# ISFSI Neutron Dose Monitoring

**Radiological Effluents and Environmental Workshop**
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# Introduction

- Why monitor ISFSI neutron dose?
- TLD system characterization
  - Calibration
  - Detection sensitivity
- Neutron dose results
- Recent developments in dose analysis

# NUHOMS® Spent Fuel Storage Modules

# ISFSI - Looking North

# ISFSI - Looking East

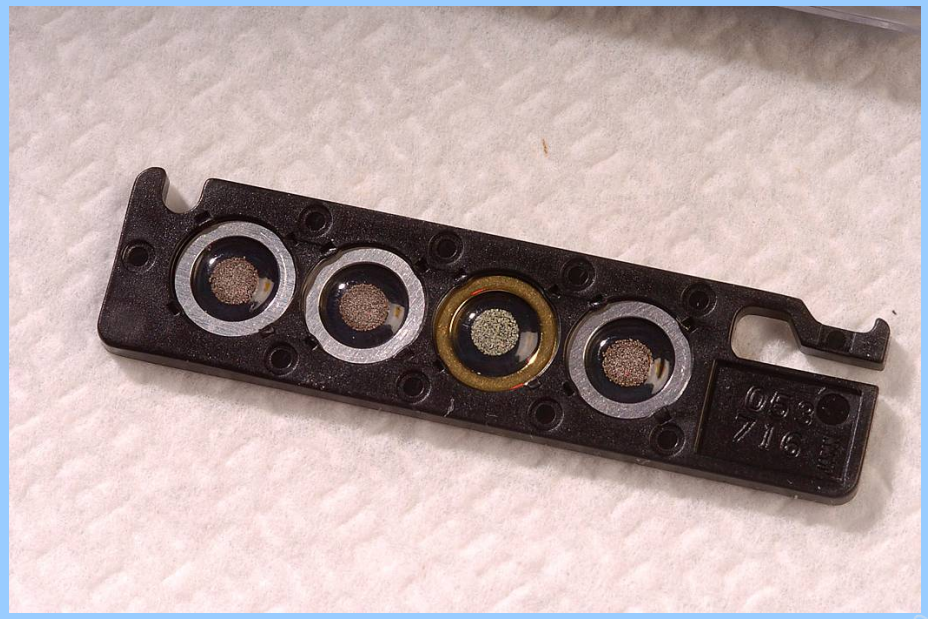
# ISFSI - Looking South

# ISFSI - Looking West

# 808/814 Neutron TLD Badge

## Lithium Borate Elements

- 808 depleted of $^{6}Li$ and $^{10}B$ (gamma signal only)
- 814 $^{6}Li$ and $^{10}B$ natural abundance (gamma & neutron)
  - $^{6}Li$ and $^{10}B$ high thermal neutron cross-section (n:α)



# ISFSI Neutron TLD Calibration Considerations

- **Determination of reference neutron dose**
  - **Choice of instruments and methods**
  - **Choice of location (proximity to ISFSI)**
- **TLD irradiation and interpretation**

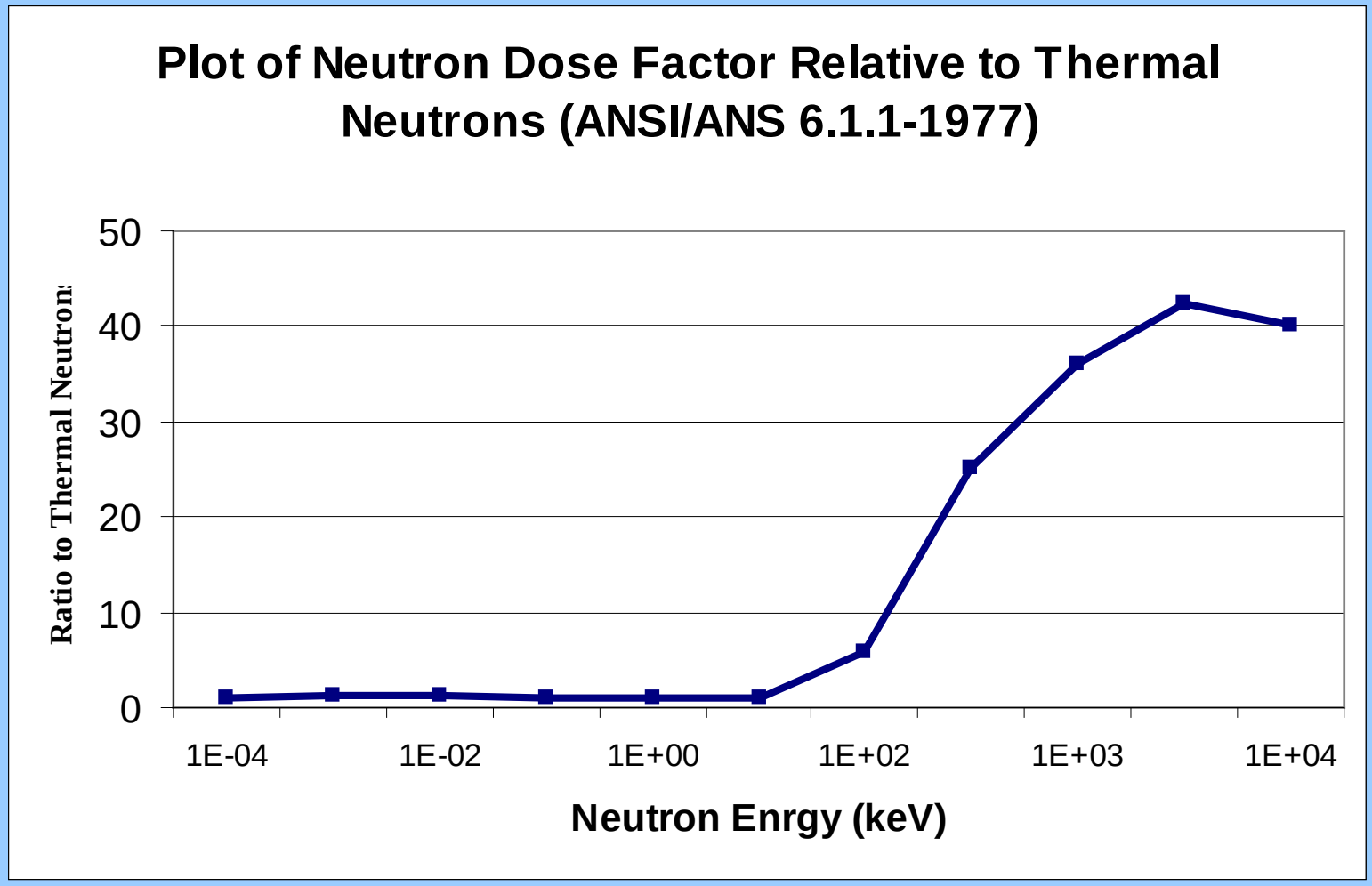
# ISFSI Neutron TLD Calibration Considerations (Continued)

- **Instruments and Methods**
  - **Neutron spectrum converted to dose (e.g. Bonner Sphere measurements)**
    - **NUHOMS® MCNP calculations**
  - **Tissue Equivalent Proportional Chambers (TEPC)**
    - **Health Physics Instruments REM-500**
    - **ANI Bulletin 11-02 *Neutron Monitoring* preferred**
    - **Detects heavy charged particles (recoil protons)**
  - **REM-Ball type survey instruments**
    - **$BF_3$ tube detects thermal neutrons**

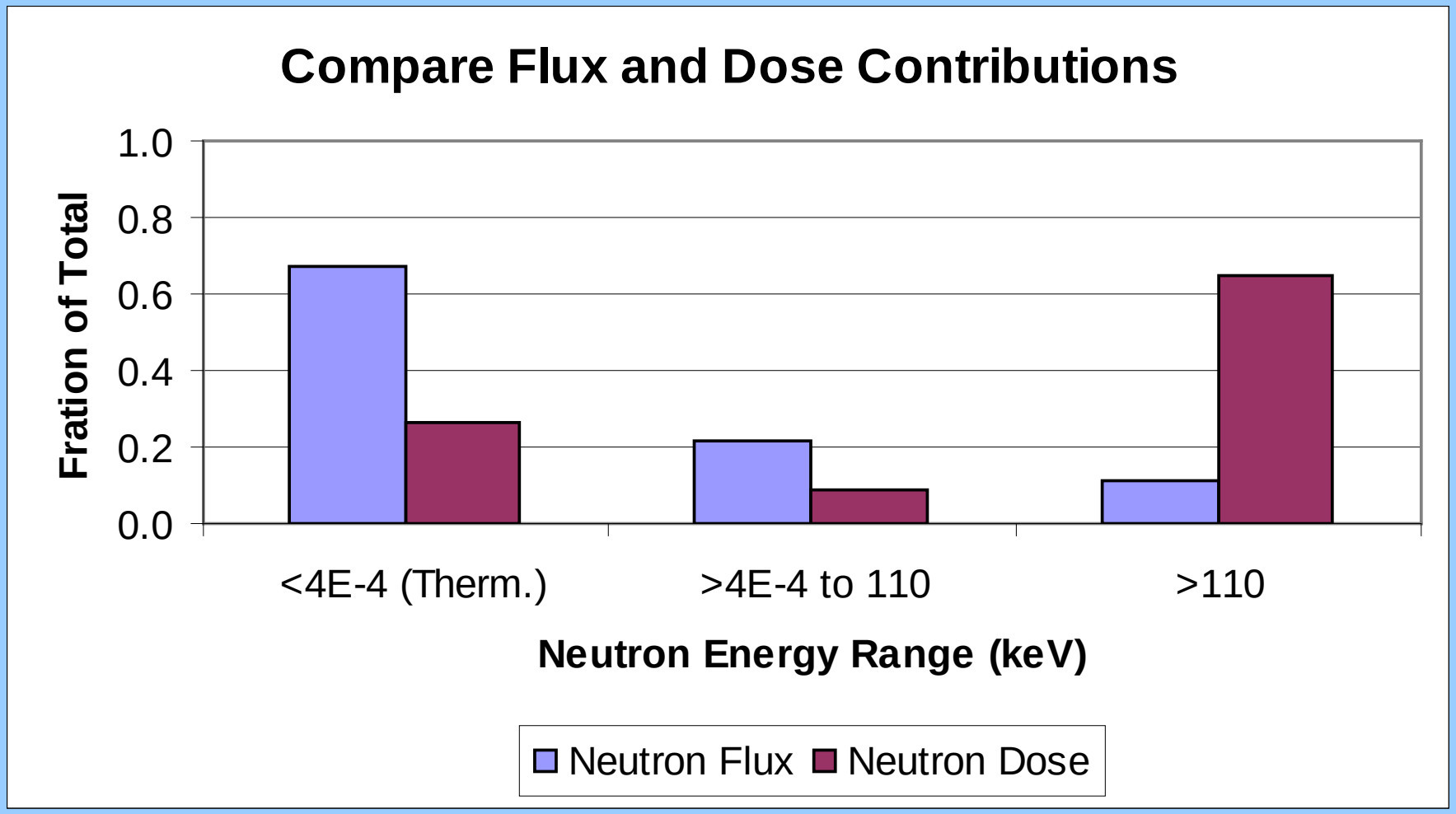
# NUHOMS® MCNP Neutron Spectrum

| Energy Group | Group Upper Neutron Energy (MeV) | ANSI Dose Factor (mrem/h)/ (n/cm2/s) | Half of Front on the LHS from Centerline Neutron Flux (n/cm2/s) | Dose Rate (mrem/h) | Percent Contribution |
|---|---|---|---|---|---|
| 1 | 4.14E-07 | 4.0E-03 | 56.04 | 2.23E-01 | 26.5% |
| 2 | 1.12E-06 | 4.0E-03 | 2.25 | 8.96E-03 | 1.1% |
| 4 | 1.01E-05 | 4.0E-03 | 2.57 | 1.02E-02 | 1.2% |
| 6 | 1.01E-04 | 4.0E-03 | 2.66 | 1.06E-02 | 1.3% |
| 8 | 3.35E-03 | 4.0E-03 | 3.12 | 1.24E-02 | 1.5% |
| 9 | 1.11E-01 | 2.4E-02 | 5.94 | 1.40E-01 | 16.7% |
| 10 | 5.50E-01 | 1.0E-01 | 2.52 | 2.55E-01 | 30.3% |
| 11 | 1.11E+00 | 1.3E-01 | 0.66 | 8.70E-02 | 10.3% |
| 12 | 1.83E+00 | 1.3E-01 | 0.25 | 3.33E-02 | 3.9% |
| 13 | 2.35E+00 | 1.3E-01 | 0.12 | 1.61E-02 | 1.9% |
| 14 | 2.46E+00 | 1.3E-01 | 0.03 | 4.02E-03 | 0.5% |
| 16 | 4.06E+00 | 1.4E-01 | 0.02 | 2.74E-03 | 0.3% |
| 18 | 6.36E+00 | 1.4E-01 | 6.518E-03 | 9.17E-04 | 0.1% |
| 20 | 1.00E+01 | 1.5E-01 | 1.641E-04 | 2.4073E-05 | 0.0% |
| Total | | | 83.86 | 0.842 | |
| Contribution below 10 keV: | | | | | 35% |
| Contribution above 10 keV: | | | | | 65% |

# NUHOMS® Neutron Dose Factors



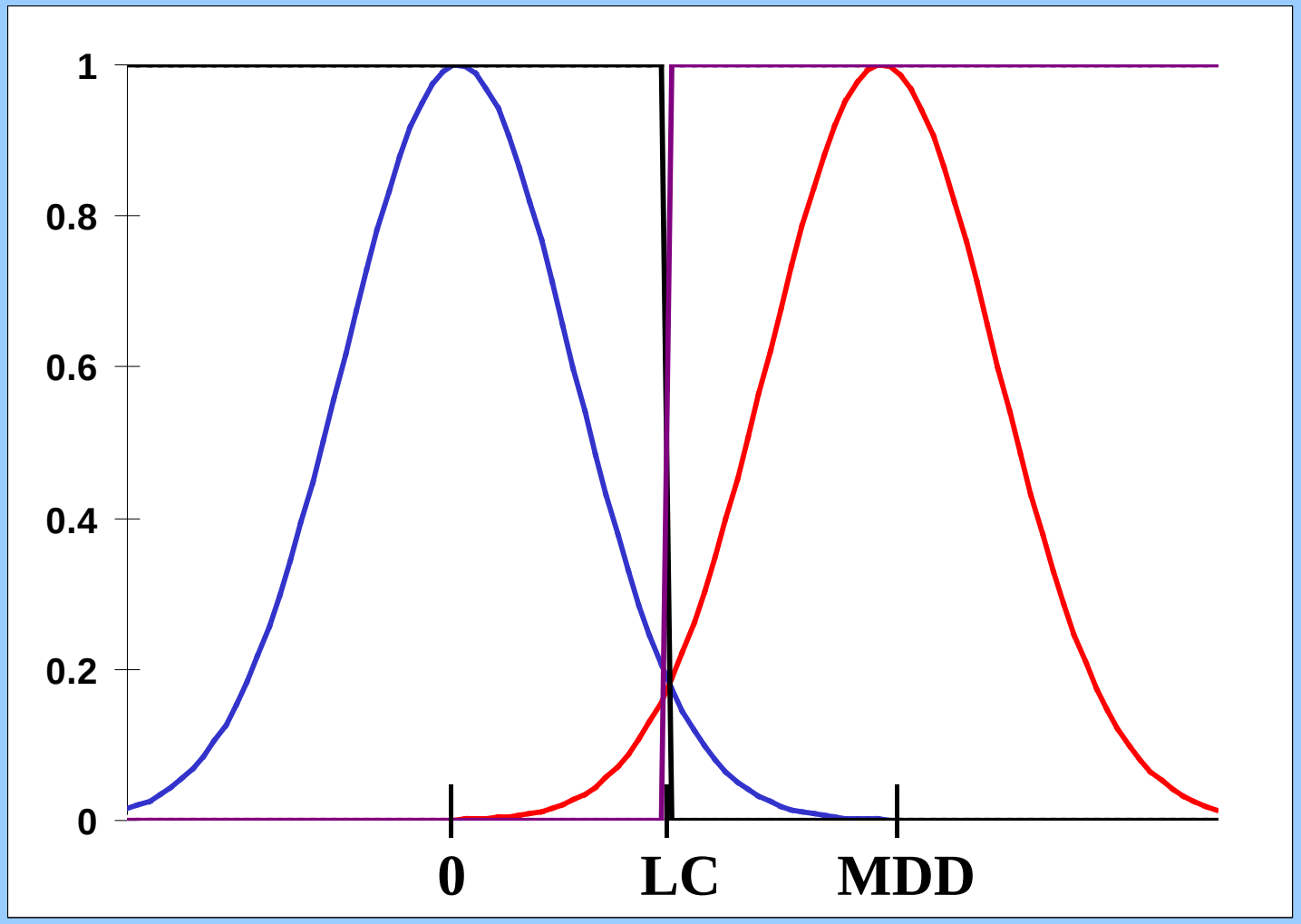
# NUHOMS® Neutron Spectrum



# ISFSI Neutron TLD Calibration Considerations (Continued)

- **Choice of location (proximity to ISFSI)**
  - **Neutron dose decreases with distance**
  - **Neutron energy spectrum decreases with distance**
  - **TLD detects thermal neutrons; NCF changes with neutron energy spectrum (e.g. $ISFSI_{NCF}$ ~8x $^{252}Cf_{NCF}$)**
- **Dosimeter irradiation and interpretation**
  - **Characterize neutron dose rate at chosen location**
  - **Irradiate TLDs <u>without</u> albedo back-scatter phantom (e.g. $ISFSI_{NCF}$ with phantom ~2x without phantom)**
  - **TLD processor determines NCF (TLD signal/dose)**

# Neutron Detection Probability Analysis
# Neutron Signal Detection at 95% Confidence Interval



# Neutron Minimum Detectable Dose and Critical Level Evaluation

- **Based on uncertainty in signal ($s_n$)** **[Currie, L.A]**
  - $MDD_n = (4.65 * \sigma_n) / NCF$
  - $LC_n = (2.33\ \sigma_n) / NCF$

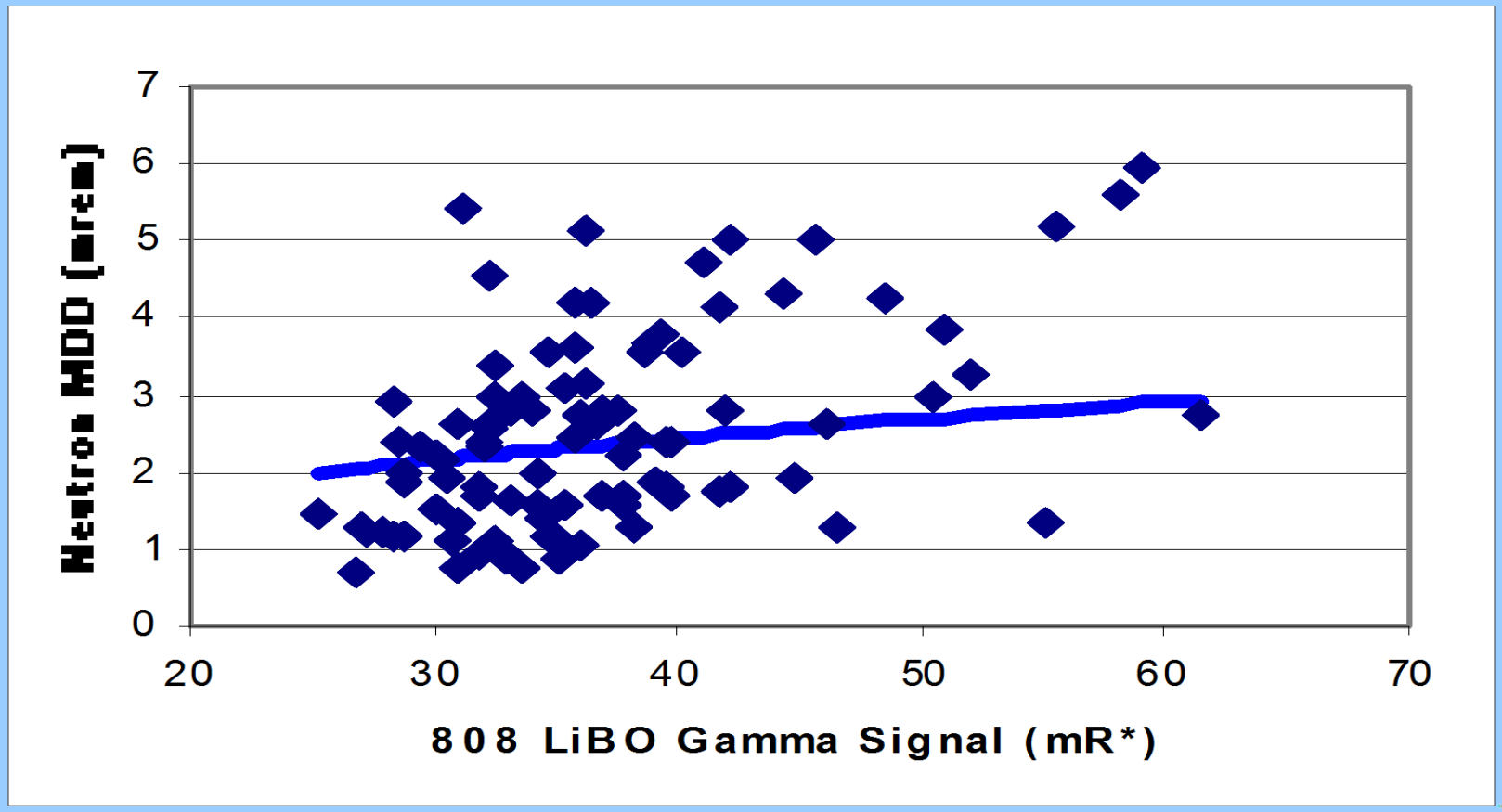
**[NCF = 10.5 R/$rem_n$ Neutron Correction Factor]**

- **TLD system prediction versus gamma signal level**
  - $MDD_n = 0.494 * (LiBO_g)^{0.4331}$
  - $LC_n = 0.248 * (LiBO_g)^{0.4331}$

# MDD Equation Comparison

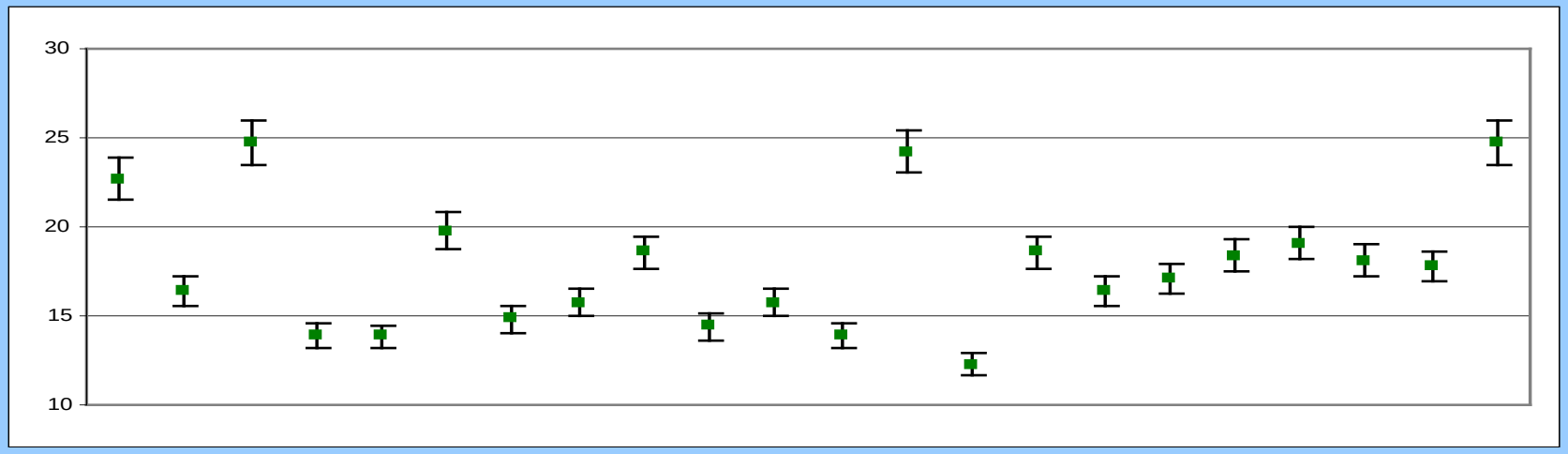
## Quarterly TLD Data Prior to Spent Fuel Storage

## $MDD_n$ Points and Predicted Line for Gamma Level

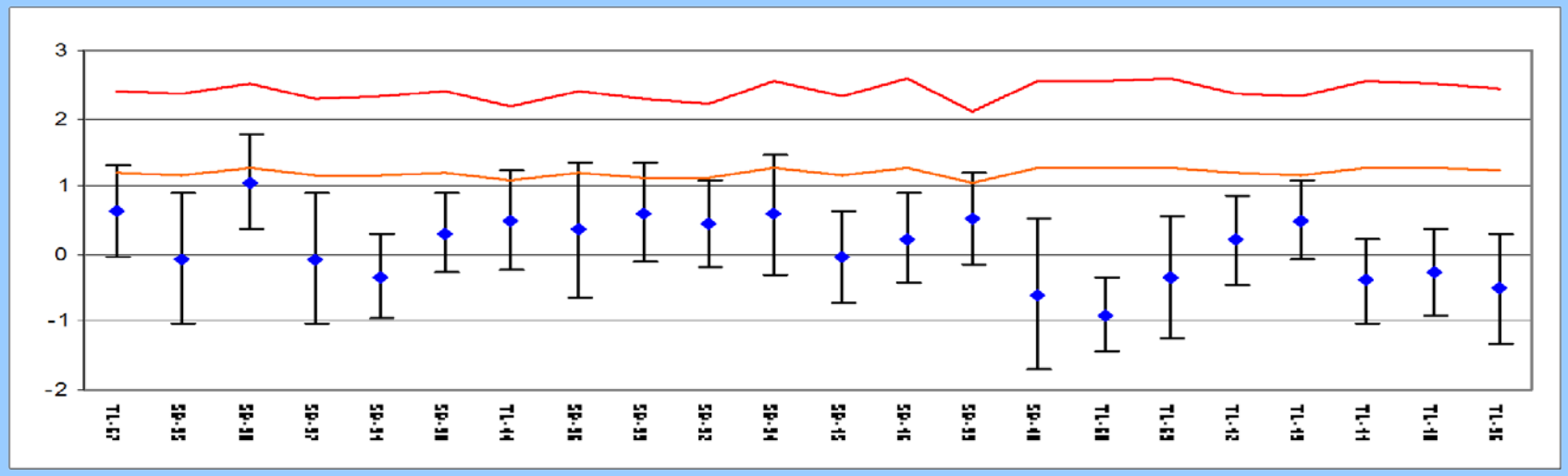


# Quarterly Results Prior to Spent Fuel Storage

Gamma Result (mR)

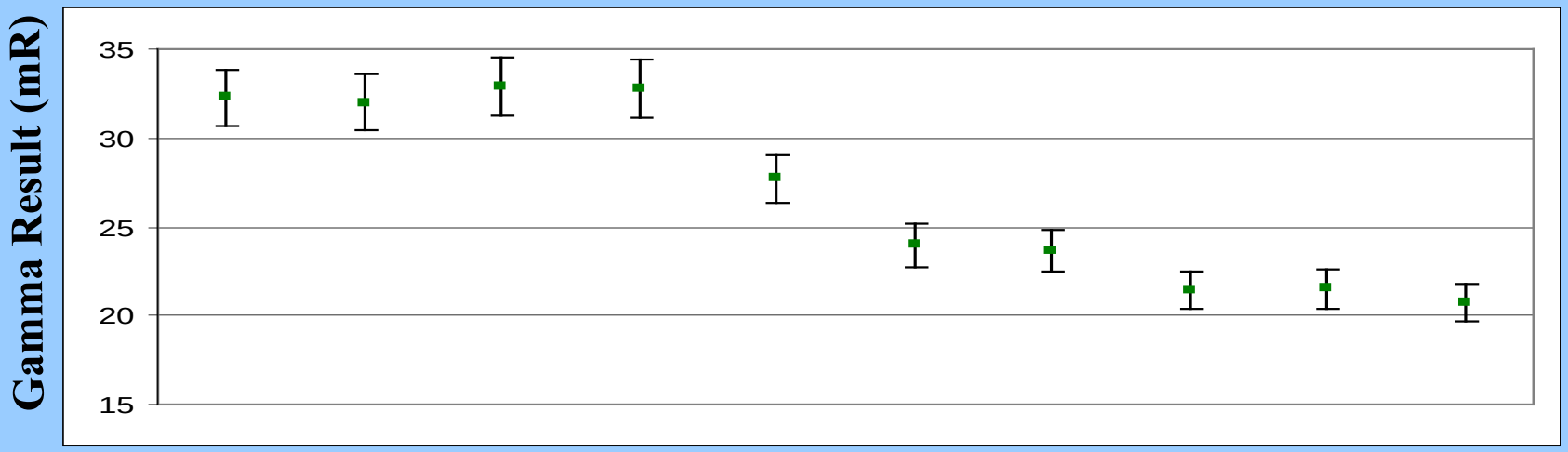


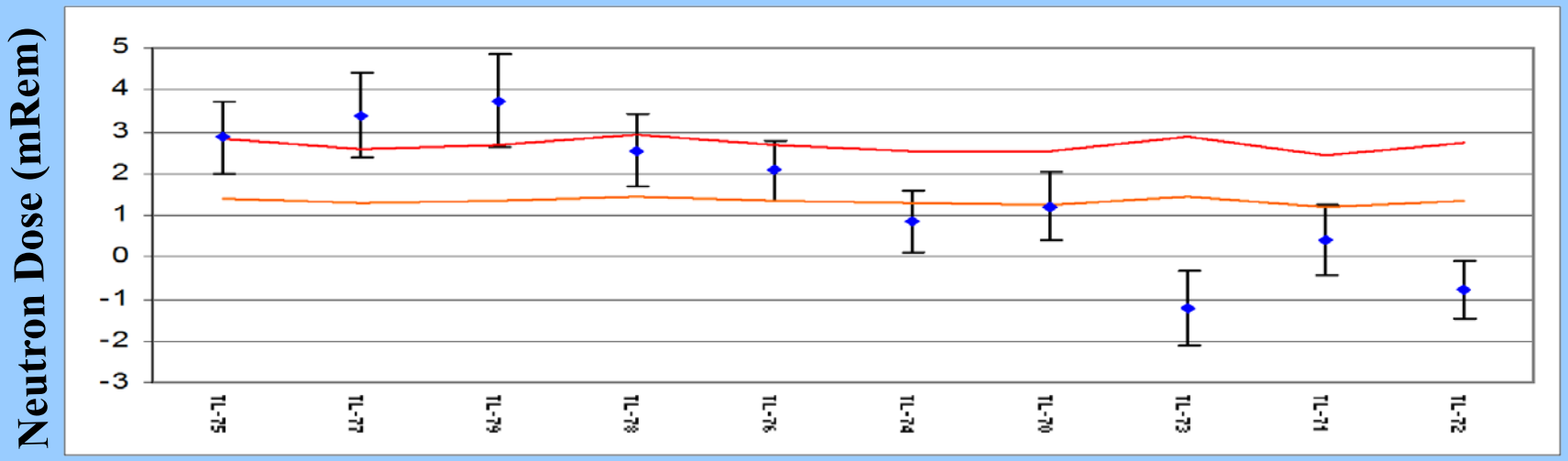

Neutron Dose (mRem)




(Orange and red lines indicate LC and MDD values, respectively)

# Quarterly Fence Doses After Spent Fuel Storage




**(Orange and red lines indicate LC and MDD values, respectively)**

# Example of ISFSI Fence Maximum Dose

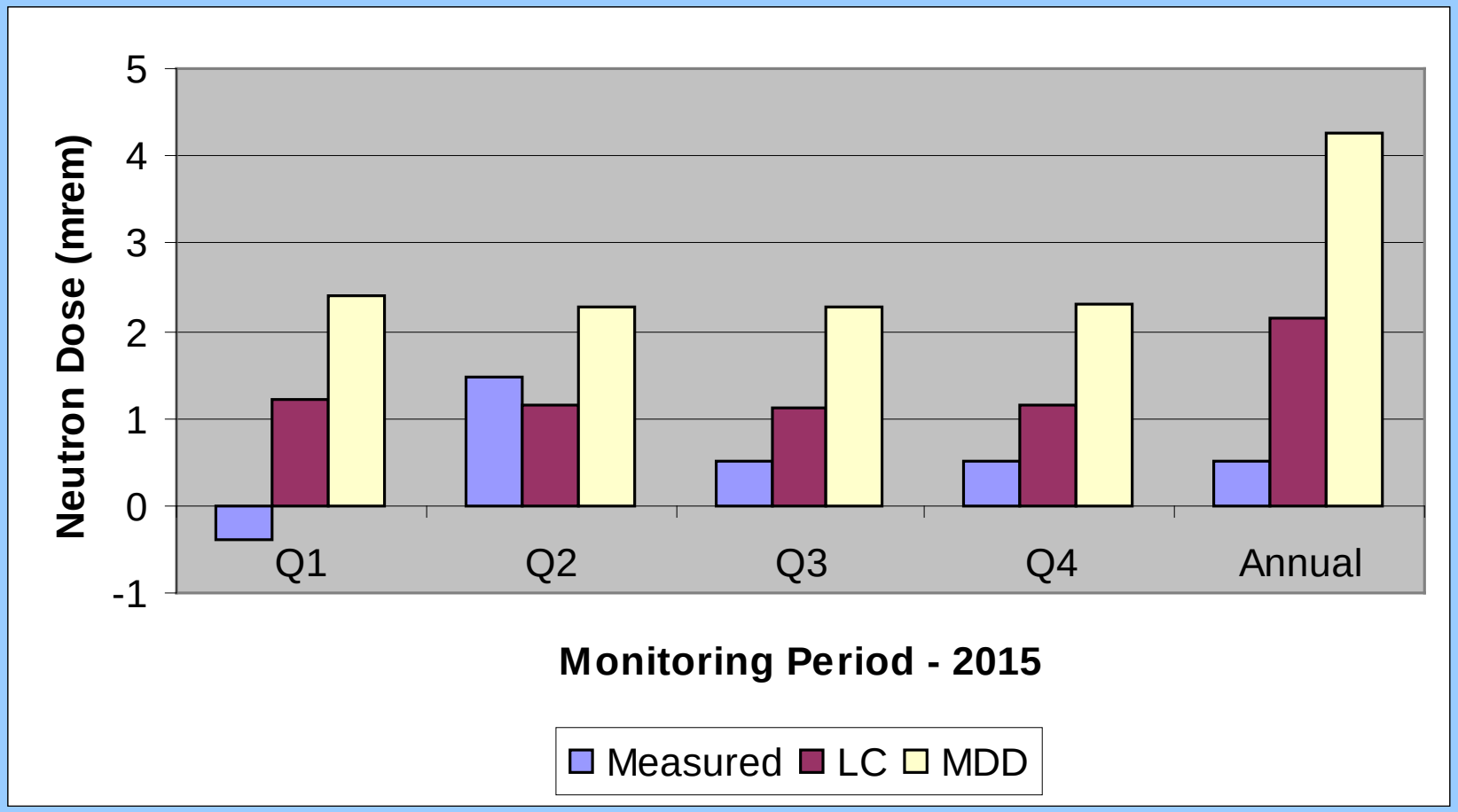
| Annual Net Gamma (mrem) | | Annual Net Neutron (mrem) | | Annual Net Total (mrem) | 2000 hour Occupancy Total (mrem) | 500 hour Occupancy Total (mrem) |
|---|---|---|---|---|---|---|
| 114 | 80% | 28 | 20% | 142 | 32.5 | 8.1 |

**100 mrem annual limit for members of public (10CFR20.1301)**

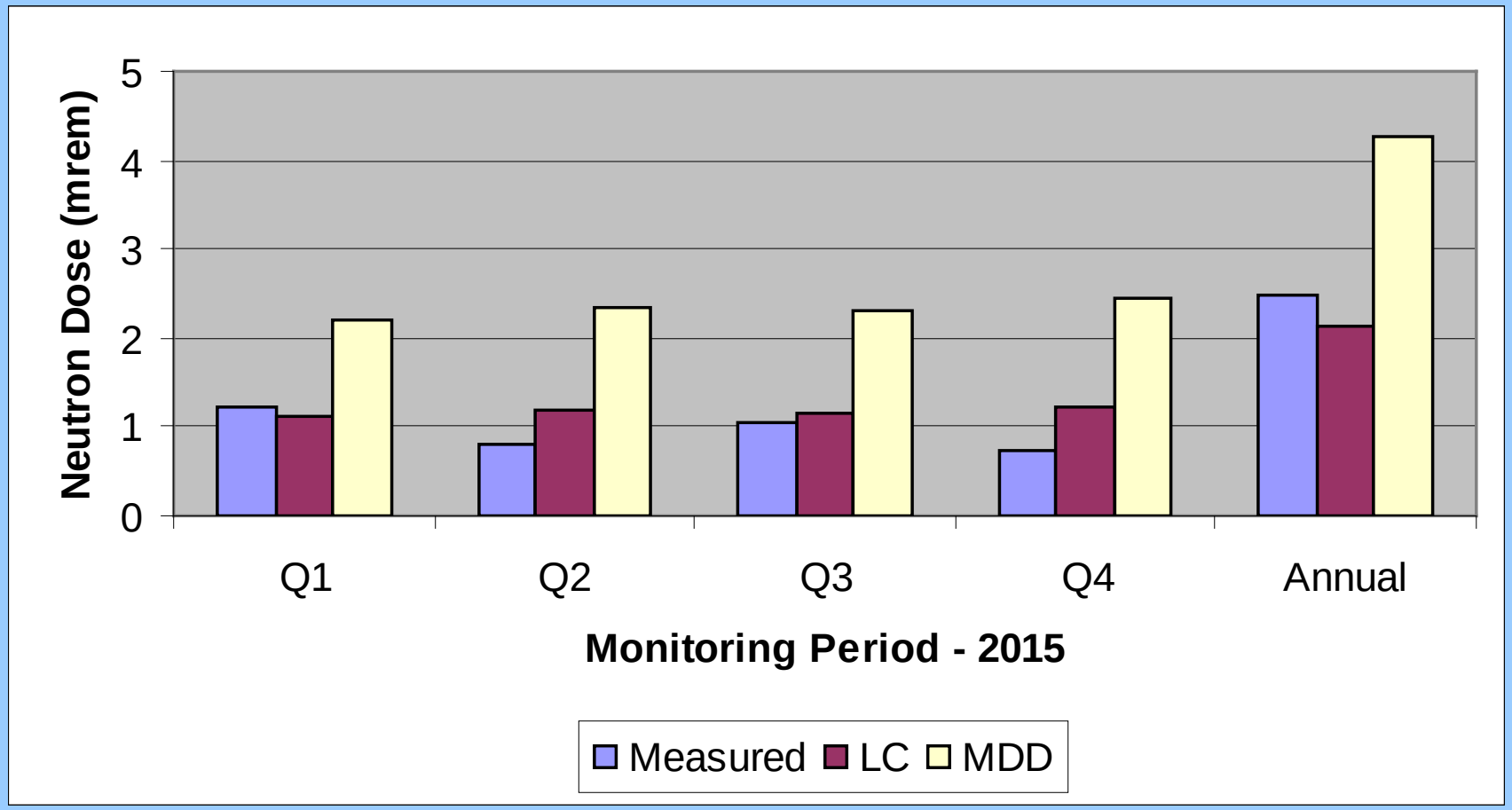
# Latest Developments in Neutron Dose Analysis

- **Improve Neutron Monitoring Sensitivity**
  - **Combine quarterly TLD element responses into an "Annual Neutron TLD Response"**
  - **Use Annual Neutron TLD Response to determine annual neutron dose, LC and MDD**

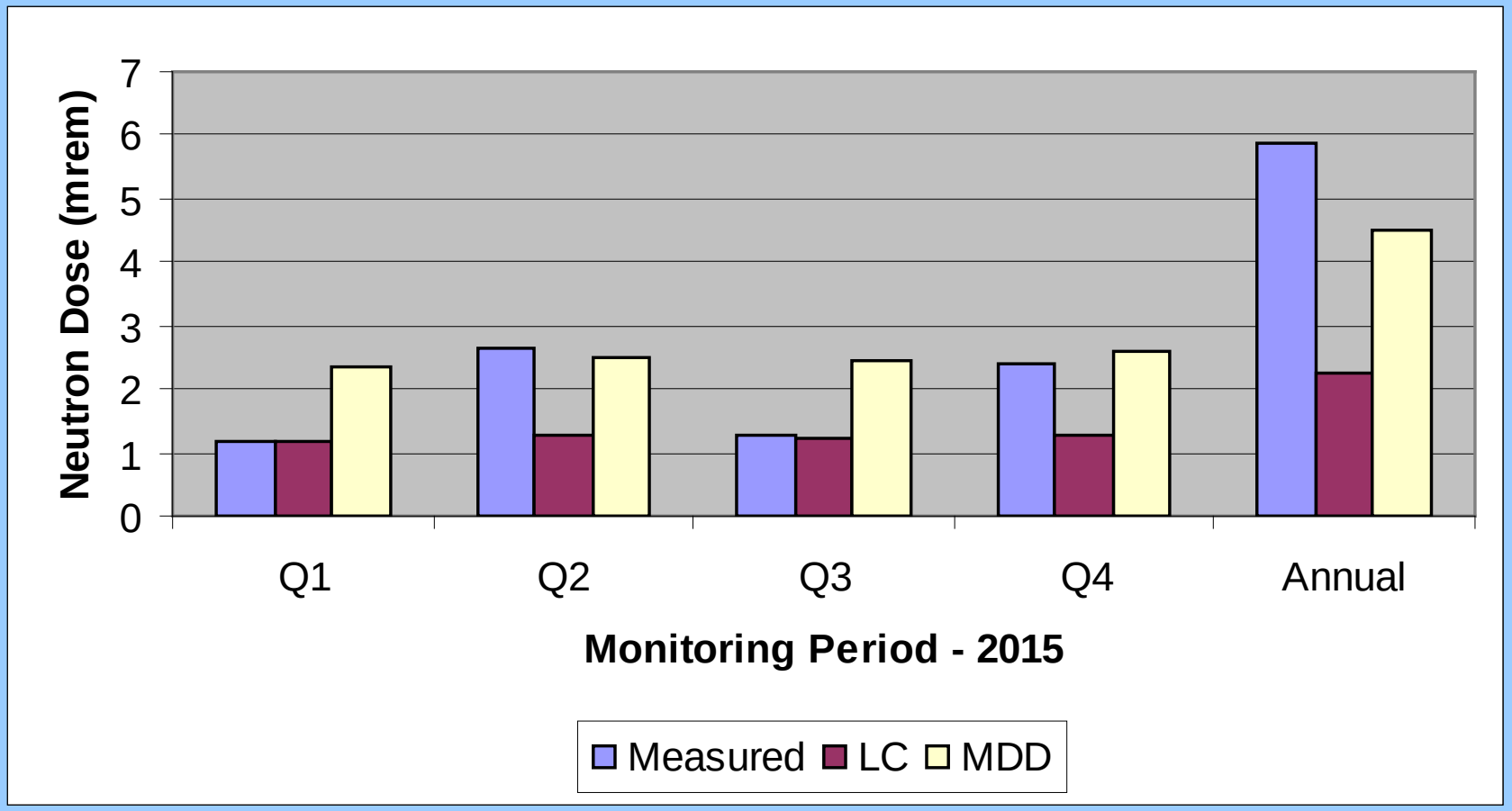
# Example Annual Neutron TLD Response #1 Analyze Location with >LC Response



# Example Annual Neutron TLD Response #2 Analyze Location with >LC Response



# Example Annual Neutron TLD Response #3 Analyze Location with >MDD Response



# ISFSI Neutron Dose Monitoring Conclusions

- **Neutron dose monitoring is justified (~ 20% of fence dose)**
- **Selection of calibration location is important (neutron energy spectrum shifts with distance)**
- **$MDD_n$ and $LC_n$ curves versus gamma dose level needed (use TLD system uncertainty characterization)**
- **Combining quarterly TLD responses into an annual neutron TLD response looks promising for analysis at low neutron dose levels**

# Questions?