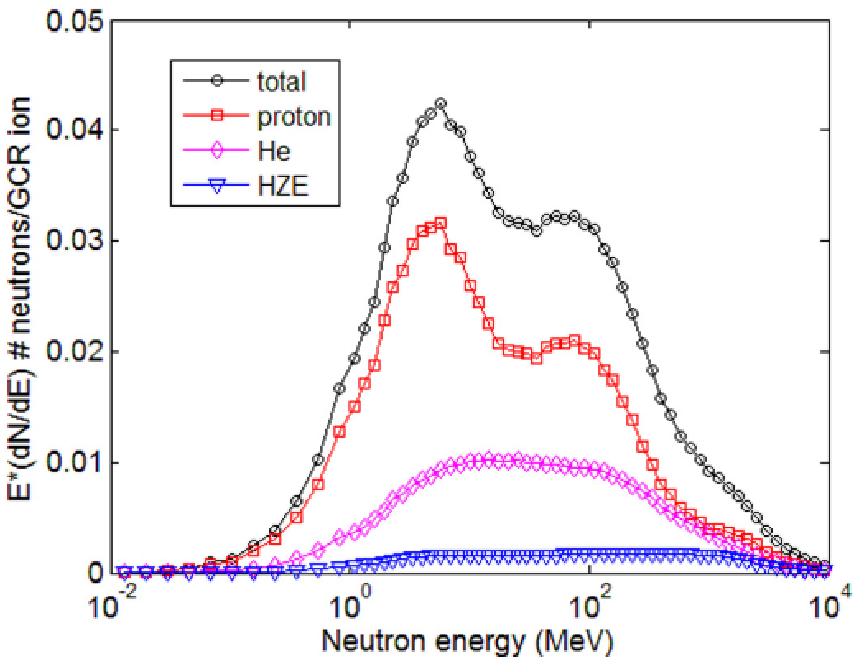
The energy spectrum of cosmic-ray induced neutrons measured on an airplane over a wide range of altitude and latitude

P. Goldhagen, J. M. Clem, J. W. Wilson

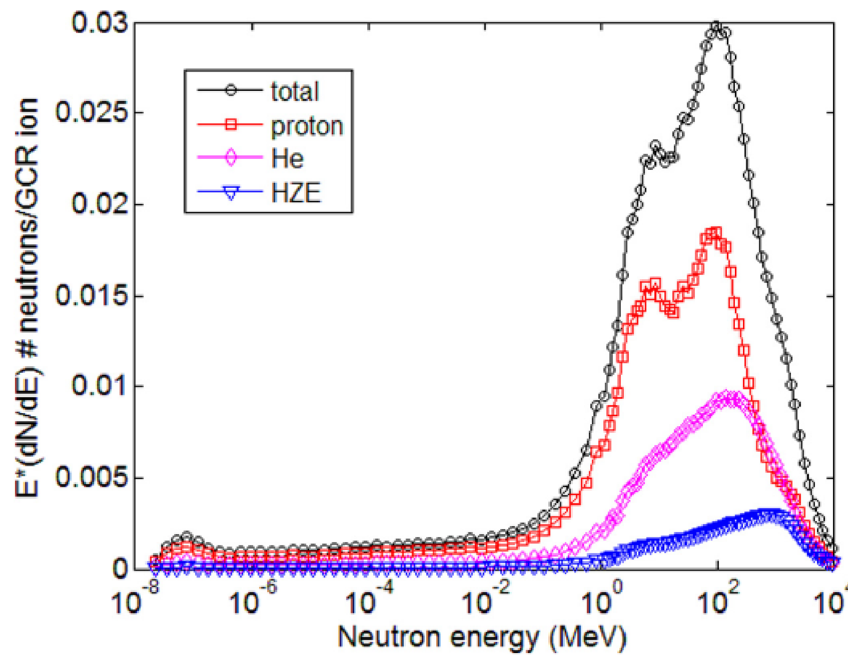
Radiation Protection Dosimetry, Volume 110, Issue 1-4, 1 August 2004, Pages 387–392,
https://doi.org/10.1093/rpd/nch216
Published: 01 August 2004

Neutron production from cosmic rays in matter (Monte Carlo)

2.7 g cm^{-2} water



2.7 g cm^{-2} aluminium



ELSEVIER

Life Sciences in Space Research

Volume 7, November 2015, Pages 90-99

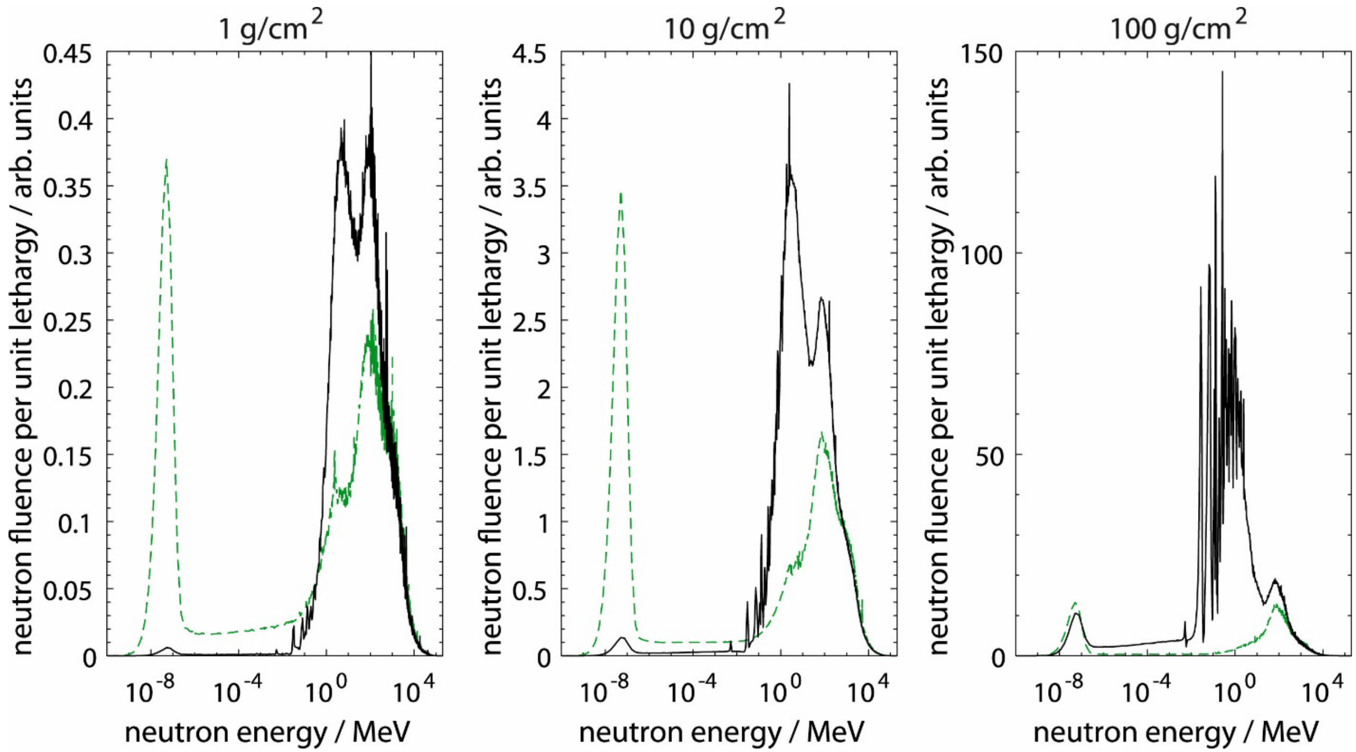
Neutron yields and effective doses produced by Galactic Cosmic Ray interactions in shielded environments in space

Lawrence H. Heilbronn [a], Thomas B. Borak [b], Lawrence W. Townsend [a], Pi-En Tsai [a], Chelsea A. Burnham [a], Rafe A. McBeth [b]

Energy spectra of neutrons impinging on an ICRU sphere for a solar maximum GCR spectrum

- - - - - - polyethylene

——— aluminium



ELSEVIER

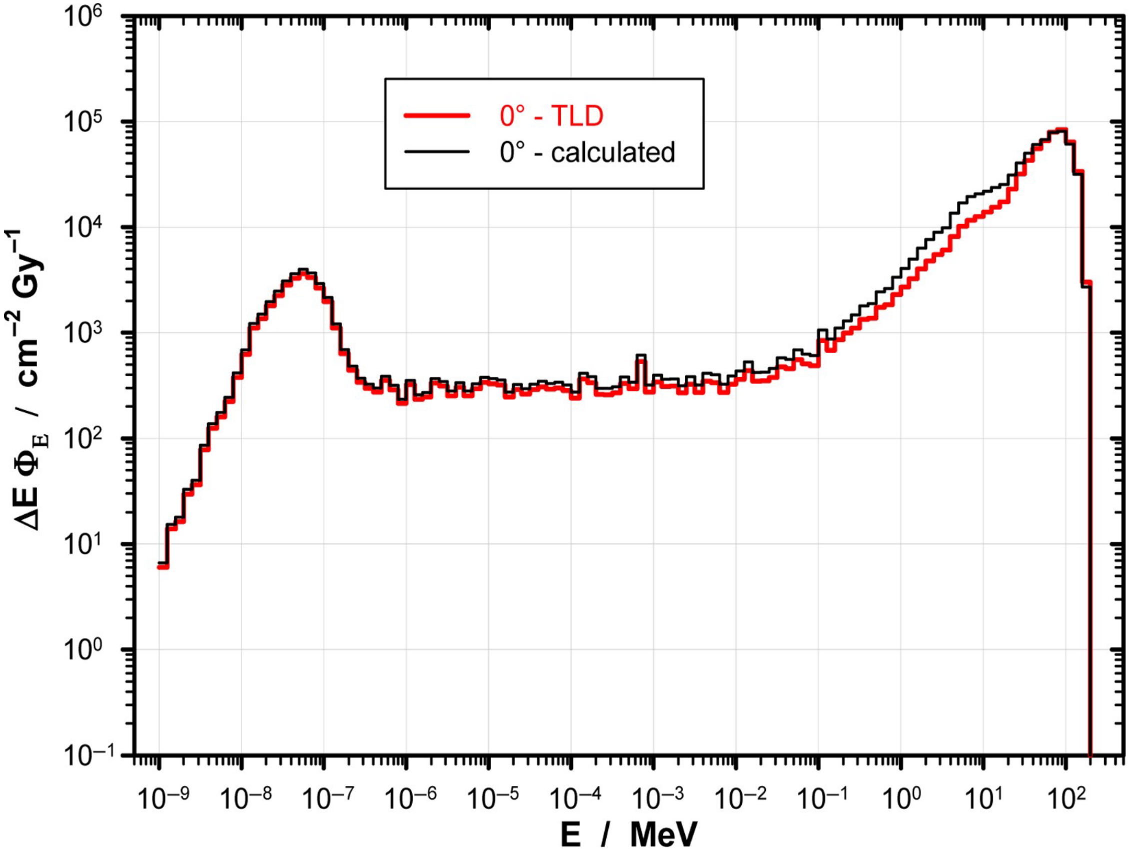
Life Sciences in Space Research

Volume 33, May 2022, Pages 58-68

Thick shielding against galactic cosmic radiation: A Monte Carlo study with focus on the role of secondary neutrons

Felix Horst [a], Daria Boscolo [a], Marco Durante [a, b], Francesca Luoni [a, b], Christoph Schuy [a], Uli Weber [a]

Neutron spectrum measured in a nylon phantom for E_p = 200 MeV



JOURNAL ARTICLE

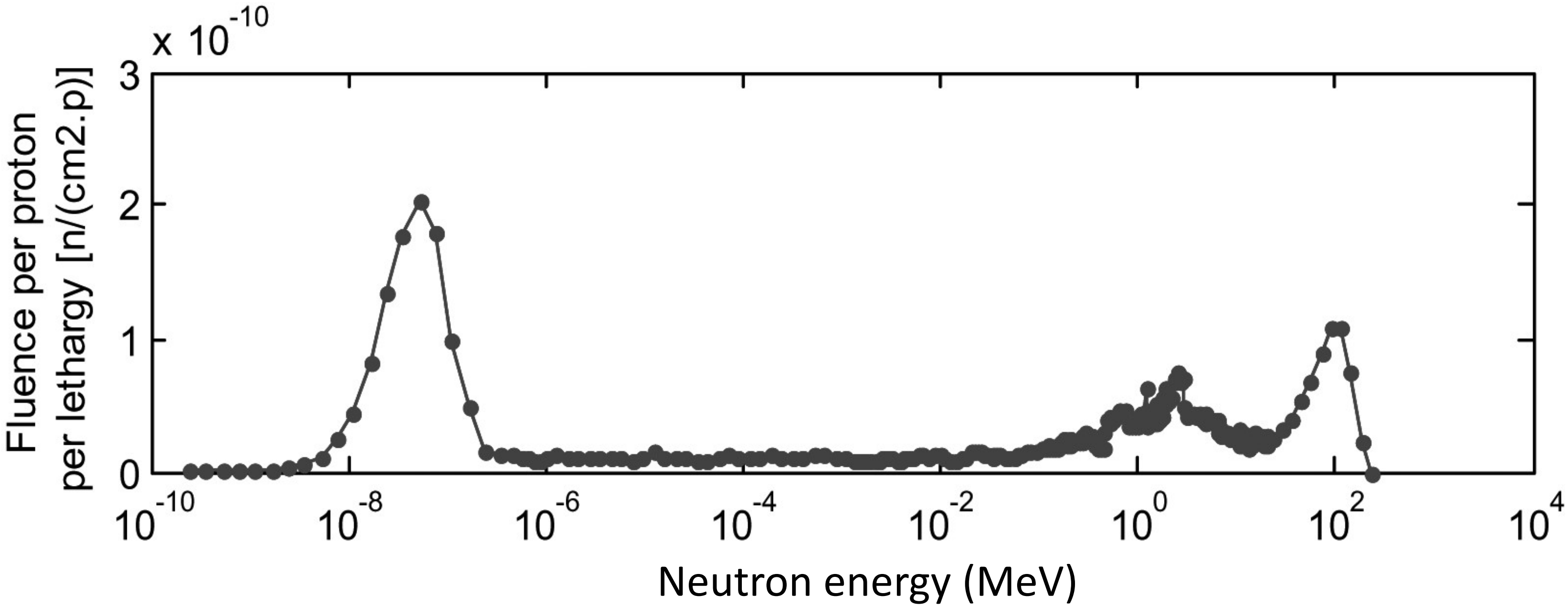
MEASUREMENT OF SECONDARY NEUTRONS GENERATED DURING PROTON THERAPY

Z. Vykydal ✉, M. Andrlík, H. Bártová, M. Králík, J. Šolc, V. Vondráček

Radiation Protection Dosimetry, Volume 172, Issue 4, 2 December 2016, Pages 341–345, https://doi.org/10.1093/rpd/ncv504

Published: 02 January 2017 **Article history ▾**

Neutron spectrum measured in water phantom for E_p = 227 MeV



JOURNAL ARTICLE

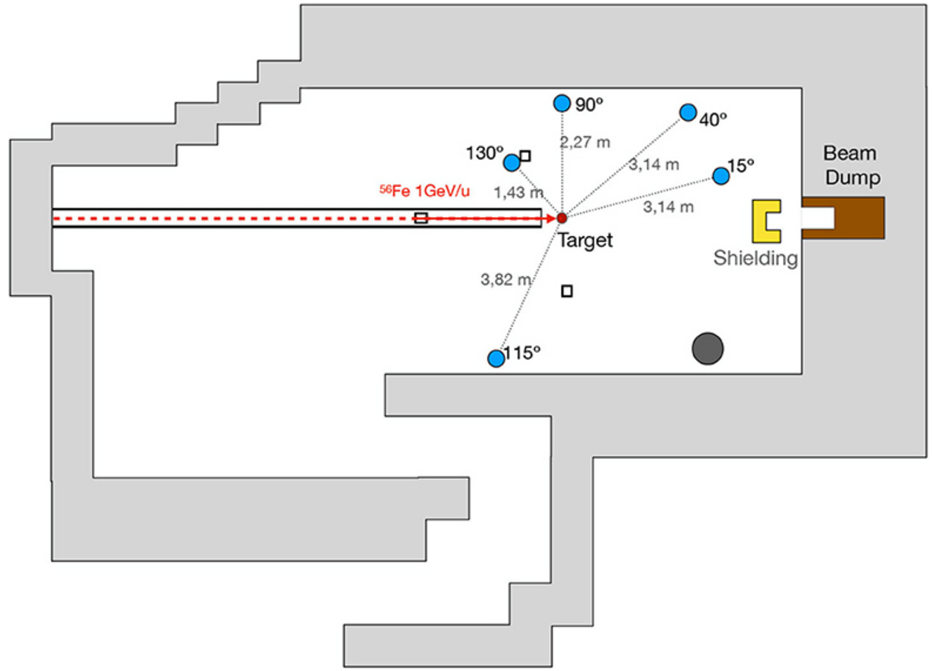
SECONDARY NEUTRON DOSES IN A PROTON THERAPY CENTRE

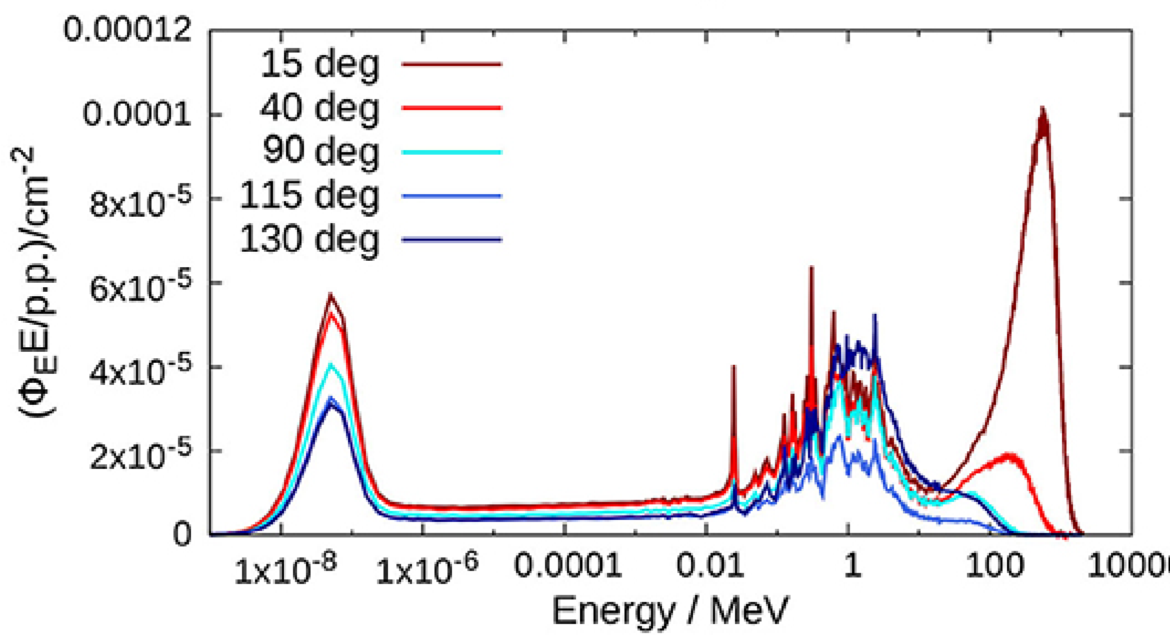
M. De Saint-Hubert ✉, C. Saldarriaga Vargas, O. Van Hoey, W. Schoonjans, V. De Smet, G. Mathot, F. Stichelbaut, G. Manessi, N. Dinar, E. Aza, C. Cassell, M. Silari, F. Vanhavere

Radiation Protection Dosimetry, Volume 170, Issue 1-4, September 2016, Pages 336–341, https://doi.org/10.1093/rpd/ncv458

Published: 07 September 2016

Energy spectra of neutrons at various positions in Cave A at GSI for a 1 GeV/u ^{56}Fe beam





ORIGINAL RESEARCH article

Front. Phys., 29 October 2020
Sec. Radiation Detectors and Imaging
Volume 8 - 2020 | https://doi.org/10.3389/fphy.2020.00365

This article is part of the Research Topic
Applied Nuclear Physics at Accelerators
View all 57 Articles >

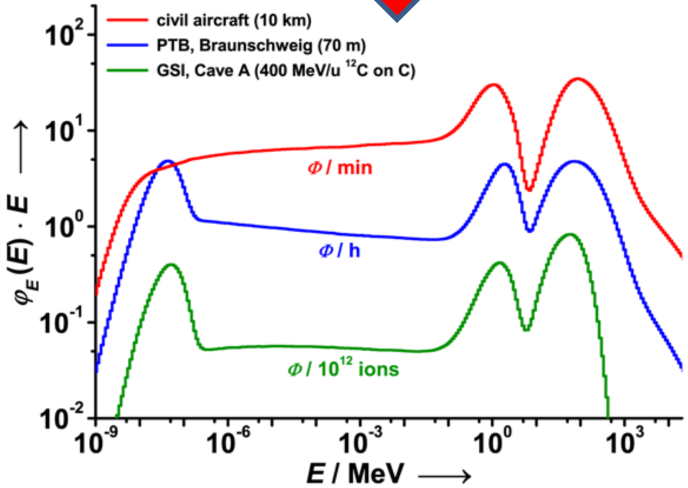
Characterization of the Secondary Neutron Field Produced in a Thick Aluminum Shield by 1 GeV/u ^{56}Fe Ions Using TLD-Based Ambient Dosimeters

Daria Boscolo[1], Daniela Scognamiglio[1,2], Felix Horst[1,3*], Uli Weber[1], Christoph Schuy[1], Marco Durante[1,4], Chiara La Tessa[5], Ekaterina Kozlova[1], Alexey Sokolov[1], Irina Dinescu[6], Torsten Radon[1], Désirée Radeck[7] and Miroslav Zbořil[7]

Charged particles of energy >100 MeV (accelerator, GCR, SPE)

Spallation in "any" material

neutrons



- **Dosimetry**
- **Metrology**

IOP Publishing Metrologia
Metrologia 48 (2011) S292–S303 doi:10.1088/0026-1394/48/6/S06

Quasi-monoenergetic high-energy neutron standards above 20 MeV

Hideki Harano[1] **and Ralf Nolte**[2]

[1] National Metrology Institute of Japan (NMIJ), Japan
[2] Physikalisch-Technische Bundesanstalt (PTB), Germany

Received 28 March 2011, in final form 20 June 2011
Published 28 October 2011
Online at stacks.iop.org/Met/48/S292

Abstract
This paper provides an overview of high-energy quasi-monoenergetic neutron sources and facilities above 20 MeV around the world. Various technical matters are discussed which are required in characterizing the neutron fields by spectrometry, fluence and beam profile measurements. Important topics regarding the calibration of neutron detectors are also introduced with emphasis on beam monitoring, tail correction, background subtraction and fluence-to-dose conversion. Efforts to standardize the high-energy neutron fluence in Japan and by the German national metrology institute in collaboration with Belgian and South African institutions are also presented.

Two useful documents

EURADOS
European Radiation Dosimetry Group e. V.

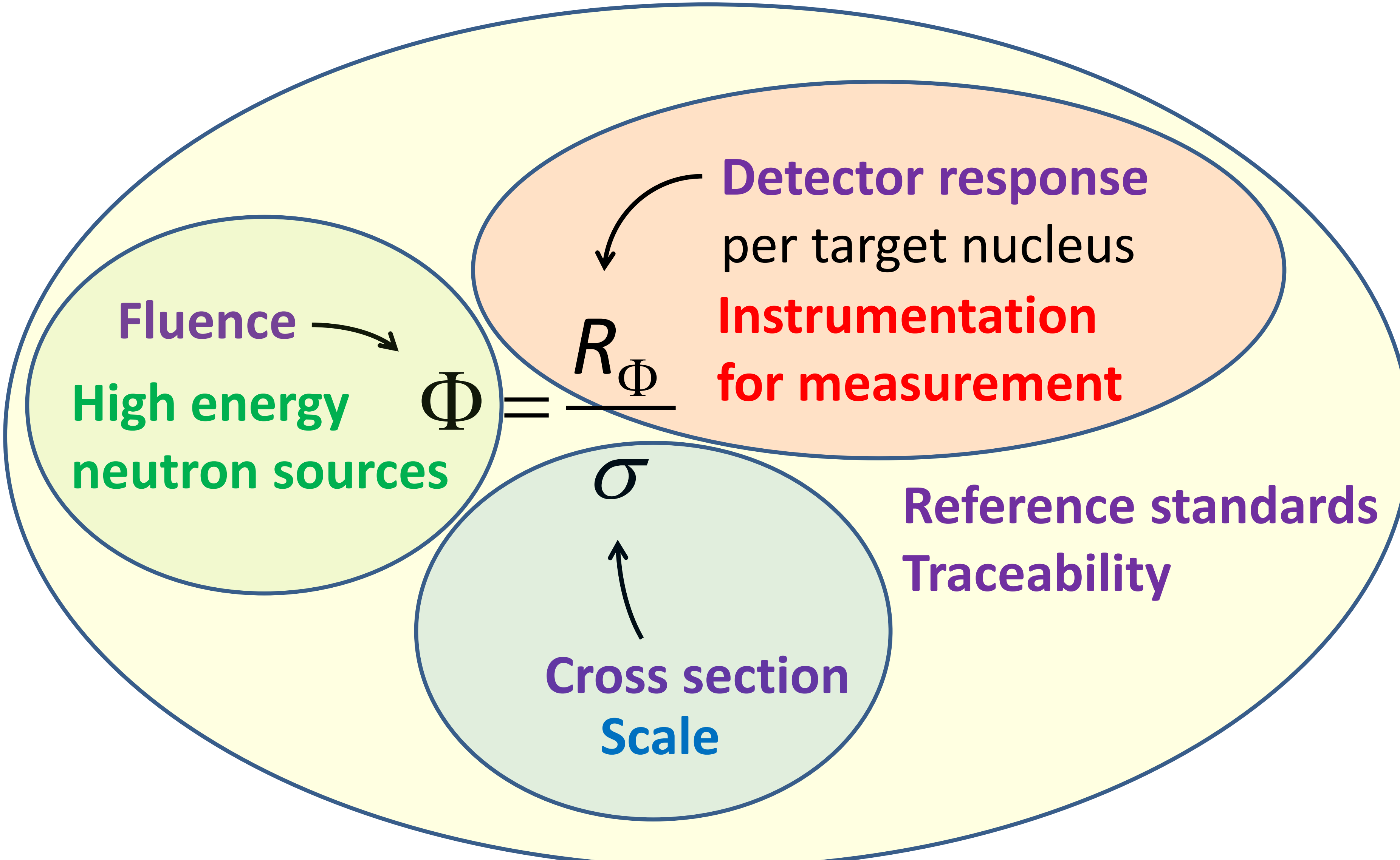
EURADOS Report 2013-02
Braunschweig, May 2013

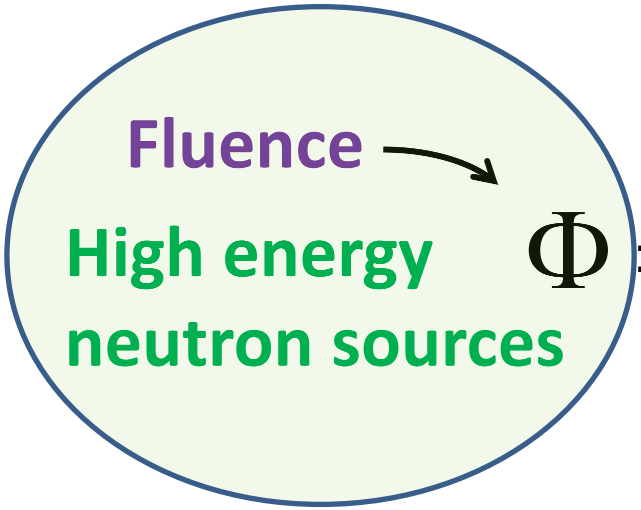
High-energy quasi-monoenergetic neutron fields: existing facilities and future needs

Pomp S., Bartlett D.T., Mayer S., Reitz G., Röttger S., Silari, M., Smit F.D., Vincke H., and Yasuda H.

ISSN 2226-8057
ISBN 978-3-943701-04-3

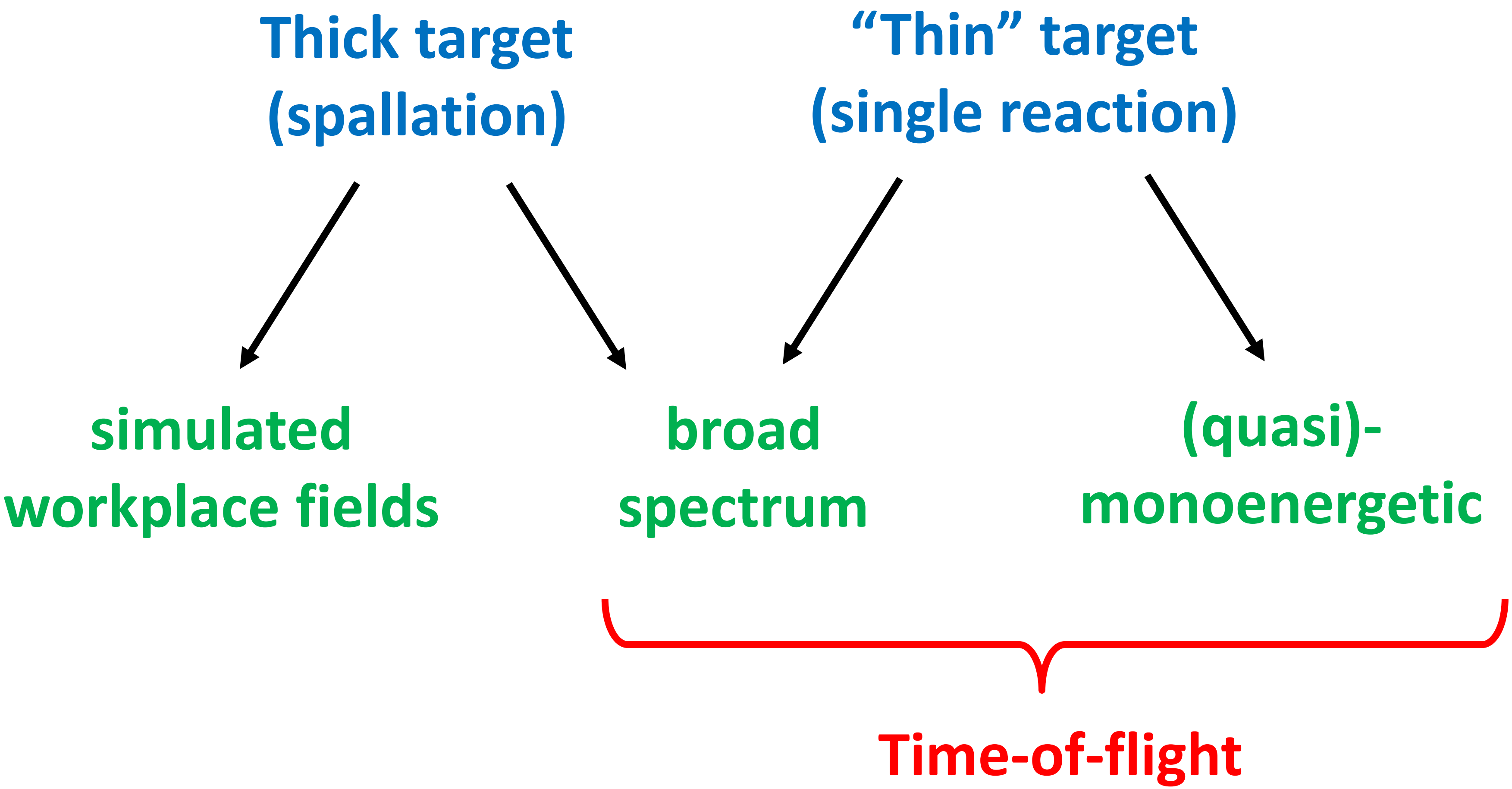
High level measurement equation



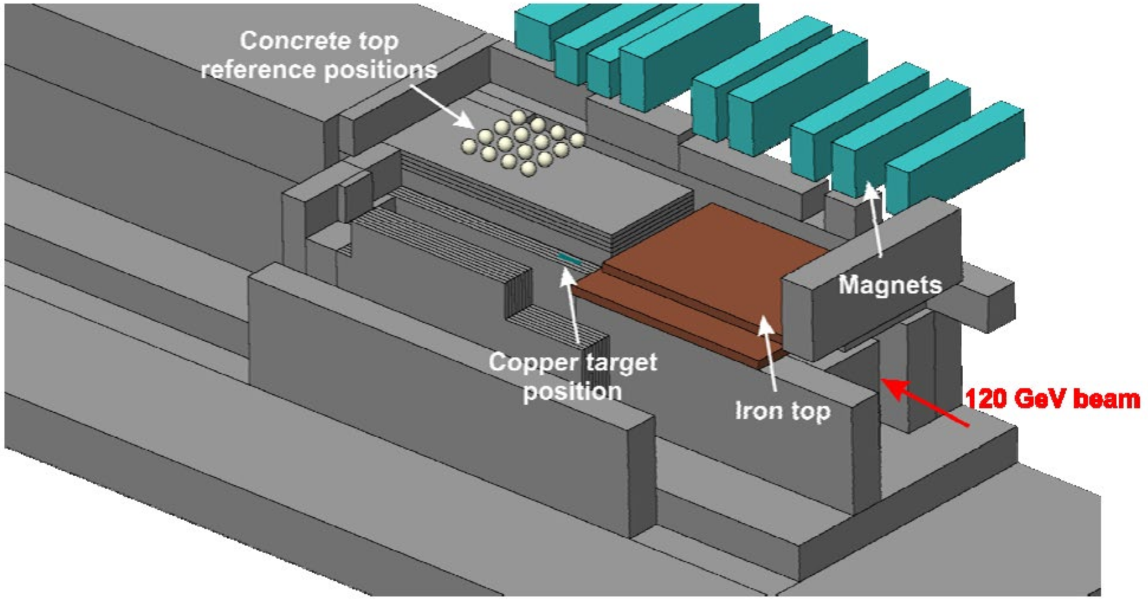


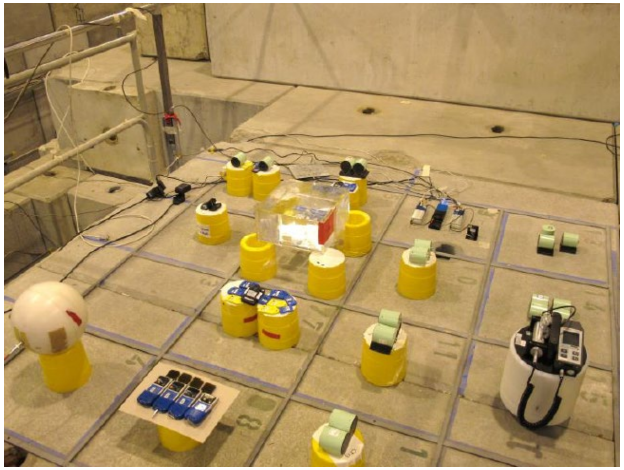
$$\Phi = \frac{R_{\Phi}}{\sigma}$$

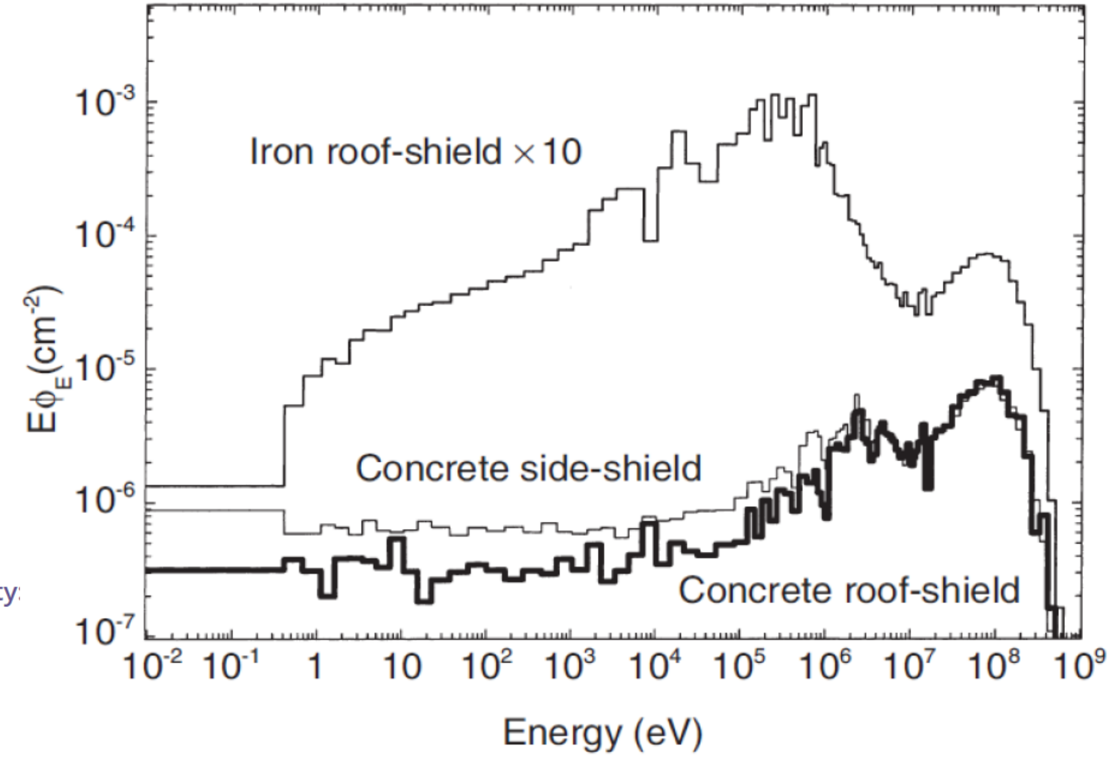
Two “categories” of accelerator-based neutron fields



The CERN-EU high energy Reference Field (CERF)







EPJ Web of Conferences **153**, 03001 (2017)
https://doi.org/10.1051/epjconf/201715303001

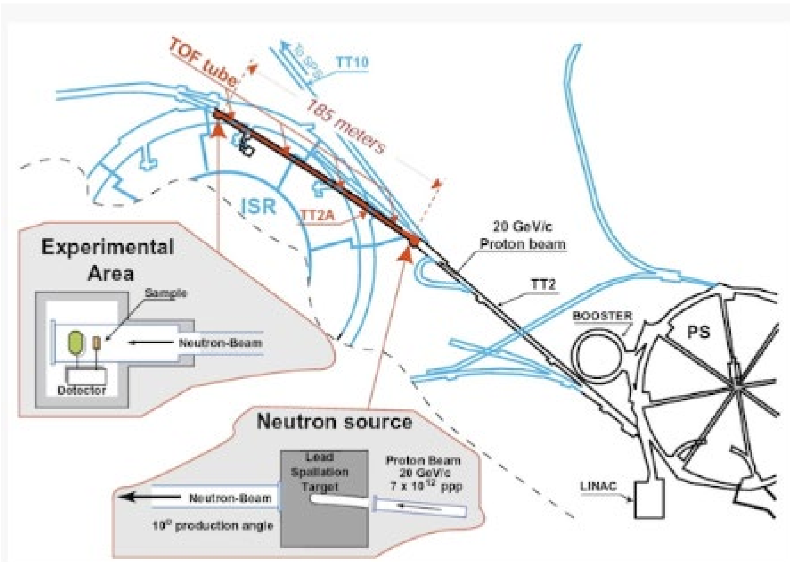
The CERN-EU high-energy Reference Field (CERF) facility: applications and latest developments

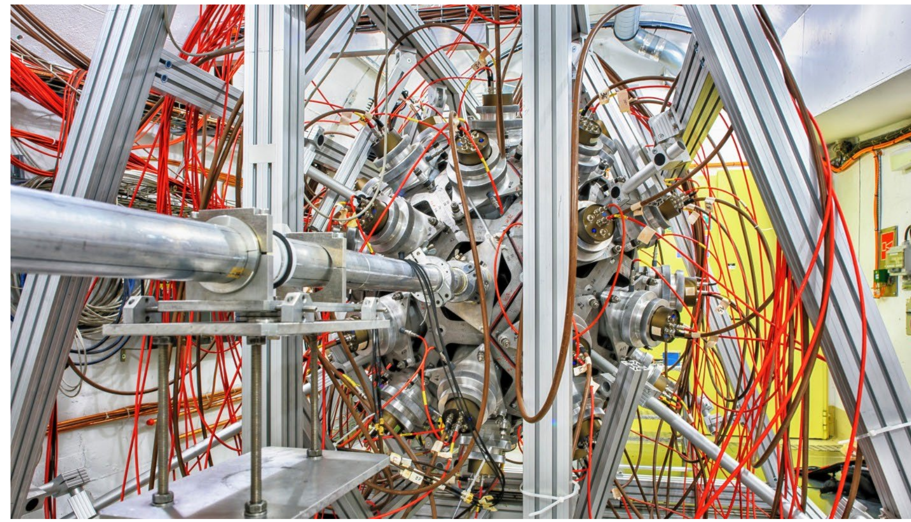
Marco Silari* and Fabio Pozzi

CERN, 1211 Geneva 23, Switzerland

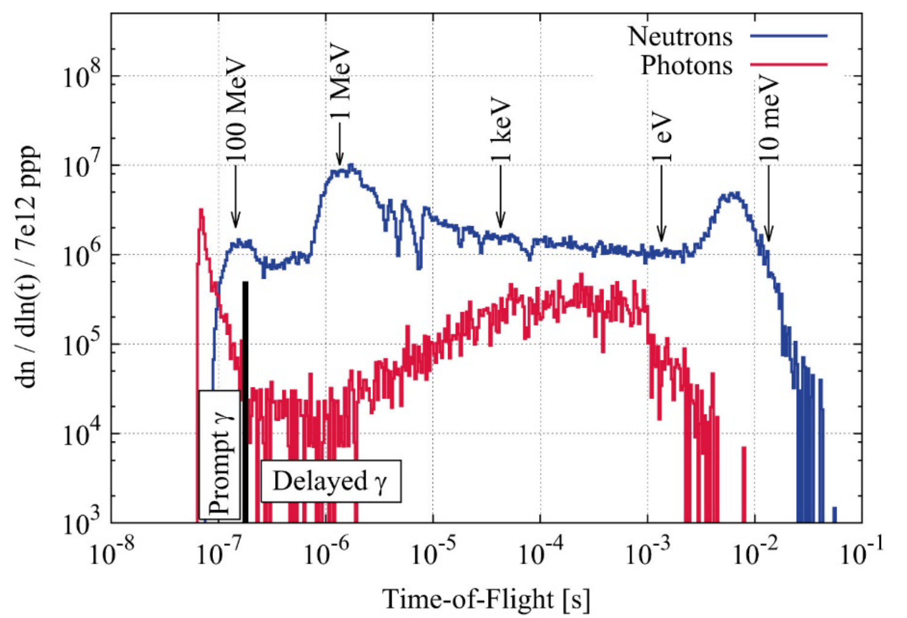
n_TOF

CERN





BaF$_2$ Total Absorption Calorimeter



ELSEVIER

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

Volume 799, 1 November 2015, Pages 90-98

The new vertical neutron beam line at the CERN n_TOF facility design and outlook on the performance

C. Weiß [a], E. Chiaveri [a], S. Girod [a], V. Vlachoudis [a], O. Aberle [a], S. Barros [b], I. Bergström [a], E. Berthoumieux [c], M. Calviani [a], C. Guerrero [d, a], M. Sabaté-Gilarte [d, a], A. Tsinganis [a, e], J. Andrzejewski [f], L. Audouin [g], M. Bacak [h], J. Balibrea-Correa [i], M. Barbagallo [j], V. Bécares [i], C. Beinrucker [k], F. Belloni [c] ...P. Žugec [n]

GCR simulators

Present:

Brookhaven National Laboratory

NASA Space Radiation Laboratory

PLOS BIOLOGY

OPEN ACCESS PEER-REVIEWED

METHODS AND RESOURCES

NASA's first ground-based Galactic Cosmic Ray Simulator: Enabling a new era in space radiobiology research

Lisa C. Simonsen, Tony C. Slaba, Peter Guida, Adam Rusek

Published: May 19, 2020 • https://doi.org/10.1371/journal.pbio.3000669

Future:

FAIR

GSI

ORIGINAL RESEARCH article

Front. Phys., 31 August 2020
Sec. Medical Physics and Imaging
Volume 8 - 2020 | https://doi.org/10.3389/fphy.2020.00337

This article is part of the Research Topic
Applied Nuclear Physics at Accelerators
View all 57 Articles

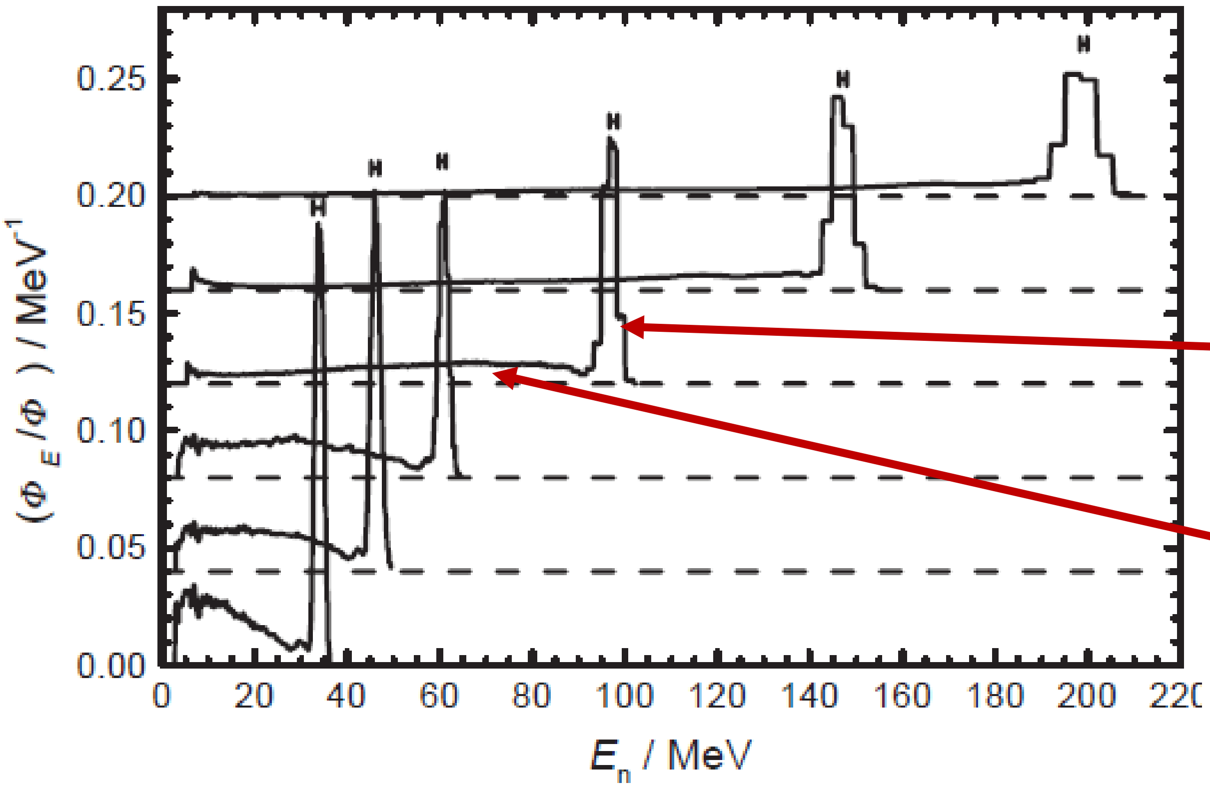
Hybrid Active-Passive Space Radiation Simulation Concept for GSI and the Future FAIR Facility

Christoph Schuy[1], Uli Weber[1] and Marco Durante[1,2*]

[1] GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany
[2] Institut für Festkörperphysik, Technische Universität Darmstadt, Darmstadt, Germany

Quasi-monoenergetic beams

^{7}Li(p,n)^{7}Be is often used (Q = -1.6 MeV)

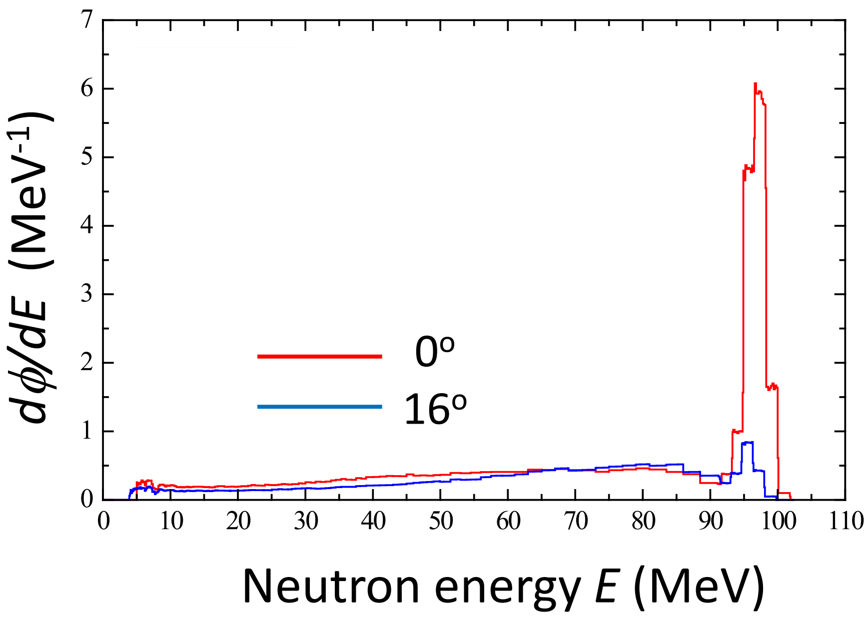


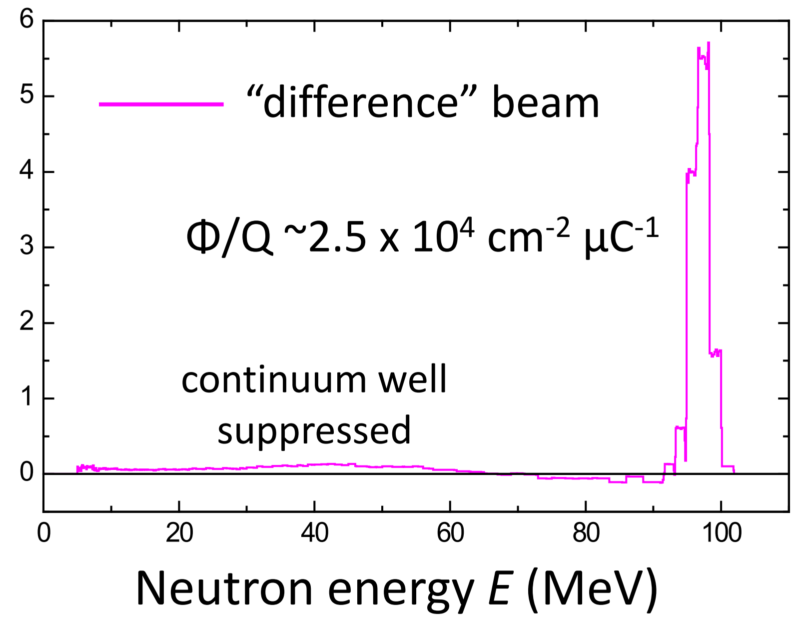
Radiation Protection Dosimetry (2004), Vol. 110, Nos 1-4, pp. 97–102
doi:10.1093/rpd/nch195

QUASI-MONOENERGETIC NEUTRON REFERENCE FIELDS IN THE ENERGY RANGE FROM THERMAL TO 200 MeV

R. Nolte[1,*], M. S. Allie[2], R. Böttger[1], F. D. Brooks[2], A. Buffler[2], V. Dangendorf[1], H. Friedrich[1], S. Guldbakke[1], H. Klein[1], J. P. Meulders[3], D. Schlegel[1], H. Schuhmacher[1] and F. D. Smit[4]
[1]Physikalisch-Technische Bundesanstalt, P.O. Box 3345 D-38116 38023 Braunschweig, Germany
[2]Physics Department, University of Cape Town, Rondebosch, 7700, South Africa
[3]Institut de Physique Nucléaire, Université Catholique de Louvain, B-1348 Louvain-la-Neuve, Belgium
[4]iThemba Laboratory for Accelerator-Based Sciences, Somerset West, 7129, South Africa

Time-of-flight measurement of neutrons produced by a 100 MeV proton beam irradiating a 5.0 mm Li target (with BC-501A at 8.00 m from the target).





Time-of-flight measurement of neutrons produced by a 80 MeV proton beam irradiating a 10.0 mm Be target (with BC-501A at 8.00 m from the target).

Available online at www.sciencedirect.com

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Nuclear Instruments and Methods in Physics Research B 240 (2005) 617–624

NIM B Beam Interactions with Materials & Atoms

www.elsevier.com/locate/nimb

Cross-section measurements for neutron-induced reactions in copper at neutron energies of 70.7 and 110.8 MeV

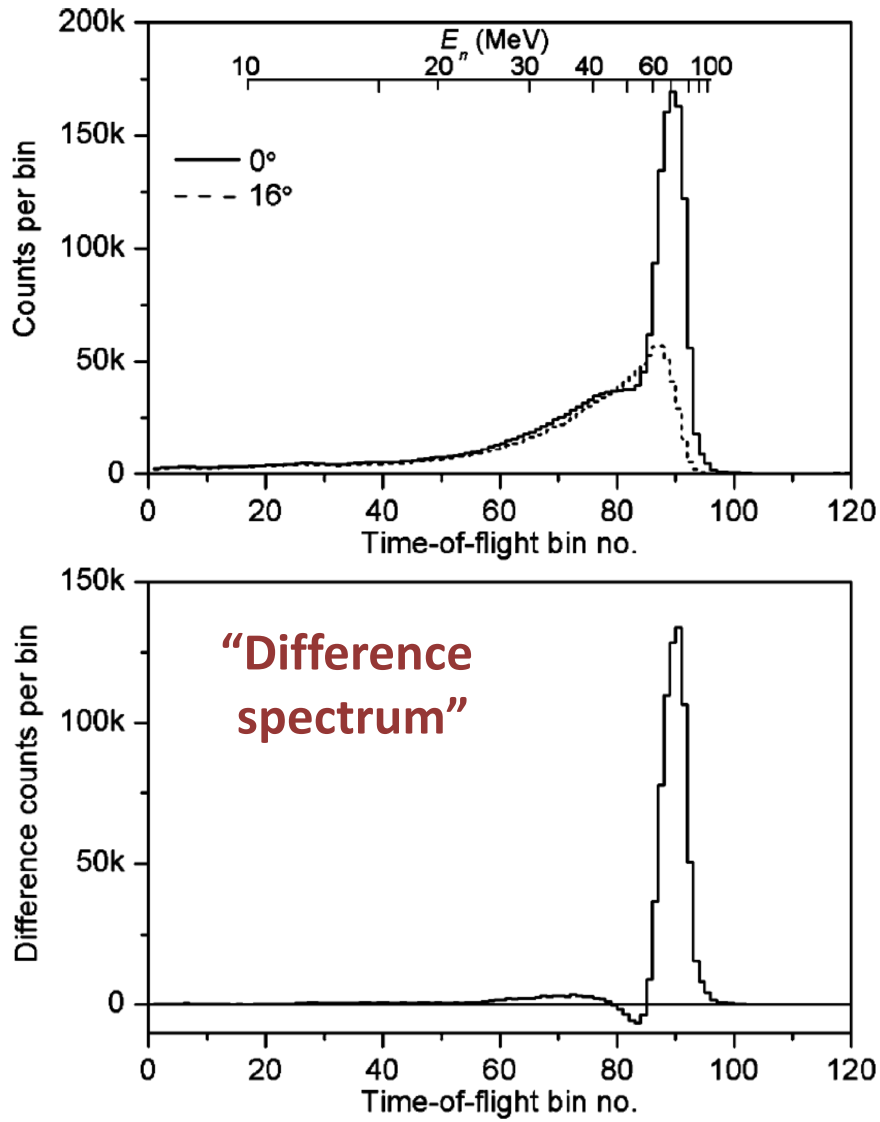
J.M. Sisterson [a,*], F.D. Brooks [b], A. Buffler [b], M.S. Allie [b], D.T.L. Jones [c], M.B. Chadwick [d]

[a] Northeast Proton Therapy Center, Massachusetts General Hospital, 30 Fruit Street, Boston, MA 02114, USA and the Harvard Medical School

[b] Department of Physics, University of Cape Town, Rondebosch, South Africa

[c] iThemba LABS, Box 722, Somerset West 7129, South Africa

[d] Advanced Simulation and Computing, Los Alamos National Laboratory, Los Alamos, NM 87544, USA



Three important high energy neutron facilities closed over last decade:

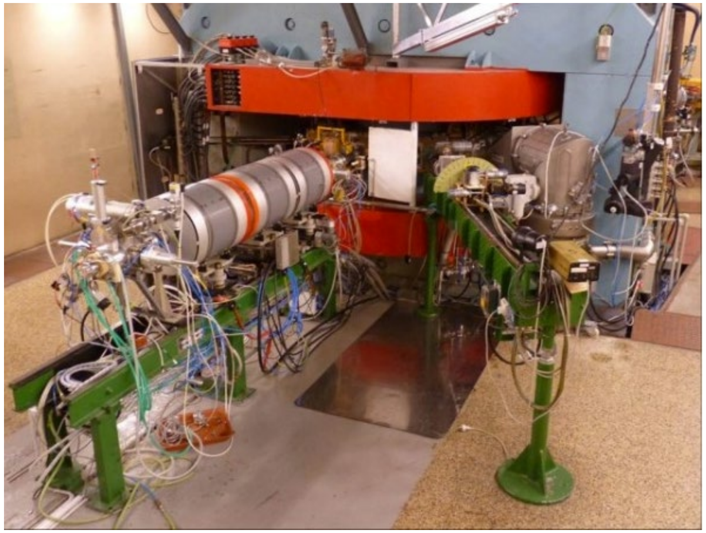
- Cyclotron Research Centre,
  Catholic University of Louvain-la-Neuve, Belgium
- The Svedburg Laboratory,
  Uppsala University, Sweden
- Indiana University Cyclotron Facility,
  Indiana University, USA

Fast neutron facility at CAS Nuclear Physics Institute

NUCLEAR PHYSICS INSTITUTE CAS
public research institution

The Czech Academy of Sciences

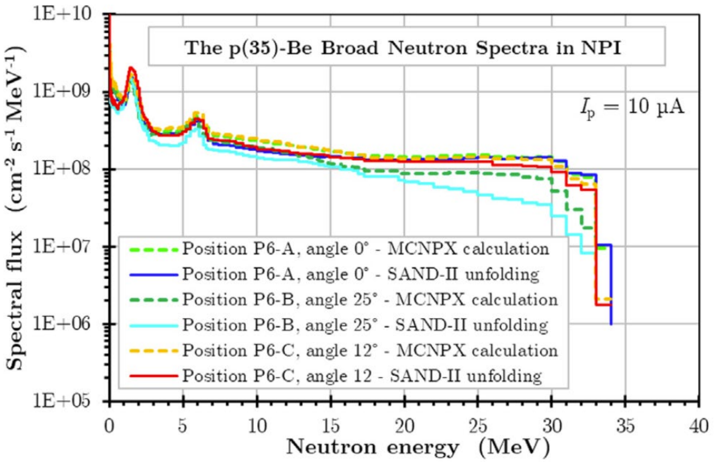
Řež, Czech Republic

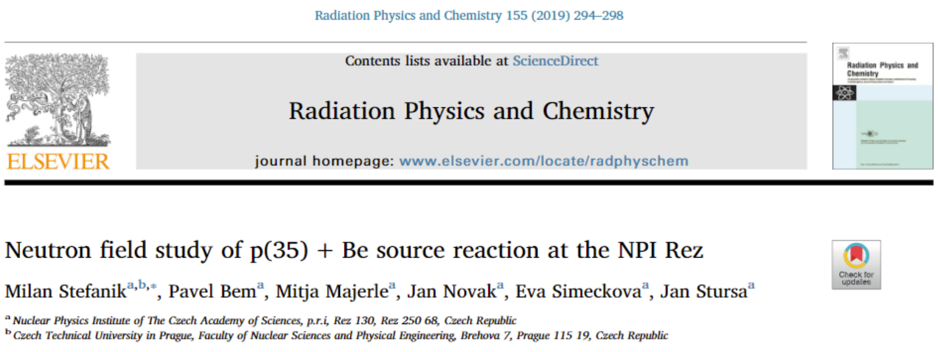


- Isochronous cyclotron U-120M
- Proton beams 1-37 MeV

- p + D_2O (thick):
  High flux broad neutron spectra

- p + Li(thin):
  Quasi-monoenergetic neutrons





Radiation Physics and Chemistry 155 (2019) 294–298

Contents lists available at ScienceDirect

Radiation Physics and Chemistry

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

ELSEVIER

Neutron field study of p(35) + Be source reaction at the NPI Rez

Milan Stefanik[a,b,*], Pavel Bem[a], Mitja Majerle[a], Jan Novak[a], Eva Simeckova[a], Jan Stursa[a]

[a] Nuclear Physics Institute of The Czech Academy of Sciences, p.r.i, Rez 130, Rez 250 68, Czech Republic
[b] Czech Technical University in Prague, Faculty of Nuclear Sciences and Physical Engineering, Brehova 7, Prague 115 19, Czech Republic

Neutrons For Science Facility of GANIL/SPIRAL2

Caen, France

GANIL spiral2 — laboratoire commun CEA/DRF CNRS/IN2P3

- Superconducting LINAC
- Thick Be converter
- Thin Be and Li targets
- Time-of-flight hall: 28 m
- Neutron beams 1-40 MeV
- High flux

Target station

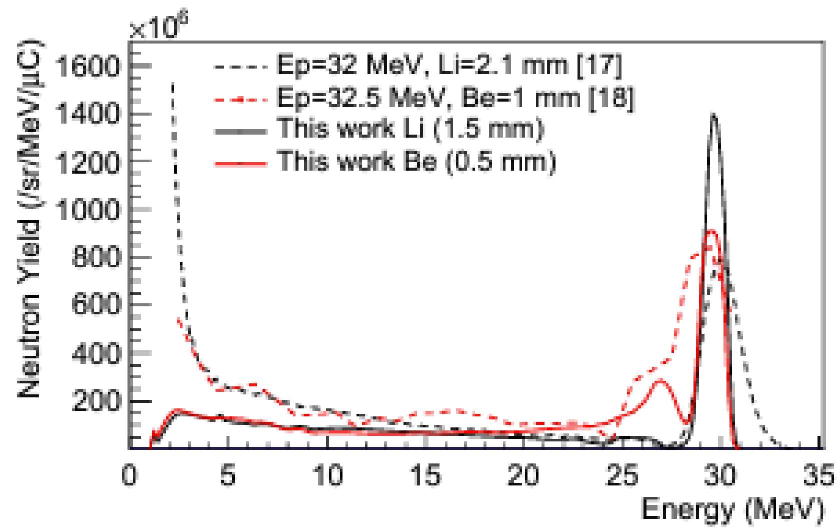
ToF hall

Eur. Phys. J. A (2021) 57:257
https://doi.org/10.1140/epja/s10050-021-00565-x
THE EUROPEAN PHYSICAL JOURNAL A

Letter to the Editor

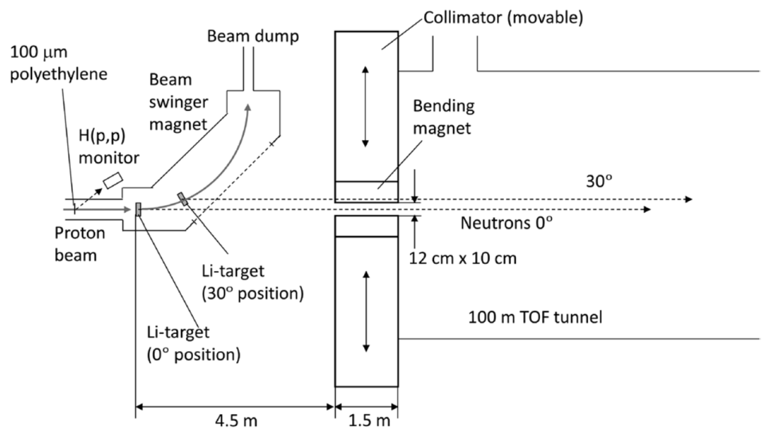
First beams at neutrons for science

X. Ledoux[1,a], J. C. Foy[1], J. E. Ducret[1], A. M. Frelin[1], D. Ramos[1], J. Mrazek[2], E. Simeckova[2], R. B
L. Caceres[1], V. Glagolev[2], B. Jacquot[1], A. Lemasson[1], J. Pancin[1], J. Piot[1], C. Stodel[1], M. Vandebrouck[3]
[1] Grand Accélérateur National d'Ions Lourds, CEA/DRF-CNRS/IN2P3, B.P. 55027, 14076 Caen, France
[2] Nuclear Physics Institute of the Czech Academy of Sciences, 250 68 Řež, Czech Republic
[3] IRFU, CEA, Université Paris-Saclay, 91191 Gif-sur-Yvette, France



Research Center of Nuclear Physics

Osaka University, Japan



ELSEVIER

Nuclear Instruments and Methods in Physics Research A 476 (2002) 176–180

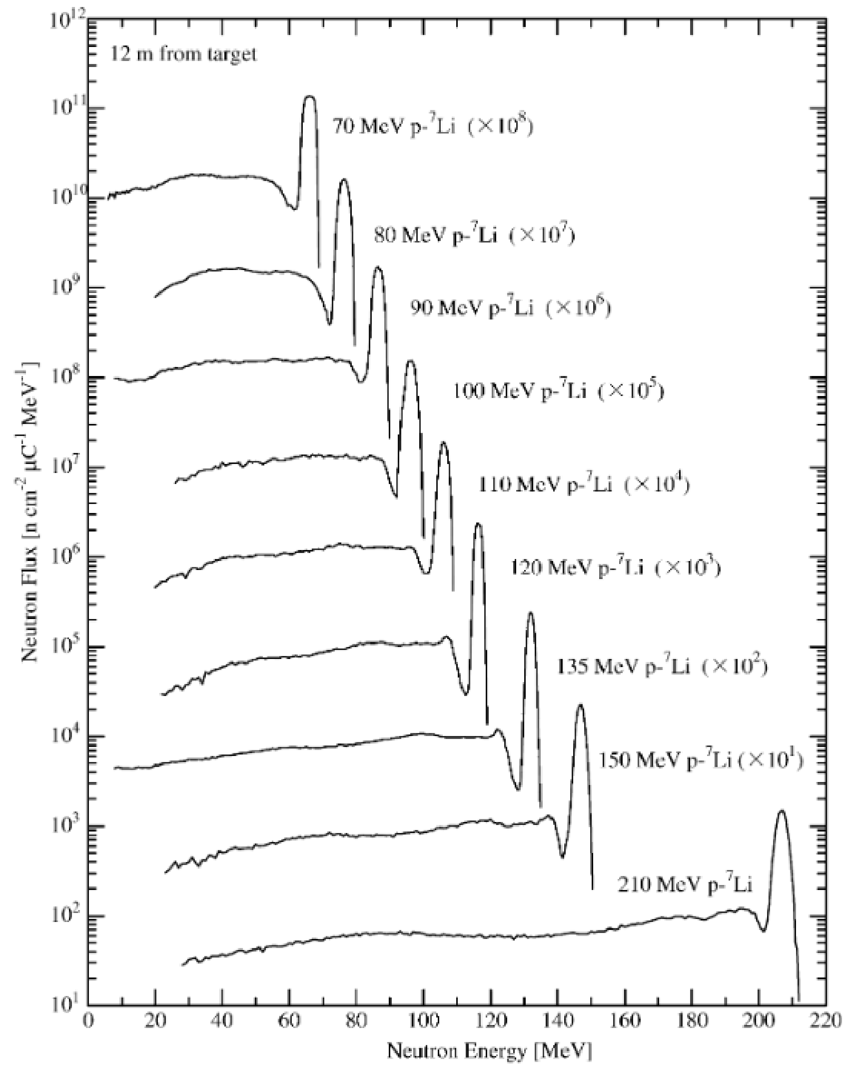
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

www.elsevier.com/locate/nima

Development of a quasi-monoenergetic neutron field and measurements of the response function of an organic liquid scintillator for the neutron energy range from 66 to 206 MeV

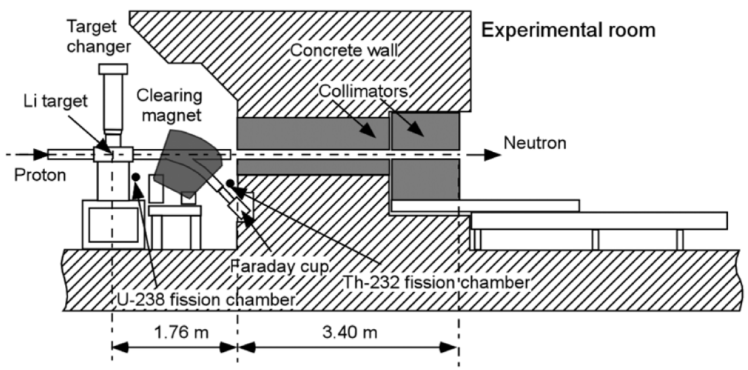
Noriaki Nakao[a,*], Tadahiro Kurosawa[b,1], Takashi Nakamura[b], Yoshitomo Uwamino[c]

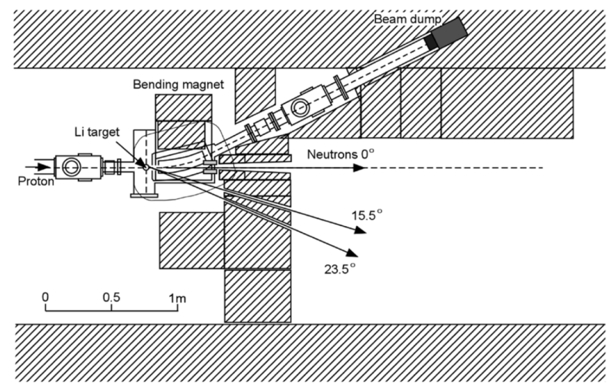
[a] High Energy Accelerator Research Organization (KEK), Oho, Tsukuba, Ibaraki 305-0801, Japan
[b] Department of Quantum Science and Energy Engineering, Tohoku University, Sendai, Miyagi 980-8579, Japan
[c] The Institute of Physical and Chemical Research (RIKEN), Wako, Saitama 351-0198, Japan



Takasaki Ion Accelerators for Advanced Radiation Application (TIARA) in the Takasaki Advanced Radiation Research Institute (TARRI) of the Japan Atomic Energy Agency

Cyclotron and Radioisotope Center (CYRIC) Tohoku University Sendai, Japan





Investigation of properties of the TIARA neutron beam facility of importance for calibration applications

Get access >

Y. Shikaze ✉, Y. Tanimura, J. Saegusa, M. Tsutsumi, Y. Yamaguchi, Y. Uchita

Radiation Protection Dosimetry, Volume 126, Issue 1-4, August 2007, Pages 163–167, https://doi.org/10.1093/rpd/ncm035

Published: 22 May 2007

ELSEVIER

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

Volume 491, Issue 3, 1 October 2002, Pages 419-425

New fast-neutron time-of-flight facilities at CYRIC

A Terakawa [a], H Suzuki [a], K Kumagai [a], Y Kikuchi [a], T Uekusa [a], T Uemori [a], H Fujisawa [a], N Sugimoto [a], K Itoh [a], M Baba [a], H Orihara [a] ✉, K Maeda [b]

Fast neutron facility of the China Institute of Atomic Energy

Beijing, China

- CYCIAE-100 high current cyclotron
- 75 – 100 MeV protons
- Broad and quasi-monoenergetic neutron beams

中国原子能科学研究院
CHINA INSTITUTE OF ATOMIC ENERGY

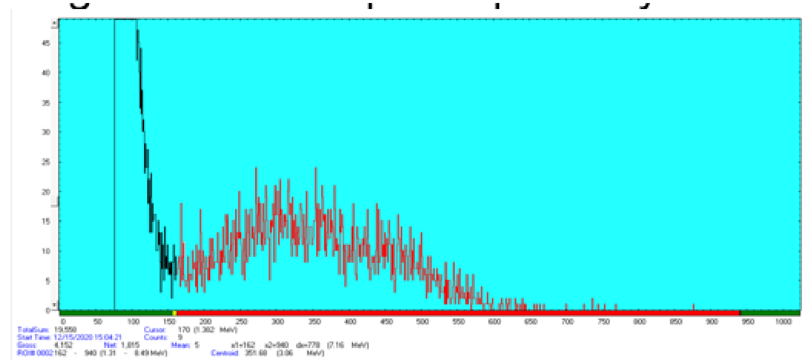
The development of (70 ~ 100) MeV Mono-energetic neutron reference fields based on the 100 MeV Cyclotron

Jiaoting Yu, Wei Li, Shiyao Li, XI Qin, Xinqi Luo, Xueying Deng, An Du, Hailiang Qin, Yujun Mo, Yuyang He, Bin Shi, Shufeng Zhang, Yuntao Liu

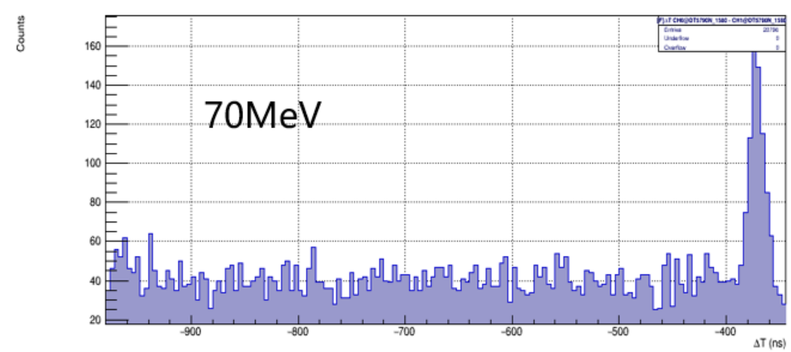
Neutron metrology laboratory
Department of application of nuclear technology
China institute of atomic energy

12.9.2022, Beijing Cyclotron

NEW!



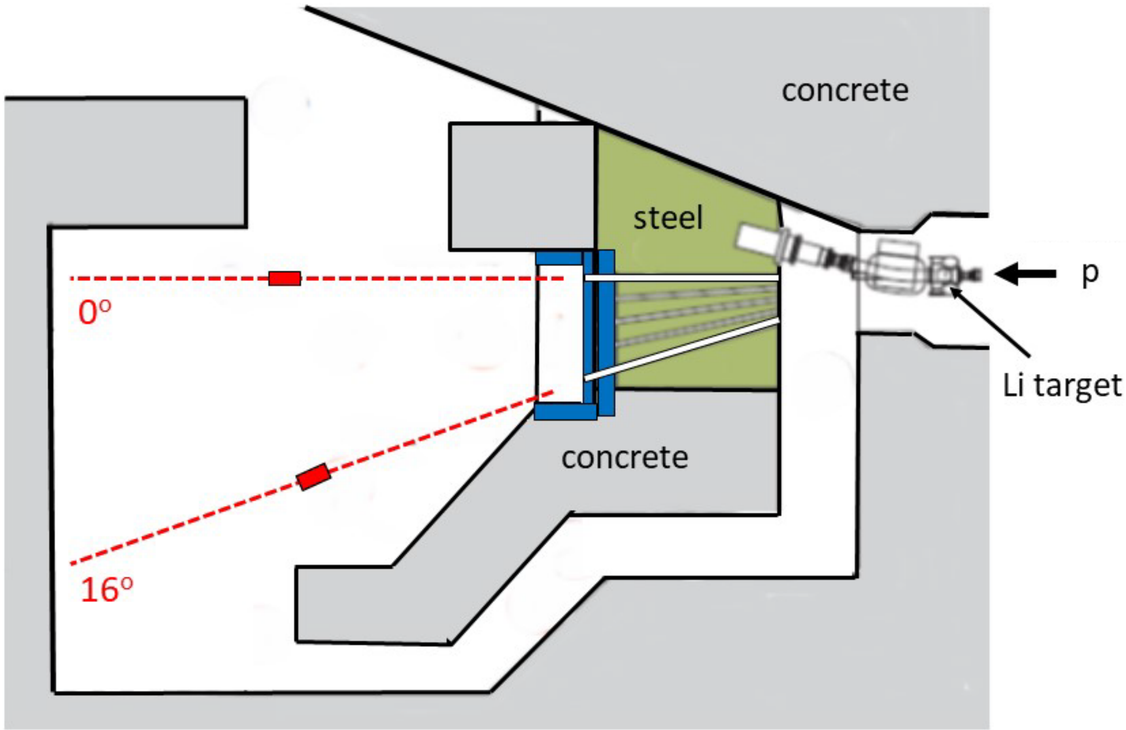
Pulse height spectrum from U-8 FC



TOF Spectrum

Fast neutron beam facility at iThemba LABS

Cape Town, South Africa



- k = 200 cyclotron
- neutrons produced via Li(p,n)
- ns-pulsed beams (time-of-flight)
- quasi-monoenergetic neutron beams 30-200 MeV

Development towards an ISO-accredited reference facility

FIRST ADDENDUM TO AGREEMENT

2013

Between:

THE NATIONAL RESEARCH FOUNDATION

NRF National Research Foundation | iThemba LABS Laboratory for Accelerator Based Sciences

And

NATIONAL METROLOGY INSTITUTE OF SOUTH AFRICA

nmisa National Metrology Institute of South Africa

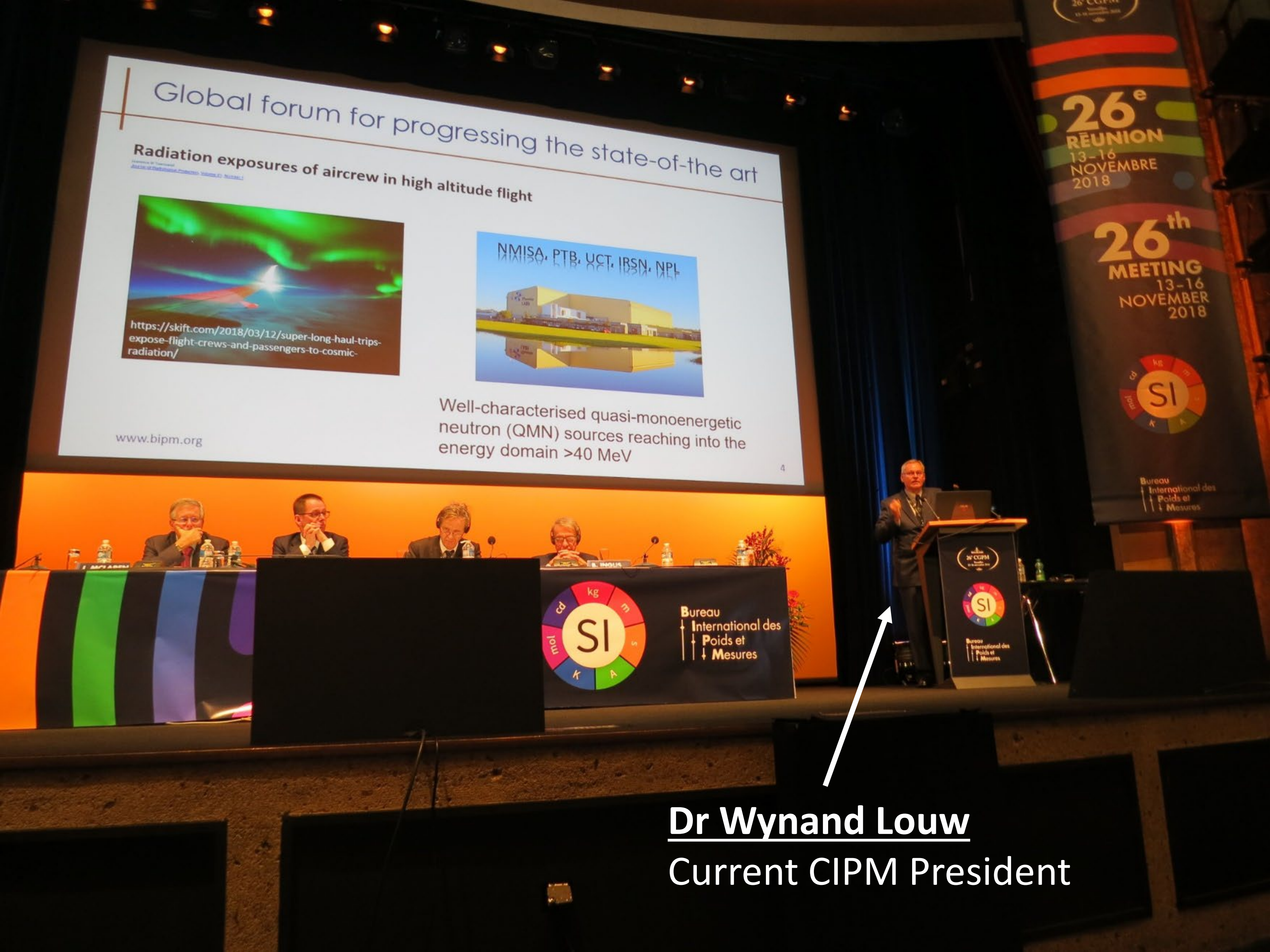
MOU between iThemba LABS and the National Metrology Institute of South Africa

Cooperate in the Development of the iThemba LABS Neutron D-Line

NMISA through this addendum enables the formulation of a project with UCT Physics, PTB and the IRSN to develop and utilise the iThemba LABS quasi-monoenergetic neutron (QMN) laboratory of the iThemba LABS for neutron dosimetry metrology activities.

	Initial	Witnesses:	Witnesses:
iThemba	FA	[illegible]	[illegible]
NMISA	[illegible]	[illegible]	

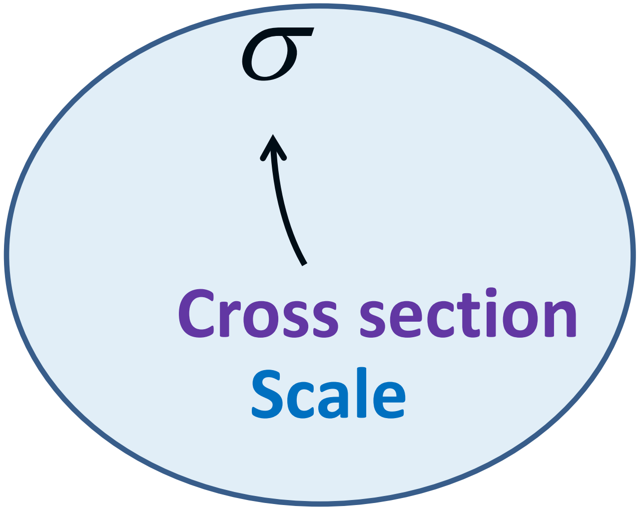
iThemba LABS commit to upgrade the neutron beam line to make it compatible with metrology requirements, and once the beam line is completed, to make it available to research, including metrology applications/services.



Dr Wynand Louw

Current CIPM President

$$\Phi = \frac{R_\Phi}{\sigma}$$



https://www-nds.iaea.org/standards/

IAEA.org International Atomic Energy Agency

› Nuclear Data

IAEA Nuclear Data Services Home Page

› STANDARDS 2017

HOME

Nuclear Data Sheets 148 (2018) 143-188

Neutron Standards Data in the ENDF-6 Formatted Files, presentation by V.G. Pronyaev, December 2019

› STANDARDS 2006

STD 2006

Technical Report

› Downloads

Codes and Programs

Test cases

Most recent calculations

› Documents

Documents and Reports

IAEA NEUTRON DATA STANDARDS (2017)

A.D. Carlson, et al., Nuclear Data Sheets 148 (2018) 143-188

#	Reaction	Energy Range	ENDF-6 formatted data	Free text format
1	H(n,n)	Standard range: 1 keV to 20 MeV	std17-001_H_001.endf	std17-001_H_001.txt
2	^{3}He(n,p)	Standard range: 0.0253 eV to 50 keV	std-002_He_003.endf	not available
3	^{6}Li(n,t)	1e-5 eV to 4 MeV (Standard range: Thermal - 1 MeV)	std17-003_Li_006.endf	std17-003_Li_006.txt
4	^{10}B(n,α);(n,$\alpha_1\gamma$)	1e-5 eV to 1 MeV (Standard range: Thermal - 1 MeV)	std17-005_B_010.endf	std17-005_B_010.txt
5	^{nat}C(n,n)	up to 6.45 MeV (Standard range: 1keV - 1.8 MeV)	std17-006_C_000.endf	std17-006_C_000.txt
6	^{197}Au(n,γ)	2.5 keV to 2.8 MeV (Standard range: Thermal, 200keV - 2.5MeV)	std17-079_Au_197.endf	std17-079_Au_197.txt
7	^{235}U(n,f)	150 eV to 200 MeV (Standard range: Thermal, 150keV - 200MeV)	std17-092_U_235.endf	std17-092_U_235.txt
8	^{238}U(n,f)	0.5 to 200 MeV (Standard range: 2 - 200MeV)	std17-092_U_238.endf	std17-092_U_238.txt
9	Thermal Neutron Constants: nubar, (n_{th},f), (n_{th},el), (n_{th},g) cross sections for fissile targets ^{233}U, ^{235}U, ^{239}Pu, ^{241}Pu. Total nubar ^{252}Cf(sf).	0.0253 eV (2200 m/s)		Standards2017_TNC.txt
10	^{197}Au(n,γ)	MACS (30 keV)= 620(11) mb		
11	^{235}U(n,f)	Integral from 7.8 eV to 11 eV = 247.5(3.3) b*eV		

IOP Publishing Metrologia

Metrologia **48** (2011) S328–S345 doi:10.1088/0026-1394/48/6/S09

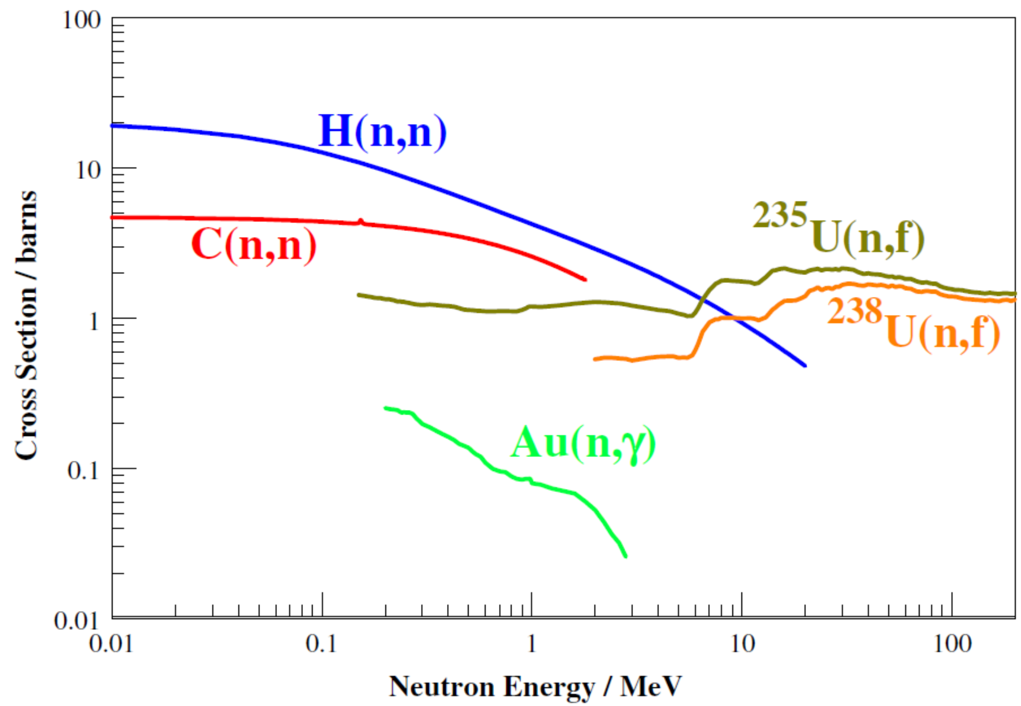
The neutron cross section standards, evaluations and applications

A D Carlson

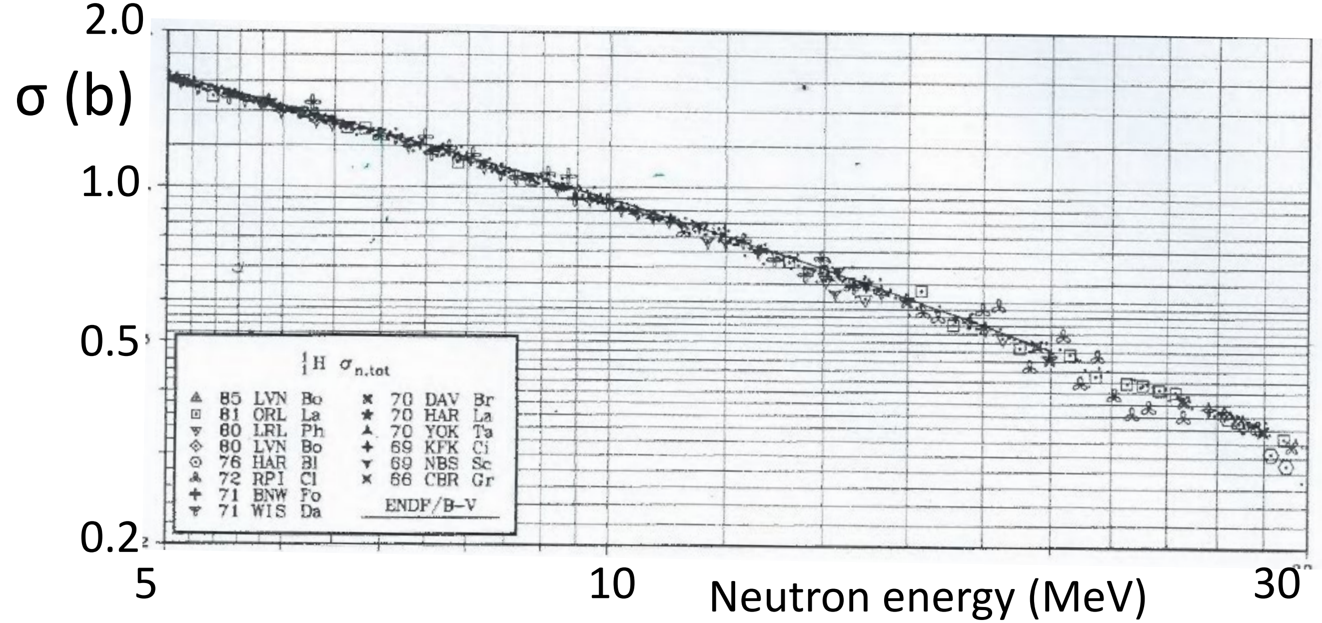
National Institute of Standards and Technology, STOP 8463, Gaithersburg, MD 20899, USA

E-mail: carlson@nist.gov

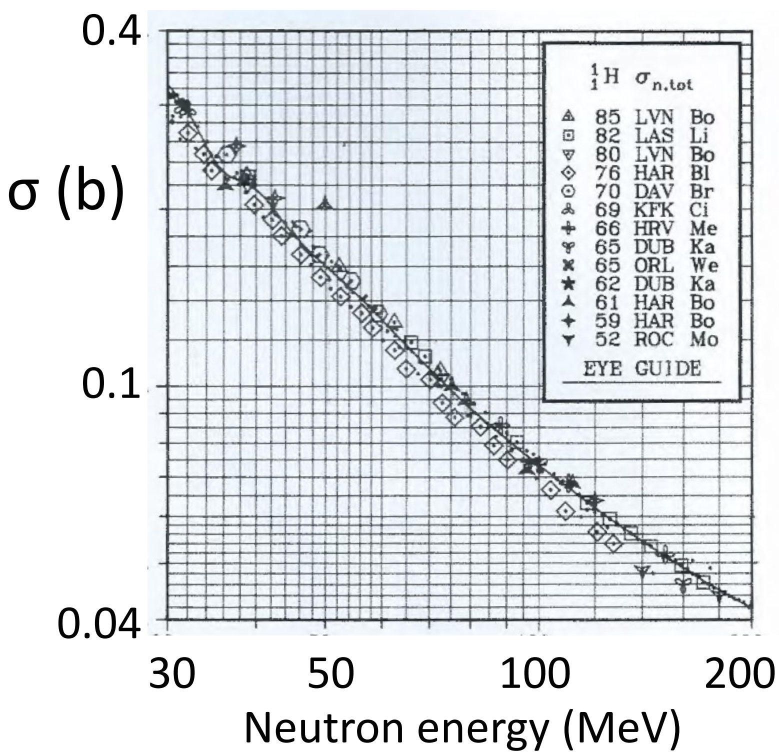
Received 21 April 2011, in final form 19 June 2011
Published 28 October 2011
Online at stacks.iop.org/Met/48/S328



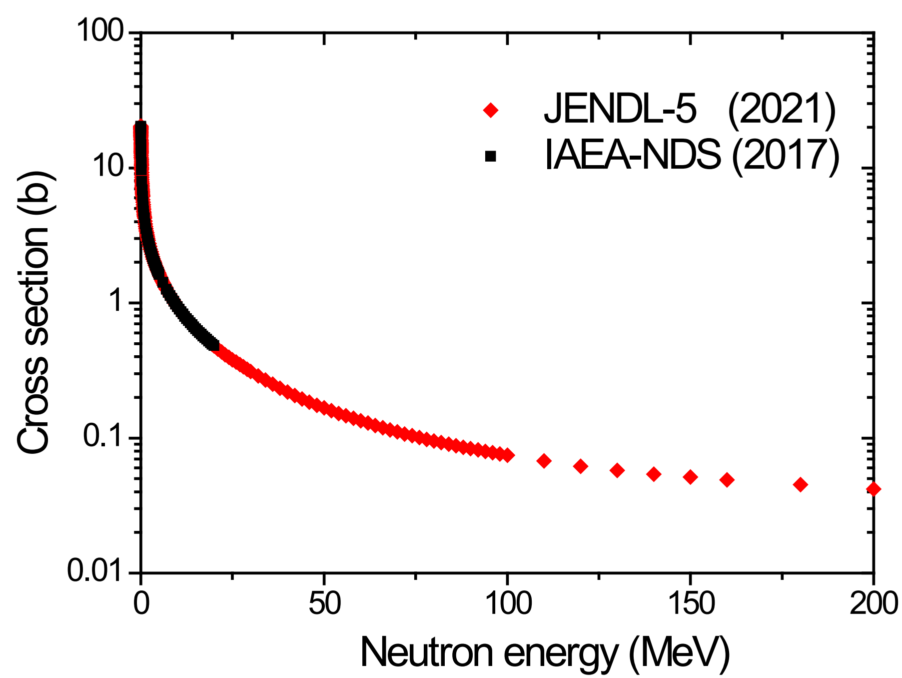
$^{1}H(n,n)^{1}H$



σ (b)
2.0
1.0
0.5
0.2
5
10
30
Neutron energy (MeV)
$^{1}_{1}H$ $\sigma_{n,tot}$
85 LVN Bo
81 ORL La
80 LRL Ph
80 LVN Bo
76 HAR Bl
72 RPI Cl
71 BNW Fo
71 WIS Da
70 DAV Br
70 HAR La
70 YOK Ta
69 KFK Ci
69 NBS Sc
66 CBR Gr
ENDF/B-V



0.4
σ (b)
0.1
0.04
30
50
100
200
Neutron energy (MeV)
$^{1}_{1}H$ $\sigma_{n,tot}$
85 LVN Bo
82 LAS Li
80 LVN Bo
76 HAR Bl
70 DAV Br
69 KFK Ci
66 HRV Me
65 DUB Ka
65 ORL We
62 DUB Ka
61 HAR Bo
59 HAR Bo
52 ROC Mo
EYE GUIDE

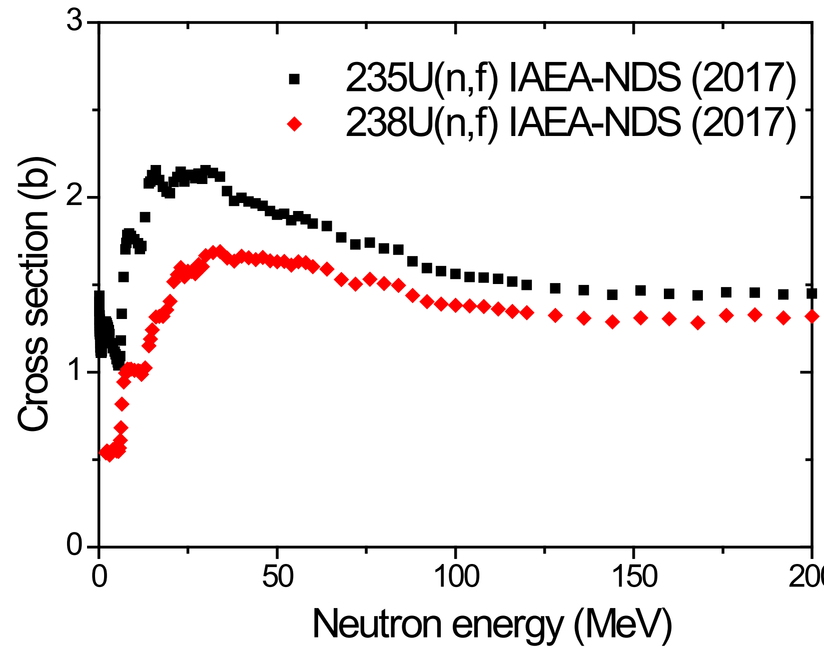


100
10
1
0.1
0.01
Cross section (b)
0
50
100
150
200
Neutron energy (MeV)
JENDL-5 (2021)
IAEA-NDS (2017)

$^{235}U(n,f)$

$^{238}U(n,f)$

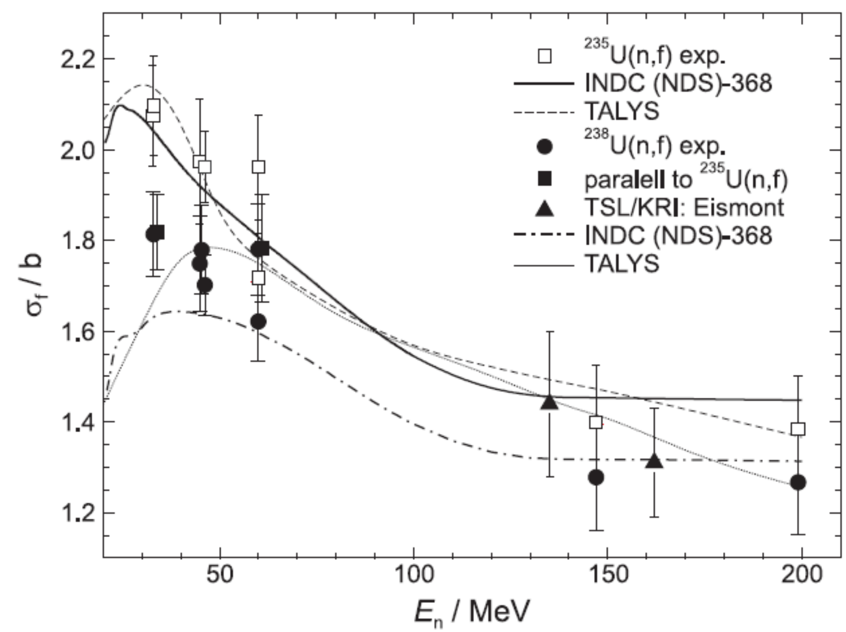
(^{209}Bi, ^{nat}Pb, …)



Journal of NUCLEAR SCIENCE and TECHNOLOGY, Supplement 2, p. 311–314 (August 2002)

Measurement of ^{235}U, ^{238}U, ^{209}Bi and ^{nat}Pb Fission Cross Sections using Quasi-monoenergetic Neutrons with Energies from 30 MeV to 150 MeV

Ralf NOLTE[1,*], M. Saalih ALLIE[2], Peter J. BINNS[3,§], Frank D. BROOKS[2], Andy BUFFLER[2], Volker DANGENDORF[1], Katia LANGEN[3], Jean-Pierre MEULDERS[4], Wayne D. NEWHAUSER[1,&], Frank ROOS[1] and Helmut SCHUHMACHER[1]
[1]*Physikalisch-Technische Bundesanstalt, Braunschweig, Germany*
[2]*University of Cape Town, Cape Town, South Africa*
[3]*National Accelerator Centre, Faure, South Africa*
[4]*Université Catholique de Louvain, Louvain-la-Neuve, Belgium*
[§]*present address: Massachusetts Institute of Technology, Cambridge, USA*
[&]*present address: Harvard Cyclotron Laboratory, Cambridge, USA*



$$\Phi = \frac{R_{\Phi}}{\sigma}$$

Detector response

per per target nucleus

Instrumentation

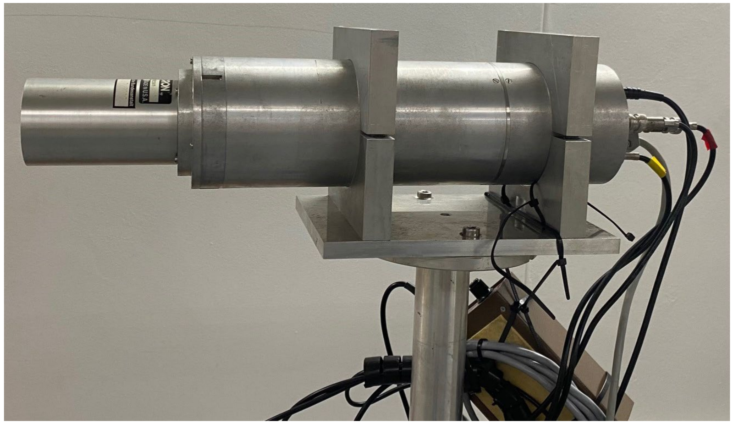
for measurement

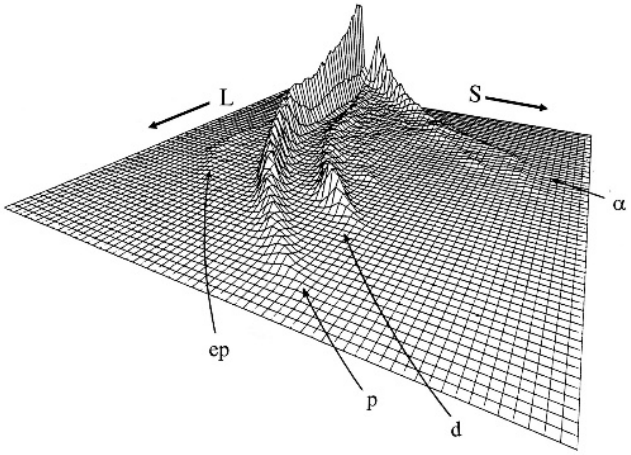
High energy neutron metrology is time-consuming

- Scintillation detectors
- Proton recoil telescopes
- Fission ionization chambers
- Bonner sphere systems
- (Monitors)

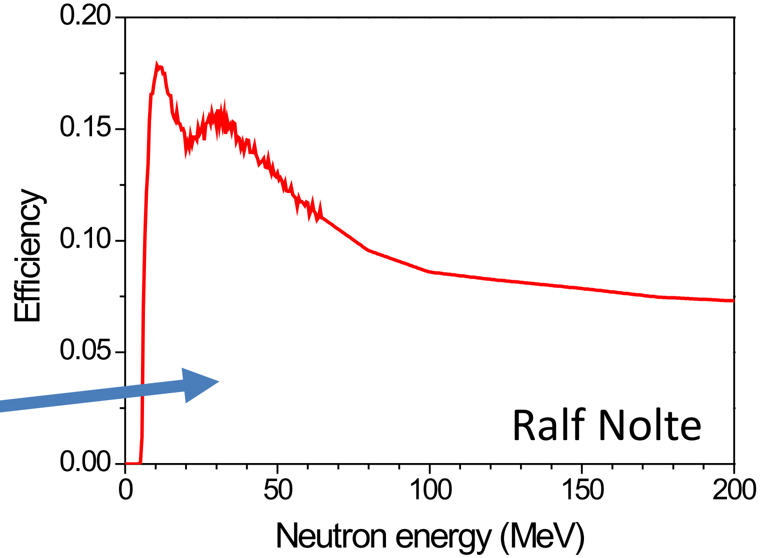
Liquid scintillator: NE-213 / BC-501A / EJ-301

iThemba LABS version:

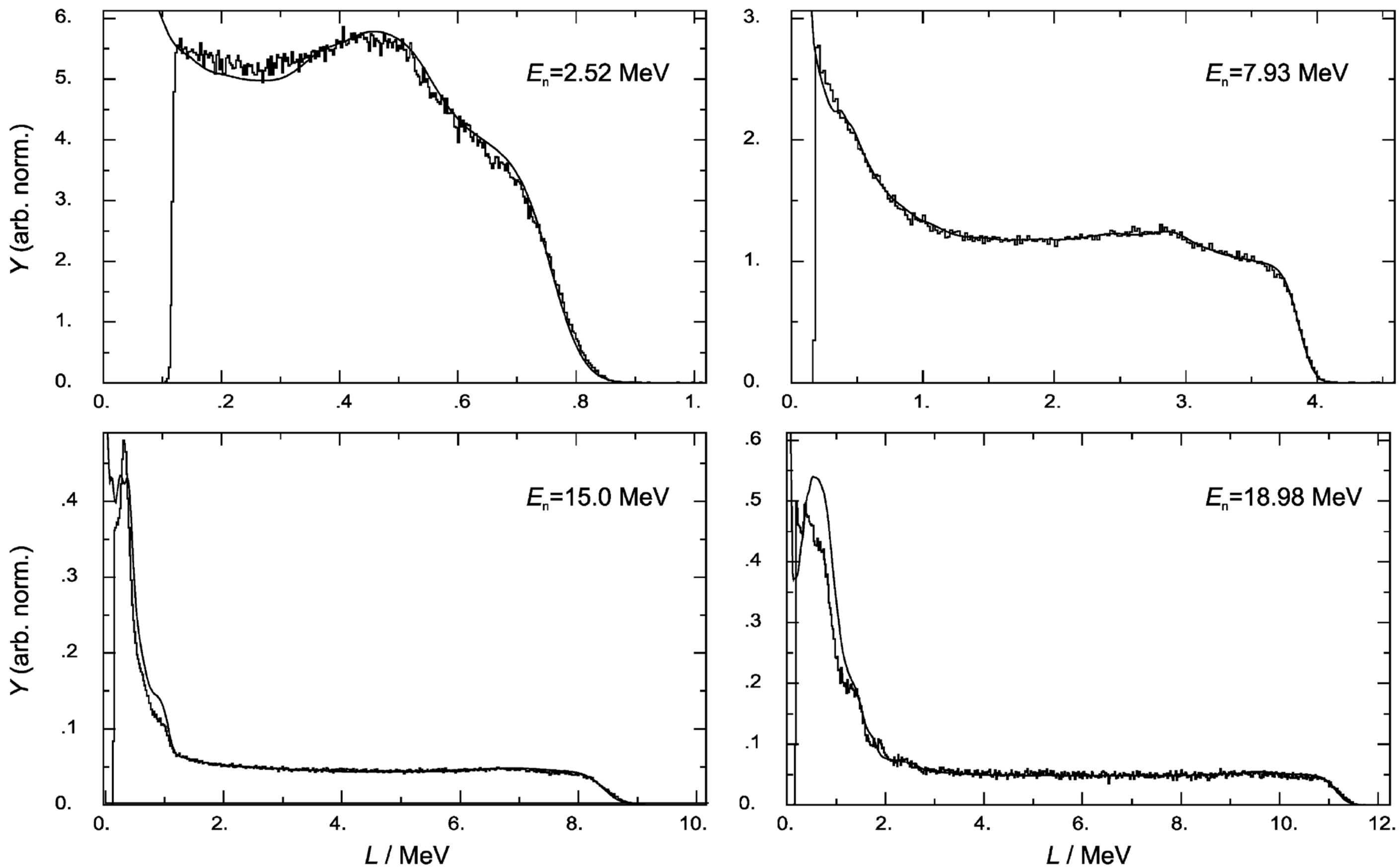




- 102 mm length, 51 mm diameter
- gain-stabilised photomultiplier
- neutron-gamma discrimination
- time resolution 2 ns (FWHM)
- **efficiency** calculated
  with MC codes SCINFUL and MCNPX



Neutron pulse height spectra in NE-213 measured (histograms) and calculated (lines) with NRESP



ELSEVIER
Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment
Volume 476, Issues 1–2, 1 January 2002, Pages 132-142

Neutron and photon spectrometry with liquid scintillation detectors in mixed fields

Horst Klein, Sonja Neumann

Neutron reactions on ^{12}C (at 90 MeV)

production of carbon isotopes

^{12}C (n;n) ^{12}C
^{12}C (n;3n) ^{12}C
^{12}C (n;2n) ^{12}C

production of boron isotopes

^{12}C (n;p) ^{12}B
^{12}C (n;p,2n) ^{10}B
^{12}C (n;d) ^{11}B
^{12}C (n;p,d,3n) ^{8}B
^{12}C (n;t,2n) ^{8}B
^{12}C (n;p,n) ^{11}B
^{12}C (n;p,4n) ^{8}B
^{12}C (n;d,n) ^{10}B
^{12}C (n;t) ^{10}B

production of beryllium isotopes

^{12}C (n;2p,n) ^{10}Be
^{12}C (n;2p,4n) ^{7}Be
^{12}C (n;d,p,n) ^{9}Be
^{12}C (n;2d) ^{9}Be
^{12}C (n;t,p) ^{9}Be
^{12}C (n;t,d,n) ^{7}Be
^{12}C (n;α,2n) ^{7}Be
^{12}C (n;2p,2n) ^{9}Be
^{12}C (n;d,p) ^{10}Be
^{12}C (n;d,p,3n) ^{7}Be
^{12}C (n;2d,2n) ^{7}Be
^{12}C (n;t,p,2n) ^{7}Be
^{12}C (n;α) ^{9}Be

production of Be* → 2α

^{12}C (n;α,n) 2α
^{12}C (n;2p,3n) 2α
^{12}C (n;p,2d,n) 2α
^{12}C (n;d,t) 2α
^{12}C (n;^{3}He,2n) 2α
^{12}C (n;p,d,2n) 2α
^{12}C (n;p,t,n) 2α

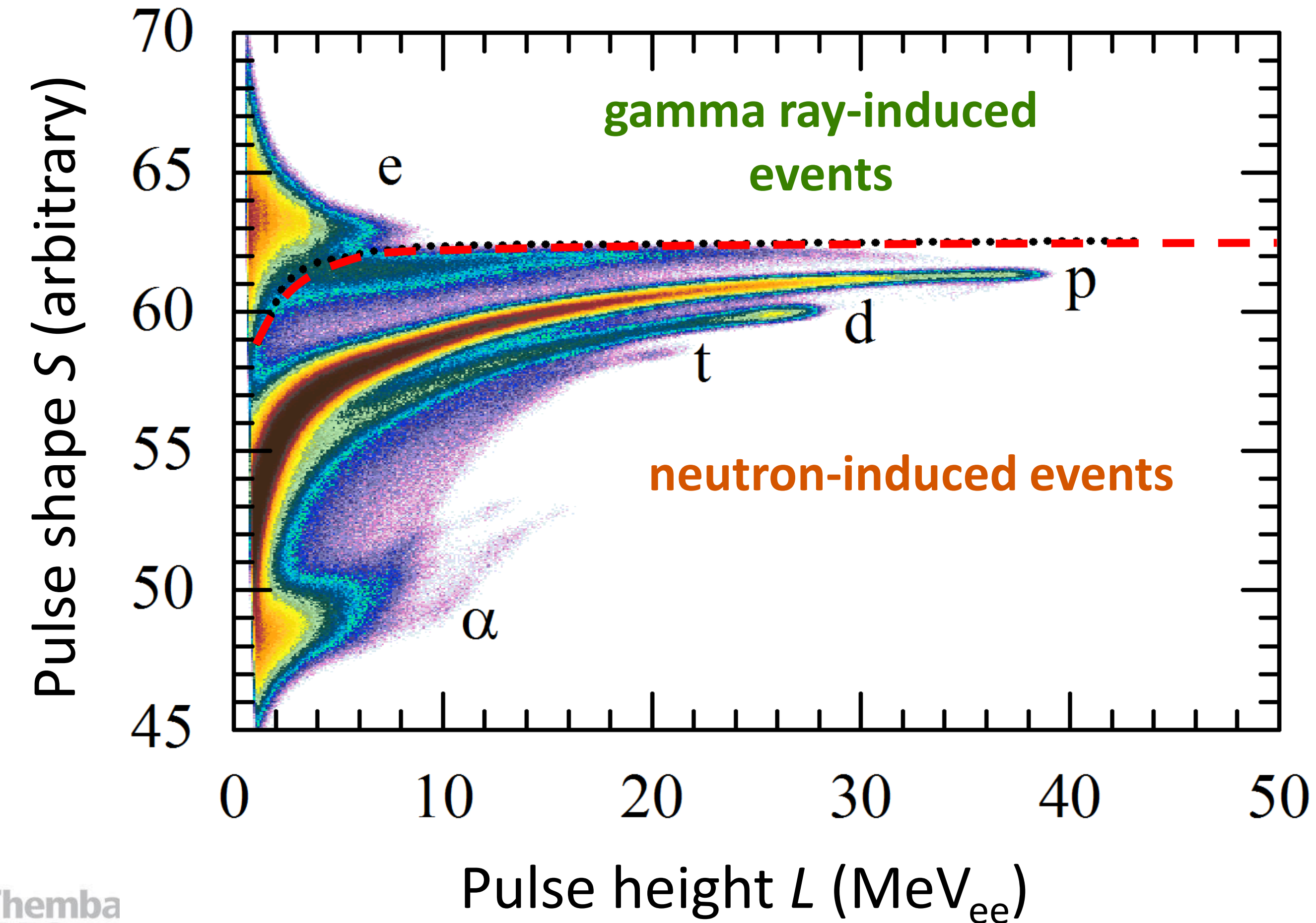
production of lithium isotopes

^{12}C (n;3p,n) ^{9}Li
^{12}C (n;3p,3n) ^{7}Li
^{12}C (n;p,^{3}He) ^{9}Li
^{12}C (n;p,^{3}He,2n) ^{7}Li
^{12}C (n;p,α) ^{8}Li
^{12}C (n;p,α,2n) ^{6}Li
^{12}C (n;d,^{3}He,n) ^{7}Li
^{12}C (n;2p,d) ^{9}Li
^{12}C (n;2p,d,2n) ^{7}Li
^{12}C (n;p,2d) ^{8}Li
^{12}C (n;p,2d,2n) ^{6}Li
^{12}C (n;d,α,n) ^{6}Li
^{12}C (n;t,^{3}He,n) ^{6}Li
^{12}C (n;3d) ^{7}Li
^{12}C (n;p,d,t,n) ^{6}Li
^{12}C (n;^{6}Li,n) ^{7}Li
^{12}C (n;2d,t) ^{6}Li
^{12}C (n;3p,2n) ^{8}Li
^{12}C (n;3p,4n) ^{6}Li
^{12}C (n;p,^{3}He,n) ^{8}Li
^{12}C (n;p,^{3}He,3n) ^{6}Li
^{12}C (n;p,α,n) ^{7}Li
^{12}C (n;d,^{3}He) ^{8}Li
^{12}C (n;d,^{3}He,2n) ^{6}Li
^{12}C (n;2p,d,n) ^{8}Li
^{12}C (n;2p,d,3n) ^{6}Li
^{12}C (n;p,2d,n) ^{7}Li
^{12}C (n;d,α) ^{7}Li
^{12}C (n;t,^{3}He) ^{7}Li
^{12}C (n;3d) ^{7}Li
^{12}C (n;p,d,t) ^{7}Li
^{12}C (n;^{6}Li) ^{7}Li
^{12}C (n;t,α) ^{6}Li

[Kellogg (1956)]

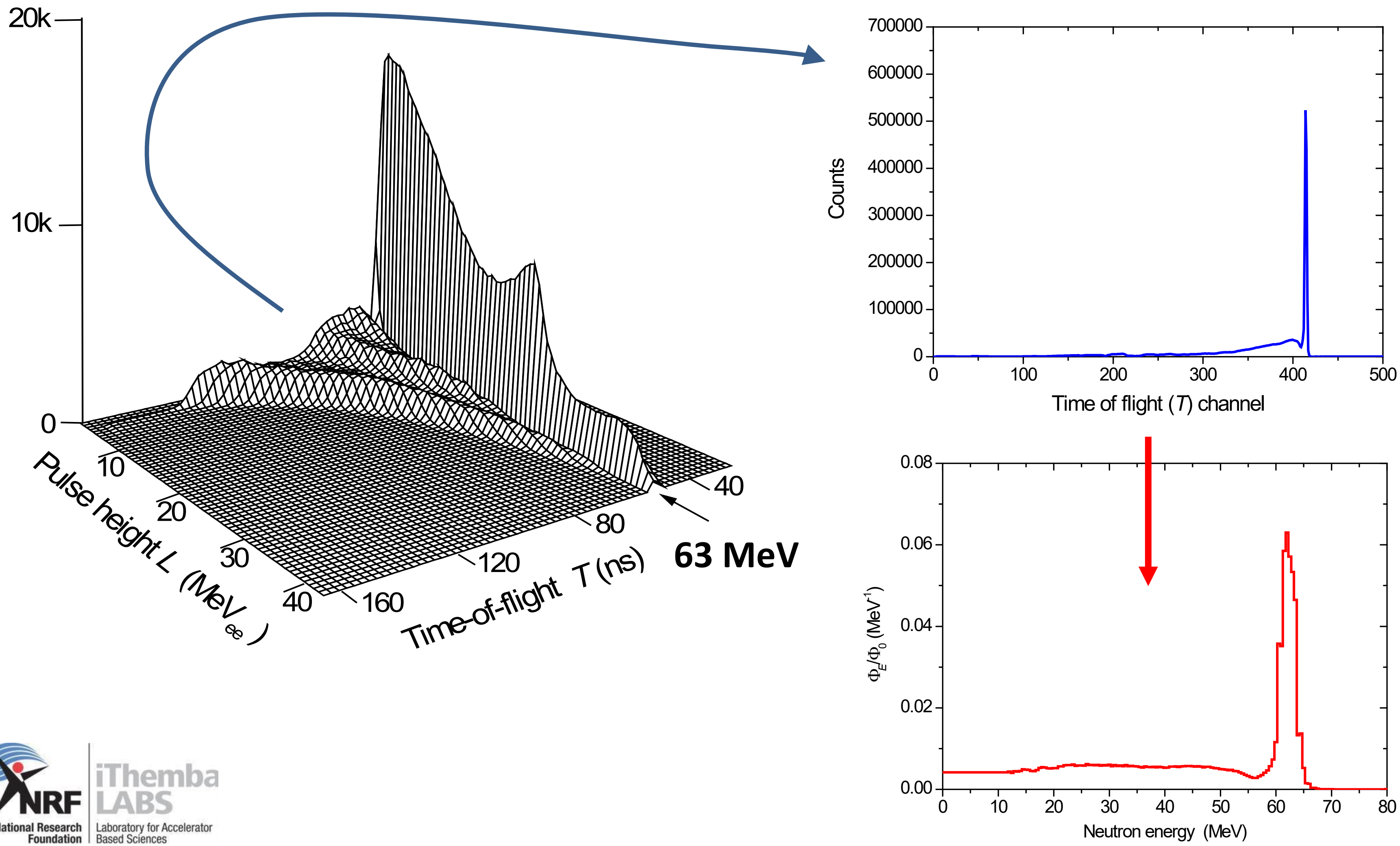
… detector response must be <u>measured</u> …

Neutrons and gamma-rays produced by a 66 MeV proton beam irradiating a 6.0 mm Li target, measured by a 2" x 4" BC-501A detector at 0^o.



NRF National Research Foundation
iThemba LABS Laboratory for Accelerator Based Sciences

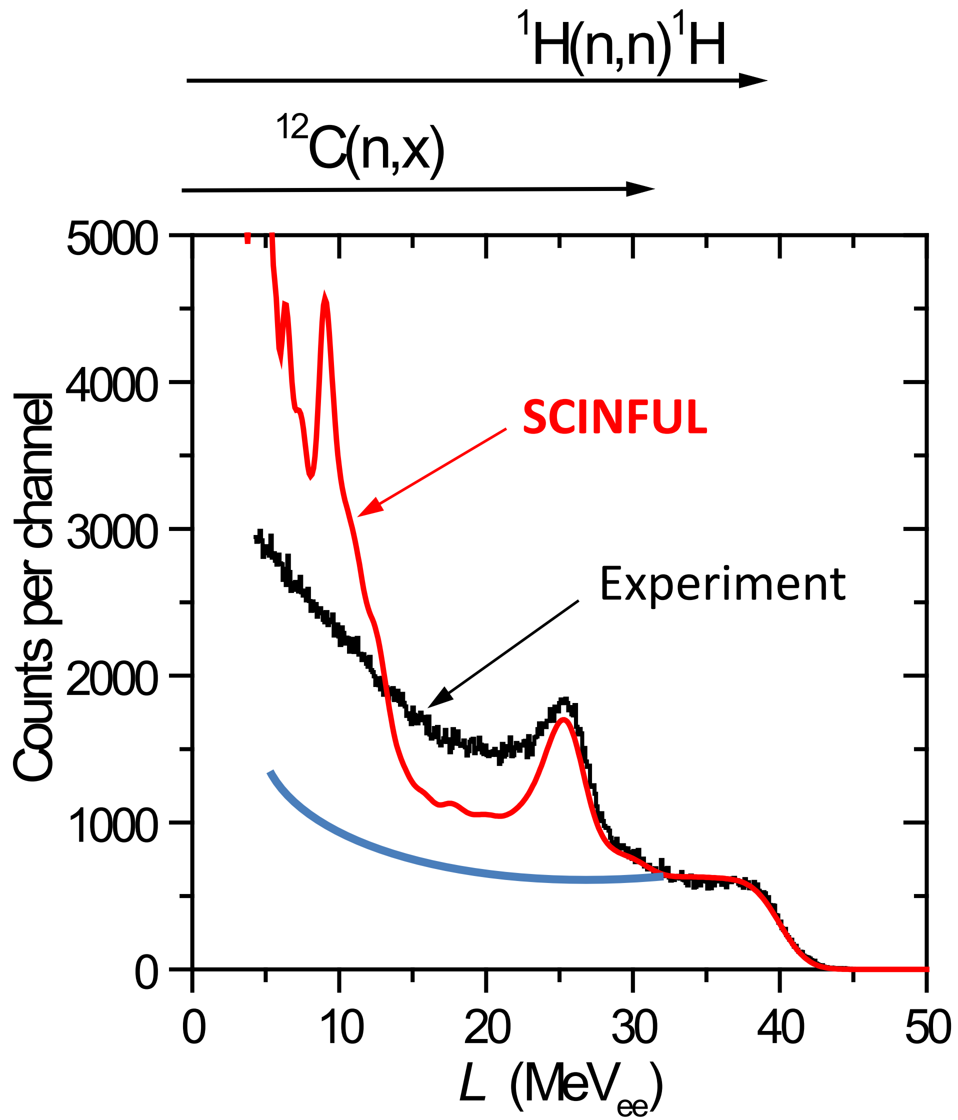
Time-of-flight measurement of neutrons produced by a 66 MeV proton beam irradiating a 6.0 mm Li target. (Measurements at 8.00 m from the target at 0º).



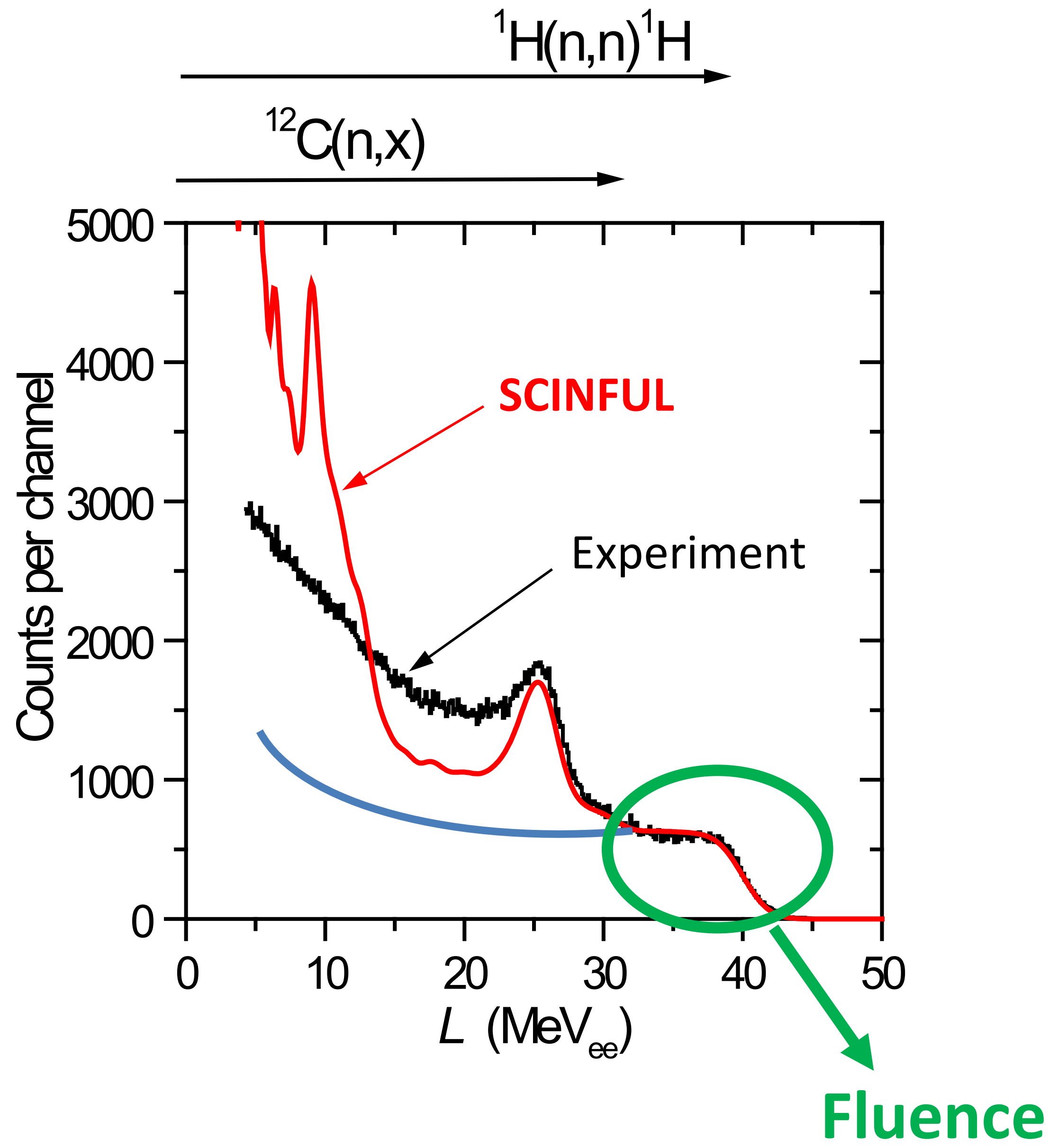
National Research Foundation

iThemba LABS
Laboratory for Accelerator Based Sciences

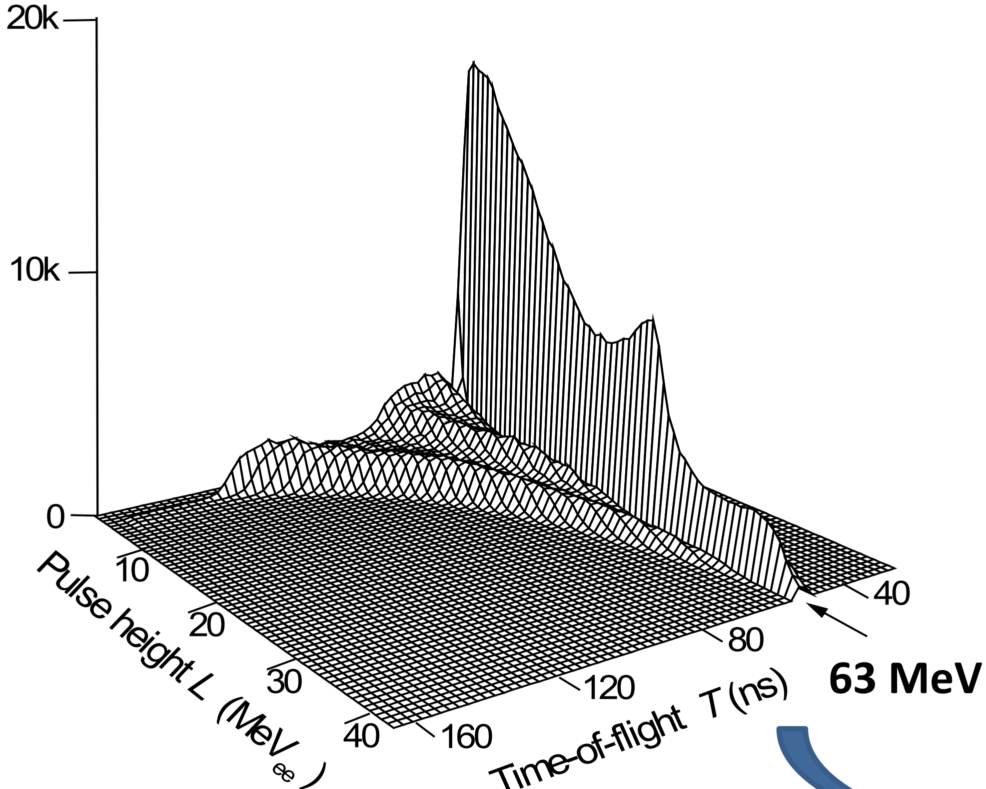
Pulse height spectrum of 63 MeV neutrons in BC-501A detector selected by time-of-flight

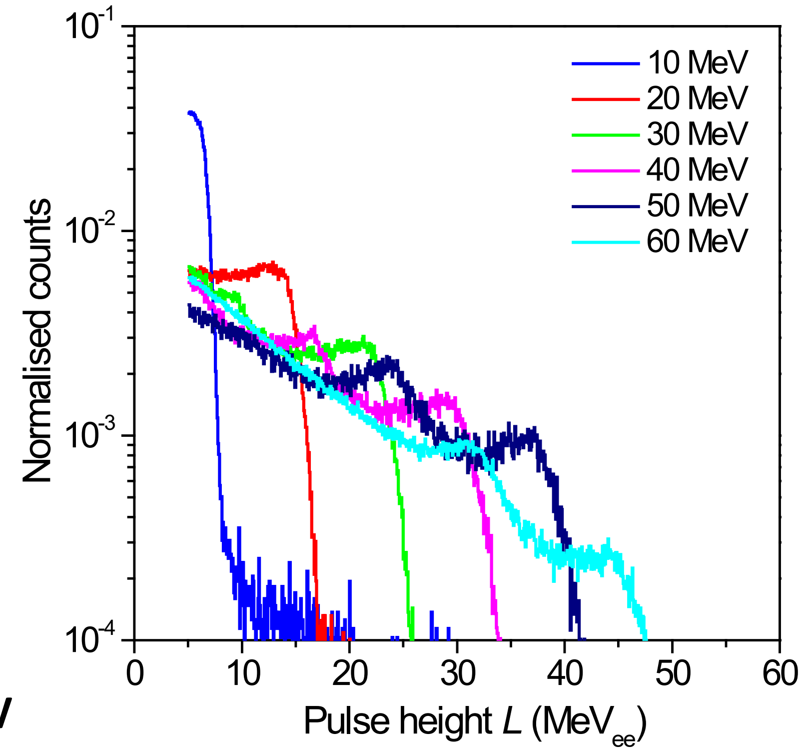


Pulse height spectrum of 63 MeV neutrons in BC-501A detector selected by time-of-flight



Time-of-flight measurement of neutrons produced by a 66 MeV proton beam irradiating a 8.0 mm Li target. (Measurements at 8.00 m from the target at 0º).





Narrow cuts in T (E_n) produce nearly monoenergetic response functions

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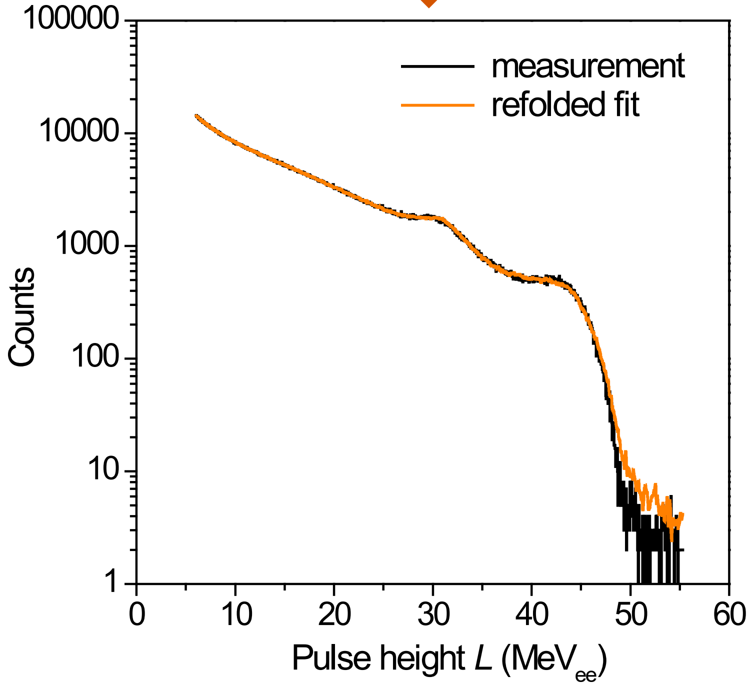
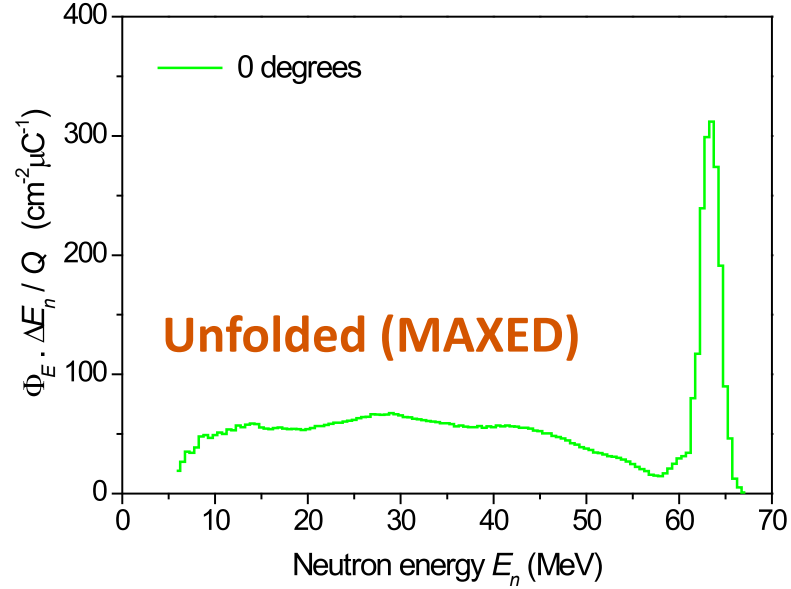
iThemba LABS Laboratory for Accelerator Based Sciences

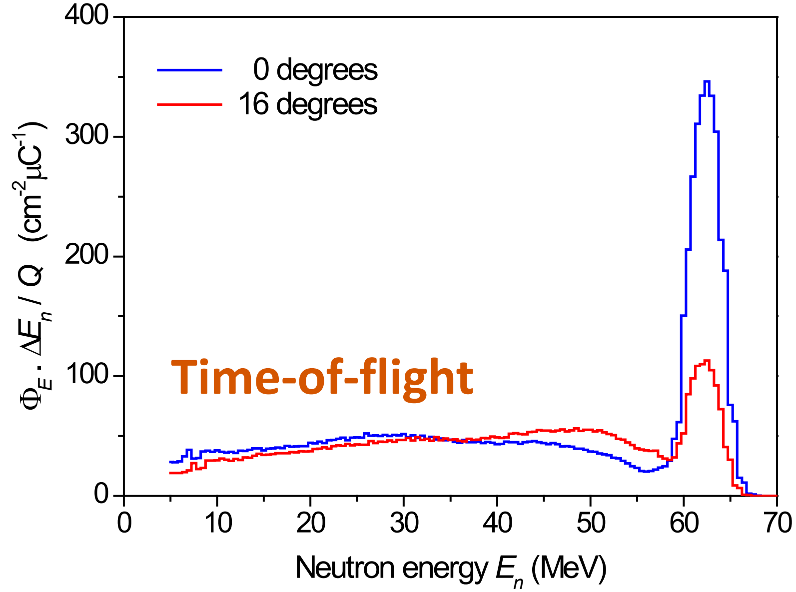
Spectrum unfolding (BC-501A reference detector) with measured detector response functions (5 - 65 MeV)

June 2022 data

Neutron light output spectrum measured at 0° for a 66 MeV proton beam on 8.0 mm Li target

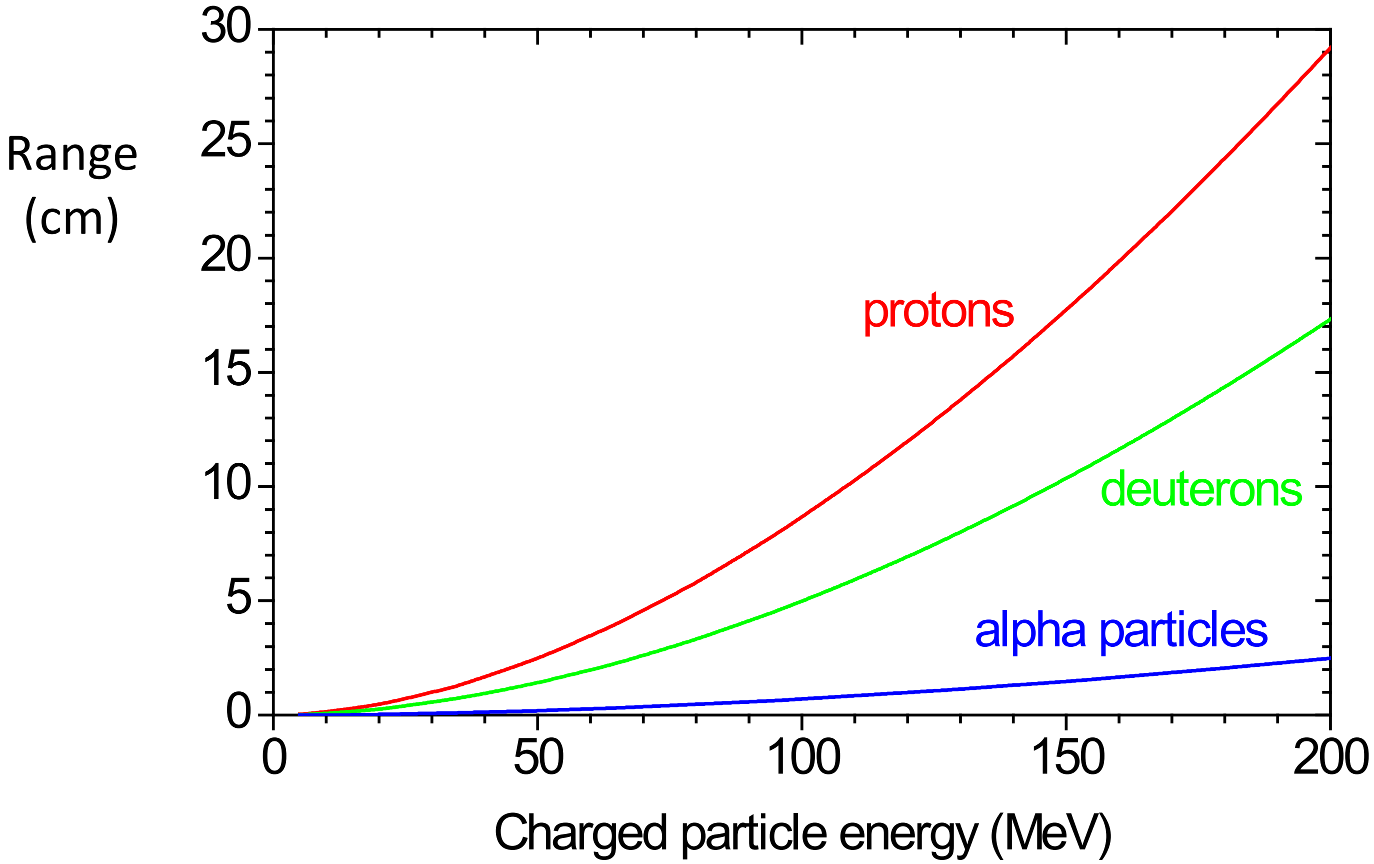






PhD: Kutullo Maibane

Range of charged particles in NE-213 / BC-501A / EJ-301

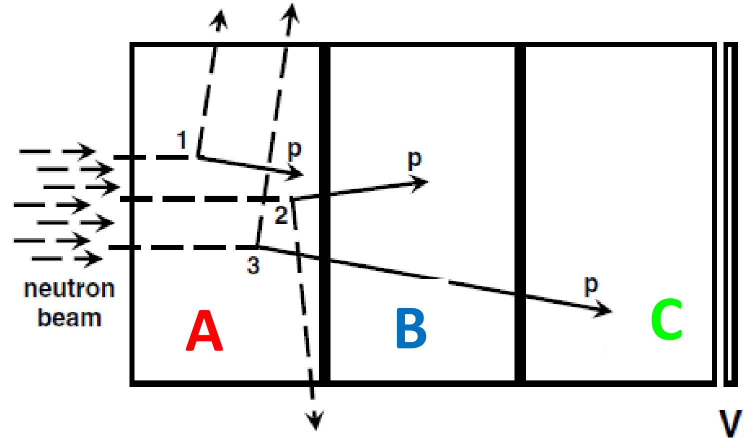


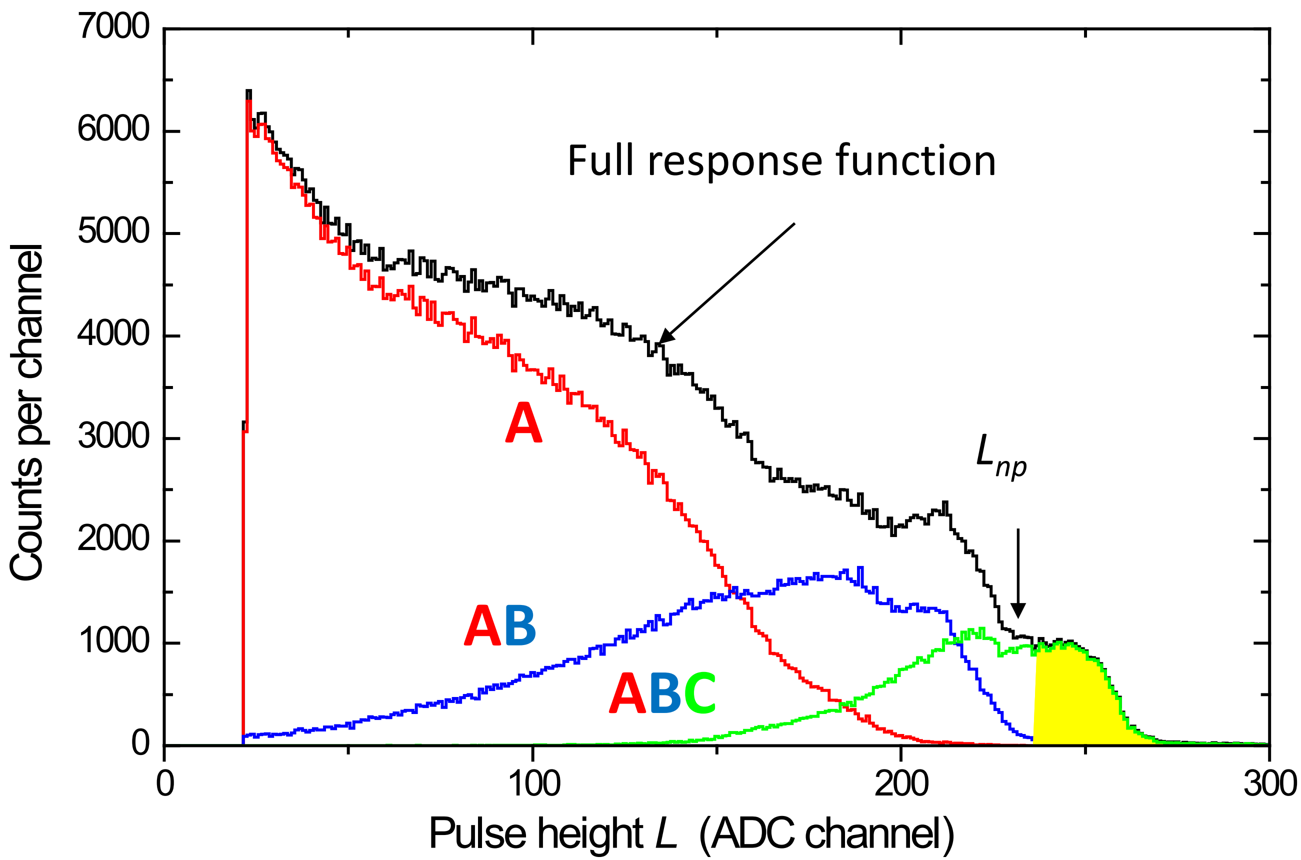
Triple scintillator system

Radiation Protection Dosimetry (2004), Vol. 110, Nos 1-4, pp. 151–155
doi:10.1093/rpd/nch213

MEASUREMENT OF NEUTRON FLUENCE SPECTRA UP TO 150 MeV USING A STACKED SCINTILLATOR NEUTRON SPECTROMETER

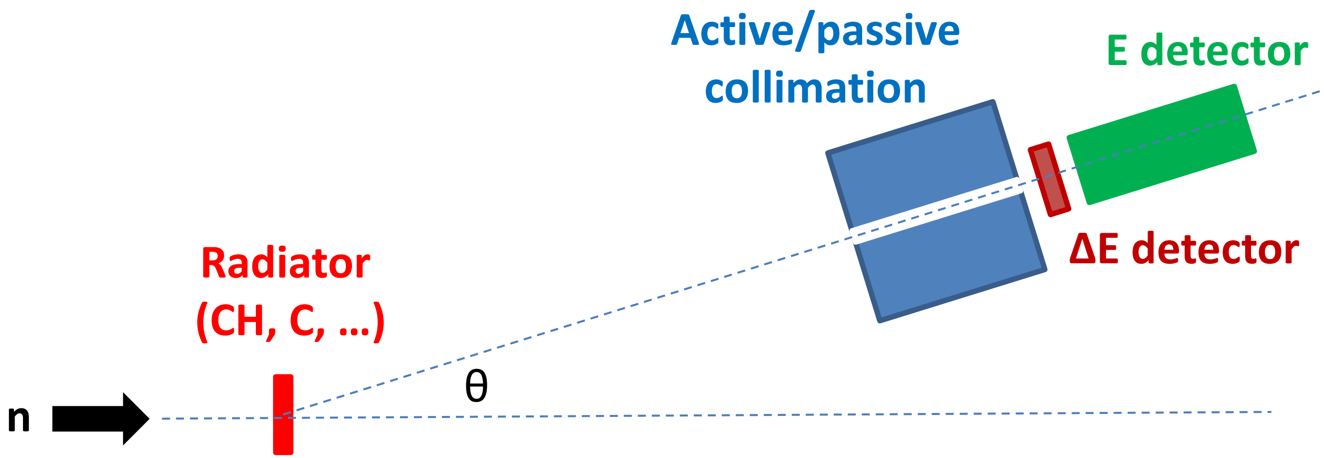
F. D. Brooks[1,*], M. S. Allie[1], A. Buffler[1], V. Dangendorf[2], M. S. Herbert[1], S. A. Makupula[1], R. Nolte[2] and F. D. Smit[3]
[1]Physics Department, University of Cape Town, Rondebosch, 7700, South Africa
[2]Physikalisch-Technische Bundesanstalt, D-38116 Braunschweig, Germany
[3]iThemba Laboratory for Accelerator-Based Sciences, Somerset West, 7129, South Africa

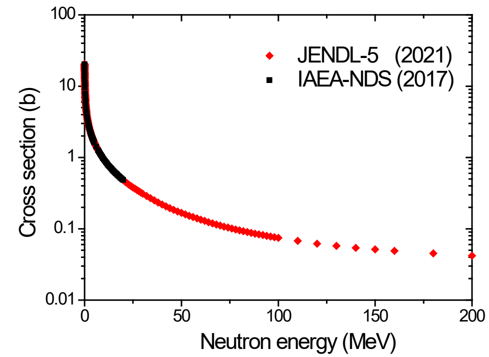


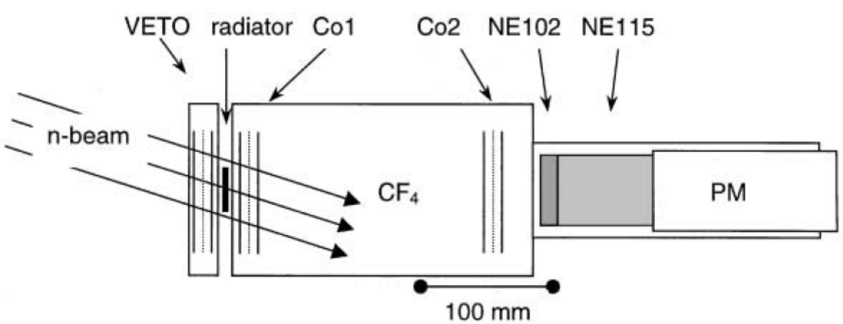


National Research Foundation NRF | iThemba LABS Laboratory for Accelerator Based Sciences

Proton recoil telescope







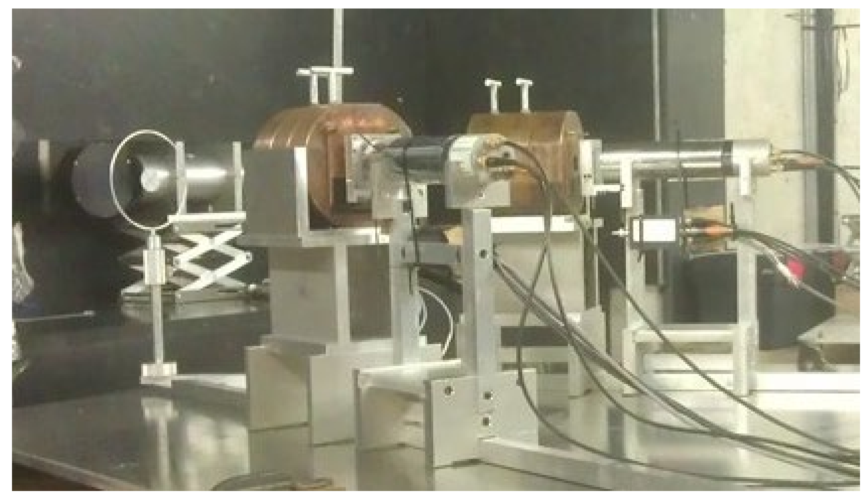
ELSEVIER
Nuclear Instruments and Methods in Physics Research A 469 (2001) 205–215
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

Proton recoil telescopes for fluence measurement in neutron beams of 20–200 MeV energy

V. Dangendorf*, R. Nolte, F. Roos, H. Schuhmacher, B.R.L. Siebert, M. Weyrauch

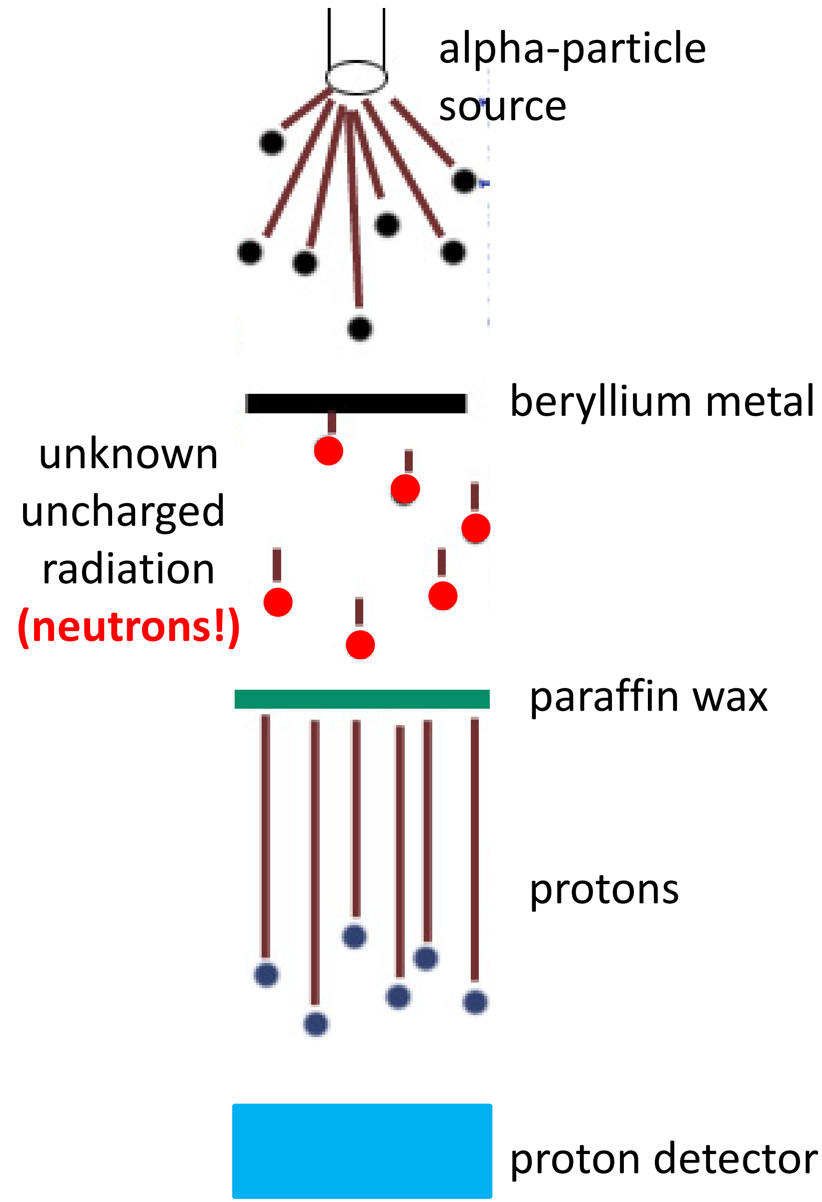
Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

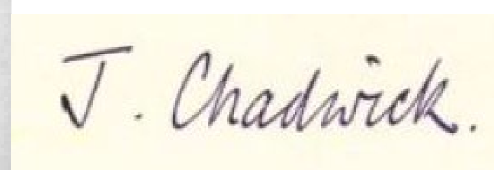
Received 18 December 2000; accepted 5 February 2001



PTB Physikalisch Technische Bundesanstalt

NRF National Research Foundation | iThemba LABS Laboratory for Accelerator Based Sciences


alpha-particle source
beryllium metal
unknown uncharged radiation
(neutrons!)
paraffin wax
protons
proton detector


J. Chadwick.

Proton recoil telescope

Nuclear Instruments and Methods in Physics Research A 615 (2010) 211–219

Contents lists available at ScienceDirect

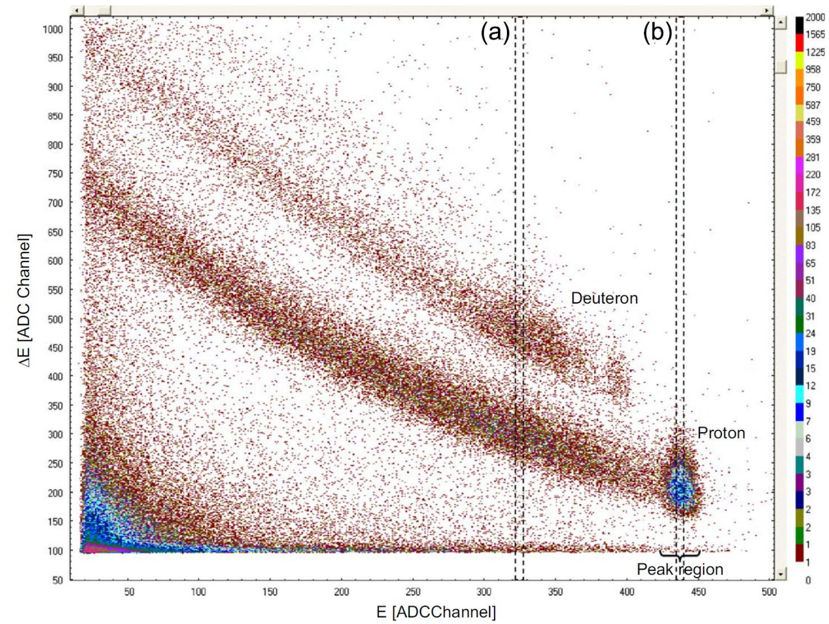
Nuclear Instruments and Methods in Physics Research A

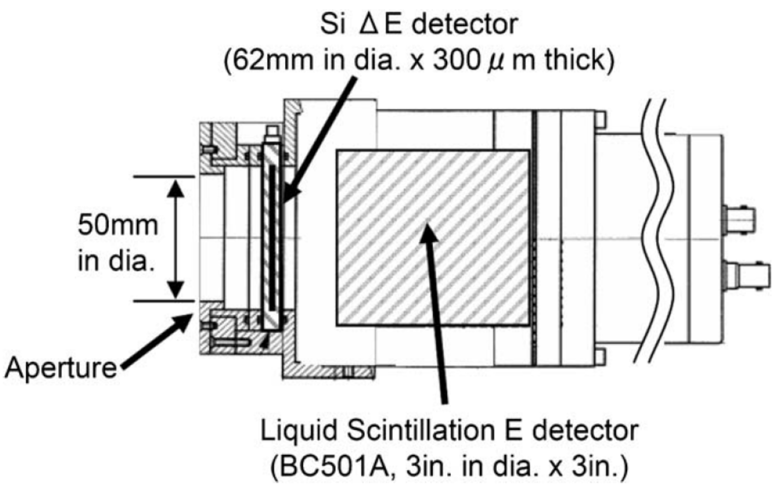
journal homepage: www.elsevier.com/locate/nima

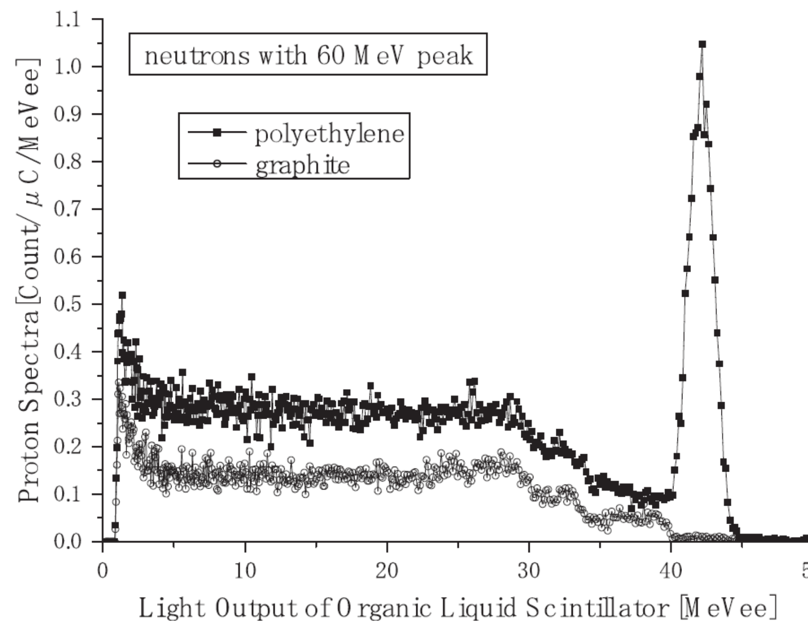
Development of highly efficient proton recoil counter telescope for absolute measurement of neutron fluences in quasi-monoenergetic neutron calibration fields of high energy

Yoshiaki Shikaze *, Yoshihiko Tanimura, Jun Saegusa, Masahiro Tsutsumi

Department of Radiation Protection, Nuclear Science Research Institute, Japan Atomic Energy Agency, Tokai-mura, Naka-gun, Ibaraki 319-1195, Japan

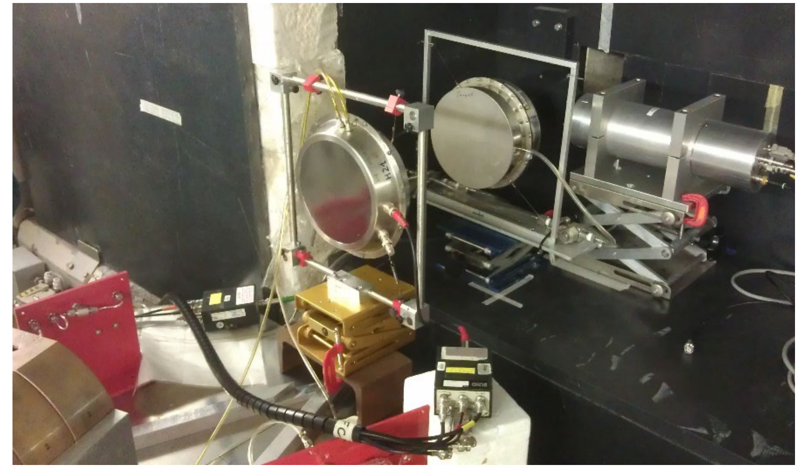


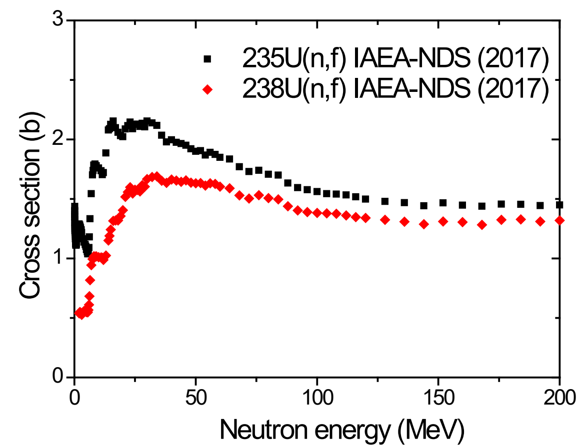




^{238}U (or ^{235}U) fission ionization chamber

$$N_f = N_U \sigma_0 \Phi_0 \prod_i k_i$$





Φ_0 **peak neutron fluence [unknown]**

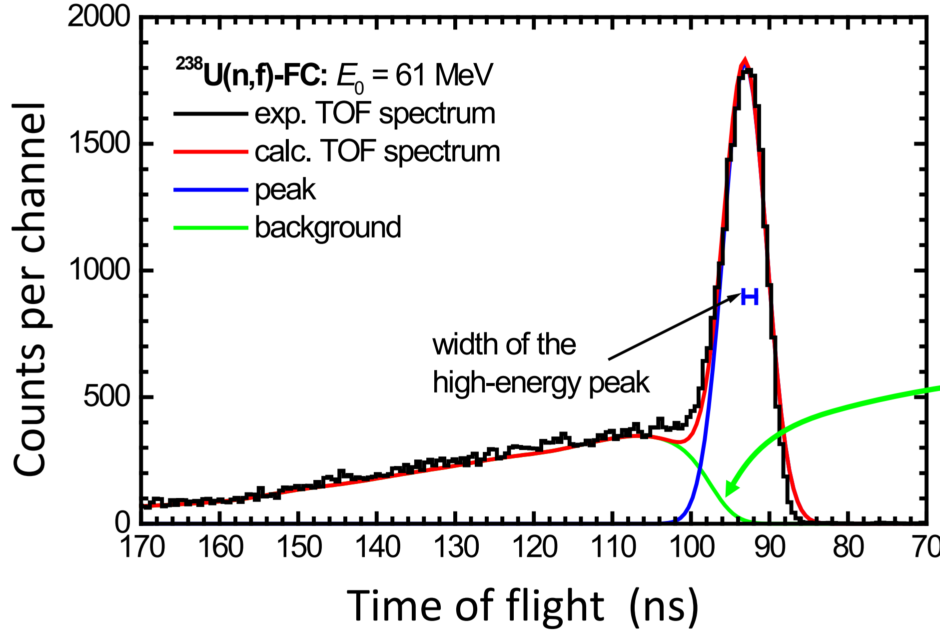
N_f number of peak fission events (measured)

σ_0 fission cross section (known quite well)

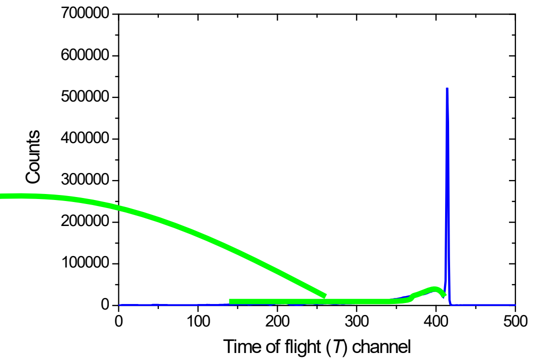
N_U number of ^{238}U atoms in FC (known very well)

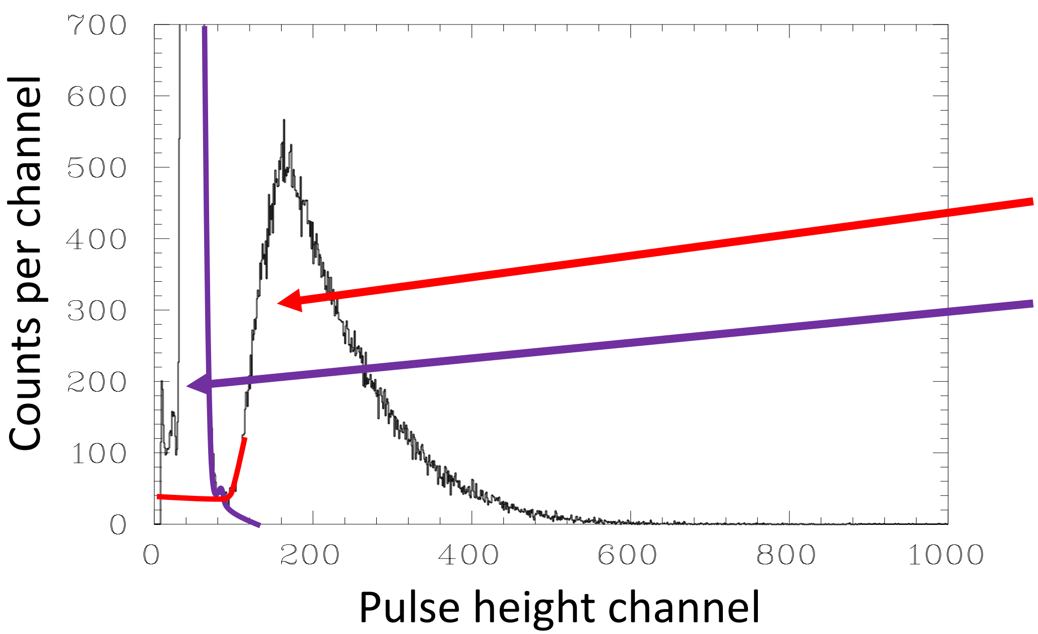
$\prod_i k_i$ correction factors for efficiency (96%), neutron absorption and multiplication in the FC, loss of events below threshold, dead time, neutron attenuation in air, beam profile and time resolution (together add about 5% to total uncertainty in fluence)

^{238}U fission ionization chamber



BC-501A TOF spectrum





fission events clearly separated from α-events in the pulse height spectrum

Bonner Sphere Systems

3582 IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 56, NO. 6, DECEMBER 2009

Optimization Using Monte Carlo Calculations of a Bonner Sphere Spectrometer Extended to High Energies for the Neutron Environments Characterization

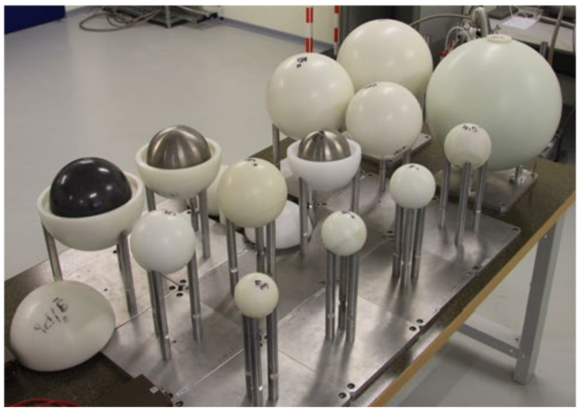
S. Serre, K. Castellani-Coulié, D. Paul, and V. Lacoste

The HERMEIS system

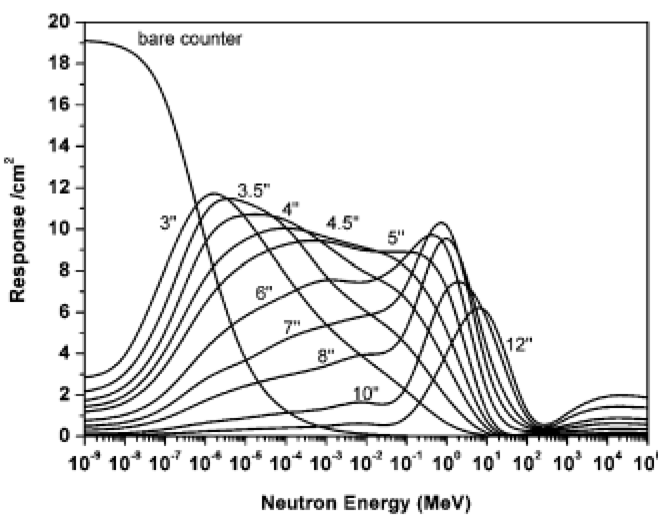
13 spheres:

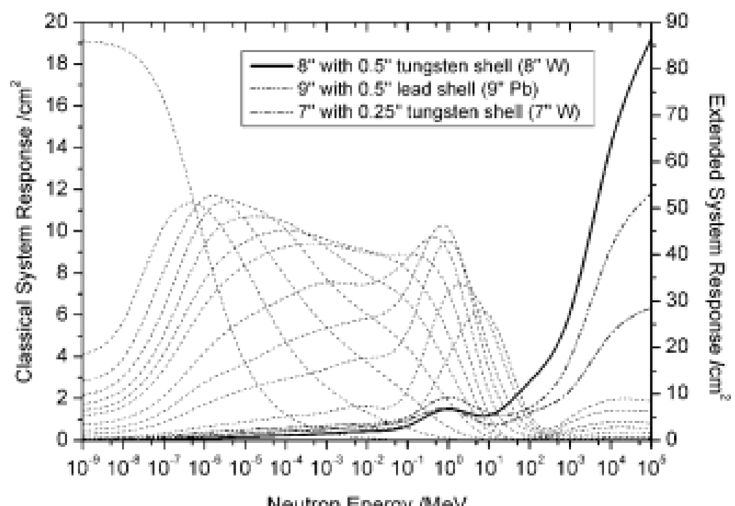
Ten polyethylene: 3” – 12”

Three additional spheres 9” Pb, 8” W and 7” W



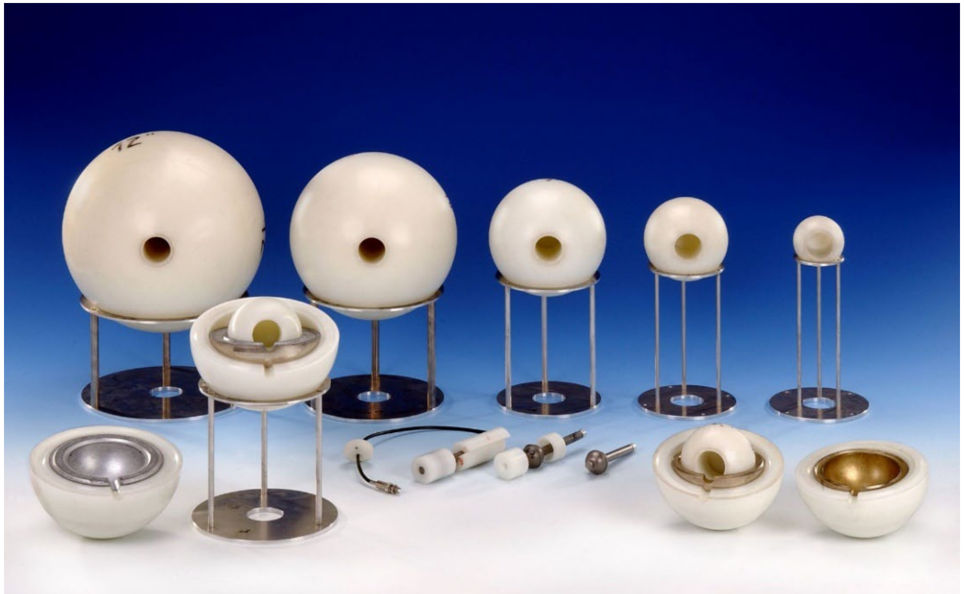
IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE





Bonner Sphere Systems

Physikalisch-Technische Bundesanstalt
Nationales Metrologieinstitut



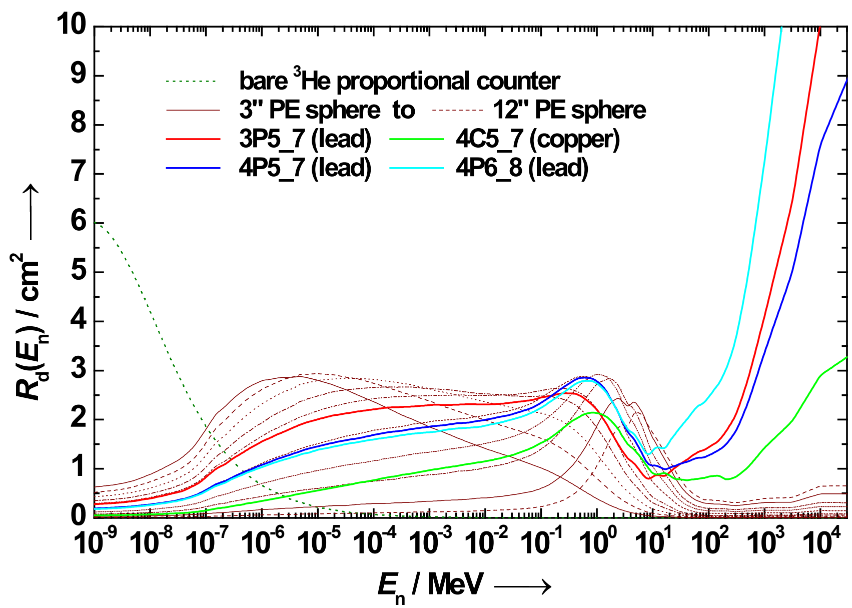
NEMUS

ELSEVIER

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment
Volume 476, Issues 1–2, 1 January 2002, Pages 36-41

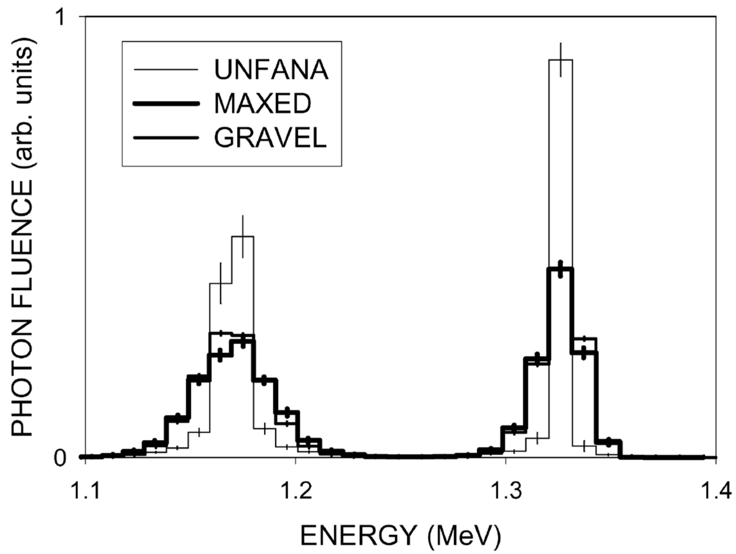
NEMUS—the PTB Neutron Multisphere Spectrometer: Bonner spheres and more

B Wiegel, A.V Alevra

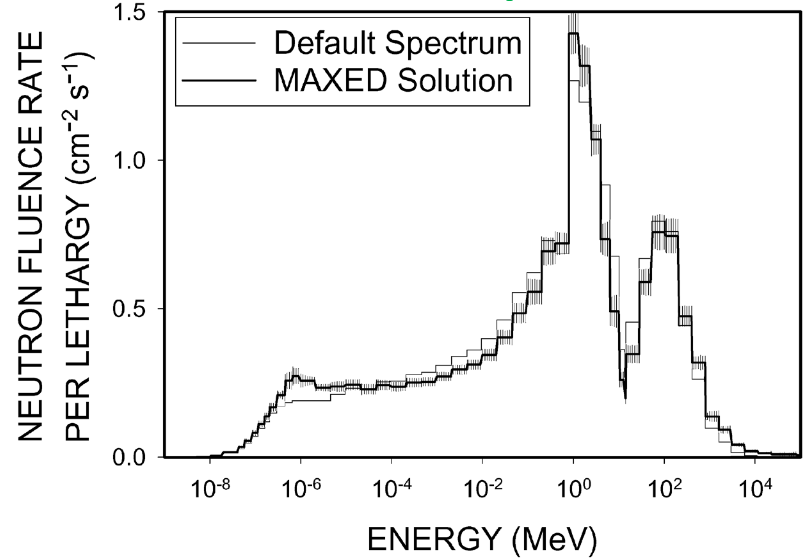


Unfolding

Scintillator



Bonner Spheres



ELSEVIER

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

Volume 476, Issues 1–2, 1 January 2002, Pages 242-246

Spectrum unfolding, sensitivity analysis and propagation of uncertainties with the maximum entropy deconvolution code MAXED

Marcel Reginatto [a], Paul Goldhagen [a], Sonja Neumann [b, 1]

EURADOS

home • events overview • course on unfolding of bonner sphere spectrometer neutron measurements

Course on Unfolding of Bonner Sphere Spectrometer Neutron Measurements

$$\Phi = \frac{R_\Phi}{\sigma}$$

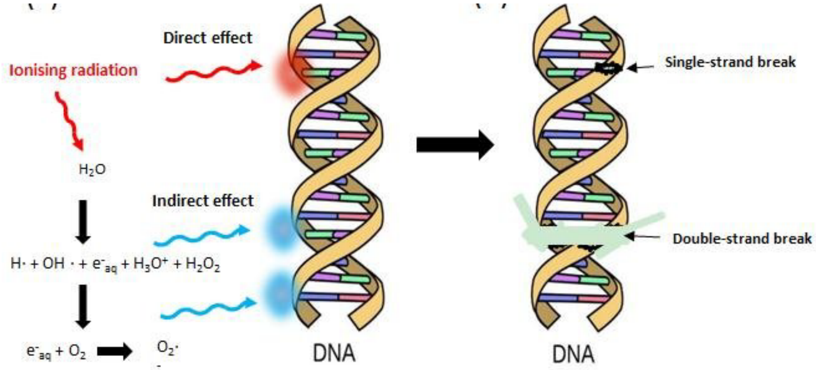
↓

Applications

1. Effects
2. Cross sections
3. Instrumentation

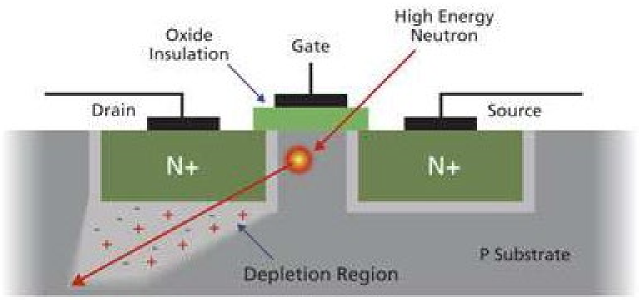
Applications:
1. Effects

Biological systems:
Errors in DNA nucleotide replication



10.21926/rpm.2002012

Electronic systems:
Soft bit-level errors in hardware

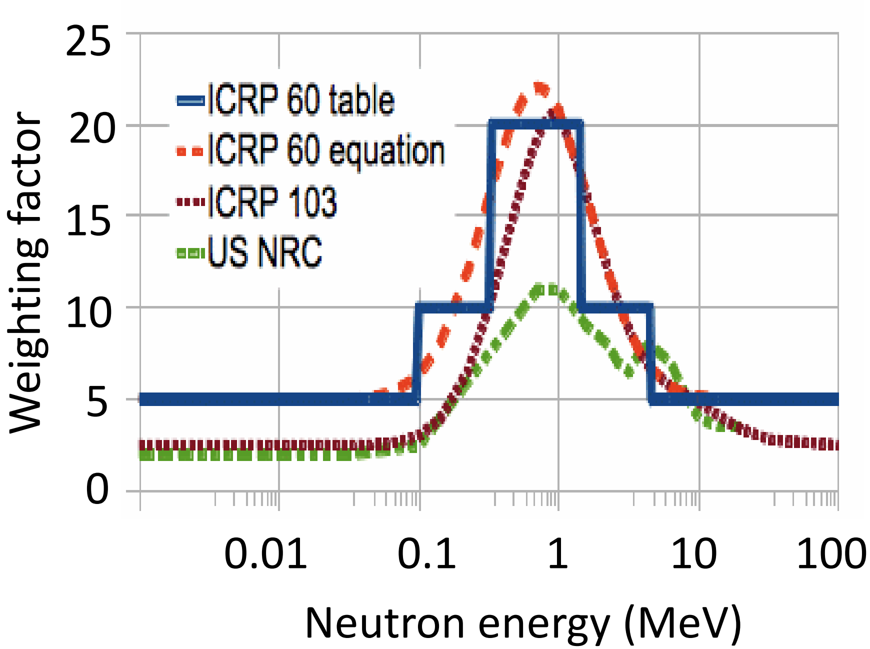


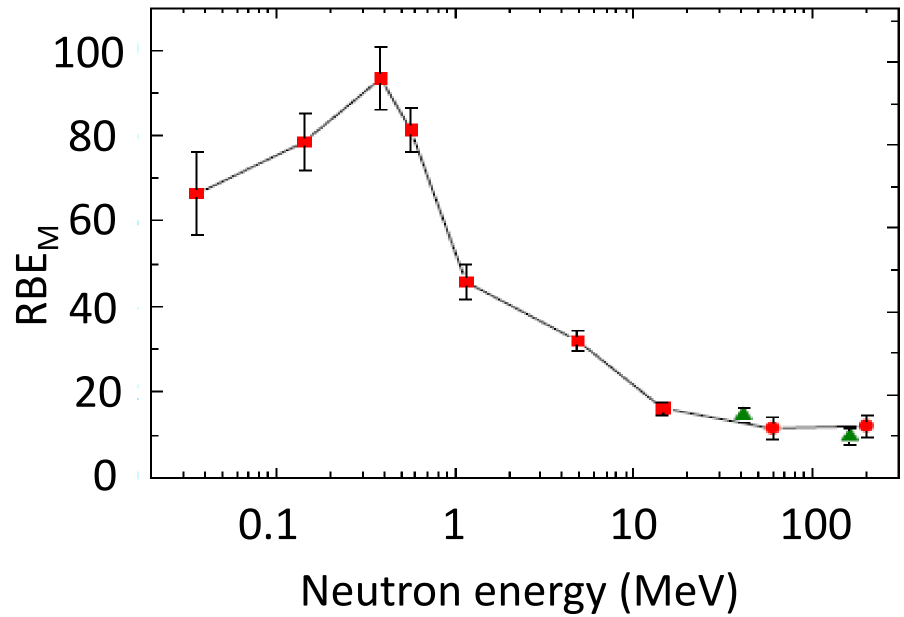
… both occur at the same rate for the same dose.

Relevant for aviation, space missions, workplace exposure, radiation therapy, ...

Radiation weighting factors and RBE_M for neutrons (low dose, low dose rate)

Large uncertainties and sparse data





Annals of the ICRP

PUBLICATION 103

The 2007 Recommendations of the International Commission on Radiological Protection

Editor
J. VALENTIN

PROCEEDINGS OF SCIENCE

Relative Biological Efficiency of 192 MeV Neutron Radiation for the Induction of Chromosome Aberrations in Human Lymphocytes of the Peripheral Blood

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G. Stephan
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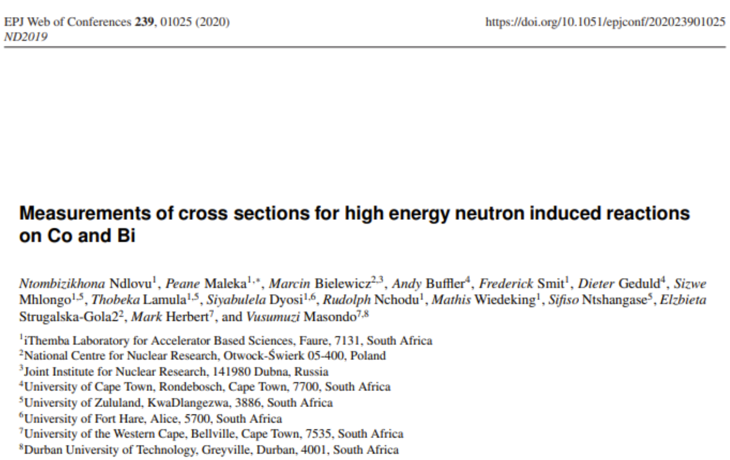
E-mail: gstephan@bfs.de

PoS(FNDA2006)082

Applications:
2. Cross sections

- Astrophysics models, including background reactions in ultrasensitive double beta decay experiments (C, Te, Cd, …)
- International Reactor Dosimetry and Fusion File (IRDIFF) library (Co, Bi, …) for IFMIF, ….

IFMIF/EVEDA
BA-Engineering Validation and Engineering Design Activities
for the Fusion Materials Irradiation Facility


EPJ Web of Conferences **239**, 01025 (2020)
ND2019
https://doi.org/10.1051/epjconf/202023901025

Measurements of cross sections for high energy neutron induced reactions on Co and Bi

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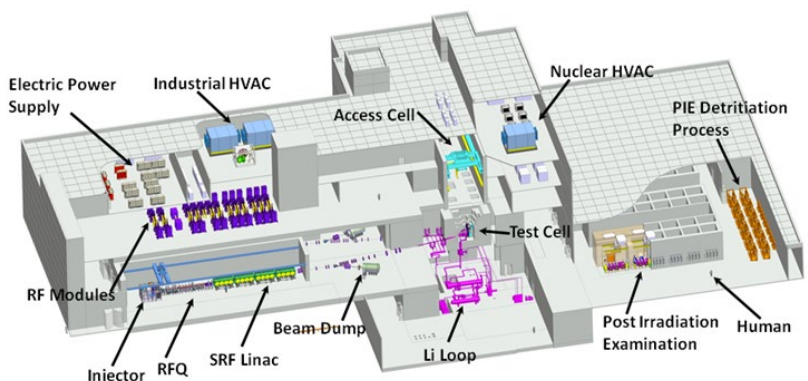
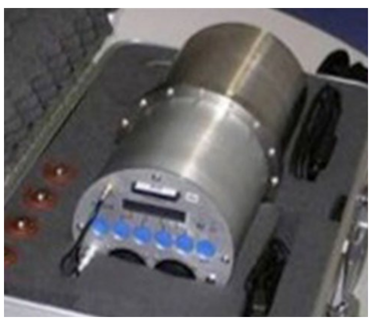


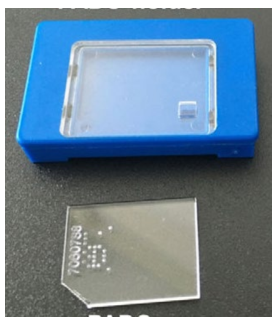
Li(d,xn)

Applications:
3. Characterisation of instrumentation

Dosimetry: Earth, Aviation, Earth orbit, Moon, Mars, …)

Scintillators, Si, TEPC, TLD, PADC, ….





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Calibration and Characterization of the Radiation Assessment Detector (RAD) on Curiosity

C. Zeitlin, D. M. Hassler, R. F. Wimmer-Schweingruber, B. Ehresmann, J. Appel, T. Berger, E. Böhm, S. Böttcher, D. E. Brinza, S. Burmeister, J. Guo, J. Köhler, H. Lohf, C. Martin, D. Matthiä, A. Posner, S. Rafkin, G. Reitz, Y. D. Tyler, M. Vincent, G. Weigle, Y. Iwata, H. Kitamura & T. Murakami

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ISO 20785-1:2020

Dosimetry for exposures to cosmic radiation in civilian aircraft — Part 1: Conceptual basis for measurements

ISO 20785-2:2020

Dosimetry for exposures to cosmic radiation in civilian aircraft — Part 2: Characterization of instrument response

ISO/FDIS 20785-3

Dosimetry for exposures to cosmic radiation in civilian aircraft — Part 3: Measurements at aviation altitudes

ISO 20785-4:2019

Dosimetry for exposures to cosmic radiation in civilian aircraft — Part 4: Validation of codes

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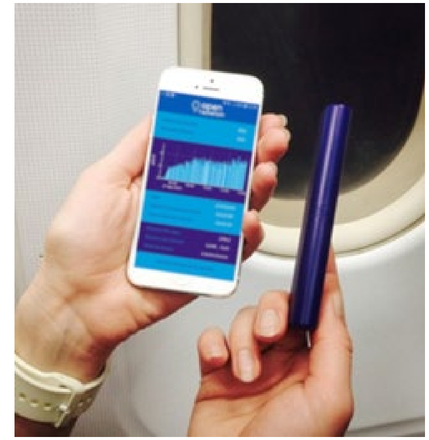
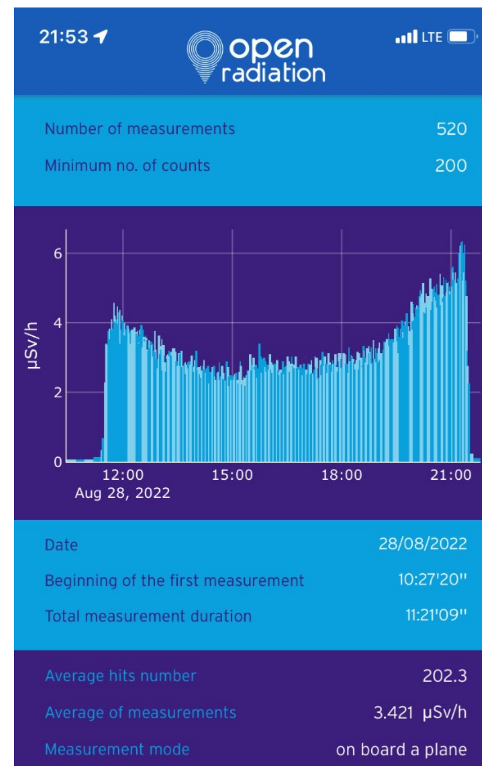
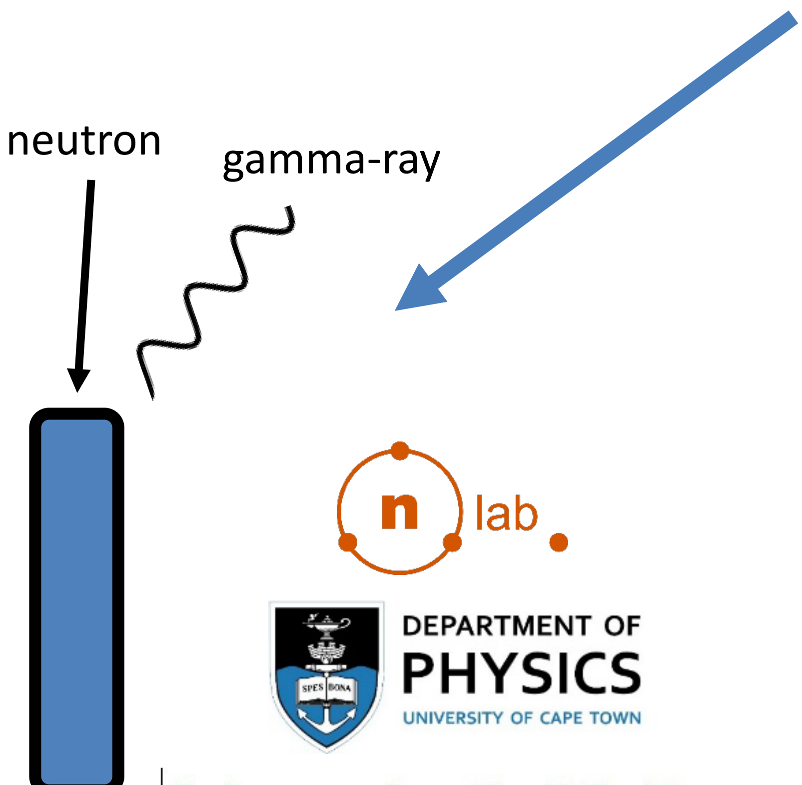
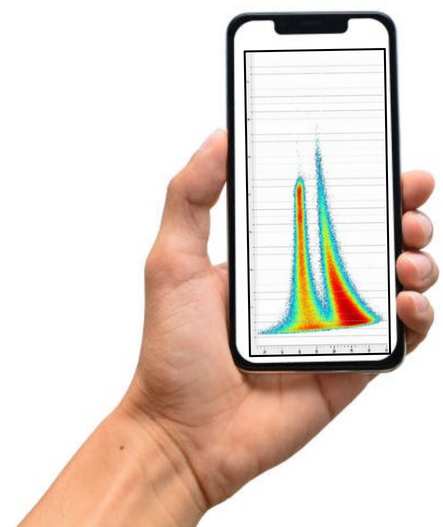
COSMIC ON AIR

open radiation









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DEPARTMENT OF PHYSICS
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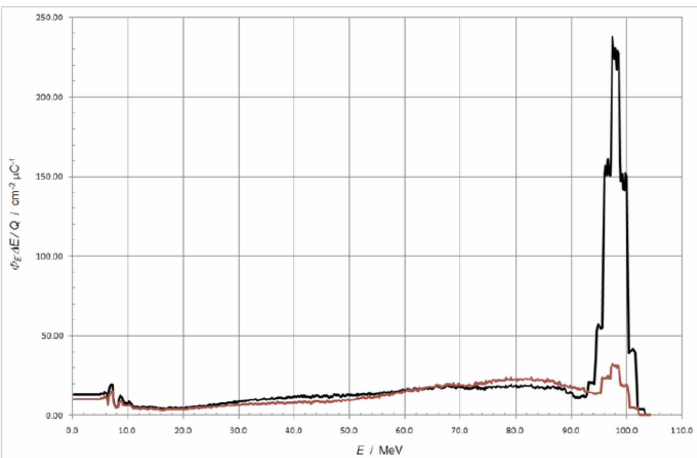

Figure 3.2.2: Spectral fluence (Φ_E $\Phi_{E/Q}$) normalized to beam charge at a distance of 8 m from the Li target for neutron emission angles of 0° (black) and 16° (red) and a proton energy of Ep = 99.35 MeV. The fluence ratio between 0° and 16° is ($\Phi_{0°}/\Phi_{16°}$) = 1.640

EURADOS

Working Group 11

EURADOS
European Radiation Dosimetry Group e. V.

EURADOS Report 2016-02
Neuherberg, June 2016

Irradiations at the High-Energy Neutron Facility at iThemba LABS

A. Buffler, G. Reitz, S. Röttger, F. D. Smit, F. Wissmann (Eds.)

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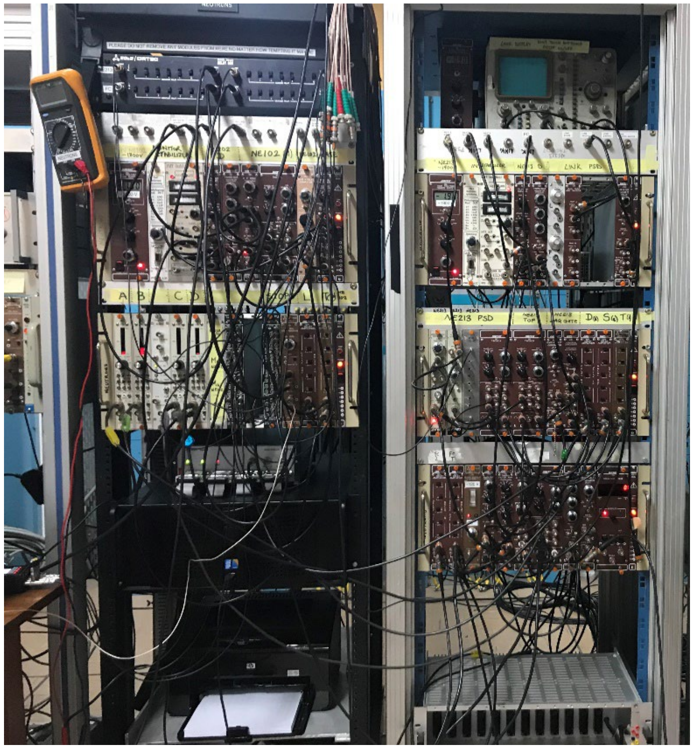
Challenge: Data acquisition



In principle, modern digital acquisition systems are cheaper, more compact, and allow flexible post-acquisition processing …

… but remain uncharacterized for <u>metrology</u> applications.

1780 IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 69, NO. 7, JULY 2022

Benchmarking a New Digital Data Acquisition System for Fast Neutron Metrology

Chloé Sole, Andy Buffler, Tanya Hutton, Tom Leadbeater, Richard Babut, Vincent Gressier, and Michaël Petit

Summary
High energy neutron metrology above 20 MeV

1. Growing demand for improved reference standards from radiation protection, dosimetry, physics and biology.

2. Instrumentation is well established and will continue to evolve.

3. Cross section reference standards not sufficient.

4. Status of accelerator-based reference facilities (>40 MeV) highly insufficient.

Recommendations

… that there is much stronger **international coordination and cooperation** … including a database of current status.

… that **ISO 17025 guidelines** are urgently drafted to guide the evolution of existing and new facilities … covering … beam focusing and stability, neutron production, collimation, backgrounds, neutron beam size and profile, field characterization instrumentation and methods, beam monitoring, primary fluence measurement including data acquisition, and reporting.

… that plans are designed to guide **key comparison studies** between participating facilities.

… that the nuclear data community renews efforts to extend and improve **primary cross section standards**.

Thank you

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