



Comprehensive Angular Response Study of LLNL Panasonic Dosimeter Configurations and Artificial Intelligence Algorithm

Revision 0

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Auspices

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Introduction

In April of 2016, the Lawrence Livermore National Laboratory External Dosimetry Program underwent a Department of Energy Laboratory Accreditation Program (DOELAP) on-site assessment. The assessment reported a concern that the study performed in *2013 Angular Dependence Study Panasonic UD-802 and UD-810 Dosimeters LLNL Artificial Intelligence Algorithm* was incomplete. Only the responses at $\pm 60^\circ$ and 0° were evaluated and independent data from dosimeters was not used to evaluate the algorithm. Additionally, other configurations of LLNL dosimeters were not considered in this study. This includes nuclear accident dosimeters (NAD) which are placed in the wells surrounding the TLD in the dosimeter holder.

Table 1. Dosimeter Configurations for Angular Study

Dosimeter Configurations
UD-802
UD-810
UD-810 + CR-39
UD-810 + NAD
UD-810 + NAD + CR-39

Purpose

The purpose of this study is to provide a demonstration of angular dependence of each dosimeter configuration listed in Table 1 at seven angles between $\pm 85^\circ$ in vertical and horizontal orientations. There is no current guidance or standard that includes a protocol for performing angular dependence studies for whole body dosimeters; this study was performed in accordance with the protocol described in the superseded DOE standard *Department of Energy Standard for the Performance Testing of Personnel Dosimetry Systems* (DOE/EH-0027). Each configuration was exposed to the photon and neutron fields in Table 2 at the following angles of exposure: 0° , $\pm 40^\circ$, $\pm 60^\circ$ and $\pm 85^\circ$.

Table 2. Radiation Fields Tested
(a)Fluence average energy (ANSI/HPS N13.11-2009)

Source	Radiation Type	Average Energy (keV)
^{137}Cs	Photon	662
M150	Photon	73
M30	Photon	20
M60	Photon	35
M100	Photon	53
H150	Photon	118
H250	Photon	204
^{252}Cf (bare)	Neutron	2130 ^(a)
^{252}Cf (15-cm D ₂ O moderated)	Neutron	550 ^(a)

For personnel monitoring, LLNL primarily uses the Panasonic TLD system, using UD-802 and UD-810 dosimeters. The UD-802 dosimeter it uses four phosphor elements, where elements 1 and 2 (E1 & E2) are made of natural lithium borate (${}^7\text{Li}_2{}^{\text{n}}\text{B}_4\text{O}_7$) and elements 3 and 4 (E3 & E4) are made of calcium sulfate (CaSO_4). Each element has distinct filtration: E1 has a Mylar window for possible beta radiation monitoring, E2 and E3 have plastic filters, and E4 has both a plastic and a lead filter. The UD-810 dosimeter is a custom-designed dosimeter for LLNL. It consists of four elements, where E1 and E2 are made of ${}^7\text{Li}_2{}^{11}\text{B}_4\text{O}_7$ and are neutron insensitive, E3 is made of ${}^6\text{Li}_2{}^{10}\text{B}_4\text{O}_7$ and is sensitive to thermal neutrons, and E4 is made of CaSO_4 . The filtration for the UD-810 consists of a Mylar window for E1, plastic filters for E2 and E4, and plastic and aluminum filters for E3. There is no lead filter in the UD-810. These dosimeter descriptions are specified in *LLNL Whole Body Dosimeter Descriptions* and are summarized in Table 3.

*Table 3. Front Filtration of Different Dosimeter Types and Holders
(density thickness in mg cm^{-2})*

Dosimeter Type	Filter	Element 1	Element 2	Element 3	Element 4
UD-802	Dosimeter	14	160	160	800 Pb + 60 plastic
	Holder + Flap	0	350	320	350
	Total	14	510	480	1210
UD-810	Dosimeter	14	160	160	160
	Holder + Flap	0	350	320 plastic + 80 Al	350
	Total	14	510	560	510

The LLNL dosimeter holder configuration consists of three parts: the holder, the retaining cover, and the decorative cover.

The dosimeter holder is a blue case made of injection-molded acrylonitrile butadiene styrene (ABS) polymer. The dosimeter sits in the holder such that the element phosphors are centered in the holder. The dosimeter is indexed and can only be placed in the holder in one orientation. There are three wells surrounding the dosimeter which can house NAD materials and can be seen in Figure 1. The NAD material is sealed into the holder. Some holders are adapted to fit CR-39 foils behind the TLD and are paired with the UD-810.

The retaining cover is indexed; it slides into the holder in only one orientation and keeps the dosimeter in place. It is also made of ABS polymer plastic and comes in blue or black colors. The colors of the cover slide are linked to the dosimeter being used. UD-802s use a blue cover. UD-810s use a black cover with an aluminum filter over E3. The cover has a Mylar beta window over E1. For elements 2 and 4 the filtration is plastic.

The decorative cover is a 110 mg cm^{-2} thick styrene flap that is placed over the retaining cover. The flap provides identical filtration over each element except for the opening over E1. The figure below illustrates how the dosimeter components are configured.



Figure 1. (A) Expanded view of contents of LLNL Dosimeter (B) Assembled LLNL Dosimeter

LLNL uses an artificial intelligence (AI) algorithm implemented through The Doctor's Software, Inc. This algorithm compares dosimeter element responses to patterns of element values known as fingerprints. The fingerprints are based on known responses to different radiation sources and types, and are maintained in a matrix. The AI algorithm optimizes itself automatically to any addition, removal or change to the matrix fingerprints. The algorithm can consider normal incidence exposures, angular exposures and mixtures of different radiation fields. This method initially calculates the shallow dose and then calculates deep and eye doses by applying the appropriate weighting factors to the shallow dose.

Method

The dosimeters selected for this study were chosen from a newer batch of dosimeters from Panasonic. Dosimeters out of this set were chosen based on dose history such that dosimeters with lower cumulative doses were selected rather than those with high cumulative doses. Once selected, new element correction factors (ECFs) were generated for the population. The dosimeters were then annealed down to be issued for this study. Additional dosimeters were selected from this newer batch to accommodate additional shots. After the dosimeters were issued, they were assembled in their appropriate configurations as shown in Table 1.

For performing exposures, the dosimeters were placed on a 30 × 30 × 15 cm polymethyl methacrylate (PMMA) phantom and were oriented within a 15 × 15 cm area about the center of the phantom. The dosimeters were held onto the phantom using tape, which allowed for little to no air gap between the dosimeter and the phantom. They were oriented based on the description in the *American National Standard, Personnel Dosimetry Performance - Criteria for Testing* (ANSI/HPS N13.11-2009), where the top of the dosimeter is where the hanger tab is located. The vertical orientation has the hanger tab upwards, as it would normally be worn by the user. For the horizontal orientation, the hanger tab is to the right as viewed from the source. Three dosimeters were placed on the phantom for each shot, as seen below for each orientation.

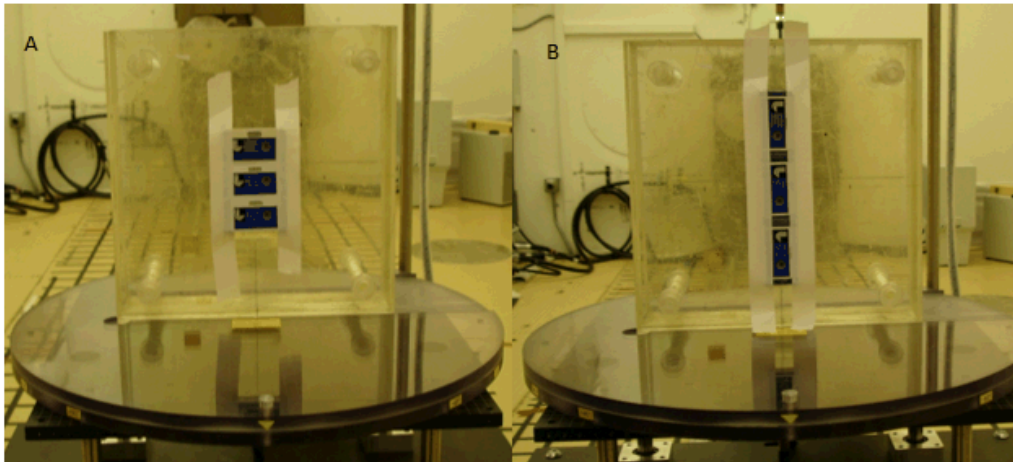


Figure 2. Vertical (A) and Horizontal (B) Orientation of LLNL Dosimeters

Nine radiation sources were used to test angular dependence, displayed in Table 2. Each shot was exposed for the same duration for each angle to observe relative changes in dosimeter response. This was performed for angles 0° , $\pm 40^\circ$, $\pm 60^\circ$ and $\pm 85^\circ$, where positive refers to a clockwise rotation of the phantom as viewed from above.

Results

The dosimeters were then read 24 hours after exposure to eliminate any low energy traps, and then a dose calculation was performed using the AI algorithm. The algorithm applies the appropriate ECF, reader calibration factor (RCF), and background subtraction for each dosimeter and finds the best fit from the fingerprint matrix to calculate shallow, deep, and eye doses. The data was further analyzed by plotting the response at each angle normalized to the response at the (0°) angle. This analysis was performed for each dosimeter type/configuration and each radiation field. The following charts display the normalized response at each angle for deep dose and shallow dose. The black bars in the charts represent the upper and lower 30% boundaries allowed by CAT II and CAT V of ANSI/HPS 13.11-2009.

References

Topper, J.D. 2013 *Angular Dependence Study Panasonic UD-802 and UD-810 Dosimeters LLNL Artificial Intelligence Algorithm*, 2013.

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DOE/EH-0027, *Department of Energy Standard for the Performance Testing of Personnel Dosimetry Systems*, U.S. Department of Energy, December 1986.

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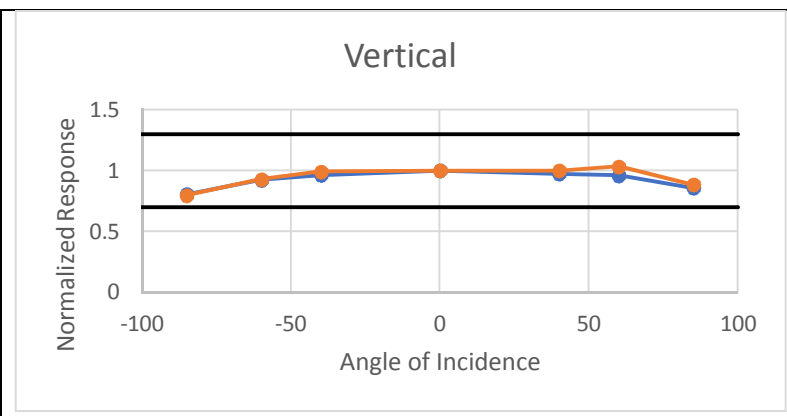
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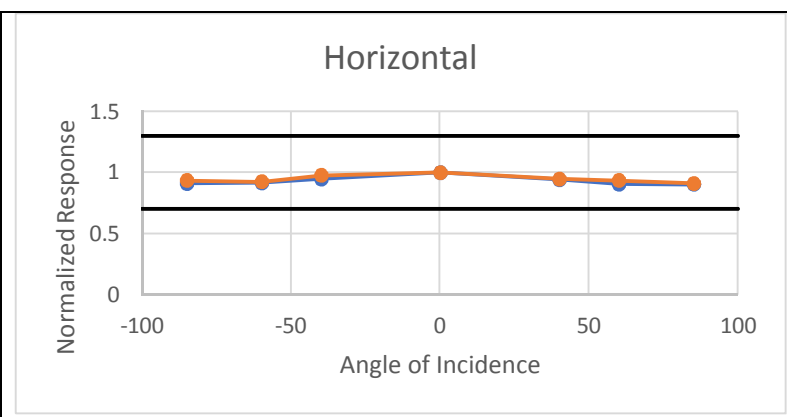
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¹³⁷Cs: UD-802

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	440	0.806	433	0.799
-60	505	0.924	504	0.930
-40	526	0.963	537	0.992
0	546	1.000	542	1.000
40	532	0.974	543	1.002
60	525	0.961	560	1.034
85	469	0.858	479	0.884

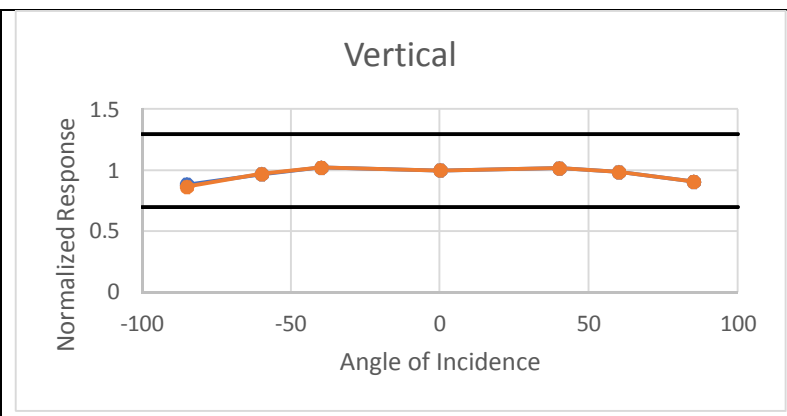


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	498	0.913	507	0.936
-60	501	0.918	501	0.925
-40	518	0.949	529	0.976
0	546	1.000	542	1.000
40	515	0.943	513	0.947
60	495	0.906	506	0.934
85	494	0.905	493	0.910

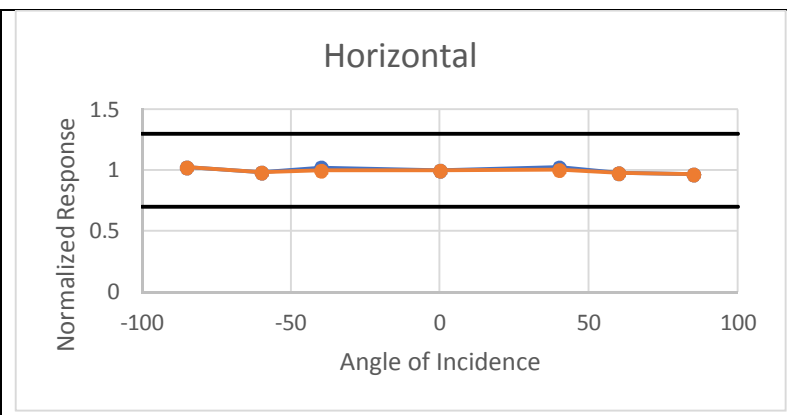


¹³⁷Cs: UD-810

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	481	0.884	503	0.865
-60	527	0.969	563	0.969
-40	557	1.024	595	1.024
0	544	1.000	581	1.000
40	554	1.018	592	1.018
60	537	0.987	574	0.987
85	493	0.906	527	0.906

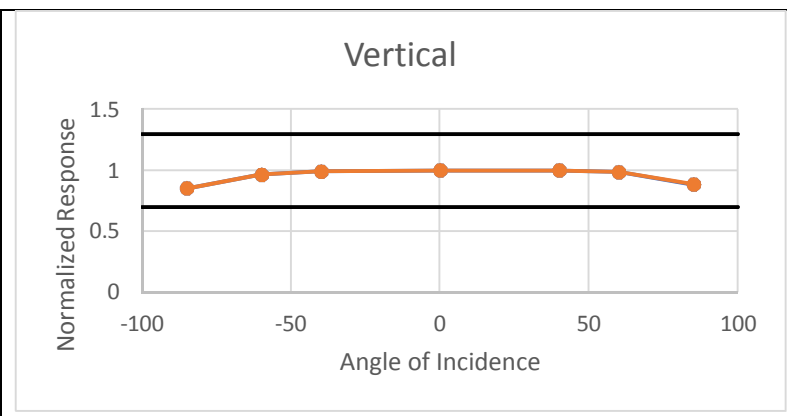


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	558	1.026	596	1.024
-60	535	0.983	571	0.983
-40	556	1.021	581	1.000
0	544	1.000	581	1.000
40	558	1.026	584	1.004
60	532	0.979	569	0.978
85	526	0.966	562	0.966

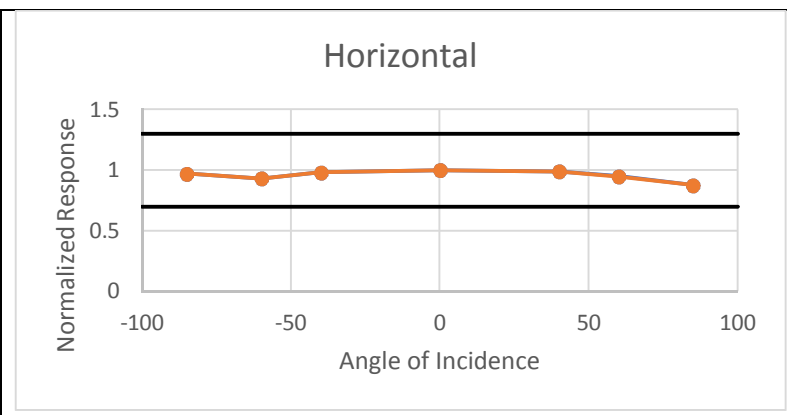


¹³⁷Cs: UD-810 + NAD + CR-39

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	453	0.853	484	0.852
-60	513	0.964	548	0.964
-40	527	0.991	563	0.991
0	532	1.000	568	1.000
40	531	0.999	567	0.999
60	524	0.985	559	0.985
85	470	0.885	503	0.885

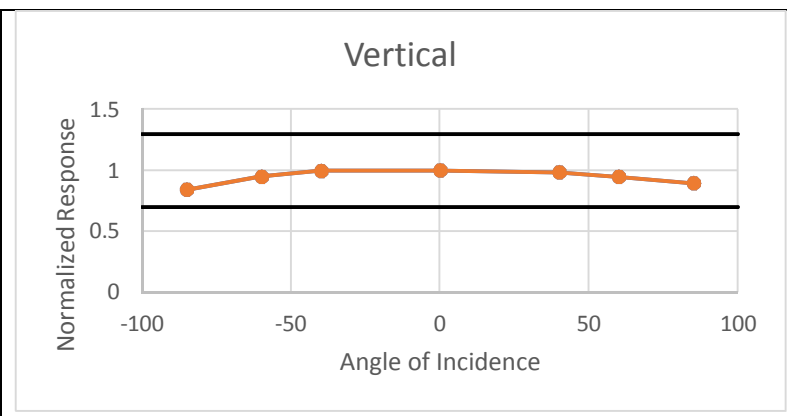


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	516	0.970	551	0.969
-60	495	0.931	529	0.931
-40	522	0.981	557	0.981
0	532	1.000	568	1.000
40	526	0.989	562	0.989
60	504	0.949	539	0.948
85	466	0.876	498	0.877

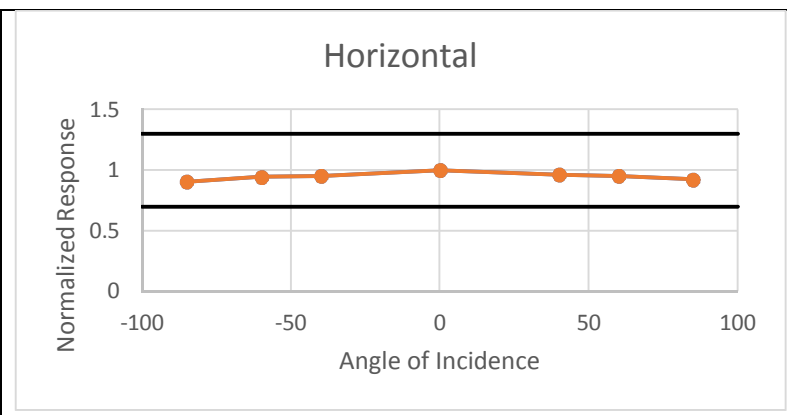


¹³⁷Cs: UD-810 + CR-39

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	466	0.840	499	0.841
-60	527	0.949	563	0.949
-40	553	0.996	590	0.996
0	555	1.000	593	1.000
40	546	0.984	584	0.984
60	525	0.945	561	0.946
85	496	0.893	530	0.893

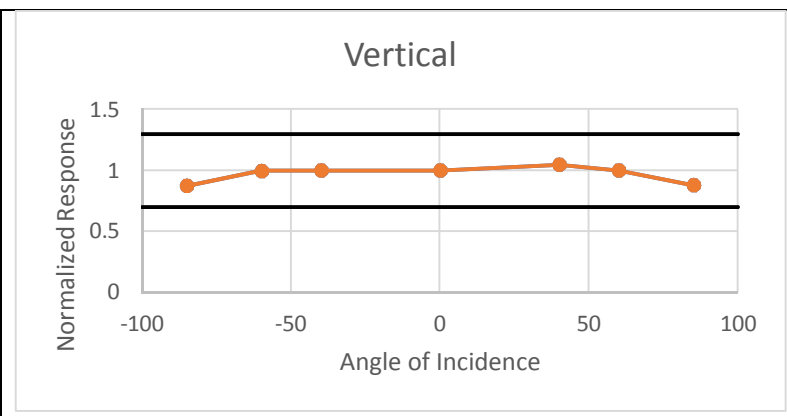


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	502	0.904	536	0.904
-60	525	0.945	560	0.945
-40	528	0.952	564	0.952
0	555	1.000	593	1.000
40	534	0.963	571	0.963
60	529	0.953	565	0.953
85	512	0.923	547	0.922

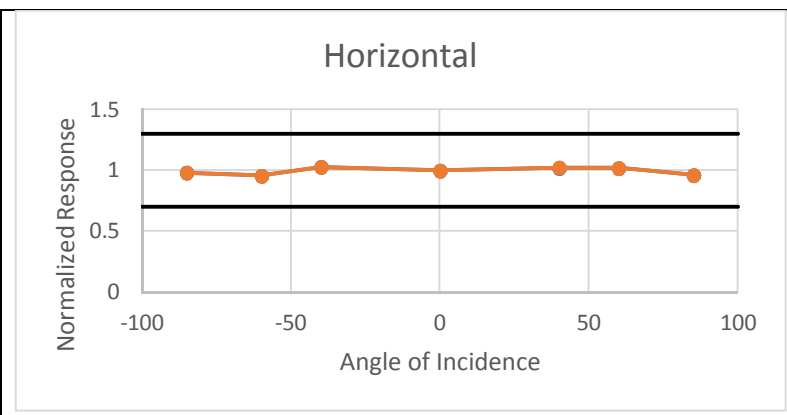


¹³⁷Cs: UD-810 + NAD

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	480	0.874	512	0.874
-60	547	0.997	585	0.998
-40	549	0.999	586	0.999
0	549	1.000	586	1.000
40	574	1.046	613	1.046
60	549	0.999	586	1.000
85	482	0.877	515	0.878

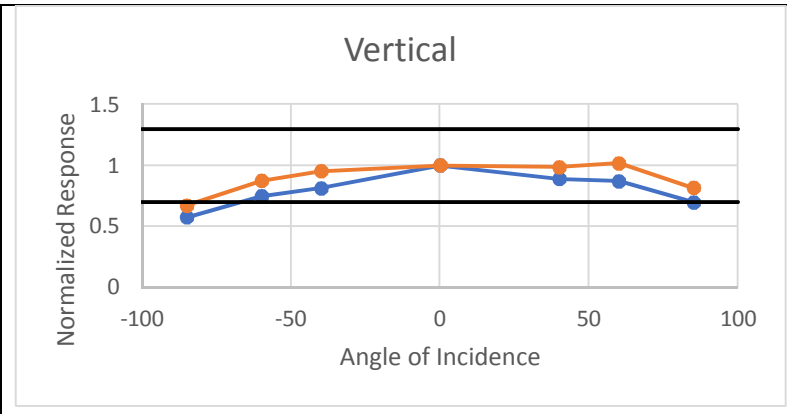


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	539	0.981	576	0.982
-60	526	0.957	561	0.957
-40	565	1.029	603	1.028
0	549	1.000	586	1.000
40	561	1.021	599	1.022
60	559	1.019	598	1.020
85	528	0.961	564	0.961

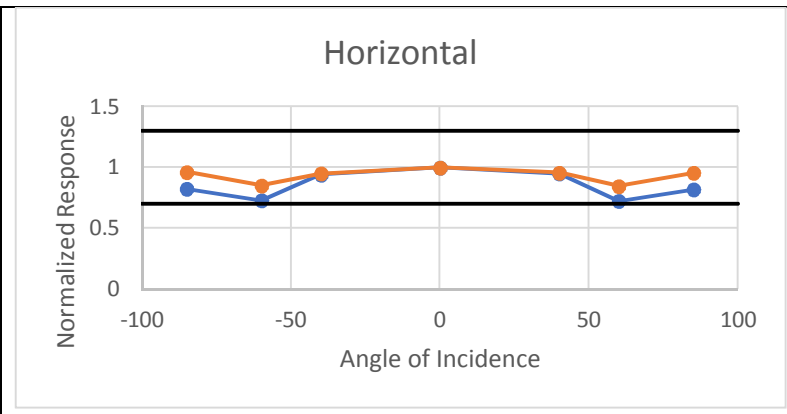


M150: UD-802

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	275	0.573	295	0.670
-60	358	0.746	384	0.872
-40	390	0.813	419	0.951
0	480	1.000	440	1.000
40	427	0.889	434	0.985
60	418	0.871	449	1.019
85	335	0.697	359	0.815

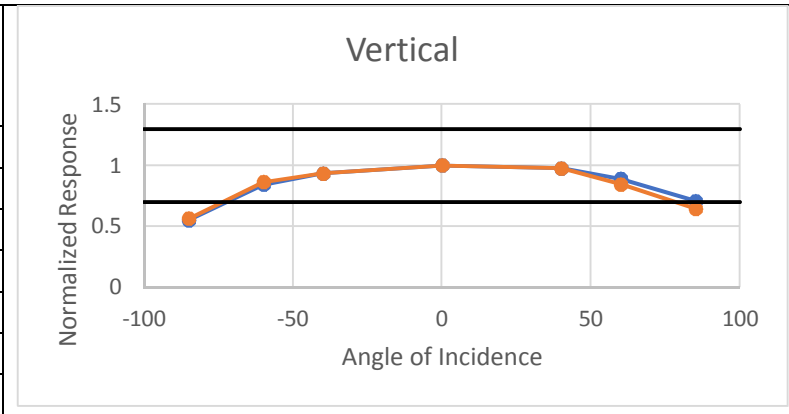


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	395	0.823	424	0.963
-60	349	0.728	375	0.851
-40	452	0.941	418	0.949
0	480	1.000	440	1.000
40	456	0.949	422	0.957
60	348	0.724	373	0.848
85	392	0.817	421	0.955

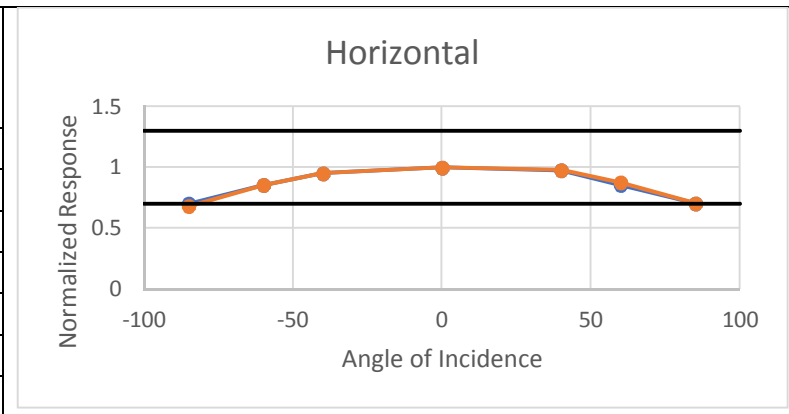


M150: UD-810

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	242	0.550	260	0.564
-60	371	0.841	398	0.863
-40	411	0.933	430	0.933
0	441	1.000	461	1.000
40	430	0.976	450	0.975
60	392	0.889	389	0.843
85	311	0.707	297	0.644

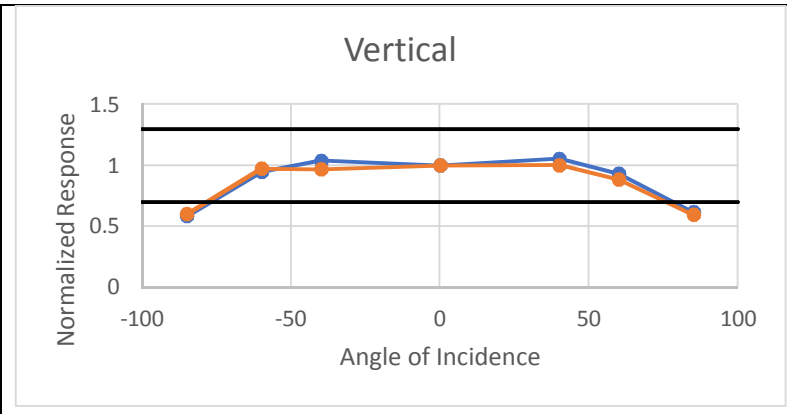


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	309	0.701	314	0.682
-60	377	0.856	394	0.855
-40	419	0.952	438	0.951
0	441	1.000	461	1.000
40	430	0.977	450	0.977
60	377	0.855	404	0.876
85	311	0.706	325	0.706

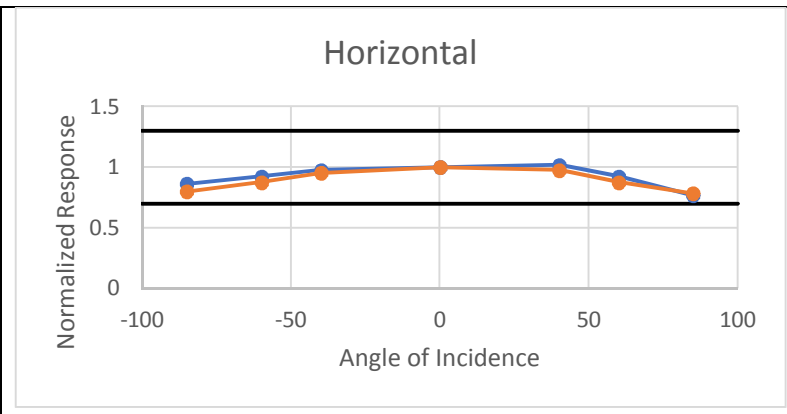


M150: UD-810 + NAD + CR-39

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	250	0.584	269	0.600
-60	406	0.946	435	0.972
-40	446	1.040	434	0.968
0	429	1.000	448	1.000
40	452	1.055	449	1.002
60	399	0.932	396	0.885
85	263	0.614	266	0.594

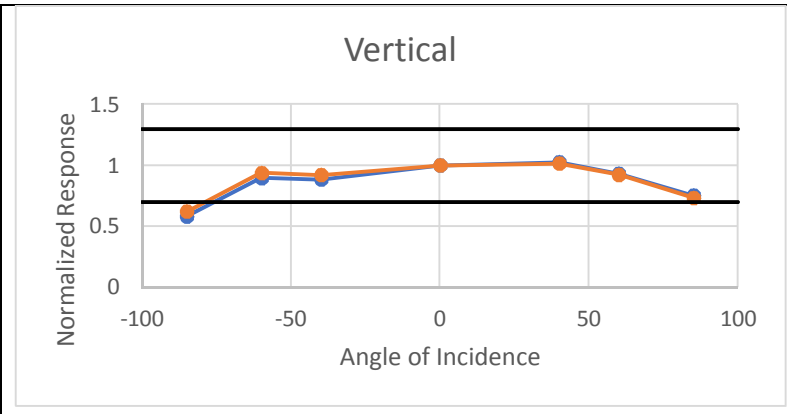


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	370	0.862	358	0.800
-60	396	0.923	393	0.876
-40	418	0.975	426	0.952
0	429	1.000	448	1.000
40	436	1.017	437	0.976
60	396	0.923	393	0.876
85	329	0.768	351	0.783

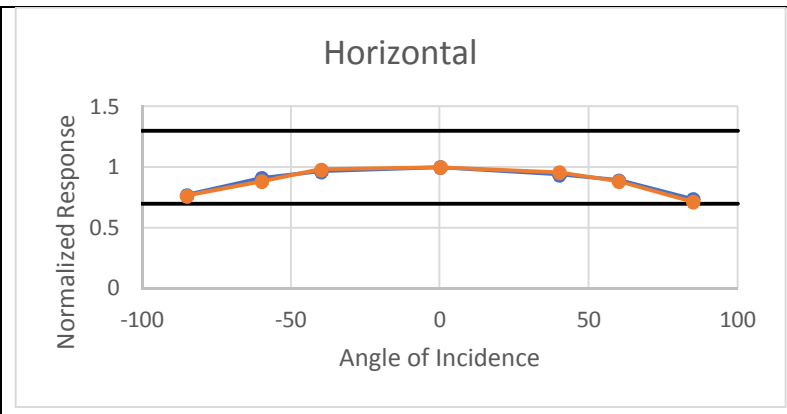


M150: UD-810 + CR-39

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	266	0.581	285	0.622
-60	411	0.897	430	0.938
-40	404	0.883	422	0.921
0	458	1.000	459	1.000
40	469	1.025	466	1.016
60	427	0.932	424	0.924
85	345	0.753	336	0.733

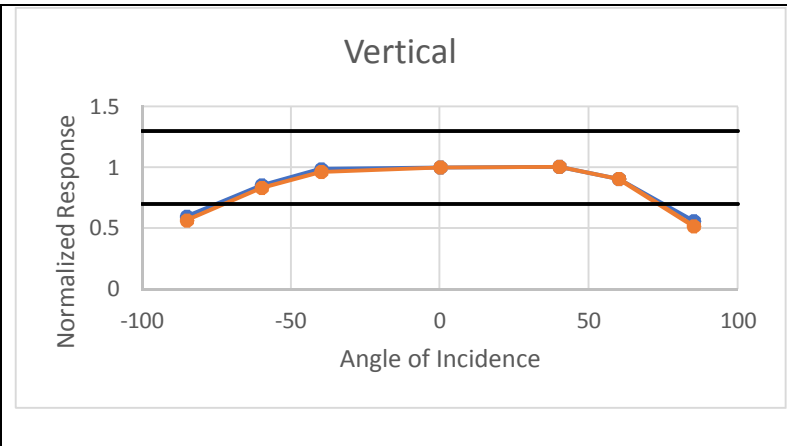


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	353	0.771	350	0.764
-60	417	0.910	405	0.884
-40	442	0.966	450	0.982
0	458	1.000	459	1.000
40	430	0.939	439	0.956
60	408	0.892	405	0.883
85	337	0.736	328	0.715

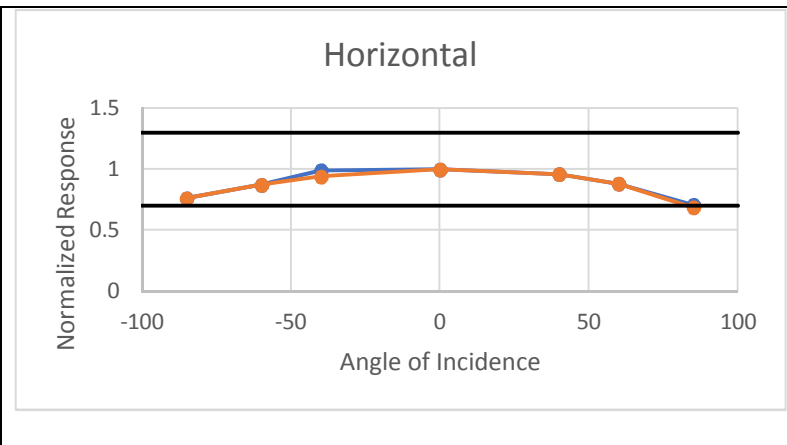


M150: UD-810 + NAD

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	248	0.597	252	0.565
-60	355	0.853	371	0.831
-40	411	0.988	430	0.963
0	416	1.000	446	1.000
40	418	1.005	448	1.004
60	376	0.905	404	0.906
85	234	0.562	232	0.520

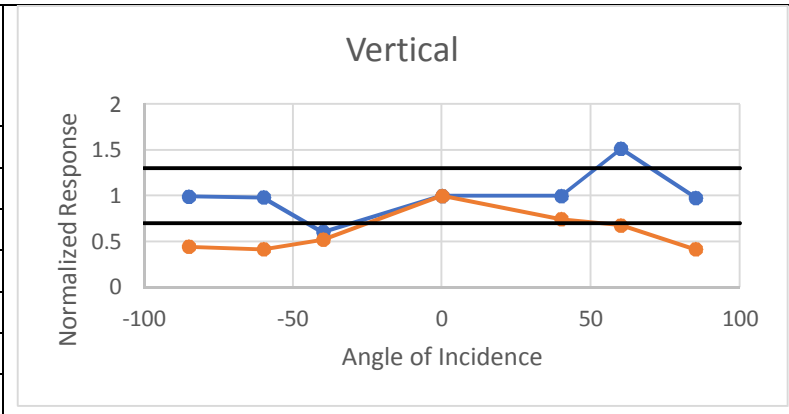


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	317	0.763	340	0.763
-60	363	0.873	390	0.875
-40	413	0.992	420	0.942
0	416	1.000	446	1.000
40	399	0.959	428	0.960
60	366	0.881	393	0.881
85	295	0.709	307	0.688

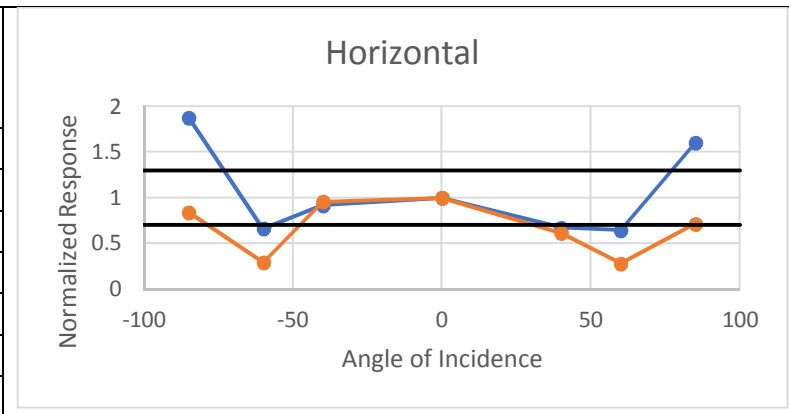


M30: UD-802

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	376	0.992	404	0.444
-60	372	0.982	377	0.413
-40	228	0.602	473	0.519
0	379	1.000	911	1.000
40	379	0.999	676	0.742
60	574	1.514	617	0.677
85	372	0.980	377	0.414

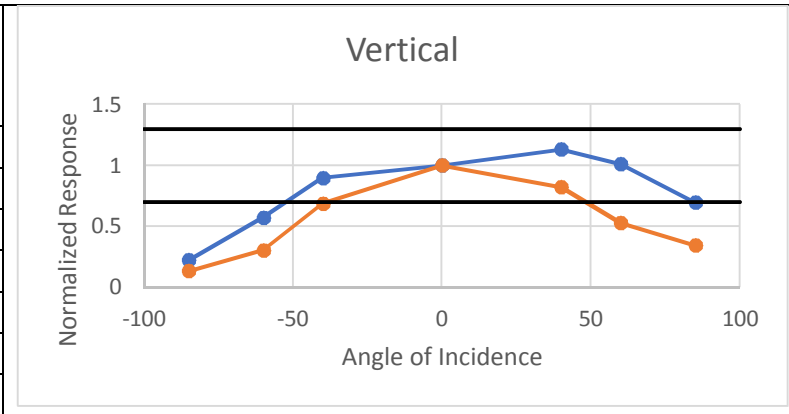


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	712	1.878	764	0.838
-60	252	0.663	266	0.292
-40	348	0.918	872	0.957
0	379	1.000	911	1.000
40	256	0.674	560	0.614
60	244	0.644	258	0.283
85	608	1.603	652	0.716

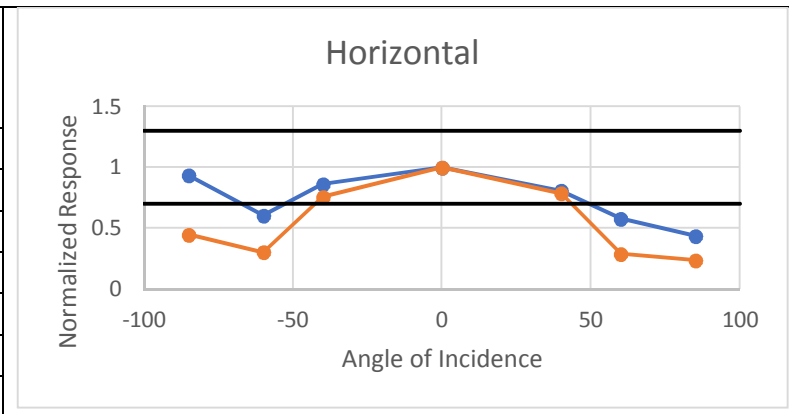


M30: UD-810

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	109	0.221	135	0.133
-60	282	0.571	308	0.303
-40	443	0.898	698	0.687
0	493	1.000	1016	1.000
40	558	1.131	833	0.820
60	499	1.011	533	0.525
85	342	0.694	348	0.342

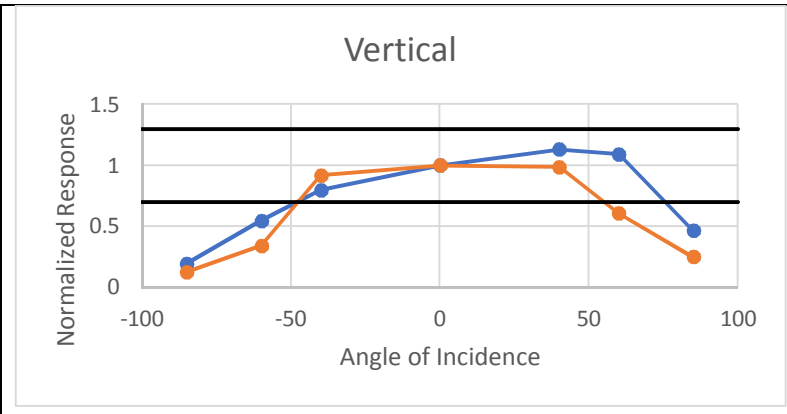


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	460	0.933	455	0.448
-60	299	0.605	307	0.302
-40	426	0.864	769	0.757
0	493	1.000	1016	1.000
40	398	0.807	800	0.787
60	286	0.579	294	0.289
85	215	0.436	242	0.238

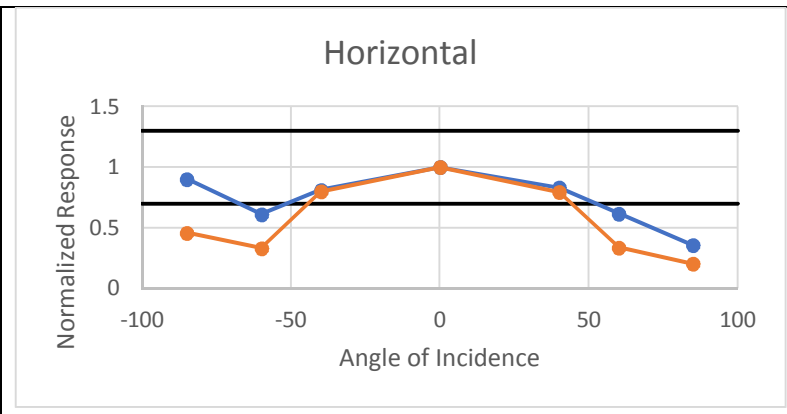


M30: UD-810 + NAD + CR-39

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	82	0.193	102	0.124
-60	232	0.546	280	0.340
-40	339	0.796	755	0.917
0	426	1.000	823	1.000
40	481	1.131	811	0.985
60	464	1.090	497	0.604
85	197	0.462	205	0.249

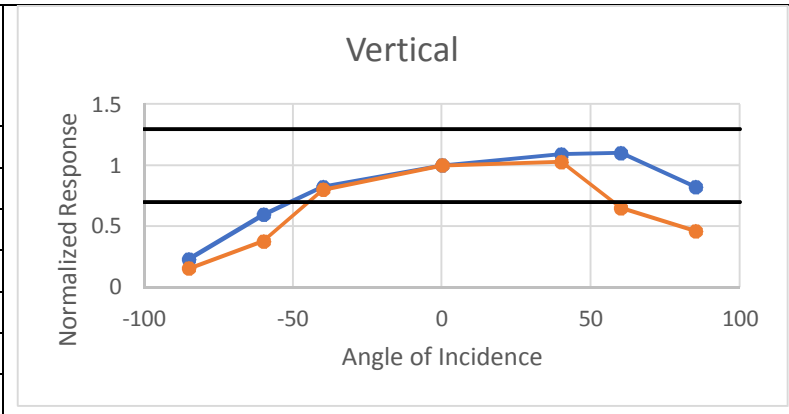


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	384	0.901	379	0.460
-60	261	0.613	275	0.334
-40	346	0.813	658	0.800
0	426	1.000	823	1.000
40	353	0.830	654	0.795
60	263	0.618	277	0.337
85	151	0.356	168	0.205

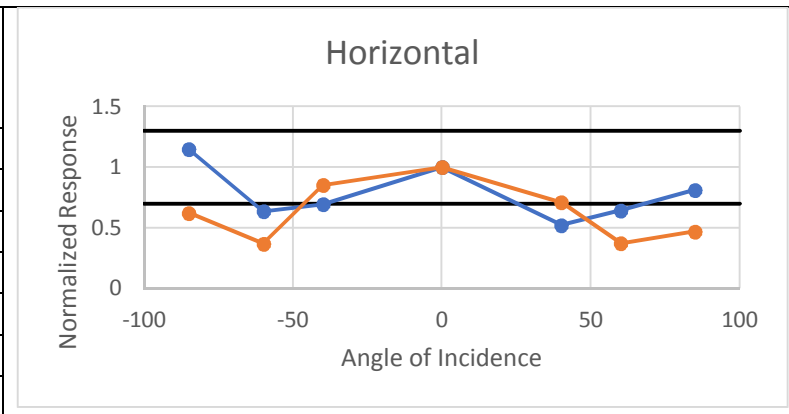


M30: UD-810 + CR-39

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	95	0.229	115	0.152
-60	248	0.596	284	0.375
-40	343	0.824	606	0.801
0	416	1.000	756	1.000
40	454	1.092	778	1.029
60	458	1.103	491	0.649
85	342	0.824	349	0.461

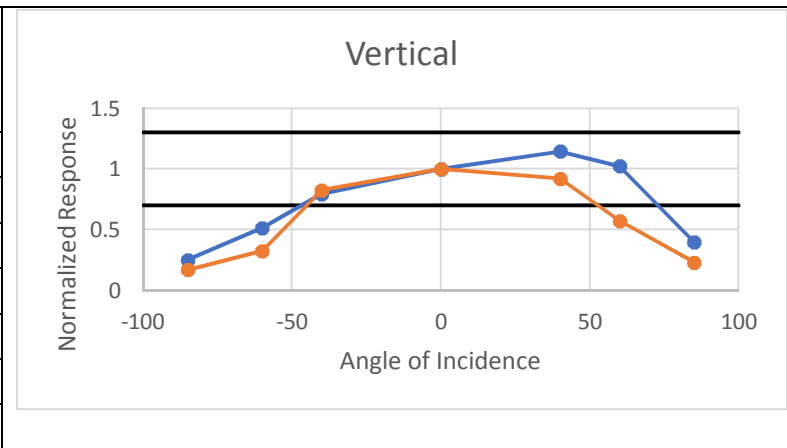


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	477	1.148	471	0.622
-60	264	0.636	279	0.369
-40	288	0.694	645	0.853
0	416	1.000	756	1.000
40	218	0.524	536	0.709
60	267	0.643	282	0.373
85	338	0.813	355	0.469

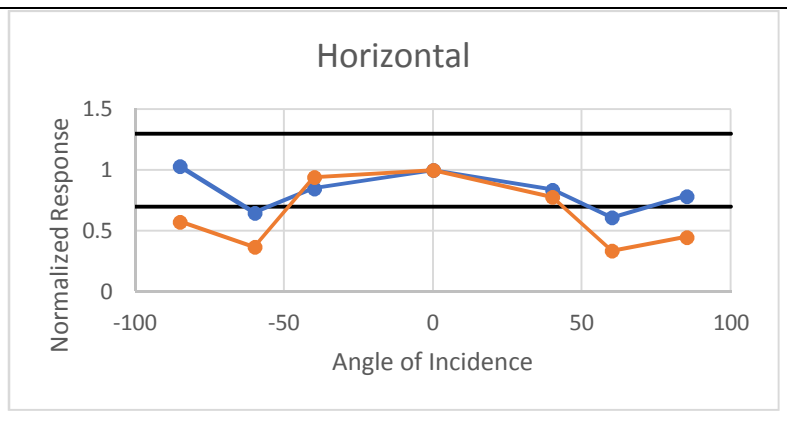


M30: UD-810 + NAD

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	117	0.251	143	0.169
-60	241	0.516	276	0.325
-40	371	0.795	703	0.828
0	467	1.000	849	1.000
40	534	1.145	782	0.921
60	478	1.024	488	0.574
85	185	0.396	196	0.230

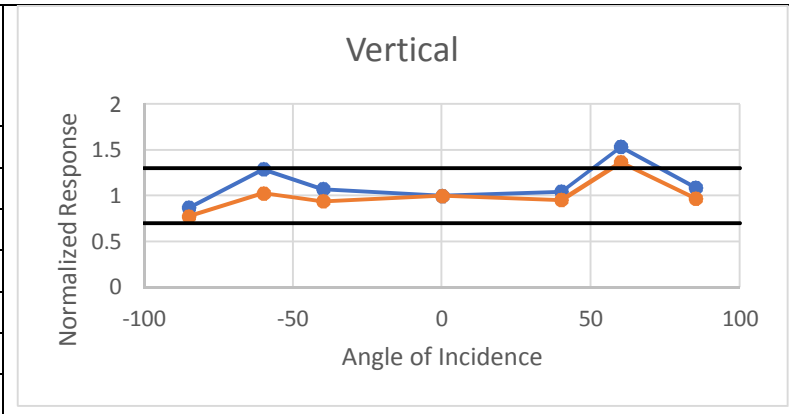


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	481	1.031	490	0.577
-60	303	0.650	312	0.367
-40	396	0.849	801	0.943
0	467	1.000	849	1.000
40	392	0.839	662	0.780
60	284	0.609	286	0.336
85	368	0.788	380	0.448

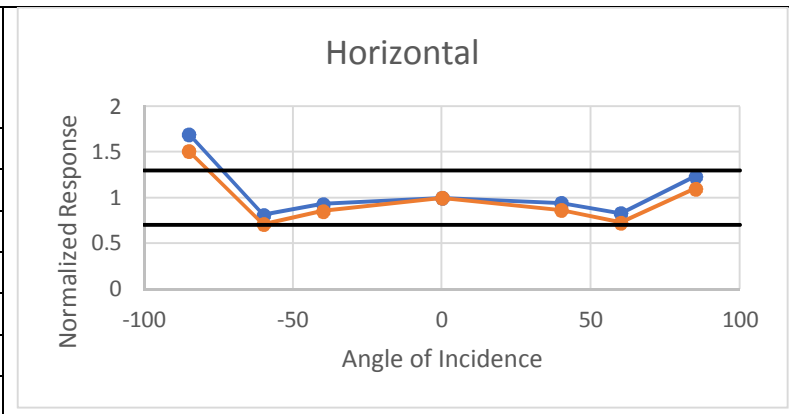


M60: UD-802

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	394	0.869	422	0.774
-60	584	1.289	561	1.027
-40	486	1.074	513	0.940
0	453	1.000	546	1.000
40	473	1.043	521	0.955
60	696	1.536	746	1.368
85	494	1.091	531	0.973

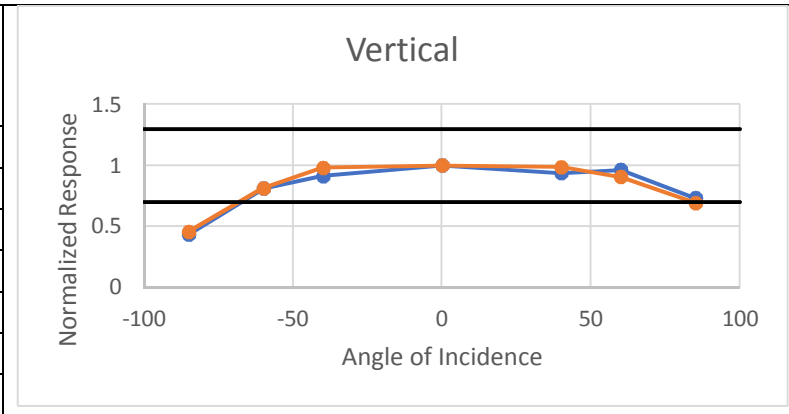


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	768	1.695	824	1.509
-60	368	0.813	389	0.712
-40	423	0.933	467	0.855
0	453	1.000	546	1.000
40	427	0.943	472	0.865
60	377	0.831	397	0.728
85	560	1.235	601	1.101

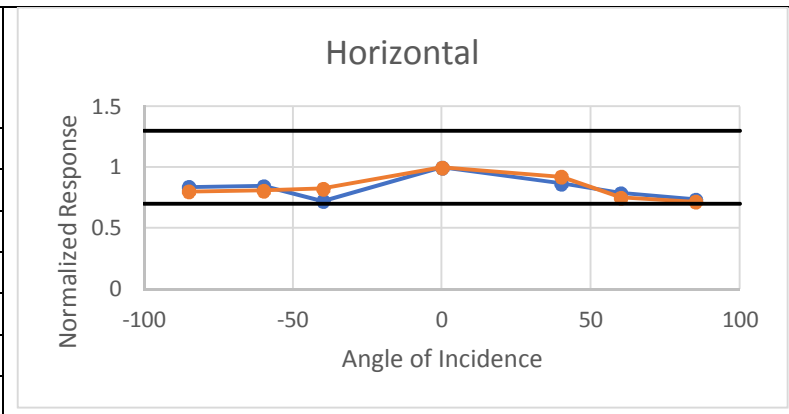


M60: UD-810

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	228	0.433	251	0.455
-60	427	0.811	450	0.814
-40	480	0.913	542	0.981
0	526	1.000	553	1.000
40	493	0.937	546	0.987
60	506	0.963	500	0.905
85	384	0.731	383	0.692

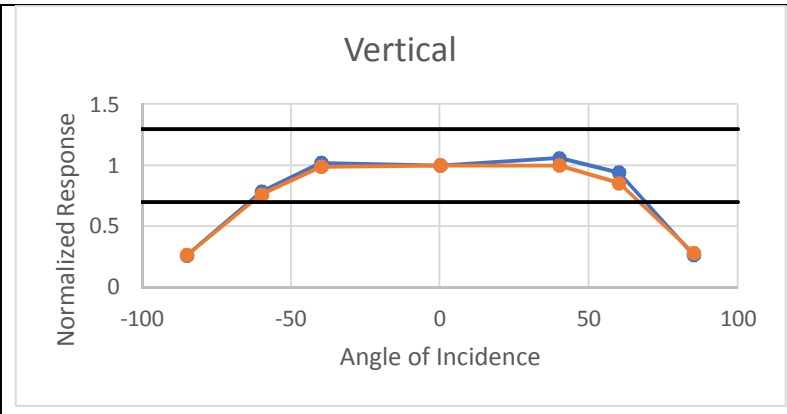


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	441	0.838	443	0.801
-60	446	0.847	447	0.809
-40	380	0.722	456	0.824
0	526	1.000	553	1.000
40	457	0.869	510	0.923
60	414	0.788	416	0.753
85	387	0.735	397	0.718

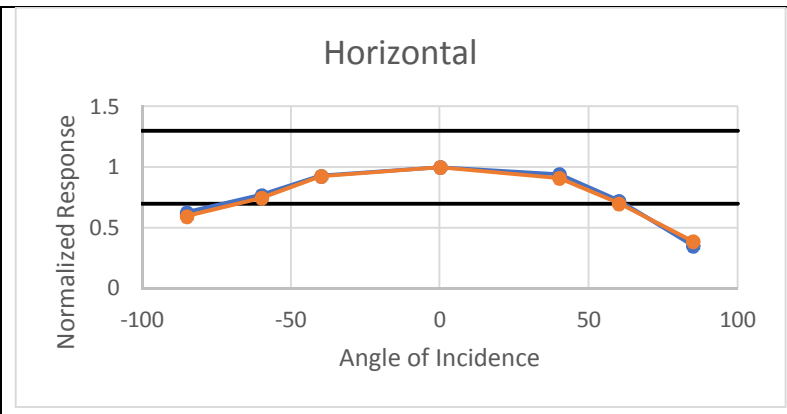


M60: UD-810 + NAD + CR-39

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	119	0.260	131	0.262
-60	359	0.783	379	0.760
-40	467	1.020	492	0.988
0	458	1.000	498	1.000
40	485	1.059	498	0.999
60	431	0.941	426	0.855
85	122	0.265	141	0.282

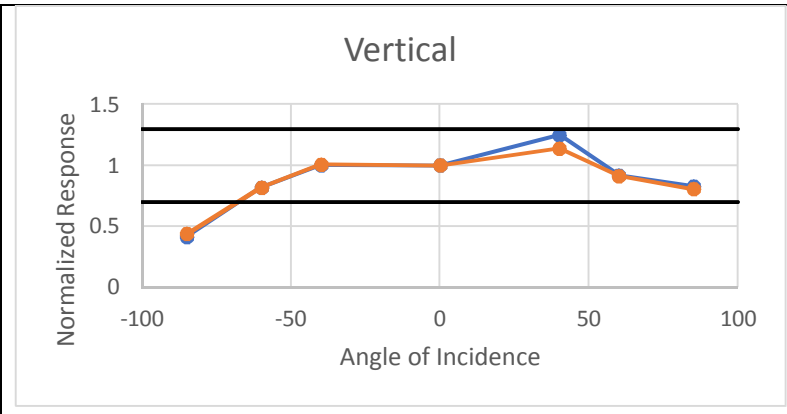


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	288	0.628	297	0.596
-60	353	0.771	372	0.748
-40	426	0.929	462	0.927
0	458	1.000	498	1.000
40	432	0.943	454	0.911
60	332	0.724	350	0.702
85	163	0.355	193	0.388

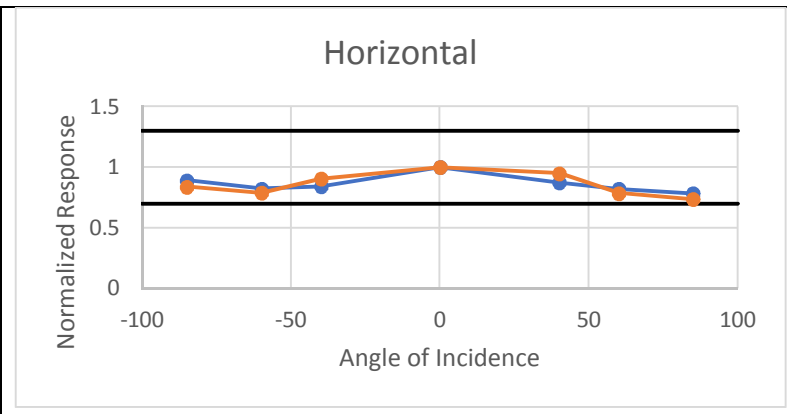


M60: UD-810 + CR-39

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	201	0.414	222	0.436
-60	398	0.819	418	0.819
-40	487	1.003	514	1.008
0	486	1.000	510	1.000
40	607	1.250	581	1.138
60	446	0.918	466	0.914
85	403	0.829	410	0.804

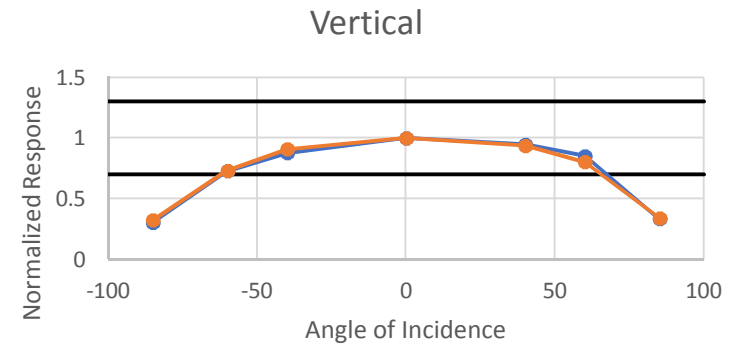


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	433	0.892	428	0.838
-60	401	0.824	402	0.788
-40	409	0.842	462	0.905
0	486	1.000	510	1.000
40	425	0.874	485	0.950
60	399	0.822	402	0.787
85	381	0.783	376	0.736

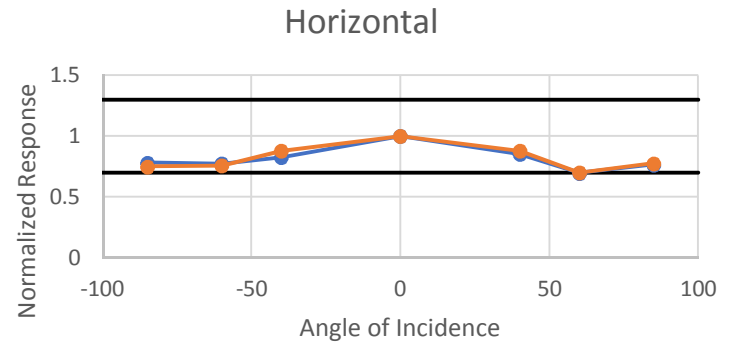


M60: UD-810 + NAD

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	164	0.306	182	0.323
-60	391	0.728	412	0.731
-40	471	0.878	511	0.908
0	537	1.000	563	1.000
40	509	0.948	527	0.936
60	458	0.853	452	0.803
85	180	0.335	192	0.341

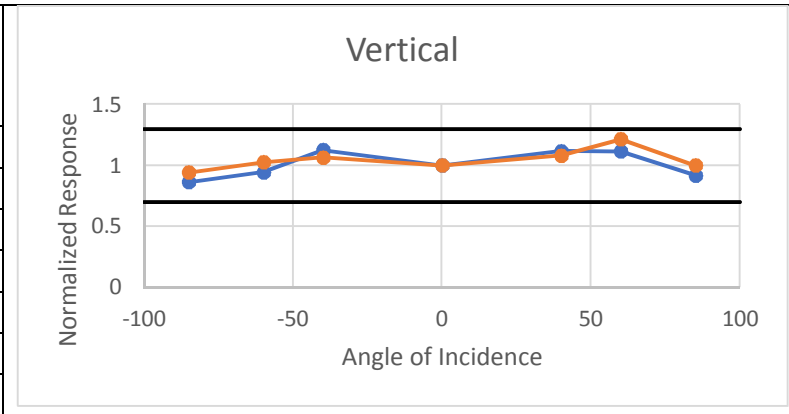


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	420	0.783	422	0.750
-60	415	0.773	427	0.757
-40	444	0.827	495	0.879
0	537	1.000	563	1.000
40	457	0.852	496	0.880
60	375	0.698	394	0.699
85	411	0.766	437	0.775

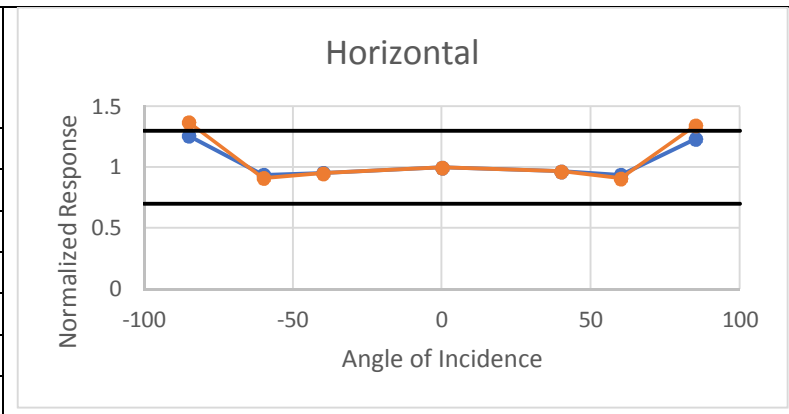


M100: UD-802

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	401	0.864	431	0.940
-60	438	0.943	470	1.026
-40	523	1.126	488	1.065
0	465	1.000	458	1.000
40	519	1.116	495	1.082
60	518	1.115	556	1.214
85	427	0.918	458	0.999

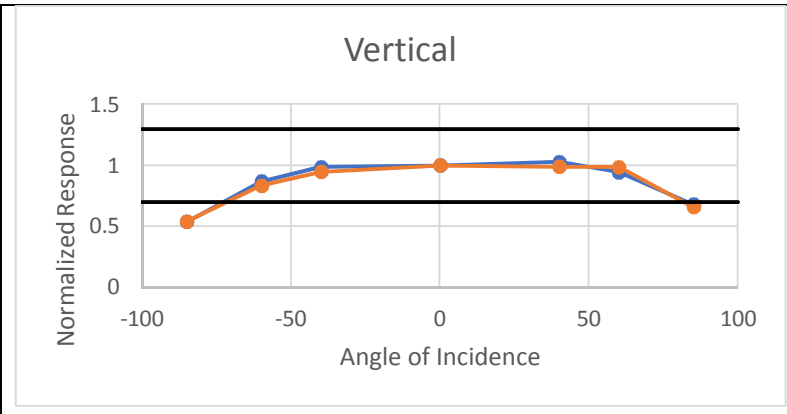


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	585	1.258	627	1.368
-60	437	0.940	417	0.911
-40	443	0.953	436	0.952
0	465	1.000	458	1.000
40	450	0.968	444	0.969
60	437	0.940	417	0.910
85	573	1.232	615	1.342

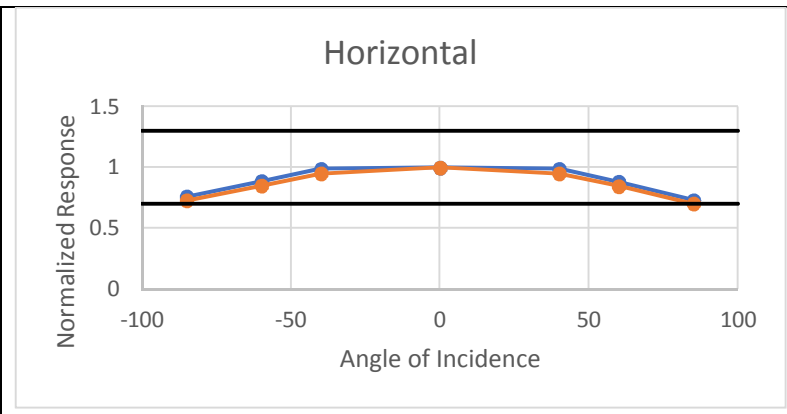


M100: UD-810

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	255	0.538	263	0.539
-60	412	0.869	407	0.833
-40	469	0.987	462	0.947
0	475	1.000	488	1.000
40	488	1.028	482	0.988
60	448	0.945	481	0.986
85	322	0.679	321	0.657

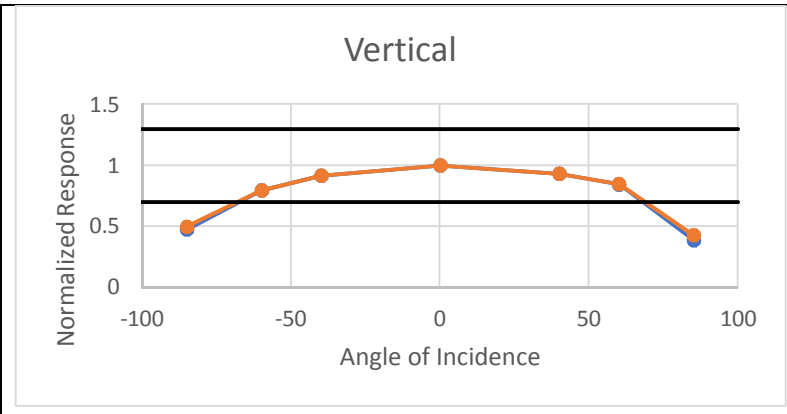


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	360	0.759	356	0.730
-60	420	0.886	415	0.850
-40	469	0.989	463	0.949
0	475	1.000	488	1.000
40	469	0.987	463	0.948
60	418	0.880	413	0.846
85	347	0.732	343	0.703

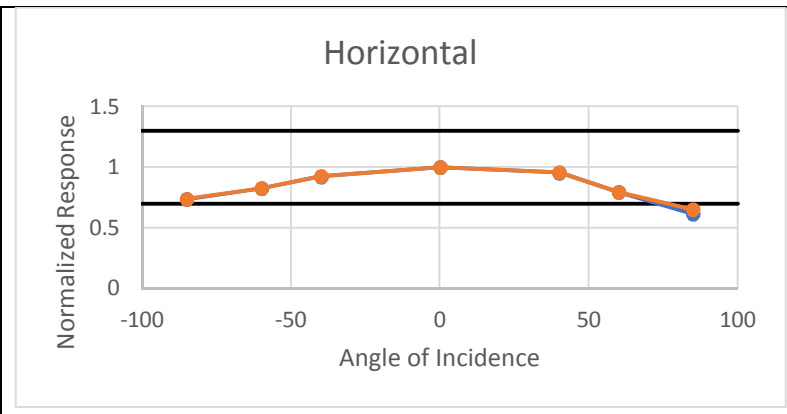


M100: UD-810 + NAD + CR-39

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	223	0.472	231	0.497
-60	375	0.794	369	0.794
-40	432	0.915	425	0.915
0	472	1.000	465	1.000
40	439	0.930	433	0.931
60	398	0.844	393	0.846
85	182	0.386	198	0.426

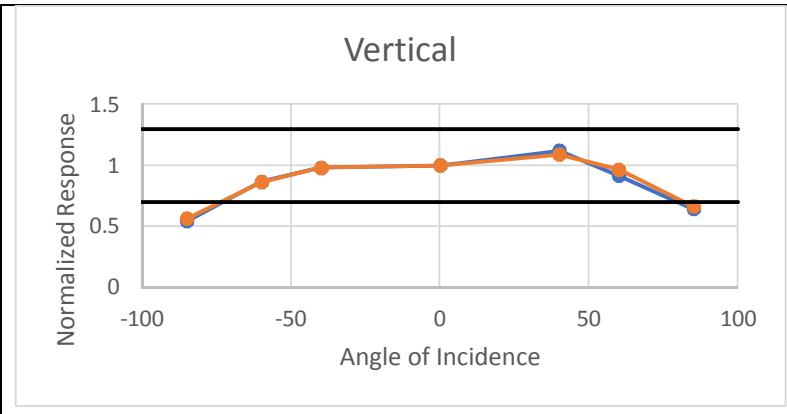


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	348	0.737	344	0.739
-60	390	0.826	384	0.827
-40	436	0.924	430	0.925
0	472	1.000	465	1.000
40	451	0.956	445	0.957
60	375	0.794	369	0.794
85	290	0.614	303	0.651

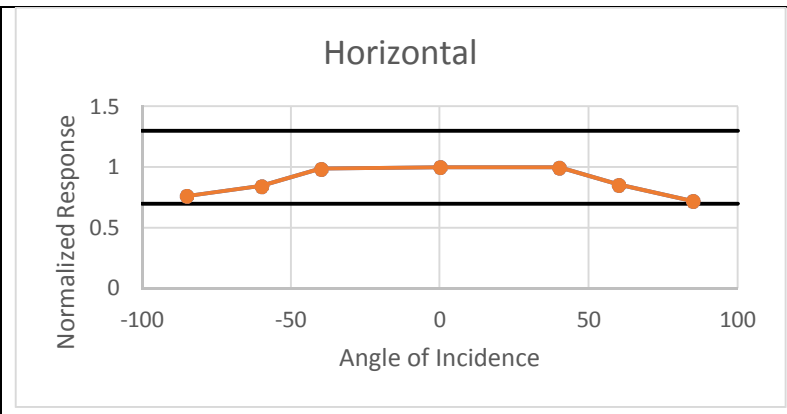


M100: UD-810 + CR-39

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	255	0.541	262	0.564
-60	407	0.865	401	0.863
-40	462	0.981	456	0.981
0	471	1.000	465	1.000
40	527	1.120	506	1.088
60	431	0.914	449	0.966
85	302	0.642	308	0.662

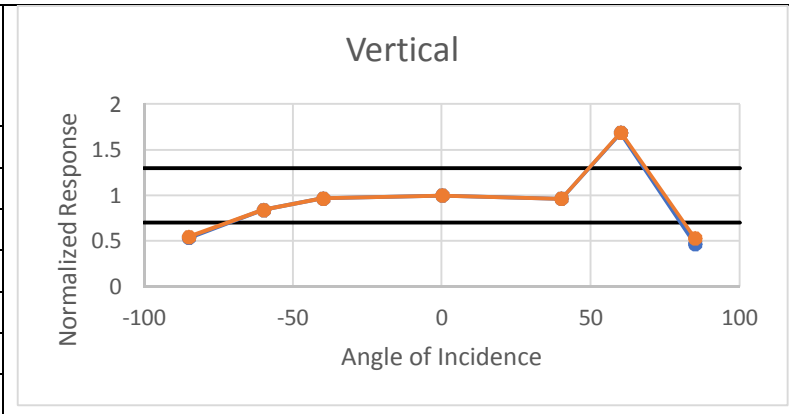


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	359	0.763	355	0.763
-60	398	0.844	392	0.844
-40	465	0.987	459	0.987
0	471	1.000	465	1.000
40	470	0.998	464	0.998
60	402	0.854	397	0.854
85	339	0.720	335	0.720

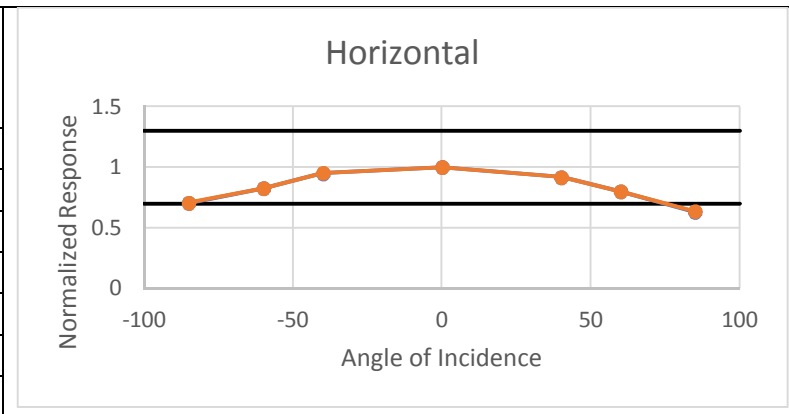


M100: UD-810 + NAD

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	265	0.535	267	0.547
-60	415	0.840	409	0.840
-40	478	0.967	471	0.967
0	495	1.000	487	1.000
40	476	0.963	470	0.965
60	835	1.687	825	1.692
85	232	0.470	257	0.528

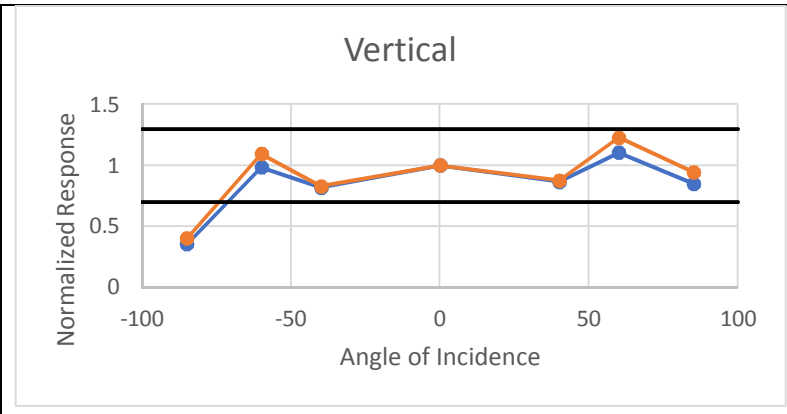


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	349	0.705	344	0.707
-60	408	0.825	403	0.826
-40	470	0.951	464	0.953
0	495	1.000	487	1.000
40	454	0.918	448	0.919
60	395	0.799	390	0.800
85	312	0.631	309	0.635

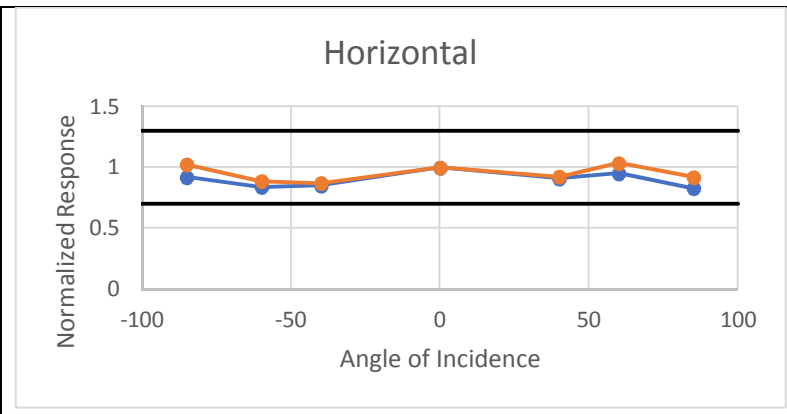


H150: UD-802

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	177	0.354	190	0.400
-60	493	0.984	520	1.095
-40	409	0.818	393	0.827
0	501	1.000	475	1.000
40	433	0.864	416	0.875
60	552	1.103	583	1.227
85	425	0.849	449	0.945

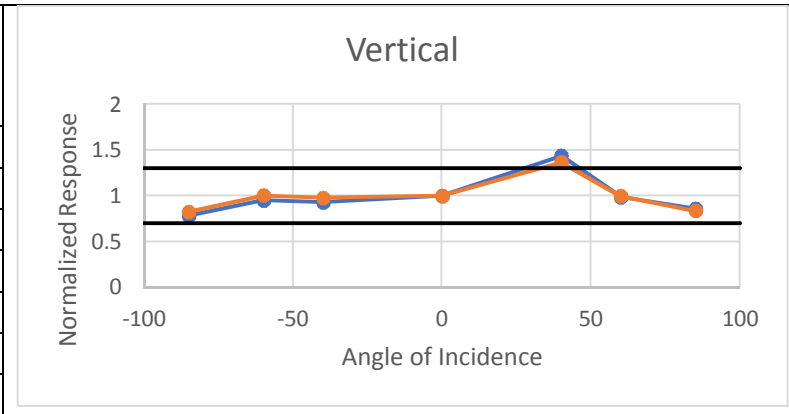


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	461	0.920	486	1.023
-60	420	0.840	421	0.886
-40	427	0.853	413	0.870
0	501	1.000	475	1.000
40	456	0.911	438	0.922
60	477	0.953	493	1.036
85	414	0.827	438	0.921

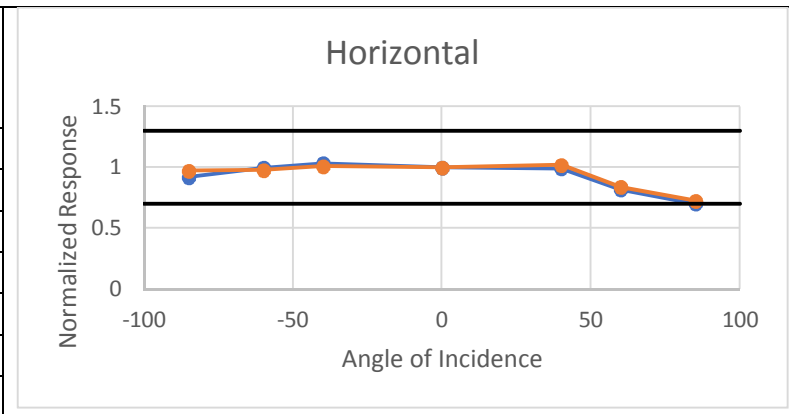


H150: UD-810

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	388	0.784	410	0.825
-60	471	0.951	498	1.004
-40	460	0.928	486	0.980
0	495	1.000	496	1.000
40	711	1.436	679	1.369
60	488	0.986	494	0.996
85	425	0.859	414	0.833

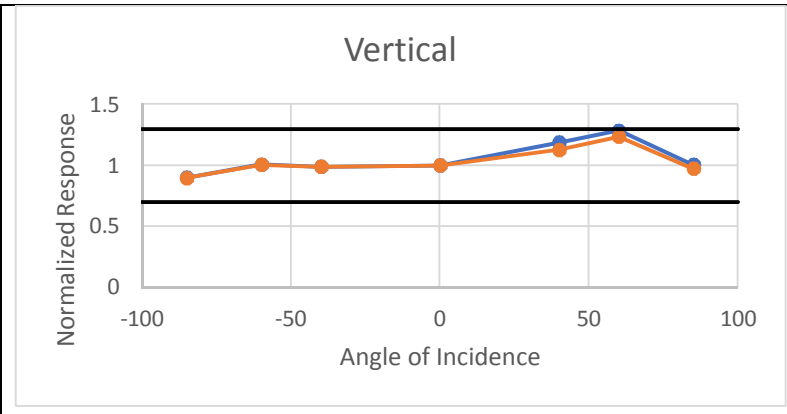


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	456	0.920	483	0.973
-60	494	0.997	486	0.979
-40	512	1.034	502	1.011
0	495	1.000	496	1.000
40	491	0.991	507	1.021
60	406	0.819	416	0.839
85	348	0.703	360	0.725

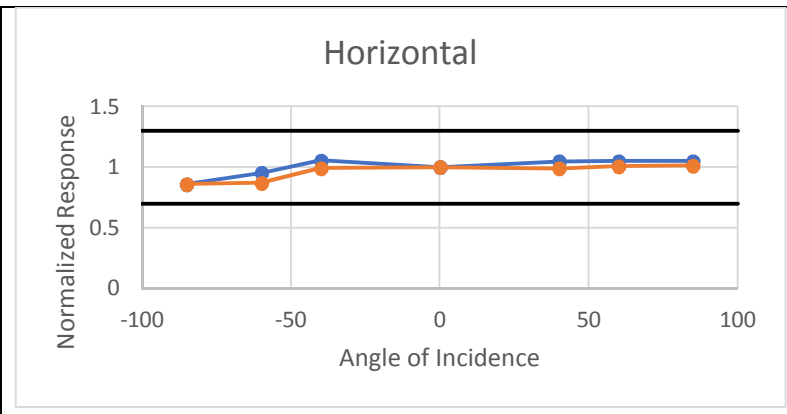


H150: UD-810 + NAD + CR-39

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	359	0.899	379	0.897
-60	401	1.006	424	1.006
-40	395	0.989	418	0.990
0	399	1.000	422	1.000
40	474	1.189	476	1.129
60	513	1.285	522	1.237
85	400	1.003	411	0.973

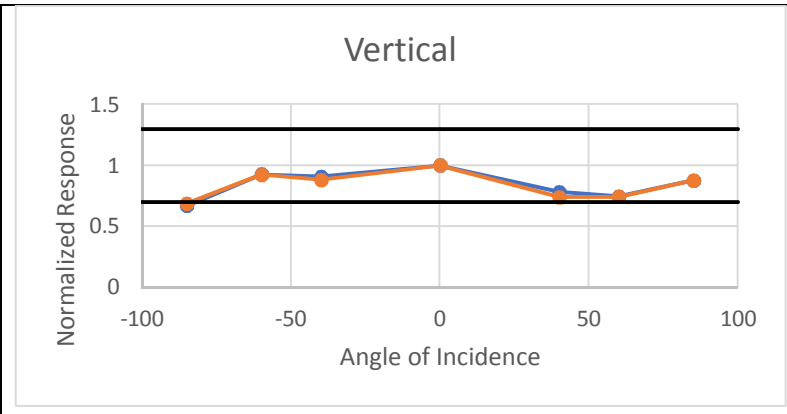


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	343	0.860	363	0.859
-60	380	0.952	367	0.870
-40	421	1.056	419	0.992
0	399	1.000	422	1.000
40	418	1.048	418	0.991
60	419	1.051	426	1.009
85	419	1.049	428	1.013

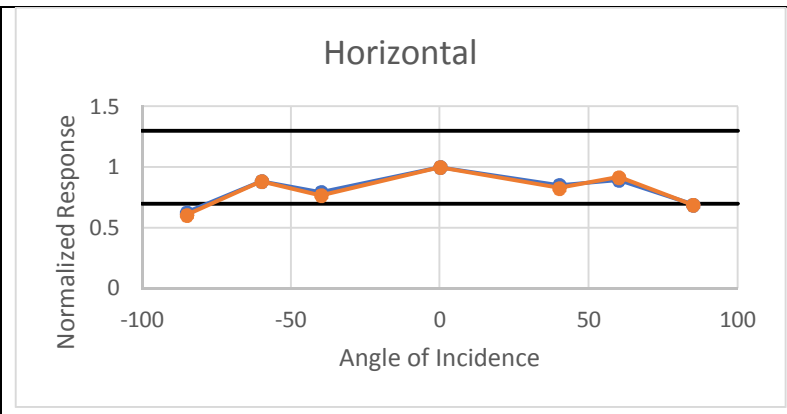


H150: UD-810 + CR-39

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	354	0.669	374	0.686
-60	490	0.926	504	0.924
-40	480	0.907	481	0.882
0	530	1.000	546	1.000
40	413	0.780	403	0.739
60	394	0.743	405	0.742
85	464	0.876	478	0.877

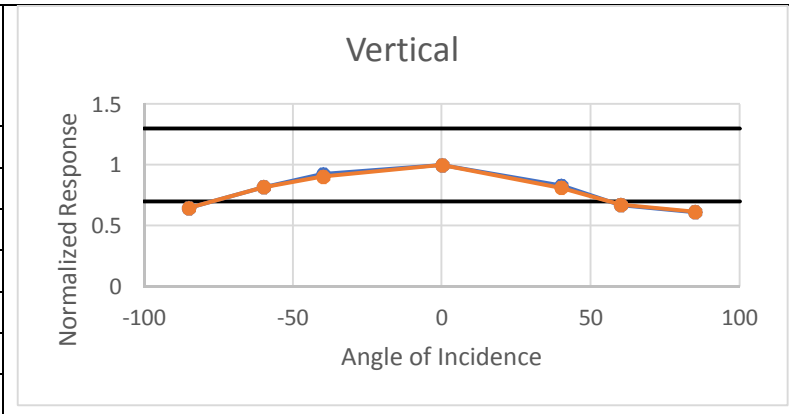


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	332	0.627	331	0.607
-60	468	0.884	482	0.884
-40	421	0.795	419	0.767
0	530	1.000	546	1.000
40	451	0.851	452	0.828
60	474	0.895	501	0.918
85	366	0.691	376	0.690

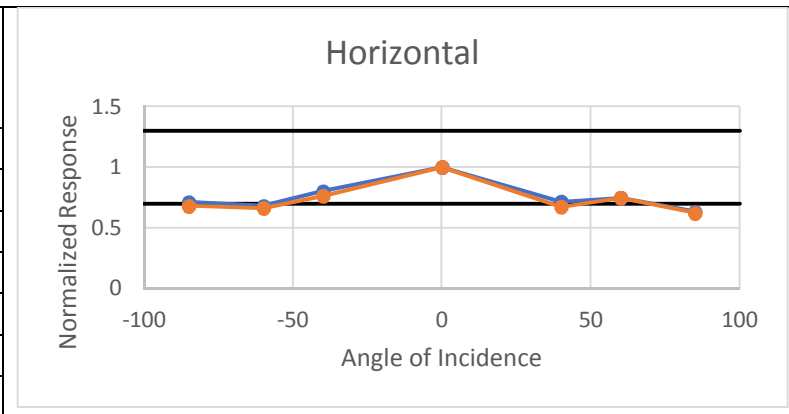


H150: UD-810 + NAD

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	398	0.646	421	0.646
-60	504	0.817	533	0.818
-40	572	0.927	589	0.904
0	617	1.000	652	1.000
40	514	0.833	529	0.812
60	414	0.672	439	0.673
85	377	0.611	400	0.614

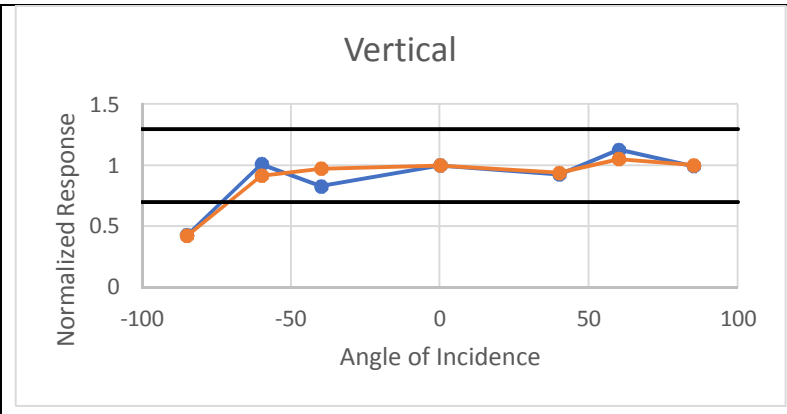


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	439	0.712	444	0.682
-60	420	0.680	431	0.662
-40	495	0.802	496	0.762
0	617	1.000	652	1.000
40	440	0.714	438	0.672
60	460	0.746	486	0.746
85	391	0.634	406	0.623

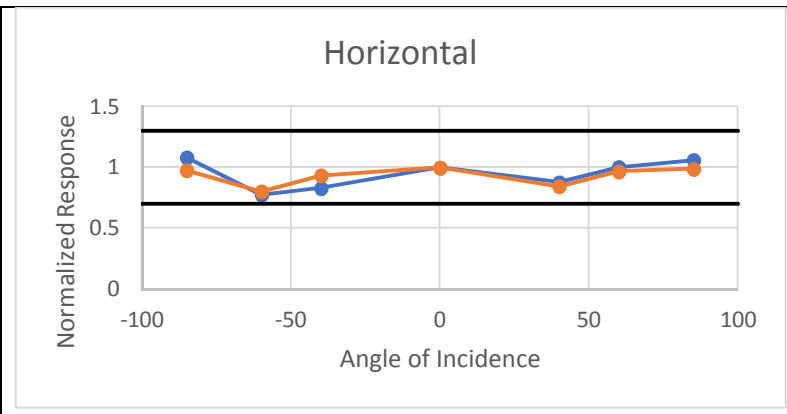


H250: UD-802

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	185	0.427	197	0.422
-60	437	1.010	426	0.916
-40	358	0.827	453	0.972
0	432	1.000	466	1.000
40	400	0.924	437	0.938
60	488	1.128	490	1.052
85	429	0.993	467	1.002

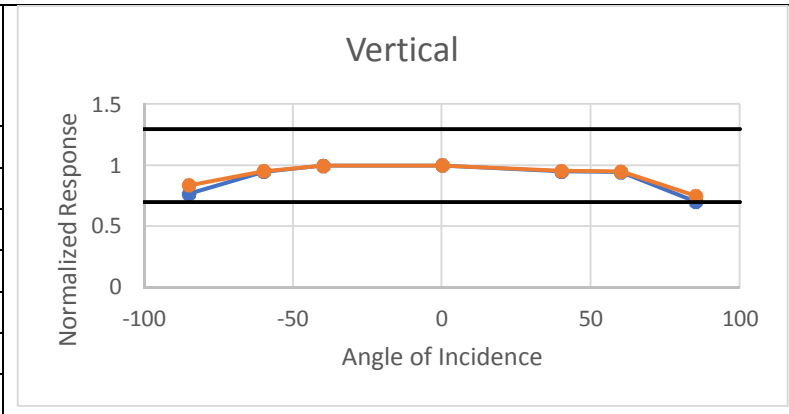


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	467	1.081	454	0.976
-60	335	0.776	373	0.802
-40	360	0.832	434	0.932
0	432	1.000	466	1.000
40	379	0.877	393	0.844
60	433	1.002	450	0.967
85	458	1.060	460	0.988

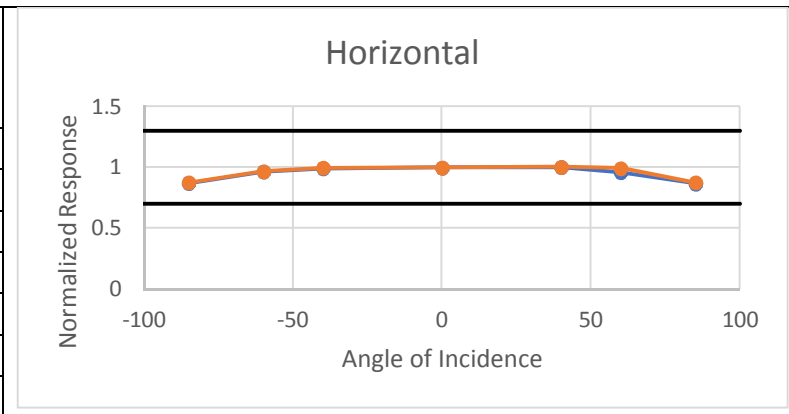


H250: UD-810

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	388	0.766	413	0.837
-60	480	0.947	469	0.951
-40	504	0.995	492	0.997
0	506	1.000	493	1.000
40	481	0.949	471	0.954
60	478	0.944	468	0.949
85	356	0.703	370	0.751

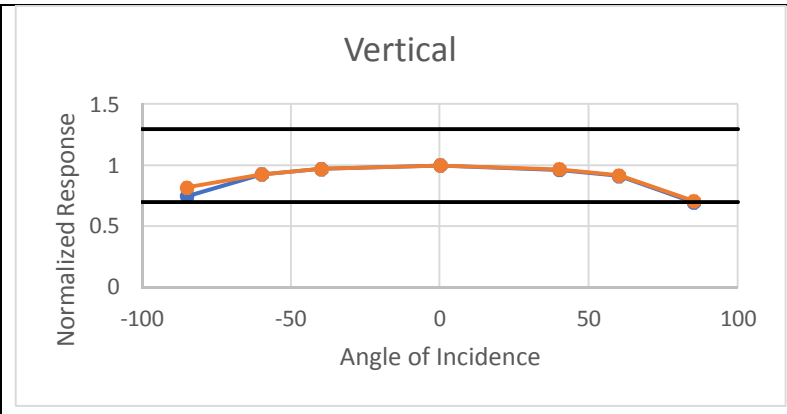


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	441	0.870	432	0.875
-60	488	0.964	477	0.968
-40	502	0.992	492	0.997
0	506	1.000	493	1.000
40	507	1.001	495	1.004
60	486	0.961	490	0.993
85	440	0.868	431	0.874

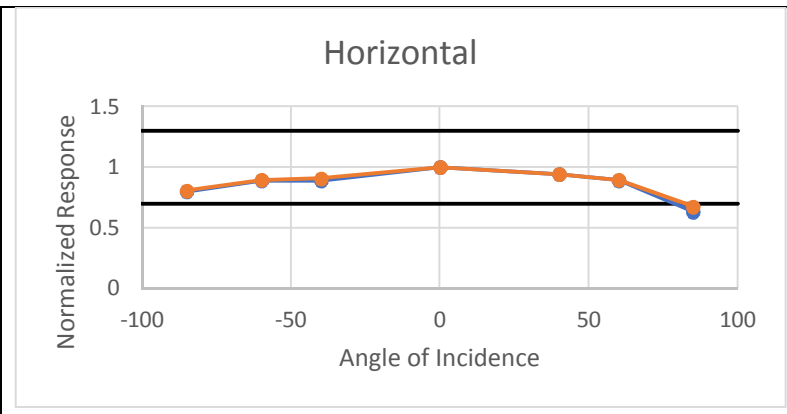


H250: UD-810 + NAD + CR-39

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	392	0.748	417	0.818
-60	485	0.925	473	0.926
-40	509	0.971	496	0.971
0	525	1.000	510	1.000
40	504	0.961	494	0.967
60	479	0.913	469	0.919
85	366	0.698	361	0.707

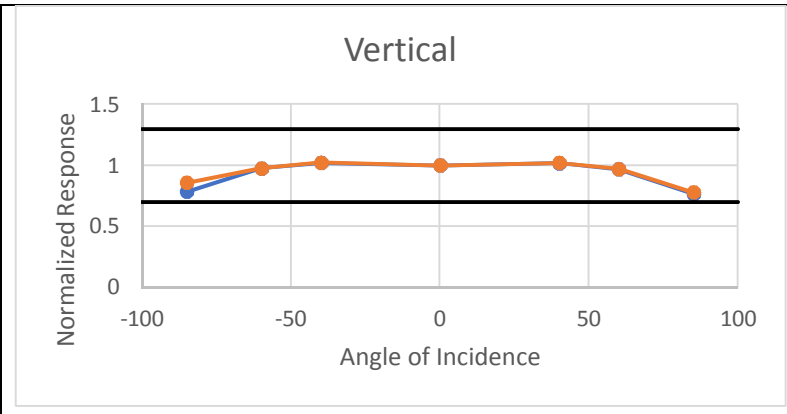


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	420	0.801	412	0.808
-60	467	0.890	456	0.894
-40	467	0.889	463	0.908
0	525	1.000	510	1.000
40	494	0.942	481	0.943
60	468	0.893	457	0.895
85	332	0.633	345	0.675

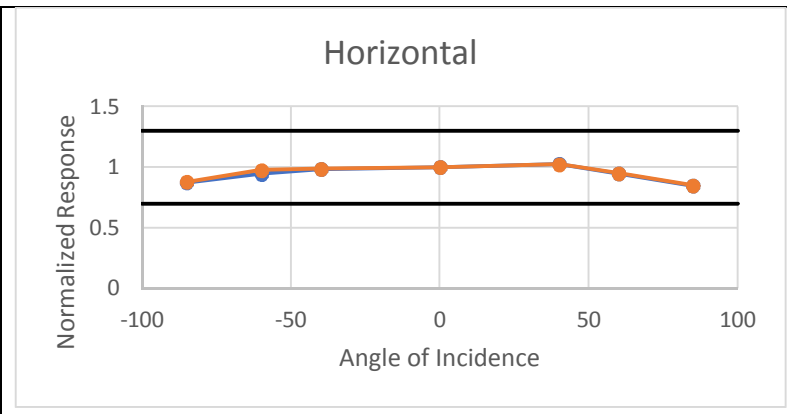


H250: UD-810 + CR-39

Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	393	0.784	418	0.858
-60	489	0.976	476	0.977
-40	511	1.019	498	1.022
0	501	1.000	487	1.000
40	510	1.017	497	1.021
60	484	0.967	473	0.971
85	384	0.766	379	0.778

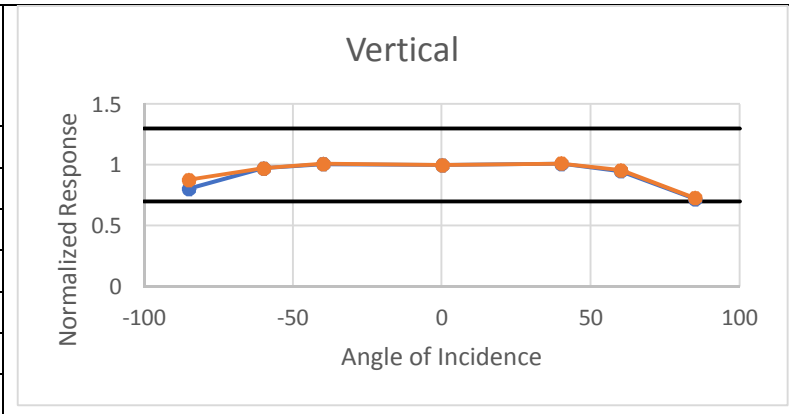


Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	438	0.874	428	0.878
-60	473	0.945	475	0.975
-40	493	0.984	480	0.986
0	501	1.000	487	1.000
40	514	1.025	499	1.025
60	475	0.947	462	0.949
85	424	0.846	414	0.850

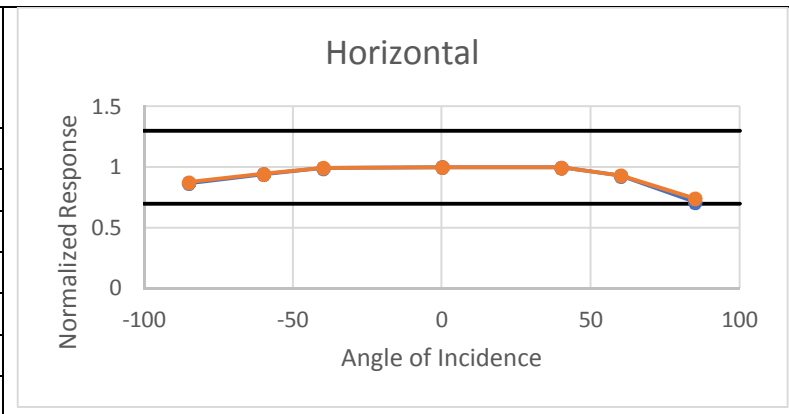


H250: UD-810 + NAD

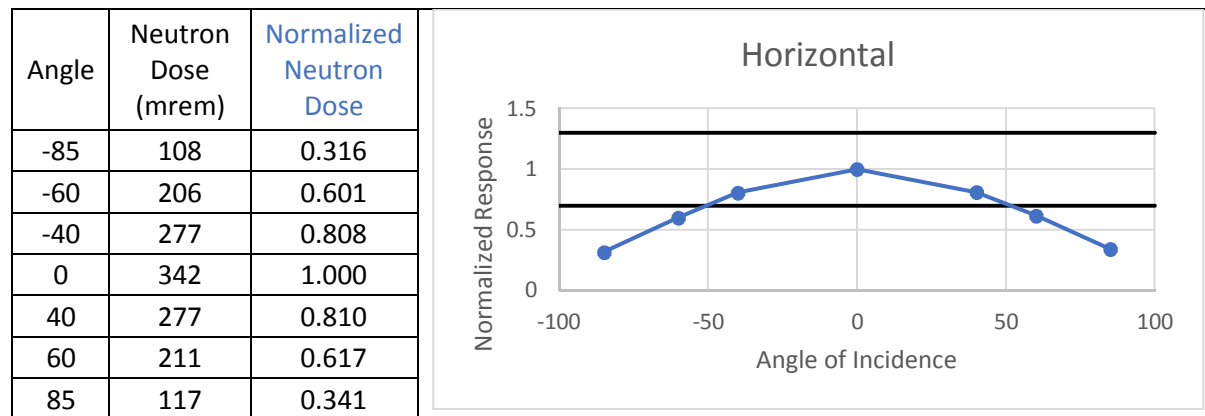
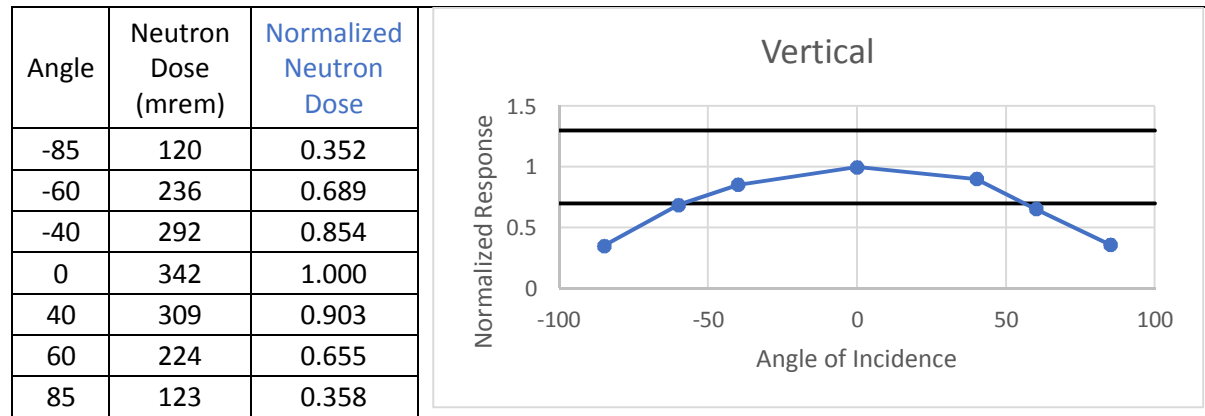
Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	406	0.804	432	0.880
-60	491	0.974	478	0.974
-40	509	1.009	496	1.009
0	505	1.000	491	1.000
40	510	1.010	497	1.012
60	480	0.950	470	0.957
85	364	0.721	358	0.729



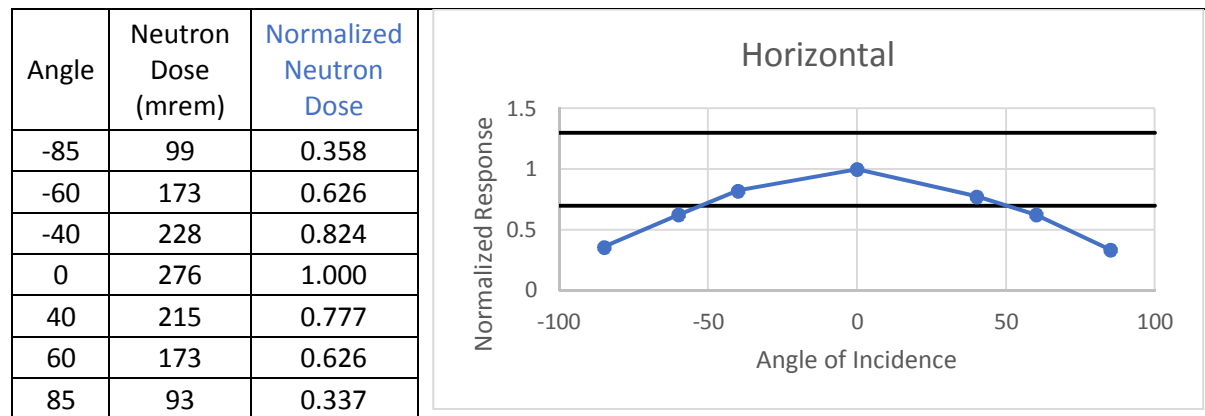
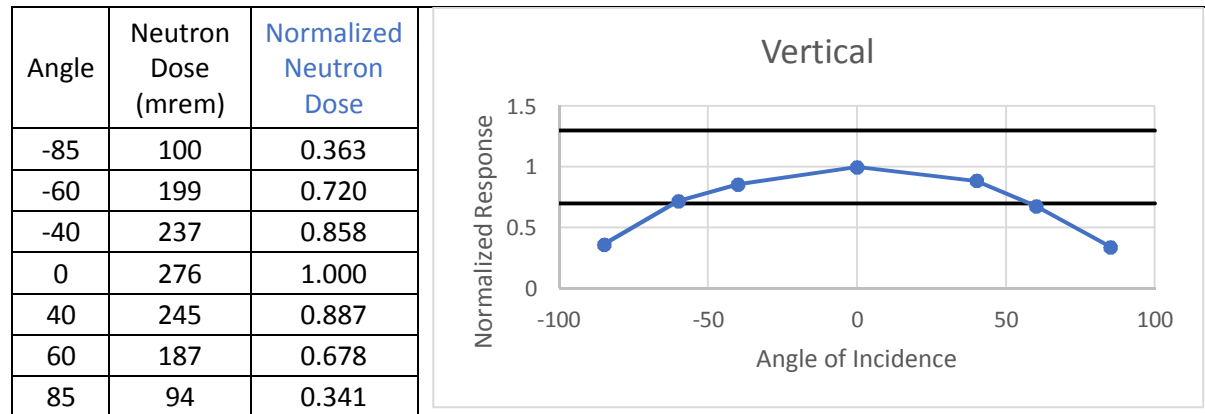
Angle	Deep Dose (mrem)	Normalized Deep Dose	Shallow Dose (mrem)	Normalized Shallow Dose
-85	439	0.869	430	0.876
-60	475	0.941	464	0.945
-40	501	0.992	488	0.993
0	505	1.000	491	1.000
40	504	0.998	490	0.997
60	469	0.929	458	0.931
85	360	0.713	364	0.742



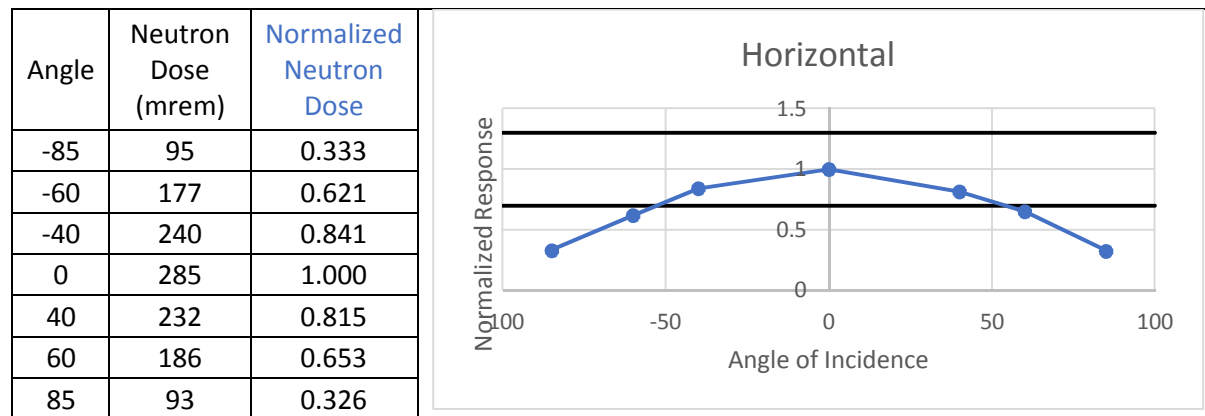
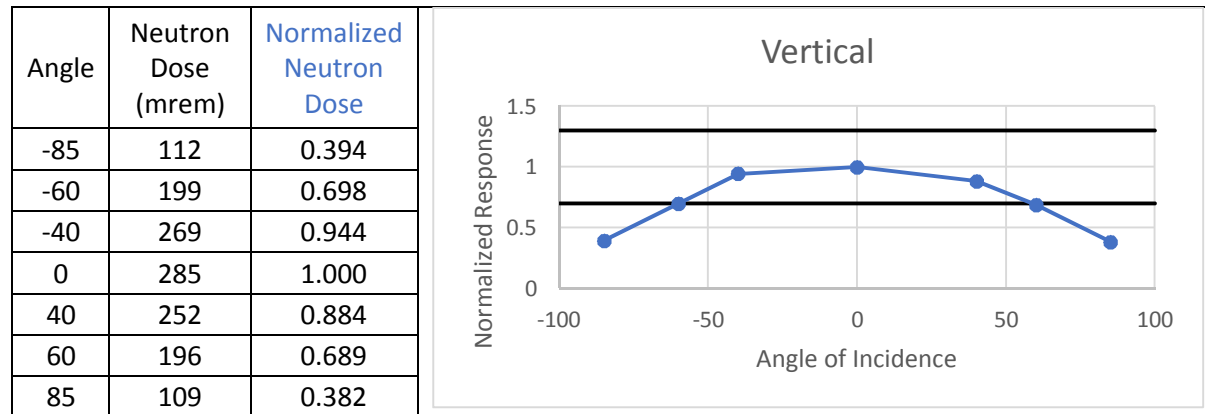
Bare ^{252}Cf : UD-810



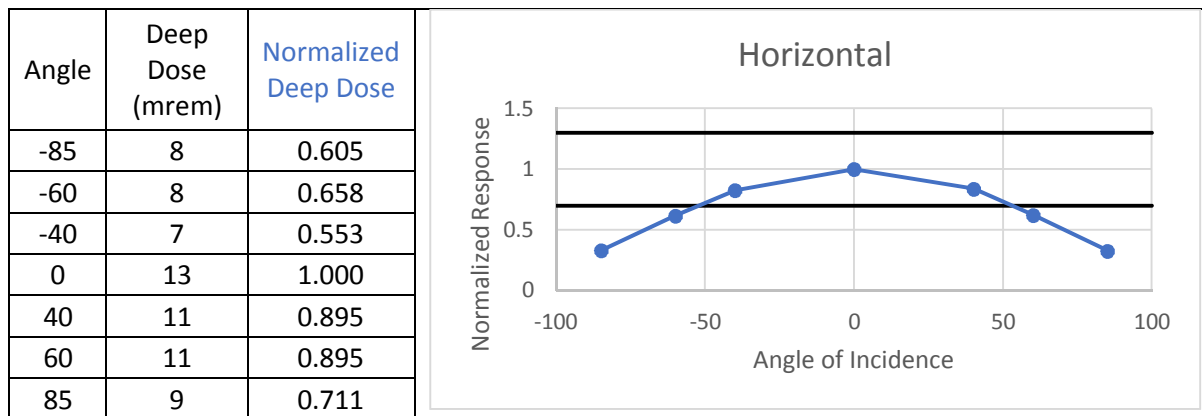
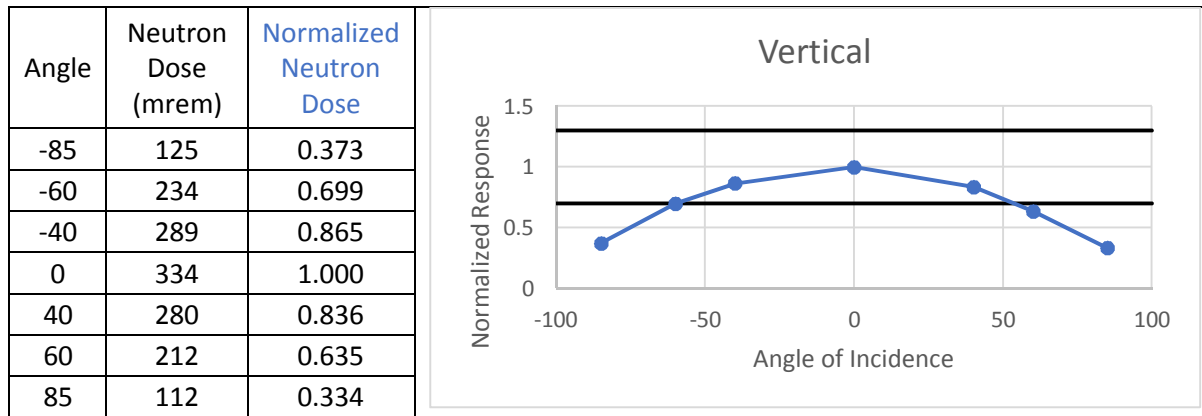
Bare ²⁵²Cf: UD-810 + CR39 + NAD



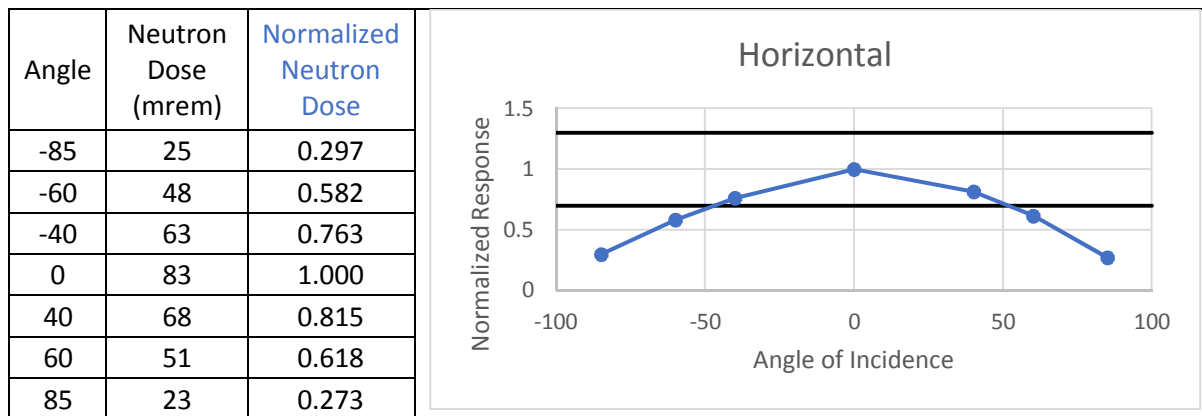
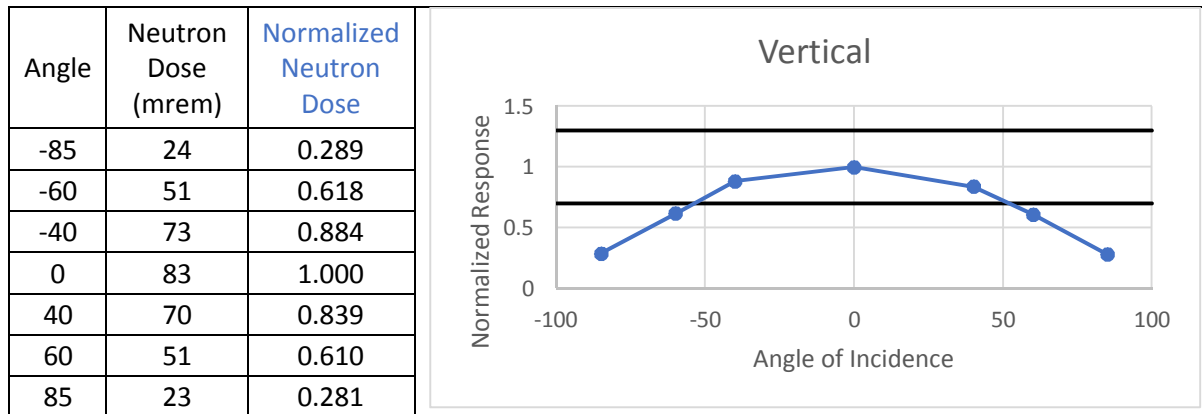
Bare ²⁵²Cf: UD-810 + CR39



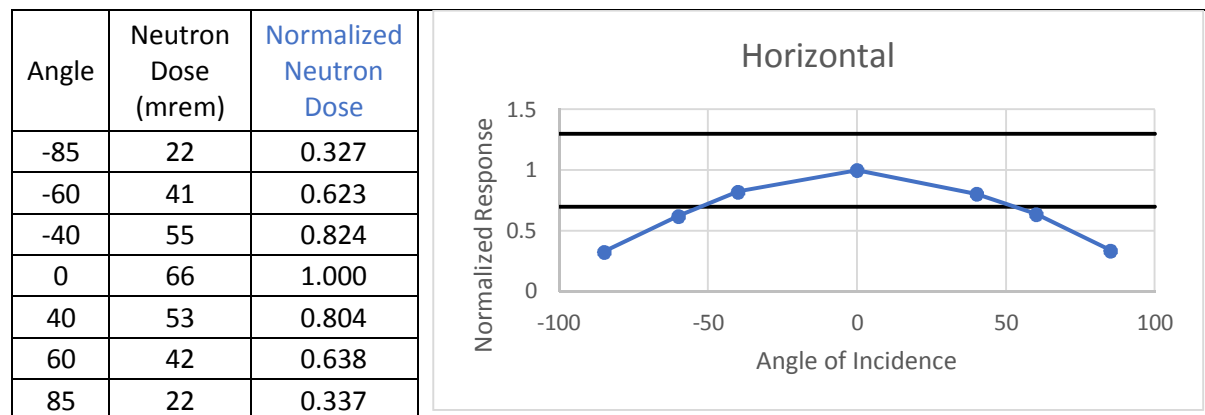
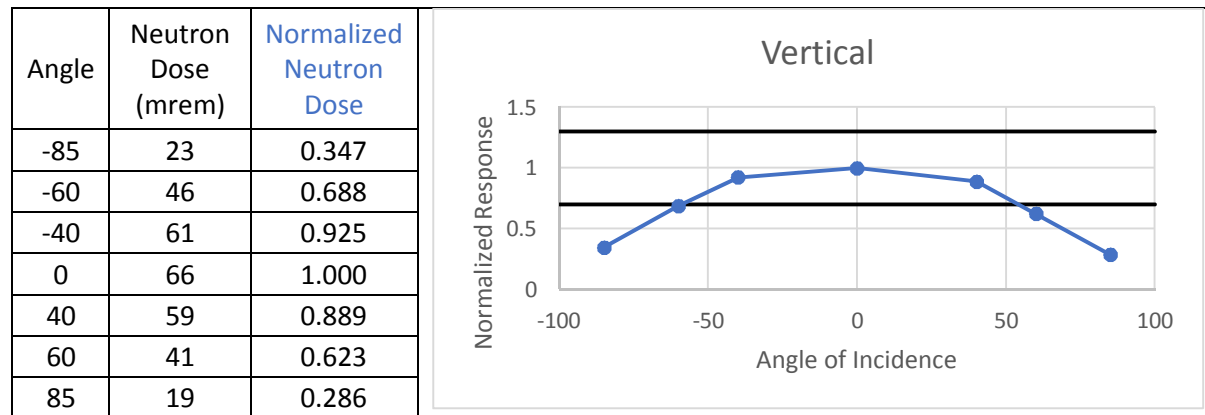
Bare ²⁵²Cf: UD-810 + NAD



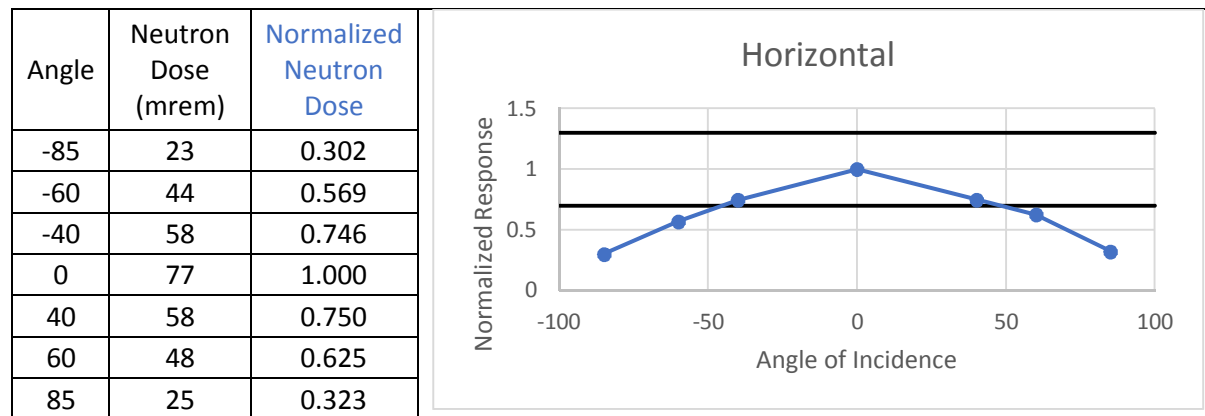
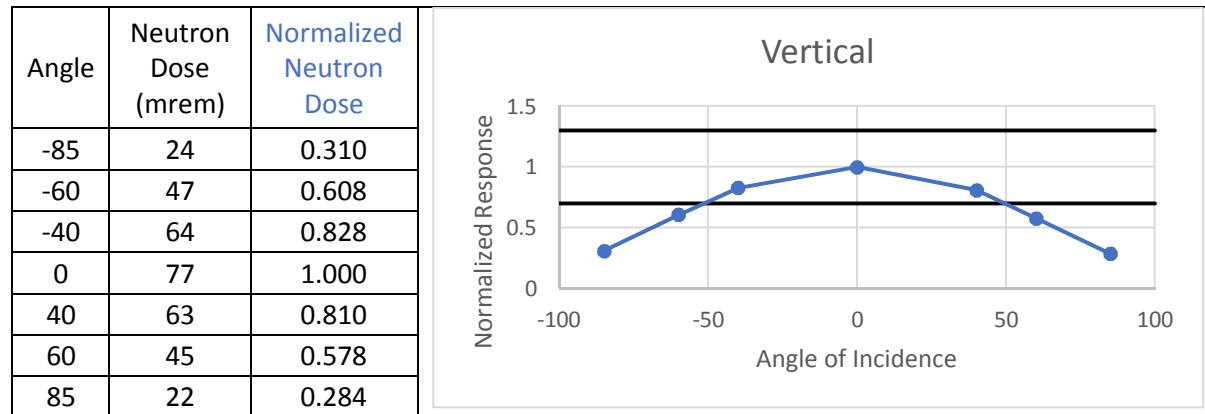
Moderated ²⁵²Cf: UD-810



Moderated ²⁵²Cf: UD-810 + CR39 + NAD



Moderated ^{252}Cf : UD-810 + CR39



Moderated ^{252}Cf : UD-810 + NAD

