Neutron Dosimetry in the Presence of Strong Photon Radiation Fields

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Outline

- Neutron dose rates inside High Energy electron accelerators:
  - Important for radiation safety, radiation damage, activation
  - Difficult to measure due to overwhelming photon radiation
  - Monitors fail: radiation damage, high photon background
  - Passive dosimetry: lack of online monitoring capability, generally small dynamic range

- Need in the new neutron dosimetry techniques:
  - On-line monitoring
  - Insensitive to photon background
  - Large dynamic range

- The new detection system (work in progress):
  - High pressure ionization chambers filled with $^3\text{He}$ and $^4\text{He}$
  - Neutron moderator with Beryllium-loaded reflector / multiplier
  - Simulations, prototype design, preliminary results presented
Radiation Environment at Jlab (1)

- Radiation monitoring in the Experimental Halls: $\gamma$, $n$
- Prompt dose rates observed at the back of the Halls: up to ~10 rad/h photons, ~1 rem/h neutrons:

- Prompt dose rates downstream from the targets:
  - many kilorad/h photons (measured with Ion Chambers)
  - hundreds(?) rem/h neutrons (not measured)
Radiation Environment at Jlab (2)

- Radiation monitoring around C100 cryomodules: $\gamma$, $n$
- Dose rates observed at 1 foot, ~100 rad/h $\gamma$, ~10 rem/h $n$:

Photons
- RM-103(g probe 1) (mrad/h) - Tunnel Cryo Test

Neutrons
- RM-103(n probe 2) (mrem/h) - Tunnel Cryo Test

- JLab standard CARM probes do not survive for long
- Typical proportional neutron counters won’t work: long cables, high rates, sensitivity to gammas
- Need radiation-hard photon- and neutron-sensitive ICs with remote front-end and DAQ electronics
Original Idea (2016)

- Propose to use two small LND ICs, filled with $^3$He and $^4$He (10 atm gas pressure) placed together in a poly moderator, with lead or tungsten shield
- $^4$He and $^3$He: $\sim 0.1$ pA in 1 rad/h $\gamma$
- $^3$He: $\sim 10$ pA in 1 rem/h neutrons

LND 52120
Detector next to a thick target at 2.2 GeV

**FLUKA:** Showing energy density in the air, and in the detector.

The ratio of currents from $^3$He IC to $^4$He IC equals to 5.

**Face Dose Rates (Total and Neutron):**

![Energy Deposition (keV/cm³) per beam electron at 2 GeV, Z-Y middle plane](image)

- **Energy Deposition**
  - Total: 30 x
  - Neutron: 5 x
FLUKA Model, Be Loaded Moderator

LND 52120 Ionization Chambers, 10 atm

- $^3$He
- $^4$He
- Poly
- Al shell
- 10%BeCu shell
- Polyethylene shell

Cylindrical moderator assembly

Ion Chamber Quote: $(1350+750)$
Energy Dependence of Detector Response

Response to Neutron Dose Equivalent, Function of Energy

Response = Current in $^3$He IC minus current in $^4$He IC

Detector Current per Dose-Eq Rate (pA mSv$^{-1}$ h$^{-1}$)

Neutron Energy (GeV)

- Cylindrical moderator with Beryllium multiplier layer (BeCu)
- ±10%
- ±25%
- WENDI-type moderator (without Beryllium multiplier layer)
- Tungsten layer in place of BeCu
- Symmetrical ($^3$He-, $^4$He-filled) Ion Chamber Neutron Detectors
Prototype Assembly Drawings

Triax $^3$He
HV $\sim$1kV
Triax $^4$He
HV leads

Detector core
Neutron converter
Poly moderator
Poly moderator and insulator

Signal leads
Guard leads

IC shells at HV
Electrical ground
Prototype Detectors
Detector cores in ~100 rad/h photon field

Keithley 6512 electrometer

Ion Chamber currents in gamma radiation field (approx. 100 rad/h)

Fill: 7372 Torr $^3$He and 228 Torr CO$_2$

Fill: 7600 Torr $^4$He

Detector 1

Detector 2
Detector cores in ~1 rem/h neutron field

$^3$He Ion Chambers: 48.0 ± 1.0 pA

$^4$He Ion Chambers: 0.17 ± 0.03 pA

(difference of about a factor 280)

Detectors #1 and #2 agree well within the errors
Full detector in ~10 mrem/h neutron field

Response to Neutron Dose Equivalent, Function of Energy

Response = Current in $^3$He IC minus current in $^4$He IC

- Cylindrical moderator with Beryllium multiplier layer: ±25%
- WENDI-type moderator (without Beryllium multiplier layer): ±10%
- Symmetrical ($^3$He-, $^4$He-filled) Ion Chamber Neutron Detectors: AmBe source test result
Electronics front-end under development

Evaluation boards:

Logarithmic amplifiers ADL5304 by Analog Devices
Dynamic range from 1 pA to 3 mA
Summary

- Two JLab Invention Disclosures:
  - Neutron detector for use in strong gamma-radiation fields
  - Improving sensitivity and energy response of neutron detectors using moderators with embedded Beryllium-loaded materials

- Combined into the “NDX” detector design, solving the problems:
  - Neutron detection in the presence of overwhelming photon radiation fields, in particular at JLab:
    - around the C100 cryomodules at full gradients
    - at the experimental halls
  - Improving quality of the neutron ambient dose equivalent measurements at high neutron energies up to 10 GeV
  - Radiation hardness, large dynamic range, stability of the neutron detection, characteristic for Ion Chamber operation

- Preliminary prototype test results are in agreement with expectations
- Plans for deployment at JLab under development
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Spherical Moderator Design

LND 52103 Ionization Chambers, 20 atm

\[ ^{3}\text{He} \quad ^{4}\text{He} \]

Polyethylene shell

10\%BeCu shell

Al shell

Poly

\[ ^{4}\text{He} \quad ^{3}\text{He} \]

Spherical moderator assembly

Same sensitivity

Better directional uniformity

Optimal weight of the moderator
Slide by Joseph C. McDonald (PNNL)
Figure 2: Response of the rem-counter WENDI-II from Thermo Eberline in comparison to the conversion function for the ambient dose equivalent. The data show the results of the MCNPX Monte-Carlo simulations from Olsher et al. [1] for the exposition of the detector from the side and from the end of the cylindrically shaped moderator.
References (incomplete)
