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Calibrated Irradiators at the Radiation Protection Instrumentation Calibration Lab

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Radiation Protection

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Outline

- Overview
- Radiation Standard Facility
  - Gamma Source Range (GSR)
  - Shepherd Irradiator
  - Neutron Source Range (NSR)
- Application of Modeling & Simulation with MCNP
- MCNP Results and Analysis
- Summary
- Future Plans

Objective

This presentation is intended to serve as an overview of Radiation Protection Instrumentation Calibration Laboratory with focus on calibrated irradiators.

Radiation Protection Instrumentation Calibration Laboratory (RPICL)

RPICL provides radiation detection equipment calibration including specification, selection and approval, procurement, installation, testing, calibration recall, maintenance, repair, quality assurance (QA), inventory, disposition, use, and records management.

RPICL Mission Statement

We develop and deliver high-quality calibration and maintenance of radiation instrumentation that meets or exceeds applicable standards and accreditations, such as the International Standards Organization (ISO) 17025.

Elements of Calibration Program

- Facilities and Equipment
- Personnel
- Procedures
- Staff Training
- Asset Management Database
- Internal Assessment
- Quality Assurance Program
- Traceability and Accreditation
- Records Management

Radiation Standard Facility

This secondary facility was established in 1983. It is equipped with high strength gamma and neutron sources to provide known doses and dose rates for certifying survey meters, verifying dosimeter response, R&D and exposing items submitted by customers.

Resources:

- Gamma Source Range (GSR)
- Shepherd Irradiator
- Neutron Source Range (NSR)

Radiation Standard Facility used for neutron and photon irradiation.

Available Calibrated Sources

Source	Geometry	Rate	Energy (MeV)
Cs-137	Well	0.13-55[a] mR/h	0.662
	Well	0.02-10[a] R/h	
	Well	0.87-120[a] R/h	
	Well	not used	
	Box Calibrator	1-150[b] mR/h	
	Box Calibrator	0.2-900(c) R/h	
Cf-252 (bare)	Open (4π)	434.0[d] mrem/h	2.1[e]
Pu-Be	Open (4π)	49.4[d] mrem/h	4[e]
	Open (4π)	60.8[d] mrem/h	
	Open (4π)	593.5[d] mrem/h	
	Open (4π)	654.3[d] mrem/h	

(a) 11/9/2014
(b) 3/5/2015 40.8-29.6 cm
(c) 3/5/2015 33.8-29.3 cm
(d) 3/15/2015 @ 15 cm
(e) average neutron energy

Gamma Source Range

- GSR is made up of four separate exposure holes each measuring 15 inches in diameter and 35 feet deep
- Each hole contains different Cs-137 source strength positioned on a movable tray
- Overall range of exposure rates from 0.0001 to 1000 R/hr can be achieved
- Calibration is performed using an ion chamber traceable to NIST

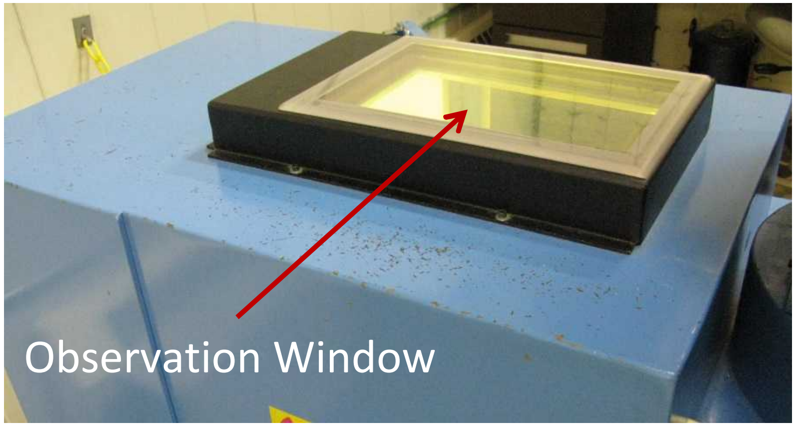
Gamma Source Range

Four calibration source wells are used for calibration of exposure rate instruments from about 0.1 mR/h to 100 R/h

Shepherd Irradiator

- Shepherd irradiator (Model: 89) is used for calibration of instrumentation
  - Pocket Ion Chamber Dosimeter
  - Electronic Personal Dosimeter
  - Teletector Dose Rate Meter
- Source strength: 130 mCi and 400 Ci Cs-137 (as of 12/3/1993)
- Attenuators, made from various material are used to reduce the gamma ray flux (0 – x1000)
- The radiation field is calibrated using an ion chamber
- Calibration measurements made over full range of track for each source/attenuator
- Actual data fit to polynomial equation for exposure rate vs. distance

Shepherd Irradiator

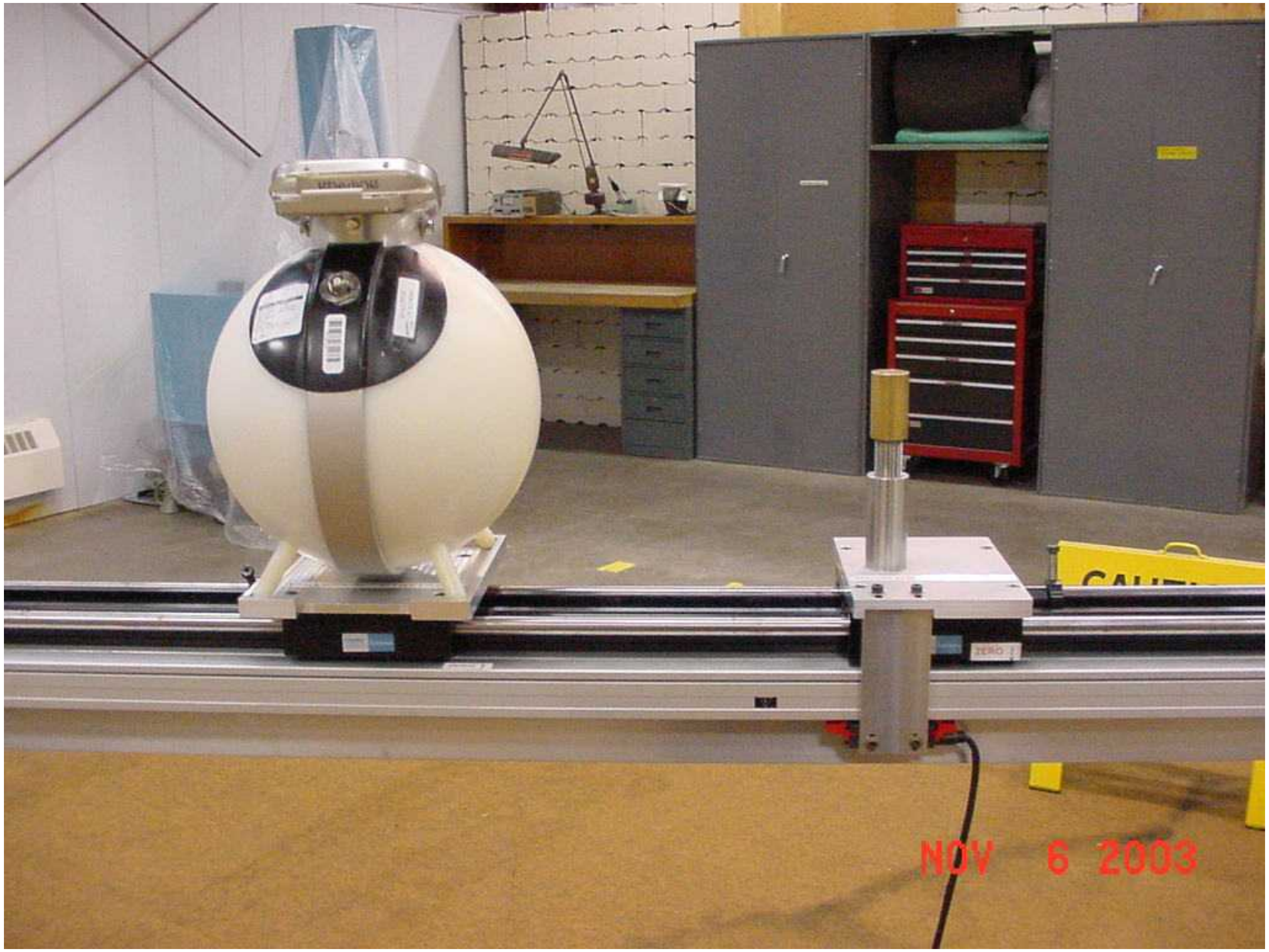


Neutron Source Range

- Consist of lightweight aluminum honeycomb flooring over a 12 foot radius hemispherical pit to reduce scattering
- Horizontal track is used for aligning experimental items and radioactive sources
- Sources stored in locked floor tubes:
  - Pu-Be
  - Cf-252
  - Am-Be

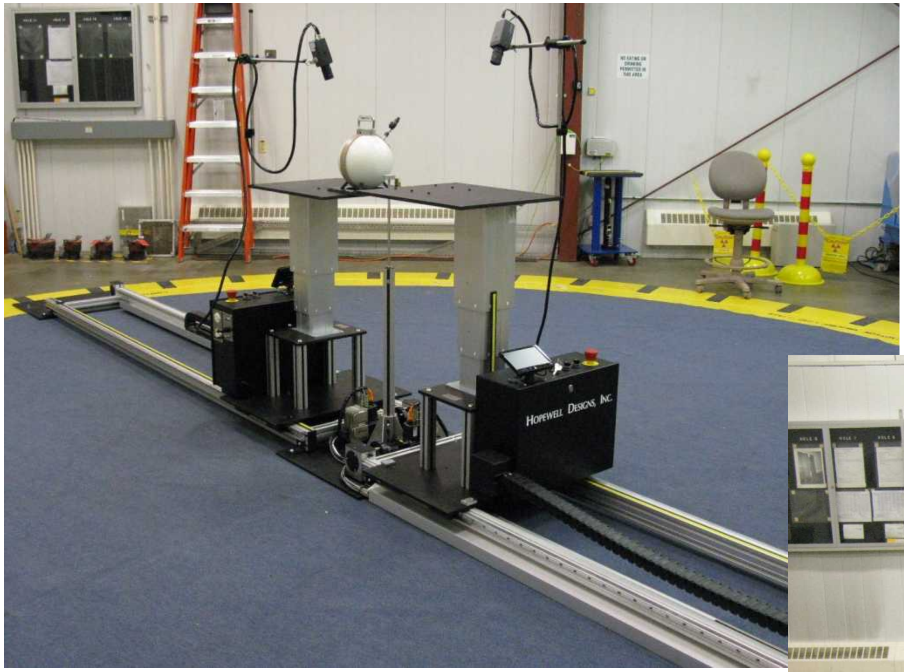
Neutron Source Range

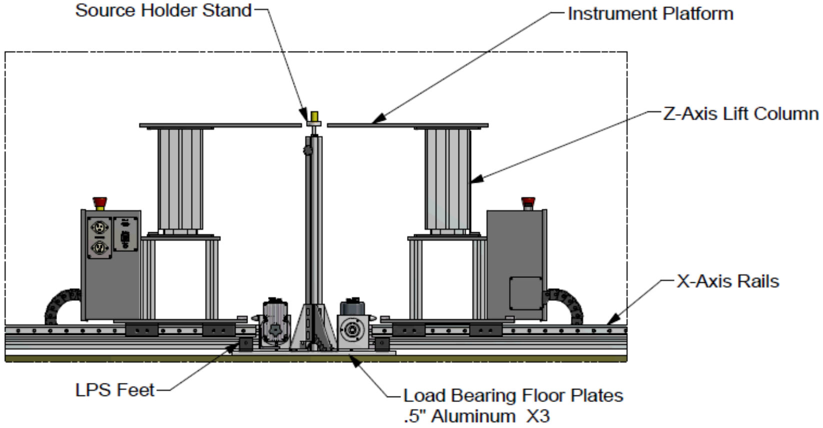
Typical Experimental Setup

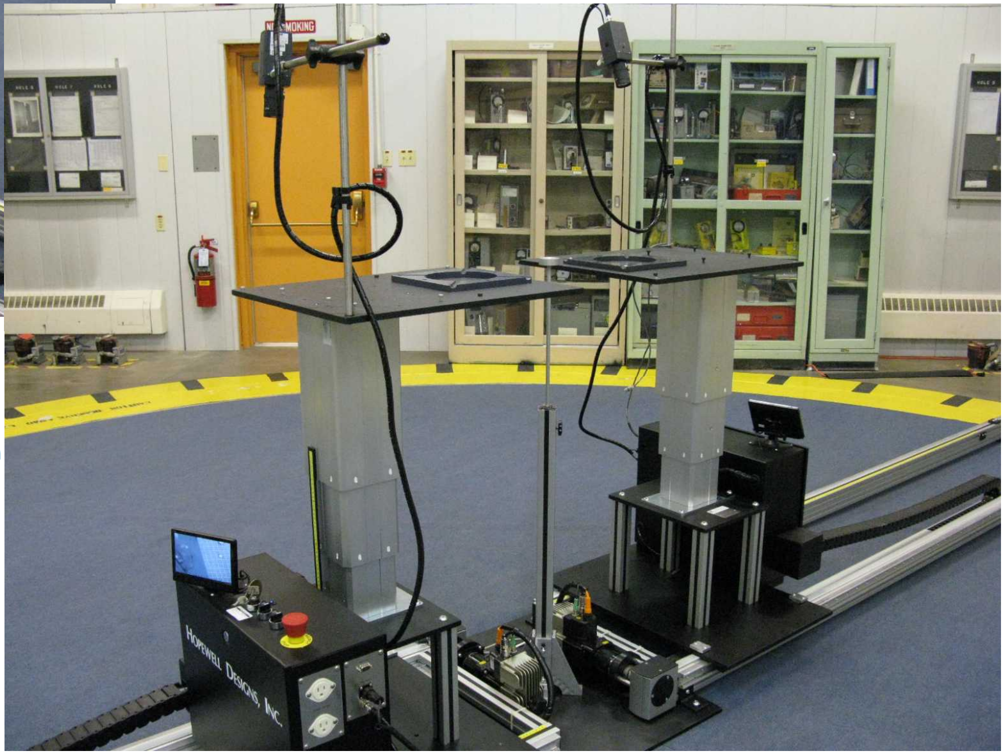


New Linear Positioning Track

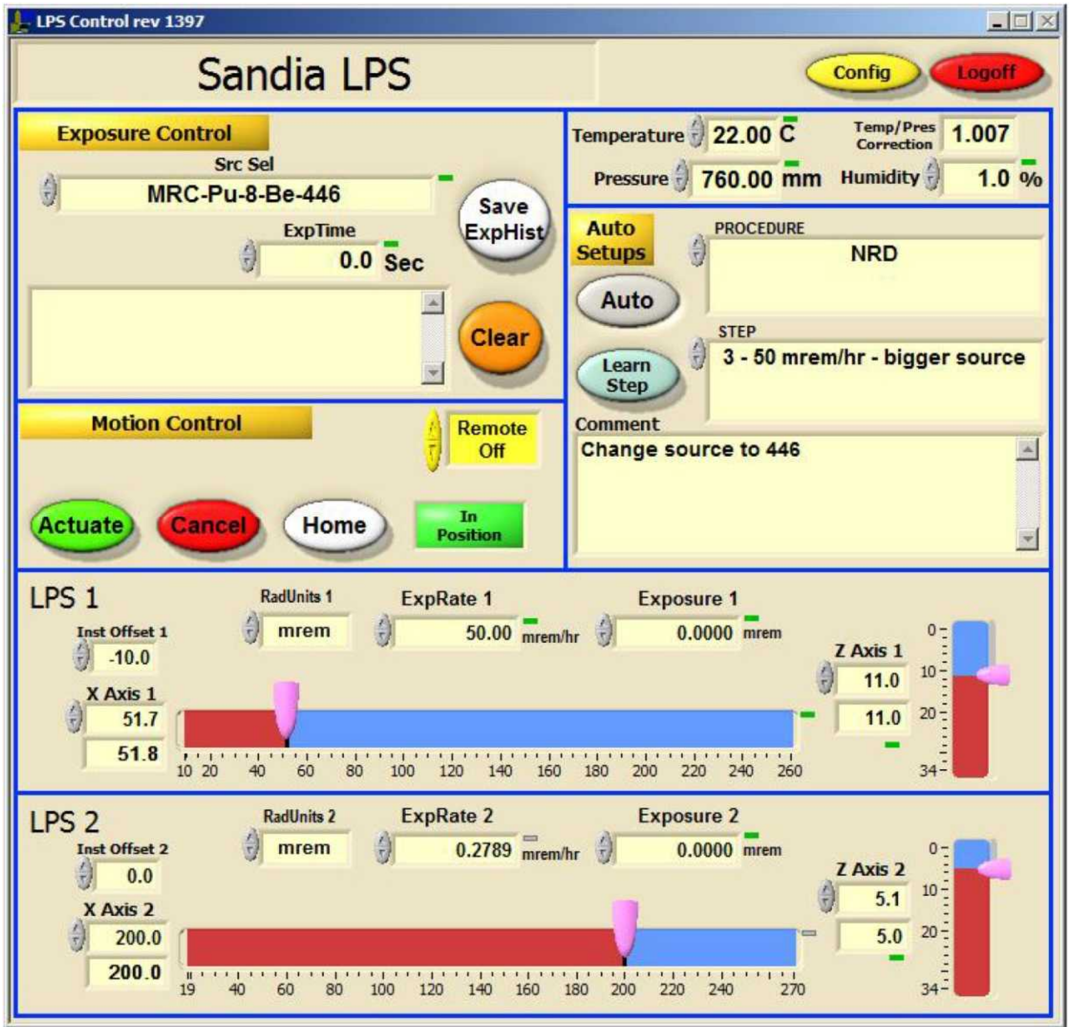
Neutron Source Range available for irradiation and instrument response evaluation. Laser-alignment is used to aid in device positioning. Cameras are positioned to remotely monitor instrument readings during irradiation.

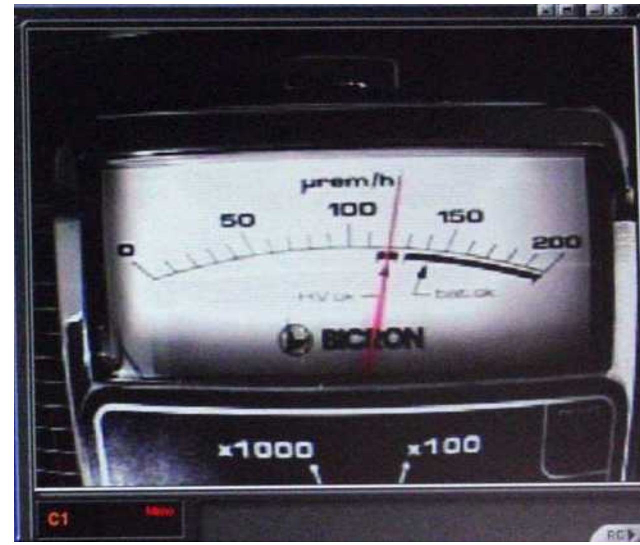






Control Screen with Instrument Viewing





Monitor used to view the instrument as it is being calibrated.

Main control screen divided into sections.

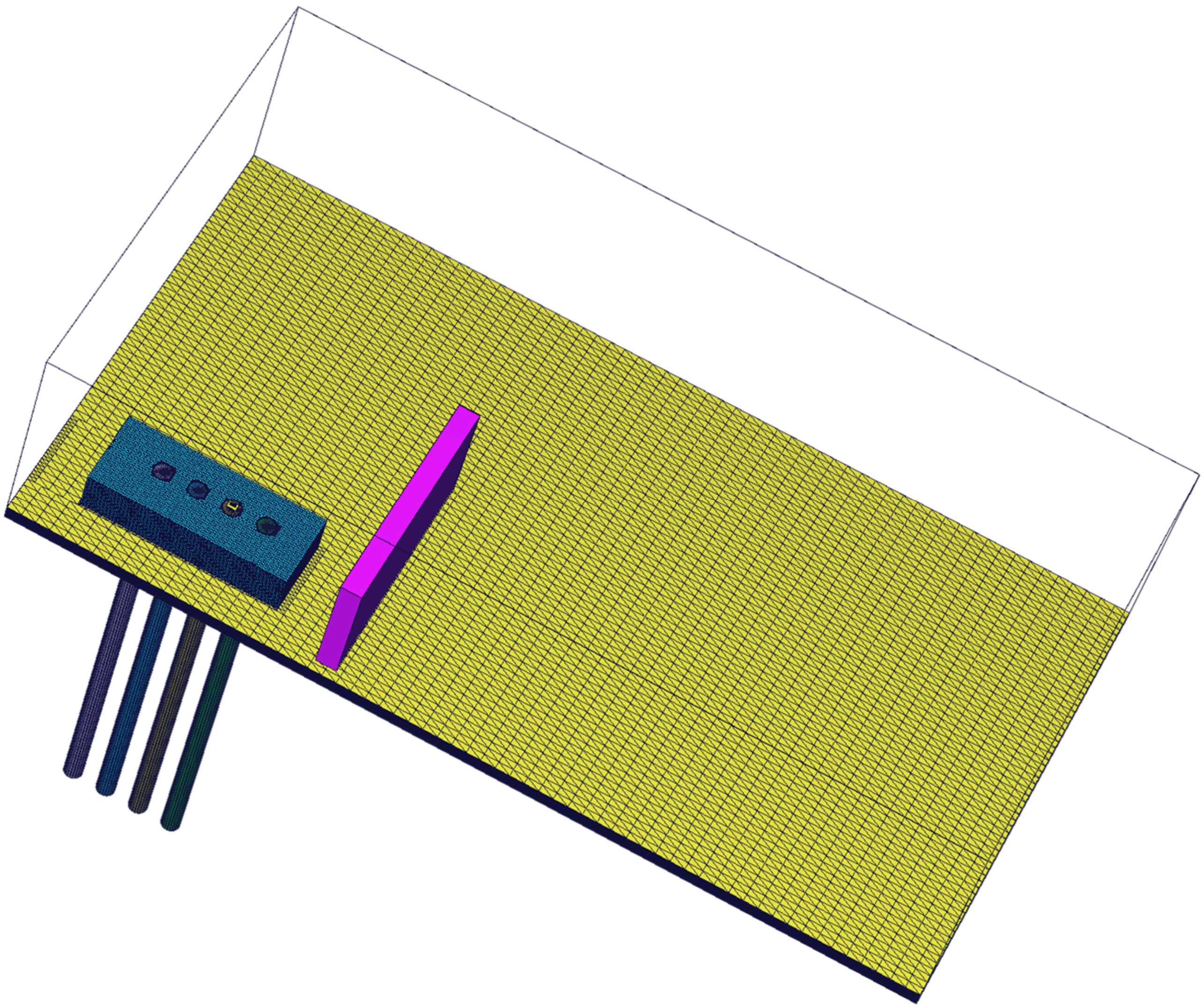
Benefits

- Simple to operate via user-friendly interface
- Meeting ALARA goals by reducing radiation dose to affected workers
  - Automated control from distance
  - One button setup for position
  - Camera monitors instrument reading
- Ability to simultaneously calibrate 2 devices
- Repeatable positioning will result in better measurements
- Exposure rate calculator

Applications of Modeling & Simulation with MCNP

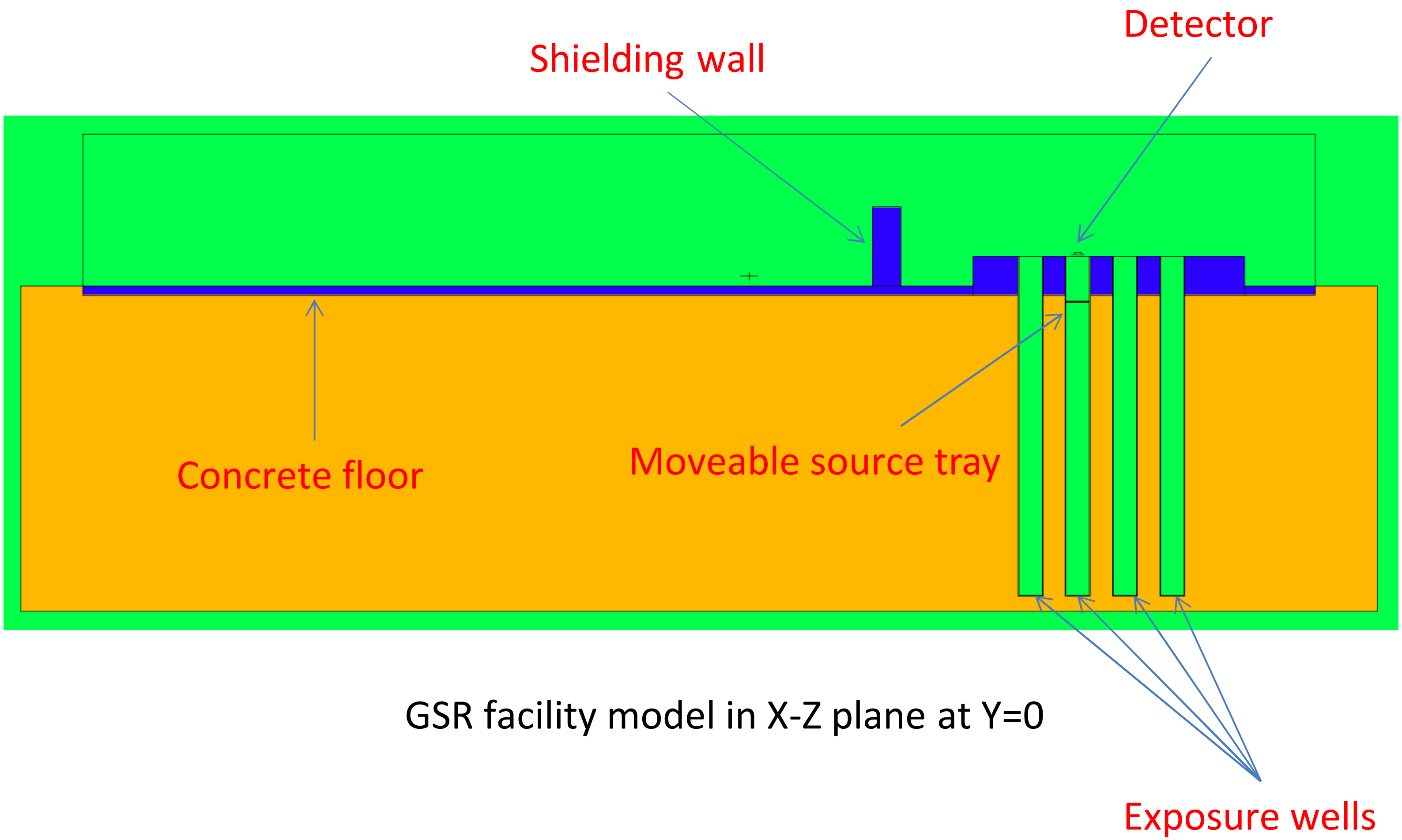
- Today, with continuing advances in both methods and computing, the use of modeling is rapidly becoming routine for applications once thought unthinkable
- MCNP is a powerful tool which can be of great aid in the analysis and validation of measured data and a diagnostic tool for troubleshooting
- It can be used to simulate the detection process in order to obtain spectrum peaks and to determine the efficiency curve for each modelled geometry
- Learn by simulating lots of case studies which can be automated using a batch file
- Data can be obtained more quickly and economically
- Permit early exploration of alternatives
- Allows visual interrogation of the final calculated results providing insight into options for making improvements

MCNP 3D Geometry



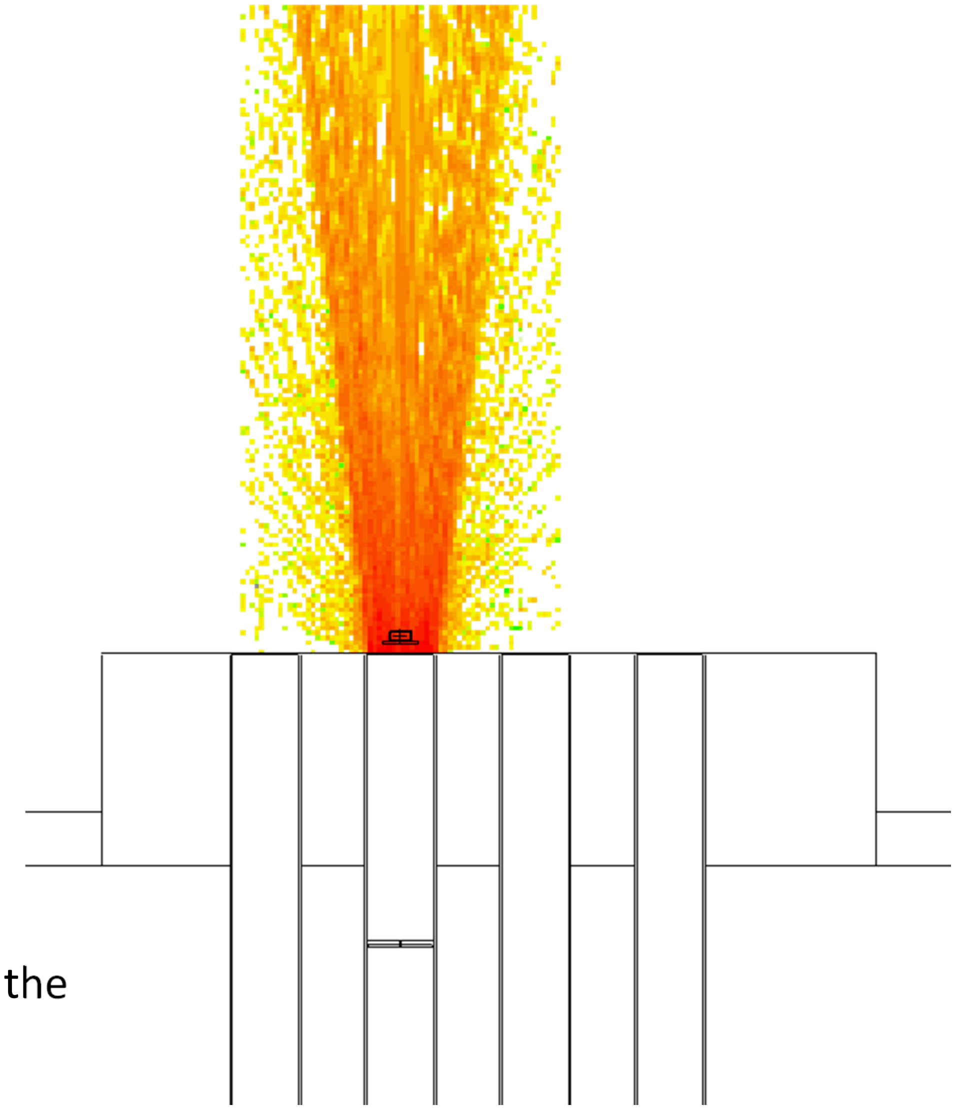
3D view of our GSR facility showing 4 separate exposure holes

MCNP 2D Geometry



GSR facility model in X-Z plane at Y=0

Visualization of Photon Fluence Output Data Using MESH Tally



MESH Tally plot on top of the geometry.

Expected Exposure Rates

To gain some insight into MCNP calculation an oversimplified equation for a point source exposure rate [10] was used,

$X = 5.263\times10^{-6}.A.E.Y.(\mu_{en}/\rho)_{air}.(1/r^2)$

X = Exposure Rate (R/h)

A = Activity (Becquerels)

E = Photon Energy (MeV)

Y = Fractional Yield

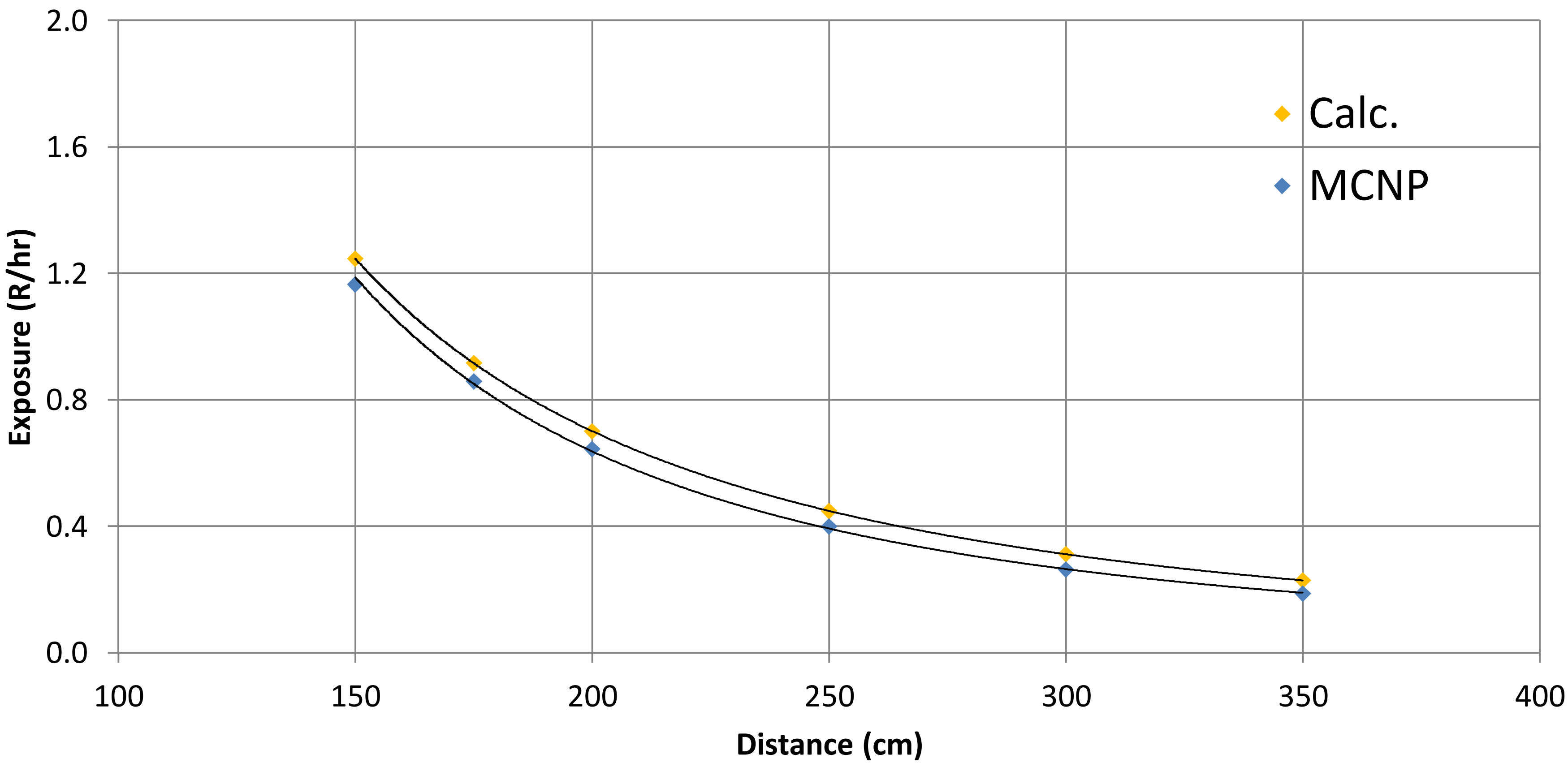
$(\mu_{en}/\rho)_{air}$ = Mass Energy Absorption Coefficient (cm^2/g)

r = Distance (cm)

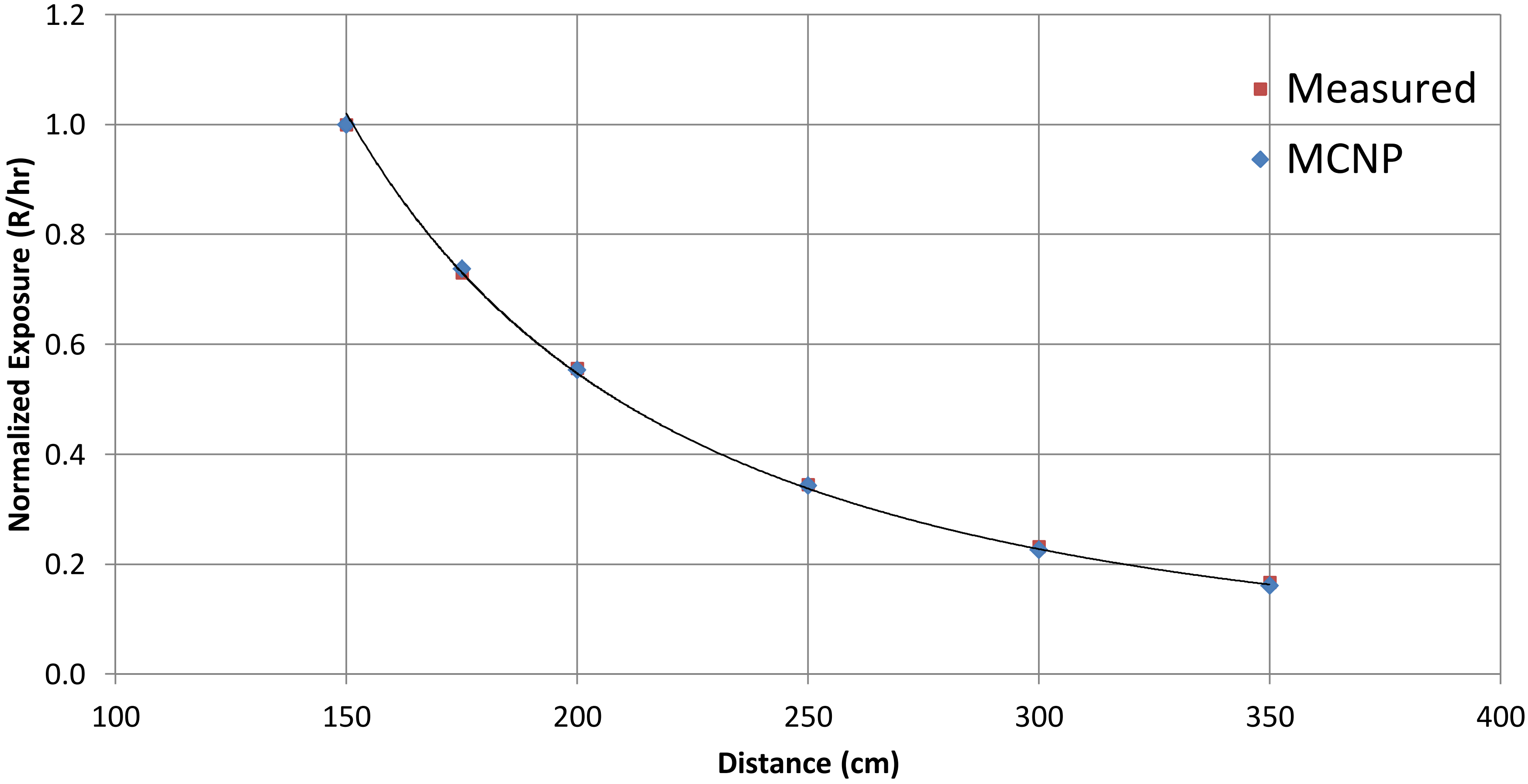
No.	Photon Energy (MeV)	Emission Probability Y (E)	$(\mu_{en}/\rho)_{air}$
1	0.0045	0.0091	57.80
2	0.0318	0.0199	0.20
3	0.0322	0.0364	0.20
4	0.0364	0.0131	0.10
5	0.6616	0.8510	0.03

r (cm)	X (R/h)
150	1.246
175	0.915
200	0.701
250	0.449
300	0.311
350	0.229

MCNP Results vs Expected



MCNP Results vs Measured



Data Provided by the Supplier are Necessary for Modeling

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- Exact plans are confidential and certain parameters (materials and dimensions) are even not known exactly to the producer
- Ask for information when you buy the instrument, otherwise you may have to pay for it

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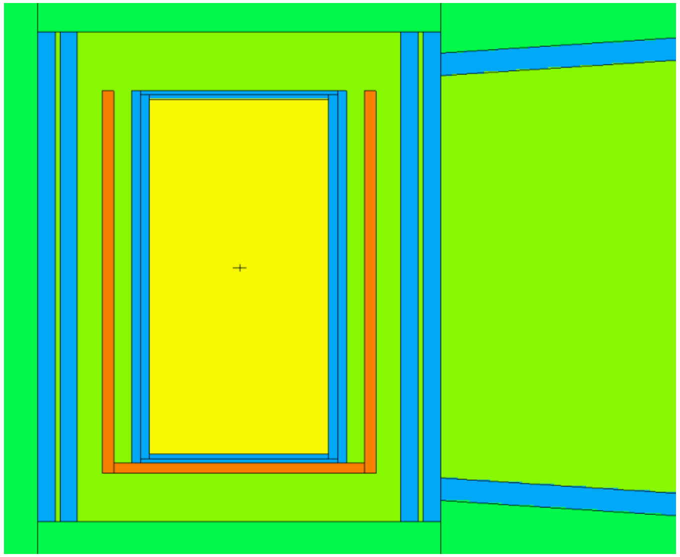
Date: 6/26/14
From: [engineering@jlshephed.com]
To: Kevin Norbash [ksnorba@sandia.gov]\
Re: Model 89 data

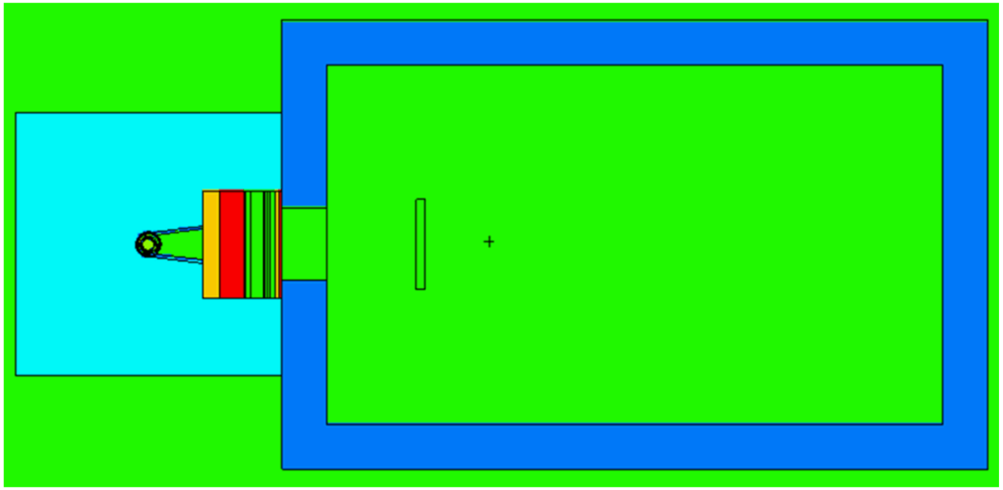
MCNP input files not available. Fabrication drawings are proprietary.

For as-built dimensions we suggest using a scale, adjustable tape and adjustable protractor and making desired measurements hands-on. We can provide the following data for the 400 Ci (original) source facing the beam port, the thickness of the attenuators and the materials encasing the lead in the beam port area.

MCNP 2D Geometry

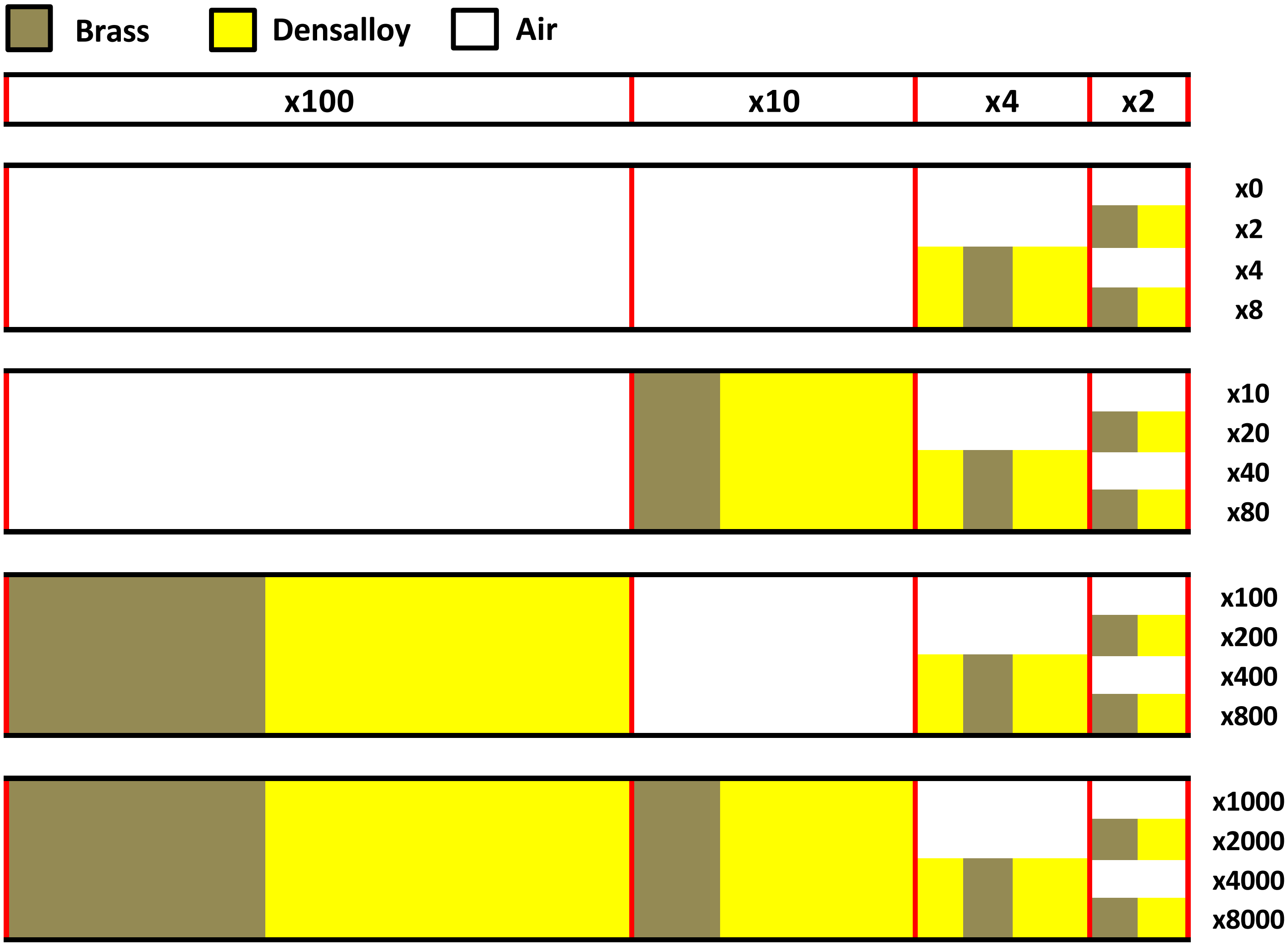


Cross Sectional View of Cs-137 Source in the X-Z Plane at Y=0



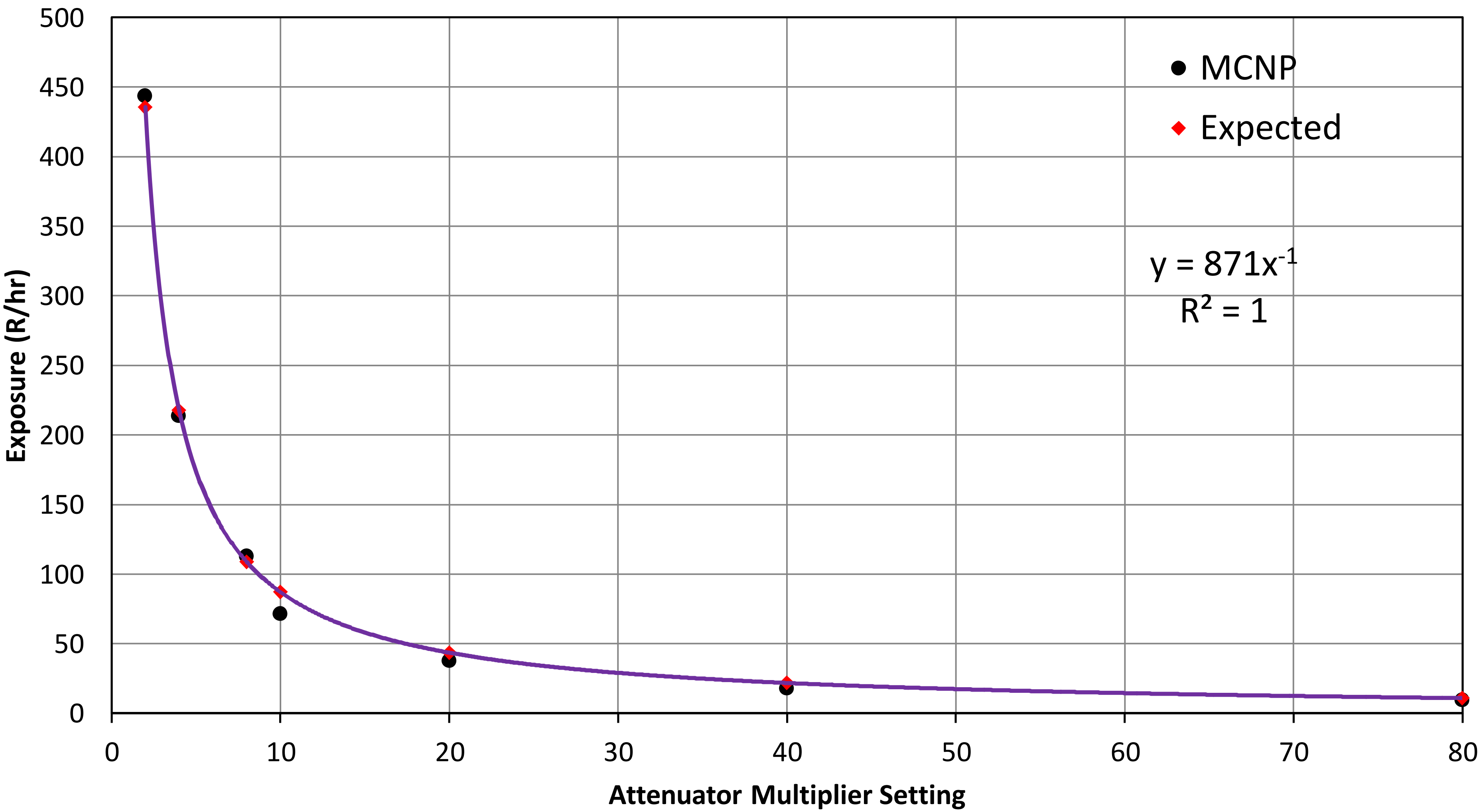
Shepherd Irradiator Model in the X-Y Plane at Z=0

Graded-Z Attenuator

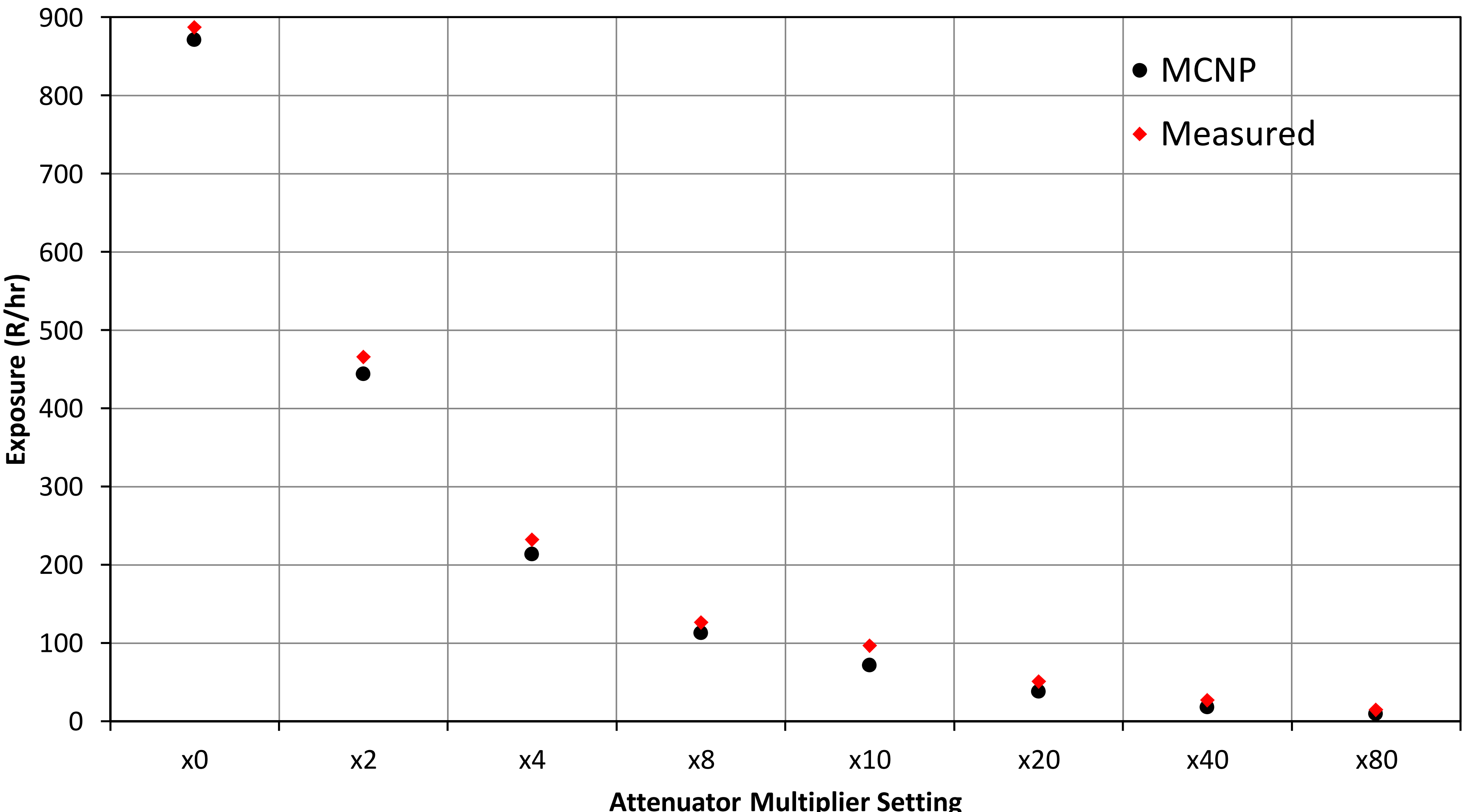


Lamination of Brass and Densalloy having low and high z values

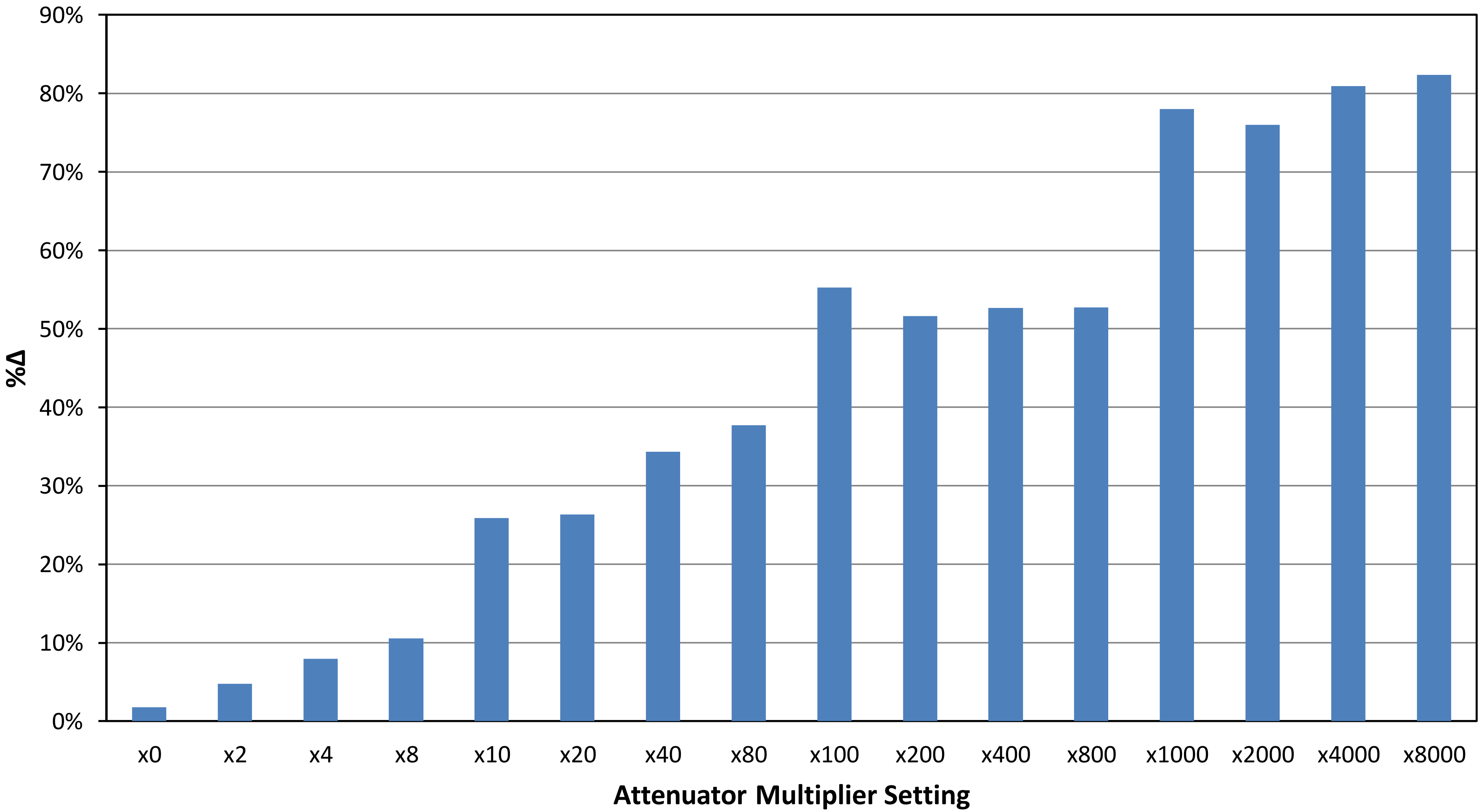
MCNP Results vs Expected



MCNP Results vs Measured



MCNP vs Measured



Conclusions

- The attenuation factors may not be exactly as they are intended to be
- Data shows group discontinuity
- The attenuation of gamma radiation will result in any of the common gamma interaction processes emitting secondary photons
- The increase in %Δ between calculated versus measured values and grouping observed is due to each subsequent attenuator multiplier setting adding more mass (thickness) and varying the number and position of different shielding layers (densalloy, brass, air) gamma radiation must travel through

Discrepancy with Measured Data

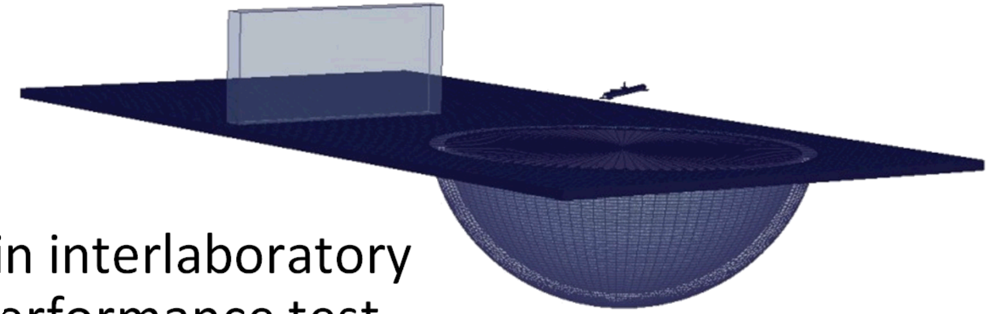
- Lack of knowledge regarding the exact chemical composition and density of material
- The MCNP geometry may not be exactly correct. For instance, in the case of Shepherd Irradiator the fabrication drawings are proprietary
- Need to know the exact source strength instead of the nominal value
- Uncertainty in mass energy-absorption coefficient, $(\mu_{en}/\rho)_{air}$ in converting fluence to R

Summary

- The Radiation Standard Facility make it possible to perform calibrations and evaluation over a wide range of exposures rates
- The MCNP code, based on the Monte Carlo method, is a powerful and useful tool to validate measured data
- The simulated and experimental exposure rates follow the same trend and are in pretty good agreement
- Discrepancies observed may be due to lack of adequate material composition and geometry knowledge
- Additional refinement such as more detailed geometry may produce better data
- With the model created, other studies can easily be conducted by making small changes
- It is expected that this study should be directly useful for shielding effectiveness and future exposure estimation

Future Plans

- Utilize computational methods for detector calibration more routinely at RPICL whenever feasible
- Calculate exposure rates for the neutron source range



- Recommend: Participate in interlaboratory comparison program or performance test
  - Helps identify problems in the laboratory
  - Strengthens the quality assurance program
- Recommend: Participate in calibration training and workshops
  - Designed to provide more in-depth and / or less formal discussion
  - Vendors can hold User's Group meetings and training

References

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Thank You All For Listening!

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