Minimizing the neutron background for the Magnetic Recoil Spectrometer (MRS) at OMEGA and the NIF

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Abstract

The Magnetic Recoil Spectrometer (MRS) is currently being implemented, at both OMEGA and the NIF, for measurements of down-scattered neutrons from which the $\rho R$ of cryogenic DT implosions can be inferred [J. A Frenje et al., Rev. Sci Instrum 72, 854 (2001)]. The MRS uses CR-39 detectors to detect recoil protons (or deuterons), which are also sensitive to background neutrons. Minimizing this neutron background at both OMEGA and the NIF is important for its successful implementation. At both OMEGA and the NIF, neutron shielding will reduce the neutron background. The OMEGA MRS will also utilize the coincidence counting technique to reject additional background. The Monte Carlo code TART was used to calculate the background neutron fluence, design the neutron shielding, and to design the neutron collimator for the NIF. Descriptions of these calculations for the MRS at OMEGA and the NIF are provided in this poster as well as images of the OMEGA MRS which is currently being installed. This work was supported in part by the U.S. Department of Energy (Grant No. DE-FG03-03SF22691), LLE (subcontract Grant No. 412160-001G), LLNL (subcontract Grant No. B504974).
The principle of the Magnetic Recoil Spectrometer (MRS)

CH-foil or CD-foil

Target

Magnet

Detecter housing

Magnet housing

Entrance

Exit

$10 \text{ cm (Ω)}$

$40 \text{ cm (NIF)}$

$215 \text{ cm (Ω)}$

$1800 \text{ cm (NIF)}$

$6-28 \text{ MeV (p)}$

$3-14 \text{ MeV (d)}$

J. A. Frenje et al., MRS Preliminary Design Review, LLE, October 12th, 2006

Signal Detection Efficiency

- The detection efficiency ($\varepsilon_{\text{MRS}}$)

\[ \varepsilon_{\text{MRS}} = \frac{\Omega_n}{4\pi} \cdot n_i \cdot t \int \frac{d\sigma}{d\Omega_{\text{lab}}} \cdot d\Omega \]

- Maximum differential cross section at forward scattering angles and focusing, which allows for a larger aperture, both significantly enhance $\varepsilon_{\text{MRS}}$.

- Absolute yields will be measured since $\Omega_n$, $n_i$, $t$, $\frac{d\sigma}{d\Omega}$, and $\Omega_r$ are known.
The MRS designs at OMEGA and the NIF were driven by LASNEX simulations.

- Cerjan and Hatchett - 1D failure and ignited (timing of 2nd shock)
- Cerjan and Hatchett - 1D failure and ignited (timing of 4th shock)
- Haan - 2D failures and ignited
- Wilson - 2D failures
- Olsen - 2D failure and ignited
The OMEGA MRS point design

- Magnet aperture distance to TCC: 225 cm
- Magnet aperture area: 22 cm²
- CH-foil distance to TCC: 10 cm
- CH-foil area: 13 cm²
- CH-foil thickness: 600 μm
The OMEGA MRS is currently being installed

- OMEGA Target Chamber
- Magnet housing
- Detector housing
- Access to CR-39 detectors
The NIF MRS point design

- Magnet aperture distance to TCC: 1800 cm
- Magnet aperture area: 20 cm²
- CH-foil distance to TCC: 40 cm
- CH-foil area: 20 cm²
- CH-foil thickness: 600 μm

** The CH-foil will be inserted by the 90°-315° DIM
Motivation for the MRS at OMEGA and the NIF

• Measure absolute neutron spectrum of cryo DT implosions in the range of 6-32 MeV
• Infer \( \rho R \) from the down-scattered neutron spectrum (6-10 MeV)
• Measure absolute neutron yield
• Determine fuel ion temperature from Doppler broadened primary neutron spectrum
• Infer \( \rho R \) from the tertiary neutron spectrum (20-32 MeV) (NIF)

Minimizing the neutron background is critical for the successful implementation of the MRS at OMEGA and the NIF
The required $S/B > 10$ defines the tolerable neutron fluence at the MRS detector at OMEGA and the NIF

$$\frac{S}{B} > 10 \quad \Rightarrow \quad \frac{S}{F_n \cdot A \cdot \varepsilon_{CR39}} > 10 \quad \Rightarrow \quad F_n \leq \frac{2.75 \times 10^{-2} \cdot \rho R \cdot Y_{1n} \cdot \varepsilon_{MRS}}{10 \cdot \varepsilon \cdot A \cdot Y_{1n}}$$

**OMEGA MRS**

$A \sim 40 \text{ cm}^2$

$\varepsilon_{MRS} \sim 9 \times 10^{-9}$*

$\varepsilon_{CR39} \sim 6 \times 10^{-5}$** (6 hrs etch)

For $\rho R \geq 0.1 \text{ g/cm}^2$

$F_n \leq 1 \times 10^{-9} \text{ 1/cm}^2$

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**NIF MRS**

$A \sim 24 \text{ cm}^2$

$\varepsilon_{MRS} \sim 10^{-11}$*

$\varepsilon_{CR39} \sim 6 \times 10^{-5}$** (6 hrs etch)

For $\rho R \geq 0.3 \text{ g/cm}^2$

$F_n \leq 5 \times 10^{-12} \text{ 1/cm}^2$

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* $\varepsilon_{MRS}$ J. A Frenje et al., MRS System Design Review 4/27/2006 (for 6-10MeV $\Delta E=3$ MeV)

TART calculations at OMEGA agree with experiments and show background must be reduced ~750 times.

TART calculations indicate Neutron fluence at MRS is \(~7.7 \times 10^{-7} \text{ cm}^{-2}\) per produced neutron.

To achieve a S/B=10 this must be reduced ~750 times.
TART calculations show polyethylene shielding will reduce the background ~50 times** for the OMEGA MRS

* Images of MRS and Shielding from Bill Owens - LLE
** OMEGA MRS Neutronics Analysis from TART - D. T. Casey et al., APS 2005
Although not required at the NIF, the Coincidence Counting Technique (CCT) will reduce the background another ~15 times at OMEGA.

Incident Neutron

Incident proton / deuteron

Correlation Radius ($R_c$)
A background reduction of ~15 times was demonstrated using knock-on deuteron data at OMEGA. Data was obtained from the CPS2 magnetic charged particle spectrometer.
The CCT has also been applied to DHe$^3$ accelerator protons

Protons produce using our accelerator

The MRS can operate in proton or deuteron recoil mode by using a CH or CD foil
TART is being used to characterize and minimize the neutron fluence for the NIF MRS

The NIF TART model* now includes the MRS

* Full NIF TART model and advice courtesy of Peter Song and NIF neutronics team
The current NIF MRS TART model includes the magnet and a simple neutron beam dump.

- Magnet
- Neutron Beam Dump
- Detector housing
- Vacuum tube
- Borated poly slug
- CR-39 Detectors
NIF MRS neutron fluence for different collimator hole openings

Neutron Fluence at CR39 for Different Collimator Configurations

- 3 Deg Cone Source
- Over $4\pi$

Neutron Background from Switchyard
All $E_n$ found < 0.3MeV

~0.6 CPU Years

*Most TART runs now being performed on high performance LLNL machines thanks to help from Mike Moran, Peter Song, and Carlos Barrera*
Fluence can be combined with CR39 detection efficiency to estimate S/B ratio

\[ S \approx 2.75 \times 10^{-2} \cdot \rho R \cdot Y_{1n} \cdot \varepsilon_{MRS} \]

\[ B_n = A_{CR39} Y_{1n} \int F_n(E) \cdot \varepsilon_{CR39}(E) dE \]

Where \( \varepsilon_{MRS} \) (6-10 MeV) \( \approx 10^{-11} \)

and \( F_n \) is the fluence per source neutron

\[ S/B_n = \frac{2.75 \times 10^{-2} \cdot \rho R \cdot \varepsilon_{MRS}}{A_{CR39} \int F_n(E) \cdot \varepsilon_{CR39}(E) dE} \]

*CR39 Detection efficiency curve generated by Johan Frenje
NIF MRS S/B for different collimator opening areas for 
\( \rho R = 0.3 \text{ g/cm}^2 \)

S/B for Different Collimator Configurations

- Uncertainty in this point is very large
- S/B = 10 MRS SDR Requirement
- Minimum Collimator Area

Peter Song is now adding the NIF MRS to the NIF MCNP model which is in relatively good agreement with TART
Conclusions and future work

**OMEGA**
- The OMEGA MRS background must be reduced ~750 times
- Shielding will reduce background by ~50 times
- The CCT will reduce the background for the OMEGA MRS by at least another 15 times.

**NIF**
- Preliminary calculations indicate S/B goal can be reached using a collimator in target bay wall and a neutron beam dump.
- Neutron beam dump should be optimized
- Peter Song has added the NIF MRS to the NIF MCNP model and collimator calculations will be continued using MCNP