HSE
Radiation Protection

Challenges and developments in Neutron Metrology for high energy workplace radiation fields

nBHEAM 2025 Workshop at IAEA

7-8 July 2025, Vienna

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EDMS 3319565 v.1.0

Outline

- **Introduction**
  - Glossary
  - Calibration process
  - Workplace radiation fields and ISO 12789
- **Workplace radiation fields**
  - **Simulated**: CERF (CERN), CSBF (CERN), PSAIF (CERN) and HE neutron test facility at PSI
  - **Measurements** in **workplace radiation fields**: Maastro (proton therapy), ELI Beamlines (laser-driven facility), CLEAR (electron accelerator)
- **New metrology challenges**: the new ICRU/ICRP operational quantities
- **Conclusions** and **future perspectives**

Introduction

Glossary

- **Workplace radiation field**
  - An environment with **specific radiation characteristics** (type, energy spectrum, fluence, dose rate, spatial distribution) where **workers** may be **occupationally exposed** to during the course of their duties
    - Example: outside the shielding of a particle accelerator
- **Simulated workplace radiation field**
  - A **controlled radiation environment** that **mimics** the characteristics (radiation type, energy spectrum, fluence, dose rate, spatial distribution) of radiation fields typically encountered in **actual workplace settings**
    - Example: a Cf-252 source moderated with polythylene reproduces the energy spectrum observed outside the shielding of a nuclear reactor
- **High energy (HE) neutrons**
  - Neutrons with **energy > 20 MeV** → More a **convention** than a strict energy threshold!
    - In Monte Carlo codes (e.g. FLUKA), below 20 MeV cross-sections are taken from evaluated nuclear data (rich structure of resonances) and above 20 MeV cross-sections are obtained from physics models
- **Calibration**
  - A set of operations that establish, under specified conditions, the relationship between values of quantities indicated by a measuring instrument or measuring system, or values represented by a material measure or a reference material, and the corresponding values realized by standards
- **Standards dosimetry laboratory**
  - A laboratory, designated by the relevant national authority, that possesses certification or accreditation necessary for the purpose of developing, maintaining or improving primary or secondary standards for radiation dosimetry
- **In-field calibration**
  - The process of **calibrating radiation instruments** (such as dosimeters or survey meters) **directly at the workplace** where measurements are performed, rather than in a controlled laboratory setting. This ensures that the instruments' response accurately reflects the specific radiation field characteristics present in that environment. The process relies on the knowledge of the **detector response function** and of the **characteristics** of the **workplace radiation field**

Standard calibration process

Need for calibration

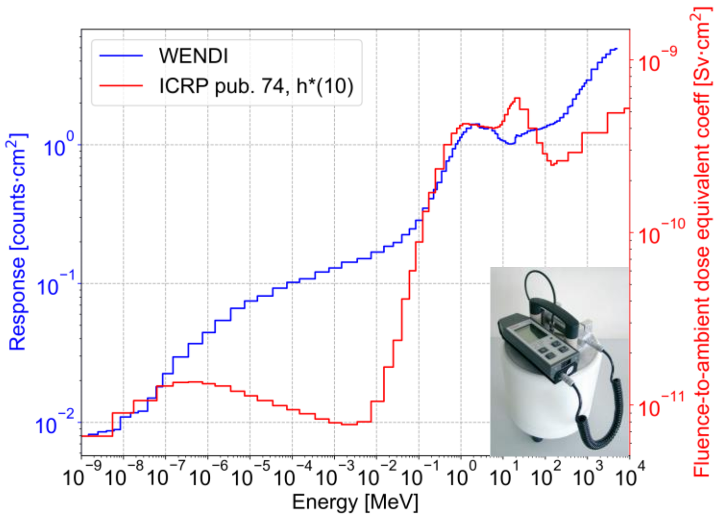
Dosimeters and area survey meters shall be periodically calibrated

ISO 8529 series

Standards for the production, characterization, and application of reference neutron radiation fields used for calibrating neutron-measuring devices and evaluating their response

Standard dosimetry laboratory

Provides calibration services and is traceable to the International system of Units



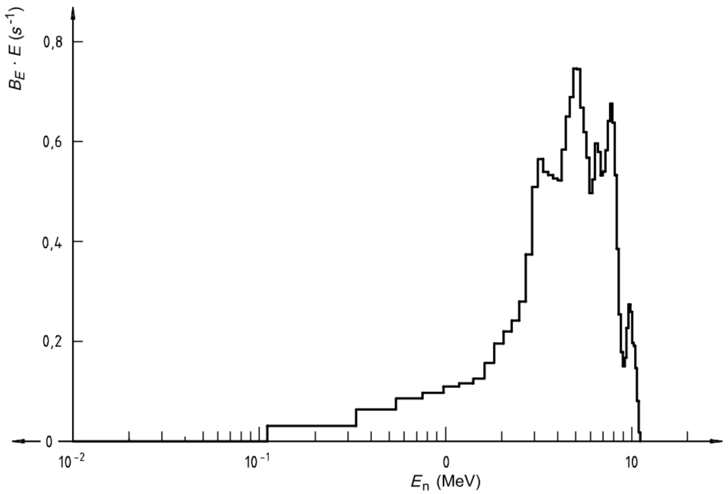
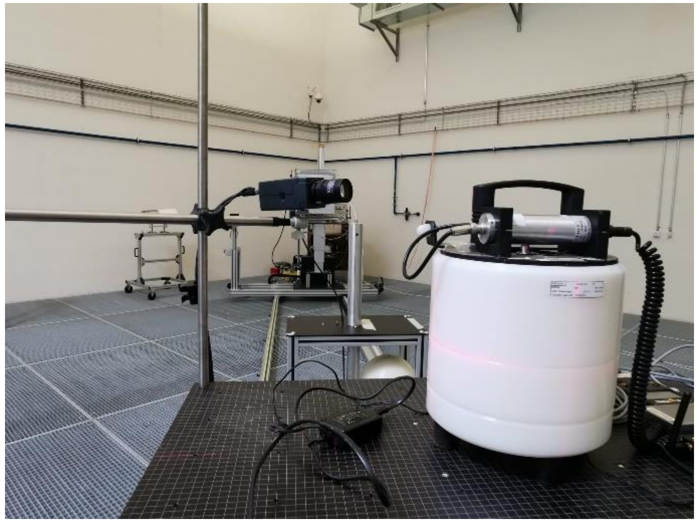
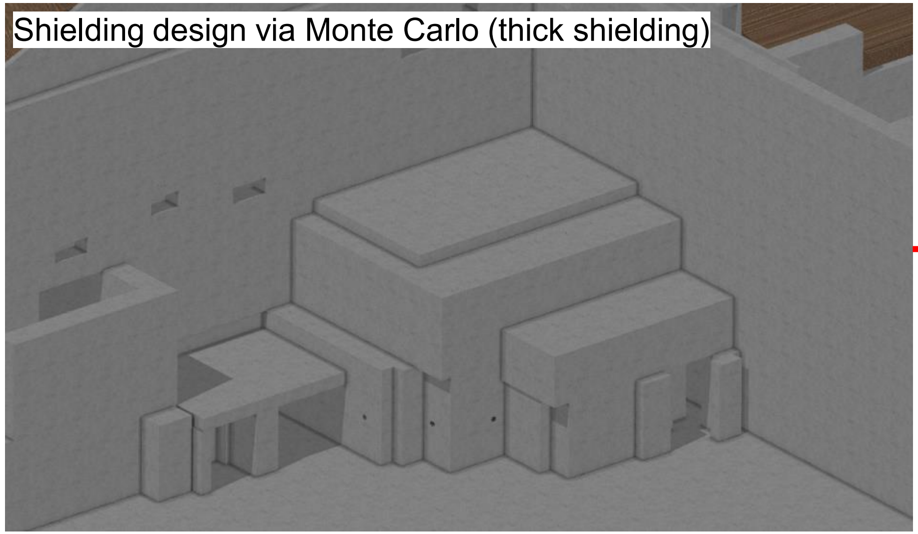


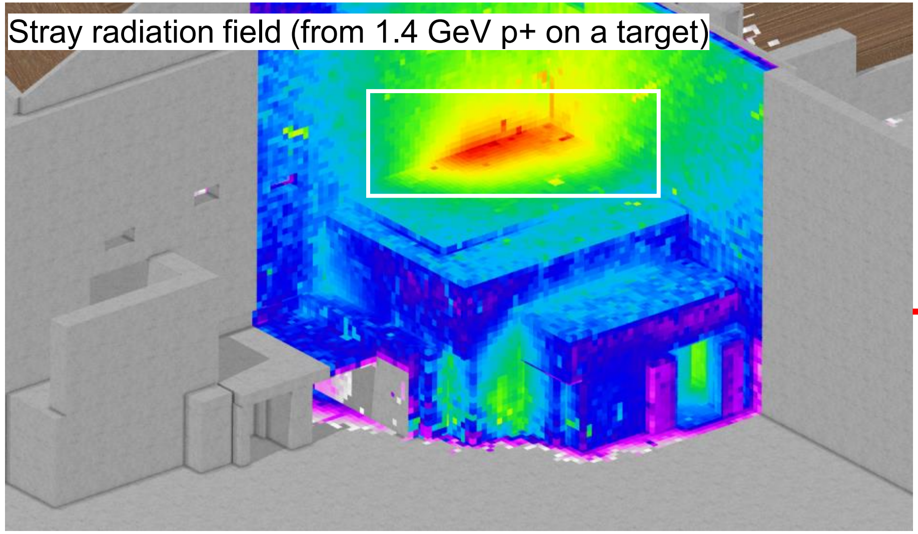
Figure A.4 — Neutron spectrum from a ^{241}Am-Be(α,n) source



Workplace radiation field

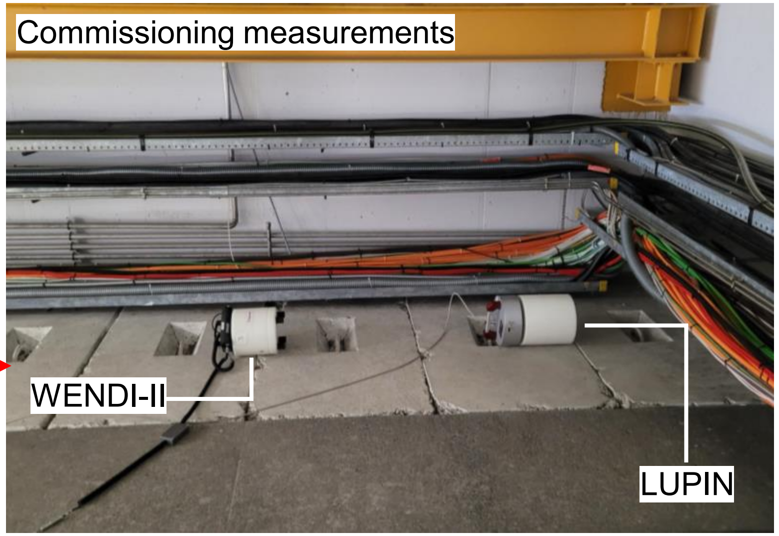


Shielding design via Monte Carlo (thick shielding)



Stray radiation field (from 1.4 GeV p+ on a target)

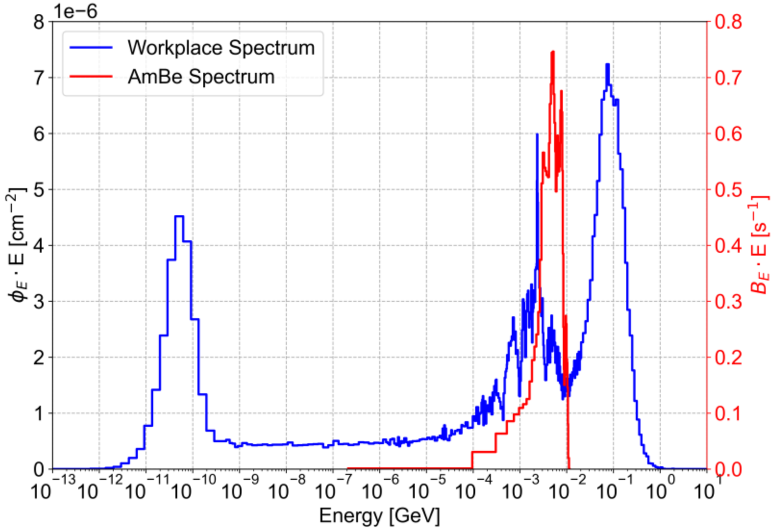
Radiation measurements
(e.g. facility commissioning)



Commissioning measurements

Monte Carlo can also provide information on the **neutron spectrum**

which can be very different from the one used for calibration!



Is the "**calibrated**" response of the detector **representative** when used in this radiation field?

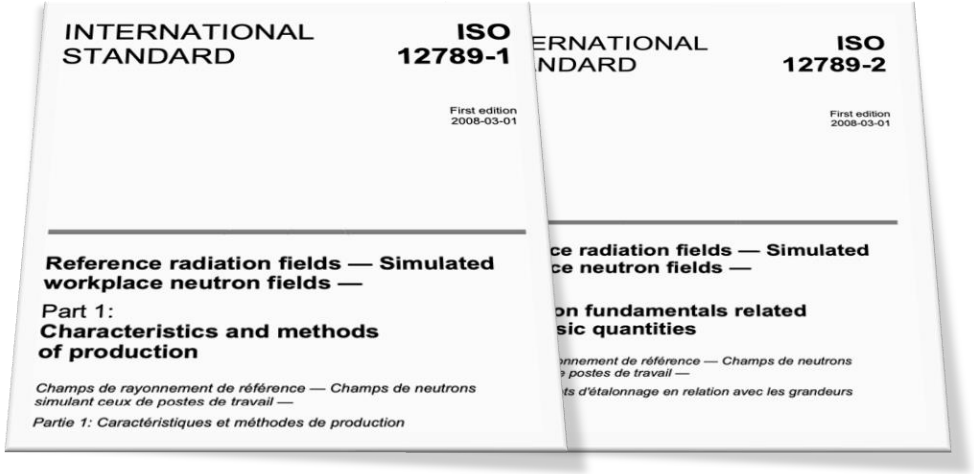
A database of neutron spectra, instrument reponse functions and dosimetric conversion factors for Radiation Protection Applications, Naismith and Siebert, Radiat. Prot. Dosim., 70, (1996)

What does ISO 12789 series tell us?

Catalogue of **neutron fluence spectra** at workplace (measured and/or simualted)

Production
Radionuclide neutron sources, accelerators and reactors (+absorbing/scattering materials)

Spectrometry measurements
BSS (limited energy resolution and uncertainty in data analysis), integral value, intercomparison



INTERNATIONAL STANDARD

ISO 12789-1

First edition
2008-03-01

Reference radiation fields — Simulated workplace neutron fields —

Part 1:
Characteristics and methods of production

Champs de rayonnement de référence — Champs de neutrons simulant ceux de postes de travail —

Partie 1: Caractéristiques et méthodes de production

ERNATIONAL
NDARD

ISO 12789-2

First edition
2008-03-01

ce radiation fields — Simulated
ce neutron fields —

on fundamentals related
sic quantities

nnement de référence — Champs de neutrons
postes de travail —
ts d'étalonnage en relation avec les grandeurs

Characterisation
Measurements + Simulations
field uniformity, angular distribution, neutron fluence, dose equivalent rates, portion of contaminating photons
expected agreement of integral quantities +/-20%)

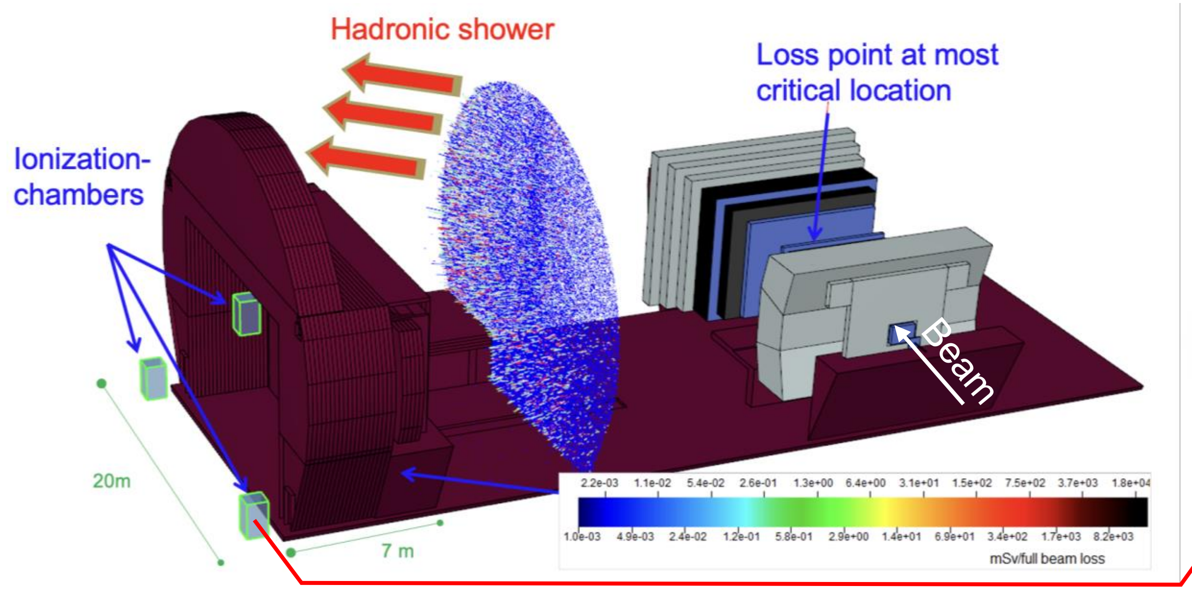
Simulations
Internationally tested computer codes, version, document initial conditions (intercomparison), uncertainty difficult to estimate (irradiation geometry/material, cross-sections)

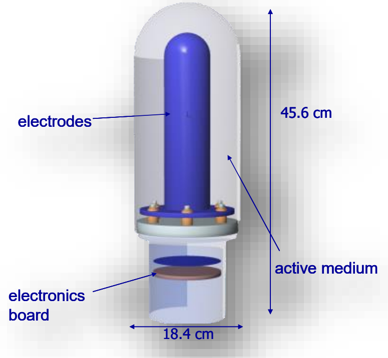
At present, no simple methods exist to provide traceability of the operational quantities from a national standards institute to the simulated workplace neutron fields.

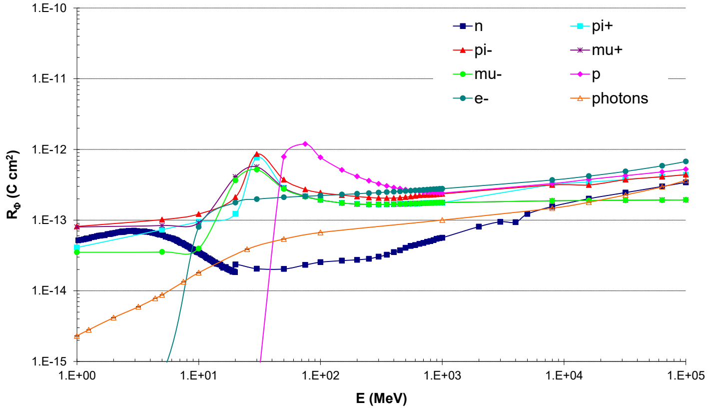
How to calibrate a detector for measurement in a workplace field?

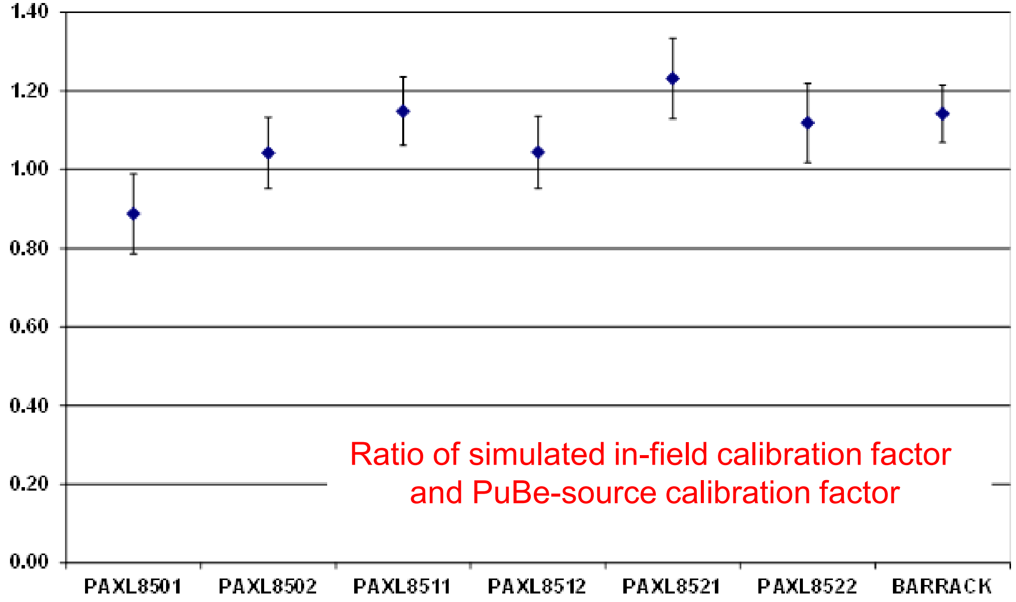
1. The **neutron spectrum** of the workplace field can be **calculated** and/or **measured**, and a **correction factor** calculated to normalize the energy-dependent response of the detector
2. A **facility** can be **constructed** to produce a neutron field that simulates the energy spectrum found in the workplace

Example of in-field calibration: LHCb at CERN









Ratio of simulated in-field calibration factor and PuBe-source calibration factor

Procedure

1. **FLUKA simulation** of
    - **Energy-** and **particle**-dependent **response functions**
    - **Fluence** spectra at detector locations
    - **H*(10)** at detector locations
2. **Folding** of response functions and fluence spectra
3. Ratio of **simulated H*(10)** and **collected charge**
    →in-field calibration factor!

Workplace radiation fields

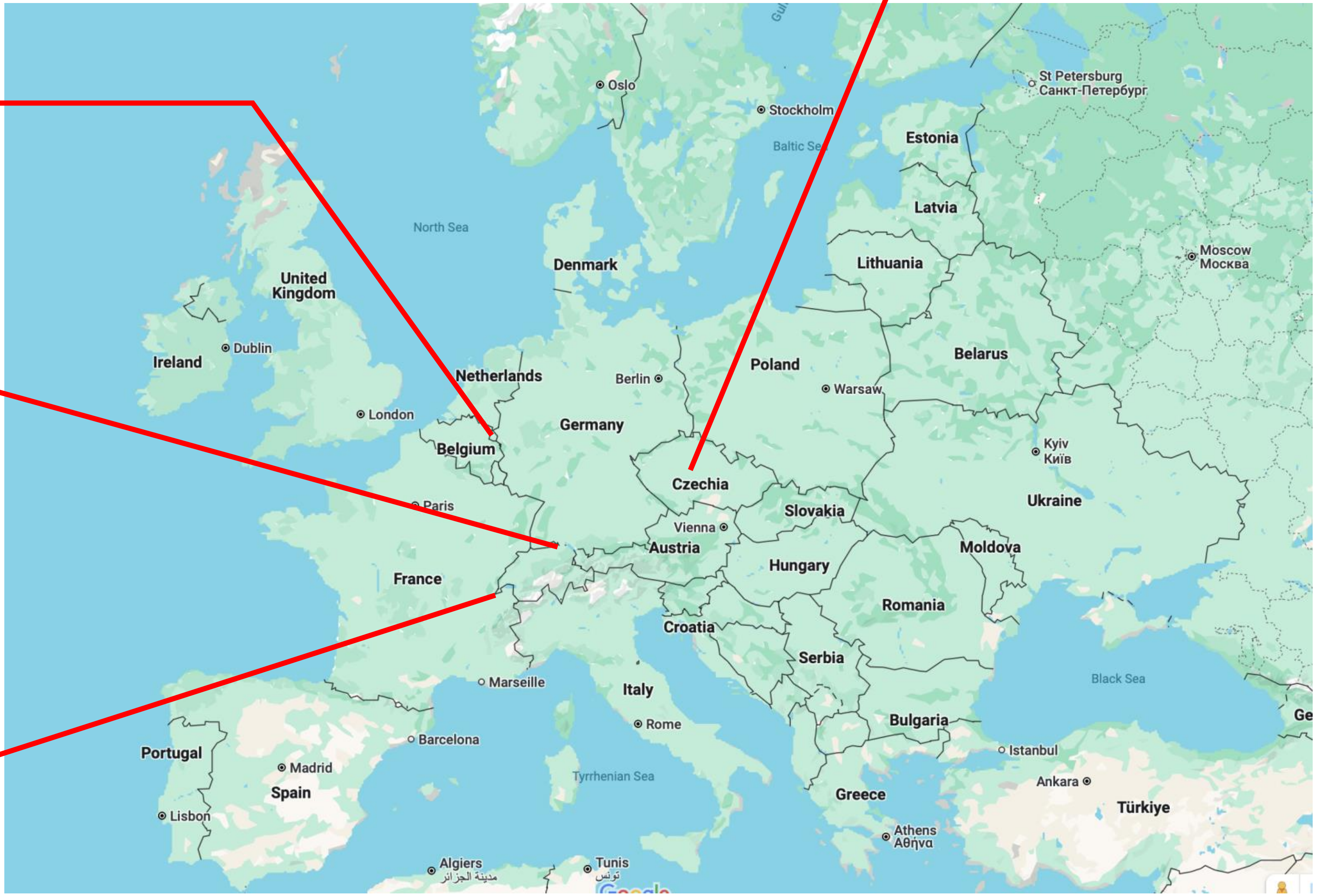
(some) Workplaces in Europe

ELI Beamlines
Dolní Břežany, Czech Republic
Workplace radiation field

Maastro
Maastricht, Netherlands
Workplace radiation field

HE neutron test facility at PSI
Villigen, Switzerland
Simulated workplace radiation field

CERN facilities
Geneva, Switzerland



(some) CERN workplace radiation fields

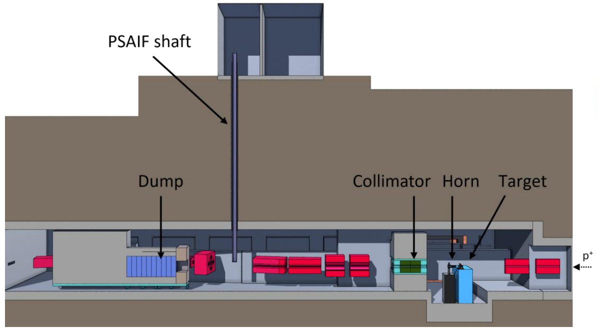
CERF

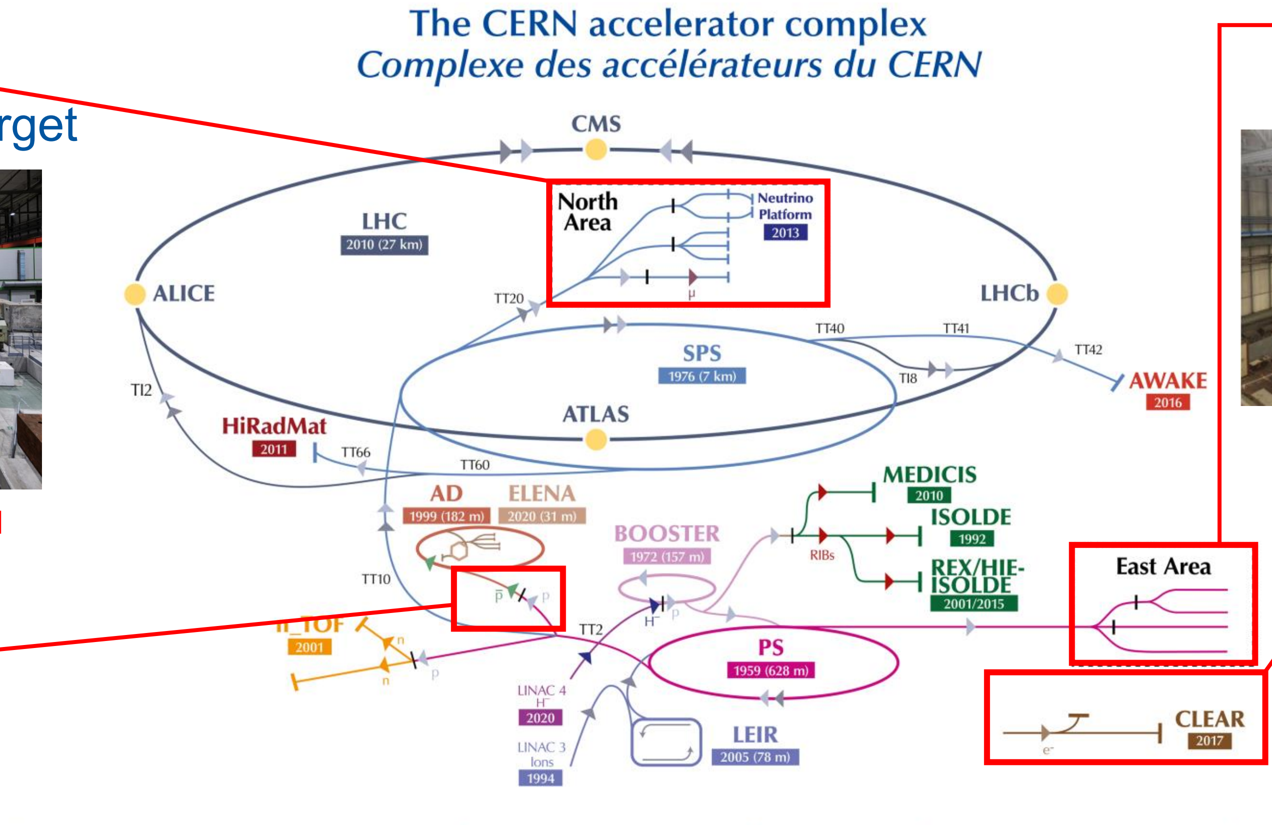
120 GeV/c p+/π+ on Cu target

Simulated workplace radiation field

PSAIF

26 GeV/c p+ on Ir target





▶ H^- (hydrogen anions) ▶ p (protons) ▶ ions ▶ RIBs (Radioactive Ion Beams) ▶ n (neutrons) ▶ $\bar{p}$ (antiprotons) ▶ e^- (electrons) ▶ μ (muons)

LHC - Large Hadron Collider // SPS - Super Proton Synchrotron // PS - Proton Synchrotron // AD - Antiproton Decelerator // CLEAR - CERN Linear Electron Accelerator for Research // AWAKE - Advanced WAKefield Experiment // ISOLDE - Isotope Separator OnLine // REX/HIE-ISOLDE - Radioactive EXperiment/High Intensity and Energy ISOLDE // MEDICIS // LEIR - Low Energy Ion Ring // LINAC - LINear ACcelerator // n_TOF - Neutrons Time Of Flight // HiRadMat - High-Radiation to Materials // Neutrino Platform

CSBF

24 GeV/c p+ on Cu/Al targets

Simulated workplace radiation field

CLEAR

200 MeV e- on beam dump

Pulsed radiation field (not a workplace!)

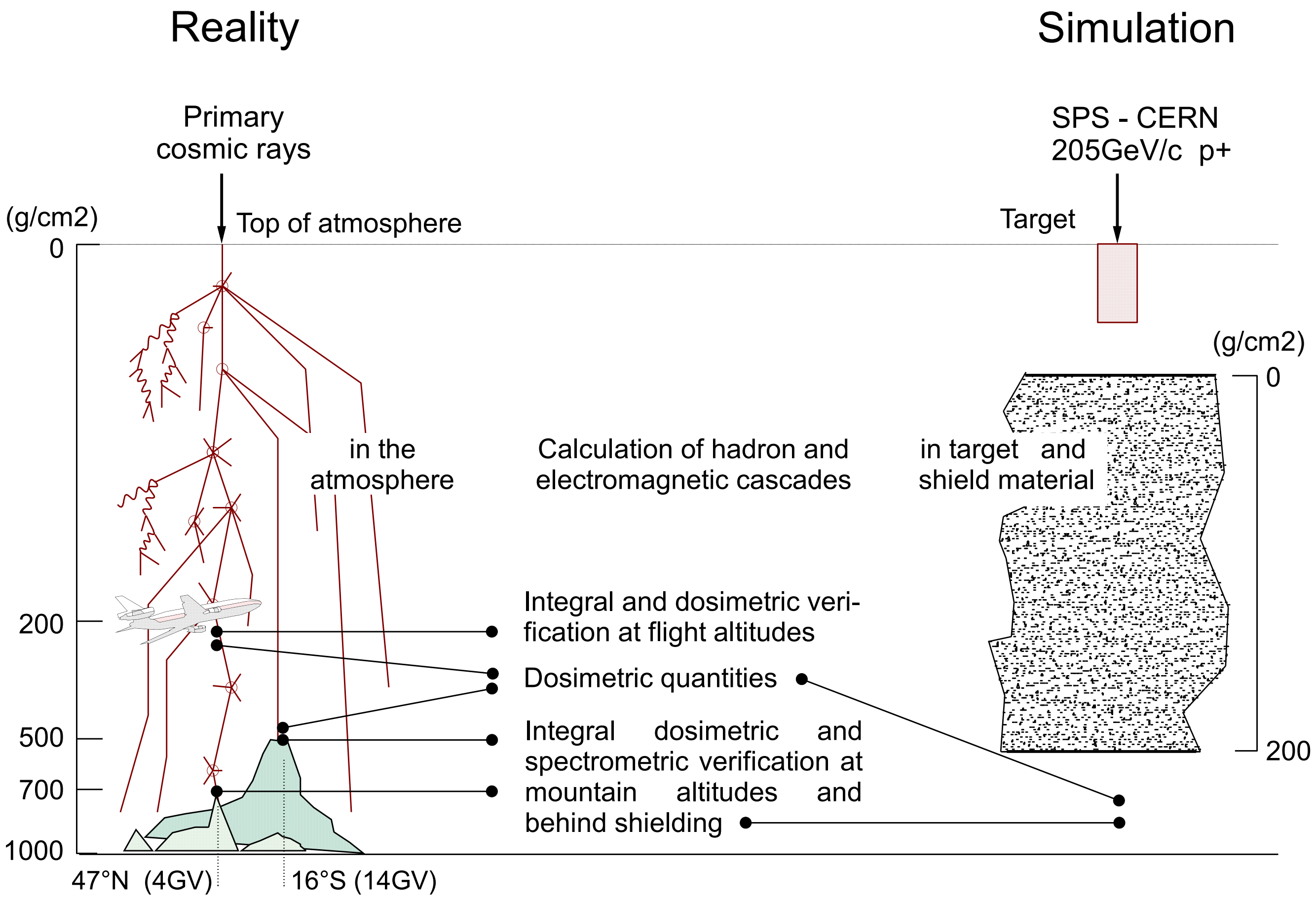
Simulated workplace radiation fields: CERF, CSBF, PSAIF and HE neutron test facility at PSI

The CERN-EU high-energy Reference Field (CERF) facility: New FLUKA Ference values of spectral fluences, present and newly proposed operational quantities, Pozzi and Silari, Nucl. Instrum. Methods Phys. Res., A 079 (2020)

CERF: why?

CERN-**EU** high-energy **R**eference **F**ield

Simulated workplace field for RP instrumentation used at **high-energy particle accelerators** and for detectors and dosimeters used for **aircrew dosimetry**


Reality

Simulation

Primary cosmic rays

Top of atmosphere

SPS - CERN 205GeV/c p+

Target

in the atmosphere

Calculation of hadron and electromagnetic cascades

in target and shield material

Integral and dosimetric verification at flight altitudes

Dosimetric quantities

Integral dosimetric and spectrometric verification at mountain altitudes and behind shielding

CERF: what?

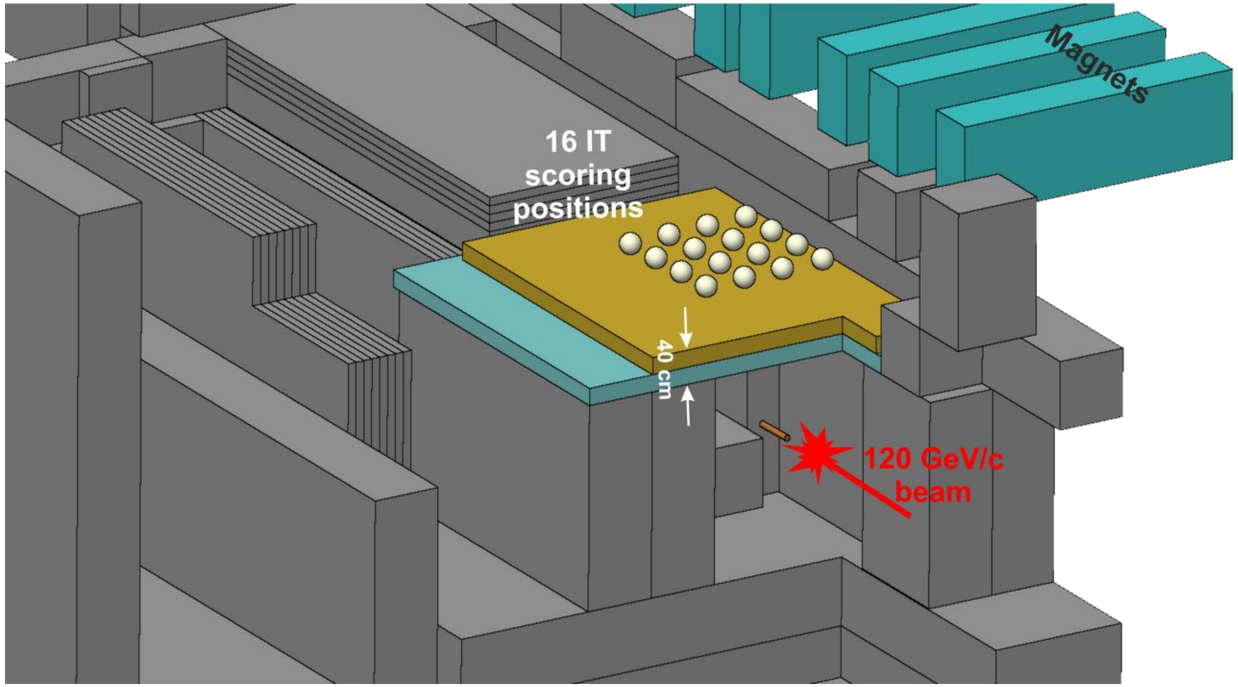
North Experimental Area

CERF concrete top (CT)

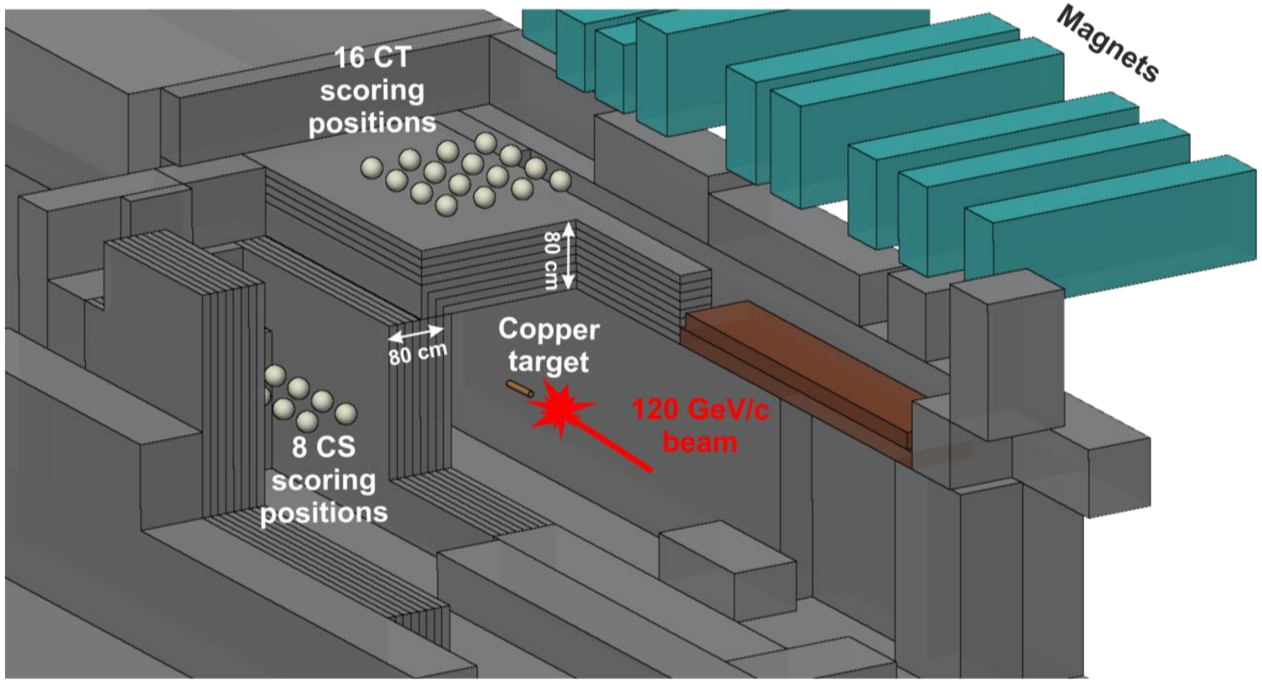
CERF target area

Particle	2/3 π+ and 1/3 p+
Momentum	120 GeV/c
Beam intensity	10^6 – 10^8 positive hadrons per extraction (~5 s)
H*(10)	10 – 300 μSv/h
Target	Copper

CERF: FLUKA model

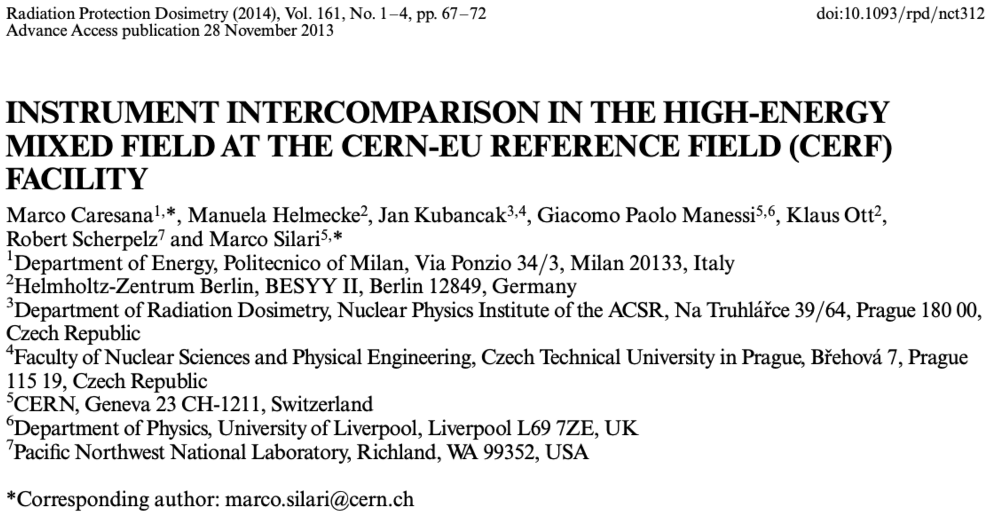


Cross sectional view of the ***iron location***



Cross sectional view of the ***concrete location***

CERF: intercomparison campaigns



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doi:10.1093/rpd/nct312

INSTRUMENT INTERCOMPARISON IN THE HIGH-ENERGY MIXED FIELD AT THE CERN-EU REFERENCE FIELD (CERF) FACILITY

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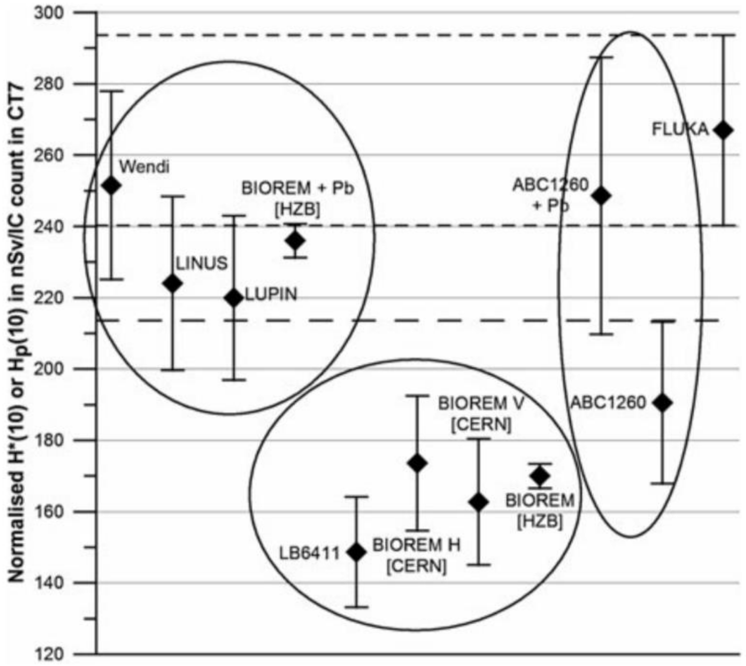
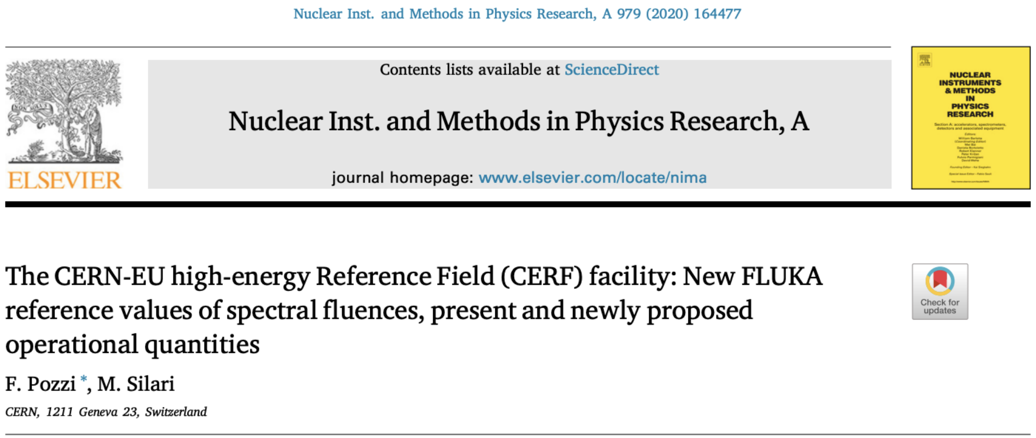


Figure 1. Comparison between the $H^*(10)$ values measured by the extended range rem counters (left), conventional rem counters (centre) and the ABC 1260 detector (right). The reference value derived from FLUKA simulations is also shown, together with the $\pm 1\sigma$ (small dashed line) and the $\pm 2\sigma$ deviations (big dashed line).

Some highlights

- *Extensive **RP instrument intercomparison** campaign*
- *Satisfactory **agreement** with **former FLUKA reference** values (back to 1992)*

CERF: characterisation and benchmark



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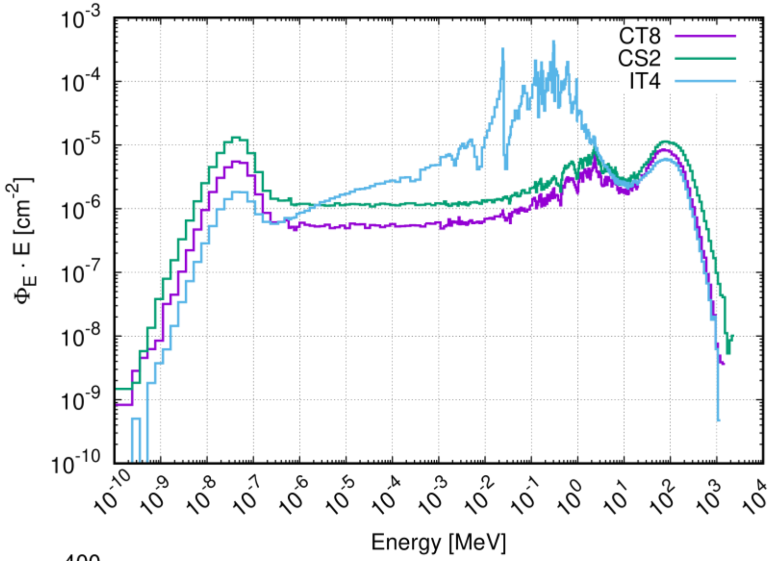
Nuclear Inst. and Methods in Physics Research, A

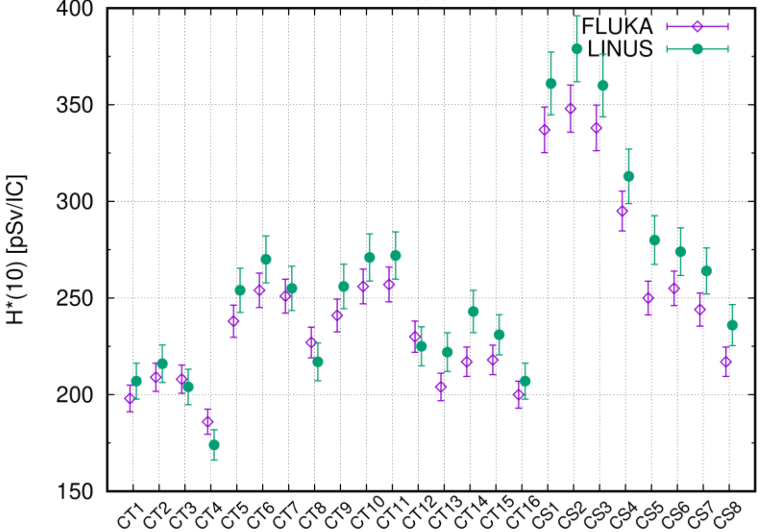
journal homepage: www.elsevier.com/locate/nima

The CERN-EU high-energy Reference Field (CERF) facility: New FLUKA reference values of spectral fluences, present and newly proposed operational quantities

F. Pozzi *, M. Silari

CERN, 1211 Geneva 23, Switzerland

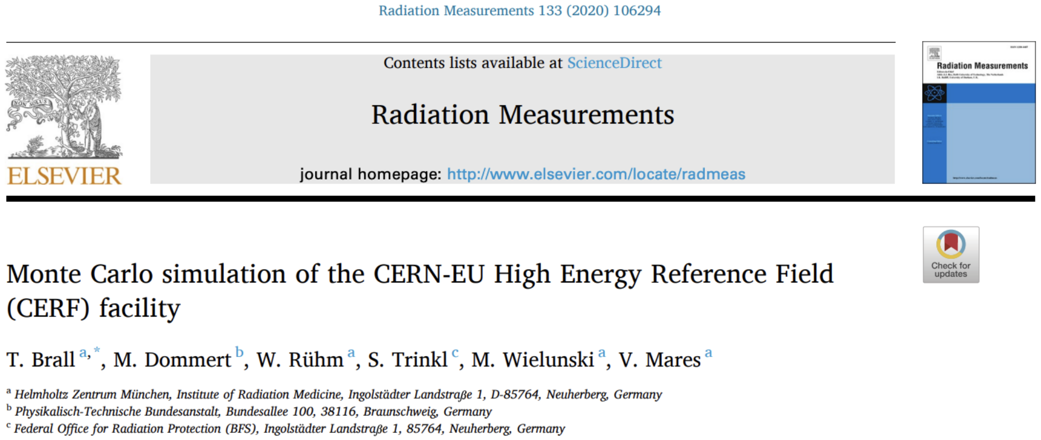




Some highlights

- *Results from the **latest FLUKA version** at that time (FLUKA2011 Version2x.2/4)*
- *Extensive **H*(10) benchmark** with measurements from **LINUS extended-range rem-counter***

CERF: Monte Carlo intercomparison



Radiation Measurements 133 (2020) 106294

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Monte Carlo simulation of the CERN-EU High Energy Reference Field (CERF) facility

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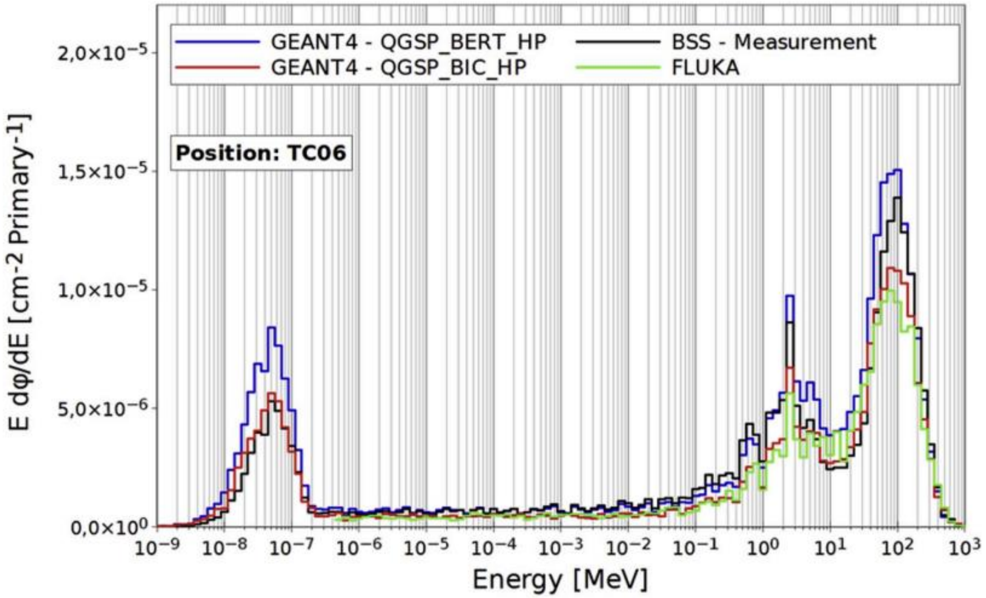


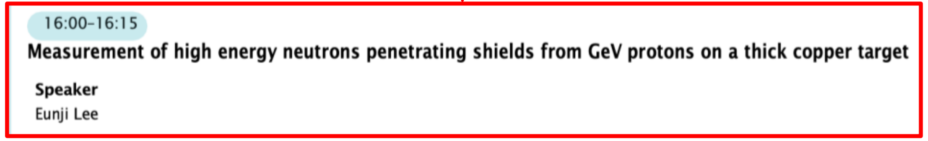
Fig. 4. Neutron energy spectra for pos. 6 on top of the concrete roof (TC06), simulated with GEANT4 (two physics lists) and compared to the re-binned FLUKA reference spectrum (http://tis-div-rp-cerf.web.cern.ch/tis-div-rp-cerf).

Some highlights

- *A **first approach** in the direction of **Monte Carlo code intercomparison** (GEANT4, FLUKA) although not the same geometry/materials*
- ***Good agreement** among **Monte Carlo codes** and **measurements for integral quantities** (H*(10))*

Energy spectra of neutrons penetrating concrete and steel shielding blocks from 24 GeV/c protons incident on thick copper target, Lee et al., Nucl. Instrum. Methods Phys. Res., A 998 (2021)

See also E. Lee's talk


16:00-16:15

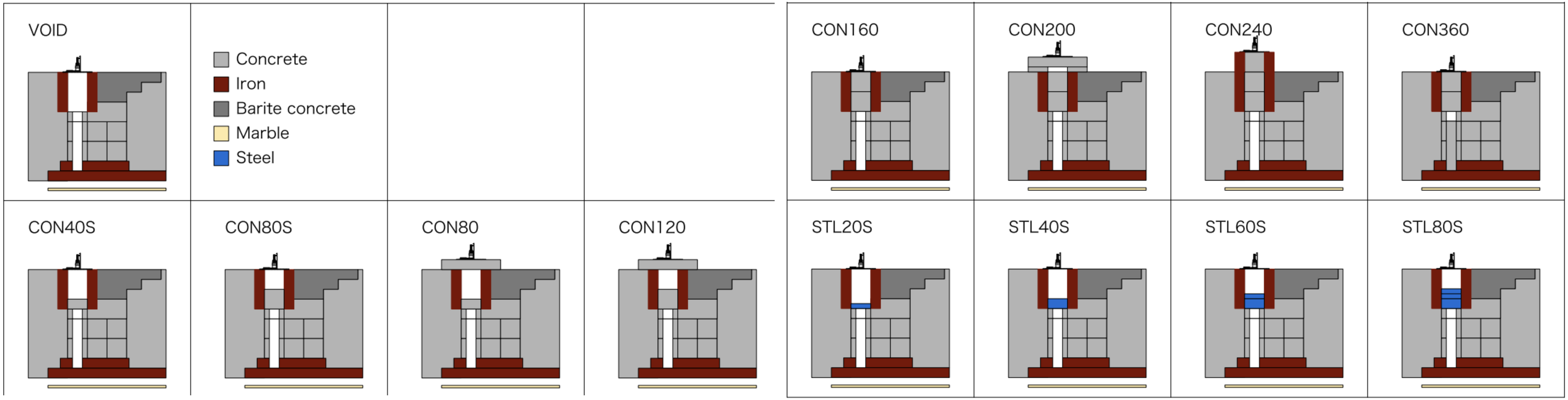
Measurement of high energy neutrons penetrating shields from GeV protons on a thick copper target

Speaker
Eunji Lee

CSBF: why?

CERN **S**hielding **B**enchmark **F**acility

A facility dedicated to **testing** and **validating radiation shielding materials**, as well as **benchmarking Monte Carlo simulation codes** in scenarios involving **thick shielding** of **variable thickness**.
It supports a range of shielding configurations using different materials and thicknesses.



CSBF: what?

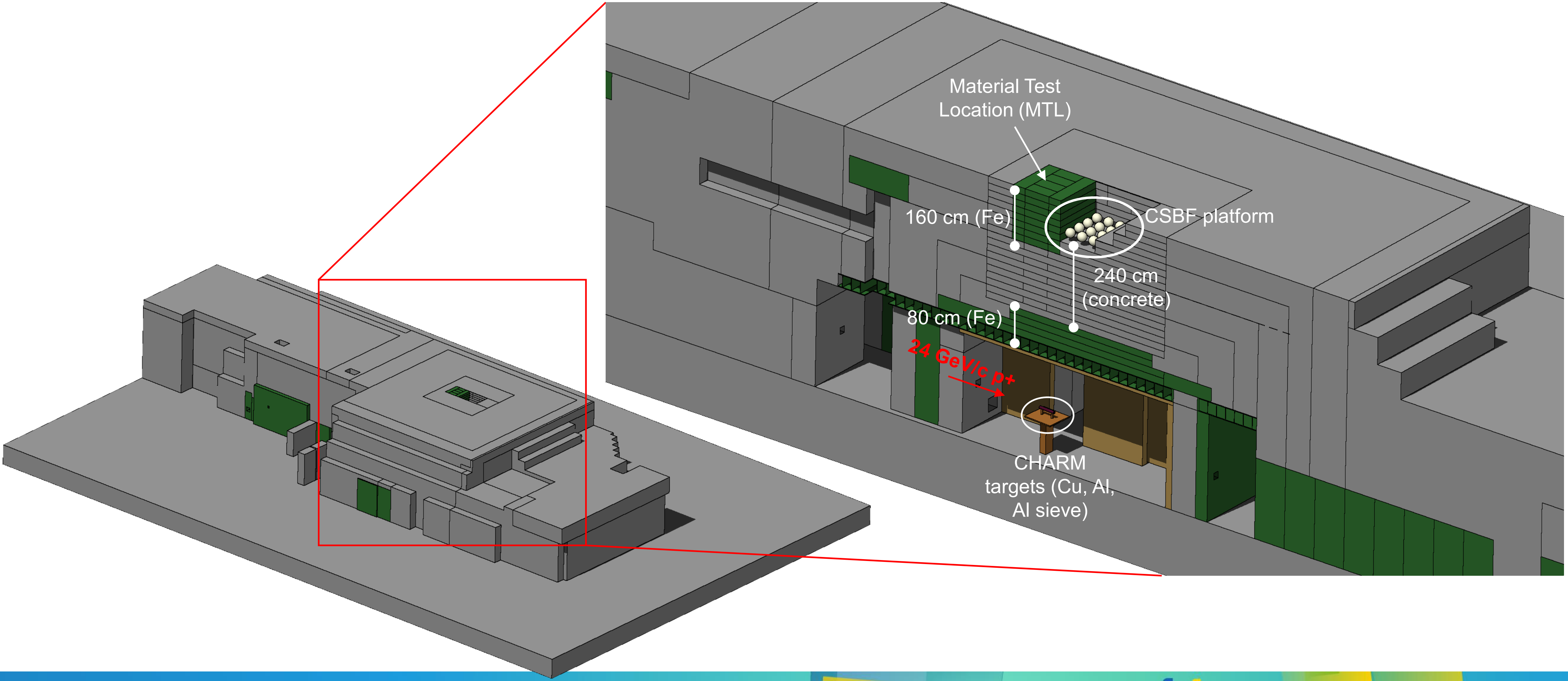
Target holder

Material Test Location

CSBF platform

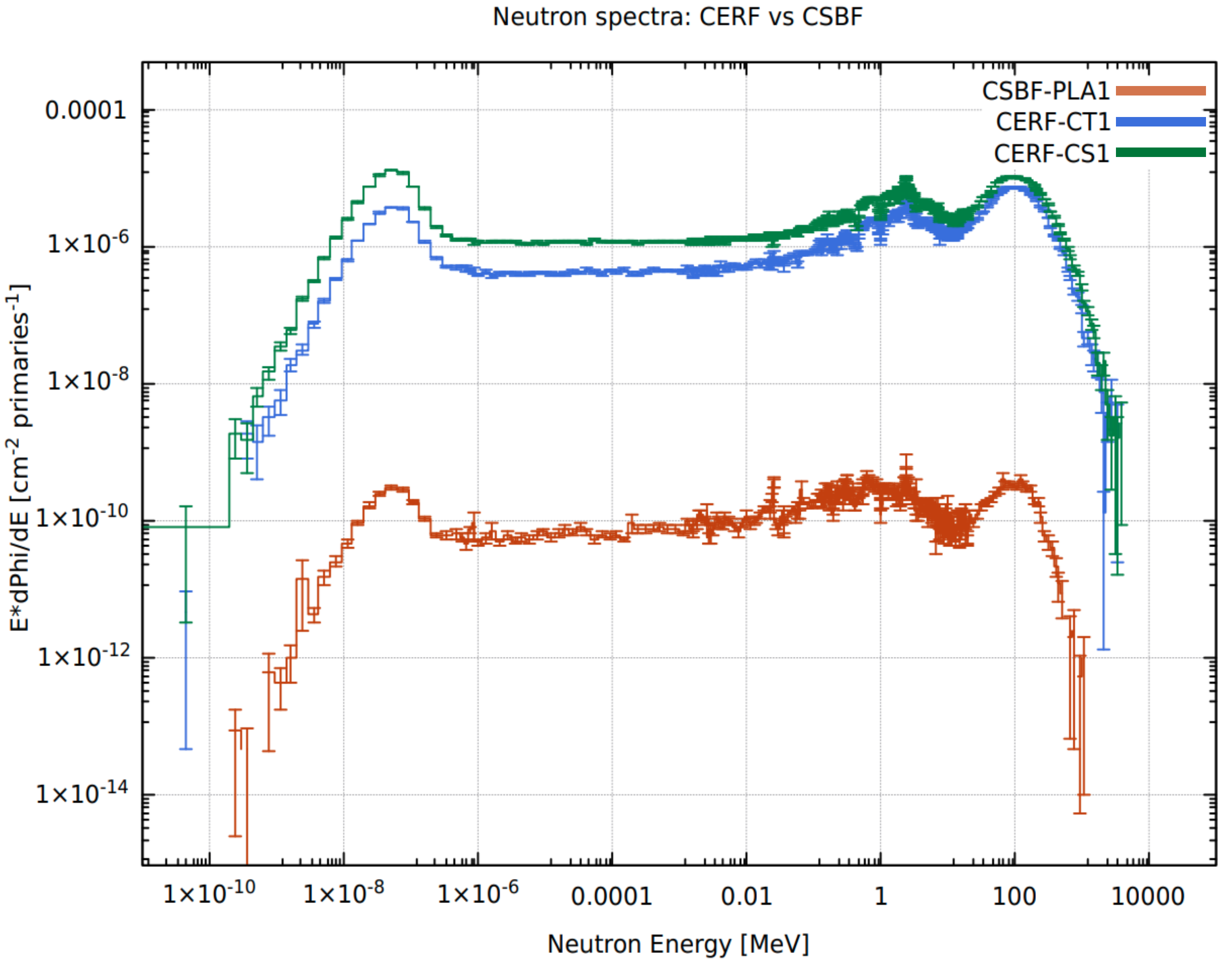
Particle	p+
Momentum	24 GeV/c
Beam intensity	10^{10} – 10^{11} protons per extraction (400 ms)
H*(10)	10-100 μSv/h
Target	Copper, aluminum and aluminum sieve

CSBF: FLUKA model

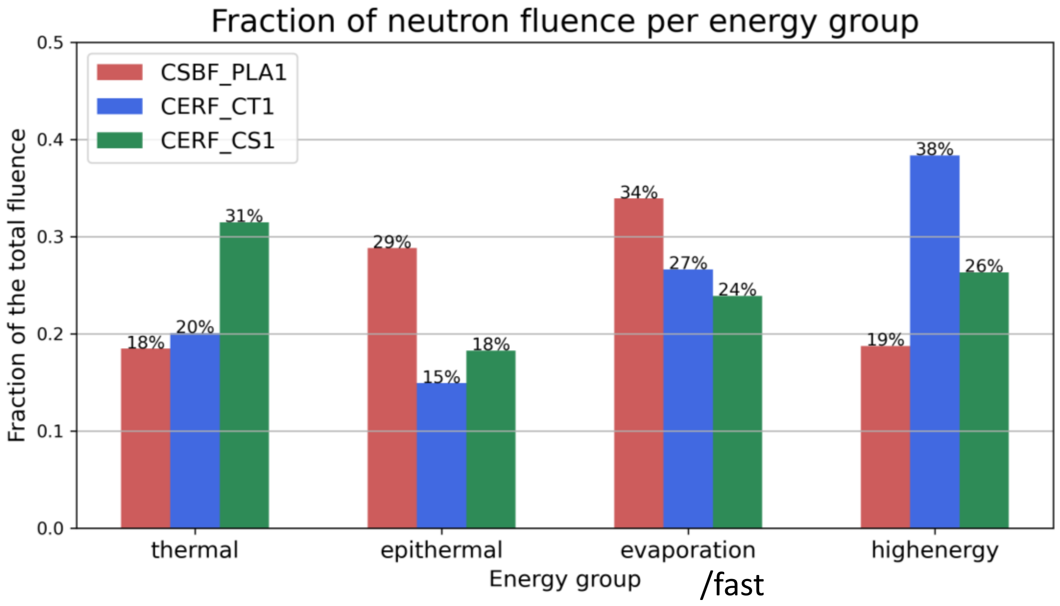


CERF simulations: FLUKA2011 Version 2x.2
CSBF simulations: FLUKA hosted by CERN Version 4-3.0

CSBF and CERF: integral fluence

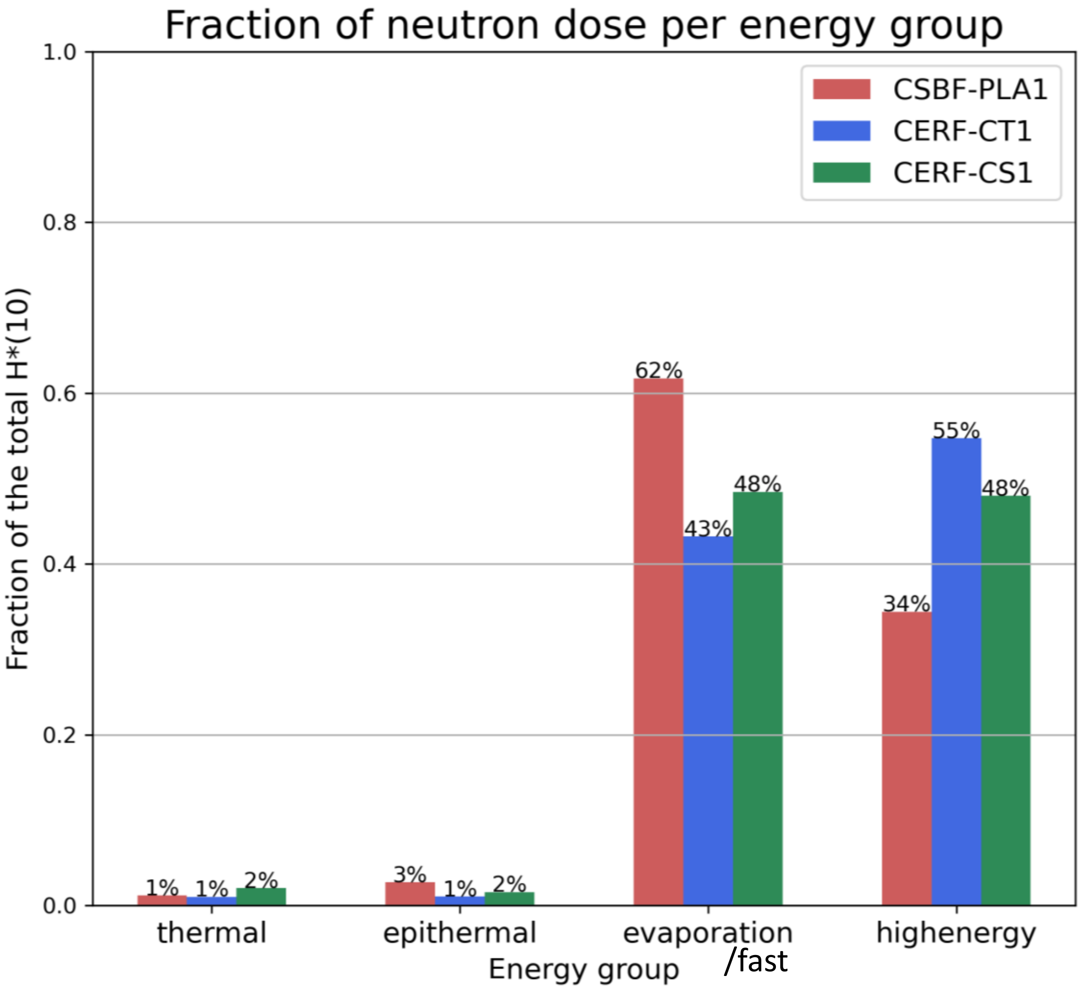


Energy groups	E_{min}	E_{max}
Thermal	0.01 meV	0.5 eV
Epithermal	0.5 eV	100 keV
Evaporation/fast	100 keV	20 MeV
High energy	20 MeV	100 GeV



CERF simulations: FLUKA2011 Version 2x.2
CSBF simulations: FLUKA hosted by CERN Version 4-3.0

CSBF and CERF: neutron H*(10)



Energy groups	E_{min}	E_{max}
Thermal	0.01 meV	0.5 eV
Epithermal	0.5 eV	100 keV
Evaporation/fast	100 keV	20 MeV
High energy	20 MeV	100 GeV

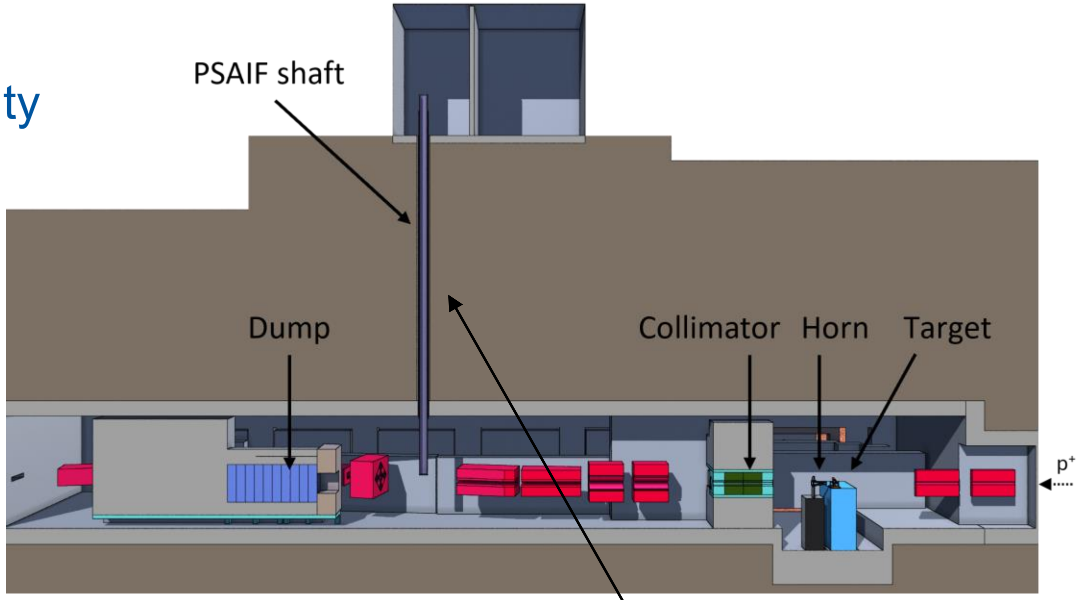
- On the **CSBF** platform most dose is coming from **evaporation/fast** neutrons (62%).
- At **CERF** (both concrete top and concrete side) most dose is coming **high energy** neutrons.

Facility	Neutron H*(10) rate[1]
CSBF_PLA1	119.2 uSv/h
CERF_CT1	145.3 uSv/h
CERF_CS1	246.6 uSv/h

[1] Calculated with the highest beam intensity available and spill frequency given in slide 8

PSAIF at CERN

PS-AD Irradiation Facility



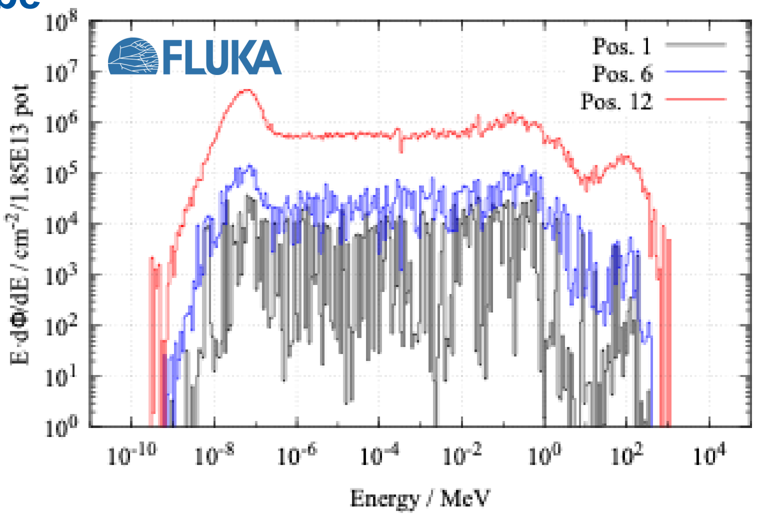
Highlights

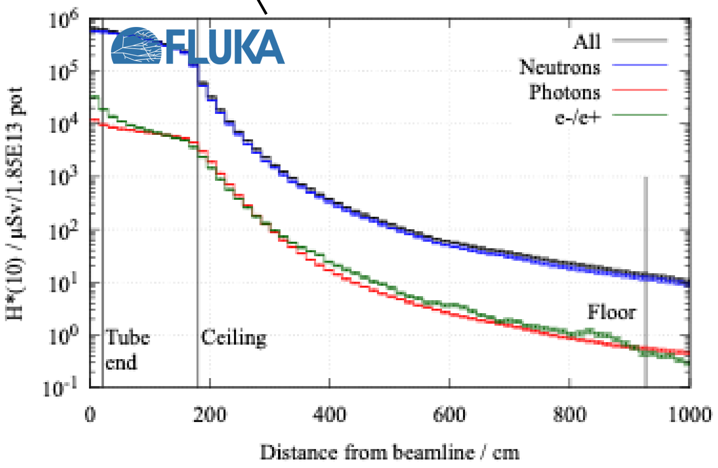
- **Used** as **simulated workplace** radiation field
- **Characterisation** ongoing (Monte Carlo simulations (FLUKA), passive dosimeters, ionization chambers)
- **Neutron dominated** radiation field (87 % to H*(10))
- **Pulsed field, low repetition rate**

Metrology relevant aspects

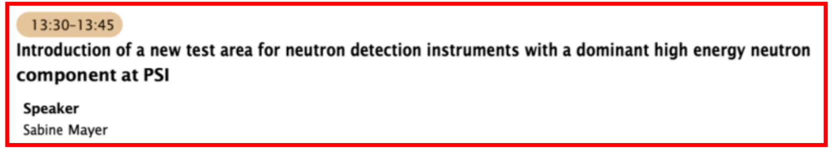
- **Availability** (parasitic to accelerator operation)
- **Neutrons scattered along the PSAIF tube**
- **Wide dose range**
- **Tube diameter ~20 cm**

Particle	p+
Momentum	26 GeV/c
Current	1.8 x 10^{13} every 100s (5 pulses, 8 ns long spaced over ~500 ns)
H*(10)	10 – 10^5 μSv/beam pulse
Target	Iridium





See also S. Mayer's talk


13:30–13:45

Introduction of a new test area for neutron detection instruments with a dominant high energy neutron component at PSI

Speaker

Sabine Mayer

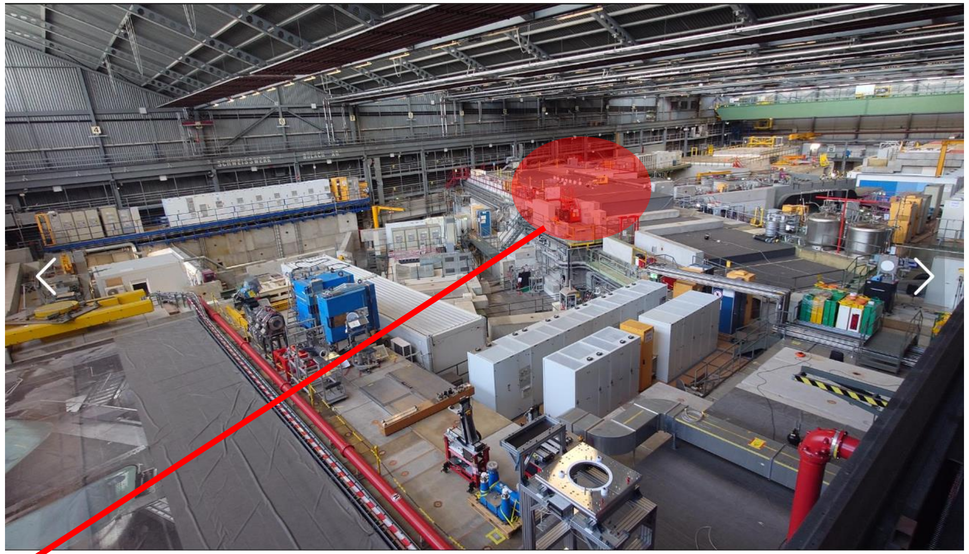
HE neutron test area at PSI

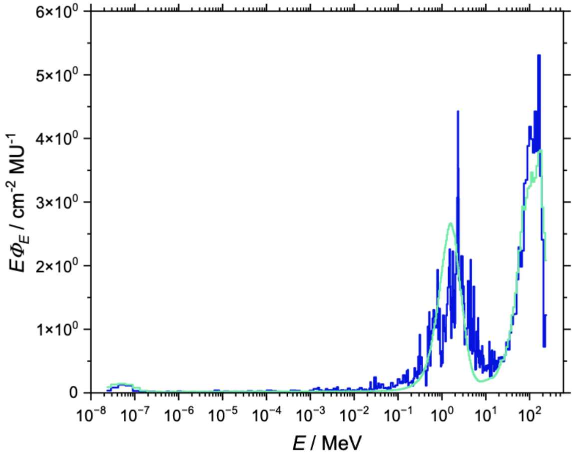
Highlights

- **Used** as **simulated workplace** radiation field (similar to CERF)
- **Extensive characterisation** ongoing (BSS, rem-counters, Monte Carlo simulations), including photon field (!)

Metrology relevant aspects

- **Availability** (mainly parasitic to accelerator operation)
- **Reference instrument** and its traceability
- **Characterisation** procedures / **intercomparisons**
- **Monte Carlo** modelling (geometry and materials)





Particle	p+
Energy	590 MeV
Current	2 mA (~continuous beam)
H*(10)	1-10 μSv/h (>50% due to HE neutrons)
Target	Graphite

Metrology aspects and challenges

Metrology aspects and challenges

Operational constraints

- Beamtime/facility availability often limited
- **Beam availability** dependent on the operational reliability of the accelerator (technical issues may lead to reduced or cancelled shifts)
- Limited **resources** (best-effort support by groups in charge)
- Not available during shutdowns of accelerator (e.g. 1-3 years every ~10 years for Long Shutdowns at CERN)

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Additional sources of uncertainties

- Shielding material composition → huge effort for **material characterisation** (chemical composition, thickness, density)
- **Calibration** of **beam monitors** for their use with high-energy beams*

*Single- and multi-foils 27Al(p,3pn)24Na activation technique for monitoring the intensity of high-energy beams, *Curioni et al., Nucl. Instrum. Methods Phys. Res., A 858 (2017)*

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Characterisation: Monte Carlo

- Can **Monte Carlo** be used to provide **reference** values?
- If yes, **which Monte Carlo code** (combination of results from more MC codes)?
- **Re-characterise** every time that major improvements are introduced in the reference code
- **Radiation field characterisation** would benefit from a **Monte Carlo intercomparison exercise**

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Characterisation: measurements

- Which **reference instrument** (traceability)?
- Lack of **standardized measurement protocol**
- **Benchmark campaigns** (rem-counters, passive/active dosimeters, foil activation)
- Centralized **collection** of **results** from **measurement** campaigns

Single- and multi-foils 27Al(p,3pn)24Na activation technique for monitoring the intensity of high-energy beams, Curioni et al., Nucl. Instrum. Methods Phys. Res., A 858 (2017)*

Measurements in workplace radiation fields: Maastro, ELI beamlines and (CLEAR)

EURADOS rem-counter intercomparison at Maastro proton therapy centre: comparison with literature data, Zorloni et al., Radiat. Prot. Dosim. 198 (2022)

Maastro

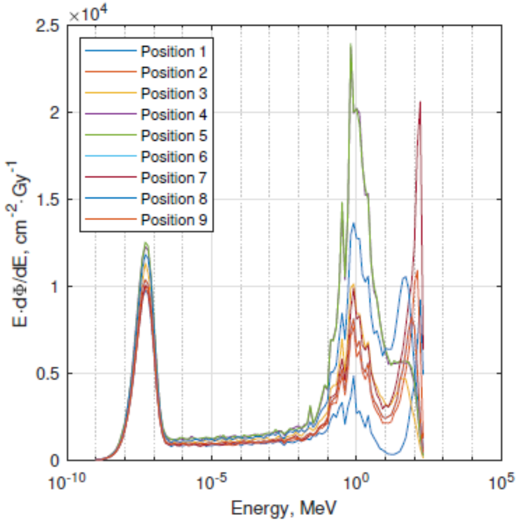
Highlights EURADOS

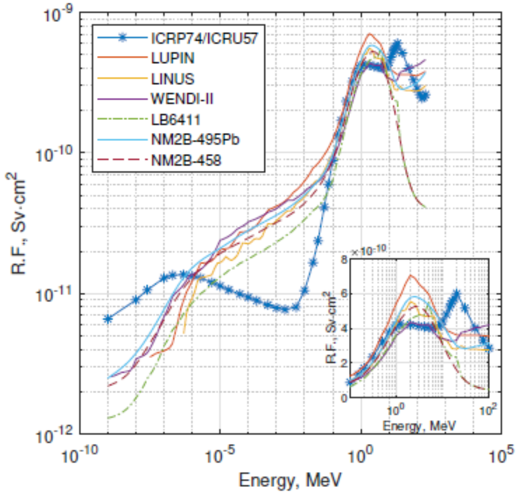
- **EURADOS intercomparison** campaign in **proton therapy** centre (secondary **pulsed** neutron dose)
- Mevion S250i Hyperscan (pencil-beam pulsed synchrocyclotron)
- **Rem-counter linearity issue** > **tens** of **nSv/pulse**

How could HE neutron metrology have helped the campaign?

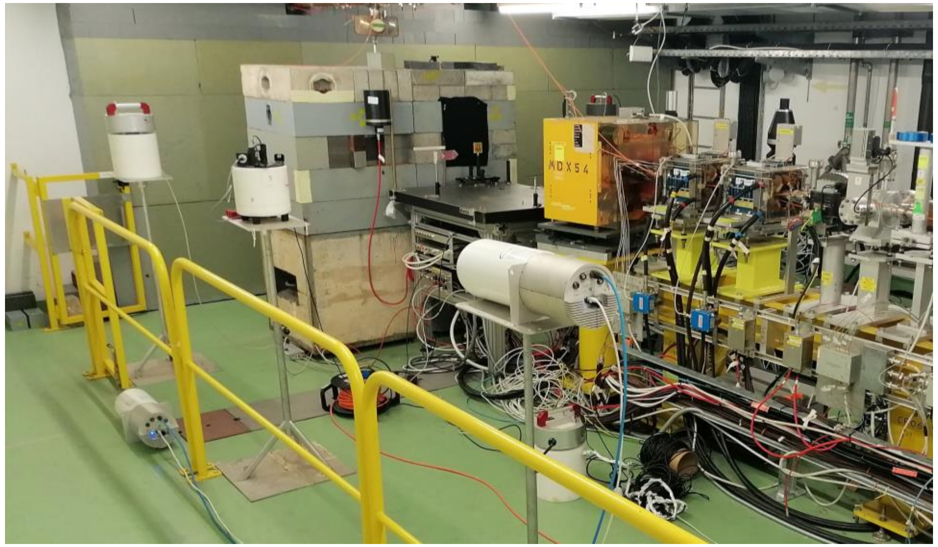
- **Traceability/availability**: simulated workplace not existing for proton therapy centres
- **Protocol** for radiation field **characterisation**

Particle	p+
Energy	227 MeV (energy degradation to yield the required clinical volume)
Pulse width	10 µs
Repetition frequency	Max. 750 Hz (1 pulse every 1.3 ms)
Charge per pulse	Up to 8 pC/pulse
Dose per pulse	Up to 200 nSv/pulse
Target(s)	Polycarbonate plates (energy degrader) Nickel allowy multi-leaf collimator system Water phantom ("patient")





CLEAR CERN **L**inear **E**lectron **A**ccelerator for **R**esearch



Highlights

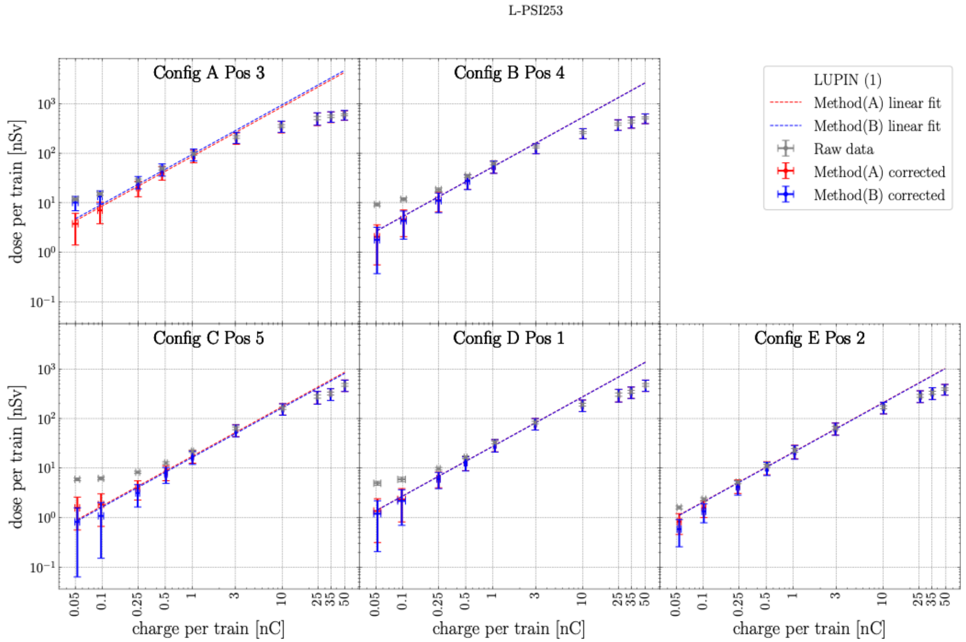
- **EURADOS intercomparison** in realistic **pulsed and mixed radiation** field (active and passive detectors)
- Several **challenges** encountered: *a priori* unknown beam losses, dark current, beam stability, detector set-up complexity

How could HE neutron metrology have helped the campaign?

- **Test/in-field calibration** of detectors in known and well-characterised pulsed radiation environment (**traceability** and reduced uncertainty)
- **Comparing** detector **performances prior to deployement** → better understanding of measurement results (early indentification of anomalous behaviours)
- Benefit of established **measurement protocols** specific to pulsed neutron fields

Particle	e-
Energy	200 MeV
Repetition frequency	0.83 – 10 Hz
Charge per train	0.2 – 75 nC/train (0.1 ps – 100 ns)
Dose per train	Up to ~1 mSv/train
Target(s)	Two beam dumps + ad-hoc target design

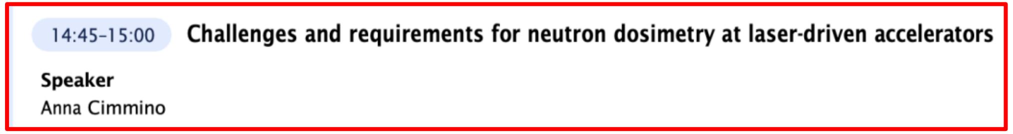
} Pulsed radiation field!



Neutron dose assessment in laser-generated ultra-short pulsed fields, *Olšovcová et al., Radiat. Prot. Dosim. 199 (2023)*

ELI Beamlines experience

See also A. Cimmino's talk


14:45-15:00 **Challenges and requirements for neutron dosimetry at laser-driven accelerators**

Speaker
Anna Cimmino

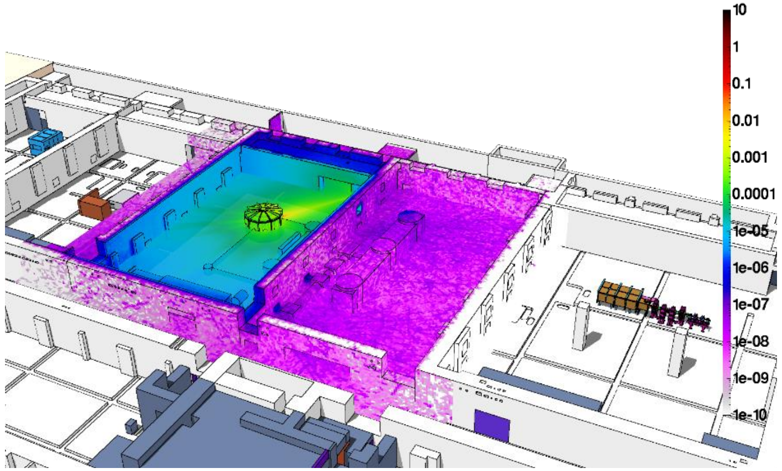
Considerations

- **Active measurements** (necessary for operational **radiation protection** and **MC validation**) very challenging in UH intensity laser facility:
  - **fs-ps pulse** duration
  - **reproducibility**
- **Lack of standards** for **laser-driven facilities** and of **simulated workplace** radiation fields
- Monte Carlo relies on (among others) to the knowledge of the source term (**laser-target interaction**) → **still subject of research**

EURADOS

EURADOS has recently started a task to address this topic (coordinated effort!)

Particle	Laser-driven (e- up to tens of GeV and p+ up to hundreds of MeV)
Laser Power	Up to 10 PW
Pulse width	fs-ps
Repetition frequency	Up to 1 kHz
Target(s)	Examples: vanadium, copper and iron (thin targets)



New metrology challenges: the new ICRU/ICRP operational quantities

ICRU 2020. Operational Quantities for External Radiation Exposure, ICRU Report 95. J. ICRU 20(1)
ICRU Report 95: New operational quantities for external radiation exposure, Otto, ICRP 2021 Proceeding (2023)

ICRU Report 95: new operational quantities

Main aspects

- Current **operational quantities** (*Hp(10)* and *H*(10)*, ICRU Report 51) provide **approximate values for E**
- **ICRU** evaluated alternatives and agreed on *Hp(α)* and ***H****
- **New operational quantities** provide a **better estimate** of the **protection quantities**

→ **over/underestimation** (e.g. at high radiation field energies)

→ **ICRU** Report **95** (2020)

→ **H*** contains a **maximisation** of the quantity value over the direction of incidence


Volume 20 • Number 1 • 2020

Journal of the ICRU

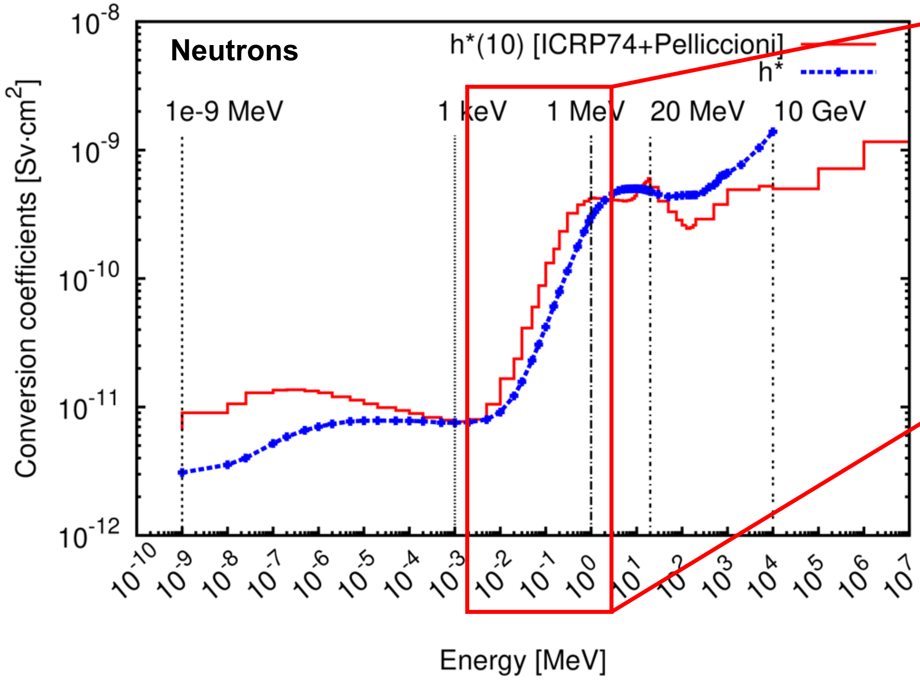
ICRU REPORT 95

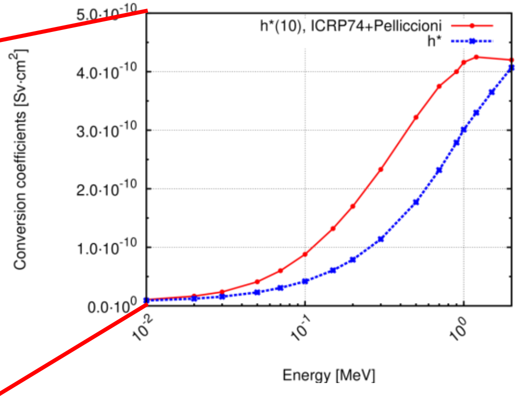
Operational Quantities for External Radiation Exposure

ICRP

journals.sagepub.com/home/icru
ISSN: 1473-6691

INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS

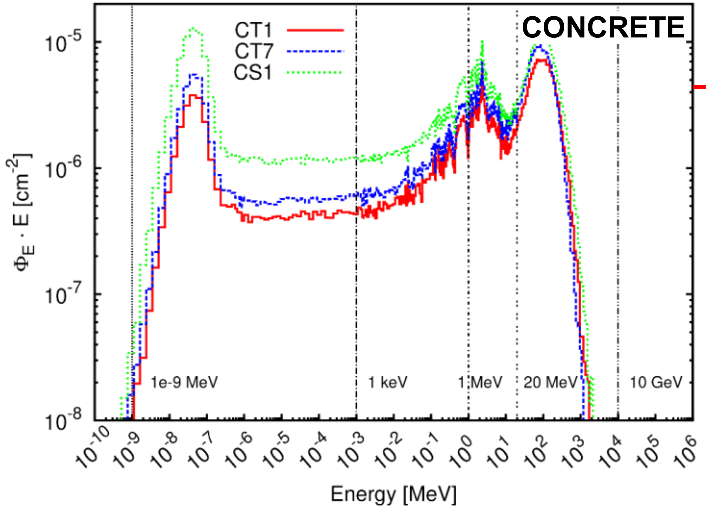




Which impact on simulated workplace radiation fields?

Impact of the newly proposed ICRU/ICRP quantities on neutron calibration fields and extended range neutron rem-counters, Pozzi et al., J. Radiol. Prot. 39 (2020)

H*(10) and H* at CERF



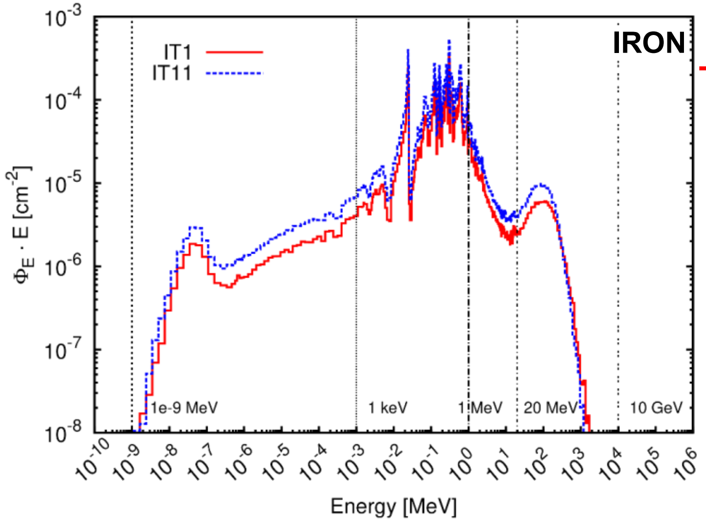
From fluence to ambient dose (equivalent)

Position	H*(10) [nSv/IC]	H* [nSv/IC]	H*/H*(10)
CT1	0.199	0.226	1.14
CT7	0.251	0.279	1.11
CS1	0.337	0.370	1.10

Contribution to ambient dose (equivalent) by energy range

Emin	Emax	CT1		CT7		CS1	
MeV	MeV	H*(10)	H*	H*(10)	H*	H*(10)	H*
10^{-9}	10^{-3}	1%	1%	2%	1%	3%	1%
10^{-3}	1	11%	6%	11%	6%	14%	7%
1	20	33%	30%	34%	31%	36%	33%
20	10^{4}	55%	64%	53%	62%	48%	59%

Contribution from HE neutrons +20%



From fluence to ambient dose (equivalent)

Position	H*(10) [nSv/IC]	H* [nSv/IC]	H*/H*(10)
IT1	1.365	0.904	0.67
IT11	2.254	1.468	0.65

Contribution to ambient dose (equivalent) by energy range

Emin	Emax	IT1		IT11	
MeV	MeV	H*(10)	H*	H*(10)	H*
10^{-9}	10^{-3}	<1%	<1%	<1%	<1%
10^{-3}	1	76%	62%	77%	64%
1	20	17%	24%	16%	23%
20	10^{4}	7%	14%	7%	13%

Contribution from neutrons 1 keV – 1 MeV –20%
Contribution from HE neutrons +100%

Impact of the newly proposed ICRU/ICRP quantities on neutron calibration fields and extended range neutron rem-counters, *Pozzi et al., J. Radiol. Prot. 39 (2020)*

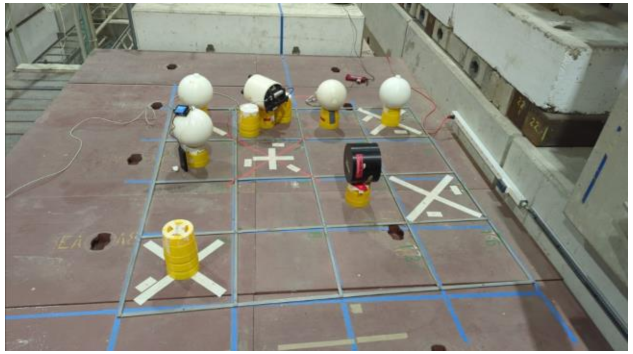
Impact on HE neutron metrology?

Most extended-range rem-counters do **not require** design **changes** for use outside particle accelerator shielding (concrete) or on-board aircraft (aircrew dosimetry)

How will the WENDI-II look like in the ICRU 95 era?

A r**e-characterisation (Monte Carlo + measurements)** of (simulated) workplace radiation field is likely to be **required**
Opportunity to **align characterization protocols** among different workplace?

In-field calibration may be **required** for detectors used in radiation fields with **very peculiar neutron energy distribution** (e.g. outside iron shielding at particle accelerators)



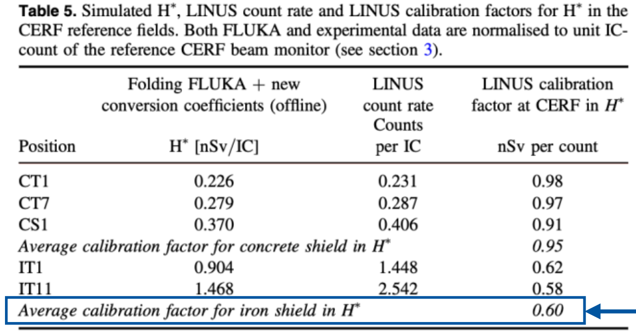


Table 5. Simulated H*, LINUS count rate and LINUS calibration factors for H* in the CERF reference fields. Both FLUKA and experimental data are normalised to unit IC-count of the reference CERF beam monitor (see section 3).

Position	Folding FLUKA + new conversion coefficients (offline) H* [nSv/IC]	LINUS count rate Counts per IC	LINUS calibration factor at CERF in *H** nSv per count
CT1	0.226	0.231	0.98
CT7	0.279	0.287	0.97
CS1	0.370	0.406	0.91
*Average calibration factor for concrete shield in H**			*0.95*
IT1	0.904	1.448	0.62
IT11	1.468	2.542	0.58
*Average calibration factor for iron shield in H**			*0.60*

CF (H*, AmBe) = 0.97 nSv/count

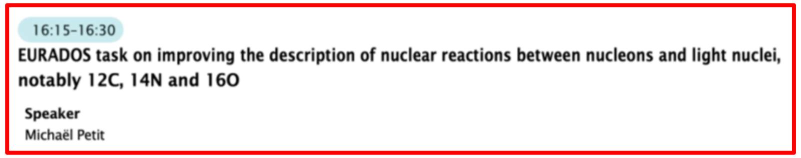
Conclusions and future perspective

Conclusions and future perspectives

- Several (simulated) **HE workplace radiation fields** exist **worldwide**
  - **Workplaces presented here** are **not exhaustive!**
  - A **comprehensive catalogue or database** – similar in scope to that of Naismith and Siebert (slide 7) – would be highly **beneficial**
  - The work performed by several research groups (and presented here) is essential for:
    - **Advancing HE neutron metrology**
    - **Supporting national authorities** and regulatory bodies

Demonstrate the reliability of radiation measuring instruments in HE neutron workplace fields

- **Benchmarks** and **validation** of **Monte Carlo** codes
  - **Improving physics models** in MC codes requires active involvement from Monte Carlo code developers
    - In this respect, a task under EURADOS is ongoing (see M. Petit's talk)
  - Numerous **benchmarking activities** are already in place
    - Example: within the FLUKA collaboration, a Code Development Support WP was established in 2021 to perform benchmark exercises (some conducted at CERF)
    - How to improve a coordinated effort in this respect?



16:15-16:30

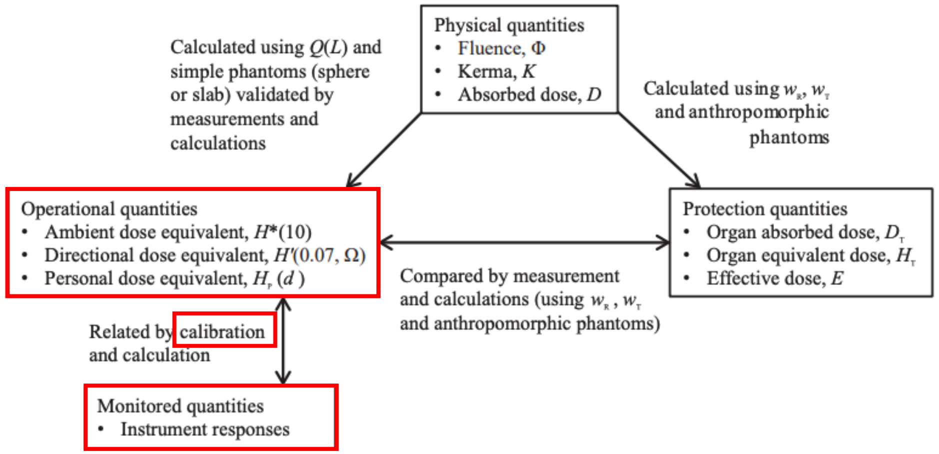
EURADOS task on improving the description of nuclear reactions between nucleons and light nuclei, notably 12C, 14N and 16O

Speaker
Michaël Petit

- **Update** and **expand ISO 12789** framework
  - Provide guidance on **characterisation procedures** for various radiation fields (HE, pulsed radiation, laser-driven facilities)
  - Detail how to **improve traceability** in radiation measurements **at workplace radiation fields**
  - Regularly update the list of available (simulated) workplace radiation (**catalogue-approach**)
  - **Include metrology** aspects resulting from the **ICRU Report 95**
  - Develop **recommendations** about **Monte Carlo code intercomparisons** (not necessarily in ISO 12789)

Back-up slide

Why a calibration?



Physical quantities
- Fluence, Φ
- Kerma, K
- Absorbed dose, D

Calculated using $Q(L)$ and simple phantoms (sphere or slab) validated by measurements and calculations

Calculated using w_R, w_T and anthropomorphic phantoms

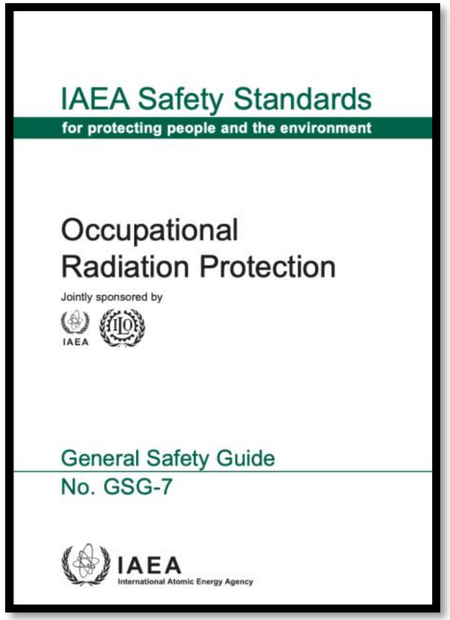
Operational quantities
- Ambient dose equivalent, $H^*(10)$
- Directional dose equivalent, $H'(0.07, \Omega)$
- Personal dose equivalent, $H_p(d)$

Protection quantities
- Organ absorbed dose, D_T
- Organ equivalent dose, H_T
- Effective dose, E

Compared by measurement and calculations (using w_R, w_T and anthropomorphic phantoms)

Related by calibration and calculation

Monitored quantities
- Instrument responses



IAEA Safety Standards
for protecting people and the environment

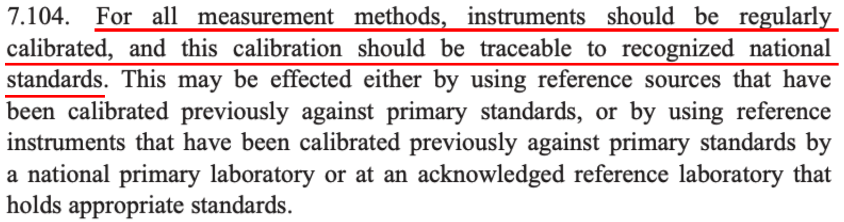
Occupational Radiation Protection

Jointly sponsored by

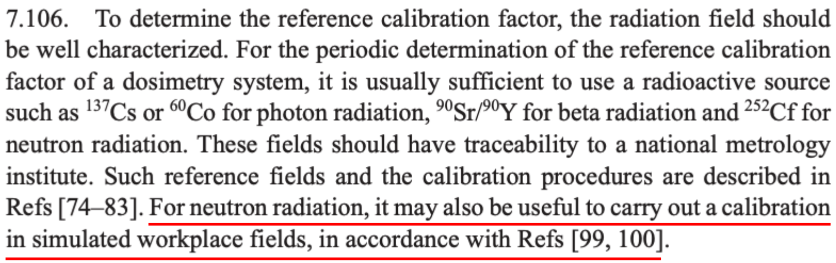
IAEA ILO

General Safety Guide
No. GSG-7

IAEA
International Atomic Energy Agency



7.104. For all measurement methods, instruments should be regularly calibrated, and this calibration should be traceable to recognized national standards. This may be effected either by using reference sources that have been calibrated previously against primary standards, or by using reference instruments that have been calibrated previously against primary standards by a national primary laboratory or at an acknowledged reference laboratory that holds appropriate standards.



7.106. To determine the reference calibration factor, the radiation field should be well characterized. For the periodic determination of the reference calibration factor of a dosimetry system, it is usually sufficient to use a radioactive source such as ^{137}Cs or ^{60}Co for photon radiation, ^{90}Sr/^{90}Y for beta radiation and ^{252}Cf for neutron radiation. These fields should have traceability to a national metrology institute. Such reference fields and the calibration procedures are described in Refs [74–83]. For neutron radiation, it may also be useful to carry out a calibration in simulated workplace fields, in accordance with Refs [99, 100].

Occupational Radiation Protection, IAEA GSG-7 (2018)