ALD of SnO_2 as the active component of a Plastic Microchannel-Based Direct Fast Neutron Detector

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Outline

- Arradiance and the Microchannel Plate Amplifier (MCP)
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  - Timing
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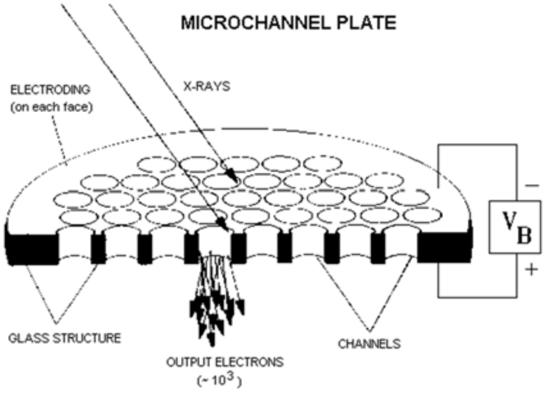
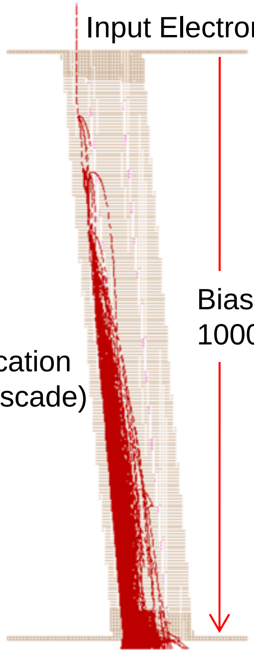
What is a Micro Channel Amplifier?

Very Fast – Very Low Noise - Charged Particle Amplifier



Single Micro Channel Amplifier



Input Electron

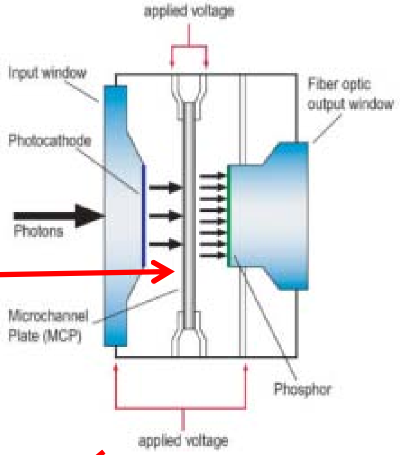
Bias
1000 V

Amplification
(SE Cascade)

High Gain up to 1e6
Low noise – Very fast
Pico Second Response

Micro Channel Plate
(MCP -Array of pores)

Micro Channel Plate
Used In Light Amplification

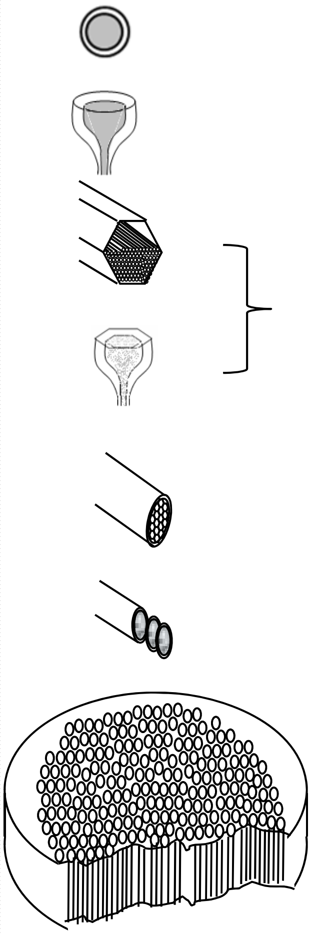


Finished Night Vision Tube

NV Application

A 50 year old MEMS Process

Substrate Fabrication



1” Etch-able Core
Lead Glass Rod

Draw Tower

Stacked
Draw Tower
Repeated

Boule
5-100mm Dia

Diced
0.2-0.3 mm thick

Etched
Producing >5M
2-10 um pores

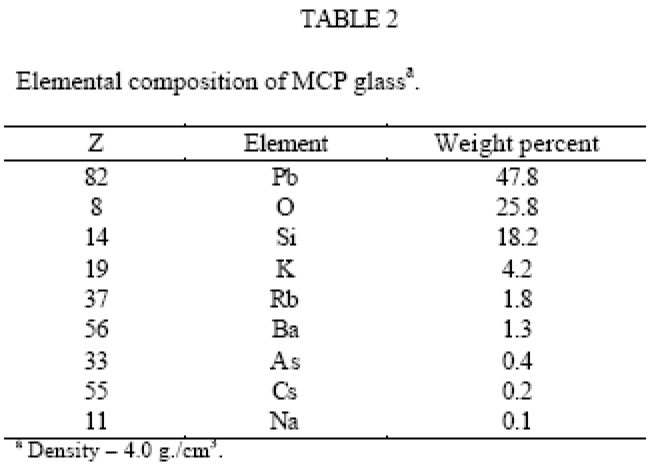


TABLE 2

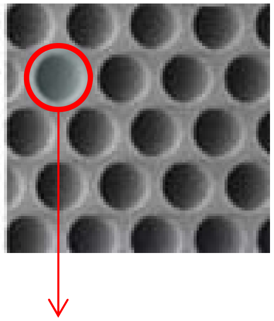
Elemental composition of MCP glass[a].

Z	Element	Weight percent
82	Pb	47.8
8	O	25.8
14	Si	18.2
19	K	4.2
37	Rb	1.8
56	Ba	1.3
33	As	0.4
55	Cs	0.2
11	Na	0.1

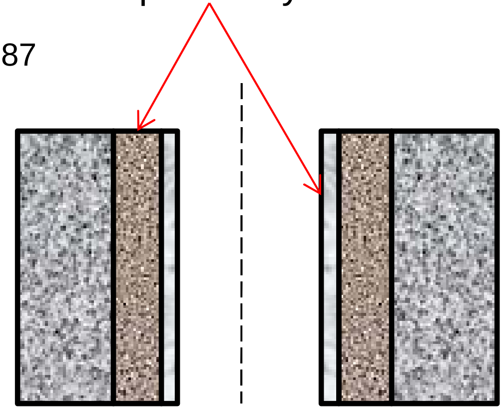
[a] Density – 4.0 g./cm^3.

Wiza, Nuclear Inst. & Meth., Vol 162, 1979, 587

Substrate Functionalize

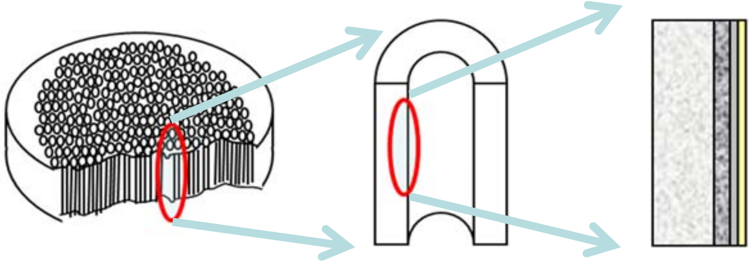


Furnace H_2 Firing
Both conduction and emission layer produced simultaneously;
cannot be optimized independently

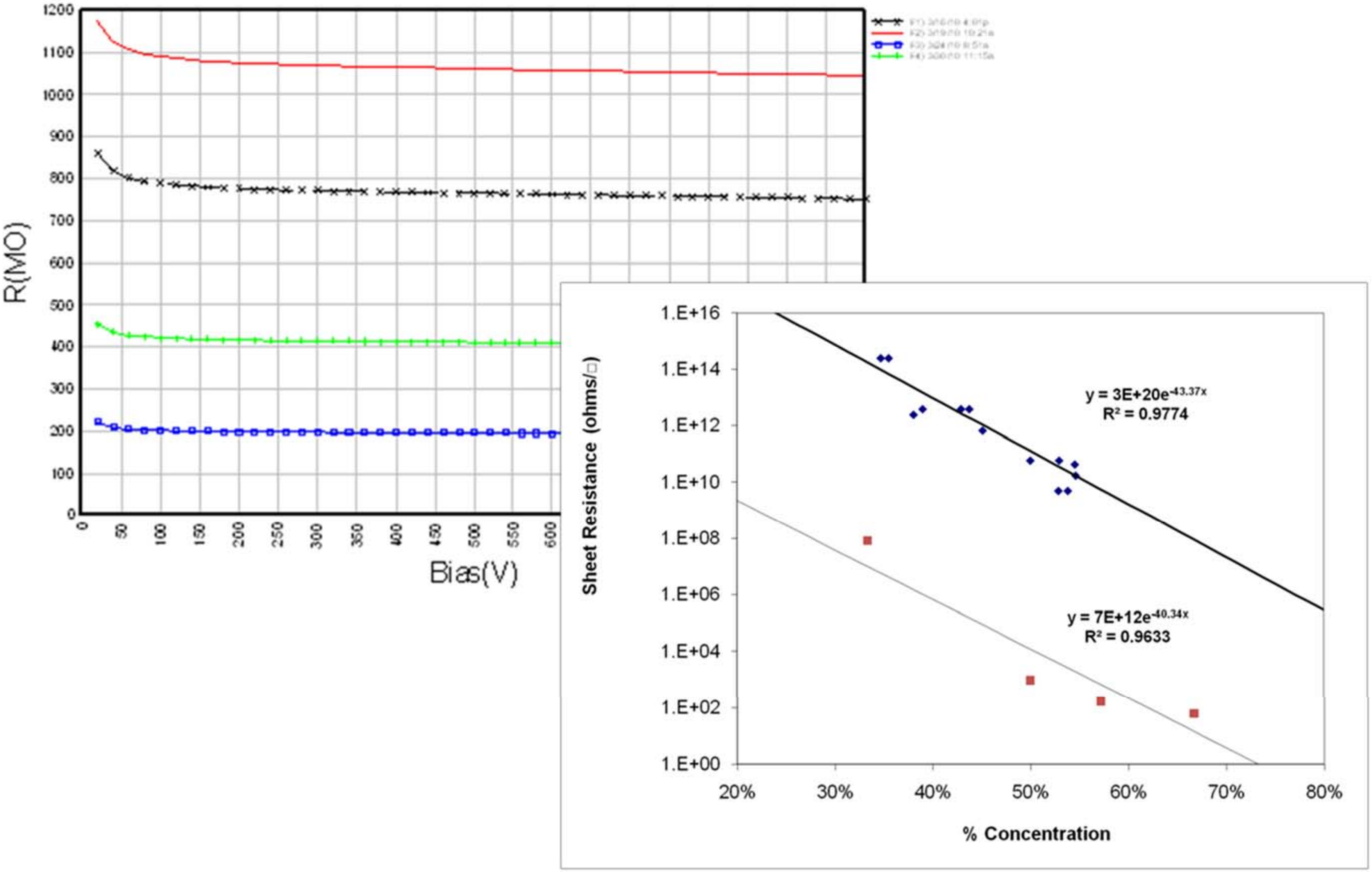


Arradiance MCP Technology

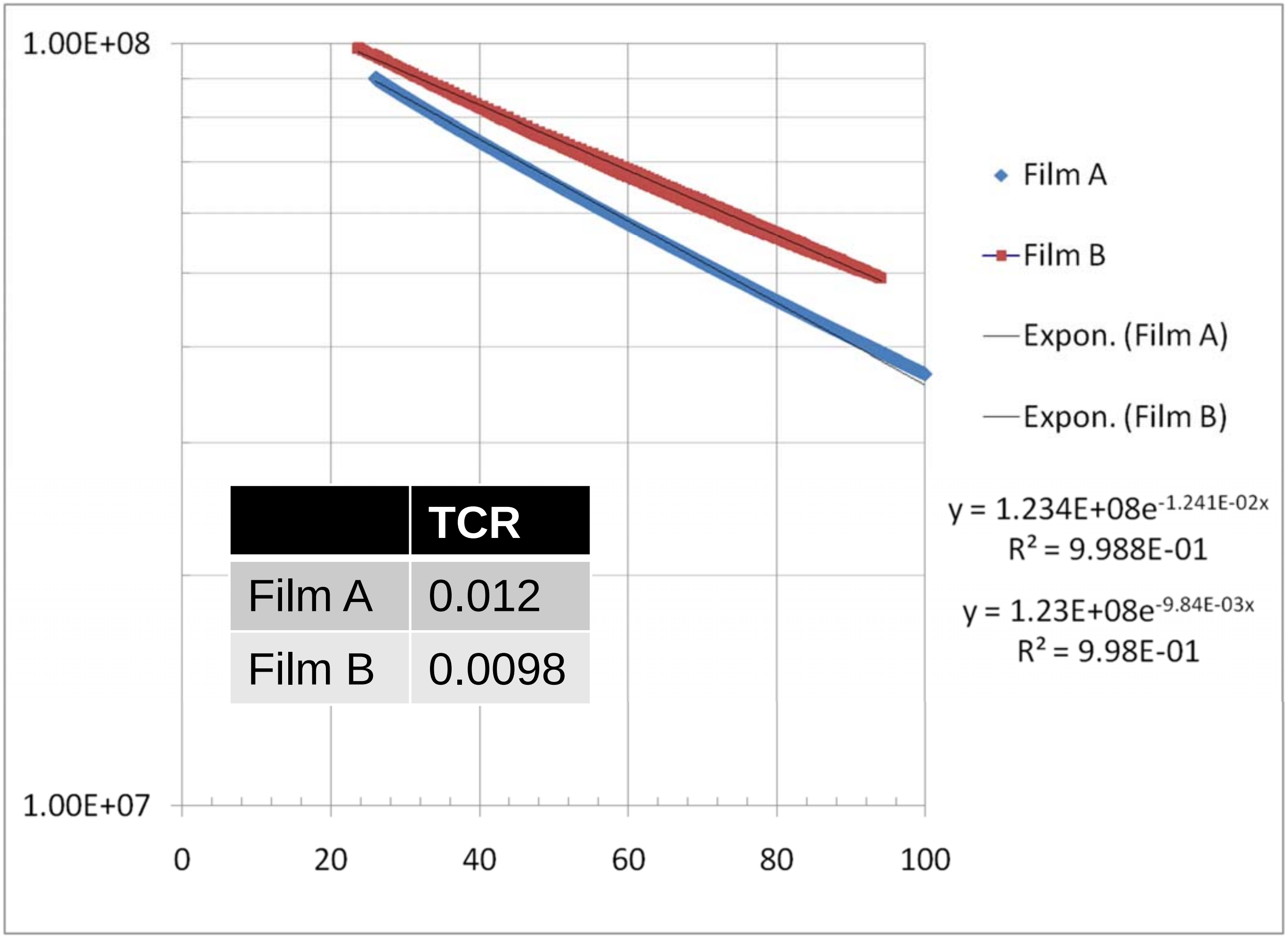
- Substrate
  - Rigid and electrically insulating
- Conductive layer
  - ~10^{13} - 10^{14} Ohms/Sq
  - Conformal & uniform up to 200 : 1
    - Thickness and Resistivity
  - Low field effects = Low TCR
- Emissive layer
  - Conformal & uniform
  - High secondary yield
    - Contaminants can effect yield
- MCP Device
  - High Gain
  - Resistance stability and matching
  - Stable gain following “scrub”
  - Low outgassing



Process: Conductive film



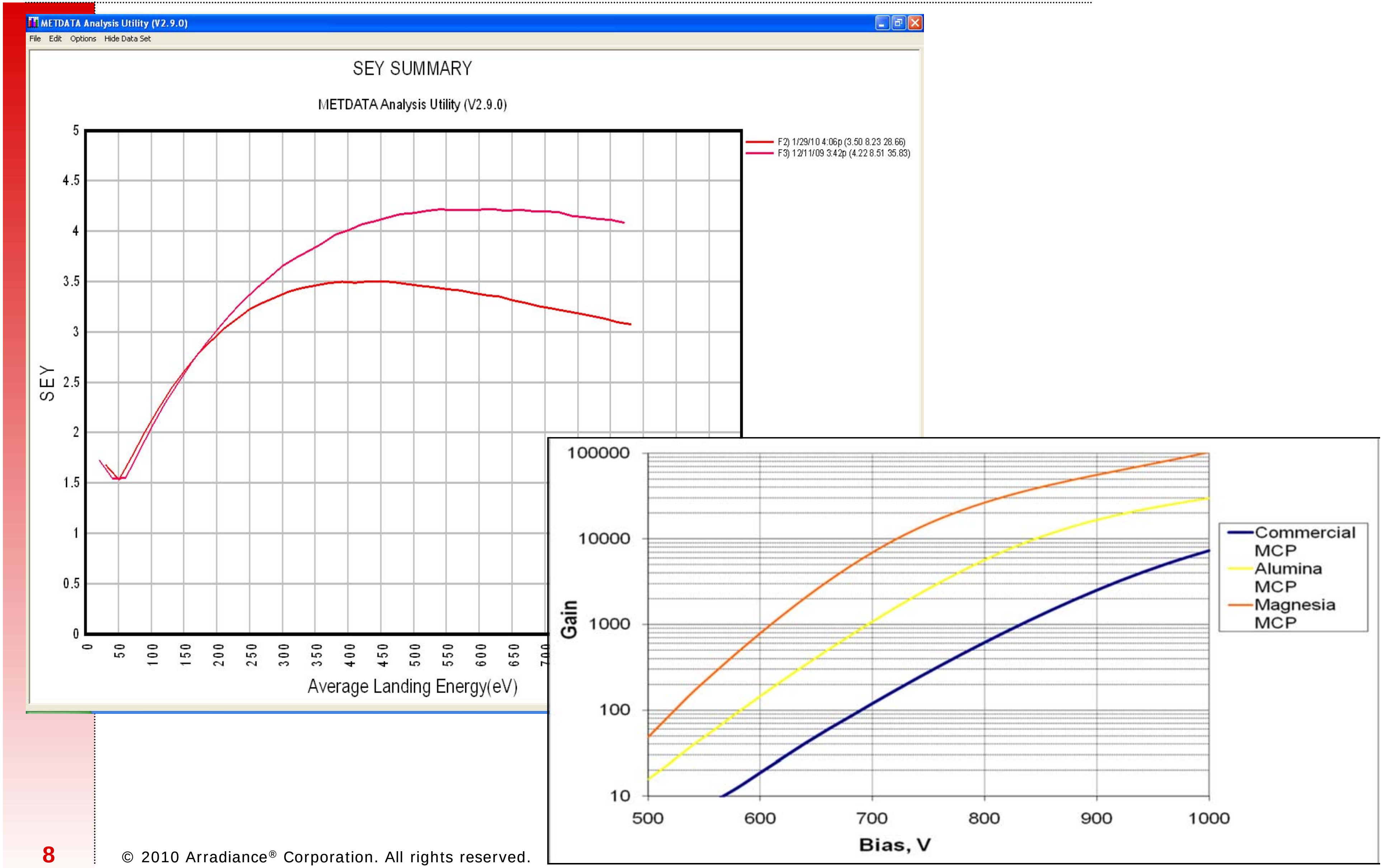
Process: Conductive film - TCR



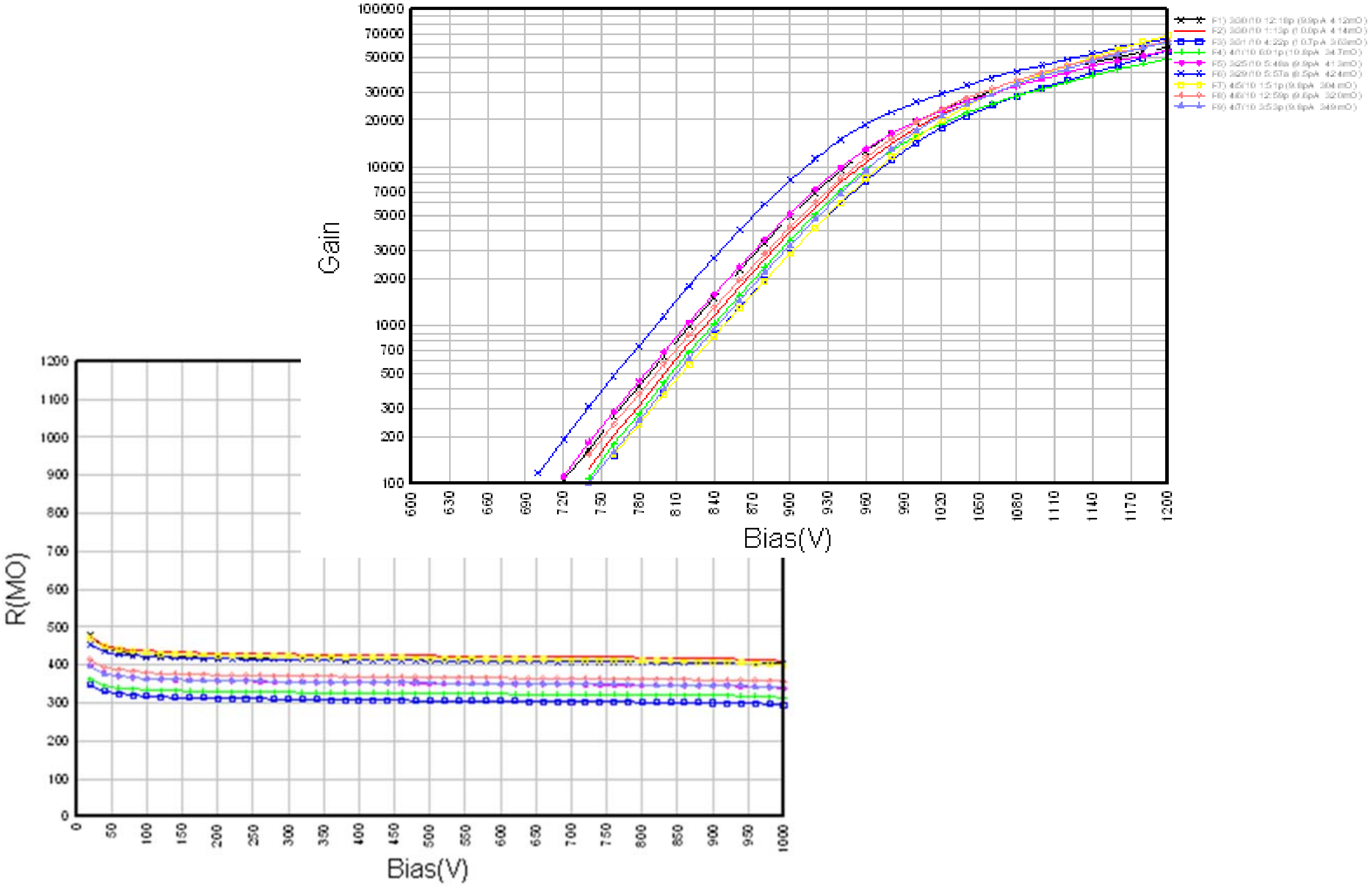
	TCR
Film A	0.012
Film B	0.0098

Thermal coefficient of resistance on par (Bτ < 0.01) with current state-of-the-art for two Arradiance conductive films

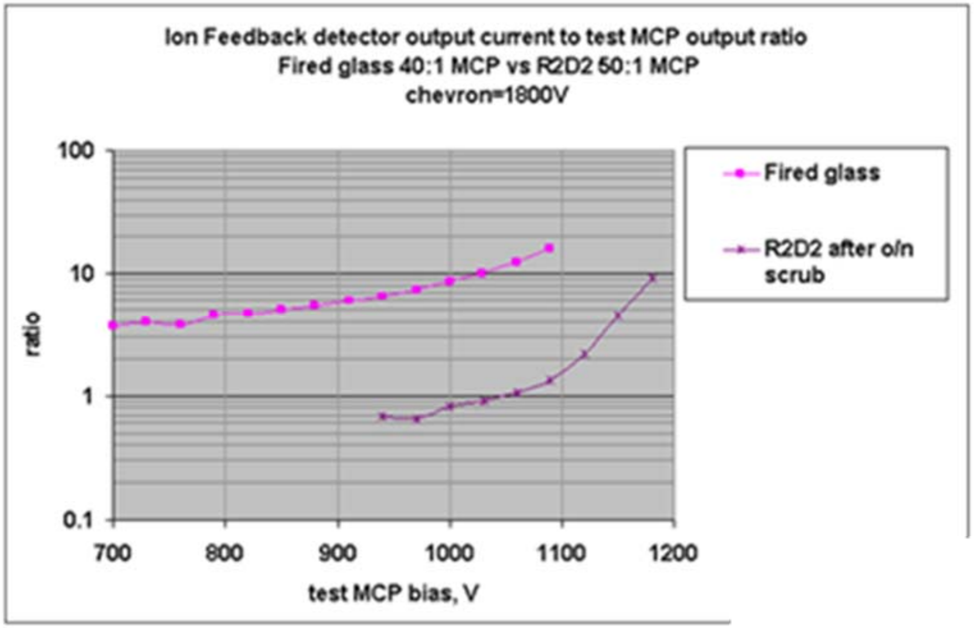
Process: Secondary electron yield & device gain



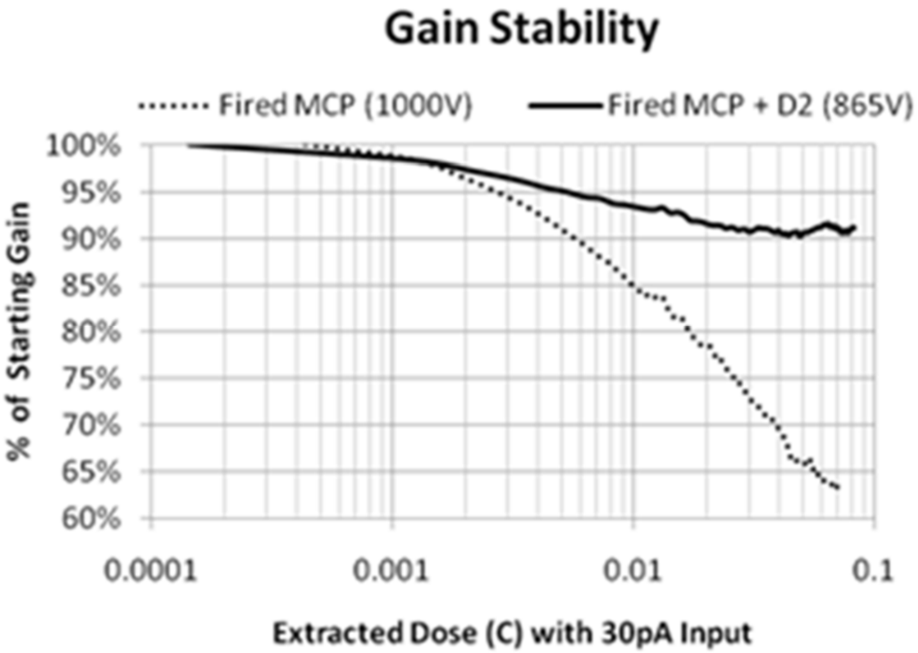
Results - Incom 66:1, 20um, 60% OAR
March 2010



Improved Lifetime of Thin Film MCP over Conventional



- Reduced ion feedback
  - Reduce diffusion of mobile ions
- Sustained emission layer response with extracted dose



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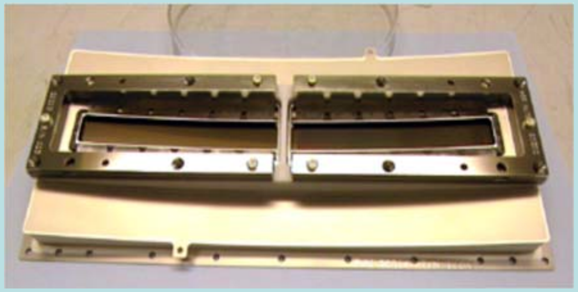
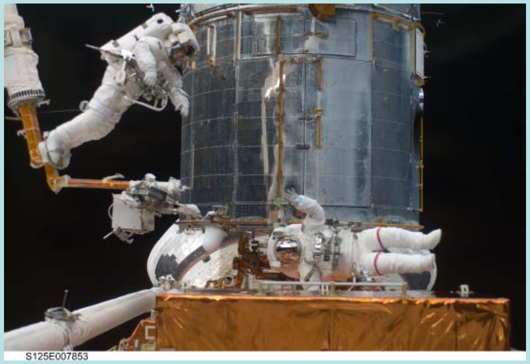
Motivation in Two Parts

- Scientific Curiosity
  - All microchannel plate amplifiers on the market are made from a glass substrate
  - Can Arradiance make an MCP out of a seemingly more challenging material like plastic?
  - Is there a way to make our high temperature MCP films compatible with plastic?
  - What could a functioning plastic MCP be used for?
    - Large area robust MCPs?
    - MCP-PMTs?
    - Detectors?
- Revenue Generating Applications
  - Detection of Special Nuclear Materials
  - Fast neutron counting/spectroscopy

Plastic MCP Applications

Large area MCP (current)





COS detector Hubble telescope

Plastic MCPs are robust and can be potentially be made in large areas for less cost

Market (now): $100k/year

Large Area(>4”) MCP-PMT (Future)


*


‡

Homeland security X-Ray detection: $100M/year

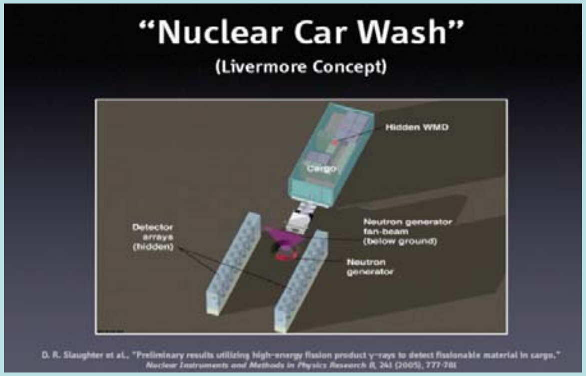
Medical Imaging: $200M/year

Scientific (DUSEL et al): $20-50M/year.

*BURLE TECHNOLOGIES, INC.
http://www.burle.com/mcp_pmts.htm

‡ Philips Healthcare

Nuclear Detection



“Nuclear Car Wash”

(Livermore Concept)

D. R. Slaughter et al., "Preliminary results utilizing high-energy fission product γ-rays to detect fissionable material in cargo," *Nuclear Instruments and Methods in Physics Research B*, 241 (2005), 777-781

Active Scanning

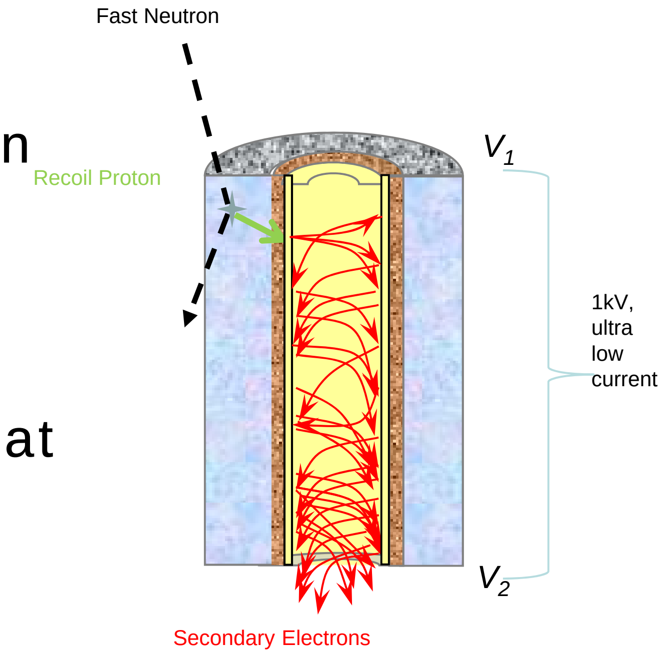
Passive Scanning

Neutron-proton interaction yields detection capabilities

Potential replacement candidate for He-3 detectors
Market: >$1B/year

SNM detection technology overview

- Hydrogen-rich PMMA microchannel structure
- Graded Temperature ALD deposition
    - Active films deposition at 140C
- Neutron-proton recoil reaction within plastic at better than 1% efficiency
- Proton initiated secondary electron cascade
- Output pulse $10^3 – 10^6$ electrons
- Standard readout electronics
- Technology scalable to large format



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Some polymer candidates and a precursor candidate

Material	Tg	MP	CTE	Water Absorption	H Content (mol H/cm^3)	Is Substrate Manufacturable?
Radel-R5000 (a polyphenylsulfone)	220°C	360°C	56 µm/m-°C	0.4%	0.018	No
PMMA	105°C	160°C	75 µm/m-°C	0.3%	**0.094**	Yes
HDP Polyethylene	-78°C	130°C	25 µm/m-°C	0.05%	0.073	Yes
Polypropylene	-10°C	165°C	90 µm/m-°C	0.01%	**0.128**	Work in progress

- SnO_2 as conductive layer, Al_2O_3 as emission layer
- Tin (II) cyclic stannylene – Gordon group Harvard
  - 30 Torr at 60˚C
  - Reacts readily with hydrogen peroxide
  - **ALD window 50-150˚C**
  - Conductive
  - Compatible with TMA

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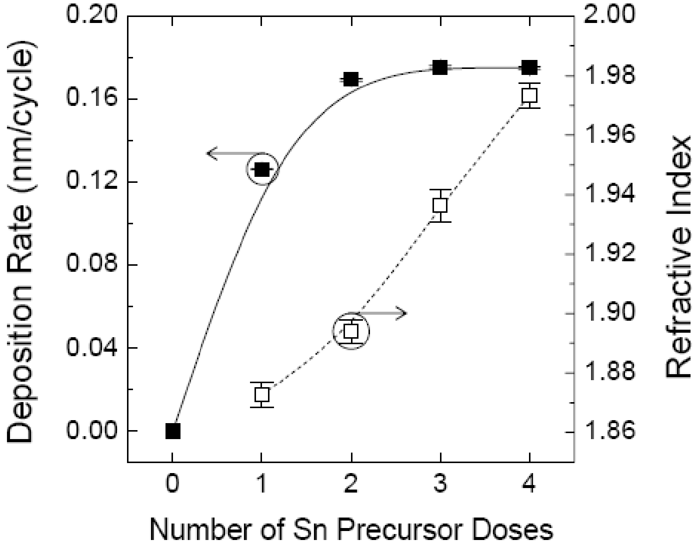
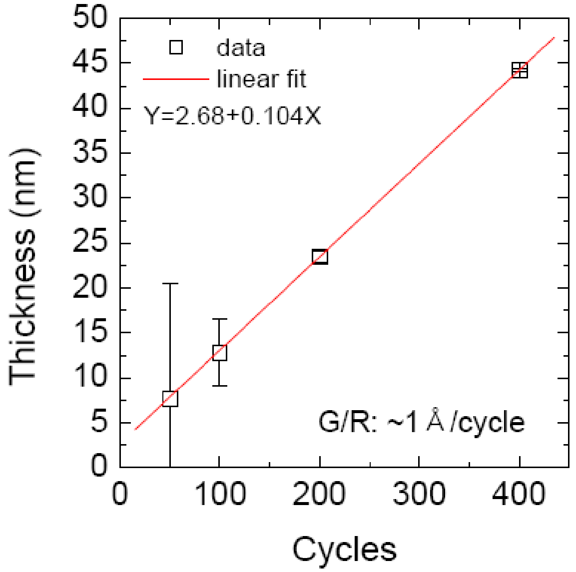
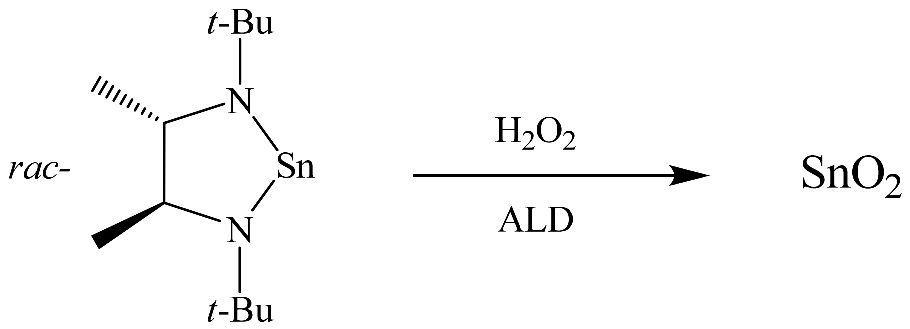
SnO_2 ALD


(1) Sn precursor saturation

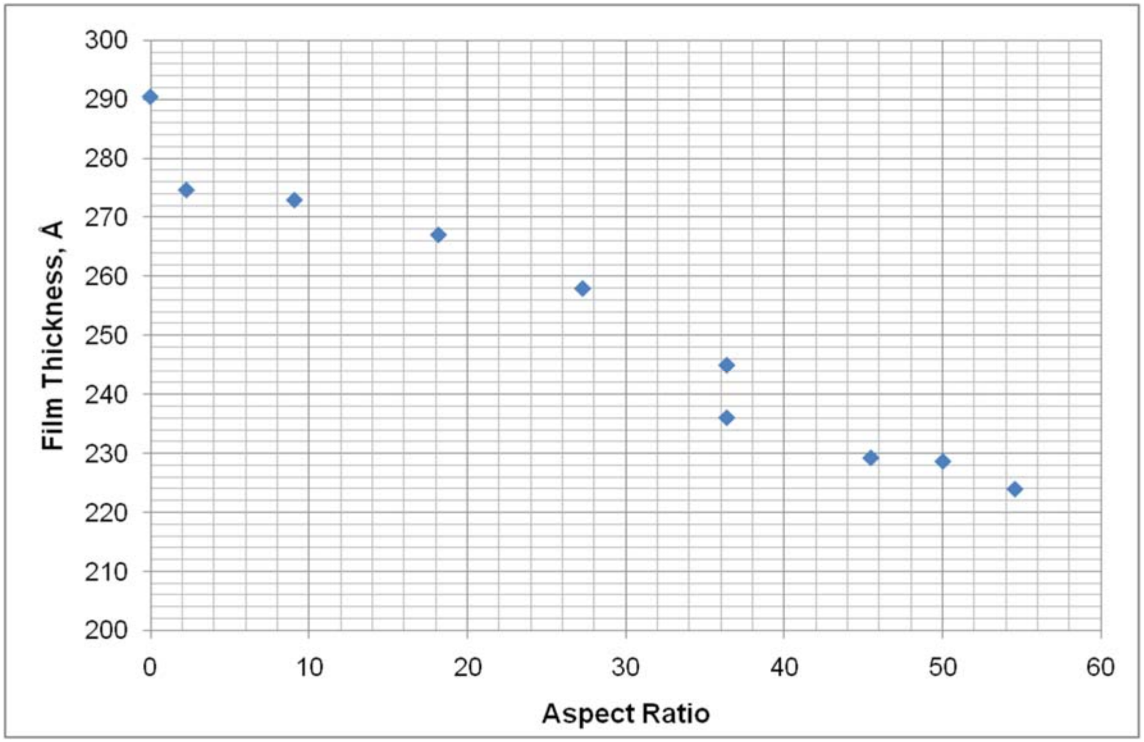

(2) AlOx test @120C (TMA+H_2O_2)



For further discussion of ALD characteristics of this precursor system see talks given by Roy Gordon ALD 2010 and Adam Hock ALD 2010

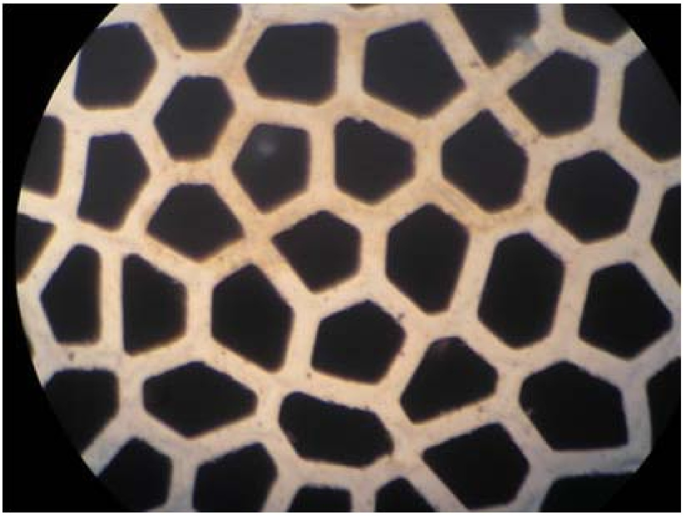
Properties vs Aspect Ratio

- Nanolaminate structure of SnO_2 and Al_2O_3
- Deposition temp 85°C

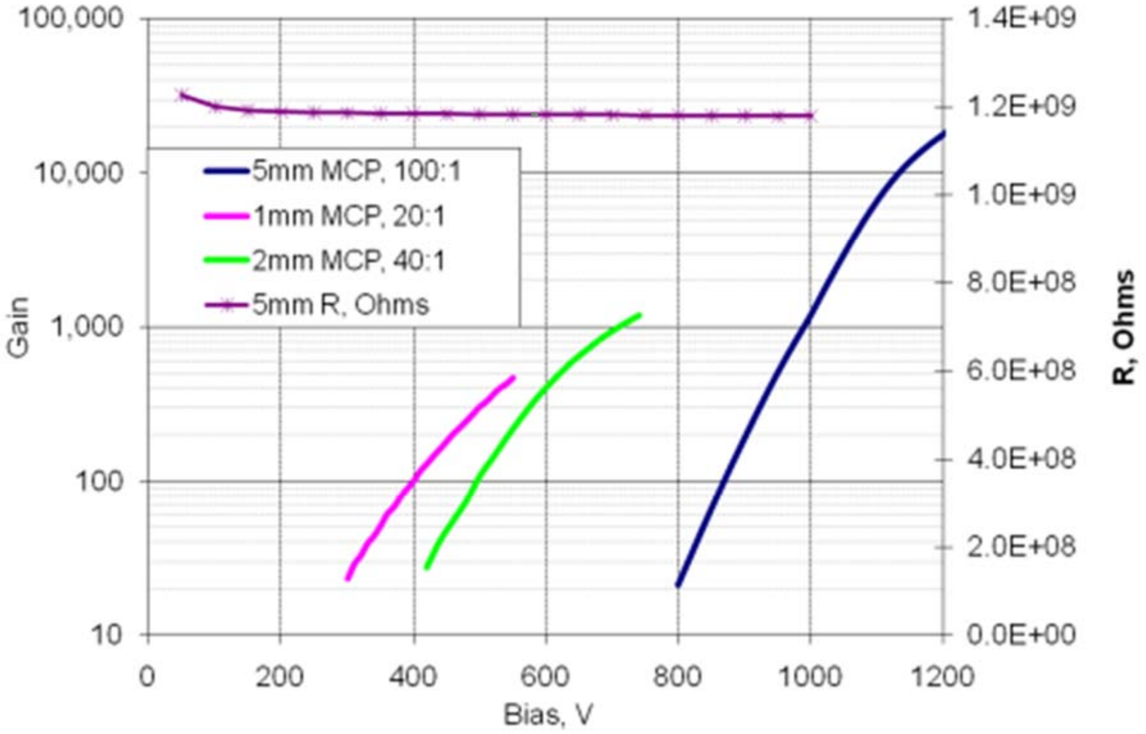


- Gradient of film thickness for current process
- Likely resistivity gradient as well
- Goal: flatten this curve, then create MCP devices

Plastic substrate MCP (alternative material)



- Reasonable gain for electron amplification, limited by L:D
- Uniform response
- Stable operation
- ALD at higher temperatures (limits plastic choices)



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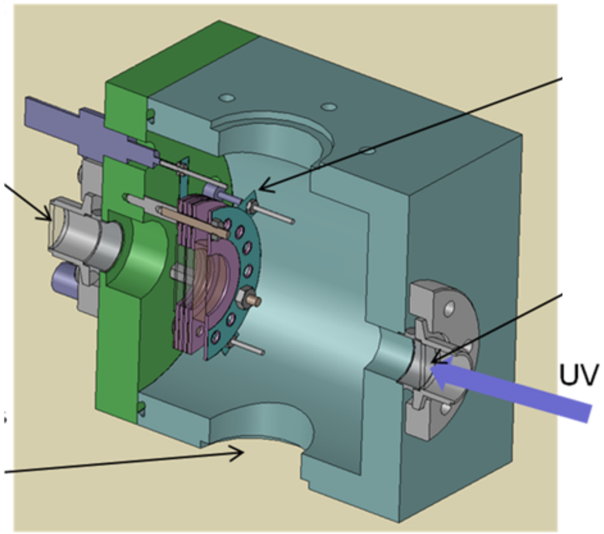
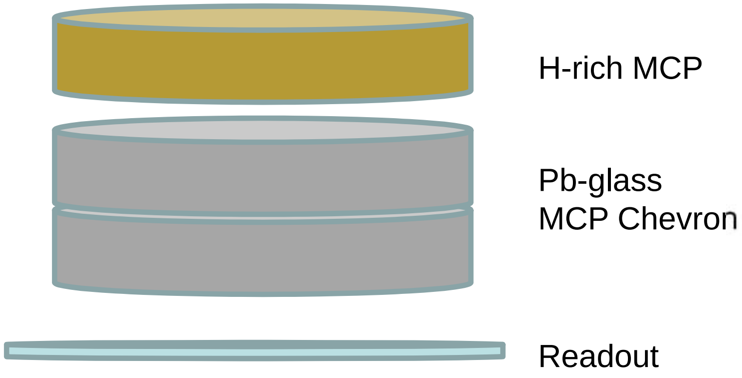
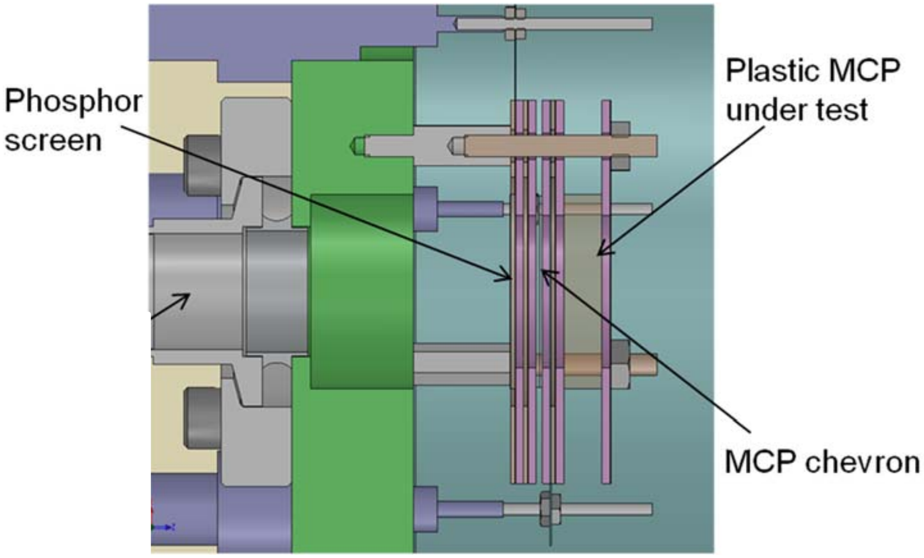
Detector Hardware Experimental Setup

- 2 & 5 mm polymer MCP, ~50 µm pores, 20 µm walls, 5° bias angle
- Installed above a chevron stack of 50:1 L/D MCPs
- Phosphor screen readout
- Canberra preamp and postamplifier







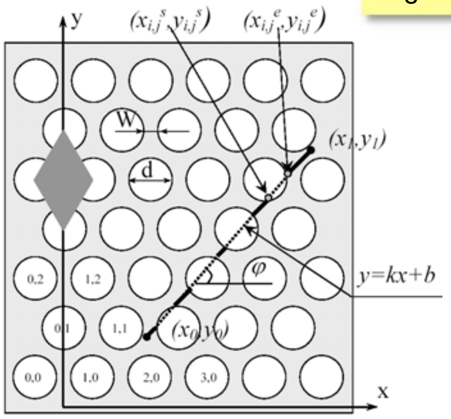
Neutron detection simulation

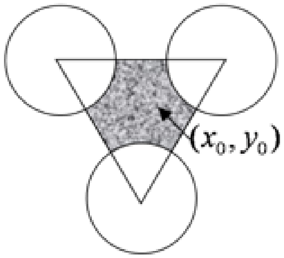
$$P_{detection} = P_1 * P_2 * P_3$$

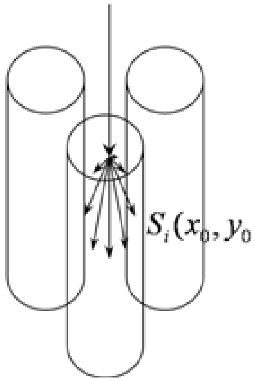
P_1 – n-p recoil within the MCP substrate

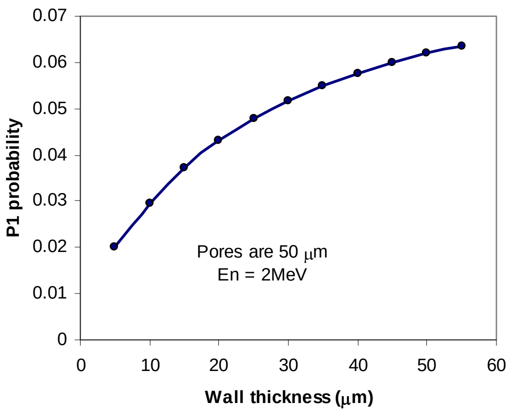
P_2 – proton escape into MCP pore

P_3 – electron avalanche is formed (MCP ~1)

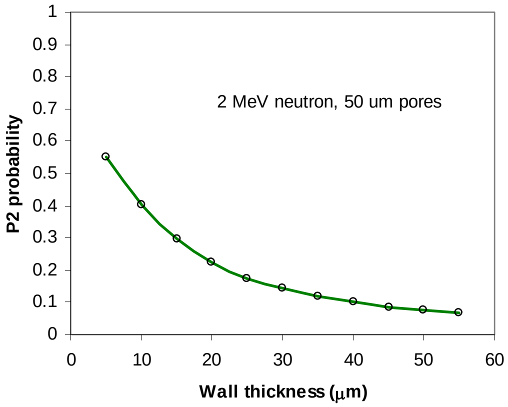




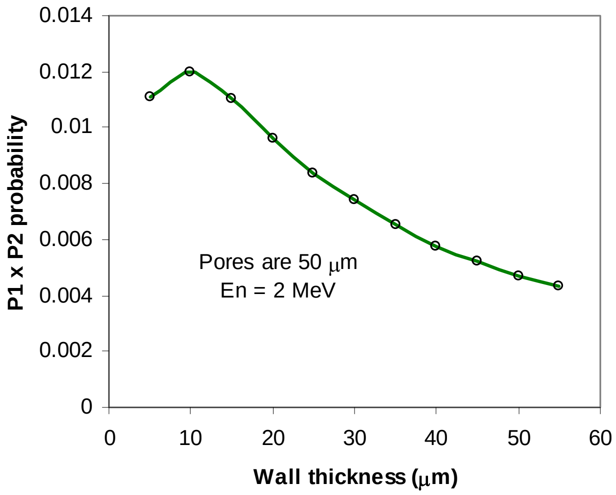




P_1



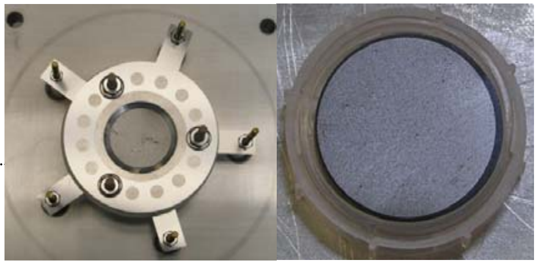
P_2



$P_1 \times P_2$

$P_1 \times P_2 \times P_3$ = ~1% for 2MeV neutrons with 20μm pore walls

Efficiency Results: UNH Beam Line



Isotope sources:

- Placed 6” from detector
- Stilbene scintillator with a single channel PMT (UNH) for calibration
- Cf-252, Am-241/Be (n, γ)
- Cs-137, Co-60, Am-241 (γ)

Cf-252
Neutron Detection Efficiency

Face-on

n QE = 0.747%

Edge-on

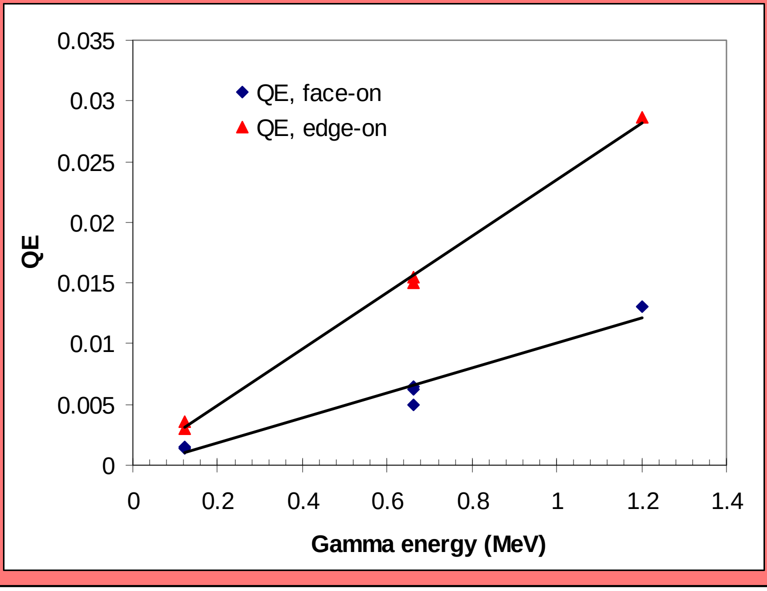
n QE = 2.46%

Measured neutron efficiency matches theoretical (0.8%)

Low dark counts (dark count ~0.3 c/cm²/s)

Gamma only source

γ-energy	Face-on	Edge-on
0.122 MeV	0.15%	0.33%
0.661 MeV	0.6%	1.5%
~1.2 MeV	1.3%	2.87%



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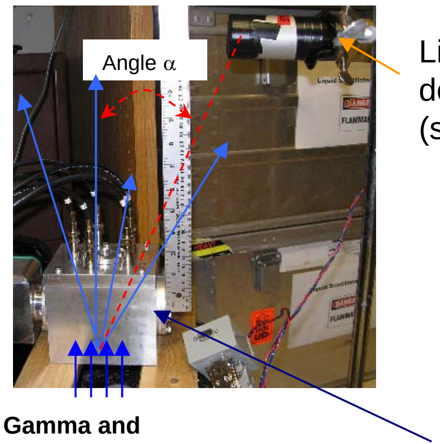
Timing and Coincidence

- Experiment Summary
  - Using 2 detectors offset and some distance apart
  - Measure events in Arradiance and commercial detectors
  - Gamma or neutron signal detected by Arradiance- starts acquisition window and timer for scintillator
  - Time-of-flight is calculated for each event
  - Statistics collected on each TOF and analyzed

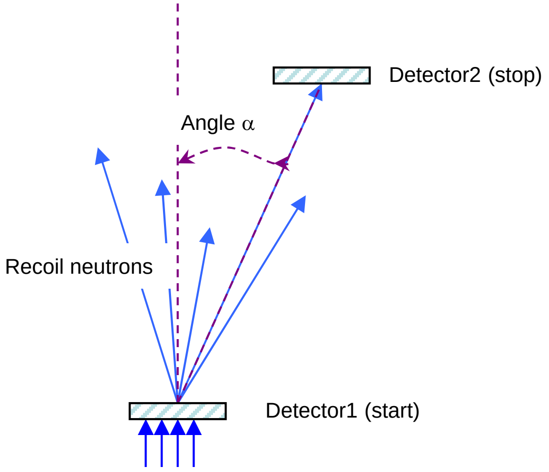
Coincidence measurements for gamma (35 cm distance)



Liquid scintillator detector (BC519) (stop signal at TAC)

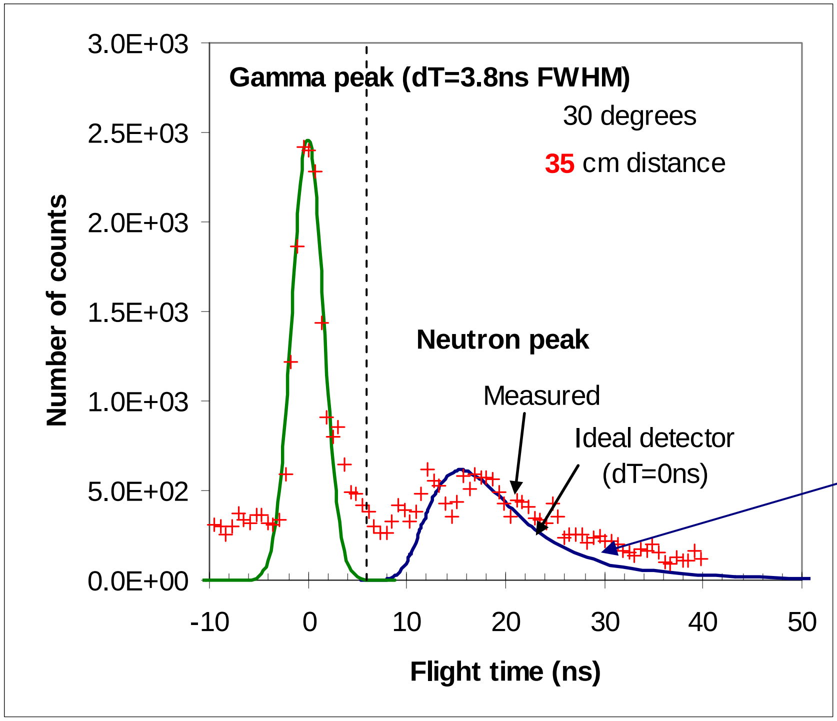
Gamma and neutrons from Cf^{252}

Plastic MCP detector (start signal at TAC)



Coincidence gamma rejection plus timing through TOF

Gamma travel at speed of light – detection in two detectors <u>should</u> happen within ~1 ns



Recoil neutrons arrive with a delay dT to detector2

Temporal Resolution

~3-4 ns

Nanosecond resolution = differentiation between incoming gamma and fast neutron radiation

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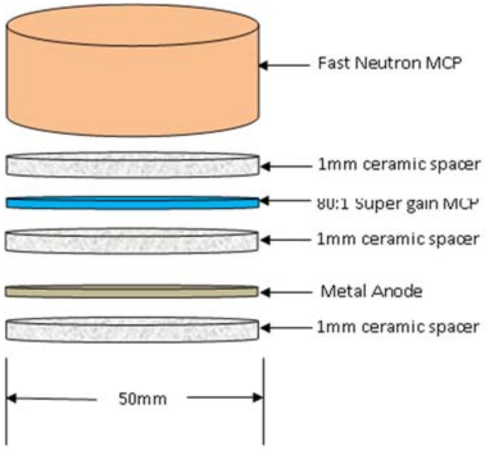
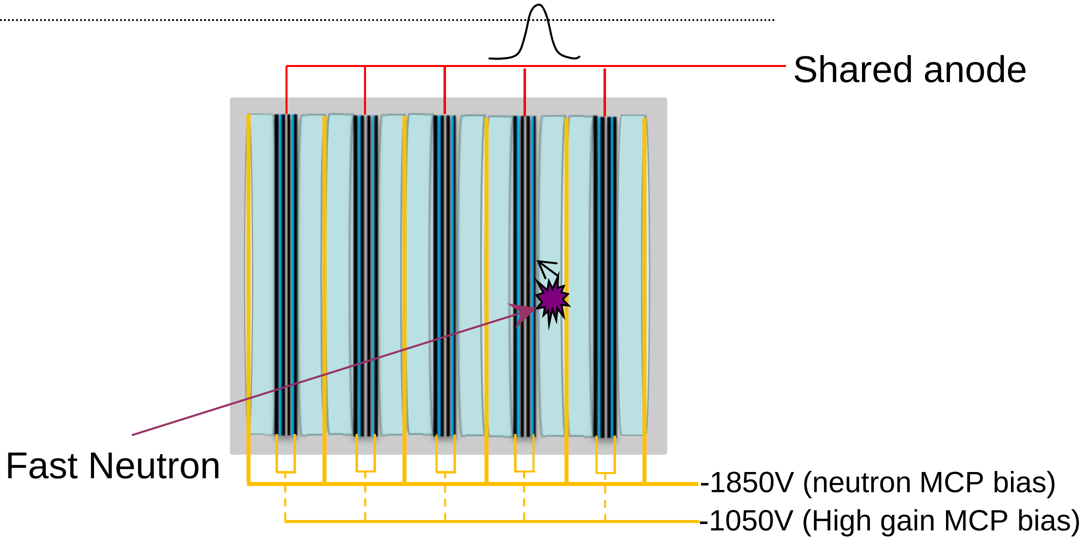
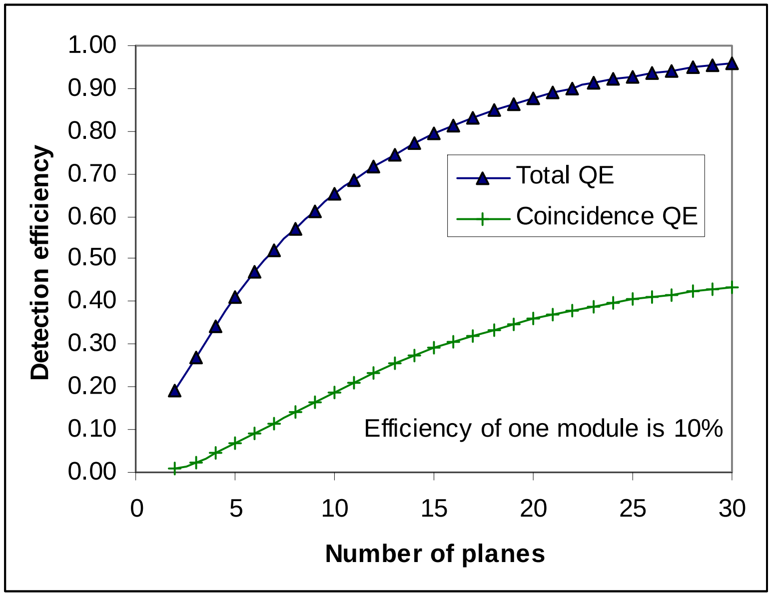
Creating a usable detector that can compete

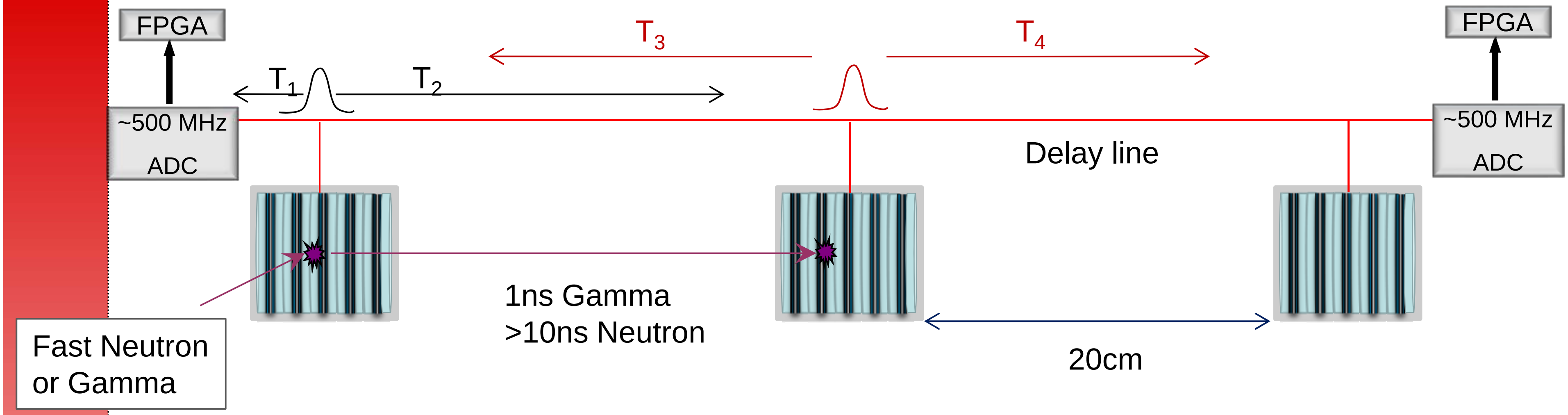




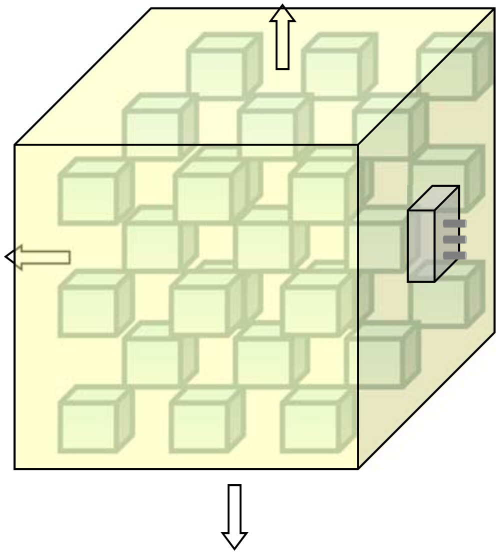


- Combining multiple 50mm plastic MCPs QE goes up
- With 10 planes QE is ~60%
- In coincidence mode ~10%

Package of Multiple 50mm³ Detection Cubes



- Coincidence techniques can differentiate Gammas and Neutrons
- Combining coincidence with the high efficiency cube yields a state-of-the-art detector
    - Provides directionality
    - Provides discrimination between neutrons and gammas
    - Is sensitive to a large energy range of neutrons and less sensitive to low energy background gammas (not shown)
- Compares favorably with liquid scintillator technology



3 x 3 x 3 cube array in an aluminum enclosure
<u>Directionality of source in all spatial dimensions</u>

Acknowledgements

- Dr. James M. Ryan, Professor of Physics, University of New Hampshire
- Mr. Jason S. Legere, Research Project Engineer III Space Science Center, University of New Hampshire
- Dr. Richard Lanza, Senior Research Scientist, MIT Dept. of Nuclear Science and Engineering
- Dr. Gordon Kohse, Ph.D; Principal Research Engineer, MIT Nuclear Reactor Laboratory
- The rest of the Arradiance Team
- DOE LAPPD Collaboration
- NASA SBIR NNX10CD59P

Background

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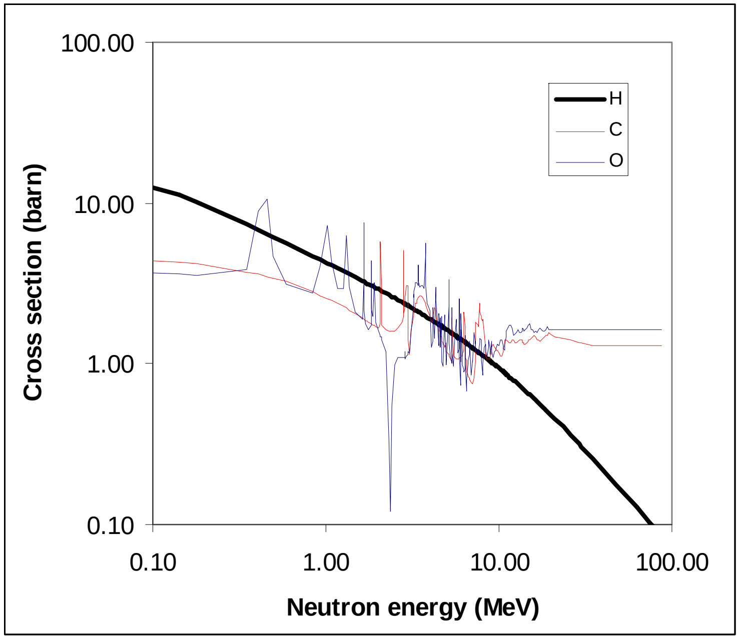
Neutron detection simulation: proton recoil - P1

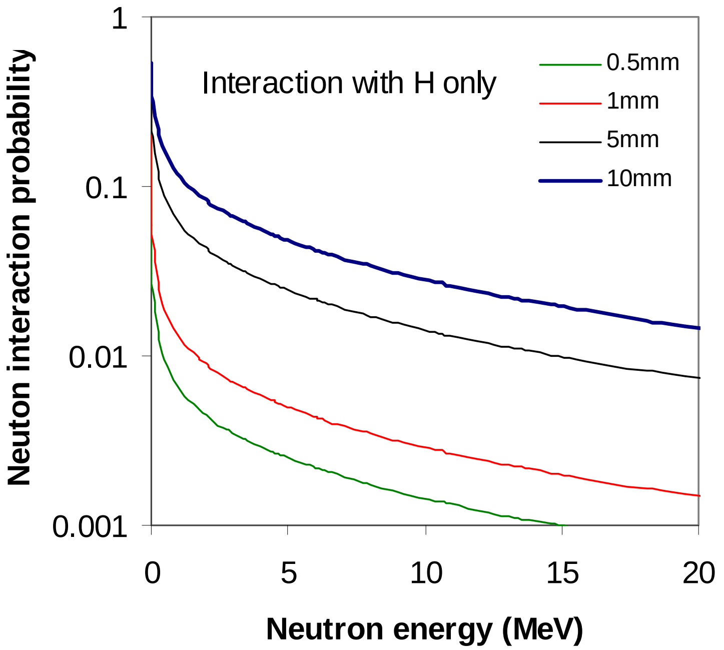
PMMA $(C_5\text{-}O_2\text{-}H_8)_n$

monomers / cm^3	7.16×10^{21}
H atoms / cm^3	**5.73×10^{22}**
C atoms / cm^3	3.58×10^{22}
O atoms / cm^3	1.43×10^{22}

Cross section of neutron interaction

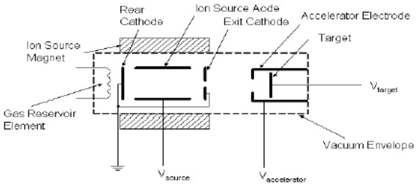


$P = [1 - \exp(-N_i \sigma_i L)](1-A)$

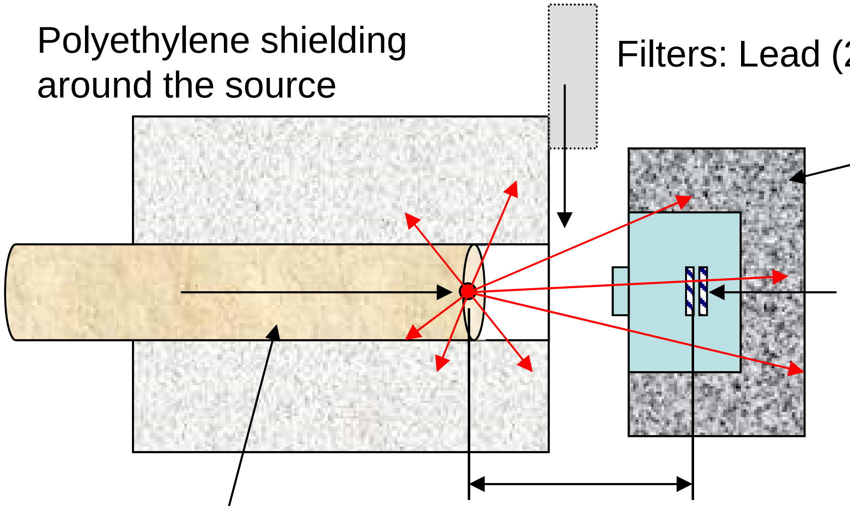


50 µm circular pores, 20 µm walls, 1.19 g/cm^3

D-T Source (Thermo 320) Experimental Setup



NEUTRON TUBE SCHEMATIC



Polyethylene shielding around the source

Filters: Lead (2”), polyethylene (1”, 2”), borated plastic (1”)

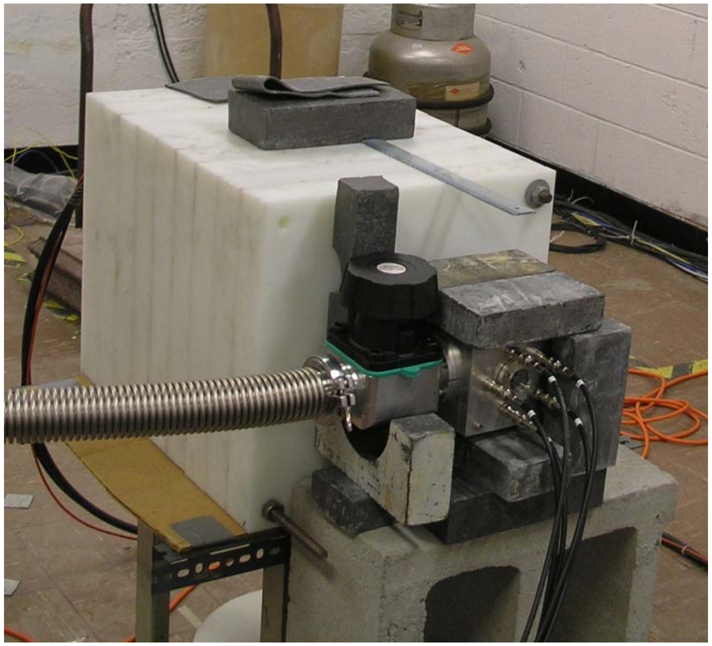
Lead shielding around the detector

MCPs

5 mm PMMA MCP,
~50 µm pores, 20 µm walls, 5º bias angle
installed above a chevron stack
of 50:1 L/D MCPs

Source

~30 cm



Technical Specifications	
Neutron Yield	1.0E+08 n/s
Neutron Energy	14 MeV
Typical Lifetime	1,200 hours @ 1x10⁸ n/s
Pulse Rate	250 Hz to 20 kHz, continuous
Duty Factor	5% to 100%
Minimum Pulse Width	5 µsec
Pulse Rise Time	Less than 1.5 µsec
Pulse Fall Time	Less than 1.5 µsec
Maximum Accelerator Voltage	95 kV
Beam Current	60 µamps