CCLRC
Rutherford Appleton Laboratory

Radiological Protection

R. Clarke, D. Neely, R. Heathcote, P. Wright

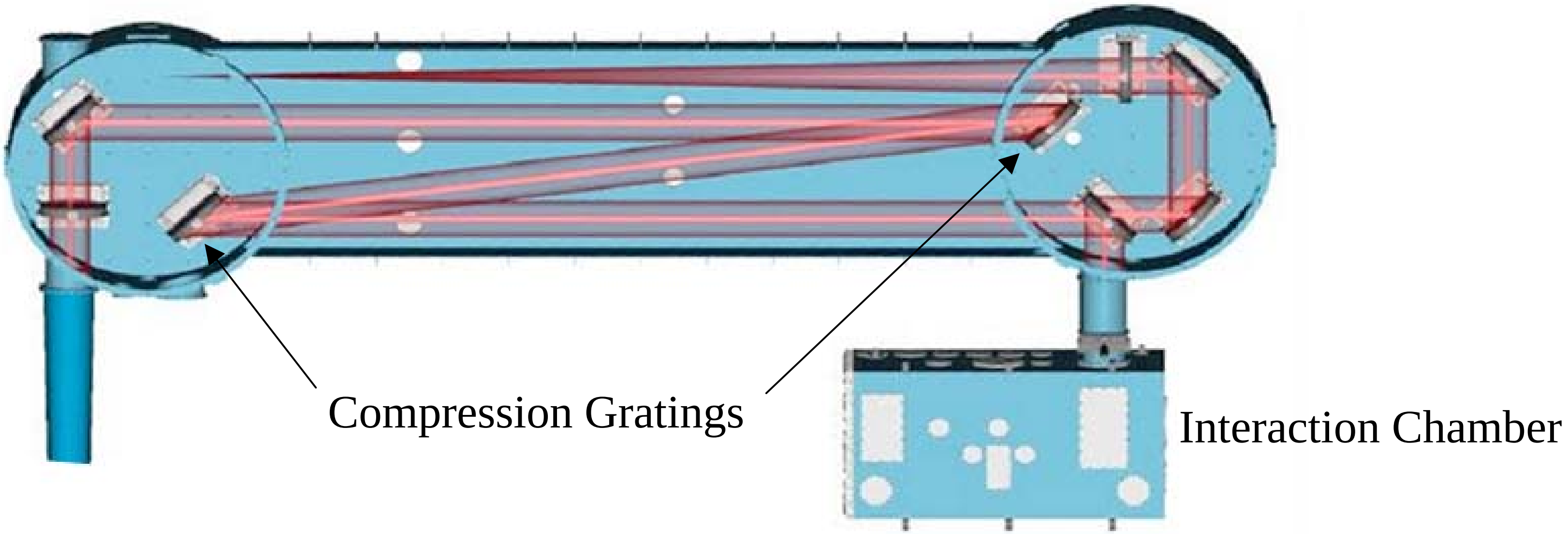
R. Edwards (AWE Aldermaston)

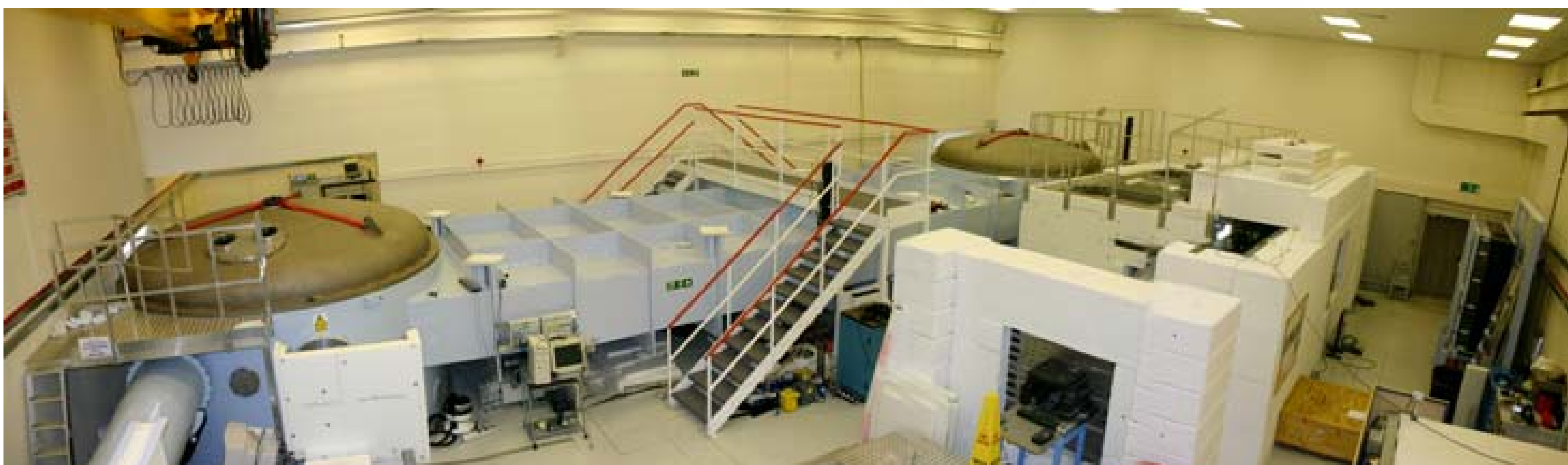
Rob Clarke
CLF Target Area Group

Introduction

- RAL Petawatt Target Area
- Primary Radiation Emission (γ,p,n)
- Shielding
- Activation
- Control Methods
- High Repetition Facilities
- Conclusion

Petawatt Target Area





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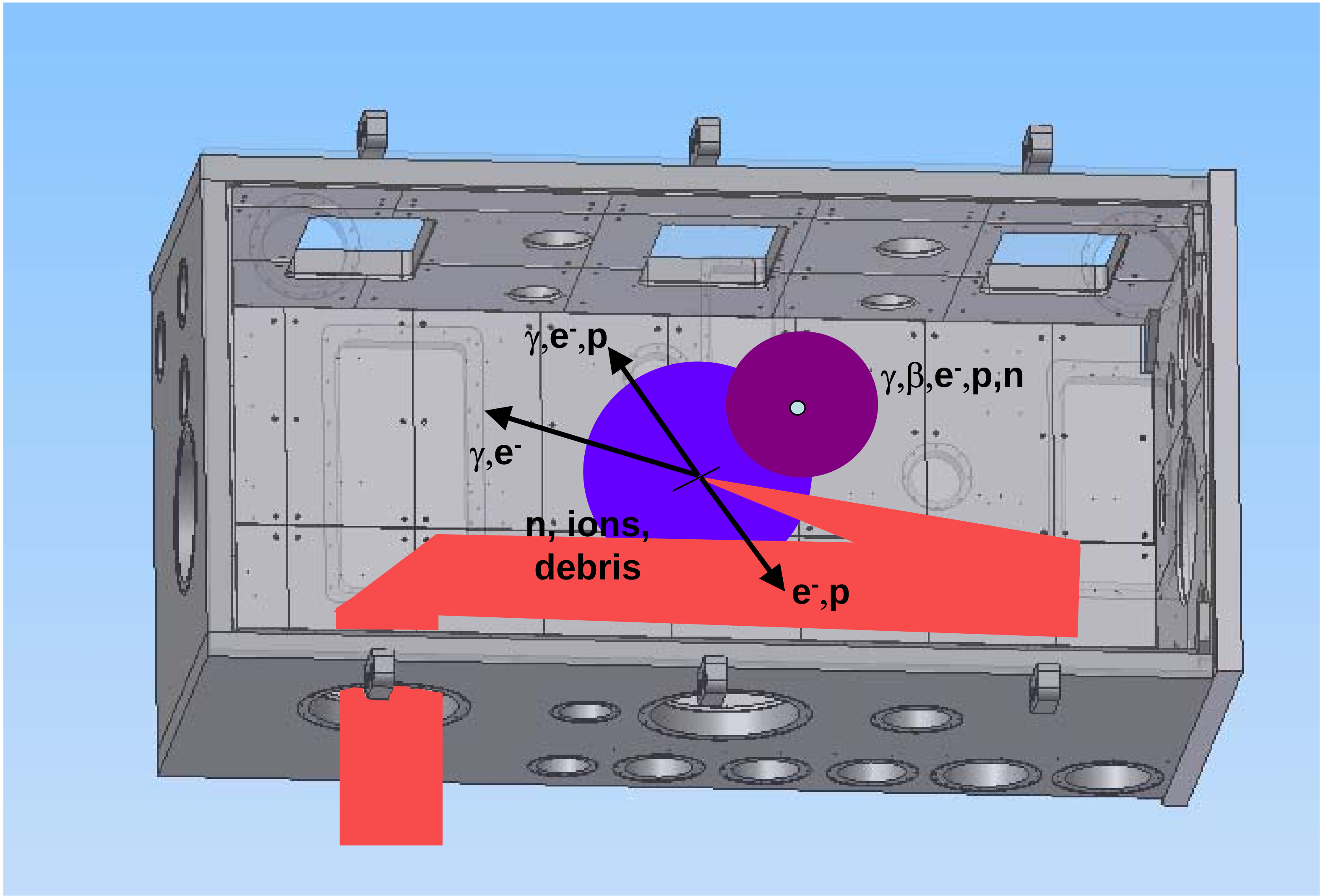
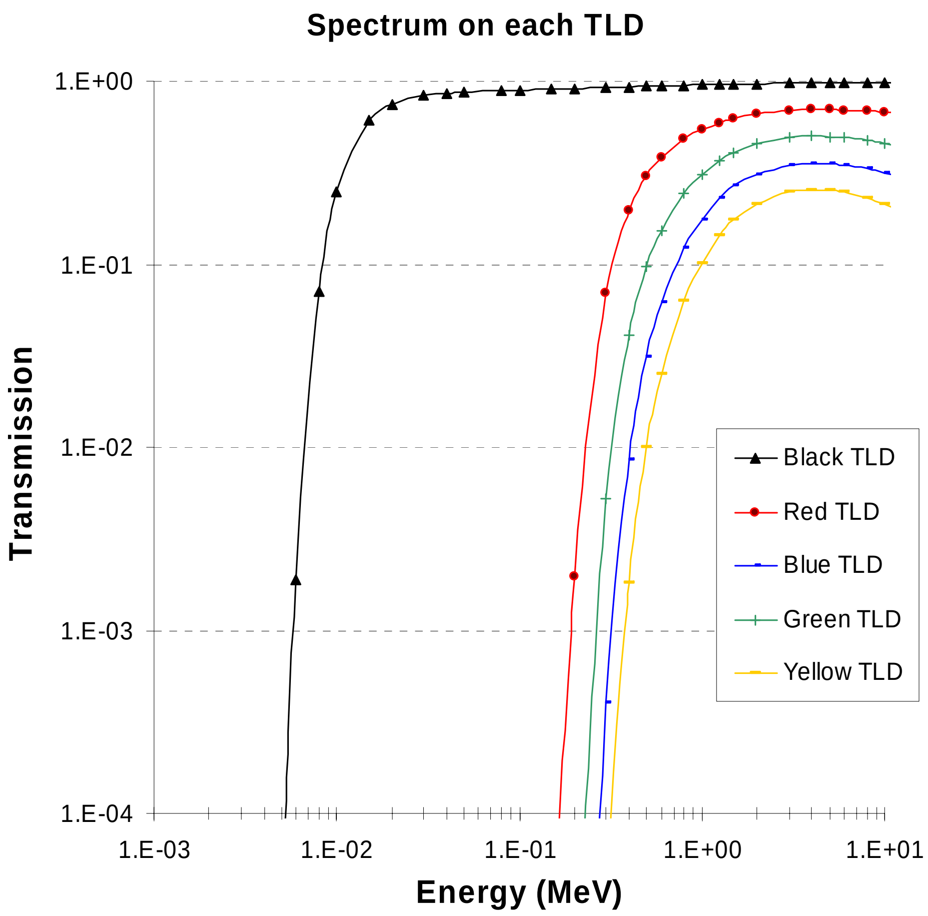
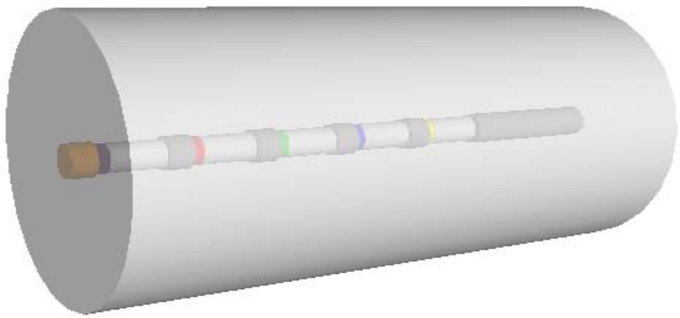
Radiation Emission



TLD Measurements

- Thermo Luminescent Detector
- 30mg TLD100 (LiF) powder
- Tungsten Filter for Energy determination
- Sensitivity ± 2 μSv
- (100mR = 1mSv for γ radiation)
- 0.01 - 10 MeV





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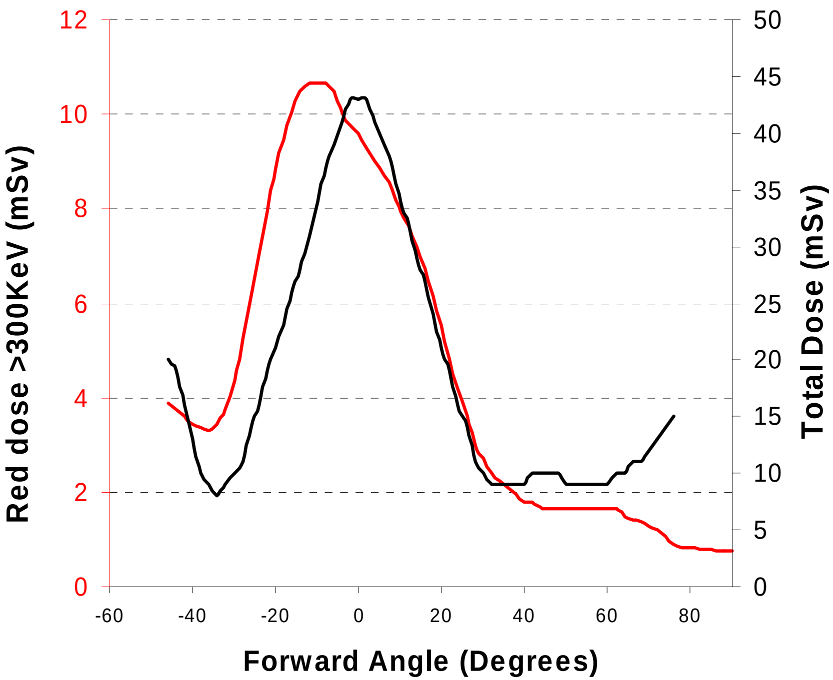
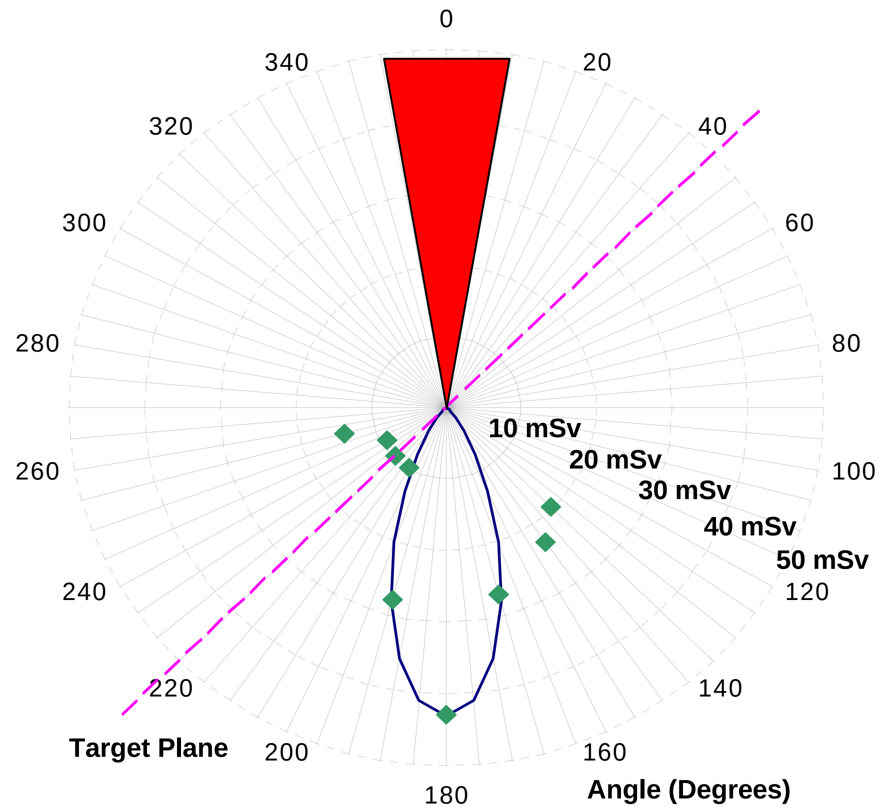
PetaWatt Gamma Yield

- 1mm Gold Target @ 45º
- ~400TW on Target
- ~ 4×10^{20} W/cm^2
- 43 mSv @ 1m peak forward dose
- 40° forward cone





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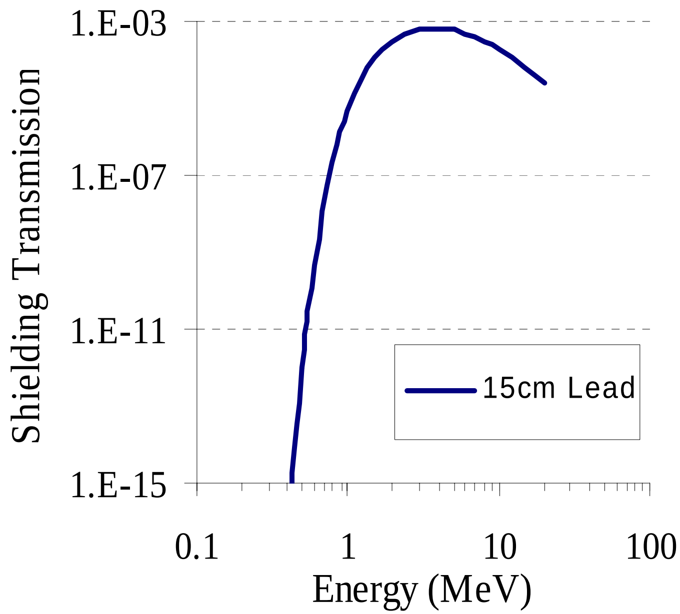
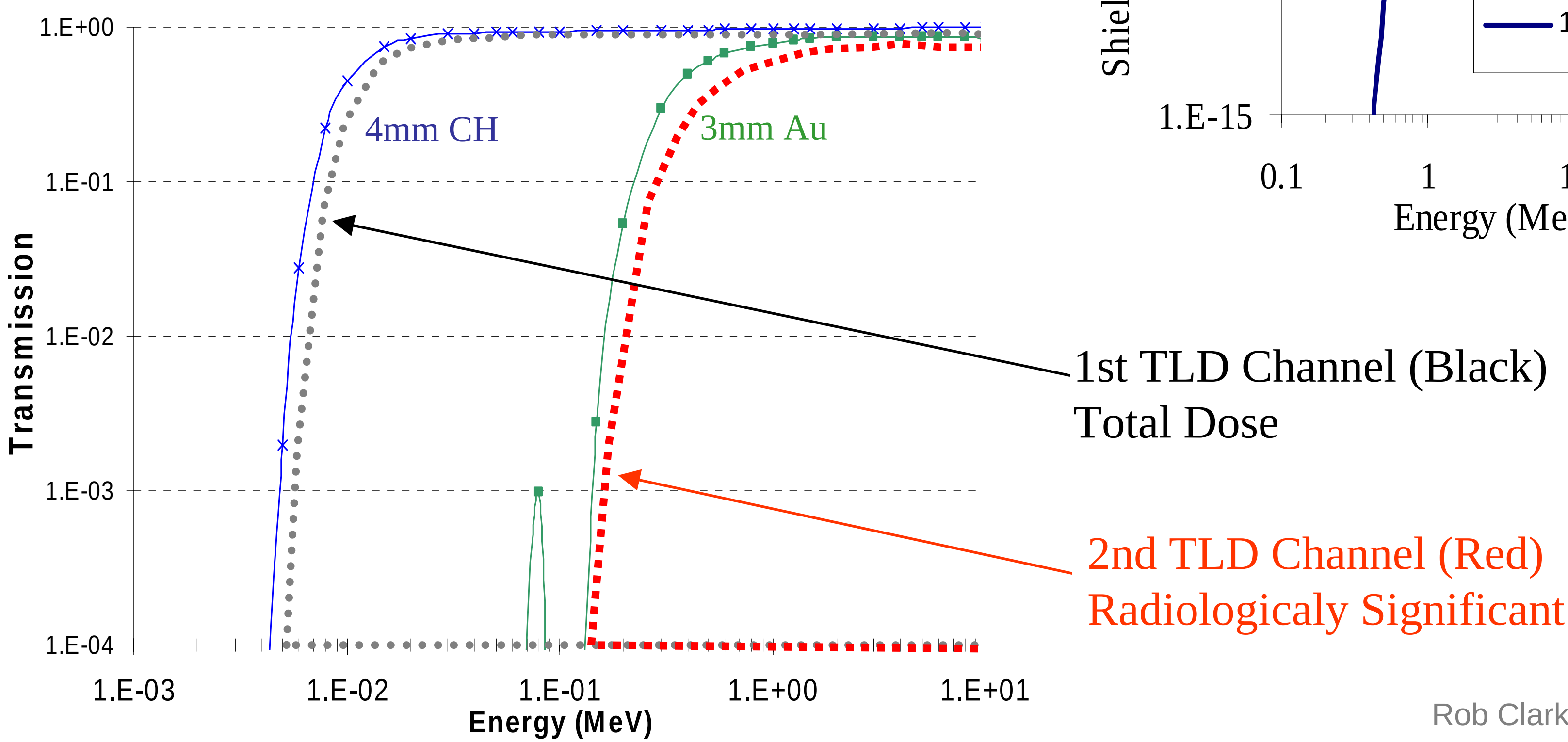
TLD measurements

Transmission of Radiation through target effects total dose measurements

Radiation < 300KeV cannot penetrate shielding





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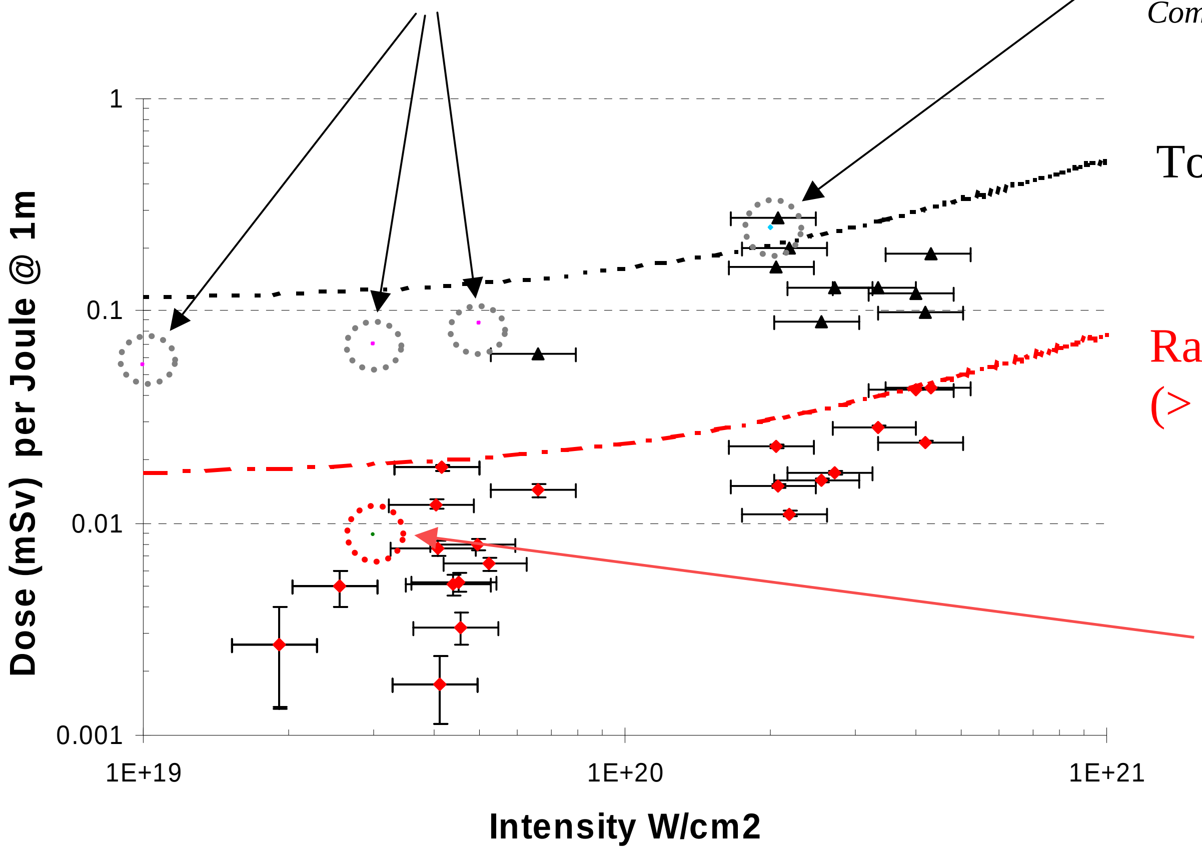
Collected Gamma Data

Calculations & Measured Data
Erik Lefebvre, CEA/DIF, France
Lasernet meeting on Radiation Protection
Sept 2003, Ecole Polytechnique

20mSv @ 1m raw dose, LLNL.

Communication with LLNL, 2000



Total Dose

Radiologicaly Significant Dose (> 300KeV)

42mSv @ 0.5m outside chamber, 150 shots, LULI.

Radiation Protection Dosimetry Vol. 102, #1 p61-70, 2002

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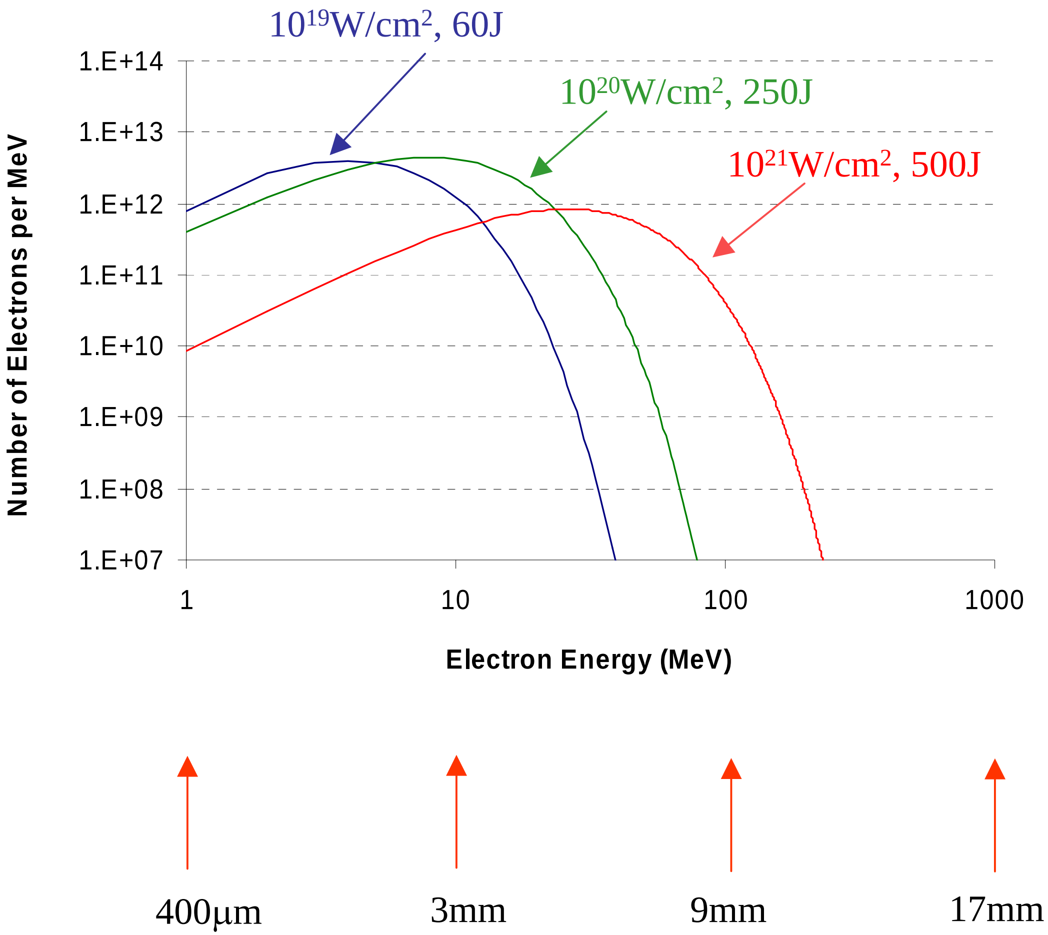
Electron Spectrum



Electron stopping range in Gold

Calculated electron spectrum shows a shift to higher energies as Intensity increases:

For thin targets, radiation emission decreases as number of electrons at lower energy decreases.

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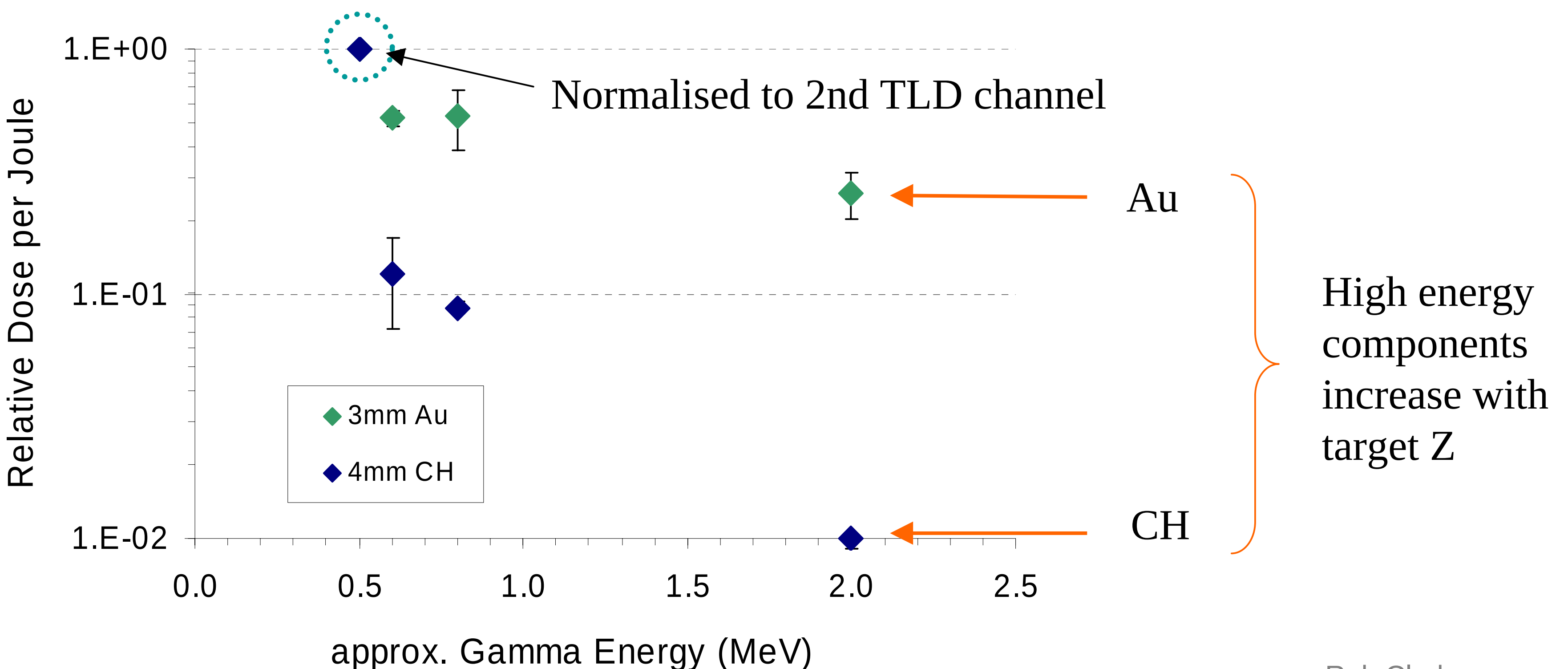
Spectral components

Low Z targets have less radiological impact due to the small contribution of high energy photons

Remember - Lead shielding peaks at 3MeV
Concrete at 20MeV



Forward Dose

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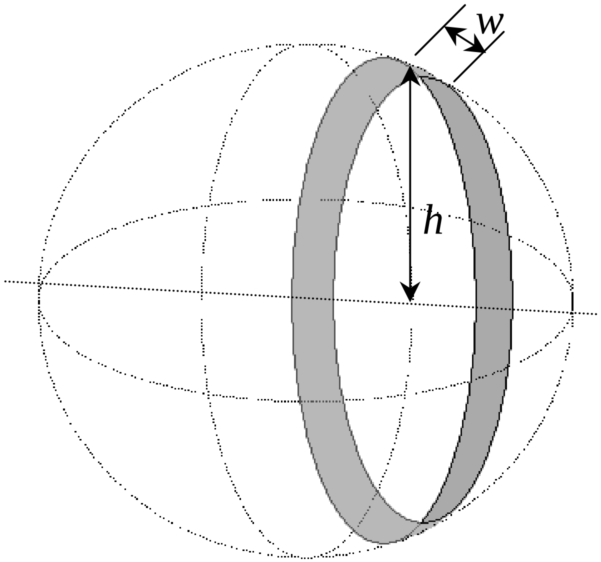
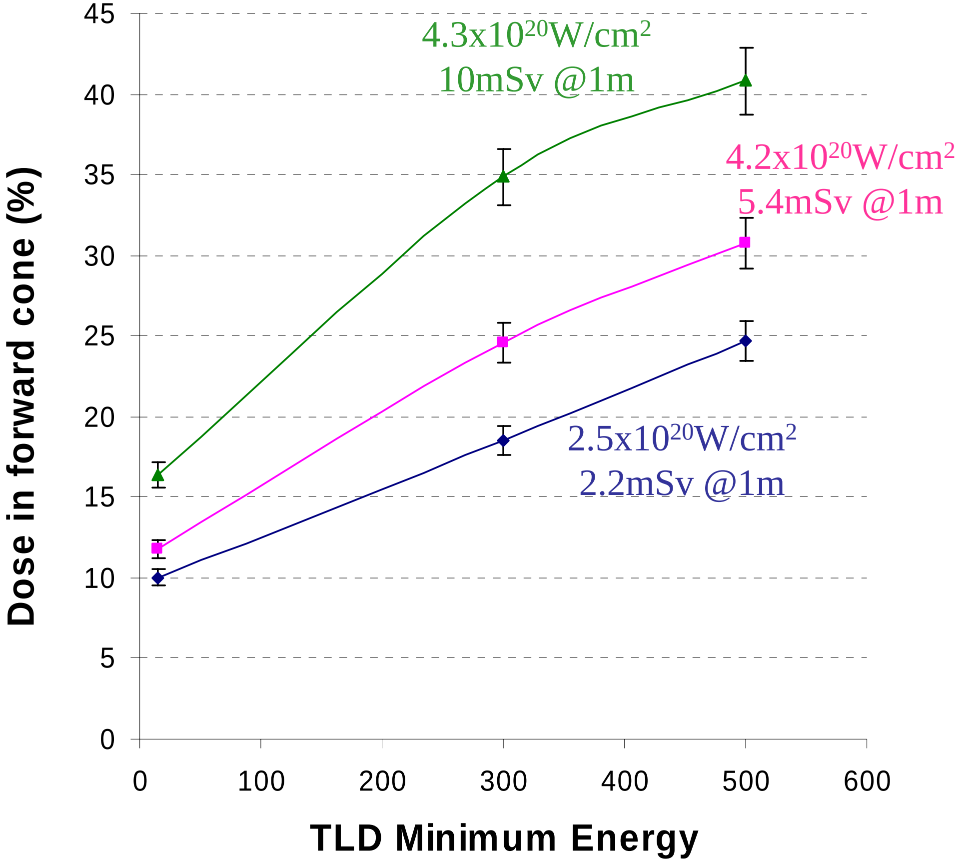
Up to 40% of High Energy components in forward cone

Only 15% of low energy in forward cone.

Importance of shielding over 360°





Area of segment (s) = $2\pi.h.w$

Integrated Dose $=\Sigma s_{n.}D_n$

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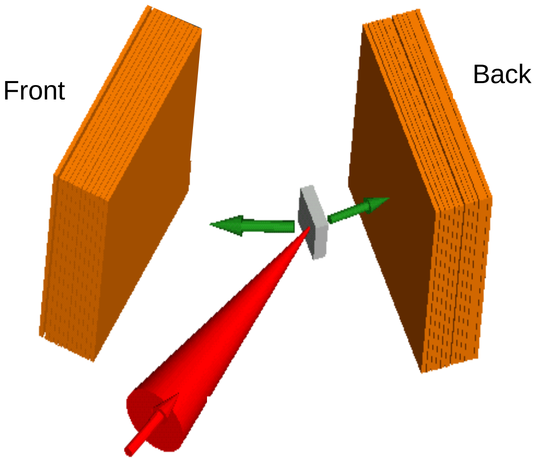
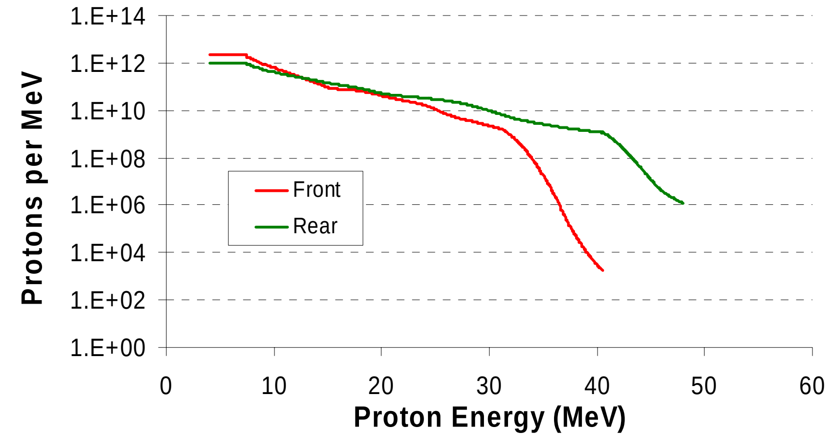
Proton Measurements

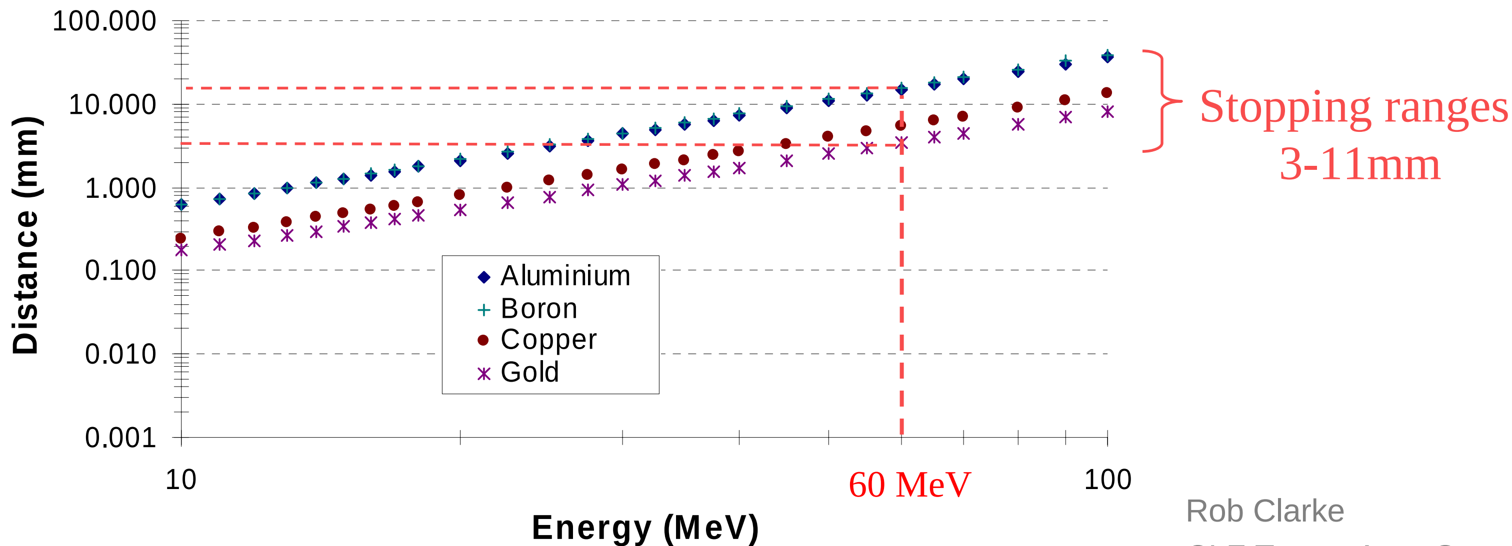
^{63}Cu (p,n) ^{63}Zn



3x10[20] W/cm[2] Optimised Proton shot



Proton Stopping ranges



K. Leddingham et al,
University of Strathclyde,
Glasgow

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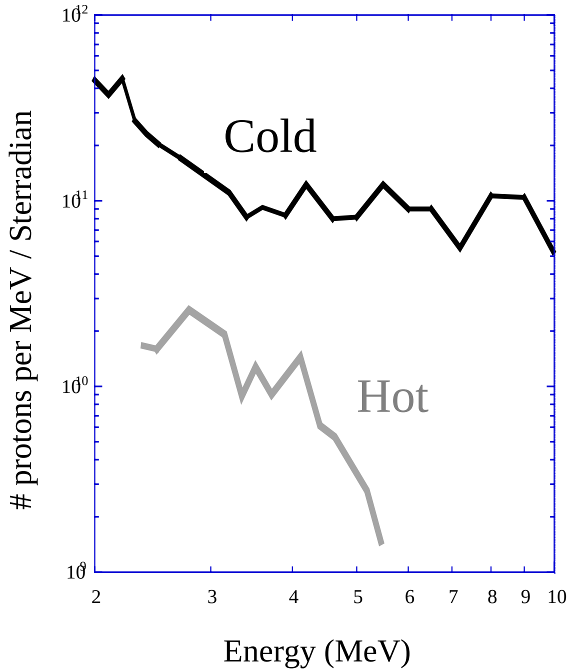
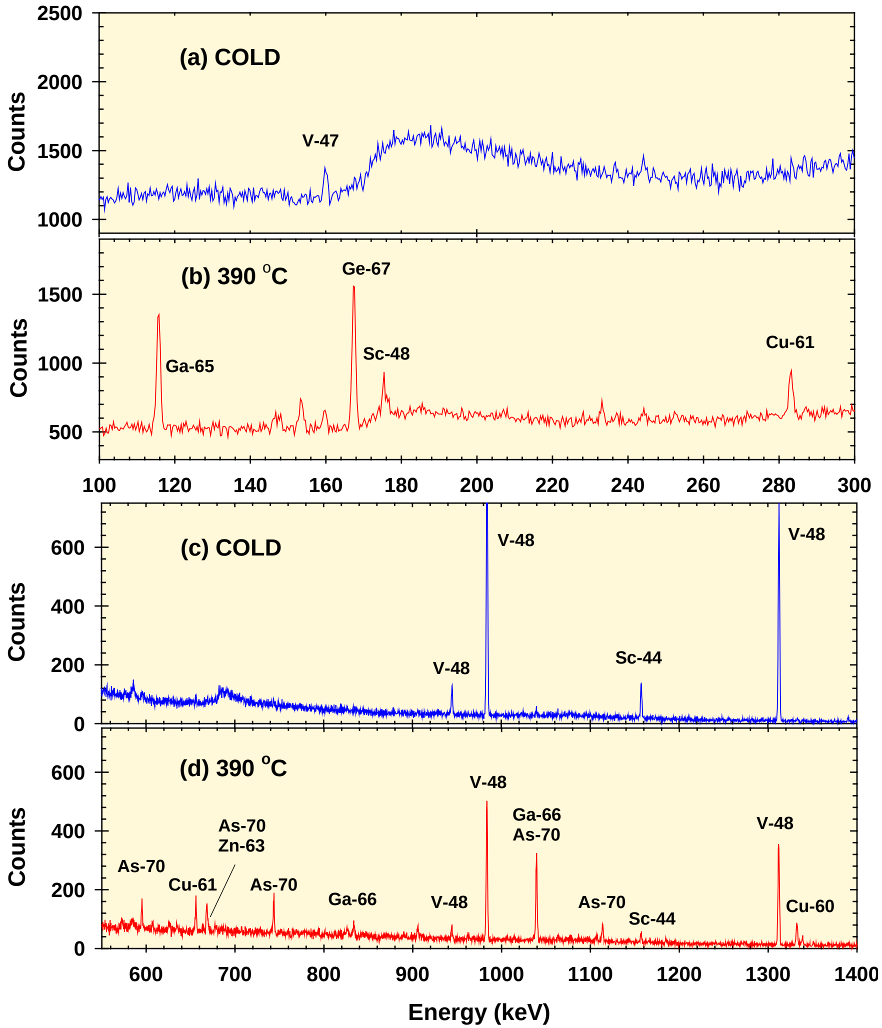
Proton Reduction

Proton reduction observed through target heating.

Heavy Ion reactions observed.

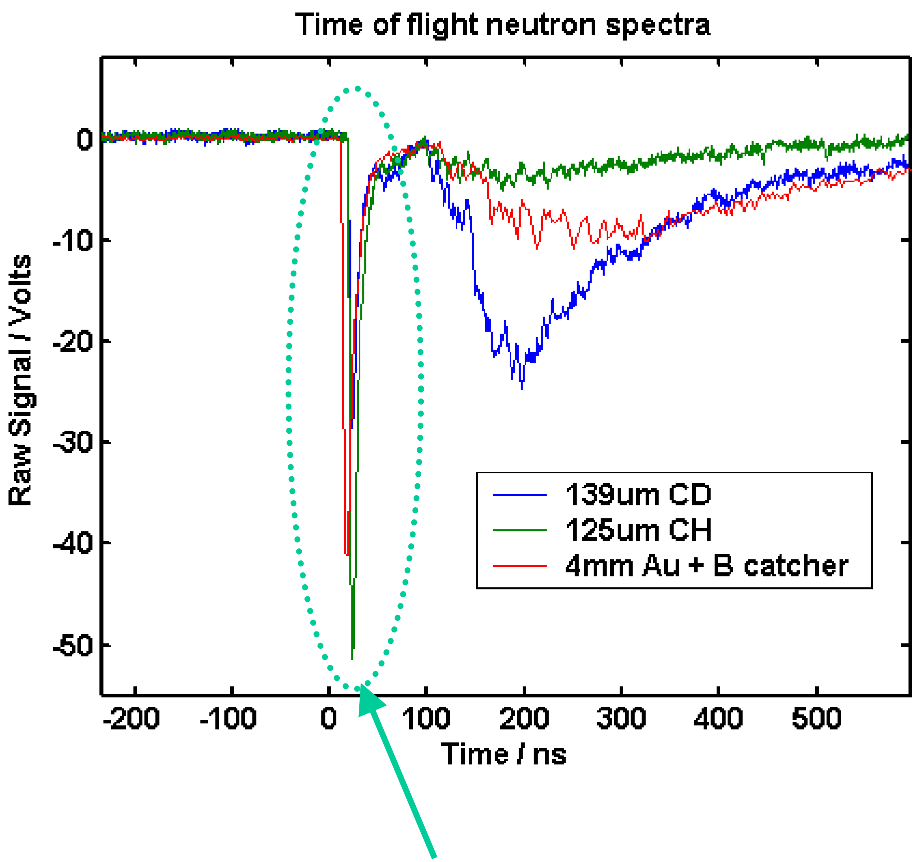




Imperial College London, University of Strathclyde
RAL 00-01 report

McKenna P, Ledingham KWD, McCanny T, et al.
Effect of Target Heating on Ion-induced reactions in High-Intensity Laser-Plasma Interactions
APPL PHYS LETT 83 (14): 2763-2765 OCT 6 2003

Neutron Generation



prompt gamma flash

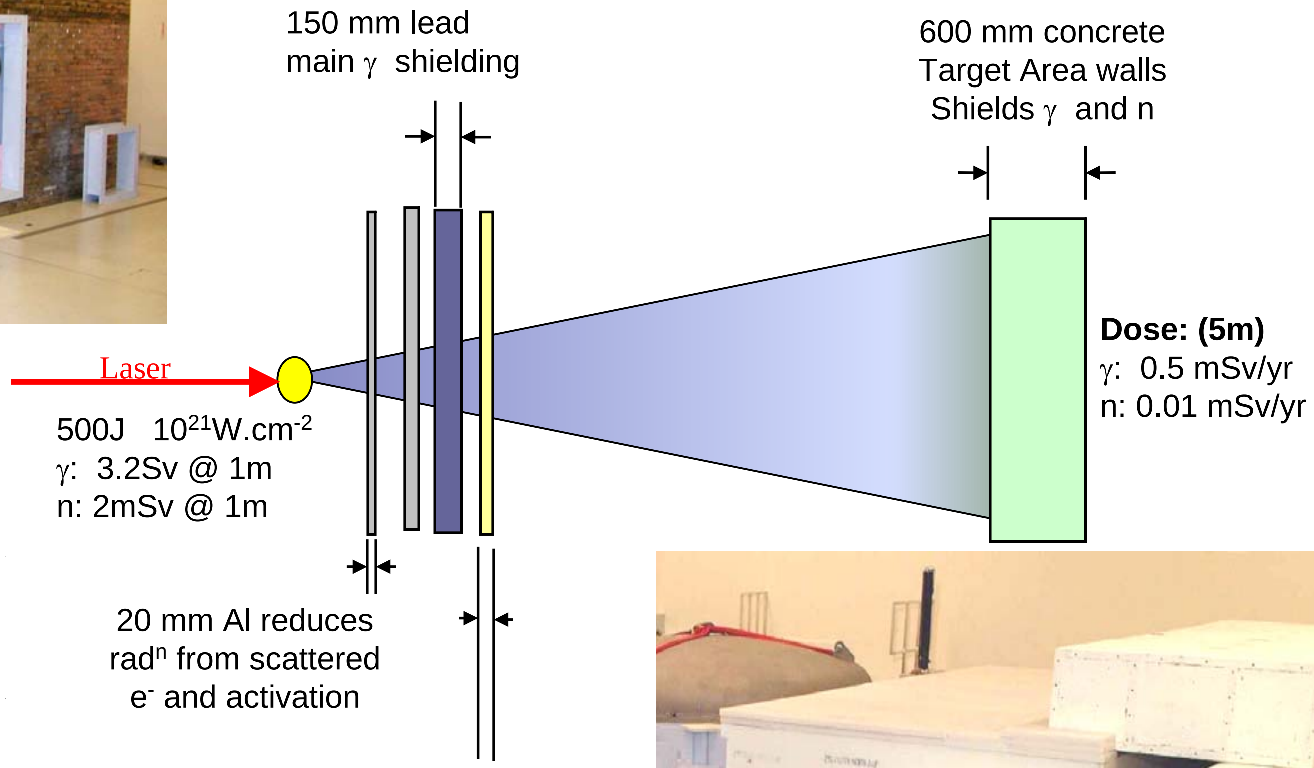
Estimates of 10^{10} - 10^{12} neutrons from Au targets with ^{11}B (p,n) ^{11}C reactions.

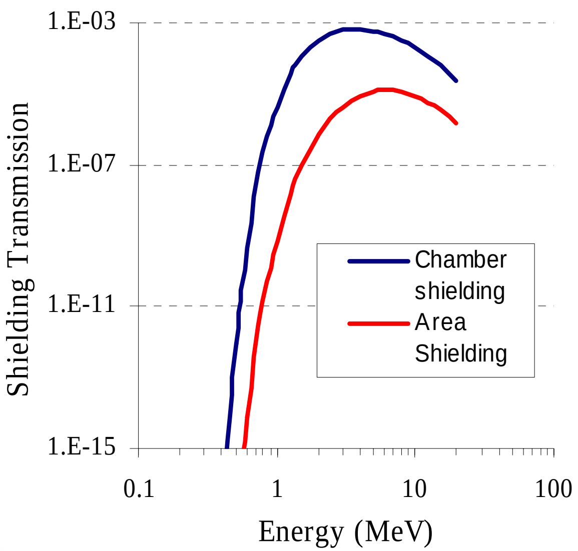
"Normal" neutron emission from targets less than that from secondary reactions.

Current mode detector
Vulcan PW shots:
CH shot – 220J
AU + front B catcher – 327J
CD shot – 255J

K. Lancaster, P. Norreys et al
RAL 2003

Petawatt Chamber Shielding





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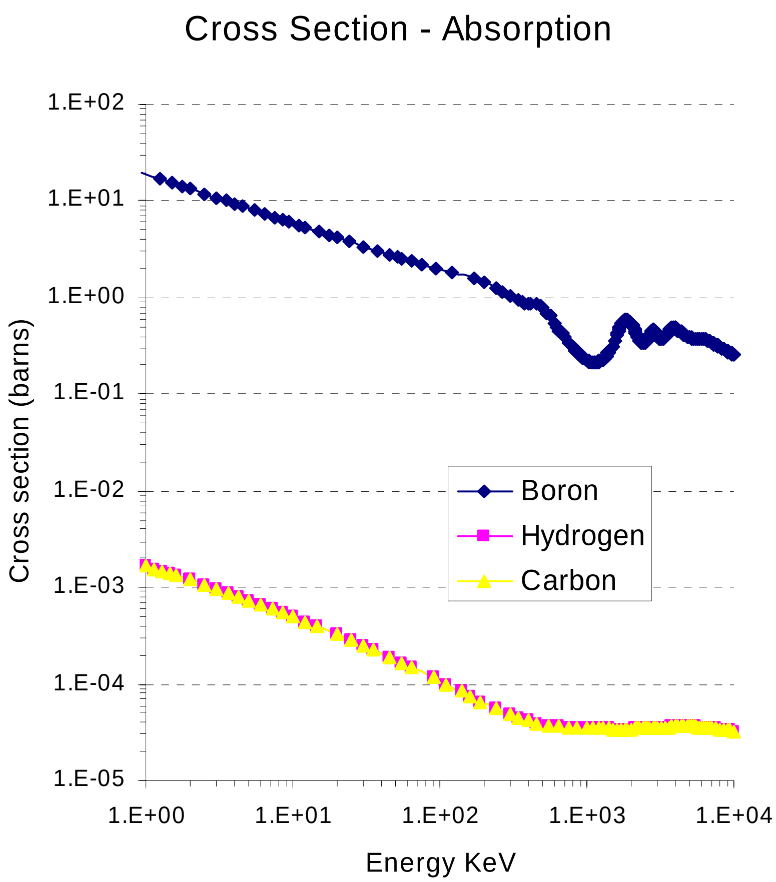
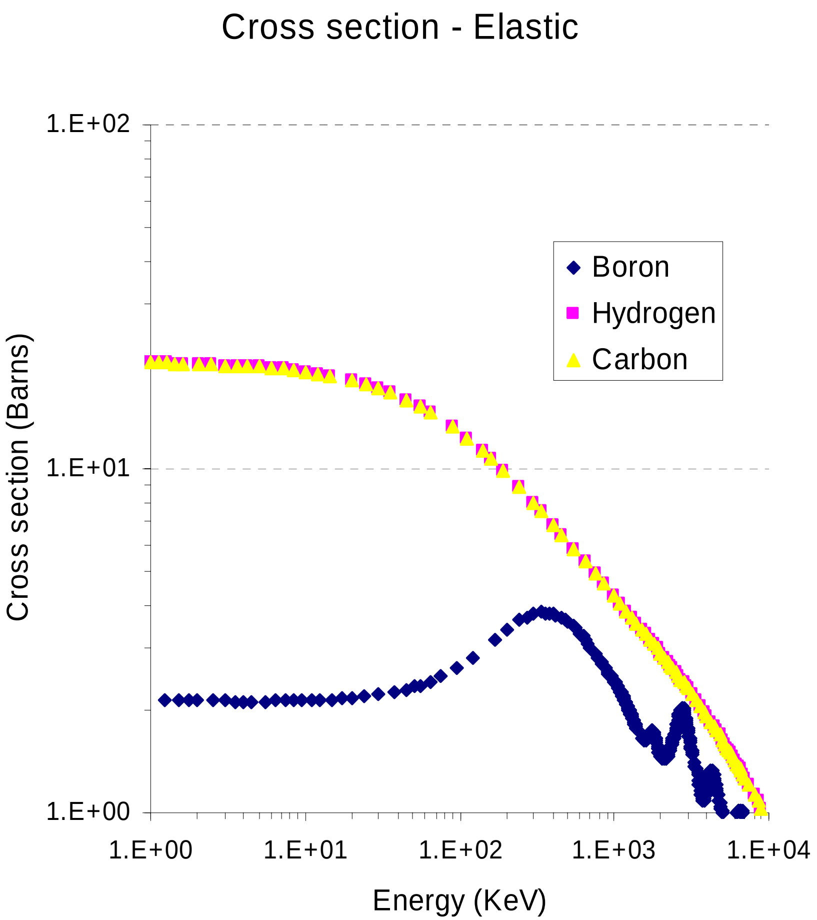
Neutron Cross-sections





Addition of 5% Boron provides increased neutron absorption.
Hydrogen & Carbon provide scattering.

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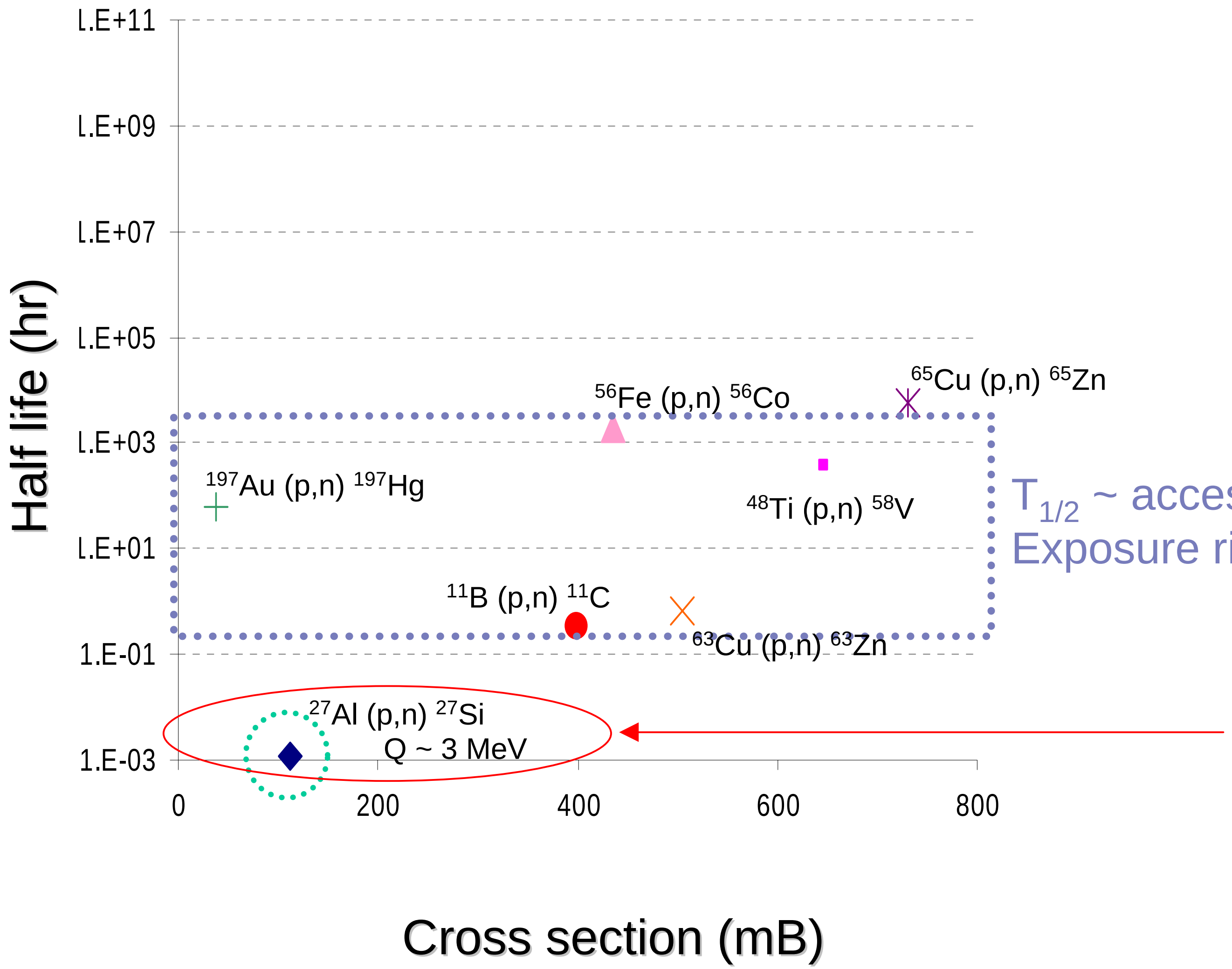
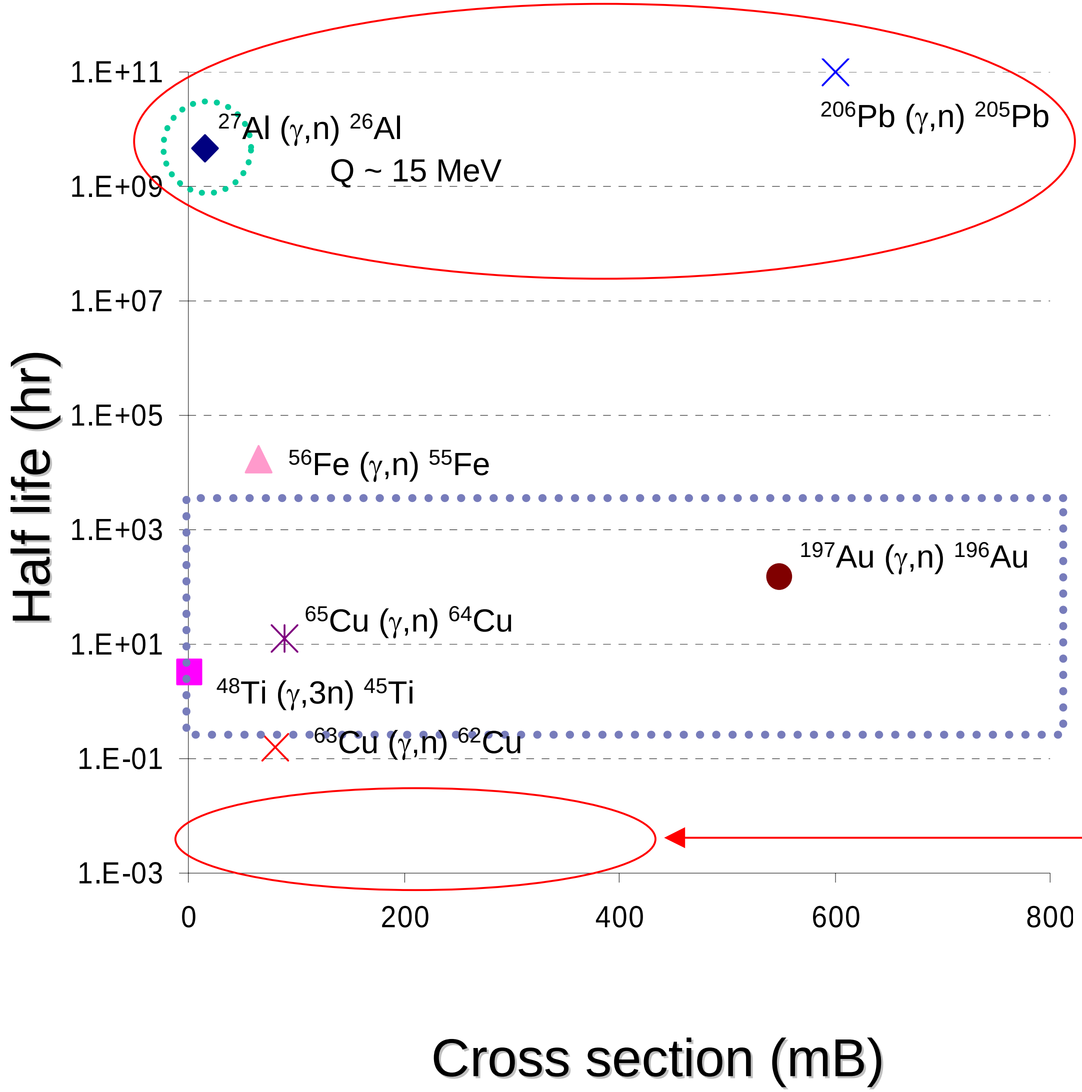
p,n Reactions



$T_{1/2}$ ~ access periods.
Exposure risks

Optimum Material choice
- Low cross-section
- Short half life

γ,n Reactions

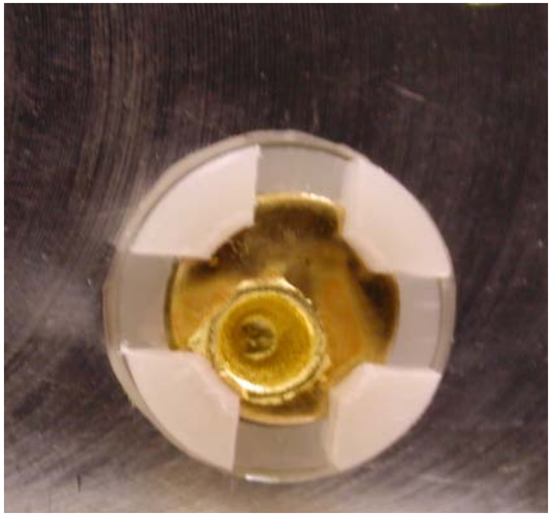


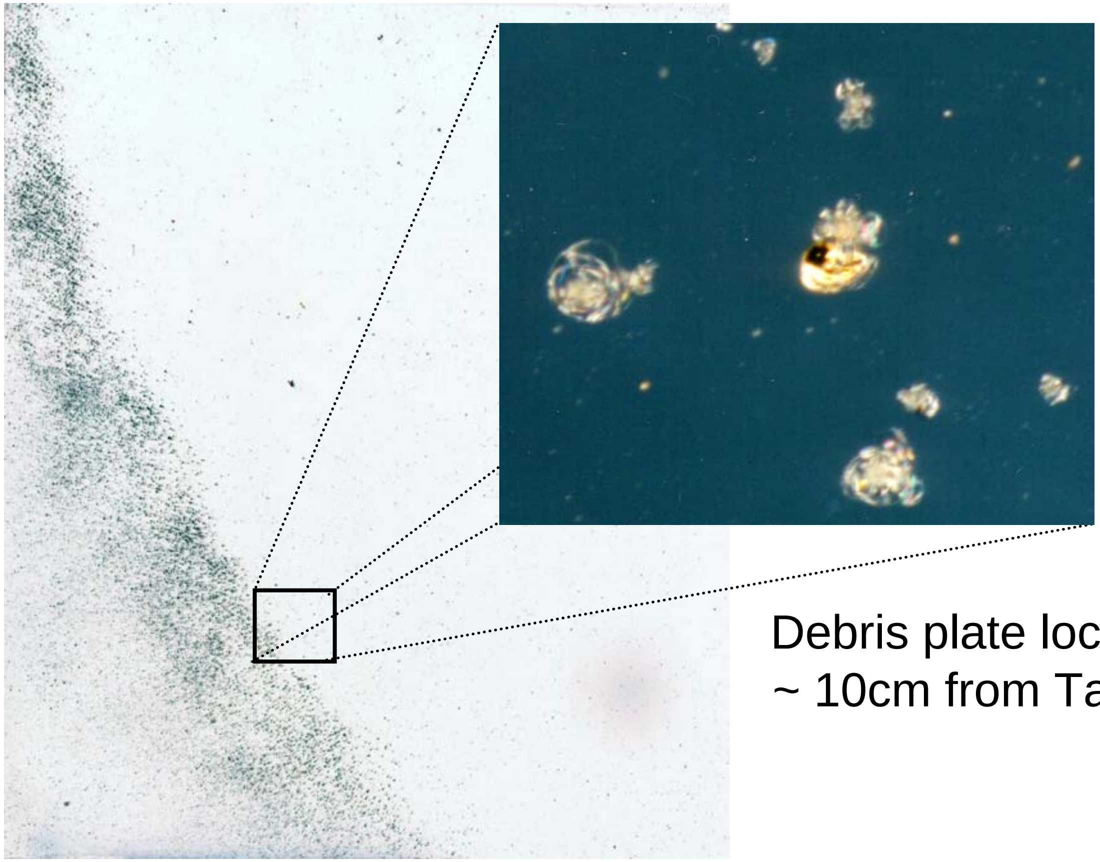
Long term issues
- Low dose rates
- Long-term build-up

$T_{1/2}$ ~ access periods.
Exposure risks

Optimum Material choice
- Low cross-section
- Short half life

Activated Debris





Debris plate located ~ 10cm from Target

Active debris from up to 30μSv/hr @ 10cm

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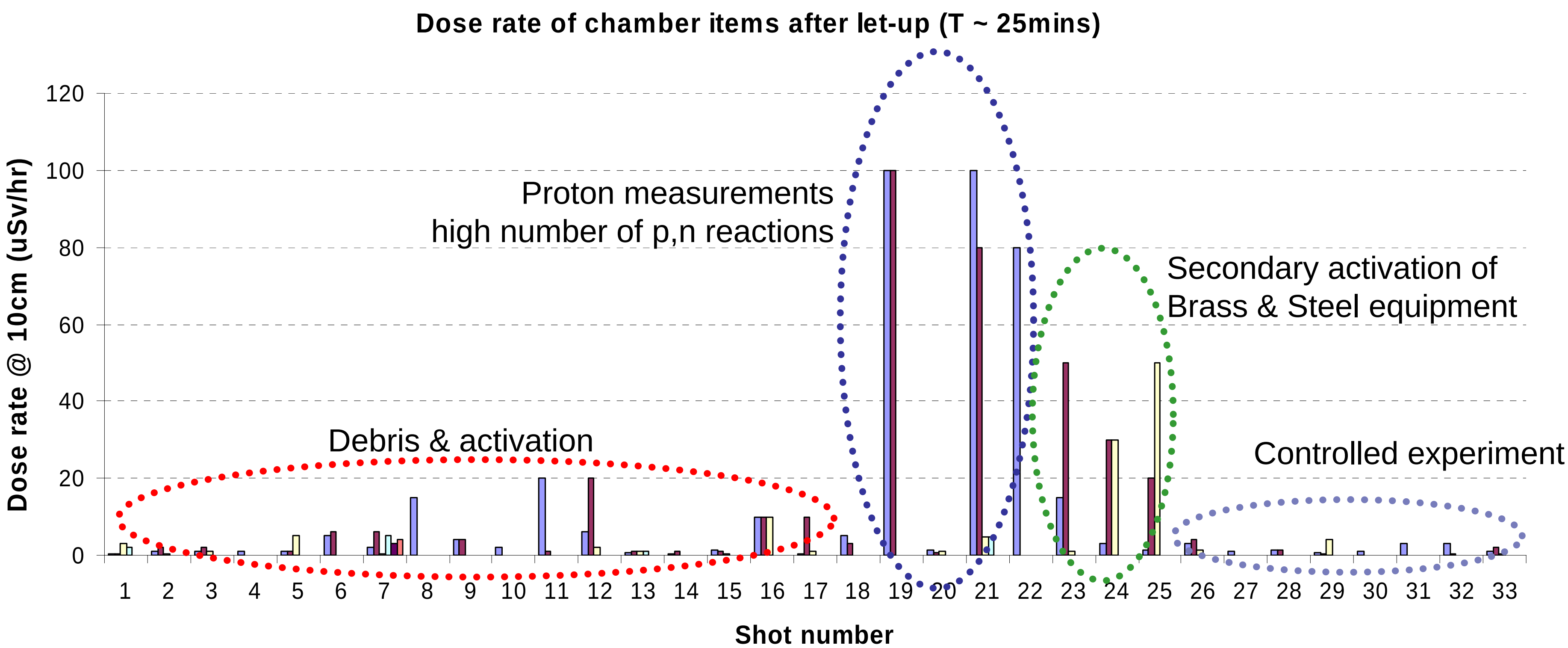
Activation Measurements

p,(x)n p,p+(x)n
p,γ γ,(x)n

n,(x)n n,n+α
n,γ n,(x)p
n,α n,d



Material Selection to Reduce Neutron Activation in a Petawatt Laser Target Chamber
Myung Chul Jo, Steven Oberg, Environmental Health & Safety, University of Nevada
William McCarthy, Massachusetts Institute of Technology
ILSC 2003 Conference Proceedings p201

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Control Methods

- **Target Chamber entry points generate shielding problems**
  - *Bunker design preferred to localised shielding*

- **High level of activation encountered**
  - *Radiological monitoring of experimental personnel*
  - *Multiple target mounts*
  - *Remote Insertion Devices*

- **Choice of engineering materials extremely important**
  - *Aluminium is a good material, but careful of impurities & long half-life issues*
  - *Steel has Chromium content (usually @15%)*

^{52}Cr (p,n) $^{52(m)}$Mn *($T_{1/2}$ ~ 21 min, σ=550mB, Q ~ 7MeV)*

High repetition facilities

- Quickly build up activity from secondary reactions.
  - *Choose Materials* $T_{1/2}$ << *laser Repetition*
  or with high activation thresholds (Q-value)

- Design Facility with long term activation in mind
  - *Removable chamber lining / catcher plates*

- Low energy means low γ emission
  but large number of shots

Conclusion

- Radiological Impact of primary γ,p,n doses becoming understood.
- Primary activation at RAL from p,(x)n reactions.
- Investigations into neutron activation at other facilities
- Primary shielding in forward direction for high energy photons
- Secondary shielding to protect from lower energies & scattered radiation