PNNL-30240

PNNL Measurement Results for the 2018 FlatTop Criticality Nuclear Accident Dosimetry Exercise at the Nevada National Security Site (IER-253)

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JA Stephens

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Pacific Northwest National Laboratory
Richland, Washington 99352

Acronyms and Abbreviations

ABS	acrylonitrile butadiene styrene
ANSI	American National Standards Institute
AWE	Atomic Weapons Establishment (U.K.)
BEGe	Broad Energy Germanium
BOMAB	Bottle Mannikin Absorber
Cd	Cadmium
DAF	device assembly facility
EOB	end of burst
FIA	Free in Air
FNAD	fixed nuclear accident dosimeter
FWHM	full width at half maximum
GM	Geiger-Mueller tube
Ge	Germanium
HD	high dose
HPGe	high purity germanium
HPS	Health Physics Society
LANL	Los Alamos National Laboratory
LD	low dose
LED	light emitting diode
LLNL	Lawrence Livermore National Laboratory
mil	one thousandth of an inch
NAD	nuclear accident dosimeter
NaI	Sodium Iodide
NCERC	Nuclear Criticality Experimental Research Center
NNSS	Nevada National Security Site
NRC	Nuclear Regulatory Commission (U.S.)
OSL	optically stimulated luminescence
OSLN	optically stimulated luminescence (neutron sensitive)
PMMA	polymethylmethacrylate
PNAD	personal nuclear accident dosimeter
PNS	Passive Neutron Spectrometer
URSA	Universal Radiation Spectrum Analyzer

Contents

Appendices

1.0 Introduction

The Pacific Northwest National Laboratory (PNNL) participated in the FlatTop exercise IER-253 at the National Nuclear Security Site (NNSS) during the week of May 21, 2018. This report summarizes the measurements of the personal nuclear accident dosimeters (PNAD). Additionally, portable survey instrument readings and measurements of the simulated biological samples are included. The FlatTop exercise (IER-253) tested only PNADs and did not include fixed nuclear accident dosimeters (FNAD).

Previous PNAD results obtained in 2016 at the Godiva-IV exercise IER-148 were summarized in *PNNL Measurement Results for the 2016 Criticality Accident Dosimetry Exercise at the Nevada National Security Site IER-148* (PNNL-26497). The results clearly indicated that the previous dose conversions were a historical legacy of the Hanford Site and corresponded closer to kerma dose (or first collision dose, and not to $H_p(10)$ dose). The technical basis for PNAD dose was based on the Godiva-IV exercise and documented in *A New Dose Calculation Methodology for New PNAD and FNAD Designs at PNNL* (PNNL-27023). The configuration of the PNAD was described in these two documents.

The FlatTop exercise was the first time PNNL tested this new dose calculation methodology. Results were generally favorable with some results conservatively over reported that fell above the performance criteria. The reported gamma dose results fell non-conservatively low because only the default parameters obtained from the Godiva-IV exercise were used, and because the OSL gamma dosimeter has an energy dependency. The results from the simulated biological samples were also favorable, and in several cases conservatively over reported.

2.0 Location of Dosimetry Phantoms and Stands

The FlatTop Pulse 1 exposed four (4) PNADs on phantoms and eight (8) on aluminum stands free-in-air (FIA). The Pulse 2 exposed another four (4) PNADs on phantoms and ten (10) on stands FIA. For each pulse, only two of the PNADs were placed on the phantom front side with the other two on the phantom backside to simulate the orientation of the individual turned away from the source of the criticality. Another two PNADs exposed on stands FIA from each pulse were not disassembled for portable instrument measurements (i.e., Pulse 1 and 2 total of 30 PNADs exposed). Appendix A shows the floor plan layout and examples of PNADs on the phantoms and stands given after the exercise. Appendix B lists the dosimeter position and distances given after the exercise.

The Passive Neutron Spectrometer (PNS) was positioned in quadrant one, free and clear of the phantoms and stands located in quadrant two. The position of the PNS used to determine the criticality output appeared to be without potential additional influences of moderation or reflection. The phantoms and stands were crowded within quadrant two. Dosimeter locations were reported whether placed on the phantom or stand, and after the exercise whether at 3-meter or 4-meter distance. It was not given which number phantom or stand the PNAD was placed on. For example, it was not given whether the PNAD was placed on P1 or P2.

3.0 Spectra and Pulses

Normalized neutron spectra and pulse durations are given in Appendix C. The FlatTop neutron spectra were given in an 83-bin structure, and not binned in an ANSI N13.3-2013 53-bin structure. A brief discussion of the verified spectral information is given in the *Blind Intercomparison of Nuclear Accident Dosimetry using the Flattop Reactor at NCERC* (LLNL-TR-758222, see Appendix A), and the uncertainty estimated was approximately 8% (in the range of 5% to 10%). The spectra showed minimal high energy neutrons >1.25 MeV with the strongest neutron signal in the 0.1 MeV - 1.25 MeV region, and with a broad epithermal 0.5 eV - 0.1 MeV and a thermal feature <0.5 eV. This was a challenging test for the new dose calculation methodology because the PNAD fluence for the 0.1 MeV - 1.25 MeV region was recently updated to a weighted approximation based on the neighboring energy regions measured from the copper and indium (in Cd) metal foils. Weighting factors were based on Godiva-IV results. Doses were not later adjusted based on spectral information, and neither was the spectral information binned into the five (dose) or six (fluence) bin structures for comparison to the PNADs. Spectral information was given as relative fluence (i.e., normalized) and total fluence was not given.

Pulse durations lasted from 12-minutes for Pulse 1 and 44-minutes for Pulse 2. Correction for pulse duration time for the sulfur ^{32}P counting was made in the calculation worksheet for t_i as based on *IAEA Dosimetry for Criticality Accidents No. 211*. Correction for pulse duration time was included in the gamma analysis of the metal foils by entering the pulse start and stop date-times and selecting the deposition buildup type in the sample information.

4.0 Delivered Doses

The delivered doses are listed in Appendix D. The different versions of neutron doses were included. The PNAD on phantom results were compared to ANSI N13.3 $H_p(10)$ dose, and initially, the PNAD free-in-air results were compared to ANSI N13.3 $H^*(10)$ dose. The reported gamma dose 1-sigma uncertainty was within 8% or less.

5.0 Instrumentation and Counting Stations

The instrumentation used in the FlatTop exercise was similar to that used in the Godiva-IV exercise. Appendix E shows the instrumentation at the various counting stations.

5.1 Germanium (Ge) Detectors

The same Canberra Falcon Ge instrument was used. Two Ortec Detective Ge instruments were used, although an older Detective model, versus the mini-Detectives used during Godiva-IV. The Ge instruments were operated with laptops and analysis conducted using the Genie software. The radionuclide library used in the analysis was verified. The Ge detectors were calibrated at PNNL prior to shipping to NNSS. Calibration of the Falcon using a similar mixed-gamma 0.5-inch diameter LEPS card, RPL source number R697-b1, oriented on center-contact with the detector face showed continuity within a few percent to the Godiva-IV calibration. The Ortec detectives were calibrated similarly on center-contact with the detector faces. Calibrations for the blood vial geometry were done using a jig and a 10 mL vial, RPL source number R697-b9. Additional calibrations were performed at select distances using the detector jigs. Additional calibrations were performed using RPL source number R697-a10, filter dried in pill vial cap, considered a closer approximation to the dimensions of the PNAD copper and indium foil disks, though generally demonstrated to be within several percent of the 0.5-inch LEPS calibration. Lead bricks were stacked around each detector for maximal shielding of the portable Ge detectors, minimizing any potential from neighboring stations or samples. Analysis used interactive peak fit to improve the fitted gamma peak area (e.g., 511 keV), and included the pulse start and stop date-times and selecting the deposition buildup type in the sample information. The ^{116m}In was based on the 1293 keV energy.

All copper foils were counted on the Ge detectors. This was an improvement over the Godiva-IV exercise which counted the copper foils on NaI detectors with bench scalers, and only verified several select copper foils by Ge count. The copper foils were placed on center with and sandwiched with aluminum disks 1-inch diameter by 0.03-inch thick to ensure all positrons were converted to annihilation gammas. The copper-aluminum sandwich samples were counted on center-contact with the Ge detector face. The copper samples were also counted on the NaI detectors after the Ge detector count. Potential uncertainty for the 511 keV energy from the previous Godiva-IV data included variation in peak areas with multiplets (3% to 7%) and NaI adjusted efficiencies (3%). Later reported dose results for the FlatTop PNAD on the phantom front for Pulse 2 at the 3-meter distance did not indicate bias and was within 3% of the given dose.

5.2 Sodium Iodide (NaI) Detectors

After counting the copper samples on the Ge detectors, all the copper samples were counted on the NaI detectors. The NaI detectors used were similar to the detectors used for Godiva-IV. Lead bricks shielded the NaI detectors. The NaI detectors were used with URSA-II MCAs to visually maintain the 511 keV peak within the region of interest (ROI). This was an improvement over the Godiva-IV exercise which used bench scalers. Purchase of new NaI probes should consider auto gain adjust to eliminate apparent energy drift. For calibration, copper foils were activated at the Radiation Measurements and Irradiation facility. The activated copper-aluminum sandwich was counted on a BEGe 3830 sample counter using a jig and again on the NaI detectors. NaI detectors were calibrated prior to shipping to NNSS by calibrating a BEGe 3830 sample counter (e.g., using R697-a10), and comparing the BEGe result to the NaI-URSA region of interest count results. All copper-aluminum sandwich samples were counted on center-contact with the NaI detectors.

5.3 iSolo Counters

The sulfur pellet packs were counted in iSolo counters. The same iSolo counter that was used for Godiva-IV was used for the FlatTop exercise. The counter was verified using the Sr90-Y disk source SZ 298 at NNSS to have similar response compared to the Godiva-IV exercise to within 0.8%. A second iSolo counter was used for the FlatTop exercise. The second iSolo counter included lead shielding, model SOLO300L. A verification was made prior to shipping to NNSS by irradiating a sulfur pack at the Radiation Measurements and Irradiation facility, then counting the sulfur pack in both iSolos to within 1% agreement. The second shielded iSolo was also useful when counting lower levels of ^{32}P such as the irradiated hair samples. Hair samples were counted in the given sample envelopes, removing the iSolo sample plate, and taping down on center of the sliding sample tray to ensure clearance with the iSolo detector. Pulse 1 hair samples were counted in the first unshielded iSolo (10-minute). The Pulse 2 hair samples were counted in the second shielded iSolo for 60-minutes. A beta counting efficiency was assumed to be similar to the SZ 298 Sr90-Y source.

5.4 OSL Dosimeter InLight Readers

The two OSL InLight readers used for Godiva-IV were used for the FlatTop exercise. One was a high-level InLight reader, and the other was a standard range InLight reader. All OSLs were read first in the high-level reader, and if below dose screening levels, then measured in the second standard range reader. InLight readers were verified prior to shipment to NNSS by reading previous saved dosimeters and accounting for the approximate expected fading. InLight readers were verified again after setting up at NNSS. A couple of PNAD OSLs were measured to check for shipment scan, and this verified that the potential impacts to the PNAD OSLs were less than 0.15 rad. Similar to the Godiva-IV exercise, the InLight readings were exported from the database and OSL readings were summarized as the average of three InLight reads.

5.5 Digital Pan Balance

A digital Ohaus pan balance was also used. The scale was calibrated prior to shipment to NNSS, and a weight set was used for verification. In some instances, the pan balance stationed at the NNSS NAD lab on a marble table was used. Digital pan balances were used for measuring the mass of hair samples in grams. An improvement could be made to weigh the sample envelopes prior to irradiation. Pulse 2 hair sample weights were more accurate because the individual sample envelopes were weighed. Then, the hair samples were repackaged in the weighed sample envelopes to obtain a more accurate individual hair sample net weight.

5.6 PNAD Disassembly Station

Direct portable instrument measurements were made upon receipt of the irradiated PNADs prior to disassembly. PNADs were disassembled on the benchtop located in the general loading bay area. The PNAD number and individual component numbers were verified and recorded during disassembly. A vacuum tool was used to help manipulate the cadmium cups and metal foils. Copper foils were placed on center and sandwiched between two 1-inch diameter by 0.03-inch thick aluminum disks, and the copper foil number was recorded on the aluminum. Non-sharp forceps were used to handle the edges of the sulfur packs, and the sulfur packs were placed on stainless steel planchets (e.g., sulfur pack number facing up). The OSLs were moved to the InLight readers. Obtaining several at a time, the metal foils and sulfur packs were selectively moved to the other counting stations. After counting several of the metal foils at a time, the metal foils were returned to the disassembly station. Nearby the disassembly station in the general area of the loading bay of the NNSS NAD lab, portable instrument readings were made on a phantom.

6.0 Measurements and Calculations

6.1 Direct Portable Instruments on PNAD Front

For each pulse, two PNADs from the FIA stands were randomly selected and set aside for repeat direct measurements using portable instruments. Distance from the pulse was not known at the time of the selection. The PNADs were not disassembled. Measurements were made by placing the probe face directly on-contact with the PNAD front using a pancake GM Ludlum 26-1 and using a Ludlum 2360 with 43-93 100 cm^2 probe. Portable instrument readings were normalized to $D^*(10)_n$ FIA dose. Results are given in Appendix F. Note that the calibration facility sets the Ludlum 26-1 dead-time correction to zero.

The trendline versus time in the range of 4-hours to 12-hours approximated an effective half-time of 66 to 70-minutes. This likely corresponded to a combined set of isotopes, primarily ^{116m}In with a 54-minute half-life, combined with the presence of the other longer-lived isotopes. Pulse 2 PNADs 304 and 305 were exposed at the same 4-meter distance, so were in identical agreement. Pulse 1 PNAD 276 was at the 4-meter distance while 282 was at the 3-meter distance. Trendline for 276 followed pulse 2 since at the 4-meter distance, while 282 at the 3-meter distance consistently trended to a lower normalized response. Greater variability from the trendline for Pulse 1 than Pulse 2 readings was reflective of lower readings for Pulse 1 and from changing ambient background from other PNADs and phantoms. Pulse 1 post 10-hours exhibited a tailing reflective of the difficulty making measurements after the apparent reading returns toward background levels. The next day, Pulse 1 measurements were near background levels using the portable instruments. Direct reading on the PNAD front side using the Ludlum 43-93 100 cm^2 scintillator probe had a different fitted trendline compared to the Godiva-IV exercise (see page 145 in *PNNL Measurement Results for the 2016 Criticality Accident Dosimetry Exercise at the Nevada National Security Site IER-148* for the Ludlum 43-93 front side at 4-meter distance). This may be due to the difference in neutron energy spectra, and in part due to the few data points obtained during the Godiva-IV exercise. During the Godiva-IV exercise, pancake GM readings on a PNAD were not obtained.

After disassembly of the PNADs, it was noted that the OSL components had direct portable instrument reading. An Ortec Detective Ge count of the OSLs (from PNADs 277 and 278) revealed that the primary isotopes activated in the OSLs were ^{64}Cu and ^{56}Mn. The activation corresponded to the filters in the OSL elements two through four and primarily the copper filter. Any potential contribution of the apparent OSL reading from ^{64}Cu and ^{56}Mn in contact with the OSL element was not estimated. Repeat OSL readings were taken later (e.g., later in the evening, or next morning) and were similar to the initial readings. Thus, the repeat readings did not indicate that there was a significant continuing contribution to the OSL response from the activated filters.

6.2 Direct Portable Instruments on Phantom

Direct measurements were made on-contact with the phantom torso using portable survey instruments, the Ludlum 26-1 pancake GM (with Ludlum dose filter cover), the Ludlum 2360 with the 43-93 100 cm^2 scintillator probe, and the Thermo-Bicron micro-rem meter. The Ludlum 26-1 pancake GM has a feature to switch the display from count rate to mR/hr, and phantom readings were also recorded for the Ludlum 26-1 pancake GM using the mR/hr display. Note that the calibration facility sets the Ludlum 26-1 dead-time correction to zero. Also, the mR/hr was not calibrated and the displayed mR/hr used a default value. The default value was not known at the time of measurement, though assumed approximately 3.5 kcpm per mR/hr. It was assumed the phantoms provided were phantoms selected from the 3-meter distance. The readings on phantom using portable survey instruments were in the range of 3-hours to 10-hours after irradiation. Portable instrument readings were normalized to $D_p(10)_n$ phantom dose. Results are given in Appendix G.

General correlation of the trendline was not as strong for Pulse 1 measurements on phantom than for Pulse 2 measurements on phantom. Fewer measurements were made for Pulse 2 measurements on phantom than for Pulse 1 measurements on phantom. The Pulse 2 Ludlum 43-93 and Thermo-Bicron micro-rem measurements correlated closer to the half-life of ^{24}Na (i.e., 7.7e-4 per min for 14.96-hour half-life), while trendlines for the pancake GM readings fell on either side of this half-life. The normalized readings between Pulse 1 and Pulse 2 phantoms were similar with Pulse 1 correlations maybe 10% to 20% higher than Pulse 2 correlations. The FlatTop exercise portable survey instrument readings normalized for the given phantom neutron dose appeared about twice as high as measured at Godiva-IV. For example, the Godiva-IV 43-93 reading at 500-minutes after irradiation was 150 ncpm/rad, while the Pulse 2 FlatTop 43-93 reading at 500-minutes correlation was 270 ncpm/rad. As another example, the Godiva-IV pancake GM reading at 500-minutes was 27 ncpm/rad, while Pulse 2 FlatTop pancake GM reading at 500-minutes correlation was 46 ncpm/rad. This likely illustrated the difference between the FlatTop and Godiva-IV ^{24}Na neutron activations.

Post several hours after irradiation, the predominant isotope was ^{24}Na and drives the portable instrument measurement correlation half-time. A brief qualitative count using an unshielded portable Ge detector (Ortec Detective 7167) at 3.5-hours after irradiation (5/23/2018 at 1:19 pm, 5-minute count) indicated 10:1 ^{24}Na to ^{38}Cl activity. Back calculated for the respective decay of ^{24}Na and ^{38}Cl, this qualitatively indicated that the activity ratio was 4:1. This approximated the assumption that shortly after irradiation (e.g., within half hour after irradiation) half the apparent instrument reading was from ^{24}Na and the other half from ^{38}Cl (given the different gamma yields from ^{24}Na and ^{38}Cl, and 1 to 1.5 primary gamma emissions from ^{24}Na and ^{38}Cl at time-zero). Measurements on phantom within 170-minutes after irradiation were not possible because of the time required for retrieval and transport to the NAD lab. Additional isotopes were counted in the spectrum but expected for an unshielded Ge detector and phantom in the general loading bay receiving room.

6.3 Sulfur, Copper and Indium Measurements

Appendix H lists the measured ^{32}P sulfur counts, and the Ge detector copper and indium activities in dpm. For pulse 1, there were several ^{115}In results that were non-detectable, i.e., at or below MDA, and were entered as zero activity. For Pulse 2, higher irradiation and increased count times pushed the detection levels to obtain activities for ^{115}In. The sulfur counts for ^{32}P were corrected in the calculation sheet for t_a, t_c, t_i, and an assumed ratio of ^{31}Si activation. Copper foils were each sandwiched on center between 1-inch diameter by 0.03-inch thick aluminum disks to ensure all positrons were converted to annihilation gammas. Activities were normalized per gram (A_o dpm/g) and used to calculate fluences (Φ).

All copper foils were counted on the Ge detectors and the Ge detector activity results were used for the fluence and dose calculations. A second count of all copper foils were made on the URSA-NaI detectors to demonstrate the viability of the URSA-NaI detectors to help with overall throughput of the foil counting. Visual inspection of the gamma peak was maintained within the region-of-interest (ROI) centered at the 511 keV energy. The copper counts were temporarily entered into a calculation sheet to correct for t_a, t_c, t_i, and then compared to the Ge detector result (Appendix H). The URSA-NaI results were generally slightly higher than the Ge detector results, with an average 7% and 2% higher for Pulse1 and 6% and 9% higher for Pulse 2 (NaI 1 and NaI 2 respectively). Considerations were examined during the FlatTop exercise that the two counting approaches of the NaI ROI counts versus a Ge peak fit would likely produce a difference in the range of 5% to 10%, unless a more detailed approach between the two count methods was established. Although counting the copper foils on the Ge detectors was preferred, the URSA-NaI detector counts demonstrated the viability of counting the copper foils and provided a second instrument count for the estimated ^{64}Cu activity.

6.4 PNAD Fluence Calculation

Appendix I lists the calculated fluences Φ for the six energy ranges, where Φ_{In} for energies >1.25 MeV overlaps the last two ranges, and thus five fluence bins are used for the PNAD dose. There were instances for Pulse 1 where ^{115m}In was non-detectable and resulted in calculated Φ_b zero because the subtraction of the highest energy Φ_s from the Φ_{In} would have resulted in a negative value. It was not clear at the time of calculation whether entry of the indium MDA activity was appropriate for dose calculation, although it was supposed that entering the MDA might yield a conservative over estimate for the higher energies.

This was a challenging test for the new dose calculation methodology because the PNAD fluence for the 0.1 MeV - 1.25 MeV region was recently updated to a weighted approximation based on the neighboring energy regions measured from the copper and indium (in Cd) metal foils. Weighting factors were empirically based on Godiva-IV results. The fluence Φ_a for the 0.1 – 1.25 MeV range was based on weighting factors of 0.48 and 1.12 for the fluences of neighboring energy ranges Φ_{Cu} and Φ_{In}. Whether or not other weighting factors were more appropriate for the FlatTop spectrum, or whether the sum of the weighting factors were less than 1.6 was not examined.

A comparison of PNADs 290 and 292 exposed on the front of the Pulse 2 phantoms at 3-meter and 4-meter distances found similar copper foil ^{64}Cu activities and hence calculated fluences. This was a noted anomaly for PNADs 290 and 292 and further inquiry submitted to the inter-comparison coordinators did not shed light on why this might be the case. There was a slight increase of thermal neutron fluences for PNAD 292 as expected since located at the 4-meter distance, but all other fluences were similar between 290 and 292. The URSA-NaI ^{64}Cu activities for 290 and 292 were also similar. Further consideration was that the fluence Φ_a for the intermediate energy range 0.1 – 1.25 MeV was calculated from the other neighboring fluences using empirical weighting factors, and whether later given normalized spectra from the PNS would adjust this intermediate energy range fluence to align more with the given doses. A PNAD component that measures this intermediate energy range more directly would be optimal for the best fluence estimate, and a technology search remains for what component is best for this intermediate energy range (e.g., mercury component).

6.5 PNAD Neutron Dose Calculation

Appendix J lists the calculated neutron doses for the PNAD five energy bins. Several of the Pulse 1 doses in the 1.25 – 3.16 MeV energy range D_b were zero because of non-detectable ^{115m}In, and appeared to not account for potential dose in the range of 5 to 10 rad when comparing to the PNADs that included D_b. This did not appear to impact the reported neutron dose much since the reported neutron doses were generally higher than given, and because on average D_b accounted for less than 10% of the neutron dose. Correction for the orientation of the phantom was applied to PNADs 278, 280, 291, and 293. Initial correction factors were based on the few data points available from the Godiva-IV results and PNNL's technical basis (See *PNNL Nuclear Accident Dosimetry Technical Basis Manual* April 2017, Section 3.2.5 Figure 3, Angular Response of LANL PNAD at GODIVA Reactor, and measurements in *A New Dose Calculation Methodology for New PNAD and FNAD Designs at PNNL* October 2017). The correction factor used for PNAD 291 of 1/0.42 was also based on the estimated orientation of the phantom given the counting results of the hair that suggested a potential orientation of 45 degrees. For consistency to Pulse 2, the PNAD 293 correction factor of 1/0.35 was used for facing away 180-degree orientation at 4-meter distance, the Pulse 1 PNAD 280 had a similar correction factor of 1/0.35 (or 1/0.371) applied resulting a similar result to PNAD 279. As in the case of Pulse 1, the correction factor for the phantom orientation was first conservatively assumed to be 1/0.3 to simulate more closely an operational approach and in keeping with the spirit of blind measurements. Overall, there was not much data from the Godiva-IV and the FlatTop exercises, nor from the previous technical bases combined, that shed light on more precise orientation correction factors. Thus, the application of the orientation correction factor remained a source of some uncertainty to the final neutron dose estimate. A review of the PNAD calculated neutron dose results estimated that on average 60% of the dose was from the intermediate energy range D_a, and 80% of the dose was from the epithermal and intermediate energy ranges D_{Cu} and D_a. On average 12% or less of the calculated neutron dose was from the

>1.25 MeV energy range D_b and D_s. Qualitatively, this was consistent with the given normalized neutron energy spectrum from FlatTop.

6.6 Biological Samples

Appendix K lists the measured ^{24}Na activity in the blood vials, and the calculated dose. Two blood vials were provided from one Pulse 1 phantom corresponding to PNADs 277 and 278. It was not clear if lactate solution was pulled from the second Pulse 1 phantom. Four blood vials were provided from Pulse 2 phantoms, two vials from the first phantom at 3-meter distance associated with PNADs 290 and 291, and the other two vials from the second phantom at 4-meter distance associated with PNADs 292 and 293. There was some ambiguity in the literature if the dose conversion based on the ^{24}Na activity concentration (normalized to the mg Na) was for tissue kerma or for $D_p(10)_n$ dose. The default conversion factor results appeared more consistent with $D_p(10)_n$ and conservatively over reported in a few cases. An estimated factor corresponding to the given tissue kerma was estimated in Appendix K. It should be noted that the Pulse 2 blood vials from the phantom at 4-meter distance were proportionally 26% to 30% higher than the given neutron dose at 4-meter $D_p(10)_n$, while the blood vials from the phantom at 3-meter distance were within 2% and 4% of the given neutron dose $D_p(10)_n$. This was approximately consistent with the PNAD neutron doses reported for Pulse 2. This was additional data to consider whether the actual dose received for the second Pulse 2 phantom at 4-meter distance was in fact approximately 30% higher than given.

Ringer’s lactate solution was known to be 2.99 mg Na/mL. Operationally, the milligrams per milliliter of sodium in blood would be obtained from the occupational medicine blood analysis, while the blood vials were being counted on the Ge detectors for ^{24}Na (with the initial dose estimate using an average sodium blood concentration). Also, operationally a more accurate measurement of the volume of blood in the vial should be made by measuring the fill height and determining the corresponding volume given the standardization to a specified blood vial (e.g., part number for BD Vacutainer), with an optional weight taken as a gross check. There was a potential indication of ^{56}Mn in the Ge detector blood vial spectra (i.e., 847 keV). Further consideration was not given if this was the case, why the ringer’s lactate solution would contain iron, or if activated iron could provide further refinement to the blood sample dose.

Appendix L lists the hair sample count results and calculated activity in dpm per gram. The low levels of sulfur activation to ^{32}P from the FlatTop neutron energies made measuring the activated hair a challenge. Hair sample results were considered estimates since the iSolo beta counting efficiency was estimated, Pulse 1 hair sample weights were from a gross estimated average, and count rates were low. Pulse 2 hair results were improved by counting samples for a longer 60-minute time, and a more accurate hair sample net weight was obtained by transferring into a pre-weighed sample envelope. Qualitatively, the count results from the hair samples indicated orientation, with the Pulse 1 hair result indicating orientation away from the source, and with the Pulse 2 hair indicating that the most likely orientation was at a 45-degree angle to the source.

Appendix M lists the Pulse 1 and Pulse 2 hair sample dose estimates, and combined blood-hair dose results. The first approximation of neutron dose relied only on the hair and an assumed fraction of 0.10 for FlatTop. The PNAD neutron doses indicated that a fraction of 0.10 was applicable. Comparison of the Pulse 1 fast neutron fluence to the PNAD >1.25 MeV fluence suggested that there might have been a background subtraction bias for the low count rates from Pulse 1 hair samples. There was closer agreement when applying the previously established iSolo background used for counting sulfur packs. Pulse 2 fast neutron fluence estimate to the PNAD >1.25 MeV fluence was within a few percent. The primary literature reference for the combined blood and hair sample dose estimate was *Dosimetry of Criticality Accidents using Activations of the Blood and Hair*, Dale E. Hankins, 1980. Health Physics Vol. 38 (April), pp. 529-541. The proposed method provided a way to even out the energy response for activated ^{24}Na by combining the blood and hair results. The method applied the graphed summary to adjust the dose conversion factor for the blood vial results. There was ambiguity in the literature whether the estimated dose corresponded to tissue kerma or $D_p(10)_n$ dose. The pulse 1 blood-hair dose estimate of 100 rad was closer to the $D_p(10)_n$ dose and within 8%. The y-axis and K were also estimated for the given tissue kerma and for the given $D_p(10)_n$ dose for Pulse 1 and Pulse 2. The Pulse 1 estimate was within 20% within the reported PNAD 277 $D_p(10)_n$ dose. The Pulse 2 estimate was closer to tissue kerma and within 13%, and within -27% given the PNAD 290 $D_p(10)_n$ dose. Pulse 2 estimate was within -25% of the reported PNAD 290 $D_p(10)_n$ dose, and within -1% of given $D_p(10)_n$ dose when the y-axis was estimated to be 2.8. A fair amount of judgement remains when applying this methodology such as the faction of the total dose, selecting an intercept in the graph of two correlations (or something in between), and whether corresponding to tissue kerma or $D_p(10)_n$ (or if y-axis adjustment for $D_p(10)_n$). The Hankins graph plotted the Flattop points in a different region of the graph, and further consideration why this difference or what different configuration of the critical assembly that might explain this was not revealed.

7.0 Comparison PNAD Neutron Results to Given

Reported PNAD neutron doses were compared to given dose $D(10)_n$. The given $D_p(10)_n$ was compared to the PNADs on phantom, and the given $D^*(10)_n$ was compared to PNADs on free-in-air (FIA) stands. There were several different performance test criteria. For the purposes of this comparison, the ANSI N13.3-2013 was used. Based on ANSI N13.3-2013, the test criteria was ±50% for dose range 10 to 100 rad and ±25% for dose range 100 to 1,000 rad. Other performance criteria referenced in the *Blind Intercomparison of Nuclear Accident Dosimetry* *using the Flattop Reactor at NCERC* (LLNL-TR-758222) included the DOE-STD-1098-2017. The current PNNL Radiological Control Program Description 515 Nuclear Accident Dosimeters criteria is *Personnel nuclear accident dosimeters should be capable of measuring an absorbed dose in or on a phantom from 10 rads to approximately 1,000 rads with an accuracy of approximately ±25%* (effective date October 2018).

7.1 PNAD Neutron Reported Dose Results to Given

Appendix N lists the reported neutron dose results compared to the given $D(10)_n$ doses. For Pulse 1, all but one of the 12 PNADs passed within ±50% (92% pass rate). The one PNAD that conservatively fell above +50% was 280 because the conservative factor applied for facing directly away from the source. Pulse 1 PNAD on phantom results appeared biased high by 40% for PNADs 273, 274, and 275. PNADs free-in-air (FIA) appeared biased high by 26% at 4-meter distance. At the 3-meter distance, only one PNAD 270 under responded by 16%. It was supposed that the location of PNAD 270 was in similar proximity to PNAD 282 since the normalized portable instrument readings were lower than the other PNADs, though there was no further data to indicate this since PNAD 282 was not disassembled and analyzed, and since the PNAD 282 was at the 3-meter distance (with the other PNADs measured using portable instruments were from the 4-meter distance).

The Pulse 2 neutron doses for the phantom at 3-meter distance were within 2.52% of given, and the average of PNADs 290 and 291 was within 0.21%. For Pulse 2, all but two of the 14 PNADs passed were within ±25% (86% pass rate). The two PNADs that conservatively fell above +25% were 292 and 293. PNADs 292 and 293 were from the phantom at 4-meter distance and had anomalous copper results that were higher and matched more closely with the PNADs 290 and 291 from the phantom at 3-meter distance. Blood vial results also indicated this anomaly between the phantoms at 3-meter and 4-meter distances where the blood vial results indicated the actual dose might have been 26% to 30% higher than given for the phantom at 4-meter distance. A full analysis of the difference between the neutron energy spectra at the 3-meter and 4-meter distances with cross sections for both the copper and sodium activation to ^{64}Cu and ^{24}Na to explain an apparent 30% over response at the 4-meter distance was not done. Operationally, in the case of an actual event, it is unlikely such subtleties would be discerned from the actual unknown in-field conditions without lengthy detailed deliberation. Reported dose would likely be based on the apparent readings, especially in cases like the FlatTop results where the blood and PNAD doses were consistent.

7.2 PNAD Total Reported Dose Results to Given Total Dose

The reported total doses to the given total doses are in Appendix O. The given total doses $D_p(10)$ were the sum of the given neutron and gamma doses. The doses for PNADs on phantom were compared to Dp(10), and doses for PNADs on the free-in-air (FIA) stands were compared to $D^*(10)$.

For Pulse 1, all except three fell within the ANSI 13.3-2013 criteria, and all but one were within ±30%. The one over reported greater than +30% was due to conservatively applying the standard correction factor for rotation facing away from the source. One free-in-air PNAD under responded at the criterial level -25.5%, and as mentioned earlier possibly was associated with the PNAD 282 location, and possibly represented actual dose at that location. The design of the FlatTop exercise was ingenious in targeting Pulse 1 total dose slightly above 100 rad (i.e., see the given total doses of 102 rad and 109 rad for the 3-meter distance).

For Pulse 2, all except two fell within the ±25% ANSI 13.3-2013 criteria, and all were within ±35%. The two that fell conservatively high within +35% were anomalous since the measured ^{64}Cu activity at the 3-meter distance on phantom was similar to the measured ^{64}Cu activity at 4-meter distance on phantom (see PNADs 290 versus 292).

8.0 OSL InLight Results

The Pulse 2 OSL InLight results are in Appendix P. The OSL element E1 readings without any corrections were on average 5.7% greater than the given gamma dose. The element E1 results on the phantom front without any corrections were 50% high (i.e., factor of 2 higher than given doses). Using the default OSL parameters C_n and R obtained from the Godiva exercise for the phantom front were 30% low on average. The FIA reported gamma doses were on average 65% low, and unfortunately this skewed the reported overall gamma results lower than that achieved on phantom. This might have also skewed the reported overall dosimeter pass fail rate if half of the dosimeter results were gamma only doses. It should be noted that the given gamma dose only accounted for 15% to 20% of the given total dose, and therefore, slight improvements to the measured gamma dose had minimal impact to the total dose measured (i.e., 25% improvement to 20% of the total dose was a 5% improvement to total dose).

8.1 Estimated OSL Parameter C_n

The OSL parameter C_n is a dimensionless neutron absorbed dose factor and may be thought of as the “response” of the dosimeter (e.g., energy dependent response). The post comparison of the neutron doses measured from the metal foils and sulfur packs to the OSL readings provided an estimated value of C_n. The advantage of this was that an estimated C_n can be made for unknown measurements, while the operational disadvantage is that the measured neutron doses must be completed before the parameter C_n can be obtained for the OSL. The correction factor C_n for FIA was estimated to be 6.7, and 6.25 and 7.375 at the 3-meter and 4-meter distances respectively. The correction factor C_n for the phantom front was 10.55 at the 3-meter distance and 10.94 at the 4-meter distance. There were differences between values of C_n obtained by (E2-E1)/Given $D(10)_n$ and values estimated when compared to the measured neutron dose from the metal foils and sulfur packs. The difference was slight 10.3 for the phantom front at 3-meter, and larger for the phantom front at 4-meter because of the anomalous phantom dose at 4-meter distance, or because of the dosimeter placement on the backside of the phantom. OSL results on the backside of the phantoms were 14.45 and 13.825 at 3-meter and 4-meter and was consistent with higher C_n with more moderation. Comparison to the PNAD measured neutron doses without correction for rotation and not from the given $D(10)_n$, had the advantage to obtain C_n without additional information given later. Values of C_n obtained on phantom from the Godiva exercise, in *A New Dose Calculation Methodology for New PNAD and FNAD Designs at PNNL* (PNNL-27023), were lower in the range of 5.0 to 7.5 at 2-meter to 4-meter distance (and 2.8 to 3.7 FIA). Thus, the C_n values for FlatTop were higher than Godiva, and is consistent with an increased C_n for neutron spectrum shifted to lower energies (e.g., moderated by intervening material or a lower energy spectrum from the critical assembly).

8.2 Estimated OSL Parameter R

The OSL parameter R represents a dimensionless factor to estimate the fraction of delivered neutron absorbed dose that appears as apparent InLight OSL gamma signal (on the OSL elements E3 and E4 and corrected using the difference between E2 and E1 and C_n). The post comparison of the given gamma dose to the OSL result and using the estimated C_n yielded values of R. Although this still required the given gamma dose, this had an advantage of not needing the given neutron dose $D(10)_n$ as would be needed if C_n was post calculated by:

$$C_n = (E2 - E1)/\text{Given } D(10)_n.$$

Values of R were estimated by this approach to be 0.235 and 0.237 on the phantom front at 3-meter and 4-meter distances, and on the phantom back to be 0.304 and 0.232 at the 3-meter and 4-meter distances.

The default R value of 0.165 was based on a neutron/gamma dose ratio of 8. Values of R obtained by this approach were higher than the default, and for the FlatTop exercise, the given neutron/gamma dose ratio was in the range of 4 to 6. On the other hand, using this approach for free-in-air, the values of R obtained were notably lower 0.048 and 0.044 at 3-meter and 4-meter distances. Free-in-air values of R were lower because the apparent reading of E1, E3, and E4 were closer to given gamma dose for OSL FIA than OSL on phantom. Meaningful results from OSL FIA was a consideration because operationally OSL PNAD results would not be used free-in-air and only worn on an individual. Previous values of R used for the Godiva results reflected that the OSLs in PNADs were positioned on phantoms, and not FIA.

8.3 Calculated OSL Results Compared to Given Gamma Dose

Alternatively using the default R value of 0.165 for the FlatTop OSL data with the estimated C_n would have conservatively over reported the gamma doses on phantom in the range of 14% to 43%. Using the value for R of 0.235 for FlatTop data would have resulted in reported gamma doses on phantom with a positive bias of 16.2%, and within 1% for the phantom front. Using all four phantom measured neutron doses from Pulse 2 provided an average C_n of 12.44 and an R of 2.60. While these provided gamma doses to within ±12.5% of the given gamma doses, if the default R of 0.165 was used then the gamma doses would have been conservatively over reported in the range of 10% to 55%.

8.4 Iteration of R and Convergence

A method of obtaining R was proposed by iterating R for the gamma dose calculation $D(10)_\gamma$ and using the measured neutron dose from the metal foils. This was done for Pulse 2 PNADs 290 and 292 located on the phantom frontside. This had the advantage of obtaining an estimated R for unknowns, without needing the given doses.

Values of R were estimated based on the ratio of the calculated gamma dose after InLight reading to the measured neutron dose obtained from the metal foils, and with an offset added.

$$(\text{Calculated } D(10)_\gamma \text{ / Neutron rad from measured foils}) + \text{Offset } r =$$

$$(\gamma/n) + r$$

The calculation for R used the C_n obtained from the OSL comparison to the measured foils neutron dose. The first row of the iteration used the default R of 0.165. The offset r was assumed to be 0.05 corresponding close to the observed 5% for the E1 FIA PNAD results and was similar to the default of 0.04 (i.e., default γ/n ratio of 1/8 + 0.04 = 0.165). Each subsequent row calculated a new estimated R based on the calculated $D(10)_\gamma$ and using the measured neutron dose from the metal foils. The R estimate was used in the next row $D(10)_\gamma$ calculation and reiterated 500 times.

The iteration revealed that the value for R converges rapidly after 100 iterations to within the first couple of decimal places, and to within three or more decimal places after 200 to 500 iterations. Convergence of R was demonstrated for both 290 and 292 PNADs. Results were 0.23257 for PNAD 290 and 0.22374 for PNAD 292 at 500 iterations. Gamma dose results were 67.8 rad for PNAD 290, and 63.5 rad for PNAD 292. This was within +1.2% and +7.7% of the given gamma doses, respectively. It was noted that the PNAD 292 result aligned with the anomalous higher reported neutron dose at 4-meter distance for Pulse 2. This algorithm had the advantage of obtaining an estimated R for unknowns.

No further consideration was given whether the contribution to the apparent reading could be due to direct neutron interaction with the OSL material, or from prompt gammas, or from much shorter lived isotopes in the OSL filters (e.g., decayed off in the first couple hours before delivery to the NAD lab).

9. Discussion and Summary of Results

The FlatTop exercise was the first time PNNL tested this new dose calculation methodology. Results were generally favorable with some reported results conservatively over responding that fell above of the performance criteria. Overall, the exercise demonstrated that the methodology was generally robust enough to provide accurate neutron dose results with the ANSI 13.3-2013 criteria for all but a few of the PNADs, and the few conservatively over responded just above the ANSI 13.3-2013 criteria. All of the Pulse 2 total doses were within the ±25% criteria except for the two anomalously over responded at the 4-meter distance on phantom. These two doses on phantom at 4-meter distance conservatively fell above the criteria at 31% and 34%. The neutron dose results for Pulse 2 on the phantom at 3-meters were within 3% (see -2.52% and +2.10%).

9.1 Methodology for Estimating the Dose in the Intermediate Energy Range

The methodology had an advantage of accounting for the intermediate 0.1 MeV – 1.25 MeV energy range based on a weighted sum of contributions of the fluence from the epithermal region (0.5 eV – 100 keV, primarily measured from the activated ^{64}Cu) and the higher energy region (1.25 MeV – 3.16 MeV, primarily measured from the activated ^{115m}In). This was demonstrated for one of the most challenging cases given the energy spectrum from the FlatTop exercise yielded the majority of the dose from this intermediate energy range. Review of the intermediate energy range may include whether there were other applicable weighting factors (other than 0.48 and 1.12, and the sum other than 1.6), and whether there was a PNAD component that would measure the intermediate energy range more directly (e.g., mercury cross section applicable to the 0.1 MeV – 1.25 MeV range).

9.2 Anomalous Pulse 2 Result at 4-Meters on Phantom

Unfortunately, the two PNAD Pulse 2 neutron results that were conservatively high were anomalous since the measured ^{64}Cu activation was more consistent with that measured at the 3-meter distance. The ^{64}Cu measured counts on the NaI detectors confirmed that the activities from the 3-meter and 4-meter distances were similar, and the measured Ge detector spectra were verified (PNADs 290 and 292). The ^{24}Na simulated blood vial dose suggested that there was more activation at the 4-meter distance than expected compared to 3-meter distance when referenced to the given neutron doses. In the event of an actual criticality with unknown doses, and when the PNAD neutron result is consistent with the estimated blood ^{24}Na result, the reported neutron doses would most likely remain based on the PNAD measurements.

9.3 Rotation Correction

The one PNAD Pulse 1 neutron result that was conservatively over reported at the 4-meter distance was an artifact of the limited availability of detailed correction factors for rotation. Hence, the most conservatively factor was applied. Though measurements for phantom rotation was a goal of the FlatTop exercise, detailed correction factors for rotation remained limited since only four more data points were obtained from the FlatTop exercise, and with Pulse 2 containing anomalously higher readings at the 4-meter phantom distance. For the data where the PNAD was positioned on the backside of the phantom, the comparison to the ANSI N13.3-2013 criteria might not have been as meaningful because the dosimeter had a known under response (e.g., factor of 3). The ANSI 13.3-2013 criteria may have been more applicable to dosimeters that measure the dose more directly for rotations facing away from the source such as a belt dosimeter. The results for PNADs placed on the backside of the phantom appeared more meaningful if the corrected reported dose was only compared to whether the dose was sufficiently conservative.

9.4 Correction from Initial Reported Dose to Final Dose

Change between neutron doses reported within the 24-hour period and the final doses weeks later was minimal with only a typo corrected and one transposed number corrected (e.g., E+3 corrected to E+4 ^{64}Cu in the calculation spreadsheet for the measured activity for PNAD 299). Initial doses were generally reported within 5-hours to 7-hours after receiving the PNADs. Doses reported were not corrected using the given energy spectra. Further work remained toward a consistent methodology for updating the neutron doses based on the given energy spectra. Consideration should be given for an additional component in the PNAD that has a good flat response across a wide range of energies to supplement the refinement to final dose (e.g., tissue equivalent alanine pellet read using Magnettech MS-5000, even though the MDA may be 25 rad).

9.5 Correlation for First Approximation Estimate

A brief review of the activities from ^{32}P or ^{115m}In to neutron dose did not appear to be a reliable indicator for a first approximation dose estimate. The ^{64}Cu activity was a more reliable first approximation indicator. This was expected given the energy spectrum from FlatTop and since 80% of the reported neutron dose was based on the epithermal and intermediate energy regions. A precaution should be made prior to applying a first approximation dose based on only one isotope, because the first approximation was highly dependent on whether selected isotope was mostly applicable to the energy spectrum. The main indicators for first approximation dose were ^{115m}In for Godiva and ^{64}Cu for FlatTop, and potentially would be ^{32}P for an energy spectrum shifted higher than the Godiva spectrum.

9.6 Gamma Doses

The initial reported gamma dose results fell non-conservatively low because only the default parameters obtained from the Godiva-IV exercise were used, and the OSL gamma dosimeter has an energy dependency. A calculational approach to obtain C_n or adjustments to R were not made to the reported doses. A later calculation approach to obtain C_n was to compare the OSL neutron result to the neutron dose obtained from the metal foils and sulfur pack. This approach would have reported Pulse 2 gamma doses conservatively high, not low, using the default R of 0.165, and reported gamma dose results within 12.5% of the given gamma doses when using 0.260 for R. An algorithm was proposed to iterate R to convergence. This was demonstrated for Pulse 2 PNADs 290 and 292 on the phantoms frontside. The iteration for R was done without needing the given doses. Results were within 8% of the given gamma doses, with +1.2% and +7.7% of the given gamma doses respectively. It should be noted that the given gamma dose only accounted for 15% to 20% of the given total dose, and therefore, slight improvements to the measured gamma dose had minimal impact to the total dose measured. Gamma dose measurements on phantom were meaningful while FIA were not, since PNADs would only be worn on the individual.

9.7 Dose from Biological Samples

The results from the simulated biological samples were also favorable, and in several cases conservatively over reported. Blood dose appeared closer to Dp(10) than to tissue kerma using the default conversion factor K of 0.168 in Pulse 1 and 2. Measurements of the hair for ^{32}P were challenging because the small fraction of fast higher energy neutrons from FlatTop needed to activate the sulfur contained in the hair. Low level beta background and count time should be employed. Accurate individual hair weight could be improved by pre-weighing the hair sample collection envelopes to obtain the hair sample net weight. Physical handling of the hair outside of the collection envelope proved difficult because the hair was easily dispersed. The approximate beta counting efficiency based on the ^{90}Sr-Y source counting efficiency yielded favorable results, though a more precise count efficiency could be obtained by counting known activated hair samples and sublimated. This may be unnecessary since sublimation would always be a follow up option in the case of an actual event, and the fraction of total dose factor applied to the first approximation hair dose is more critical. The fraction of total dose factor for FlatTop was demonstrated to be closer to 0.1 than the default 0.3, as was expected for the FlatTop spectrum based on the literature and as based on the PNAD dose results for the two higher energy regions. Comparison of the fast fluence from the hair versus the PNAD was useful in the hair dose first approximation. The combined hair and blood dose estimate was favorable though difficult given the range and judgement made in the intersecting Hankins graph. The hair measurements proved most useful as a qualitative indication of orientation.

9.8 FlatTop Characterization

The FlatTop spectral fluence was characterized in May 2017. Results were presented at the NCSP Technical Seminar at LLNL on March 28-29, 2018, *Integral Experiments Accomplishments IER-252 Flattop Field Measurement and Upcoming NAD Exercise (IER-253)*. The FlatTop characterization information contained important information regarding several positions (e.g., see positions 3, 4, and 7). The FlatTop characterization was idealized energy spectra largely based on the PNS information, and therefore, appeared to represent spectral information for free-in-air (FIA) and not on phantom. The FlatTop characterization summarized other important information such as variability as a function of distance and height. This FlatTop characterization information was not provided after the FlatTop inter-comparison exercise. Future inter-comparison exercises should consider sharing this information after final doses are reported. Future inter-comparison exercises should report additional characterization information for the location of the PNADs, and report the neutron spectral energy fluence in a 53-bin structure in accordance with ANSI N13.3-2013, *Dosimetry for Criticality Accidents*.

10. Conclusions

PNAD neutron and total dose results were favorable with the majority of the PNADs within the ANSI 13.3-2013 criteria. All except one of the PNAD total doses were within 35% of the given dose. One was conservatively reported above thirty five percent because the most conservative rotation factor was applied.

All but one neutron dose result in Pulse 1 and all but two in Pulse 2 passed the ANSI 13.3-2013 criteria of ±50% for dose range 10 to 100 rad and ±25% for dose range 100 to 1,000 rad. This was an overall ANSI 13.3-2013 pass rate of 23 out of 26 or 88%. The few that were outside the criteria were typically conservatively over reported, and unfortunately were due to applying the most conservative rotation factor, and due to the anomalous activated copper result for Pulse 2 at 4-meters.

All but three total dose results in Pulse 1 and all but two in Pulse 2 passed the ANSI 13.3-2013 criteria of ±50% for dose range 10 to 100 rad and ±25% for dose range 100 to 1,000 rad. This was an overall ANSI 13.3-2013 pass rate of 21 out of 26 or 81%, with the few not passing typically conservatively over reported. The design of the FlatTop exercise was ingenious in targeting Pulse 1 total dose slightly above 100 rad such that the criteria of ±25% applied (see the 3-meter position). All but one of the PNAD total doses were within 35% of the given dose, or 25 out of 26.

Initially, the gamma dose results were under reported because the default OSL parameters from the Godvia exercise were used, and a methodology for obtaining the OSL parameters C_n and R was not developed prior to the FlatTop exercise. An approach was outlined to obtain the OSL parameter C_n based on the measured metal foils and sulfur packs. A method for obtaining R was proposed and demonstrated for Pulse 2 PNADs 290 and 292. The algorithm for obtaining R demonstrated that R could be iterated to convergence. This algorithm did not use the given doses and had the advantage of estimating R for unknowns. It was noted that the gamma dose only accounted for less than 20% of the total, and therefore, slight improvements to the gamma dose will have minimal impact to the total dose. OSL response on phantom was in contrast to the OSL response free-in-air (FIA). The OSL FIA results were not as meaningful as the OSLs on phantom because the PNAD would only be worn on the individual.

The results from the simulated biological samples were also favorable, and in several cases conservatively over reported. Results corresponded closer to $D_p(10)_n$ dose than to tissue kerma. Results were within 30% of $D_p(10)_n$. The reported blood dose compared to the reported PNAD dose was within 14%, and for Pulse 2 at 3-meters within 6%. Hair results mainly proved useful for qualitatively indicating orientation. Combined blood-hair dose was within 8% for Pulse 1, though some uncertainty was associated with the judgement of the Hankins graph intersection used for the combined blood-hair dose. The doses were closer to $D_p(10)_n$ than to tissue kerma.

11. References

A New Dose Calculation Methodology for New PNAD and FNAD Designs at PNNL (PNNL-27023).

ANSI N13.3-2013, *Dosimetry for Criticality Accidents*

Blind Intercomparison of Nuclear Accident Dosimetry using the Flattop Reactor at NCERC (LLNL-TR-758222)

Dosimetry of Criticality Accidents using Activations of the Blood and Hair, Dale E. Hankins, 1980. Health Physics Vol. 38 (April), pp. 529-541

IAEA Report No. 211, *Dosimetry for Criticality Accidents*

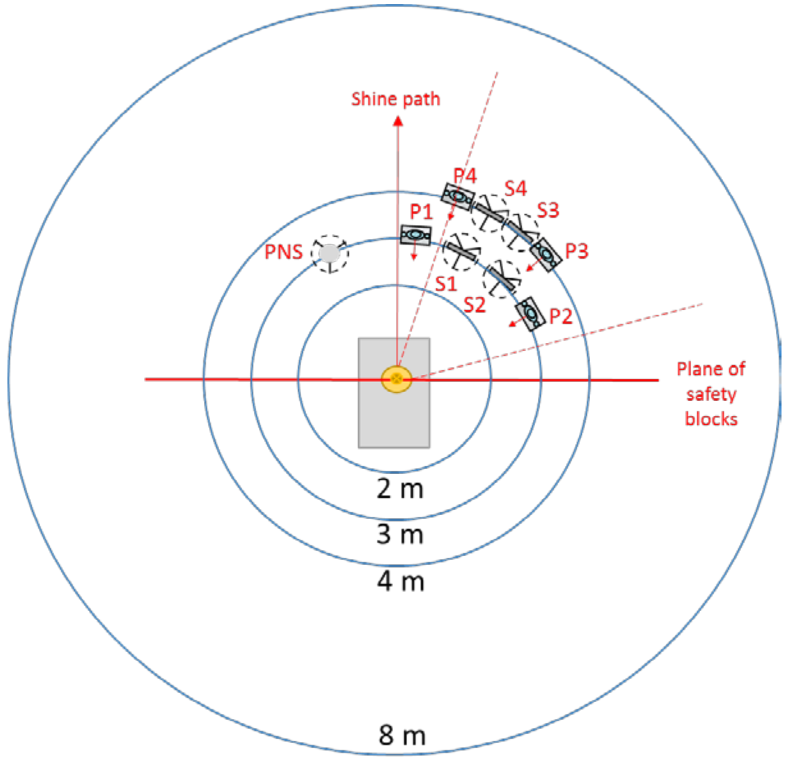
NCSP Technical Seminar at LLNL on March 28-29, 2018, *Integral Experiments Accomplishments IER-252 Flattop Field Measurement and Upcoming NAD Exercise (IER-253)*

PNNL Measurement Results for the 2016 Criticality Accident Dosimetry Exercise at the Nevada National Security Site IER-148 (PNNL-26497)

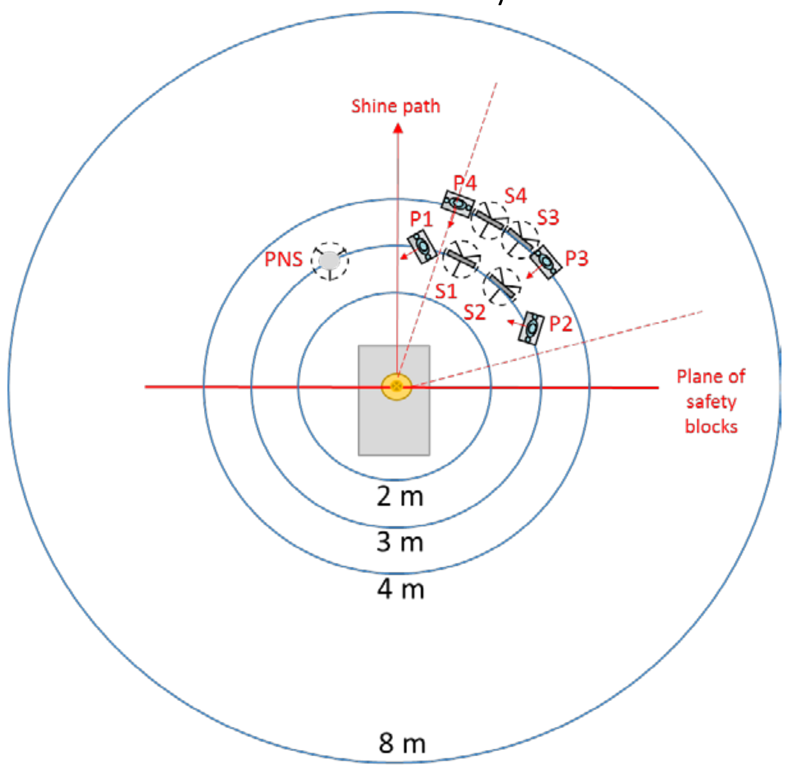
PNNL Radiological Control Program Description Article 515, *Nuclear Accident Dosimeters*

10 CFR 835 Section 1304, *Nuclear Accident Dosimetry*

Appendix A. Floor Plan and Layout.



Pulse 1 Floor Plan Layout.



Pulse 2 Floor Plan Layout.

(P = Phantom, S = Free-in-Air Stand, PNS = Passive Neutron Spectrometer)

Pulse 2 Example of PNADs on Phantoms.

Pulse 2 Example of PNADs on Aluminum Stands Free-In-Air (FIA).

Appendix B. Listing of Dosimeter Positions and Distances.

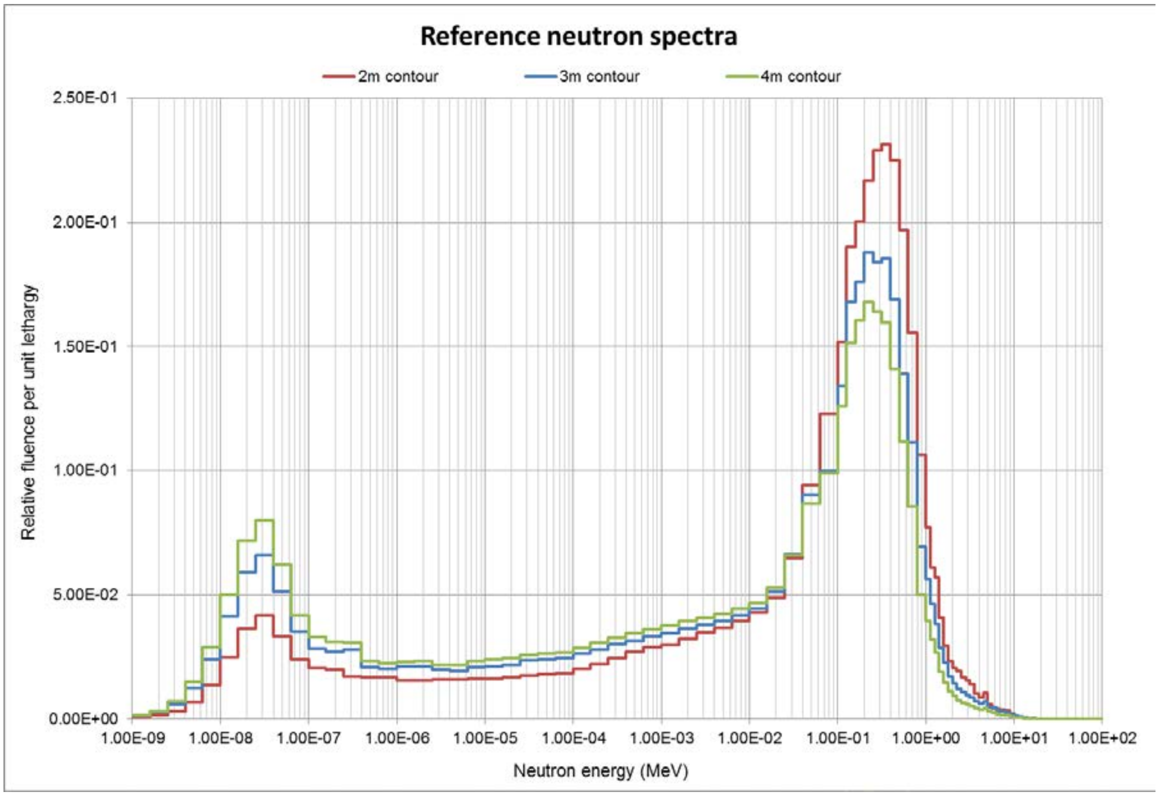
Irradiation 1			
Dosemeter ID	Mount	Orientation	Distance from core
#			m
277	BOMAB	0	3
278	BOMAB	180	3
272	Free-in-air stand	N/A	3
271	Free-in-air stand	N/A	3
270	Free-in-air stand	N/A	3
281	Free-in-air stand	N/A	3
282	Free-in-air stand	N/A	3
283	Free-in-air stand	N/A	3
279	BOMAB	0	4
280	BOMAB	180	4
275	Free-in-air stand	N/A	4
276	Free-in-air stand	N/A	4
273	Free-in-air stand	N/A	4
274	Free-in-air stand	N/A	4

Pulse 1 Listing of Dosimeter Positions and Distances.

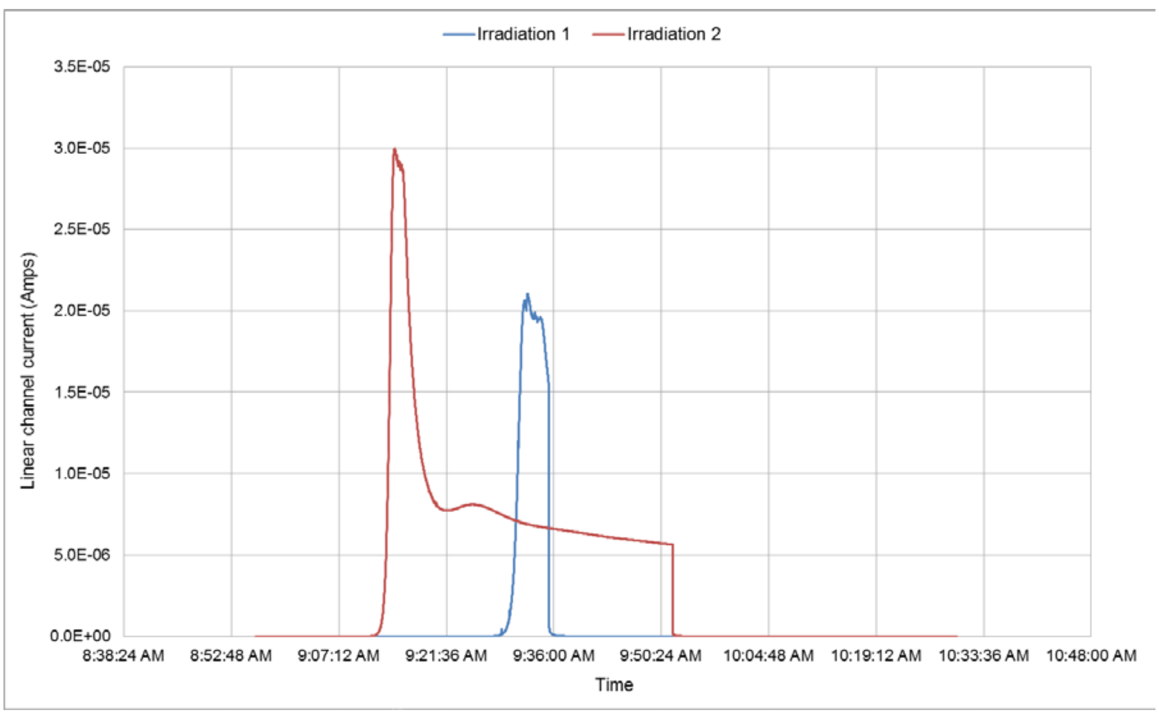
Irradiation 2			
Dosemeter ID	Mount	Orientation	Distance from core
#			m
290	BOMAB	45	3
291	BOMAB	225	3
300	Free-in-air stand	N/A	3
301	Free-in-air stand	N/A	3
302	Free-in-air stand	N/A	3
294	Free-in-air stand	N/A	3
295	Free-in-air stand	N/A	3
296	Free-in-air stand	N/A	3
292	BOMAB	0	4
293	BOMAB	180	4
303	Free-in-air stand	N/A	4
304	Free-in-air stand	N/A	4
305	Free-in-air stand	N/A	4
297	Free-in-air stand	N/A	4
298	Free-in-air stand	N/A	4
299	Free-in-air stand	N/A	4

Pulse 2 Listing of Dosimeter Positions and Distances.

Appendix C. Spectra and Pulses



FlatTop spectra given in 83-bin structure.



FlatTop pulse durations.

Appendix D. Delivered Doses (Given)

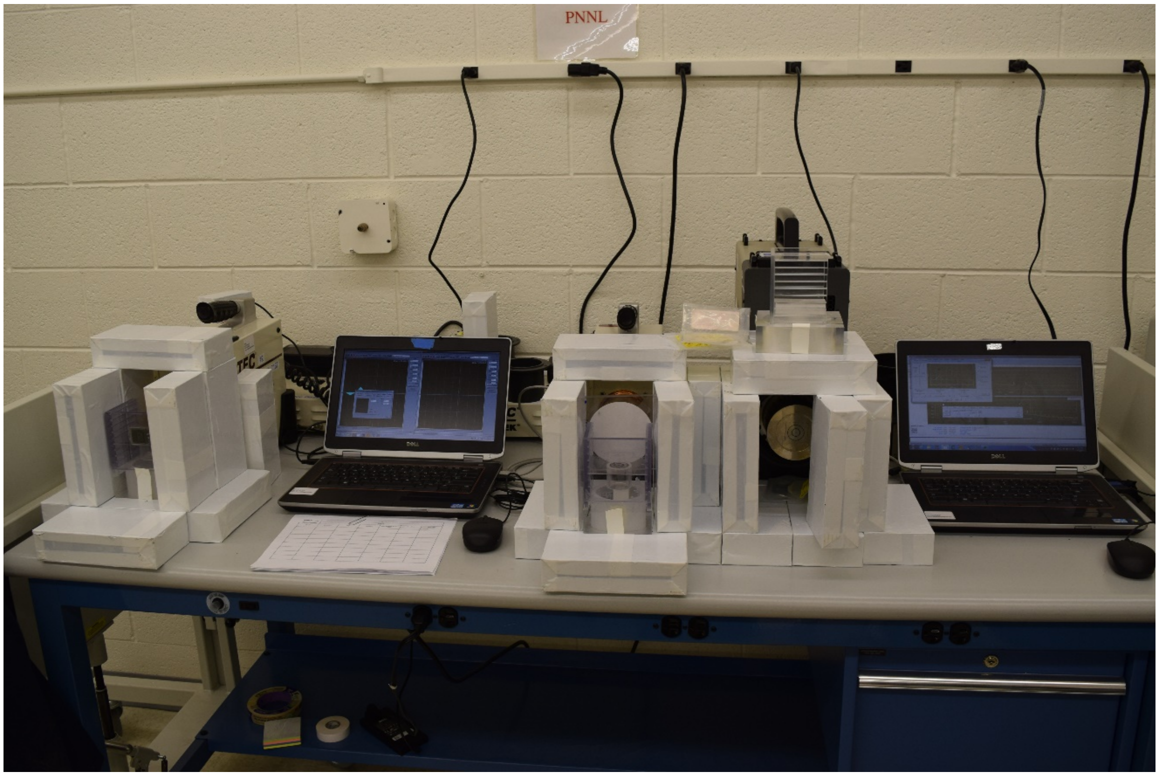
Irradiation 1

Distance	Positions	Total Fluence	TOTAL Neutron DOSES: Tiss. KERMA Dose	Air KERMA Dose	ANSI 13.3 Dp(10)	ANSI 13.3 D*(10)	Auxier et. al. Element 57	IAEA 211	NCRP 38	Gamma Dose (Gy) +/- 1s		
m	#	n/cm2	(Gy)	(Gy)	(Gy)	(Gy)	(Gy)	(Gy)	(Gy)		**+1s**	**-1s**
2	1, 2, 3	1.46E+11	1.08	0.09	1.57	1.46	1.44	1.45	1.49	0.20	0.19	0.21
3	4, 5, 6	1.03E+11	0.59	0.05	0.92	0.85	0.86	0.88	0.90	0.17	0.16	0.18
4	7, 8, 9	7.79E+10	0.37	0.03	0.61	0.56	0.58	0.59	0.61	0.15	0.14	0.16

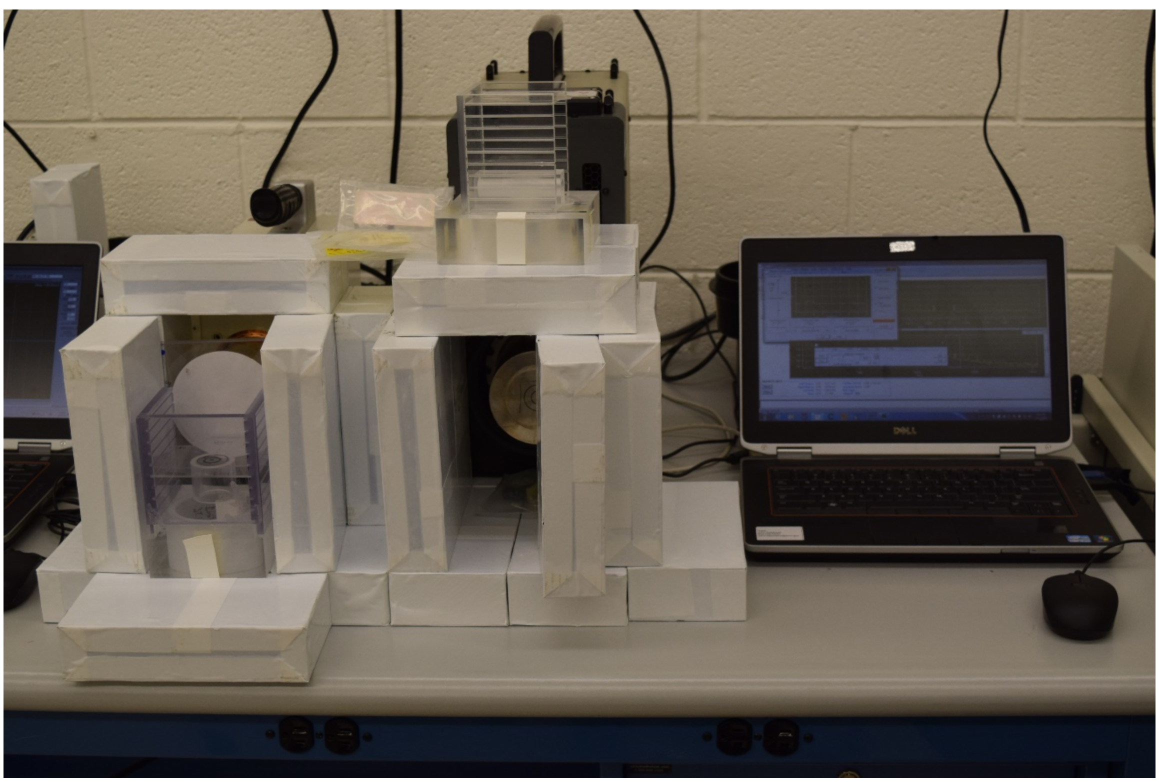
Irradiation 2

Distance	Positions	Total Fluence	TOTAL Neutron DOSES: Tiss. KERMA Dose	Air KERMA Dose	ANSI 13.3 Dp(10)	ANSI 13.3 D*(10)	Auxier et. al. Element 57	IAEA 211	NCRP 38	Gamma Dose (Gy) +/- 1s		
m	#	n/cm2	(Gy)	(Gy)	(Gy)	(Gy)	(Gy)	(Gy)	(Gy)		**+1s**	**-1s**
2	1, 2, 3	6.01E+11	4.45	0.39	6.44	6.03	5.91	5.96	6.12	0.76	0.72	0.81
3	4, 5, 6	4.26E+11	2.46	0.21	3.81	3.54	3.58	3.63	3.74	0.67	0.62	0.73
4	7, 8, 9	3.20E+11	1.52	0.12	2.50	2.31	2.39	2.44	2.51	0.59	0.55	0.63

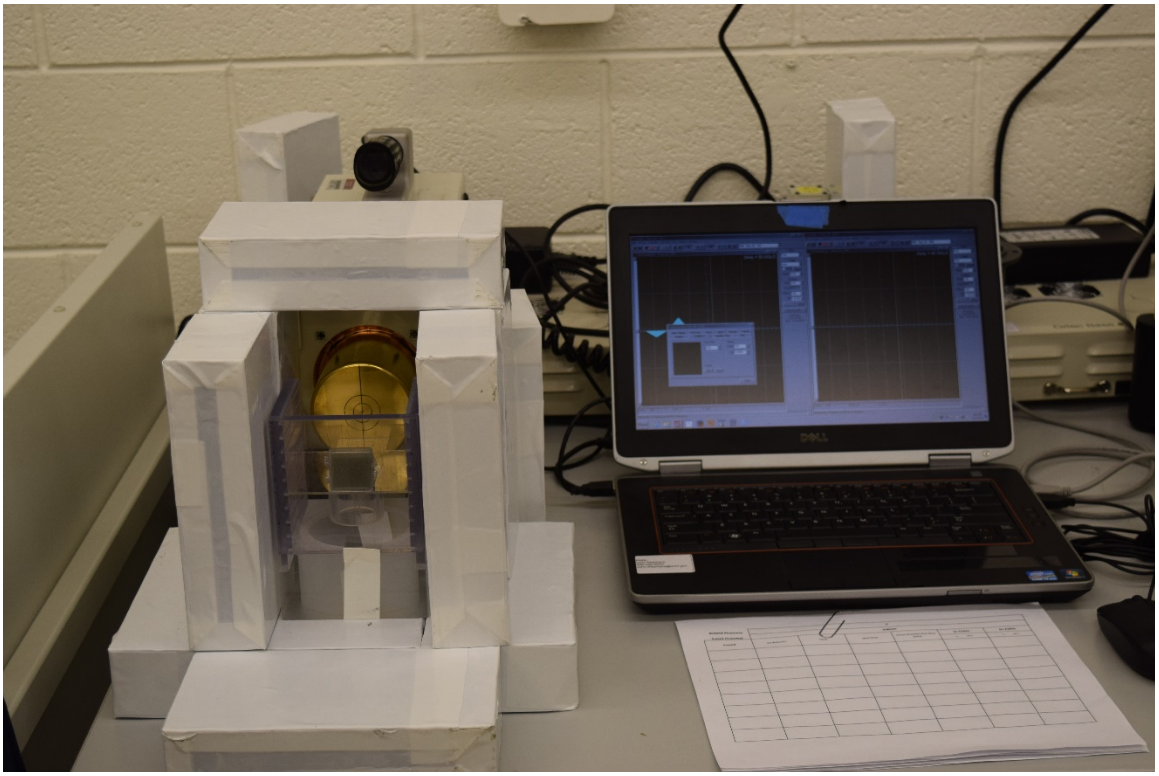
Appendix E. Instrumentation and Counting Stations



The Ge detector counting station.



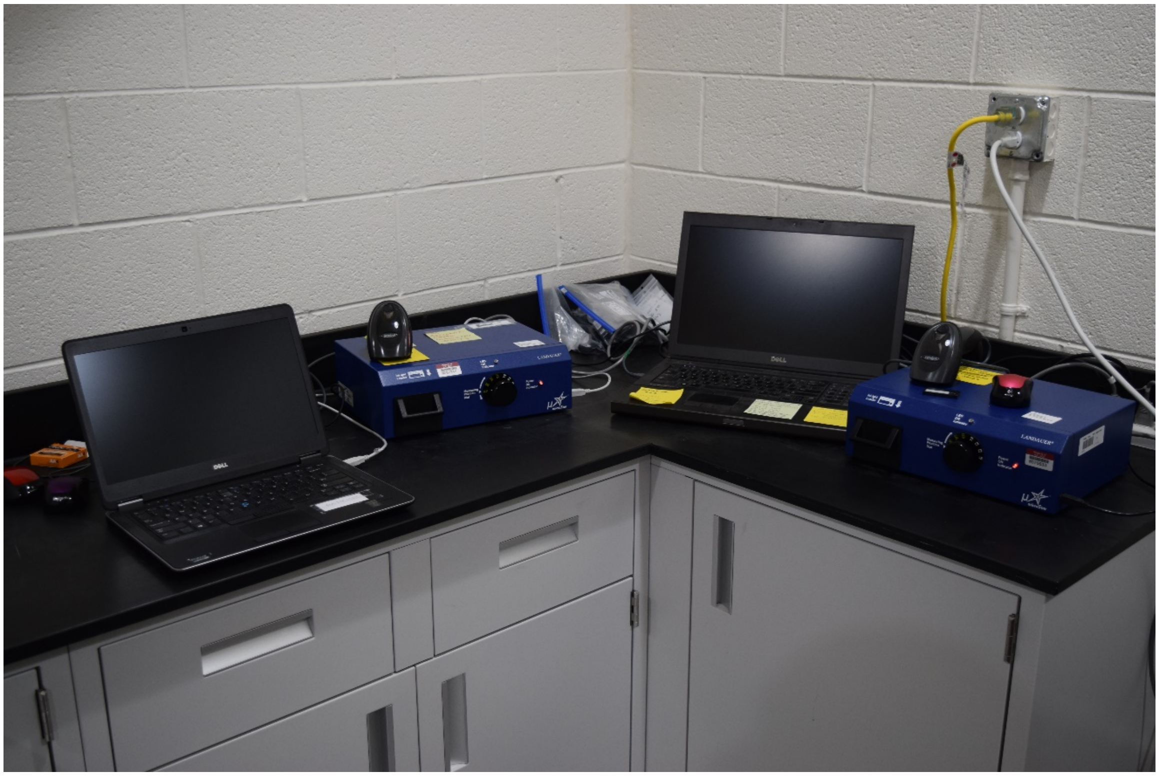
The Canberra Falcon and Ortec Detective with laptop used with the Falcon.



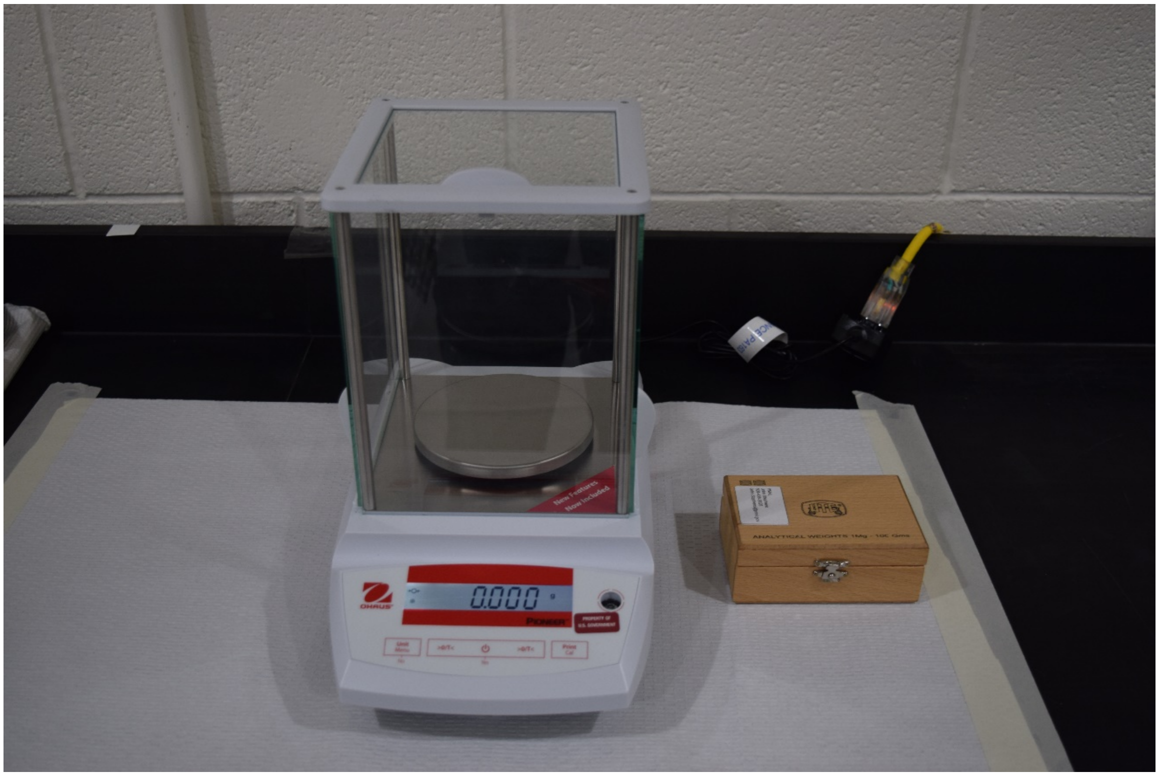
An Ortec Detective and laptop used with the Detectives.

NaI detectors with URSA-II MCAs.

iSolo counters with printers for recording beta counts and laptop for an electronic save of count data. Laptop on the right is for the NaI-URSAs.



OSL InLight readers.



Digital pan balance with weight set.

Receiving and disassembly station.

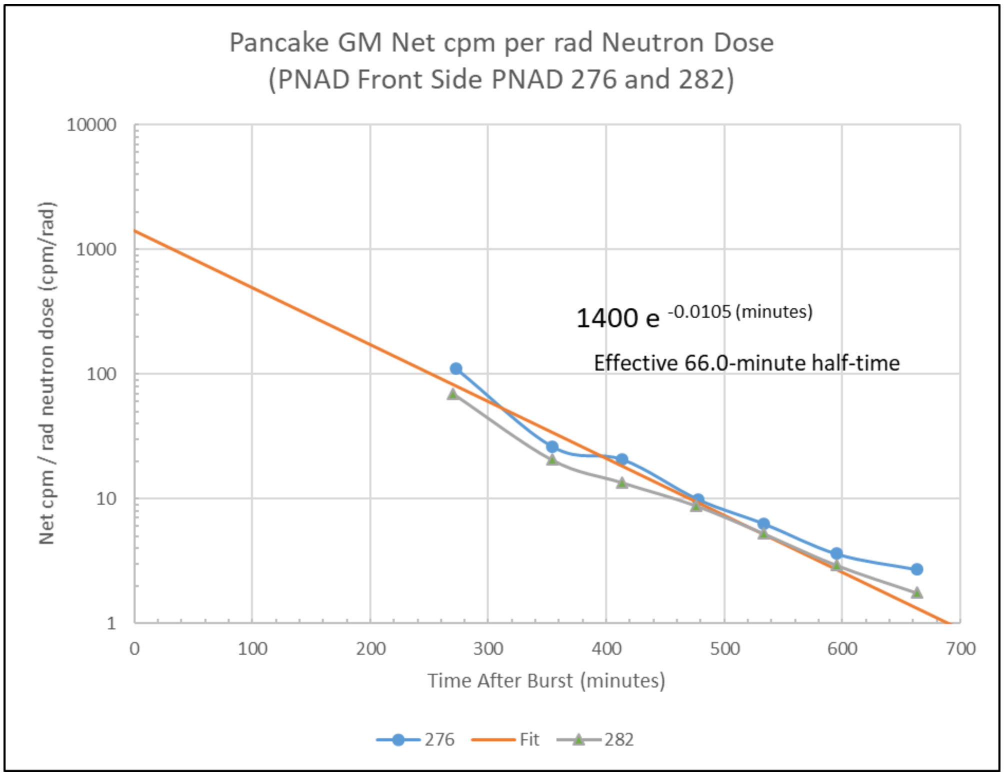
Appendix F. Portable Instrument Measurements Direct on PNAD Front

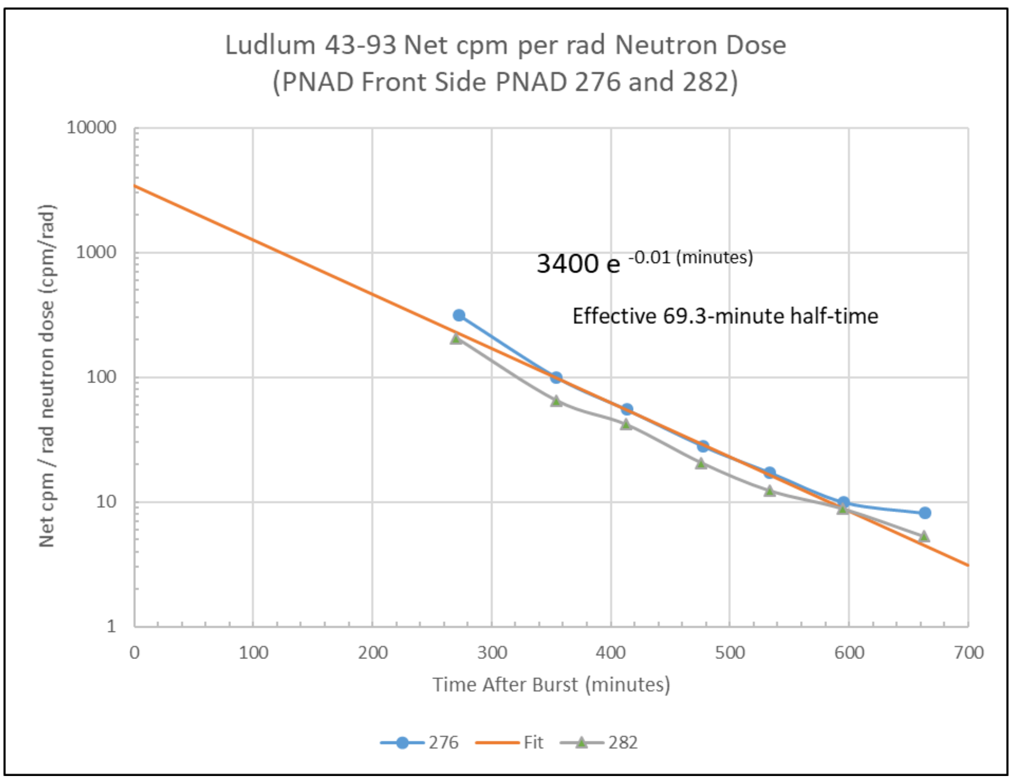
Dosimeter #	Pancake GM (gross cpm)	PNAD Front	Ludlum 43-93 (gross cpm)	PNAD Front	Date	Time	Burst End Time	Decay Time after burst end (minutes)
Background	45	**Pancake GM (net cpm)**	300	**Ludlum 43-93 (net cpm)**	5/22/2018	13:11	5/22/2018 9:36	215
277	16,000	15,955	50,000	49,700	5/22/2018	13:30	5/22/2018 9:36	234
278	7,000	6,955	25,000	24,700	5/22/2018	13:38	5/22/2018 9:36	242
279	13,800	13,755	35,000	34,700	5/22/2018	13:42	5/22/2018 9:36	246
280	7,400	7,355	20,000	19,700	5/22/2018	13:43	5/22/2018 9:36	247
271	8,800	8,755	25,000	24,700	5/22/2018	13:48	5/22/2018 9:36	252
272	9,500	9,455	15,000	14,700	5/22/2018	13:50	5/22/2018 9:36	254
273	8,400	8,355	18,000	17,700	5/22/2018	13:53	5/22/2018 9:36	257
270	6,800	6,755	24,000	23,700	5/22/2018	13:55	5/22/2018 9:36	259
275	7,200	7,155	22,000	21,700	5/22/2018	13:57	5/22/2018 9:36	261
281	7,500	7,455	16,000	15,700	5/22/2018	14:00	5/22/2018 9:36	264
283	8,000	7,955	20,000	19,700	5/22/2018	14:03	5/22/2018 9:36	267
274	7,200	7,155	16,000	15,700	5/22/2018	14:04	5/22/2018 9:36	268
282	6,000	5,955	18,000	17,700	5/22/2018	14:06	5/22/2018 9:36	270
276	6,200	6,155	18,000	17,700	5/22/2018	14:09	5/22/2018 9:36	273

276 Pancake GM (gross cpm)	PNAD 276	Pancake GM Net cpm Per rad Neutron Dose (56 rad neutron dose at 4m FIA)	276 Ludlum 43-93 (gross cpm)	PNAD 276	Ludlum 43-93 Net cpm Per rad Neutron Dose (56 rad neutron dose at 4m FIA)	Date	Time	Burst End Time	Decay Time after burst end (minutes)
50	**Pancake GM (net cpm)**		450	**Ludlum 43-93 (net cpm)**		5/22/2018	15:28	5/22/2018 9:36	352
6200	6150	110	18000	17550	313	5/22/2018	14:09	5/22/2018 9:36	273
1500	1450	26	6000	5550	99	5/22/2018	15:31	5/22/2018 9:36	355
1200	1150	21	3500	3050	54	5/22/2018	16:30	5/22/2018 9:36	414
600	550	10	2000	1550	28	5/22/2018	17:34	5/22/2018 9:36	478
400	350	6.3	1400	950	17	5/22/2018	18:30	5/22/2018 9:36	534
250	200	3.6	1000	550	10	5/22/2018	19:32	5/22/2018 9:36	596
200	150	2.7	900	450	8	5/22/2018	20:40	5/22/2018 9:36	664

282 Pancake GM (gross cpm)	PNAD 282	Pancake GM Net cpm Per rad Neutron Dose (85 rad neutron dose at 3m FIA)	282 Ludlum 43-93 (gross cpm)	PNAD 282	Ludlum 43-93 Net cpm Per rad Neutron Dose (85 rad neutron dose at 3m FIA)	Date	Time	Burst End Time	Decay Time after burst end (minutes)
50	**Pancake GM (net cpm)**		450	**Ludlum 43-93 (net cpm)**		5/22/2018	15:28	5/22/2018 9:36	352
6000	5950	70	18000	17550	206	5/22/2018	14:06	5/22/2018 9:36	270
1800	1750	21	6000	5550	65	5/22/2018	15:30	5/22/2018 9:36	354
1200	1150	14	4000	3550	42	5/22/2018	16:29	5/22/2018 9:36	413
800	750	9	2200	1750	21	5/22/2018	17:32	5/22/2018 9:36	476
500	450	5.3	1500	1050	12	5/22/2018	18:29	5/22/2018 9:36	533
300	250	2.9	1200	750	9	5/22/2018	19:31	5/22/2018 9:36	595
200	150	1.8	900	450	5	5/22/2018	20:39	5/22/2018 9:36	663

Pulse 1 PNADs 276 and 282 not disassembled and measured directly on the front face using the Ludlum 26-1 pancake GM and the Ludlum 2360 with 43-93 100cm^2 scintillator probe. Note that the calibration facility sets the Ludlum 26-1 dead-time correction to zero.





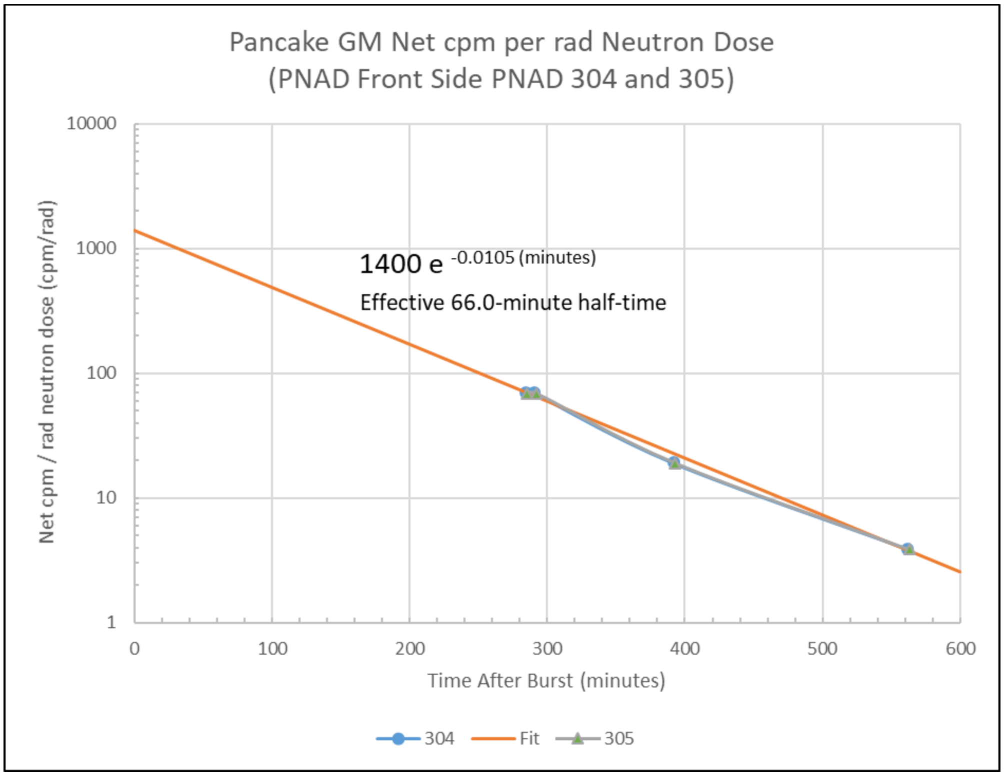
Pulse 1 PNADs 276 and 282 and normalized to given $D^{*}(10)_{n}$ FIA dose.

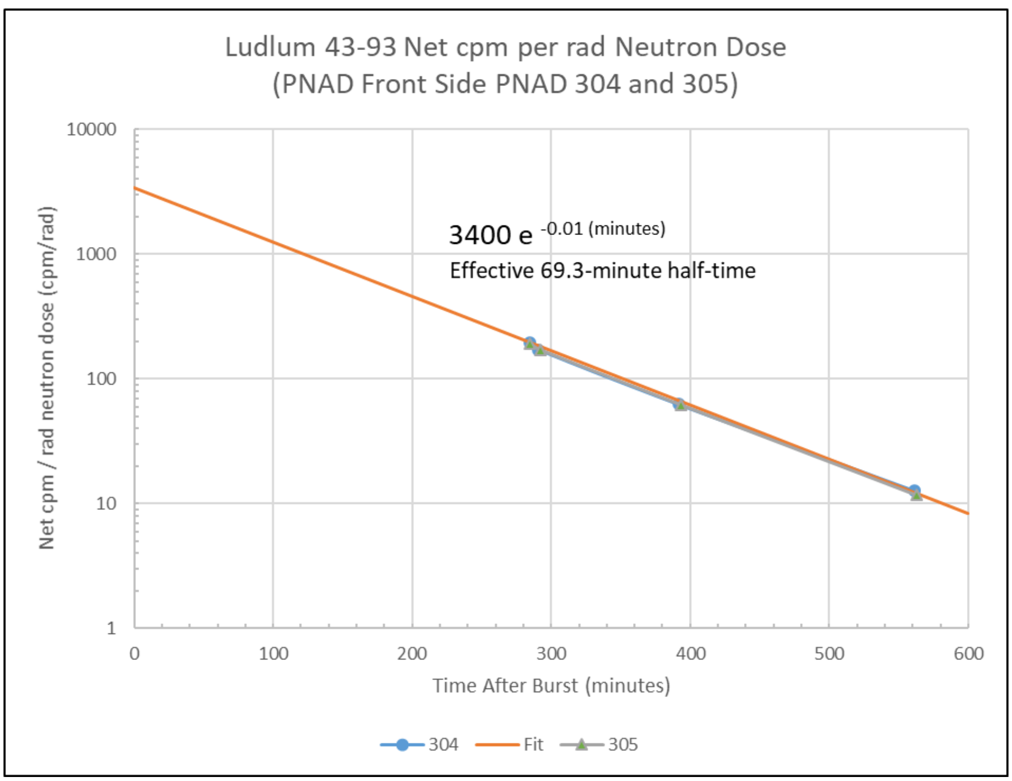
Dosimeter #	Pancake GM (gross cpm)	PNAD Front	Ludlum 43-93 (gross cpm)	PNAD Front	Date	Time	Burst End Time	Decay Time after burst end (minutes)
Background	100	**Pancake GM (net cpm)**	700	**Ludlum 43-93 (net cpm)**	5/23/2018	13:00	5/23/2018 9:52	188
290	40,000	39,900	100,000	99,300	5/23/2018	14:05	5/23/2018 9:52	253
291	25,000	24,900	65,000	64,300	5/23/2018	14:06	5/23/2018 9:52	254
292	38,000	37,900	110,000	109,300	5/23/2018	14:07	5/23/2018 9:52	255
293	20,000	19,900	50,000	49,300	5/23/2018	14:08	5/23/2018 9:52	256
294	27,000	26,900	70,000	69,300	5/23/2018	14:13	5/23/2018 9:52	261
295	21,000	20,900	70,000	69,300	5/23/2018	14:14	5/23/2018 9:52	262
296	22,000	21,900	65,000	64,300	5/23/2018	14:21	5/23/2018 9:52	269
297	19,500	19,400	50,000	49,300	5/23/2018	14:24	5/23/2018 9:52	272
298	20,000	19,900	50,000	49,300	5/23/2018	14:25	5/23/2018 9:52	273
299	18,000	17,900	45,000	44,300	5/23/2018	14:27	5/23/2018 9:52	275
300	20,000	19,900	55,000	54,300	5/23/2018	14:29	5/23/2018 9:52	277
301	20,000	19,900	50,000	49,300	5/23/2018	14:31	5/23/2018 9:52	279
302	19,000	18,900	50,000	49,300	5/23/2018	14:33	5/23/2018 9:52	281
303	18,000	17,900	48,000	47,300	5/23/2018	14:34	5/23/2018 9:52	282
304	16,000	15,900	45,000	44,300	5/23/2018	14:37	5/23/2018 9:52	285
305	16,000	15,900	45,000	44,300	5/23/2018	14:37	5/23/2018 9:52	285

304 Pancake GM (gross cpm)	PNAD 304	Pancake GM Net cpm Per rad Neutron Dose (231 rad neutron dose at 4m FIA)	304 Ludlum 43-93 (gross cpm)	PNAD 304	Ludlum 43-93 Net cpm Per rad Neutron Dose (231 rad neutron dose at 4m FIA)	Date	Time	Burst End Time	Decay Time after burst end (minutes)
100	**Pancake GM (net cpm)**		700	**Ludlum 43-93 (net cpm)**		5/23/2018	13:00	5/23/2018 9:52	188
16000	15900	69	45000	44300	192	5/23/2018	14:37	5/23/2018 9:52	285
16000	15900	69	40000	39300	170	5/23/2018	14:43	5/23/2018 9:52	291
4500	4400	19	15000	14300	62	5/23/2018	16:24	5/23/2018 9:52	392
1000	900	4	3600	2900	13	5/23/2018	19:14	5/23/2018 9:52	562

PNAD 305	Pancake GM Net cpm Per rad Neutron Dose (231 rad neutron dose at 4m FIA)	305 Ludlum 43-93 (gross cpm)	PNAD 305	Ludlum 43-93 Net cpm Per rad Neutron Dose (231 rad neutron dose at 4m FIA)	Date	Time	Burst End Time	Decay Time after burst end (minutes)
Pancake GM (net cpm)		700	**Ludlum 43-93 (net cpm)**		5/23/2018	13:00	5/23/2018 9:52	188
15900	69	45000	44300	192	5/23/2018	14:37	5/23/2018 9:52	285
15900	69	40000	39300	170	5/23/2018	14:44	5/23/2018 9:52	292
4400	19	15000	14300	62	5/23/2018	16:25	5/23/2018 9:52	393
900	4	3400	2700	12	5/23/2018	19:15	5/23/2018 9:52	563

Pulse 2 PNADs 304 and 305 not disassembled and measured directly on the front face using the Ludlum 26-1 pancake GM and the Ludlum 2360 with 43-93 100cm^2 scintillator probe. Note that the calibration facility sets the Ludlum 26-1 dead-time correction to zero.





Pulse 2 PNADs 304 and 305 and normalized to given $D^*(10)_n$ FIA dose.

****

***** N U C L I D E   I D E N T I F I C A T I O N   R E P O R T *****

****

Sample Title: O7167_P1_277_PNAD
Nuclide Library Used: C:\GENIE2K\CAMFILES\PNADsimple.NLB

.... IDENTIFIED NUCLIDES ....

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (dpm/Unit)	Activity Uncertainty
K-40	0.989	1460.75*	10.67	6.418166E+03	6.506099E+02
MN-56	0.976	846.75*	98.90	3.919251E+03	1.247338E+02
		1810.72*	27.20	3.949885E+03	3.716156E+02
		2113.05*	14.30	3.644060E+03	5.008724E+02
		2522.88	0.99		
		2657.45	0.65		
		2959.77	0.31		
		3369.60	0.17		
CU-64	0.982	511.00*	35.71	2.415258E+05	3.306616E+03
		1345.77*	0.47	2.857907E+05	1.993823E+04

* = Energy line found in the spectrum.
@ = Energy line not used for Weighted Mean Activity
Energy Tolerance : 1.000 keV
Nuclide confidence index threshold = 0.30
Errors quoted at 1.000 sigma

****

***** I N T E R F E R E N C E   C O R R E C T E D   R E P O R T *****

****

Nuclide Name	Nuclide Id Confidence	Wt mean Activity (dpm/Unit)	Wt mean Activity Uncertainty
K-40	0.989	6.4181660E+03	6.5060987E+02
MN-56	0.976	3.9076601E+03	1.1508647E+02
CU-64	0.982	2.4271066E+05	3.2620611E+03

? = Nuclide is part of an undetermined solution
X = Nuclide rejected by the interference analysis
@ = Nuclide contains energy lines not used in Weighted Mean
Activity

Errors quoted at 1.000 sigma

********** U N I D E N T I F I E D   P E A K S **********

Peak Locate Performed on: 11/21/2018 8:36:17 AM
Peak Locate From Channel: 1
Peak Locate To Channel: 65535

Peak No.	Energy (keV)	Peak Size in Counts per Second	Peak CPS % Uncertainty	Peak Type	Tol. Nuclide
3	911.34	1.38846E-02	44.94		

M = First peak in a multiplet region
m = Other peak in a multiplet region
F = Fitted singlet

Errors quoted at 1.000 sigma

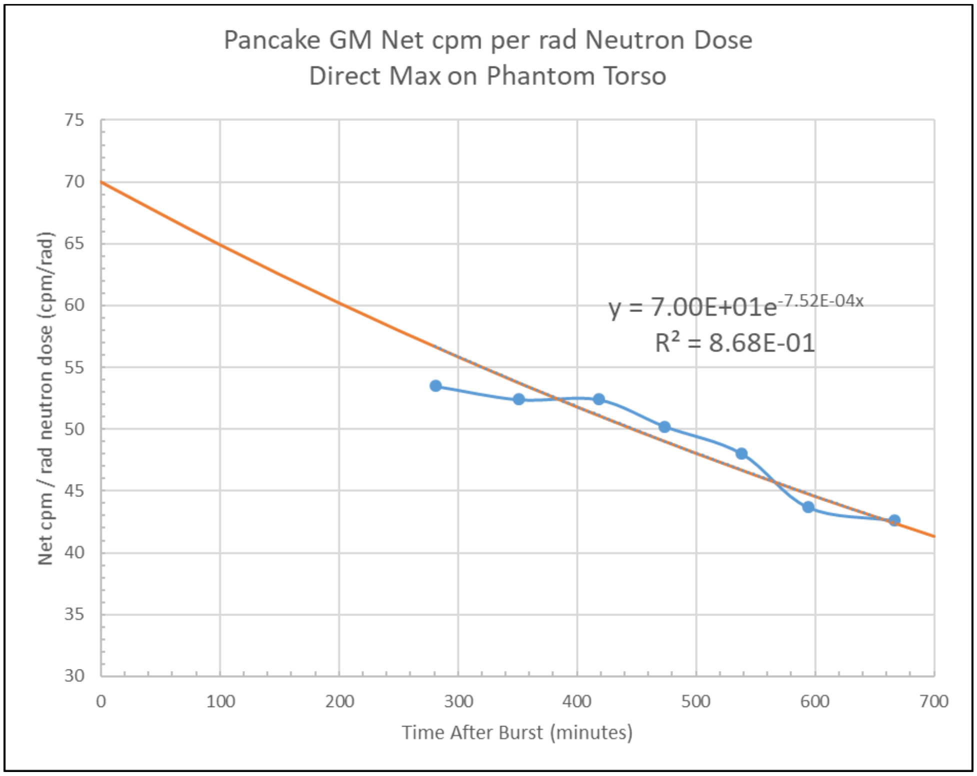
Example of PNAD 277 OSL Ge detector result.

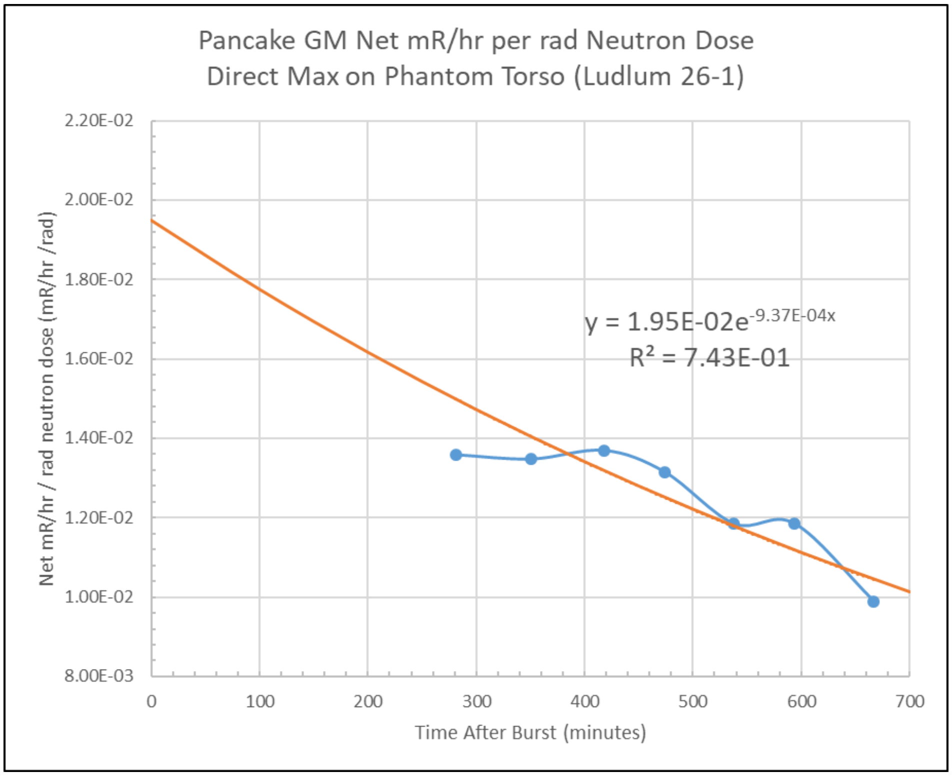
Appendix G. Portable Instrument Measurements on Phantom

Pulse 1 Direct Max Torso BOMAB Phantom	Pancake GM (Ludlum 26-1) gross cpm	Pancake GM (Ludlum 26-1) mR/hr	Ludlum 43-93 gross cpm	Thermo-Bicron Micro-rem meter urem/hr	Date	Time	Burst End Time	Decay Time after burst end (minutes)	Pancake GM Net cpm Per rad Neutron Dose (92 rad neutron dose at 3m)	Pancake GM Net mR/hr Per rad Neutron Dose (92 rad neutron dose at 3m)	Ludlum 43-93 Net cpm Per rad Neutron Dose (92 rad neutron dose at 3m)	Thermo-Bicron Micro-rem meter urem/hr Per rad Neutron Dose (92 rad neutron dose at 3m)
Background	80	0.01	450	5	5/22/2018	14:14	5/22/2018 9:36	278				
	5,000	1.3	35,000	700	5/22/2018	14:17	5/22/2018 9:36	281	53	1.36E-02	376	7.6
	4,900	1.3	32,000	700	5/22/2018	15:27	5/22/2018 9:36	351	52	1.35E-02	343	7.6
	4,900	1.3	30,000	650	5/22/2018	16:34	5/22/2018 9:36	418	52	1.37E-02	321	7.0
	4,700	1.2	28,000	600	5/22/2018	17:30	5/22/2018 9:36	474	50	1.32E-02	299	6.5
	4,500	1.1	26,000	500	5/22/2018	18:34	5/22/2018 9:36	538	48	1.18E-02	278	5.4
	4,100	1.1	25,000	500	5/22/2018	19:30	5/22/2018 9:36	594	44	1.18E-02	267	5.4
	4,000	0.9	25,000	500	5/22/2018	20:43	5/22/2018 9:36	667	43	9.89E-03	267	5.4
	2,200	0.6	15,000	250	5/23/2018	7:38	5/22/2018 9:36	1322	23	6.63E-03	158	2.7
Background	70	0.0	350	10	5/23/2018	7:35						

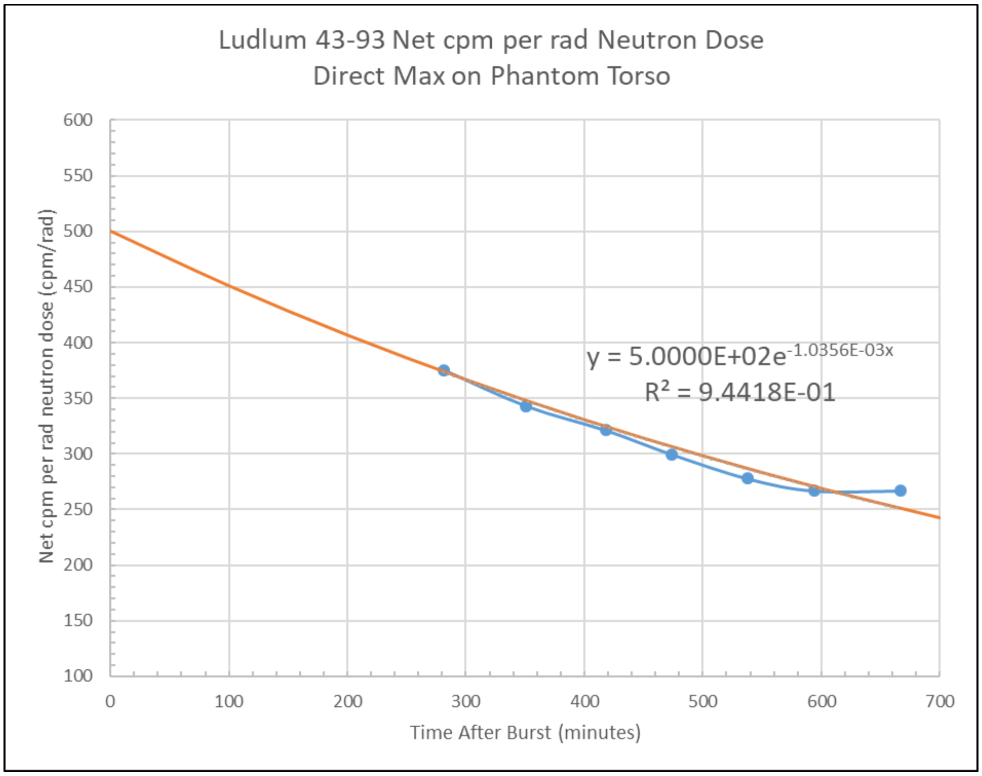
Pulse 2 Direct Max Torso BOMAB Phantom	Pancake GM (Ludlum 26-1) gross cpm	Pancake GM (Ludlum 26-1) mR/hr	Ludlum 43-93 gross cpm	Thermo-Bicron Micro-rem meter urem/hr	Date	Time	Burst End Time	Decay Time after burst end (minutes)	Pancake GM Net cpm Per rad Neutron Dose (381 rad neutron dose at 3m)	Pancake GM Net mR/hr Per rad Neutron Dose (381 rad neutron dose at 3m)	Ludlum 43-93 Net cpm Per rad Neutron Dose (381 rad neutron dose at 3m)	Thermo-Bicron Micro-rem meter urem/hr Per rad Neutron Dose (381 rad neutron dose at 3m)
Background	100	0.03	700	15	5/23/2018	12:45	5/23/2018 9:52	173				
	22,000	5.8	140,000	3,500	5/23/2018	13:01	5/23/2018 9:52	189	57	1.51E-02	366	9.1
	21,000	5.6	130,000	3,200	5/23/2018	13:11	5/23/2018 9:52	199	55	1.46E-02	339	8.4
	21,000	5.6	130,000	3,200	5/23/2018	13:21	5/23/2018 9:52	209	55	1.46E-02	339	8.4
	21,000	5.6	130,000	3,200	5/23/2018	13:31	5/23/2018 9:52	219	55	1.46E-02	339	8.4
	19,000	4.5	110,000	2,800	5/23/2018	16:28	5/23/2018 9:52	396	50	1.17E-02	287	7.3
	17,000	4.0	100,000	2,500	5/23/2018	19:13	5/23/2018 9:52	561	44	1.04E-02	261	6.5

Pulse 1 and 2 portable instrument measurements using the Ludlum 26-1 pancake GM (with Ludlum dose filter cover), the Ludlum 2360 with 43-93 100cm^2 scintillator, and the Thermo-Bicron micro-rem meter, and normalized to given $D_p(10)_n$ phantom dose. Note that the calibration facility sets the Ludlum 26-1 dead-time correction to zero.

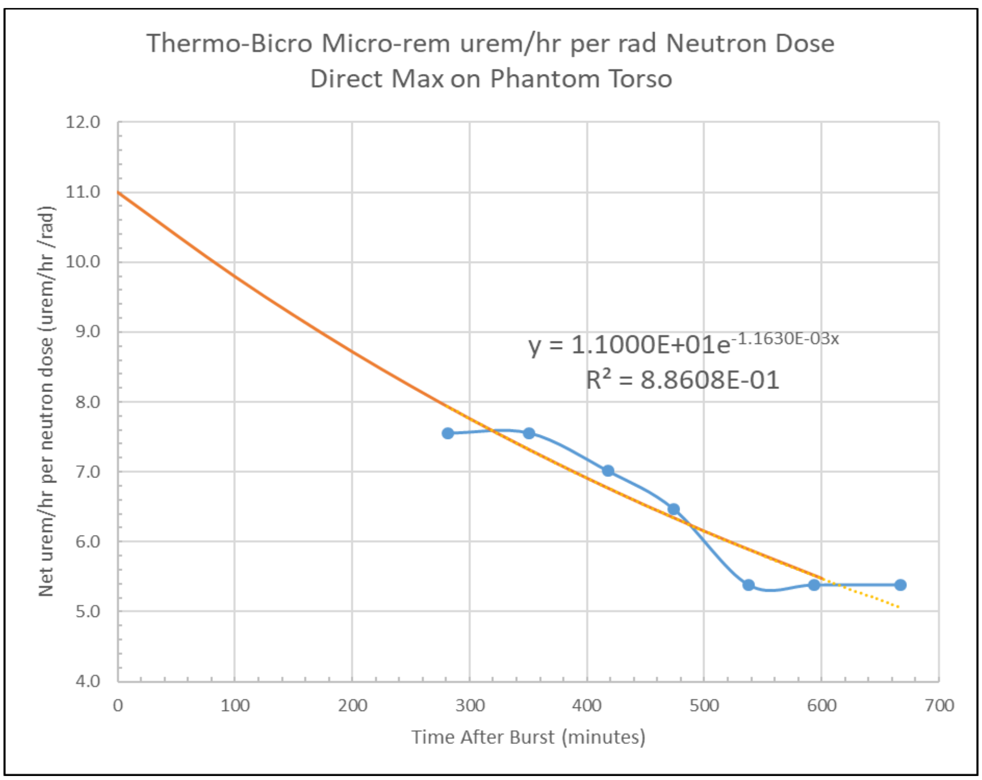




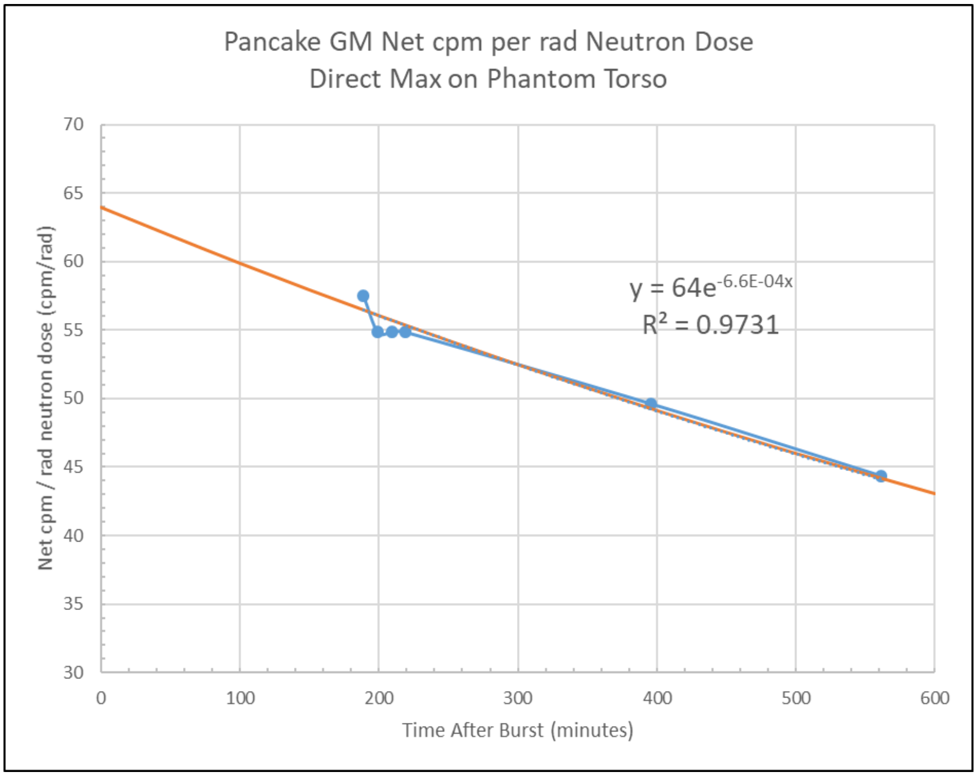
Pulse 1 Portable instrument pancake GM on phantom (Ludlum 26-1 with Ludlum dose filter cover). Note that the calibration facility sets the Ludlum 26-1 dead-time correction to zero.

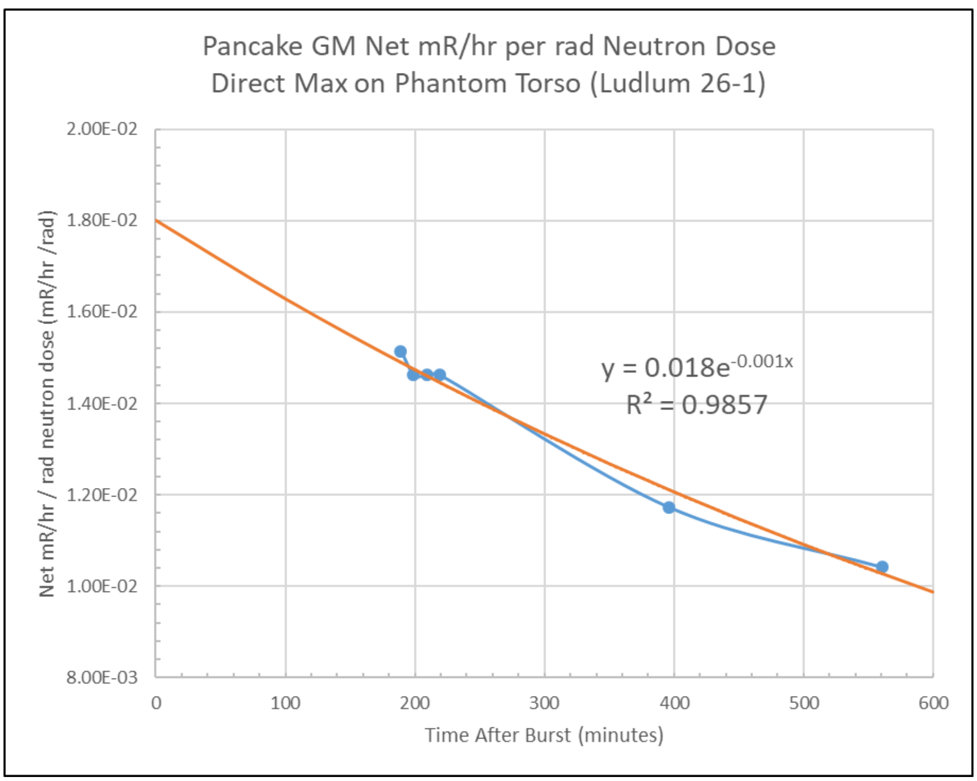


Pulse 1 Portable instrument Ludlum 43-93 100cm^2 scintillator on phantom.

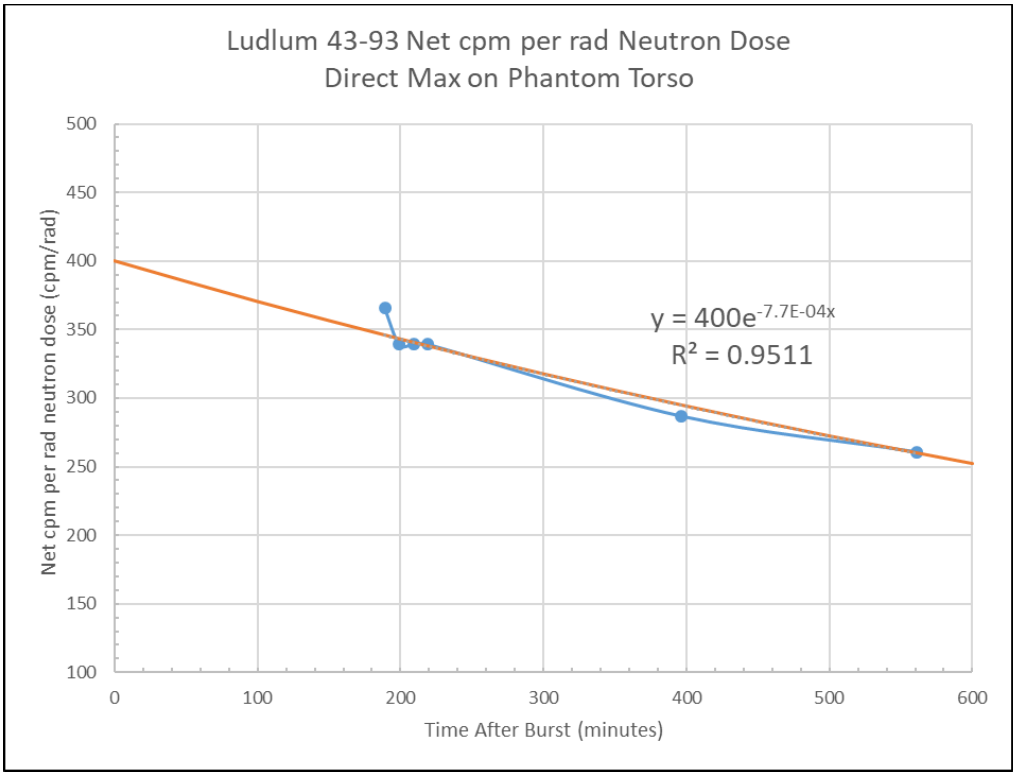


Pulse 1 Portable instrument Thermo-Bicron micro-rem meter on phantom.

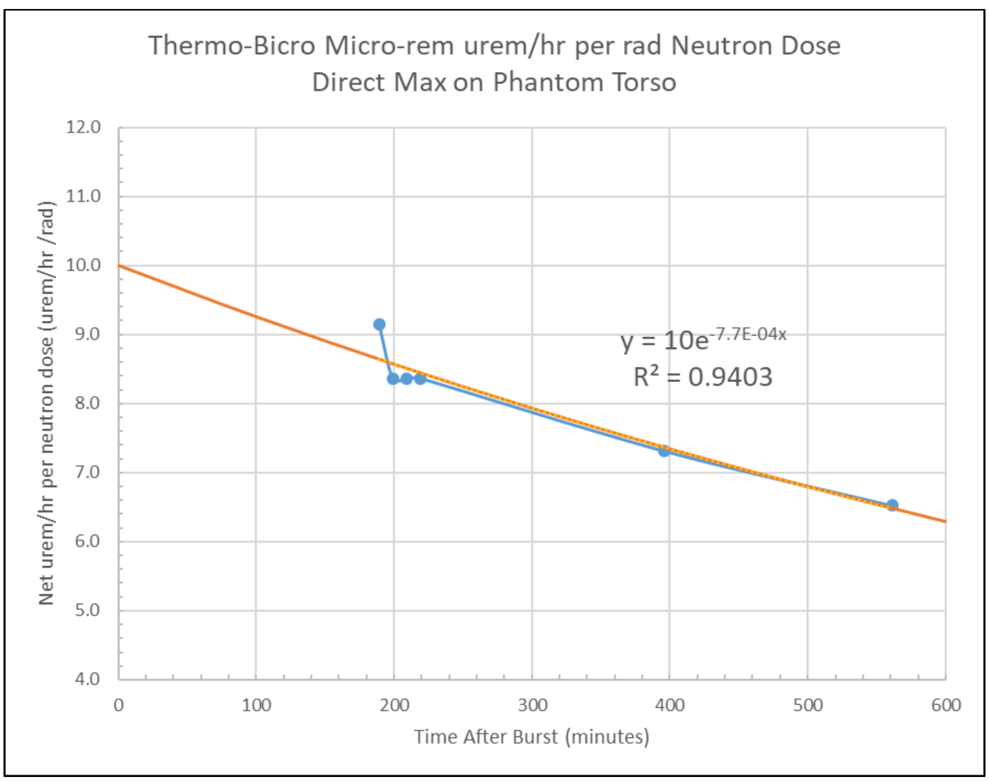




Pulse 2 Portable instrument pancake GM on phantom (Ludlum 26-1 with Ludlum dose filter cover). Note that the calibration facility sets the Ludlum 26-1 dead-time correction to zero.



Pulse 2 Portable instrument Ludlum 43-93 100cm^2 scintillator on phantom.



Pulse 2 Portable instrument Thermo-Bicron micro-rem meter on phantom

```
*************************************************************************
*****       G A M M A   S P E C T R U M   A N A L Y S I S         *****
*************************************************************************

Filename: C:\GENIE2K\CAMFILES\O7167_PHANTOM_WHOLE.CNF

Report Generated On            : 11/19/2018  3:24:53 PM

Sample Title                   : O7167_Phantom_Whole
Sample Description             :
Sample Identification          :
Sample Type                    :
Sample Geometry                :

Peak Locate Threshold          :  3.00
Peak Locate Range (in channels) :     1 - 65535
Peak Area Range (in channels)  :     1 - 65535
Identification Energy Tolerance :    1.000 FWHM

Sample Size                    :  1.0000E+00 Unit

Sample Taken On                :
Acquisition Started            : 5/23/2018   1:19:04 PM

Live Time                      :      295.4 seconds
Real Time                      :      306.4 seconds

Dead Time                      :   3.57 %

              Energy Calibration Used Done On       :
              Efficiency Calibration Used Done On   : 2/23/2018
              Efficiency ID                         : Ortec2 7167 cont

Interference Corrected Activity Report    11/19/2018  3:26:33 PM   Page  1

*************************************************************************
*****   N U C L I D E   I D E N T I F I C A T I O N   R E P O R T  *****
*************************************************************************

     Sample Title:         O7167_Phantom_Whole
     Nuclide Library Used: C:\GENIE2K\CAMFILES\PNADsimple.NLB

   ....................   IDENTIFIED NUCLIDES     ....................
```

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (uCi/Unit)	Activity Uncertainty
NA-24	0.955	1368.55*	100.00	4.360412E-02	8.602185E-04
		2754.05*	99.94	3.834313E-02	6.815386E-03
CL-38	0.927	1642.69*	31.00	3.872005E-03	8.637934E-04
		2167.68*	42.00	3.843202E-03	8.992403E-04
K-40	0.969	1460.75*	10.67	2.651579E-03	1.818792E-03
MN-56	0.649	846.75*	98.90	7.706071E-04	2.044345E-04
		1810.72	27.20		
		2113.05	14.30		
		2522.88	0.99		
		2657.45	0.65		
		2959.77	0.31		
		3369.60	0.17		
CU-64	0.983	511.00*	35.71	5.033766E-03	5.851972E-04
		1345.77	0.47		
IN-116M	0.339	138.29	3.70		
		416.90	27.20		
		818.68	12.13		
		1097.28*	58.50	1.431527E-03	6.073204E-04
		1293.56*	84.80	1.472677E-03	2.549303E-04
		1507.59	9.92		
		2112.29	15.09		
AU-198	0.983	411.80*	95.58	4.866992E-05	1.136068E-04
		675.89	0.80		
		1087.69	0.16		

```
    * = Energy line found in the spectrum.
    @ = Energy line not used for Weighted Mean Activity Energy
    Tolerance :          1.000 FWHM
    Nuclide confidence index threshold =   0.30 Errors
    quoted at         1.000 sigma
```

****
*****   I N T E R F E R E N C E   C O R R E C T E D   R E P O R T   *****
****

Nuclide Name	Nuclide Id Confidence	Wt mean Activity (uCi/Unit)	Wt mean Activity Uncertainty
NA-24	0.955	4.3521620E-02	8.5344724E-04
CL-38	0.927	3.8581826E-03	6.2294875E-04
K-40	0.969	2.6515794E-03	1.8187922E-03
MN-56	0.649	7.7060709E-04	2.0443446E-04
CU-64	0.983	5.0337664E-03	5.8519724E-04
IN-116M	0.339	1.4665126E-03	2.3506116E-04
AU-198	0.983	4.8669921E-05	1.1360681E-04

? = Nuclide is part of an undetermined solution
X = Nuclide rejected by the interference analysis
@ = Nuclide contains energy lines not used in Weighted Mean Activity

Errors quoted at 1.000 sigma

**********   U N I D E N T I F I E D   P E A K S   **********

Peak Locate Performed on: 11/12/2018 8:44:16 AM
Peak Locate From Channel: 1
Peak Locate To Channel: 65535

Peak No.	Energy (keV)	Peak Size in Counts per Second	Peak CPS % Uncertainty	Peak Type	Tol. Nuclide
9	1731.10	2.45200E+00	5.16	D-Esc.	
11	2241.59	1.68135E+00	8.13	S-Esc.	

M = First peak in a multiplet region
m = Other peak in a multiplet region
F = Fitted singlet

Errors quoted at 1.000 sigma

Pulse 2 Portable Ge detector Ortec Detective 7167 qualitative spectrum of the phantom.

Appendix H. PNAD Input Sheet of Sulfur Counts and Copper and Indium Activities.

		A				B					C					D				
		S				Cu (Cd)					In (Cd)					In				
		P-32				Cu-64								In-115m	In-116m				In-115m	In-116m
Dosimeter #	l r p	form /detector	count start	count duration (min)	net counts (cts)	detector	count start	count duration (min)	net counts (cts)	A_o (dpm)	detector	count start	count duration (min)	A_o (dpm)	A_o (dpm)	detector	count start	count duration (min)	A_o (dpm)	A_o (dpm)
277	n_	6pk_isolo	5/22/2018 15:28	10	7.34E+02	Falcon	5/22/2018 16:33			2.72E+04	7167	5/22/2018 14:14	10.5	3.52E+03	2.03E+07	falcon	5/22/2018 15:42	7.0	3.69E+03	8.63E+07
278	_g	6pk_isolo	5/22/2018 15:29	10	1.71E+02	Falcon	5/22/2018 16:46			9.58E+03	7036	5/22/2016 14:14	10.4	0.00E+00	9.59E+06	falcon	5/22/2018 15:33	7.4	0.00E+00	4.19E+07
279	_g	6pk_isolo	5/22/2018 15:41	10	4.73E+02	7167	5/22/2018 16:43			1.98E+04	falcon	5/22/2018 14:16	15.6	2.11E+03	1.56E+07	7036	5/22/2018 15:42		0.00E+00	7.59E+07
280	_is	6pk_isolo	5/22/2018 15:42	10	1.61E+02	7036	5/22/2018 16:43			8.53E+03	7167	5/22/2016 14:41	9.6	0.00E+00	7.24E+06	7167	5/22/2018 15:46		0.00E+00	3.51E+07
270	so	6pk_isolo	5/22/2018 15:55	10	6.53E+02	7167	5/22/2018 17:10			1.93E+04	7036	5/22/2018 14:56		0.00E+00	1.35E+07	7036	5/22/2018 15:46	8.3	0.00E+00	4.58E+07
271	_g	6pk_isolo	5/22/2018 15:55	10	6.33E+02	7167	5/22/2018 16:57			1.92E+04	falcon	5/22/2018 14:41	8.0	2.74E+03	1.33E+07	7036	5/22/2018 15:58		0.00E+00	4.33E+07
272	_g	6pk_isolo	5/22/2018 16:07	10	7.15E+02	7036	5/22/2018 17:10			2.11E+04	7167	5/22/2018 14:52		4.41E+03	1.46E+07	falcon	5/22/2018 16:06	4.9	0.00E+00	4.02E+07
273	_is	6pk_isolo	5/22/2018 16:07	10	4.16E+02	Falcon	5/22/2018 17:05			1.76E+04	7167	5/22/2018 15:03		1.43E+03	1.23E+07	7167	5/22/2018 15:46	9.2	0.00E+00	3.91E+07
274	so	6pk_isolo	5/22/2018 16:20	10	4.21E+02	Falcon	5/22/2018 17:18			1.59E+04	falcon	5/22/2018 15:17	10.137667	1.72E+03	1.21E+07	7167	5/22/2018 15:33		7.28E+02	4.07E+07
275	_g	6pk_isolo	5/22/2018 16:20	10	4.09E+02	Falcon	5/22/2018 17:29			1.68E+04	falcon	5/22/2016 15:17	15	2.00E+03	1.21E+07	falcon	5/22/2018 15:54	10.0	1.97E+03	3.60E+07
281	_g	6pk_isolo	5/22/2018 16:32	10	6.44E+02	7036	5/22/2018 17:23			1.97E+04	falcon	5/22/2018 15:07	4.7	3.64E+03	1.31E+07	7036	5/22/2018 15:49		0.00E+00	4.26E+07
283	_is	6pk_isolo	5/22/2018 16:32	10	6.54E+02	7167	5/22/2018 17:23			1.90E+04	falcon	5/22/2018 15:05		3.77E+03	1.39E+07	7167	5/22/2018 15:40		0.00E+00	4.67E+07

		A				B					C					D				
		S				Cu (Cd)					In (Cd)					In				
		P-32				Cu-64								In-115m	In-116m				In-115m	In-116m
Dosimeter #	l r p	form /detector	count start	count duration (min)	net counts (cts)	detector	count start	count duration (min)	net counts (cts)	A_o (dpm)	detector	count start	count duration (min)	A_o (dpm)	A_o (dpm)	detector	count start	count duration (min)	A_o (dpm)	A_o (dpm)
290	n_	6pk_isolo	5/23/2018 14:49	10	2.79E+03	**7167**	5/23/2017 15:50	3.9		8.75E+04	**Falcon**	5/23/2018 15:31	10.5	8.46E+03	5.82E+07	**7036**	5/23/2018 15:49	22.2	8.07E+03	2.12E+08
291	_g	6pk_isolo	5/23/2018 14:50	10	5.95E+02	**7167**	5/23/2017 15:55	5.6		4.01E+04	**Falcon**	5/23/2018 15:57	35.6	1.34E+03	3.43E+07	**7167**	5/23/2018 16:13	15.6	5.13E+02	1.62E+08
292	_g	6pk_isolo	5/23/2018 15:01	10	2.13E+03	**7167**	5/23/2017 16:02	3.1		8.30E+04	**Falcon**	5/23/2018 15:44	10.8	8.42E+03	6.20E+07	**7036**	5/23/2018 16:22	8.6	7.85E+03	2.73E+08
293	_is	6pk_isolo	5/23/2018 15:01	10	4.64E+02	**7167**	5/23/2017 16:05	6.0		3.21E+04	**Falcon**	5/23/2018 16:35	13.6	1.07E+03	2.62E+07	**7167**	5/23/2018 16:32	1.6	4.49E+03	1.27E+08
294	so	6pk_isolo	5/23/2018 15:23	10	2.55E+03	**7036**	5/23/2017 16:35	13.8		9.36E+04	**7036**	5/23/2018 18:38	11.6	1.20E+04	5.59E+07	**7036**	5/23/2018 18:20	15.6	1.25E+04	1.64E+08
295	_g	6pk_isolo	5/23/2018 15:24	10	2.53E+03	**7167**	5/23/2018 16:35	14.1		7.82E+04	**Falcon**	5/23/2018 18:46	13.9	1.28E+04	4.79E+07	**7167**	5/23/2018 18:37	11.6	1.08E+04	1.66E+08
296	_g	6pk_isolo	5/23/2018 15:35	10	2.51E+03	**7036**	5/23/2018 16:51	9.6		8.18E+04	**Falcon**	5/23/2018 18:15	6.3	1.15E+04	4.89E+07	**7167**	5/23/2018 18:08	10.6	1.03E+04	1.69E+08
297	_is	6pk_isolo	5/23/2018 15:35	10	1.73E+03	**7167**	5/23/2018 17:09	5.7		6.37E+04	**7167**	5/23/2018 18:56	15.4	7.53E+03	4.72E+07	**7036**	5/23/2018 17:34	8.6	6.08E+03	1.42E+08
298	so	6pk_isolo	5/23/2018 15:46	10	1.62E+03	**7036**	5/23/2018 17:17	6.9		6.64E+04	**Falcon**	5/23/2018 18:22	14.4	6.72E+03	4.43E+07	**7167**	5/23/2018 17:55	11.2	7.11E+03	1.46E+08
299	_g	6pk_isolo	5/23/2018 15:46	10	1.61E+03	**7167**	5/23/2018 17:17	6.6		5.91E+04	**Falcon**	5/23/2018 18:01	12.8	7.97E+03	4.30E+07	**7036**	5/23/2018 18:01	16.7	6.02E+03	1.43E+08
300	_g	6pk_isolo	5/23/2018 15:58	10	2.54E+03	**7167**	5/23/2018 16:51	9.3		7.90E+04	**7036**	5/23/2018 18:52	17.2	1.24E+04	5.71E+07	**7167**	5/23/2018 17:44	8.7	1.28E+04	1.61E+08
301	_is	6pk_isolo	5/23/2018 15:58	10	2.47E+03	**7167**	5/23/2018 17:02	5.9		7.31E+04	**Falcon**	5/23/2018 17:53	6.7	1.11E+04	4.78E+07	**7167**	5/23/2018 17:33	8.6	1.08E+04	1.68E+08
302	so	6pk_isolo	5/23/2018 16:10	10	2.35E+03	**7036**	5/23/2018 17:02	5.5		7.50E+04	**Falcon**	5/23/2018 18:38	7.09	1.02E+04	4.72E+07	**7036**	5/23/2018 17:44	12.9	9.25E+03	1.69E+08
303		6pk_isolo	5/23/2018 16:10	10	1.64E+03	**7036**	5/23/2018 17:09	6.4		6.89E+04	**Falcon**	5/23/2018 17:41	11.4	7.12E+03	4.47E+07	**7167**	5/23/2018 18:21	15.4	7.13E+03	1.45E+08

Pulse 1 and 2 data input sheet of sulfur counts and copper and indium activities.

	S	Cu (Cd)	In (Cd)	In (Cd)	In	In
	P-32	Cu-64	In-115m	In-116m	In-115m	In-116m
Dosimeter #	A o (dpm/g)	A o (dpm/g)	A o (dpm/g)	A o (dpm/g)	A o (dpm/g)	A o (dpm/g)
277	1.87E+02	9.64E+04	1.54E+04	8.88E+07	1.56E+04	3.65E+08
278	4.42E+01	3.41E+04	0.00E+00	4.01E+07	0.00E+00	1.86E+08
279	1.22E+02	7.03E+04	9.42E+03	6.96E+07	0.00E+00	3.34E+08
280	4.21E+01	3.04E+04	0.00E+00	3.20E+07	0.00E+00	1.47E+08
270	1.71E+02	6.88E+04	0.00E+00	6.04E+07	0.00E+00	1.93E+08
271	1.66E+02	6.82E+04	1.21E+04	5.84E+07	0.00E+00	1.92E+08
272	1.90E+02	7.44E+04	1.86E+04	6.14E+07	0.00E+00	1.80E+08
273	1.09E+02	6.24E+04	6.34E+03	5.46E+07	0.00E+00	1.72E+08
274	1.10E+02	5.67E+04	7.52E+03	5.29E+07	3.18E+03	1.78E+08
275	1.08E+02	5.94E+04	8.66E+03	5.24E+07	8.66E+03	1.59E+08
281	1.67E+02	6.97E+04	1.58E+04	5.66E+07	0.00E+00	1.91E+08
283	1.72E+02	6.75E+04	1.66E+04	6.14E+07	0.00E+00	2.07E+08

Pulse 1 calculated PNAD component activity per gram.

	S	Cu (Cd)	In (Cd)	In (Cd)	In	In
	P-32	Cu-64	In-115m	In-116m	In-115m	In-116m
Dosimeter #	A o (dpm/g)	A o (dpm/g)	A o (dpm/g)	A o (dpm/g)	A o (dpm/g)	A o (dpm/g)
290	7.09E+02	3.12E+05	3.73E+04	2.56E+08	3.62E+04	9.51E+08
291	1.52E+02	1.42E+05	5.83E+03	1.49E+08	2.24E+03	7.08E+08
292	5.38E+02	2.97E+05	3.54E+04	2.61E+08	3.46E+04	1.20E+09
293	1.17E+02	1.14E+05	4.74E+03	1.16E+08	1.96E+04	5.54E+08
294	6.46E+02	3.31E+05	5.03E+04	2.35E+08	5.32E+04	6.99E+08
295	6.50E+02	2.78E+05	5.69E+04	2.13E+08	4.57E+04	7.05E+08
296	6.48E+02	2.91E+05	4.96E+04	2.10E+08	4.59E+04	7.53E+08
297	4.50E+02	2.26E+05	3.22E+04	2.02E+08	2.65E+04	6.19E+08
298	4.19E+02	2.36E+05	2.88E+04	1.90E+08	3.07E+04	6.29E+08
299	4.20E+02	2.10E+05	3.33E+04	1.80E+08	2.65E+04	6.28E+08
300	6.71E+02	2.80E+05	5.27E+04	2.42E+08	5.63E+04	7.07E+08
301	6.37E+02	2.60E+05	4.92E+04	2.12E+08	4.68E+04	7.28E+08
302	6.12E+02	2.66E+05	4.51E+04	2.08E+08	4.04E+04	7.37E+08
303	4.25E+02	2.45E+05	3.09E+04	1.94E+08	3.10E+04	6.32E+08

Pulse 2 calculated PNAD component activity per gram.

Pulse1 PNAD	Count Start	Uncorrected Net cpm	Detector	A_o dpm from Calculation Sheet (Corrected for ta, tc, and ti)	Ge Result	NaI Relative to Ge
277	5/22/2018 19:09	264	na1	28,742	27,180	6%
278	5/22/2018 19:09	78	na2	9,508	9,582	-1%
279	5/22/2018 19:38	192	na1	21,559	19,820	9%
280	5/22/2018 19:39	68	na2	8,551	8,531	0%
270	5/22/2018 20:12	185	na1	21,349	19,340	10%
271	5/22/2018 20:12	162	na2	21,051	19,170	10%
272	5/22/2018 20:36	188	na1	22,210	21,050	6%
273	5/22/2018 20:36	133	na2	17,668	17,590	0%
274	5/22/2018 20:40	140	na1	16,618	15,930	4%
275	5/22/2018 20:40	128	na2	17,002	16,760	1%
281	5/22/2018 20:54	179	na1	21,485	19,660	9%
283	5/22/2018 20:54	146	na2	19,656	18,970	4%
						Average:
					na1	7%
					na2	2%

Pulse 1 copper foil activities calculated from count results on the URSA-NaI detectors and compared to the Ge results.

Pulse2 PNAD	Count Start	Uncorrected Net cpm	Detector	A_o dpm from Calculation Sheet (Corrected for t_a, t_c, and t_i)	Ge Result	NaI Relative to Ge
290	5/23/2018 17:42	931	na1	93,762	87,540	7%
291	5/23/2018 17:42	385	na2	43,469	40,120	8%
292	5/23/2018 17:54	894	na1	90,992	83,020	10%
293	5/23/2018 17:54	299	na2	34,117	32,080	6%
294	5/23/2018 18:08	841	na1	86,764	93,590	-7%
295	5/23/2018 18:08	737	na2	85,290	78,210	9%
296	5/23/2018 18:21	830	na1	86,627	81,820	6%
297	5/23/2018 18:21	614	na2	71,874	63,720	13%
298	5/23/2018 18:34	662	na1	69,957	66,420	5%
299	5/23/2018 18:34	543	na2	64,384	59,130	9%
300	5/23/2018 18:46	826	na1	88,182	78,970	12%
301	5/23/2018 18:46	692	na2	82,898	73,110	13%
302	5/23/2018 18:59	758	na1	81,873	75000	9%
303	5/23/2018 18:59	600	na2	73,030	68870	6%
						Average:
					na1	6%
					na2	9%

Pulse 2 copper foil activities calculated from count results on the URSA-NaI detectors and compared to the Ge results.

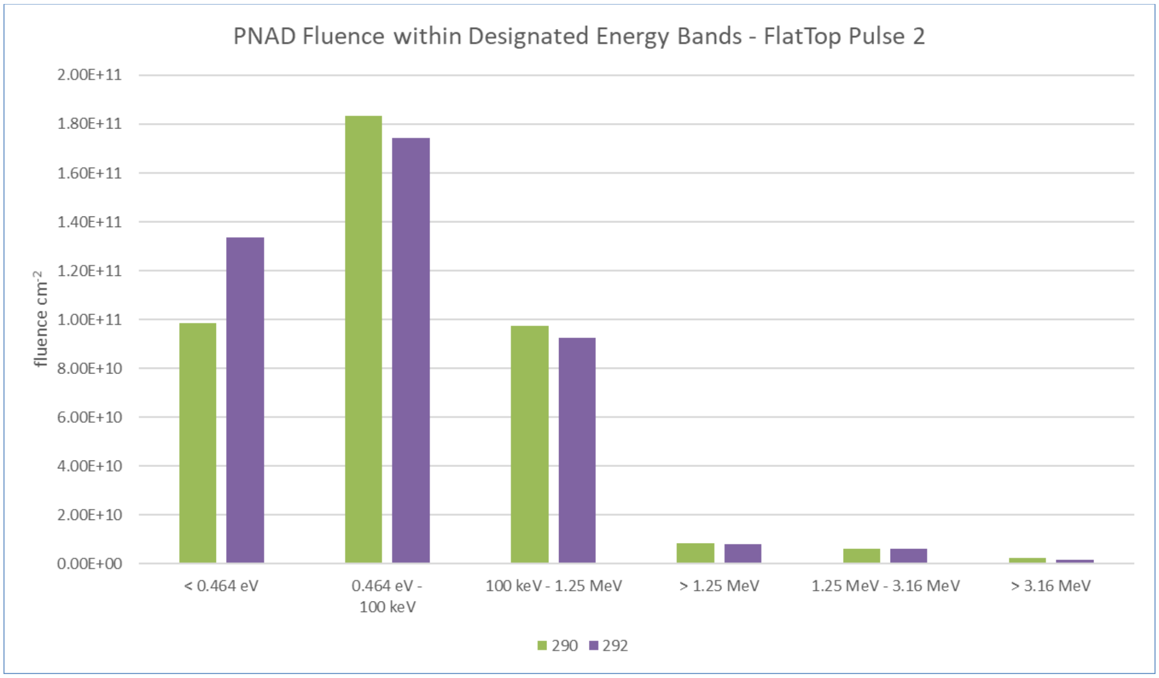
Appendix I. PNAD Fluence Calculation Sheet

	Fluence within designated energy bands					
	< 0.464 eV	0.464 eV - 100 keV	100 keV - 1.25 MeV	> 1.25 MeV	1.25 MeV - 3.16 MeV	> 3.16 MeV
	$C_{th\text{-}In}$ (min-g-cm^{-2})	C_{Cu} (min-g-cm^{-2})	0.48	C_{In} (min-g-cm^{-2})		C_S (min-g-cm^{-2})
	1.42E+02	5.88E+05	1.12	2.25E+05		3.10E+06
Dosimeter #	$\Phi_{th\text{-}In}$ (cm^{-2})	Φ_{Cu} (cm^{-2})	Φ_a (cm^{-2})	Φ_{In} (cm^{-2})	Φ_b (cm^{-2})	Φ_S (cm^{-2})
277	3.92E+10	5.67E+10	3.11E+10	3.47E+09	2.89E+09	5.79E+08
278	2.07E+10	2.01E+10	9.63E+09	0.00E+00	0.00E+00	1.37E+08
279	3.76E+10	4.13E+10	2.22E+10	2.11E+09	1.73E+09	3.79E+08
280	1.64E+10	1.79E+10	8.57E+09	0.00E+00	0.00E+00	1.30E+08
270	1.87E+10	4.05E+10	1.94E+10	0.00E+00	0.00E+00	5.31E+08
271	1.89E+10	4.01E+10	2.23E+10	2.71E+09	2.19E+09	5.13E+08
272	1.69E+10	4.38E+10	2.57E+10	4.18E+09	3.59E+09	5.88E+08
273	1.66E+10	3.67E+10	1.92E+10	1.42E+09	1.08E+09	3.39E+08
274	1.77E+10	3.33E+10	1.79E+10	1.69E+09	1.35E+09	3.41E+08
275	1.51E+10	3.50E+10	1.90E+10	1.94E+09	1.61E+09	3.35E+08
281	1.91E+10	4.10E+10	2.37E+10	3.54E+09	3.02E+09	5.17E+08
283	2.06E+10	3.97E+10	2.32E+10	3.73E+09	3.19E+09	5.34E+08

Pulse 1 PNAD calculated fluences. Note that several ^{115m}In measurements were non-detect (i.e., less than the MDA and no peak identified), hence several Φ_{In} and calculated Φ_b were zero.

	Fluence within designated energy bands					
	< 0.464 eV	0.464 eV - 100 keV	100 keV - 1.25 MeV	> 1.25 MeV	1.25 MeV - 3.16 MeV	> 3.16 MeV
	$C_{th\text{-}In}$ (min-g-cm^{-2})	C_{Cu} (min-g-cm^{-2})	0.48	C_{In} (min-g-cm^{-2})		C_S (min-g-cm^{-2})
	1.42E+02	5.88E+05	1.12	2.25E+05		3.10E+06
Dosimeter #	$\Phi_{th\text{-}In}$ (cm^{-2})	Φ_{Cu} (cm^{-2})	Φ_a (cm^{-2})	Φ_{In} (cm^{-2})	Φ_b (cm^{-2})	Φ_S (cm^{-2})
290	9.86E+10	1.83E+11	9.73E+10	8.37E+09	6.17E+09	2.20E+09
291	7.93E+10	8.37E+10	4.16E+10	1.31E+09	8.36E+08	4.72E+08
292	1.34E+11	1.74E+11	9.26E+10	7.94E+09	6.28E+09	1.67E+09
293	6.21E+10	6.72E+10	3.34E+10	1.06E+09	7.04E+08	3.61E+08
294	6.58E+10	1.95E+11	1.06E+11	1.13E+10	9.30E+09	2.00E+09
295	6.98E+10	1.64E+11	9.29E+10	1.28E+10	1.08E+10	2.01E+09
296	7.71E+10	1.71E+11	9.47E+10	1.11E+10	9.12E+09	2.01E+09
297	5.92E+10	1.33E+11	7.19E+10	7.22E+09	5.83E+09	1.39E+09
298	6.23E+10	1.39E+11	7.40E+10	6.48E+09	5.18E+09	1.30E+09
299	6.36E+10	1.23E+11	6.76E+10	7.48E+09	6.18E+09	1.30E+09
300	6.60E+10	1.65E+11	9.23E+10	1.18E+10	9.76E+09	2.08E+09
301	7.31E+10	1.53E+11	8.58E+10	1.10E+10	9.06E+09	1.97E+09
302	7.50E+10	1.56E+11	8.64E+10	1.01E+10	8.22E+09	1.90E+09
303	6.21E+10	1.44E+11	7.70E+10	6.95E+09	5.63E+09	1.32E+09

Pulse 2 PNAD calculated fluences.



Pulse 2 PNADs 290 and 292 calculated fluences. PNADs 290 and 292 were on the front of the phantoms at 3-meter and 4-meter distances, respectively.

Appendix J. PNAD Neutron Dose Calculation Sheet

	Dose from fluence within designated energy bands						
	< 0.464 eV	0.464 eV - 100 keV	100 keV - 1.25 MeV	1.25 MeV - 3.16 MeV	> 3.16 MeV		
	D_{th}/Φ_{th}	D_{Cu}/Φ_{Cu}	D_a/Φ_a	D_b/Φ_b	D_S/Φ_S		
	3.28E-10	4.19E-10	2.31E-09	3.98E-09	5.79E-09		
Dosimeter #	D_{th} (rad)	D_{Cu} (rad)	D_a (rad)	D_b (rad)	D_S (rad)	D_{total} (rad)	Orientation Corrected D_{tot} (rad)
277	1.29E+01	2.38E+01	7.19E+01	1.15E+01	3.36E+00	1.23E+02	
278	6.81E+00	8.40E+00	2.23E+01	0.00E+00	7.94E-01	3.83E+01	1.28E+02
279	1.23E+01	1.73E+01	5.13E+01	6.90E+00	2.20E+00	9.01E+01	
280	5.37E+00	7.48E+00	1.98E+01	0.00E+00	7.56E-01	3.34E+01	1.11E+02
270	6.15E+00	1.70E+01	4.49E+01	0.00E+00	3.08E+00	7.11E+01	
271	6.21E+00	1.68E+01	5.15E+01	8.73E+00	2.97E+00	8.63E+01	
272	5.54E+00	1.83E+01	5.93E+01	1.43E+01	3.41E+00	1.01E+02	
273	5.44E+00	1.54E+01	4.44E+01	4.31E+00	1.96E+00	7.15E+01	
274	5.82E+00	1.40E+01	4.14E+01	5.36E+00	1.97E+00	6.85E+01	
275	4.95E+00	1.46E+01	4.38E+01	6.40E+00	1.94E+00	7.18E+01	
281	6.26E+00	1.72E+01	5.47E+01	1.20E+01	3.00E+00	9.31E+01	
283	6.76E+00	1.66E+01	5.37E+01	1.27E+01	3.09E+00	9.29E+01	

Pulse 1 PNAD calculated neutron doses. Note that PNADs 278 and 280 from phantoms oriented 180 degrees facing away from the pulse were corrected using a single factor, i.e., 1/0.3, although a correction of 1/0.371 to 280 would match the PNAD 279 result.

	Dose from fluence within designated energy bands						
	< 0.464 eV	0.464 eV - 100 keV	100 keV - 1.25 MeV	1.25 MeV - 3.16 MeV	> 3.16 MeV		
	D_{th}/Φ_{th}	D_{Cu}/Φ_{Cu}	D_a/Φ_a	D_b/Φ_b	D_S/Φ_S		
	3.28E-10	4.19E-10	2.31E-09	3.98E-09	5.79E-09		
Dosimeter #	D_{th} (rad)	D_{Cu} (rad)	D_a (rad)	D_b (rad)	D_S (rad)	D_{total} (rad)	Orientation Corrected D_{tot} (rad)
290	3.24E+01	7.68E+01	2.25E+02	2.46E+01	1.27E+01	3.71E+02	
291	2.60E+01	3.51E+01	9.62E+01	3.33E+00	2.73E+00	1.63E+02	3.89E+02
292	4.38E+01	7.31E+01	2.14E+02	2.50E+01	9.66E+00	3.66E+02	
293	2.04E+01	2.81E+01	7.73E+01	2.80E+00	2.09E+00	1.31E+02	3.73E+02
294	2.16E+01	8.15E+01	2.45E+02	3.70E+01	1.16E+01	3.97E+02	
295	2.29E+01	6.86E+01	2.15E+02	4.28E+01	1.17E+01	3.61E+02	
296	2.53E+01	7.18E+01	2.19E+02	3.63E+01	1.16E+01	3.64E+02	
297	1.94E+01	5.57E+01	1.66E+02	2.32E+01	8.08E+00	2.73E+02	
298	2.05E+01	5.83E+01	1.71E+02	2.06E+01	7.53E+00	2.78E+02	
299	2.09E+01	5.17E+01	1.56E+02	2.46E+01	7.53E+00	2.61E+02	
300	2.17E+01	6.90E+01	2.13E+02	3.88E+01	1.21E+01	3.55E+02	
301	2.40E+01	6.41E+01	1.98E+02	3.61E+01	1.14E+01	3.34E+02	
302	2.46E+01	6.55E+01	2.00E+02	3.27E+01	1.10E+01	3.34E+02	
303	2.04E+01	6.04E+01	1.78E+02	2.24E+01	7.63E+00	2.89E+02	

Pulse 2 PNAD calculated neutron doses. PNAD 291 used a correction factor of 1/0.42 and 293 used a correction factor of 1/0.35.

Appendix K. Simulated Blood Vials (Ringer’s Lactate Solution from Phantom)

K= **0.168** rad-min-mg

Pulse 1 BOMAD Phantom	Blood ^{24}Na (dpm @t_0)	mL	^{24}Na (dpm/mL)	Total mg Na/mL	SA_o dpm ^{24}Na/mg Na	(SAo)K = Tissue Kerma Blood Dose (rad)	Given Tissue Kerma (rad)	% Diff Tissue Kerma	Given Dp(10) (rad)	% Diff Dp(10)	Reported Dp(10)n (rad)	% Diff Blood Dose/Reported Dp(10)n
277	19,848	10	1984.8	2.99	664	111.5	59	89%	92	21%	123	-9%
278	21,120	10	2112	2.99	706	118.7	59	101%	92	29%	128	-7%

Adjusted to Given Kerma:

K= **0.086** rad-min-mg

(SAo)K = Tissue Kerma Blood Dose (rad)	Given Tissue Kerma (rad)	% Diff Tissue Kerma	Given Dp(10) (rad)
57.1	59	-3%	92
60.7	59	3%	92

Pulse 1 Measured ^{24}Na activity in simulated blood vial and dose calculation.

K= **0.168** rad-min-mg

Pulse 2 BOMAD Phantom	Blood ^{24}Na (dpm @t_0)	mL	^{24}Na (dpm/mL)	Total mg Na/mL	SA_o dpm ^{24}Na/mg Na	(SAo)K = Tissue Kerma Blood Dose (rad)	Given Tissue Kerma (rad)	% Diff Tissue Kerma	Given Dp(10) (rad)	% Diff Dp(10)	Reported Dp(10)n (rad)	% Diff Blood Dose/Reported Dp(10)n
290	70,190	10	7019	2.99	2347	394.4	246	60%	381	4%	371	6%
291	68,960	10	6896	2.99	2306	387.5	246	58%	381	2%	389	0%
292	56,160	10	5616	2.99	1878	315.5	152	108%	250	26%	366	-14%
293	57,890	10	5789	2.99	1936	325.3	152	114%	250	30%	373	-13%

Adjusted to Given Kerma:

K= **0.105** rad-min-mg

(SAo)K = Tissue Kerma Blood Dose (rad)	Given Tissue Kerma (rad)	% Diff Tissue Kerma	Given Dp(10) (rad)
246.5	246	0%	381
242.2	246	-2%	381
197.2	152	30%	250
203.3	152	34%	250

Pulse 2 Measured ^{24}Na activity in simulated blood vial and dose calculation.

Appendix L. Hair Activity Results

iSolo2	SCCA2-0001					
Count Time (min)	10					
Background Counts	188					
Approximated Efficiency	30.00%					
PNAD	**Sampled**	**Hair Mass (g)**	**iSolo Beta Counts**	**Net Beta cpm**	**Approximate dpm**	**dpm/g**
277	Back	1.35	209	2.1	7.0	5.2
277	Right	1.35	236	4.8	16.0	11.9
277	Left	1.35	251	6.3	21.0	15.6
Pulse 1			Average:	5.55	18.5	13.7
Efficiency approximated based on Sr90Y.			Corrected for about 1-day of ^{32}P decay:			**14.4**
Qualitatively, the beta count rates indicated orientation of phantom facing toward the source.						
Most likely facing toward the source because the back hair result was the lowest of the three hair samples.						
And the left and right were similar results (within tolerance of 10-minute count and background).						
Hair mass approximated to be on average 1.35 g based on gross weights and average envelope weight.						

Pulse 1 Measured hair ^{32}P activity.

iSolo2	PPCA2-0001					
Count Time (min)	60					
Background Counts	592					
Approximated Efficiency	32.81%					
PNAD	**Sampled**	**Hair Mass (g)**	**iSolo Beta Counts**	**Net Beta cpm**	**Approximate dpm**	**dpm/g**
290	Back	1.0564	1521	15.5	47.2	44.7
290	Right	1.0638	1768	19.6	59.7	56.2
290	Left	1.1392	2204	26.9	81.9	71.9
Pulse 2					Average:	57.6
Efficiency from the Sr90Y iSolo Source SZ 298.				Corrected for 12-hours of ^{32}P decay:		**59.0**
Qualitatively, the beta count rates indicated orientation of phantom turned to the right with left side toward the source.						
Most likely turned approximately 45-degrees because the back hair result was the lowest of the three hair samples.						

Pulse 2 Measured hair ^{32}P activity.

Appendix M. Hair Dose Estimate and Combined Blood-Hair Dose Result.

k	6.88E-09	n*σ*λ in units cm^2/min-g
bare HPRR dose per fluence factor:	3.70E-09	rad-cm2/n
Fraction of Total Kerma	0.10	note that FlatTop may be more like 0.08 to 0.11

SBR should be in the range from 1e+11 to 1e+14

K should generally be in the approximate range of 0.045 to 0.45 rad-min-mg

Y-Axis estimate is in units of (pCi ^{24}Na/mg Na per rad) of fast neturons

Pulse 1

Initial Reported Post 24-Hour next day Intersected Y-Axis Given SBR (Hankins Graph):

PA_o (dpm/g)	Fast Neutron Fluence n/cm^2 Φ	First Approximation Dose base on Hair (rad)	SA_o = uCi ^{24}Na / mg Na	SBR = Φ/(SA_o)	Y-Axis Estimate (Figure 1 Graph)	K Estimate from Hair (rad-min-mg)	Dose = Blood(SA_o) x Hair K in rad	Given Tissue Kerma (rad)	% Diff Tissue Kerma	Given Dp(10) (rad)	% Diff Dp(10)
14	2.10E+09	78	2.990E-04	7.01E+12	3	0.150	100	59	69%	92	8%

PNAD >1.25 MeV Φ Result: 3.47E+09

PNAD within Φ Hair Result: 39.5%

Adjusted to Given Kerma for Y-Axis Estimate:

Y-Axis Estimate (Figure 1 Graph)	K Estimate from Hair (rad-min-mg)	Dose = Blood(SA_o) x Hair K in rad	Given Tissue Kerma (rad)	% Diff Tissue Kerma	Given Dp(10) (rad)	% Diff Dp(10)
5.05	0.089	59	59	0%	92	-36%

Adjusted to Given $D_p(10)_n$ for Y-Axis Estimate:

Y-Axis Estimate	K Estimate from Hair (rad-min-mg)	Dose = Blood(SA_o) x Hair K in rad	Given Tissue Kerma (rad)	% Diff Tissue Kerma	Given Dp(10) (rad)	% Diff Dp(10)	Reported Dp(10)n (rad)	% Diff Blood Dose/Reported Dp(10)n
3.25	0.139	92	59	56%	92	0%	123	-25%

Actual iSolo background counts average may be 155.

Result would be 23 dpm/g and fluence within 3.6% of PNAD fluence.

This would result in y-axis estimate closer to 3.3 and closer to given Dp(10)n dose.

k	6.88E-09	n*σ*λ in units cm^2/min-g
bare HPRR dose per fluence factor:	3.70E-09	rad-cm2/n
Fraction of Total Kerma	0.10	note that FlatTop may be more like 0.08 to 0.11

SBR should be in the range from 1e+11 to 1e+14

K should generally be in the approximate range of 0.045 to 0.45 rad-min-mg

Y-Axis estimate is in units of (pCi ^{24}Na/mg Na per rad) of fast neturons

Pulse 2

Intersected Y-Axis Given SBR (Hankins Graph):

PA_o (dpm/g)	Fast Neutron Fluence n/cm^2 Φ	First Approximation Dose base on Hair (rad)	SA_o = uCi ^{24}Na / mg Na	SBR = Φ/(SA_o)	Y-Axis Estimate (Figure 1 Graph)	K Estimate from Hair (rad-min-mg)	Dose = Blood(SA_o) x Hair K in rad	Given Tissue Kerma (rad)	% Diff Tissue Kerma	Given Dp(10) (rad)	% Diff Dp(10)
59	8.57E+09	317	1.057E-03	8.11E+12	3.8	0.119	278	246	13%	381	-27%

PNAD >1.25 MeV Φ Result: 8.37E+09

PNAD within Φ Hair Result: -2.4%

Adjusted to Given Kerma for Y-Axis Estimate:

Y-Axis Estimate (Figure 1 Graph)	K Estimate from Hair (rad-min-mg)	Dose = Blood(SA_o) x Hair K in rad	Given Tissue Kerma (rad)	% Diff Tissue Kerma	Given Dp(10) (rad)	% Diff Dp(10)
4.3	0.105	246	246	0%	381	-35%

Adjusted to Given $D_p(10)_n$ for Y-Axis Estimate:

Y-Axis Estimate	K Estimate from Hair (rad-min-mg)	Dose = Blood(SA_o) x Hair K in rad	Given Tissue Kerma (rad)	% Diff Tissue Kerma	Given Dp(10) (rad)	% Diff Dp(10)	Reported Dp(10)n (rad)	% Diff Blood Dose/Reported Dp(10)n
2.8	0.161	378	246	54%	381	-1%	371	2%

Pulse 1 and Pulse 2 hair sample dose estimates, and combined blood-hair dose results.

Appendix N. Neutron Dose Results compared to Given $D(10)_n$.

PNNL PNAD Dose Report for Flattop Exercise				Given	Reported
PNAD #	Neutron Dose D(10)n (rad)	Orientation	Distance (m)	Neutron	% Diff n
277	123	BOMAB 0	3	92.0	34.08%
278	128	BOMAB 180	3	92.0	38.61%
279	90	BOMAB 0	4	61.0	47.68%
280	111	BOMAB 180	4	61.0	82.62%
270	71	FIA	3	85.0	-16.35%
271	86	FIA	3	85.0	1.47%
272	101	FIA	3	85.0	18.70%
273	71	FIA	4	56.0	27.64%
274	68	FIA	4	56.0	22.30%
275	72	FIA	4	56.0	28.14%
281	93	FIA	3	85.0	9.57%
283	93	FIA	3	85.0	9.29%
			Total	Average	25.31%
				Median	24.97%
				Stnd Dev	25.07%
			FIA	Average	12.60%
				Median	14.14%
				Stnd Dev	15.03%
			Phantom	Average	50.75%
				Median	43.15%
				Stnd Dev	21.99%
			Phantom 3 m	Average	36.35%
				Median	36.35%
				Stnd Dev	3.20%
			Phantom 4 m	Average	65.15%
				Median	65.15%
				Stnd Dev	24.71%
			FIA 3 m	Average	4.54%
				Median	9.29%
				Stnd Dev	13.17%
			FIA 4 m	Average	26.03%
				Median	27.64%
				Stnd Dev	3.24%

Pulse 1 Reported PNAD neutron doses compared to given dose $D(10)_n$. The given $D_p(10)_n$ was compared to PNADs on phantom and $D^*(10)_n$ compared to PNADs on free-in-air (FIA) stands.

All but one of the 12 PNADs passed within $\underline{+}50\%$ (92% pass rate). The one PNAD that conservatively fell above +50% was 280 because the conservative factor applied for facing directly away from the source. Based on ANSI N13.3-2013, the test criteria was $\underline{+}50\%$ for dose range 10 to 100 rad and $\underline{+}25\%$ for dose range 100 to 1,000 rad.

PNNL PNAD Dose Report for Flattop Exercise				Given	Reported
PNAD #	Neutron Dose D(10)n (rad)	Orientation	Distance (m)	Neutron	% Diff n
290	371.4	BOMAB 45	3	381	-2.52%
291	389.0	BOMAB 225	3	381	2.10%
292	365.6	BOMAB 0	4	250	46.23%
293	373.4	BOMAB 180	4	250	49.34%
294	396.8	FIA	3	354	12.08%
295	360.7	FIA	3	354	1.88%
296	363.8	FIA	3	354	2.77%
297	272.5	FIA	4	231	17.98%
298	277.9	FIA	4	231	20.28%
299	260.9	FIA	4	231	12.94%
300	354.9	FIA	3	354	0.26%
301	334.0	FIA	3	354	-5.66%
302	333.6	FIA	3	354	-5.76%
303	288.7	FIA	4	231	24.99%
			Total	Average	12.64%
				Median	7.43%
				Stnd Dev.	17.75%
			FIA	Average	8.18%
				Median	7.43%
				Stnd Dev.	10.96%
			Phantom	Average	23.79%
				Median	24.17%
				Stnd Dev.	27.81%
			Phantom 3 m	Average	-0.21%
				Median	-0.21%
				Stnd Dev.	3.27%
			Phantom 4 m	Average	47.79%
				Median	47.79%
				Stnd Dev.	2.20%
			FIA 3 m	Average	0.93%
				Median	1.07%
				Stnd Dev.	6.59%
			FIA 4 m	Average	19.05%
				Median	19.13%
				Stnd Dev.	5.01%

Pulse 2 Reported PNAD neutron doses compared to given dose $D(10)_n$. The given $D_p(10)_n$ was compared to PNADs on phantom and $D^*(10)_n$ compared to PNADs on free-in-air (FIA) stands.

The Pulse 2 neutron doses for the phantom at 3-meter distance were within 2.52% of given, and average of PNAD 290 and 291 was within 0.21%. For Pulse 2, all but two of the 14 PNADs passed within ±25% (86% pass rate). The two PNADs that conservatively fell above +25% were 292 and 293. PNADs 292 and 293 from the phantom at 4 m distance had anomalous copper results that were higher and matched more closely with PNADs 290 and 291 from the phantom at 3-meter distance.

Appendix O. PNAD Total Reported Dose Results to Given Total Doses

PNNL PNAD Dose Report for Flattop Exercise				Given	
PNAD #	Total Dose (rad)	Orientation	Distance (m)	Total	%Diff T
277	135.1	BOMAB 0	3	109.0	23.94%
278	141.0	BOMAB 180	3	109.0	29.36%
279	96.9	BOMAB 0	4	76.0	27.52%
280	121.4	BOMAB 180	4	76.0	59.68%
270	76.0	FIA	3	102.0	-25.52%
271	92.2	FIA	3	102.0	-9.60%
272	106.9	FIA	3	102.0	4.78%
273	76.3	FIA	4	71.0	7.46%
274	73.4	FIA	4	71.0	3.39%
275	77.1	FIA	4	71.0	8.58%
281	100.1	FIA	3	102.0	-1.87%
283	99.5	FIA	3	102.0	-2.48%
			Total	Average	10.44%
				Median	6.12%
				Stnd Dev.	22.08%
			FIA	Average	-1.91%
				Median	0.76%
				Stnd Dev.	11.26%
			BOMAB	Average	35.13%
				Median	28.44%
				Stnd Dev.	16.52%
		3 m	BOMAB	Average	26.65%
				Median	26.65%
				Stnd Dev.	3.83%
		4 m	BOMAB	Average	43.60%
				Median	43.60%
				Stnd Dev.	22.74%
		3 m	FIA	Average	-6.94%
				Median	-2.48%
				Stnd Dev.	11.56%
		4 m	FIA	Average	6.48%
				Median	7.46%
				Stnd Dev.	2.73%

Pulse 1 Reported PNAD total doses compared to given total dose D(10). The given $D_p(10)$ was compared to PNADs on phantom and $D^*(10)$ compared to PNADs on free-in-air (FIA) stands. All except three fell within the +25% ANSI 13.3-2013 criteria, and all but one were within +30%. Based on ANSI N13.3-2013, the test criteria was +50% for dose range 10 to 100 rad and +25% for dose range 100 to 1,000 rad.

PNNL PNAD Dose Report for Flattop Exercise				Given	
PNAD #	Total Dose (rad)	Orientation	Distance (m)	Total	%Diff T
290	421.6	BOMAB 45	3	448.0	-5.90%
291	443.0	BOMAB 225	3	448.0	-1.12%
292	404.8	BOMAB 0	4	309.0	31.02%
293	414.8	BOMAB 180	4	309.0	34.24%
294	420.3	FIA	3	421.0	-0.17%
295	382.7	FIA	3	421.0	-9.09%
296	386.8	FIA	3	421.0	-8.12%
297	290.2	FIA	4	290.0	0.06%
298	293.8	FIA	4	290.0	1.32%
299	278.5	FIA	4	290.0	-3.96%
300	383.1	FIA	3	421.0	-9.01%
301	364.8	FIA	3	421.0	-13.36%
302	359.8	FIA	3	421.0	-14.54%
303	308.4	FIA	4	290.0	6.36%
			Total	Average	0.55%
				Median	-2.54%
				Stnd Dev.	14.79%
			FIA	Average	-5.05%
				Median	-6.04%
				Stnd Dev.	6.85%
			BOMAB	Average	14.56%
				Median	14.95%
				Stnd Dev.	21.00%
		3 m	BOMAB	Average	-3.51%
				Median	-3.51%
				Stnd Dev.	3.39%
		4 m	BOMAB	Average	32.63%
				Median	32.63%
				Stnd Dev.	2.28%
		3 m	FIA	Average	-9.05%
				Median	-9.05%
				Stnd Dev.	5.07%
		4 m	FIA	Average	0.95%
				Median	0.69%
				Stnd Dev.	4.25%

Pulse 2 Reported PNAD total doses compared to given total dose D(10). The given $D_p(10)$ was compared to PNADs on phantom and $D^*(10)$ compared to PNADs on free-in-air (FIA) stands. All except two fell within the ±25% ANSI 13.3-2013 criteria, and all were within ±35%. Based on ANSI N13.3-2013, the test criteria was ±50% for dose range 10 to 100 rad and ±25% for dose range 100 to 1,000 rad.

Appendix P. Pulse 2 OSL InLight Results

R	0.165	default 0.165 based on phantom in unmoderated fields with n/g dose ratic R is a dimensionless factor to estimate the fraction of delivered neutron absorbed dose that appears as apparent gamma signal on the gamma dose elements E3 and E4.
C_n	6.190	6.19 for Godiva, 2.90 default for on phantom at 50cm from bare Cf-252 R = 0.165 (default) This value is based on dosimeters exposed on phantom in unmoderated fields with n/γ dose ratio = 8.
Cγ	1.000	default for prompt and delayed gamma from unshielded criticalitites Used neutron dose calc sheet compared to measured foils to empirically estimate C_n.
RRF	1.000	relative response factor for Co-60 to the geometry used to calibrate the rea R = 0.0467 for FIA Average. FlatTop n/g dose ratios were 3.9 to 5.7.

rad=cGy

PNAD	E1 (rad=cGy)	E2	E3	E4	(E3+E4)/2	R*(E2 - E1)/Cn	x	$S\gamma_{34}$	$D(10)_\gamma$	Given	$D(10)_\gamma$/Given	(Given - $D(10)_\gamma$)/Given %	Distance (m)		E1 / Given	
290	129.6	4045.1	159.1	150.9	155.0	104.4	50.7	1.010101	50.2	67	0.75	-25.1%	3		1.93	
291	100.8	2460.1	119.1	115.9	117.5	62.9	54.6	1.010871	54.0	67	0.81	-19.4%	3		1.50	
292	120.4	4116.2	148.2	143.9	146.1	106.5	39.6	1.007898	39.3	59	0.67	-33.5%	4		2.04	
293	77.5	1883.0	91.9	87.9	89.9	48.1	41.8	1.00834	41.4	59	0.70	-29.8%	4		1.31	
294	68.7	2189.1	84.5	75.8	80.1	56.5	23.6	1.004722	23.5	67	0.35	-64.9%	3		1.03	
295	70.5	2278.0	84.1	77.9	81.0	58.8	22.2	1.004433	22.1	67	0.33	-67.1%	3		1.05	
296	72.0	2393.8	87.9	82.1	85.0	61.9	23.1	1.004623	23.0	67	0.34	-65.7%	3		1.08	
297	61.7	2018.6	71.5	68.2	69.9	52.2	17.7	1.003547	17.7	59	0.30	-70.1%	4		1.05	
298	62.3	2145.7	74.5	68.6	71.6	55.5	16.0	1.003212	16.0	59	0.27	-72.9%	4		1.06	
299	62.8	2094.9	74.6	69.1	71.9	54.2	17.7	1.003544	17.6	59	0.30	-70.1%	4		1.06	
300	70.4	2295.5	90.6	84.6	87.6	59.3	28.3	1.00566	28.2	67	0.42	-58.0%	3		1.05	
301	73.6	2310.3	92.4	88.8	90.6	59.6	31.0	1.006192	30.8	67	0.46	-54.0%	3		1.10	
302	70.7	2295.8	89.2	82.0	85.6	59.3	26.3	1.00526	26.2	67	0.39	-60.9%	3		1.06	
303	61.6	2088.8	76.0	71.6	73.8	54.0	19.8	1.003958	19.7	59	0.33	-66.6%	4		1.04	
												-65.0%	FIA Average		See that FIA E1/Given is close to Unity 1 (conservatively +5%)	
												-29.3%	Front Phantoms Average		1.0569	Average
												-24.6%	Back Phantoms Average			

Pulse 2 InLight Results using default parameters from Godiva-IV and compared to the given D(10)γ doses. The on phantom front OSL E1 elements over responded by a factor of 2. Note that for the FIA OSL E1 elements appeared not to require correction since average within 5.7% of the given gamma doses. Using the default parameters from Godiva-IV, the on phantom front OSL on average under responded by -30%.

C_n	6.700	C_n is the dimensionless neutron a Cn = 6.700 for average FIA and was 10.745 for front of Phantoms and 14.130 for back of Phantoms.										
		C_n may be thought of as the dose "response" of the dosimeter as defined by ISO 8529-1 (ISO, 2001).										
		The factor C_n = (E2-E1)/Dp(10)n where Dp(10)n is the delivered dose.										
							rad=cGy					
							OSLN $D(10)_n$			Given D(10)n		Cn
PNAD	E1 (rad=cGy)	E2	$S\gamma_1$	$(S_{\gamma 1})^{0.8}$	$E1/(S_{\gamma 1})^{0.8}$	$E2 - E1/(S_{\gamma 1})^{0.8}$	$[E2 - E1/(S_{\gamma 1})^{0.8}] / C_n$	Measured foils	(Measured foils-OSLN $D_p(10)_n$)/Measured foils	Distance (m)	Neutron	(E2 - E1)/Given D(10)n
290	129.6	4045.1	1.025559	1.020395	127.0	3918.0	584.8	371.4	-57.5%	3	381	10.28
291	100.8	2460.1	1.019948	1.015927	99.2	2361.0	352.4	163.4	-115.7%	3	381	6.19
292	120.4	4116.2	1.023767	1.018969	118.1	3998.1	596.7	365.6	-63.2%	4	250	15.98
293	77.5	1883.0	1.015395	1.012297	76.6	1806.4	269.6	130.7	-106.3%	4	250	7.22
294	68.7	2189.1	1.013655	1.01091	67.9	2121.2	316.6	396.8	20.2%	3	354	5.99
295	70.5	2278.0	1.01402	1.0112	69.8	2208.2	329.6	360.7	8.6%	3	354	6.24
296	72.0	2393.8	1.014314	1.011435	71.2	2322.6	346.7	363.8	4.7%	3	354	6.56
297	61.7	2018.6	1.01228	1.009812	61.1	1957.5	292.2	272.5	-7.2%	4	231	8.47
298	62.3	2145.7	1.012403	1.00991	61.7	2083.9	311.0	277.9	-11.9%	4	231	9.02
299	62.8	2094.9	1.012499	1.009987	62.2	2032.7	303.4	260.9	-16.3%	4	231	8.80
300	70.4	2295.5	1.013997	1.011182	69.6	2225.9	332.2	354.9	6.4%	3	354	6.29
301	73.6	2310.3	1.014615	1.011675	72.7	2237.6	334.0	334.0	0.0%	3	354	6.32
302	70.7	2295.8	1.014061	1.011233	70.0	2225.8	332.2	333.6	0.4%	3	354	6.29
303	61.6	2088.8	1.012269	1.009803	61.1	2027.8	302.7	288.7	-4.8%	4	231	8.78
									0.0%	FIA Average		
									-60.3%	Front Phantoms Average		
									-111.0%	Back Phantoms Average		

Example for Pulse 2 of using measured/reported neutron doses to select the energy dependence C_n factor for the FIA PNAD OSLs.

					C_n	6.250	C_n is the dimensionless neutron absorbed dose factor.					
							C_n may be thought of as the dose "response" of the dosimeter as defined by ISO 8529-1 (ISO, 2001).					
							The factor C_n = (E2-E1)/Dp(10)n where Dp(10)n is the delivered dose.					
							rad=cGy					
							OSLN $D(10)_n$			Given D(10)n		Cn
PNAD	E1 (rad=cGy)	E2	$S\gamma_1$	$(S_{\gamma 1})^{0.8}$	$E1/(S_{\gamma 1})^{0.8}$	$E2 - E1/(S_{\gamma 1})^{0.8}$	$[E2 - E1/(S_{\gamma 1})^{0.8}] / C_n$	Measured foils	(Measured foils-OSLN $D_p(10)_n$)/Measured foils	Distance (m)	Neutron	(E2 - E1)/Given D(10)n
294	68.7	2189.1	1.013655	1.01091	67.9	2121.2	339.4	396.8	14.5%	3	354	5.99
295	70.5	2278.0	1.01402	1.0112	69.8	2208.2	353.3	360.7	2.0%	3	354	6.24
296	72.0	2393.8	1.014314	1.011435	71.2	2322.6	371.6	363.8	-2.1%	3	354	6.56
300	70.4	2295.5	1.013997	1.011182	69.6	2225.9	356.1	354.9	-0.3%	3	354	6.29
301	73.6	2310.3	1.014615	1.011675	72.7	2237.6	358.0	334.0	-7.2%	3	354	6.32
302	70.7	2295.8	1.014061	1.011233	70.0	2225.8	356.1	333.6	-6.7%	3	354	6.29
									0.0%	Average		6.28

Pulse 2 with C_n adjusted for FIA 3 m distance to measured/reported neutron dose. Result was 6.25 for Cn at the 3-m distance FIA (see top of the table for Cn=6.25).

					C_n	7.375	C_n is the dimensionless neutron absorbed dose factor.					
							C_n may be thought of as the dose "response" of the dosimeter as defined by ISO 8529-1 (ISO, 2001).					
							The factor C_n = (E2-E1)/Dp(10)n where Dp(10)n is the delivered dose.					
							rad=cGy					
							OSLN $D(10)_n$			Given D(10)n		Cn
PNAD	E1 (rad=cGy)	E2	$S\gamma_1$	$(S_{\gamma 1})^{0.8}$	$E1/(S_{\gamma 1})^{0.8}$	$E2 - E1/(S_{\gamma 1})^{0.8}$	$[E2 - E1/(S_{\gamma 1})^{0.8}] / C_n$	Measured foils	(Measured foils-OSLN $D_p(10)_n$)/Measured foils	Distance (m)	Neutron	(E2 - E1)/Given D(10)n
297	61.7	2018.6	1.01228	1.009812	61.1	1957.5	265.4	272.5	2.6%	4	231	8.47
298	62.3	2145.7	1.012403	1.00991	61.7	2083.9	282.6	277.9	-1.7%	4	231	9.02
299	62.8	2094.9	1.012499	1.009987	62.2	2032.7	275.6	260.9	-5.6%	4	231	8.80
303	61.6	2088.8	1.012269	1.009803	61.1	2027.8	275.0	288.7	4.8%	4	231	8.78
									0.0%	Average		8.77

Pulse 2 with C_n adjusted for FIA 4 distance to measured/reported neutron dose. Result was 7.375 for C_n at the 4-m distance FIA.

					C_n	10.550	C_n is the dimensionless neutron absorbed dose factor.					
							C_n may be thought of as the dose "response" of the dosimeter as defined by ISO 8529-1 (ISO, 2001).					
							The factor C_n = (E2-E1)/Dp(10)n where Dp(10)n is the delivered dose.					
							rad=cGy					
							OSLN $D(10)_n$			Given D(10)n		Cn
PNAD	E1 (rad=cGy)	E2	$S\gamma_1$	$(S_{\gamma 1})^{0.8}$	$E1/(S_{\gamma 1})^{0.8}$	$E2 - E1/(S_{\gamma 1})^{0.8}$	$[E2 - E1/(S_{\gamma 1})^{0.8}] / C_n$	Measured foils	(Measured foils-OSLN $D_p(10)_n$)/Measured foils	Distance (m)	Neutron	(E2 - E1)/Given D(10)n
290	129.6	4045.1	1.025559	1.020395	127.0	3918.0	371.4	371.4	0.0%	3	381	10.28
291	100.8	2460.1	1.019948	1.015927	99.2	2361.0	223.8	163.4	-37.0%	3	381	6.19
									-18.5%	Average		8.23

Pulse 2 with C_n adjusted for phantom front at 3 m to measured/reported neutron dose. Result was 10.55 for C_n at 3-m distance on phantom front.

					C_n	10.940	C_n is the dimensionless neutron absorbed dose factor.					
							C_n may be thought of as the dose "response" of the dosimeter as defined by ISO 8529-1 (ISO, 2001).					
							The factor C_n = (E2-E1)/Dp(10)n where Dp(10)n is the delivered dose.					
							rad=cGy					
							OSLN $D(10)_n$			Given D(10)n		Cn
PNAD	E1 (rad=cGy)	E2	$S\gamma_1$	$(S_{\gamma 1})^{0.8}$	$E1/(S_{\gamma 1})^{0.8}$	$E2 - E1/(S_{\gamma 1})^{0.8}$	$[E2 - E1/(S_{\gamma 1})^{0.8}] / C_n$	Measured foils	(Measured foils-OSLN $D_p(10)_n$)/Measured foils	Distance (m)	Neutron	(E2 - E1)/Given D(10)n
292	120.4	4116.2	1.023767	1.018969	118.1	3998.1	365.5	365.6	0.0%	4	250	15.98
293	77.5	1883.0	1.015395	1.012297	76.6	1806.4	165.1	130.7	-26.4%	4	250	7.22
									-13.2%			11.60

Pulse 2 with C_n adjusted for phantom front at 4 m to measured/reported neutron dose. Result was 10.94 for C_n at 4-m distance on phantom front.

					C_n	14.450	C_n is the dimensionless neutron absorbed dose factor.					
							C_n may be thought of as the dose "response" of the dosimeter as defined by ISO 8529-1 (ISO, 2001).					
							The factor C_n = (E2-E1)/Dp(10)n where Dp(10)n is the delivered dose.					
							rad=cGy					
							OSLN $D(10)_n$			Given D(10)n		Cn
PNAD	E1 (rad=cGy)	E2	$S\gamma_1$	$(S_{\gamma 1})^{0.8}$	$E1/(S_{\gamma 1})^{0.8}$	$E2 - E1/(S_{\gamma 1})^{0.8}$	$[E2 - E1/(S_{\gamma 1})^{0.8}] / C_n$	Measured foils	(Measured foils-OSLN $D_p(10)_n$)/Measured foils	Distance (m)	Neutron	(E2 - E1)/Given D(10)n
290	129.6	4045.1	1.025559	1.020395	127.0	3918.0	271.1	371.4	27.0%	3	381	10.28
291	100.8	2460.1	1.019948	1.015927	99.2	2361.0	163.4	163.4	0.0%	3	381	6.19
									13.5%	Average		8.23

Pulse 2 with C_n adjusted for phantom back at 3 m to measured/reported neutron dose. Result was 14.45 for C_n at 3 m distance on phantom back.

					C_n	13.825	C_n is the dimensionless neutron absorbed dose factor.					
							C_n may be thought of as the dose "response" of the dosimeter as defined by ISO 8529-1 (ISO, 2001).					
							The factor C_n = (E2-E1)/Dp(10)n where Dp(10)n is the delivered dose.					
							rad=cGy					
							OSLN $D(10)_n$			Given D(10)n		Cn
PNAD	E1 (rad=cGy)	E2	$S\gamma_1$	$(S_{\gamma 1})^{0.8}$	$E1/(S_{\gamma 1})^{0.8}$	$E2 - E1/(S_{\gamma 1})^{0.8}$	$[E2 - E1/(S_{\gamma 1})^{0.8}] / C_n$	Measured foils	(Measured foils-OSLN $D_p(10)_n$)/Measured foils	Distance (m)	Neutron	(E2 - E1)/Given D(10)n
292	120.4	4116.2	1.023767	1.018969	118.1	3998.1	289.2	365.6	20.9%	4	250	15.98
293	77.5	1883.0	1.015395	1.012297	76.6	1806.4	130.7	130.7	0.0%	4	250	7.22
									10.5%			11.60

Pulse 2 with C_n adjusted for phantom front at 4 m to measured/reported neutron dose. Result was 13.825 for C_n at 4 m distance on phantom back.

R	0.235	default 0.165 based on phantom in unmoderated fields with n/g dose ratio	R is a dimensionless factor to estimate the fraction of delivered neutron absorbed dose that appears as apparent gamma signal or
C_n	10.550	6.19 for Godiva, 2.90 default for on phantom at 50cm from bare Cf-252	R = 0.165 (default) This value is based on dosimeters exposed on phantom in unmoderated fields with n/γ dose ratio = 8.
Cγ	1.000	default for prompt and delayed gamma from unshielded criticalitites	Used neutron dose calc sheet compared to measured foils to empirically estimate C_n.
RRF	1.000	relative response factor for Co-60 to the geometry used to calibrate the rea	R = 0.0467 for FIA Average. FlatTop n/g dose ratios were 3.9 to 5.7.

PNAD	E1 (rad=cGy)	E2	E3	E4	(E3+E4)/2	R*(E2 - E1)/Cn	x	$S\gamma_{34}$	$D(10)_\gamma$ (rad=cGy)	Given	$D(10)_\gamma$/Given	(Given - $D(10)_\gamma$)/Given %	Distance (m)		E1 / Given
290	129.6	4045.1	159.1	150.9	155.0	87.1	67.9	1.013503	67.0	67	1.00	0.0%	3		1.93
291	100.8	2460.1	119.1	115.9	117.5	52.5	65.0	1.012921	64.1	67	0.96	-4.3%	3		1.50

N/A	FIA Average	
0.0%	Front Phantoms Average	1.7193
-4.3%	Back Phantoms Average	

Pulse 2 with R adjusted and using C_n 10.55 for phantom front at 3 m to the given gamma dose. Result was 0.235 for R at 3 m distance on phantom front. Note that the given neutron/gamma dose ratio was in the range of 4 to 6 (not 8 assumed by the default 0.165).

R	0.237	default 0.165 based on phantom in unmoderated fields with n/g dose ratio	R is a dimensionless factor to estimate the fraction of delivered neutron absorbed dose that appears as apparent gamma signal or
C_n	10.940	6.19 for Godiva, 2.90 default for on phantom at 50cm from bare Cf-252	R = 0.165 (default) This value is based on dosimeters exposed on phantom in unmoderated fields with n/γ dose ratio = 8.
Cγ	1.000	default for prompt and delayed gamma from unshielded criticalitites	Used neutron dose calc sheet compared to measured foils to empirically estimate C_n.
RRF	1.000	relative response factor for Co-60 to the geometry used to calibrate the rea	R = 0.0467 for FIA Average. FlatTop n/g dose ratios were 3.9 to 5.7.

PNAD	E1 (rad=cGy)	E2	E3	E4	(E3+E4)/2	R*(E2 - E1)/Cn	x	$S\gamma_{34}$	$D(10)_\gamma$ (rad=cGy)	Given	$D(10)_\gamma$/Given	(Given - $D(10)_\gamma$)/Given %	Distance (m)		E1 / Given
292	120.4	4116.2	148.2	143.9	146.1	86.4	59.7	1.011884	59.0	59	1.00	0.0%	4		2.04
293	77.5	1883.0	91.9	87.9	89.9	39.0	50.9	1.010142	50.4	59	0.85	-14.6%	4		1.31

N/A	FIA Average	See that FIA
0.0%	Front Phantoms Average	1.6771
-14.6%	Back Phantoms Average	

Pulse 2 with R adjusted and using C_n 10.94 for phantom front at 4 m to the given gamma dose. Result was 0.237 for R at 4 m distance on phantom front. Note that the given neutron/gamma dose ratio was in the range of 4 to 6 (not 8 assumed by the default 0.165).

R	0.304	default 0.165 based on phantom in unmoderated fields with n/g dose ratio	R is a dimensionless factor to estimate the fraction of delivered neutron absorbed dose that appears as apparent gamma signal or
C_n	14.450	6.19 for Godiva, 2.90 default for on phantom at 50cm from bare Cf-252	R = 0.165 (default) This value is based on dosimeters exposed on phantom in unmoderated fields with n/γ dose ratio = 8.
Cγ	1.000	default for prompt and delayed gamma from unshielded criticalitites	Used neutron dose calc sheet compared to measured foils to empirically estimate C_n.
RRF	1.000	relative response factor for Co-60 to the geometry used to calibrate the rea	R = 0.0467 for FIA Average. FlatTop n/g dose ratios were 3.9 to 5.7.

PNAD	E1 (rad=cGy)	E2	E3	E4	(E3+E4)/2	R*(E2 - E1)/Cn	x	$S\gamma_{34}$	$D(10)_\gamma$ (rad=cGy)	Given	$D(10)_\gamma$/Given	(Given - $D(10)_\gamma$)/Given %	Distance (m)		E1 / Given
290	129.6	4045.1	159.1	150.9	155.0	82.2	72.8	1.014468	71.8	67	1.07	7.1%	3		1.93
291	100.8	2460.1	119.1	115.9	117.5	49.6	67.9	1.013503	67.0	67	1.00	0.0%	3		1.50

N/A	FIA Average	See that FIA
7.1%	Front Phantoms Average	1.7193
0.0%	Back Phantoms Average	

Pulse 2 with R adjusted and using C_n 14.45 for phantom back at 3 m to the given gamma dose. Result was 0.304 for R at 3 m distance on phantom front.

R	0.232	default 0.165 based on phantom in unmoderated fields with n/g dose ratio	R is a dimensionless factor to estimate the fraction of delivered neutron absorbed dose that appears as apparent gamma signal or
C_n	13.825	6.19 for Godiva, 2.90 default for on phantom at 50cm from bare Cf-252	R = 0.165 (default) This value is based on dosimeters exposed on phantom in unmoderated fields with n/γ dose ratio = 8.
Cγ	1.000	default for prompt and delayed gamma from unshielded criticalitites	Used neutron dose calc sheet compared to measured foils to empirically estimate C_n.
RRF	1.000	relative response factor for Co-60 to the geometry used to calibrate the rea	R = 0.0467 for FIA Average. FlatTop n/g dose ratios were 3.9 to 5.7.

PNAD	E1 (rad=cGy)	E2	E3	E4	(E3+E4)/2	R*(E2 - E1)/Cn	x	$S\gamma_{34}$	$D(10)_\gamma$ (rad=cGy)	Given	$D(10)_\gamma$/Given	(Given - $D(10)_\gamma$)/Given %	Distance (m)		E1 / Given
292	120.4	4116.2	148.2	143.9	146.1	66.9	79.2	1.015718	77.9	59	1.32	32.1%	4		2.04
293	77.5	1883.0	91.9	87.9	89.9	30.2	59.7	1.011882	59.0	59	1.00	0.0%	4		1.31
												N/A	FIA Average		See that FIA
												32.1%	Front Phantoms Average		1.6771
												0.0%	Back Phantoms Average		

Pulse 2 with R adjusted and using C_n 13.825 for phantom back at 4 m to the given gamma dose. Result was 0.232 for R at 4 m distance on phantom front.

R	0.048	default 0.165 based on phantom in unmoderated fields with n/g dose ratio	R is a dimensionless factor to estimate the fraction of delivered neutron absorbed dose that appears as apparent gamma signal or
C_n	6.250	6.19 for Godiva, 2.90 default for on phantom at 50cm from bare Cf-252	R = 0.165 (default) This value is based on dosimeters exposed on phantom in unmoderated fields with n/γ dose ratio = 8.
Cγ	1.000	default for prompt and delayed gamma from unshielded criticalitites	Used neutron dose calc sheet compared to measured foils to empirically estimate C_n.
RRF	1.000	relative response factor for Co-60 to the geometry used to calibrate the rea	R = 0.0467 for FIA Average. FlatTop n/g dose ratios were 3.9 to 5.7.

PNAD	E1 (rad=cGy)	E2	E3	E4	(E3+E4)/2	R*(E2 - E1)/Cn	x	$S\gamma_{34}$	$D(10)_\gamma$ (rad=cGy)	Given	$D(10)_\gamma$/Given	(Given - $D(10)_\gamma$)/Given %	Distance (m)		E1 / Given
294	68.7	2189.1	84.5	75.8	80.1	16.3	63.8	1.012702	63.0	67	0.94	-5.9%	3		1.03
295	70.5	2278.0	84.1	77.9	81.0	17.0	64.0	1.012742	63.2	67	0.94	-5.6%	3		1.05
296	72.0	2393.8	87.9	82.1	85.0	17.8	67.2	1.013357	66.3	67	0.99	-1.1%	3		1.08
300	70.4	2295.5	90.6	84.6	87.6	17.1	70.5	1.014021	69.6	67	1.04	3.8%	3		1.05
301	73.6	2310.3	92.4	88.8	90.6	17.2	73.4	1.01459	72.4	67	1.08	8.0%	3		1.10
302	70.7	2295.8	89.2	82.0	85.6	17.1	68.5	1.013625	67.6	67	1.01	0.9%	3		1.06
												0.0%	FIA Average		See that FIA
												N/A	Front Phantoms Average		1.0596
												N/A	Back Phantoms Average		

Pulse 2 with R adjusted and using C_n 6.25 for FIA at 3 m to the given gamma dose. Result was 0.048 for R at 3 m distance FIA.

R	0.044	default 0.165 based on phantom in unmoderated fields with n/g dose ratio	R is a dimensionless factor to estimate the fraction of delivered neutron absorbed dose that appears as apparent gamma signal or
C_n	7.375	6.19 for Godiva, 2.90 default for on phantom at 50cm from bare Cf-252	R = 0.165 (default) This value is based on dosimeters exposed on phantom in unmoderated fields with n/γ dose ratio = 8.
Cγ	1.000	default for prompt and delayed gamma from unshielded criticalitites	Used neutron dose calc sheet compared to measured foils to empirically estimate C_n.
RRF	1.000	relative response factor for Co-60 to the geometry used to calibrate the rea	R = 0.0467 for FIA Average. FlatTop n/g dose ratios were 3.9 to 5.7.

PNAD	E1 (rad=cGy)	E2	E3	E4	(E3+E4)/2	R*(E2 - E1)/Cn	x	$S\gamma_{34}$	$D(10)_\gamma$ (rad=cGy)	Given	$D(10)_\gamma$/Given	(Given - $D(10)_\gamma$)/Given %	Distance (m)		E1 / Given
297	61.7	2018.6	71.5	68.2	69.9	11.7	58.2	1.011589	57.5	59	0.98	-2.5%	4		1.05
298	62.3	2145.7	74.5	68.6	71.6	12.4	59.1	1.011774	58.5	59	0.99	-0.9%	4		1.06
299	62.8	2094.9	74.6	69.1	71.9	12.1	59.7	1.011893	59.0	59	1.00	0.1%	4		1.06
303	61.6	2088.8	76.0	71.6	73.8	12.1	61.7	1.012282	61.0	59	1.03	3.3%	4		1.04
												0.0%	FIA Average		See that FIA
												N/A	Front Phantoms Average		1.0529
												N/A	Back Phantoms Average		

Pulse 2 with R adjusted and using C_n 7.375 for FIA at 4 m to the given gamma dose. Result was 0.044 for R at 4 m distance FIA.

C_n	12.440

C_n is the dimensionless neutron absorbed dose factor.
C_n may be thought of as the dose "response" of the dosimeter as defined by ISO 8529-1 (ISO, 2001).
The factor C_n = (E2-E1)/Dp(10)n where Dp(10)n is the delivered dose.
rad=cGy

							OSLN $D(10)_n$			Given D(10)n		Cn
PNAD	E1 (rad=cGy)	E2	$S\gamma_1$	$(S_{\gamma 1})^{0.8}$	$E1/(S_{\gamma 1})^{0.8}$	$E2 - E1/(S_{\gamma 1})^{0.8}$	$[E2 - E1/(S_{\gamma 1})^{0.8}] / C_n$	Measured foils	(Measured foils-OSLN $D_p(10)_n$)/Measured foils	Distance (m)	Neutron	(E2 - E1)/Given D(10)n
290	129.6	4045.1	1.025559	1.020395	127.0	3918.0	315.0	371.4	15.2%	3	381	10.28
291	100.8	2460.1	1.019948	1.015927	99.2	2361.0	189.8	163.4	-16.2%	3	381	6.19
292	120.4	4116.2	1.023767	1.018969	118.1	3998.1	321.4	365.6	12.1%	4	250	15.98
293	77.5	1883.0	1.015395	1.012297	76.6	1806.4	145.2	130.7	-11.1%	4	250	7.22
									0.0%	Average		9.92

Pulse 2 with average C_n adjusted for phantom measured neutron dose, for 3 m and 4 m distances and for front and backside of phantoms. Result was 12.44 for C_n.

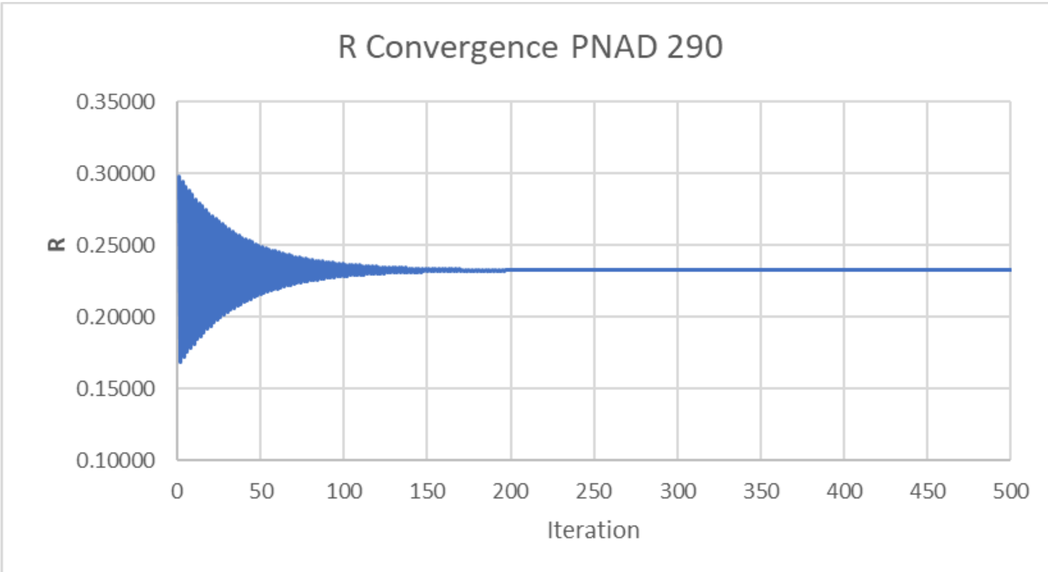
R	0.2602	default 0.165 based on phantom in unmoderated fields with n/g dose ratio
C_n	12.440	6.19 for Godiva, 2.90 default for on phantom at 50cm from bare Cf-252
Cγ	1.000	default for prompt and delayed gamma from unshielded criticalitites
RRF	1.000	relative response factor for Co-60 to the geometry used to calibrate the rea

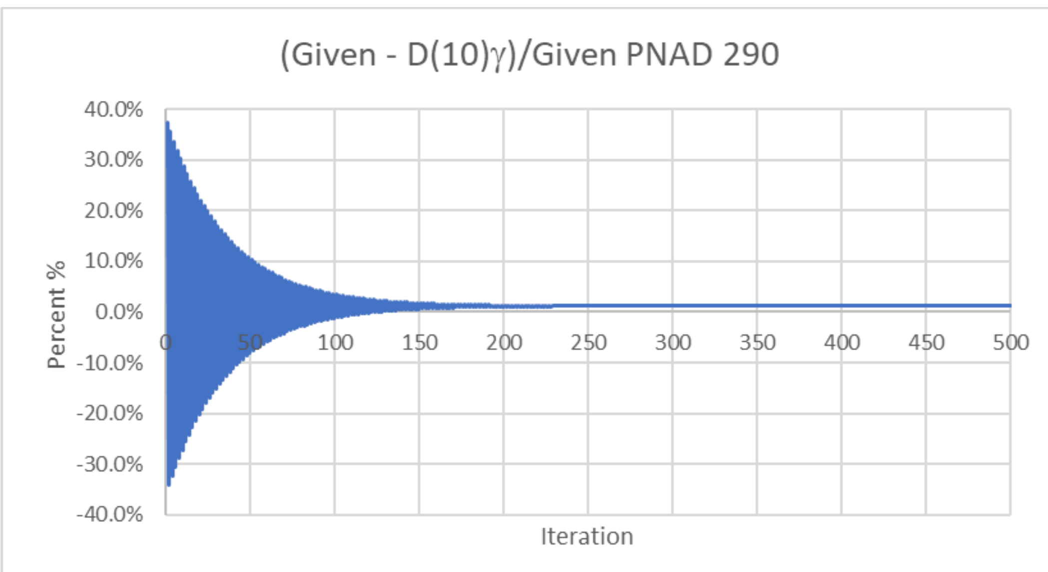
R is a dimensionless factor to estimate the fraction of delivered neutron absorbed dose that appears as apparent gamma signal on the gamm
R = 0.165 (default) This value is based on dosimeters exposed on phantom in unmoderated fields with n/γ dose ratio = 8.
Used neutron dose calc sheet compared to measured foils to empirically estimate C_n.
R = 0.0467 for FIA Average. FlatTop n/g dose ratios were 3.9 to 5.7.
rad=cGy

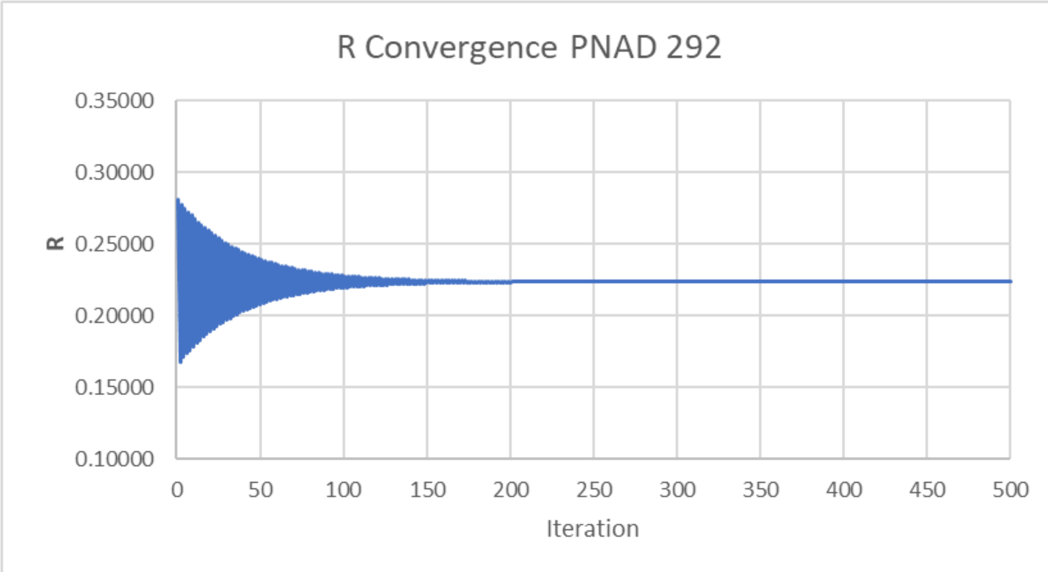
PNAD	E1 (rad=cGy)	E2	E3	E4	(E3+E4)/2	R*(E2 - E1)/Cn	x	$S\gamma_{34}$	$D(10)_\gamma$	Given	$D(10)_\gamma$/Given	(Given - $D(10)_\gamma$)/Given %	Distance (m)		E1 / Given	
290	129.6	4045.1	159.1	150.9	155.0	81.9	73.1	1.014534	72.1	67	1.08	7.6%	3		1.93	
291	100.8	2460.1	119.1	115.9	117.5	49.4	68.1	1.013542	67.2	67	1.00	0.3%	3		1.50	
292	120.4	4116.2	148.2	143.9	146.1	83.6	62.5	1.012435	61.7	59	1.05	4.6%	4		2.04	
293	77.5	1883.0	91.9	87.9	89.9	37.8	52.2	1.010392	51.6	59	0.87	-12.5%	4		1.31	
												0.0%	Phantom Average			
												6.1%	Front Phantoms Average		1.7193	Average
												-6.1%	Back Phantoms Average			

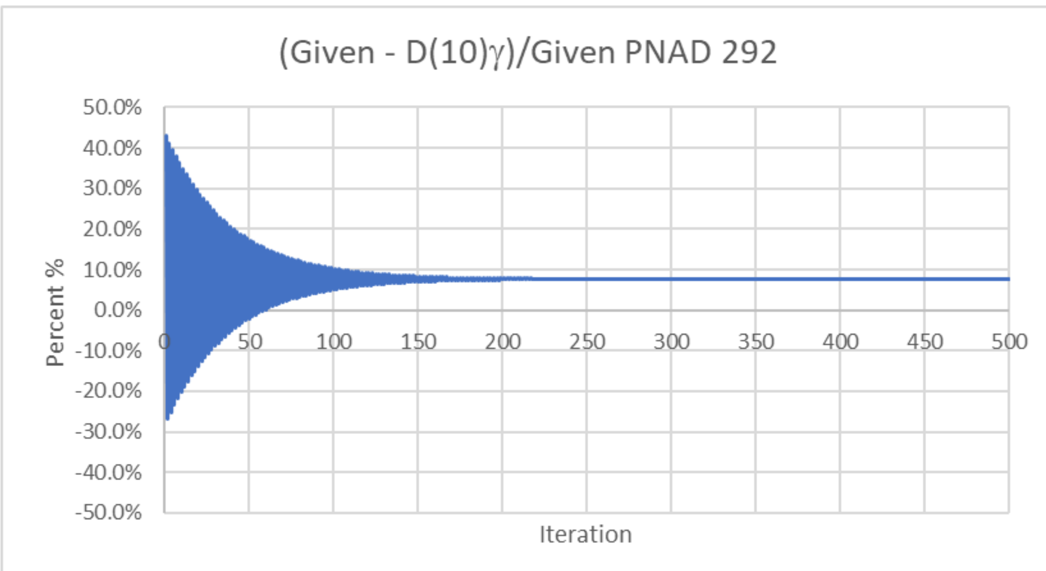
Pulse 2 with R adjusted and using C_n 12.44 for phantom measured neutron dose, for 3 m and 4 m distances and for front and backside of phantoms. Result was 2.602 for R.

Iteration of R and Convergence






R Convergence PNAD 292
0.35000
0.30000
0.25000
0.20000
0.15000
0.10000
R
0
50
100
150
200
250
300
350
400
450
500
Iteration


(Given - D(10)γ)/Given PNAD 292
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
-10.0%
-20.0%
-30.0%
-40.0%
-50.0%
Percent %
0
50
100
150
200
250
300
350
400
450
500
Iteration

R	0.165	default 0.165 based on phantom in unmoderated fields with n/g dose ratio	R is a dimensionless factor to estimate the fraction of delivered neutron absorbed dose that appears as apparent gamma signal on the
C_n	10.550	6.19 for Godiva, 2.90 default for on phantom at 50cm from bare Cf-252	R = 0.165 (default) This value is based on dosimeters exposed on phantom in unmoderated fields with n/γ dose ratio = 8, , i.e., approxi
Cγ	1.000	default for prompt and delayed gamma from unshielded criticalitites	Used neutron dose calc sheet compared to measured foils to empirically estimate C_n.
RRF	1.000	relative response factor for Co-60 to the geometry used to calibrate the rea	R = 0.0467 for FIA Average. FlatTop n/g dose ratios were 3.9 to 5.7.
r	0.050	offset for the R estimate where R is (g/n)+r. The offset r was 0.04 for the default 0.165 (see (1/8)+0.04 = 0.165), and see PNAD FIA average indicated may range up to 0.057.	

R (500 iterations)	0.23257						D($10)_\gamma$ (at 500 iterations):		67.8	67	1.01	1.2%		R estimate for iteration:
									rad=cGy				Neutron rad	(Measured-calculated $D(10)_\gamma$ / Neutron rad from measured foils) + offset r
PNAD	E1 (rad=cGy)	E2	E3	E4	(E3+E4)/2	R*(E2 - E1)/Cn	x	$S\gamma_{34}$	$D(10)_\gamma$	Given	$D(10)_\gamma$/Given	(Given - $D(10)_\gamma$)/Given %	Measured foils	= (g/n)+r
290	129.6	4045.1	159.1	150.9	155.0	61.2	93.8	1.018588	92.1	67	1.37	37.5%	371.4	0.29799
290	129.6	4045.1	159.1	150.9	155.0	110.6	44.5	1.008868	44.1	67	0.66	-34.2%	371.4	0.16865
290	129.6	4045.1	159.1	150.9	155.0	62.6	92.5	1.018323	90.8	67	1.36	35.5%	371.4	0.29447
290	129.6	4045.1	159.1	150.9	155.0	109.3	45.8	1.009127	45.3	67	0.68	-32.3%	371.4	0.17210
290	129.6	4045.1	159.1	150.9	155.0	63.9	91.2	1.018073	89.6	67	1.34	33.7%	371.4	0.29115
290	129.6	4045.1	159.1	150.9	155.0	108.1	47.0	1.009371	46.6	67	0.69	-30.5%	371.4	0.17536
290	129.6	4045.1	159.1	150.9	155.0	65.1	90.0	1.017836	88.4	67	1.32	31.9%	371.4	0.28800
290	129.6	4045.1	159.1	150.9	155.0	106.9	48.2	1.009603	47.7	67	0.71	-28.8%	371.4	0.17845
290	129.6	4045.1	159.1	150.9	155.0	66.2	88.8	1.017611	87.3	67	1.30	30.3%	371.4	0.28502
290	129.6	4045.1	159.1	150.9	155.0	105.8	49.3	1.009822	48.8	67	0.73	-27.2%	371.4	0.18137
290	129.6	4045.1	159.1	150.9	155.0	67.3	87.7	1.017399	86.2	67	1.29	28.7%	371.4	0.28220
290	129.6	4045.1	159.1	150.9	155.0	104.7	50.3	1.010029	49.8	67	0.74	-25.6%	371.4	0.18413
290	129.6	4045.1	159.1	150.9	155.0	68.3	86.7	1.017198	85.2	67	1.27	27.2%	371.4	0.27953
290	129.6	4045.1	159.1	150.9	155.0	103.7	51.3	1.010225	50.8	67	0.76	-24.2%	371.4	0.18675
290	129.6	4045.1	159.1	150.9	155.0	69.3	85.7	1.017008	84.3	67	1.26	25.8%	371.4	0.27700
290	129.6	4045.1	159.1	150.9	155.0	102.8	52.2	1.010411	51.7	67	0.77	-22.8%	371.4	0.18922
290	129.6	4045.1	159.1	150.9	155.0	70.2	84.8	1.016828	83.4	67	1.25	24.5%	371.4	0.27461
290	129.6	4045.1	159.1	150.9	155.0	101.9	53.1	1.010586	52.6	67	0.78	-21.5%	371.4	0.19156
290	129.6	4045.1	159.1	150.9	155.0	71.1	84.0	1.016657	82.6	67	1.23	23.2%	371.4	0.27235
290	129.6	4045.1	159.1	150.9	155.0	101.1	54.0	1.010752	53.4	67	0.80	-20.3%	371.4	0.19377
290	129.6	4045.1	159.1	150.9	155.0	71.9	83.1	1.016496	81.8	67	1.22	22.1%	371.4	0.27021
290	129.6	4045.1	159.1	150.9	155.0	100.3	54.8	1.010909	54.2	67	0.81	-19.1%	371.4	0.19587
290	129.6	4045.1	159.1	150.9	155.0	72.7	82.4	1.016344	81.0	67	1.21	20.9%	371.4	0.26819
290	129.6	4045.1	159.1	150.9	155.0	99.5	55.5	1.011058	54.9	67	0.82	-18.0%	371.4	0.19785
290	129.6	4045.1	159.1	150.9	155.0	73.4	81.6	1.0162	80.3	67	1.20	19.9%	371.4	0.26627
290	129.6	4045.1	159.1	150.9	155.0	98.8	56.2	1.011198	55.6	67	0.83	-17.0%	371.4	0.19972
290	129.6	4045.1	159.1	150.9	155.0	74.1	80.9	1.016063	79.6	67	1.19	18.9%	371.4	0.26446
290	129.6	4045.1	159.1	150.9	155.0	98.1	56.9	1.011331	56.3	67	0.84	-16.0%	371.4	0.20149
290	129.6	4045.1	159.1	150.9	155.0	74.8	80.3	1.015934	79.0	67	1.18	17.9%	371.4	0.26274
290	129.6	4045.1	159.1	150.9	155.0	97.5	57.5	1.011457	56.9	67	0.85	-15.1%	371.4	0.20317
290	129.6	4045.1	159.1	150.9	155.0	75.4	79.6	1.015812	78.4	67	1.17	17.0%	371.4	0.26112
290	129.6	4045.1	159.1	150.9	155.0	96.9	58.1	1.011576	57.5	67	0.86	-14.2%	371.4	0.20476
290	129.6	4045.1	159.1	150.9	155.0	76.0	79.1	1.015696	77.8	67	1.16	16.2%	371.4	0.25958
290	129.6	4045.1	159.1	150.9	155.0	96.3	58.7	1.011689	58.0	67	0.87	-13.4%	371.4	0.20626
290	129.6	4045.1	159.1	150.9	155.0	76.5	78.5	1.015587	77.3	67	1.15	15.4%	371.4	0.25813
290	129.6	4045.1	159.1	150.9	155.0	95.8	59.2	1.011795	58.6	67	0.87	-12.6%	371.4	0.20768
290	129.6	4045.1	159.1	150.9	155.0	77.1	78.0	1.015483	76.8	67	1.15	14.6%	371.4	0.25675
290	129.6	4045.1	159.1	150.9	155.0	95.3	59.8	1.011896	59.1	67	0.88	-11.9%	371.4	0.20902
290	129.6	4045.1	159.1	150.9	155.0	77.6	77.5	1.015386	76.3	67	1.14	13.9%	371.4	0.25545
290	129.6	4045.1	159.1	150.9	155.0	94.8	60.2	1.011992	59.5	67	0.89	-11.2%	371.4	0.21029
290	129.6	4045.1	159.1	150.9	155.0	78.0	77.0	1.015293	75.8	67	1.13	13.2%	371.4	0.25422
290	129.6	4045.1	159.1	150.9	155.0	94.3	60.7	1.012082	60.0	67	0.90	-10.5%	371.4	0.21149
290	129.6	4045.1	159.1	150.9	155.0	78.5	76.6	1.015205	75.4	67	1.13	12.6%	371.4	0.25305
290	129.6	4045.1	159.1	150.9	155.0	93.9	61.1	1.012167	60.4	67	0.90	-9.9%	371.4	0.21263
290	129.6	4045.1	159.1	150.9	155.0	78.9	76.1	1.015122	75.0	67	1.12	11.9%	371.4	0.25195
290	129.6	4045.1	159.1	150.9	155.0	93.5	61.5	1.012248	60.8	67	0.91	-9.3%	371.4	0.21370
290	129.6	4045.1	159.1	150.9	155.0	79.3	75.7	1.015044	74.6	67	1.11	11.4%	371.4	0.25090
290	129.6	4045.1	159.1	150.9	155.0	93.1	61.9	1.012324	61.2	67	0.91	-8.7%	371.4	0.21472
290	129.6	4045.1	159.1	150.9	155.0	79.7	75.4	1.01497	74.2	67	1.11	10.8%	371.4	0.24992
290	129.6	4045.1	159.1	150.9	155.0	92.8	62.3	1.012397	61.5	67	0.92	-8.2%	371.4	0.21568
290	129.6	4045.1	159.1	150.9	155.0	80.0	75.0	1.014899	73.9	67	1.10	10.3%	371.4	0.24898
290	129.6	4045.1	159.1	150.9	155.0	92.4	62.6	1.012465	61.9	67	0.92	-7.7%	371.4	0.21659
290	129.6	4045.1	159.1	150.9	155.0	80.4	74.7	1.014833	73.6	67	1.10	9.8%	371.4	0.24810
290	129.6	4045.1	159.1	150.9	155.0	92.1	63.0	1.01253	62.2	67	0.93	-7.2%	371.4	0.21746
290	129.6	4045.1	159.1	150.9	155.0	80.7	74.3	1.01477	73.3	67	1.09	9.3%	371.4	0.24726
290	129.6	4045.1	159.1	150.9	155.0	91.8	63.3	1.012591	62.5	67	0.93	-6.7%	371.4	0.21827
290	129.6	4045.1	159.1	150.9	155.0	81.0	74.0	1.01471	73.0	67	1.09	8.9%	371.4	0.24647
290	129.6	4045.1	159.1	150.9	155.0	91.5	63.6	1.012649	62.8	67	0.94	-6.3%	371.4	0.21904
290	129.6	4045.1	159.1	150.9	155.0	81.3	73.8	1.014654	72.7	67	1.08	8.5%	371.4	0.24572
290	129.6	4045.1	159.1	150.9	155.0	91.2	63.9	1.012704	63.1	67	0.94	-5.9%	371.4	0.21977
290	129.6	4045.1	159.1	150.9	155.0	81.6	73.5	1.014601	72.4	67	1.08	8.1%	371.4	0.24502
290	129.6	4045.1	159.1	150.9	155.0	90.9	64.1	1.012756	63.3	67	0.94	-5.5%	371.4	0.22046
290	129.6	4045.1	159.1	150.9	155.0	81.8	73.2	1.014551	72.2	67	1.08	7.7%	371.4	0.24435
290	129.6	4045.1	159.1	150.9	155.0	90.7	64.4	1.012805	63.5	67	0.95	-5.2%	371.4	0.22111
290	129.6	4045.1	159.1	150.9	155.0	82.1	73.0	1.014503	71.9	67	1.07	7.4%	371.4	0.24371
290	129.6	4045.1	159.1	150.9	155.0	90.4	64.6	1.012851	63.8	67	0.95	-4.8%	371.4	0.22173
290	129.6	4045.1	159.1	150.9	155.0	82.3	72.8	1.014458	71.7	67	1.07	7.0%	371.4	0.24311
290	129.6	4045.1	159.1	150.9	155.0	90.2	64.8	1.012895	64.0	67	0.96	-4.5%	371.4	0.22232
290	129.6	4045.1	159.1	150.9	155.0	82.5	72.5	1.014415	71.5	67	1.07	6.7%	371.4	0.24254
290	129.6	4045.1	159.1	150.9	155.0	90.0	65.0	1.012936	64.2	67	0.96	-4.2%	371.4	0.22287
290	129.6	4045.1	159.1	150.9	155.0	82.7	72.3	1.014375	71.3	67	1.06	6.4%	371.4	0.24201
290	129.6	4045.1	159.1	150.9	155.0	89.8	65.2	1.012976	64.4	67	0.96	-3.9%	371.4	0.22339
290	129.6	4045.1	159.1	150.9	155.0	82.9	72.1	1.014336	71.1	67	1.06	6.1%	371.4	0.24150
290	129.6	4045.1	159.1	150.9	155.0	89.6	65.4	1.013013	64.6	67	0.96	-3.6%	371.4	0.22389
290	129.6	4045.1	159.1	150.9	155.0	83.1	72.0	1.0143	70.9	67	1.06	5.9%	371.4	0.24102
290	129.6	4045.1	159.1	150.9	155.0	89.4	65.6	1.013048	64.8	67	0.97	-3.4%	371.4	0.22436
290	129.6	4045.1	159.1	150.9	155.0	83.3	71.8	1.014266	70.8	67	1.06	5.6%	371.4	0.24056
290	129.6	4045.1	159.1	150.9	155.0	89.3	65.8	1.013081	64.9	67	0.97	-3.1%	371.4	0.22480
290	129.6	4045.1	159.1	150.9	155.0	83.4	71.6	1.014234	70.6	67	1.05	5.4%	371.4	0.24013
290	129.6	4045.1	159.1	150.9	155.0	89.1	65.9	1.013113	65.1	67	0.97	-2.9%	371.4	0.22522
290	129.6	4045.1	159.1	150.9	155.0	83.6	71.5	1.014203	70.5	67	1.05	5.2%	371.4	0.23973
290	129.6	4045.1	159.1	150.9	155.0	89.0	66.1	1.013143	65.2	67	0.97	-2.7%	371.4	0.22561
290	129.6	4045.1	159.1	150.9	155.0	83.7	71.3	1.014174	70.3	67	1.05	5.0%	371.4	0.23934
290	129.6	4045.1	159.1	150.9	155.0	88.8	66.2	1.013171	65.4	67	0.98	-2.4%	371.4	0.22599
290	129.6	4045.1	159.1	150.9	155.0	83.9	71.2	1.014147	70.2	67	1.05	4.7%	371.4	0.23898
290	129.6	4045.1	159.1	150.9	155.0	88.7	66.4	1.013198	65.5	67	0.98	-2.3%	371.4	0.22634
290	129.6	4045.1	159.1	150.9	155.0	84.0	71.0	1.014121	70.1	67	1.05	4.6%	371.4	0.23863
290	129.6	4045.1	159.1	150.9	155.0	88.6	66.5	1.013223	65.6	67	0.98	-2.1%	371.4	0.22668
290	129.6	4045.1	159.1	150.9	155.0	84.1	70.9	1.014096	69.9	67	1.04	4.4%	371.4	0.23830
290	129.6	4045.1	159.1	150.9	155.0	88.4	66.6	1.013247	65.7	67	0.98	-1.9%	371.4	0.22700
290	129.6	4045.1	159.1	150.9	155.0	84.2	70.8	1.014073	69.8	67	1.04	4.2%	371.4	0.23800
290	129.6	4045.1	159.1	150.9	155.0	88.3	66.7	1.013269	65.8	67	0.98	-1.7%	371.4	0.22730
290	129.6	4045.1	159.1	150.9	155.0	84.4	70.7	1.014051	69.7	67	1.04	4.0%	371.4	0.23770
290	129.6	4045.1	159.1	150.9	155.0	88.2	66.8	1.013291	66.0	67	0.98	-1.6%	371.4	0.22758
290	129.6	4045.1	159.1	150.9	155.0	84.5	70.6	1.01403	69.6	67	1.04	3.9%	371.4	0.23743
290	129.6	4045.1	159.1	150.9	155.0	88.1	66.9	1.013311	66.1	67	0.99	-1.4%	371.4	0.22785
290	129.6	4045.1	159.1	150.9	155.0	84.6	70.5	1.014011	69.5	67	1.04	3.7%	371.4	0.23717
290	129.6	4045.1	159.1	150.9	155.0	88.0	67.0	1.01333	66.1	67	0.99	-1.3%	371.4	0.22811
290	129.6	4045.1	159.1	150.9	155.0	84.7	70.4	1.013992	69.4	67	1.04	3.6%	371.4	0.23692
290	129.6	4045.1	159.1	150.9	155.0	87.9	67.1	1.013348	66.2	67	0.99	-1.1%	371.4	0.22835

R	0.165	default 0.165 based on phantom in unmoderated fields with n/g dose ratio R is a dimensionless factor to estimate the fraction of delivered neutron absorbed dose that appears as apparent gamma signal on the
C_n	10.940	6.19 for Godiva, 2.90 default for on phantom at 50cm from bare Cf-252 R = 0.165 (default) This value is based on dosimeters exposed on phantom in unmoderated fields with n/γ dose ratio = 8, , i.e., approxi
Cγ	1.000	default for prompt and delayed gamma from unshielded criticalitites Used neutron dose calc sheet compared to measured foils to empirically estimate C_n.
RRF	1.000	relative response factor for Co-60 to the geometry used to calibrate the rea R = 0.0467 for FIA Average. FlatTop n/g dose ratios were 3.9 to 5.7.
r	0.050	offset for the R estimate where R is (g/n)+r. The offset r was 0.04 for the default 0.165 (see (1/8)+0.04 = 0.165), and see PNAD FIA average indicated may range up to 0.057.

R (500 iterations)	**0.22374**						**$D(10)_\gamma$ (at 500 iterations):**		63.5	59	1.08	**7.7%**		**R estimate for iteration:**
									rad=cGy				**Neutron rad**	**(Measured-calculated $D(10)_\gamma$ / Neutron rad from measured foils) + offset r**
PNAD	**E1 (rad=cGy)**	**E2**	**E3**	**E4**	**(E3+E4)/2**	**R*(E2 - E1)/Cn**	**x**	**$S\gamma_{34}$**	**$D(10)_\gamma$**	**Given**	**$D(10)_\gamma$/Given**	**(Given - $D(10)_\gamma$)/Given %**	**Measured foils**	**= (g/n)+r**
292	120.4	4116.2	148.2	143.9	146.1	60.3	85.8	1.017017	84.3	59	1.43	43.0%	365.6	0.28071
292	120.4	4116.2	148.2	143.9	146.1	102.5	43.5	1.008683	43.1	59	0.73	-26.9%	365.6	0.16801
292	120.4	4116.2	148.2	143.9	146.1	61.4	84.7	1.016801	83.3	59	1.41	41.2%	365.6	0.27780
292	120.4	4116.2	148.2	143.9	146.1	101.5	44.6	1.008894	44.2	59	0.75	-25.1%	365.6	0.17087
292	120.4	4116.2	148.2	143.9	146.1	62.4	83.6	1.016596	82.3	59	1.39	39.4%	365.6	0.27504
292	120.4	4116.2	148.2	143.9	146.1	100.5	45.6	1.009094	45.2	59	0.77	-23.4%	365.6	0.17358
292	120.4	4116.2	148.2	143.9	146.1	63.4	82.6	1.016402	81.3	59	1.38	37.8%	365.6	0.27242
292	120.4	4116.2	148.2	143.9	146.1	99.5	46.6	1.009283	46.1	59	0.78	-21.8%	365.6	0.17616
292	120.4	4116.2	148.2	143.9	146.1	64.3	81.7	1.016217	80.4	59	1.36	36.3%	365.6	0.26993
292	120.4	4116.2	148.2	143.9	146.1	98.6	47.5	1.009464	47.0	59	0.80	-20.3%	365.6	0.17860
292	120.4	4116.2	148.2	143.9	146.1	65.2	80.8	1.016042	79.5	59	1.35	34.8%	365.6	0.26757
292	120.4	4116.2	148.2	143.9	146.1	97.7	48.3	1.009634	47.9	59	0.81	-18.9%	365.6	0.18091
292	120.4	4116.2	148.2	143.9	146.1	66.1	80.0	1.015876	78.7	59	1.33	33.4%	365.6	0.26533
292	120.4	4116.2	148.2	143.9	146.1	96.9	49.1	1.009796	48.7	59	0.82	-17.5%	365.6	0.18311
292	120.4	4116.2	148.2	143.9	146.1	66.9	79.2	1.015719	77.9	59	1.32	32.1%	365.6	0.26320
292	120.4	4116.2	148.2	143.9	146.1	96.1	49.9	1.00995	49.4	59	0.84	-16.2%	365.6	0.18519
292	120.4	4116.2	148.2	143.9	146.1	67.6	78.4	1.015569	77.2	59	1.31	30.9%	365.6	0.26118
292	120.4	4116.2	148.2	143.9	146.1	95.4	50.7	1.010096	50.1	59	0.85	-15.0%	365.6	0.18717
292	120.4	4116.2	148.2	143.9	146.1	68.4	77.7	1.015428	76.5	59	1.30	29.7%	365.6	0.25927
292	120.4	4116.2	148.2	143.9	146.1	94.7	51.4	1.010235	50.8	59	0.86	-13.8%	365.6	0.18904
292	120.4	4116.2	148.2	143.9	146.1	69.0	77.0	1.015293	75.8	59	1.29	28.5%	365.6	0.25745
292	120.4	4116.2	148.2	143.9	146.1	94.0	52.0	1.010366	51.5	59	0.87	-12.7%	365.6	0.19082
292	120.4	4116.2	148.2	143.9	146.1	69.7	76.4	1.015165	75.2	59	1.27	27.5%	365.6	0.25572
292	120.4	4116.2	148.2	143.9	146.1	93.4	52.6	1.010491	52.1	59	0.88	-11.7%	365.6	0.19251
292	120.4	4116.2	148.2	143.9	146.1	70.3	75.7	1.015044	74.6	59	1.26	26.5%	365.6	0.25409
292	120.4	4116.2	148.2	143.9	146.1	92.8	53.2	1.010609	52.7	59	0.89	-10.7%	365.6	0.19411
292	120.4	4116.2	148.2	143.9	146.1	70.9	75.2	1.014929	74.0	59	1.26	25.5%	365.6	0.25253
292	120.4	4116.2	148.2	143.9	146.1	92.2	53.8	1.010721	53.2	59	0.90	-9.8%	365.6	0.19563
292	120.4	4116.2	148.2	143.9	146.1	71.5	74.6	1.01482	73.5	59	1.25	24.6%	365.6	0.25106
292	120.4	4116.2	148.2	143.9	146.1	91.7	54.4	1.010827	53.8	59	0.91	-8.9%	365.6	0.19707
292	120.4	4116.2	148.2	143.9	146.1	72.0	74.1	1.014717	73.0	59	1.24	23.7%	365.6	0.24966
292	120.4	4116.2	148.2	143.9	146.1	91.2	54.9	1.010928	54.3	59	0.92	-8.0%	365.6	0.19844
292	120.4	4116.2	148.2	143.9	146.1	72.5	73.6	1.014618	72.5	59	1.23	22.9%	365.6	0.24834
292	120.4	4116.2	148.2	143.9	146.1	90.7	55.3	1.011024	54.7	59	0.93	-7.2%	365.6	0.19973
292	120.4	4116.2	148.2	143.9	146.1	73.0	73.1	1.014525	72.1	59	1.22	22.1%	365.6	0.24708
292	120.4	4116.2	148.2	143.9	146.1	90.2	55.8	1.011115	55.2	59	0.94	-6.5%	365.6	0.20096
292	120.4	4116.2	148.2	143.9	146.1	73.4	72.6	1.014437	71.6	59	1.21	21.4%	365.6	0.24588
292	120.4	4116.2	148.2	143.9	146.1	89.8	56.2	1.011201	55.6	59	0.94	-5.7%	365.6	0.20213
292	120.4	4116.2	148.2	143.9	146.1	73.8	72.2	1.014353	71.2	59	1.21	20.7%	365.6	0.24475
292	120.4	4116.2	148.2	143.9	146.1	89.4	56.7	1.011283	56.0	59	0.95	-5.0%	365.6	0.20324
292	120.4	4116.2	148.2	143.9	146.1	74.2	71.8	1.014273	70.8	59	1.20	20.0%	365.6	0.24367
292	120.4	4116.2	148.2	143.9	146.1	89.0	57.0	1.011361	56.4	59	0.96	-4.4%	365.6	0.20429
292	120.4	4116.2	148.2	143.9	146.1	74.6	71.4	1.014198	70.4	59	1.19	19.4%	365.6	0.24265
292	120.4	4116.2	148.2	143.9	146.1	88.6	57.4	1.011434	56.8	59	0.96	-3.8%	365.6	0.20529
292	120.4	4116.2	148.2	143.9	146.1	75.0	71.1	1.014126	70.1	59	1.19	18.8%	365.6	0.24169
292	120.4	4116.2	148.2	143.9	146.1	88.3	57.8	1.011504	57.1	59	0.97	-3.2%	365.6	0.20623
292	120.4	4116.2	148.2	143.9	146.1	75.3	70.7	1.014058	69.7	59	1.18	18.2%	365.6	0.24077
292	120.4	4116.2	148.2	143.9	146.1	87.9	58.1	1.011571	57.4	59	0.97	-2.6%	365.6	0.20713
292	120.4	4116.2	148.2	143.9	146.1	75.7	70.4	1.013994	69.4	59	1.18	17.7%	365.6	0.23990
292	120.4	4116.2	148.2	143.9	146.1	87.6	58.4	1.011634	57.8	59	0.98	-2.1%	365.6	0.20798
292	120.4	4116.2	148.2	143.9	146.1	76.0	70.1	1.013932	69.1	59	1.17	17.2%	365.6	0.23907
292	120.4	4116.2	148.2	143.9	146.1	87.3	58.7	1.011693	58.1	59	0.98	-1.6%	365.6	0.20879
292	120.4	4116.2	148.2	143.9	146.1	76.3	69.8	1.013874	68.8	59	1.17	16.7%	365.6	0.23828
292	120.4	4116.2	148.2	143.9	146.1	87.0	59.0	1.01175	58.3	59	0.99	-1.1%	365.6	0.20955
292	120.4	4116.2	148.2	143.9	146.1	76.5	69.5	1.013819	68.6	59	1.16	16.2%	365.6	0.23754
292	120.4	4116.2	148.2	143.9	146.1	86.8	59.3	1.011804	58.6	59	0.99	-0.7%	365.6	0.21028
292	120.4	4116.2	148.2	143.9	146.1	76.8	69.2	1.013767	68.3	59	1.16	15.8%	365.6	0.23683
292	120.4	4116.2	148.2	143.9	146.1	86.5	59.5	1.011854	58.9	59	1.00	-0.3%	365.6	0.21097
292	120.4	4116.2	148.2	143.9	146.1	77.1	69.0	1.013717	68.1	59	1.15	15.4%	365.6	0.23616
292	120.4	4116.2	148.2	143.9	146.1	86.3	59.8	1.011903	59.1	59	1.00	0.2%	365.6	0.21162
292	120.4	4116.2	148.2	143.9	146.1	77.3	68.8	1.01367	67.8	59	1.15	15.0%	365.6	0.23553
292	120.4	4116.2	148.2	143.9	146.1	86.0	60.0	1.011949	59.3	59	1.01	0.5%	365.6	0.21224
292	120.4	4116.2	148.2	143.9	146.1	77.5	68.5	1.013626	67.6	59	1.15	14.6%	365.6	0.23492
292	120.4	4116.2	148.2	143.9	146.1	85.8	60.2	1.011992	59.5	59	1.01	0.9%	365.6	0.21283
292	120.4	4116.2	148.2	143.9	146.1	77.7	68.3	1.013583	67.4	59	1.14	14.2%	365.6	0.23435
292	120.4	4116.2	148.2	143.9	146.1	85.6	60.5	1.012034	59.7	59	1.01	1.2%	365.6	0.21339
292	120.4	4116.2	148.2	143.9	146.1	77.9	68.1	1.013543	67.2	59	1.14	13.9%	365.6	0.23381
292	120.4	4116.2	148.2	143.9	146.1	85.4	60.7	1.012073	59.9	59	1.02	1.6%	365.6	0.21392
292	120.4	4116.2	148.2	143.9	146.1	78.1	67.9	1.013505	67.0	59	1.14	13.6%	365.6	0.23329
292	120.4	4116.2	148.2	143.9	146.1	85.2	60.8	1.01211	60.1	59	1.02	1.9%	365.6	0.21442
292	120.4	4116.2	148.2	143.9	146.1	78.3	67.7	1.013469	66.8	59	1.13	13.3%	365.6	0.23280
292	120.4	4116.2	148.2	143.9	146.1	85.0	61.0	1.012145	60.3	59	1.02	2.2%	365.6	0.21490
292	120.4	4116.2	148.2	143.9	146.1	78.5	67.6	1.013434	66.7	59	1.13	13.0%	365.6	0.23234
292	120.4	4116.2	148.2	143.9	146.1	84.9	61.2	1.012179	60.5	59	1.02	2.5%	365.6	0.21535
292	120.4	4116.2	148.2	143.9	146.1	78.7	67.4	1.013402	66.5	59	1.13	12.7%	365.6	0.23190
292	120.4	4116.2	148.2	143.9	146.1	84.7	61.4	1.01221	60.6	59	1.03	2.7%	365.6	0.21578
292	120.4	4116.2	148.2	143.9	146.1	78.8	67.2	1.013371	66.3	59	1.12	12.5%	365.6	0.23148
292	120.4	4116.2	148.2	143.9	146.1	84.5	61.5	1.01224	60.8	59	1.03	3.0%	365.6	0.21619
292	120.4	4116.2	148.2	143.9	146.1	79.0	67.1	1.013342	66.2	59	1.12	12.2%	365.6	0.23108
292	120.4	4116.2	148.2	143.9	146.1	84.4	61.6	1.012269	60.9	59	1.03	3.2%	365.6	0.21658
292	120.4	4116.2	148.2	143.9	146.1	79.1	66.9	1.013314	66.1	59	1.12	12.0%	365.6	0.23071
292	120.4	4116.2	148.2	143.9	146.1	84.3	61.8	1.012296	61.0	59	1.03	3.4%	365.6	0.21694
292	120.4	4116.2	148.2	143.9	146.1	79.2	66.8	1.013287	65.9	59	1.12	11.8%	365.6	0.23035
292	120.4	4116.2	148.2	143.9	146.1	84.1	61.9	1.012322	61.2	59	1.04	3.7%	365.6	0.21729
292	120.4	4116.2	148.2	143.9	146.1	79.4	66.7	1.013262	65.8	59	1.12	11.5%	365.6	0.23001
292	120.4	4116.2	148.2	143.9	146.1	84.0	62.0	1.012346	61.3	59	1.04	3.9%	365.6	0.21762
292	120.4	4116.2	148.2	143.9	146.1	79.5	66.6	1.013239	65.7	59	1.11	11.3%	365.6	0.22969
292	120.4	4116.2	148.2	143.9	146.1	83.9	62.2	1.012369	61.4	59	1.04	4.1%	365.6	0.21794
292	120.4	4116.2	148.2	143.9	146.1	79.6	66.4	1.013216	65.6	59	1.11	11.2%	365.6	0.22938
292	120.4	4116.2	148.2	143.9	146.1	83.8	62.3	1.012391	61.5	59	1.04	4.2%	365.6	0.21823
292	120.4	4116.2	148.2	143.9	146.1	79.7	66.3	1.013195	65.5	59	1.11	11.0%	365.6	0.22910
292	120.4	4116.2	148.2	143.9	146.1	83.7	62.4	1.012412	61.6	59	1.04	4.4%	365.6	0.21851
292	120.4	4116.2	148.2	143.9	146.1	79.8	66.2	1.013174	65.4	59	1.11	10.8%	365.6	0.22882
292	120.4	4116.2	148.2	143.9	146.1	83.6	62.5	1.012432	61.7	59	1.05	4.6%	365.6	0.21878
292	120.4	4116.2	148.2	143.9	146.1	79.9	66.1	1.013155	65.3	59	1.11	10.6%	365.6	0.22856
292	120.4	4116.2	148.2	143.9	146.1	83.5	62.6	1.012451	61.8	59	1.05	4.7%	365.6	0.21904
292	120.4	4116.2	148.2	143.9	146.1	80.0	66.0	1.013137	65.2	59	1.10	10.5%	365.6	0.22831
292	120.4	4116.2	148.2	143.9	146.1	83.4	62.7	1.012469	61.9	59	1.05	4.9%	365.6	0.21928
292	120.4	4116.2	148.2	143.9	146.1	80.1	66.0	1.013119	65.1	59	1.10	10.3%	365.6	0.22808
292	120.4	4116.2	148.2	143.9	146.1	83.3	62.7	1.012485	62.0	59	1.05	5.0%	365.6	0.21951

Distribution

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Approval History

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Activity: Approval was ACCEPTED by Georgeson, Dave L (702661) on Jan 2 2020 1:28PM.

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Name		Activity Name	Date
☒ ACCEPTED	Stephens, John A	Approval	1/2/2020 9:04:36 AM
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