JLAB-TN-16-005
2014 Review of Shielding on Hall A

An external reviewer, J. Donald Cossairt, Ph.D., C.H.P., Associate Head & Radiation Protection Manager, ESH&Q Section, FNAL, was asked on May 13, 2014, to review Hall A shielding documentation and the methodology used to compute the shielding thickness. He provided a report on June 16, 2014. The following is an abstract of the report with some editorial changes by the author of this Tech Note.

From the original report:

List of Documentation Consulted

P. Degtiarenko, "Evaluation of Radiation Exposure Around End stations at JLAB", (JLAB-TN08-034, August 4, 2008)
P. Degtiarenko, "Radiological Impact of 12 GeV Beam Delivery to Hall A and to Hall D Tagger Vault" (PowerPoint™, January 2014)
P. Degtiarenko, R. May, S. Schwahn, and G. Stapleton, "Occupational and Environmental Aspects of the Radiation Control Provisions at the Jefferson Lab", (TN 97-017, May 12, 1997)
V. Vylet, Laboratory Notebook entries of 11/14/08 related to End Station A concrete shielding thicknesses.

From the original report:

Additional "As Built" Drawings Consulted:[i]

CEBAF DWG No 89-S-8-0649-029 Sheet No. S-202 (8/2/93)
CEBAF DWG No 89-S-8-0652-032 Sheet No. S-205 (8/2/93)
CEBAF DWG No 89-S-8-0665-045 Sheet No. S-218 (8/2/93)

Attachments (1 and 2 from the original report)

1) E. Winslow, Drawing S-201, August 2011
2) E. Winslow, Oct. 2011 Soil thickness and Dry Density Measurements on Hall A
3) Spreadsheet for topmost 6 points in each octant (from the original spreadsheet for readability)
4) Spreadsheet for bottommost 2 points in each octant (from the original spreadsheet for readability)

Synopsys of Report

Part 1: Soil Density Considerations

TN 97-017 provides a detailed analysis of the shielding associated with the original construction of the CEBAF facility. To achieve radiation protection goals, TN 97-017 on p. 2.6 specifies a concrete equivalent thickness of 3.94 ft. for End Stations A and B at the center (top) and 4.92 ft. at the perimeter (outer radius). This is also consistent with language in the notations on drawing S-201 (Attachment 1) within sensible round-off. From the documents supplied it can be inferred that the reference design density of structural concrete used in the roofs of the End Station domes is 145 lb-ft^{-3}. Given the structural requirements resultant from the large spans covered by the domes, there is no credible reason to doubt that concrete used for this purpose meets or exceeds this density value. It is a well-known fact at particle accelerators that soil is a reasonable substitute for concrete shielding. The attenuation properties of the two materials are essentially the same due to their being comprised of similar chemical elements. However, soil densities can vary greatly at geographical locations due to somewhat variable chemical compositions and moisture content.

In assessing the effectiveness of accelerator shielding, one must carefully consider how to account for soil shielding. In general, for a large shield such as embodied in the End Station dome shielding, if one knows the thickness of the soil shield one can determine the "concrete equivalent" thickness of the shield by multiplying the soil shield linear thickness by the ratio of the reference density of the concrete (here 145 lb-ft^{-3}) to the measured <u>wet</u> density of the soil.[ii] The moisture content of the soil local to the TJNAF site is of considerable importance to its shielding effectiveness: the local choice at TJNAF for the reference density of the soil is 125 lb-ft^{-3}. The <u>wet</u> density of the soil is readily connected to the <u>dry</u> density of the soil by increasing the latter by the measured moisture percentage by weight, a value given in the results supplied to the reviewer. In practice at accelerators it is quite common for these two densities to be confused. Civil engineers, for example, commonly prefer to reference the value of the dry density. Considering evaporation and drainage for a given soil shield, the moisture content is somewhat variable with time. In extremely arid desert environments this distinction has in rare cases been recognized to be potentially important. This confidently can be stated to not be a significant concern at the TJNAF site. There is no need to be concerned about temporal variations of the moisture content. Moreover, the approach of using the wet soil density as the basis for calculating the concrete equivalent thickness of a given layer of soil is a well-accepted practice at all large particle accelerators worldwide that consistently achieves accurate agreement between theoretical calculations and radiation measurements where such comparisons are valid.

An Excel™ spreadsheet is used to calculated thickness in terms of wet and dry density and to compare the measured values of total shielding in terms of concrete equivalent thickness (in feet) with the specifications of TN 97-017. It is done in two separate worksheets reflective of the fact the shielding specifications differ for the top of the dome and the perimeter as discussed previously. A separation, admittedly somewhat arbitrary in nature, has been made between top shielding (Attachment 3) and shielding near the base of the dome (Attachment 4). From top to bottom, the dome of Hall A is divided into the directional "octants". Soil thickness measurements were taken at 8 locations along a "longitude" line from the top of the dome to its base at the center of each octant. This is shown in Attachment 2. Attachment 3 shows the results for averaging over the topmost 6 points and Attachment 4 shows the results for bottommost 2 points within each octant.

For the beam energies at TJNAF, the field of prompt radiation that is emitted from these domes is large in size, a result of having propagated through a concrete equivalent shield of considerable thickness. Even relatively near the domes, the radiation field seen would not be sensitive to small localized variations in shield thickness given the physical processes of propagation through the shielding. To ascertain the effectiveness of the shield, it is much more relevant to take the average of this concrete shielding over some reasonable surface areas of the shield. Within the format of the data that were provided, the easiest choice is to average over several points within a given octant.

The spreadsheet was constructed so that Column 7, in Attachments A and B, represents the calculation of the concrete equivalent thickness of the soil measurements (taken in 2011) with a reference to the measured dry density. On both pages, Column 8 lists the underlying amount of concrete taken from V. Vylet's notebook referenced above. In Column 9, the concrete equivalent thickness of the soil overburden using the dry density, as described above is given. Column 10 is simply the sum of columns 8 and 9 and represents total concrete equivalent thickness (assuming dry density). Column 11 calculates the concrete equivalent thickness of the soil overburden using the wet density. Column 12 lists the total concrete equivalent thickness (assuming wet density). These are done for all measurement at the locations indicated in Attachments A and B, Column 1.

The average is then compared with the specification of 3.94 ft. applied to the top of the dome and shown as a "delta" value where a positive value indicates a surplus of shielding while a negative value evidences a deficit. This is shown in Column 13 of the spreadsheets in Attachments 3 and 4. The largest "delta" value is 0.747 ft., about 9 inches, for the octant labeled "E" for the topmost 6 points as shown in Attachment 3. A discrepancy of this size is commonly considered to be of very minor significance at most high energy accelerators. At the bottom of the page, the average value of concrete equivalent thickness is found to be 3.6 ft. with a standard deviation of 0.4 ft. This amounts to a very minor discrepancy from the specification of 3.94 ft.

Attachment 4 shows the results for averaging over the bottom 2 points within each octant. The average is then compared with the specification of 4.92 ft. applied to the top of the dome and shown as a "delta" value where a positive value indicates a surplus of shielding while a negative value evidences a deficit. The largest "delta" value is 0.749 ft., about 9 inches. This discrepancy is taken to be of very minor significance at most high energy accelerators. At the bottom of the page, the average value of concrete equivalent thickness is found to be 4.7 ft. with a standard deviation of 0.8 ft. This also amounts to a very minor discrepancy from the specification of 4.92 ft.

The reviewer concluded that, "…the materials provided to me at the outset of this review, along with other materials provided subsequently at my request, adequately demonstrate that there is no potential for radiological exposure to a member of the public that is in excess of the limits set forth by the U.S. Department of Energy or goals set forth by TJNAF. There is also no possibility of violating Revision 7 of the DOE-approved Accelerator Safety Envelope (ASE) as supported by Revision 7 of the Final Safety Assessment Document (FSAD) with respect to passive shielding requirements." The reviewer also stated, "One further observation about the shielding design calculations is worth mentioning. In TN 97017 as well as in TN 08-034 shielding calculations were made for the electron beam incident on otherwise relatively empty halls. (The shielding of the beam dumps is much more extensive and not related to that of the End Stations.) The approach of performing the shielding calculations for relatively empty halls is quite proper as it is defensible as "worst case". In actual circumstances it is "conservative" because it ignores the additional shielding provided by the experimental apparatus that can commonly be quite significant."

Part 2: TJNAF Monitoring Results and Beam Budget Procedures

At any accelerator, the monitoring program is at least as important as is the shielding design. At TJNAF it was recognized from the outset of the design that while the CEBAF accelerator and the extraction beam lines could be conservatively shielded, the large spans for the roofs of the End Stations required a more optimized approach. Throughout its operational history, prompt radiation emerging from the shielding has been monitored and compared with the theoretical calculations. Radiation monitors deployed near the site boundary have been used to continually monitor radiation levels. The prompt radiation levels due to the operation of the CEBAF accelerator at or near the site boundary at JLAB are well understood and well documented in Annual Site Environmental Reports issued since commissioning of the CEBAF accelerator, as well as technical documents such as those referenced here.

Concerning the upgrade of the beam energy from 6 to 12 GeV, the radiological effects of this change of energy are well-understood in light of the design and operating experience of other particle accelerators worldwide as this energy domain is not a new one. In particular, the PowerPoint™ presentation entitled "Radiological Impact of 12 GeV Beam Delivery to Hall A and to the Hall D Tagger Vault" provides an excellent overview of the design and the expectations for 12 GeV versus the former 6 GeV operation and how the carefully monitored and well-established radiation budget system is established and carried out. It also covers a very good summary of operational experience with respect to facility goals and U. S. Department of Energy requirements. The continued application of the radiation budget process in longstanding use at TJNAF is entirely adequate to provide the necessary protection for members of the public, employees, and visitors at TJNAF. JLAB continuously monitors radiation at site boundary. If a problem with the shielding is identified, the continuous monitoring would provide ample time to make programmatic corrections well before any risk of exceeding JLAB goals or DOE standards.

Suggestions for Improvements

All DOE facilities strive for continuous improvements. In that spirit some suggestions are offered in this section.

Suggestion No. 1: Improve Procedures for Monitoring End Station Earth Overburdens

The ASE contains a provision requiring that the shielding overburdens be reviewed to determine adequacy and initiate restoration or experimental program adjustments to maintain conformance with the JLAB Shielding Policy. As evidenced by the measurements of 2011, this provision of the ASE is being carried out. This is quite properly an element of the ASE. This provision is one that is quite important especially for the End Station domes where the shielding is relatively thin and the soil covers a dome of approximately elliptical vertical cross section. The status of the shielding should continue to be reviewed in accordance with the specified schedule and at any time there is a credible reason to believe that this shielding might have been compromised, for example after a period of heavy rainfall. TJNAF, if it has not done so already, might consider the placement of some sort of visible marking system to facilitate visual verification that the shield is intact.

Suggestion No. 2: Continue Ongoing Radiation Monitoring Program

The past history of TJNAF is that the ongoing radiation monitoring program is an effective tool in maintaining doses at the designated site boundary at designed levels with DOE requirements and TJNAF goals. Clearly the ongoing program should be maintained as planned.

Suggestions Pertaining to Documentation

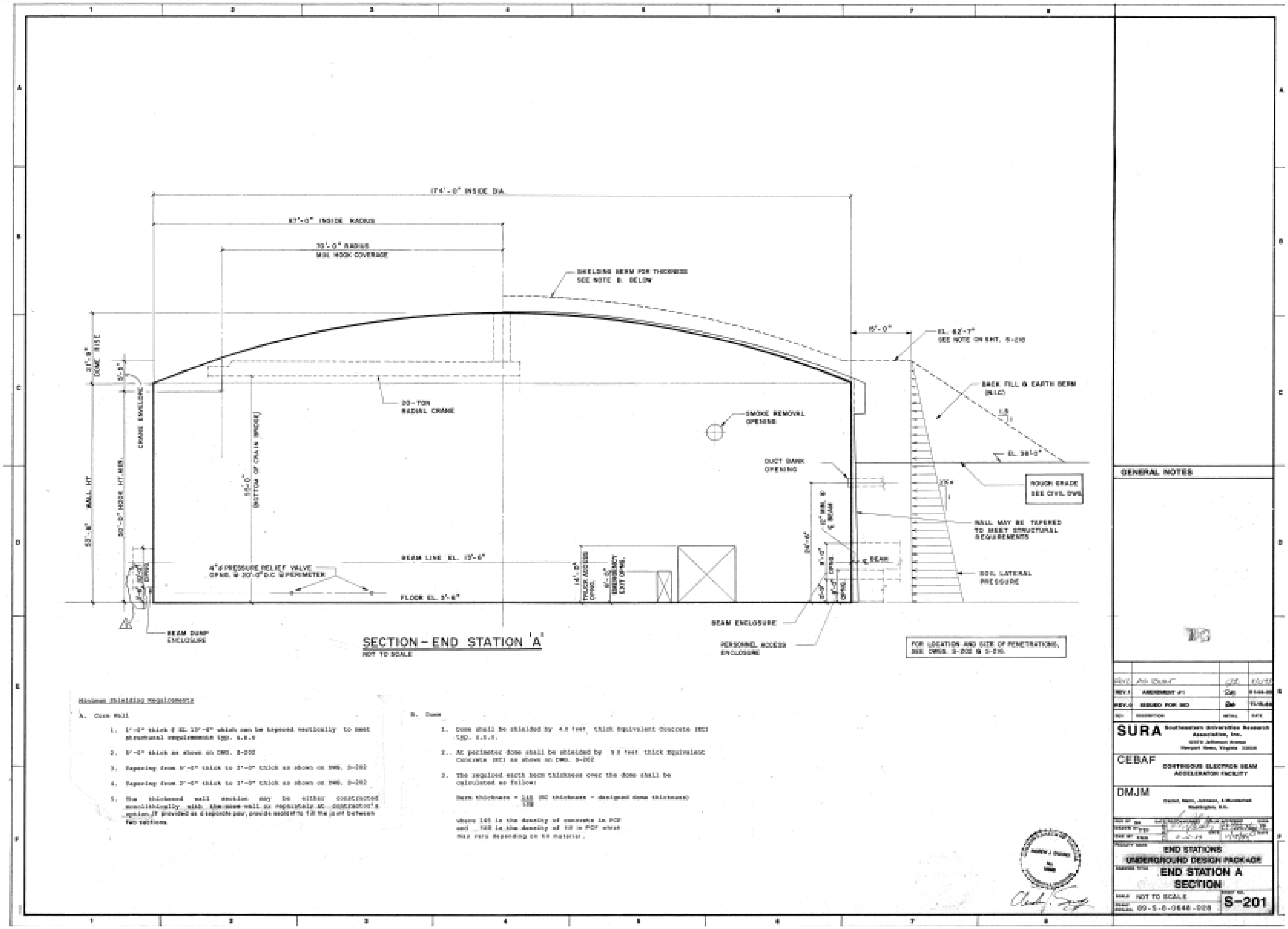
During the course of the review, there were several points identified in which existing documentation could be a bit more transparent to an outside reviewer. While nothing was found that merits immediate attention, as the various documents come up for revision the following suggestions are offered:

A. The shielding terms “concrete” and “concrete equivalent” are important in several documents including the FSAD. When making the comparison between earth and concrete shielding, at several points the specification of the densities is not immediately clear. Sometimes the density of the earth in shielding is not specified at all. A good example of this is found in Table 4-6 of the FSAD.

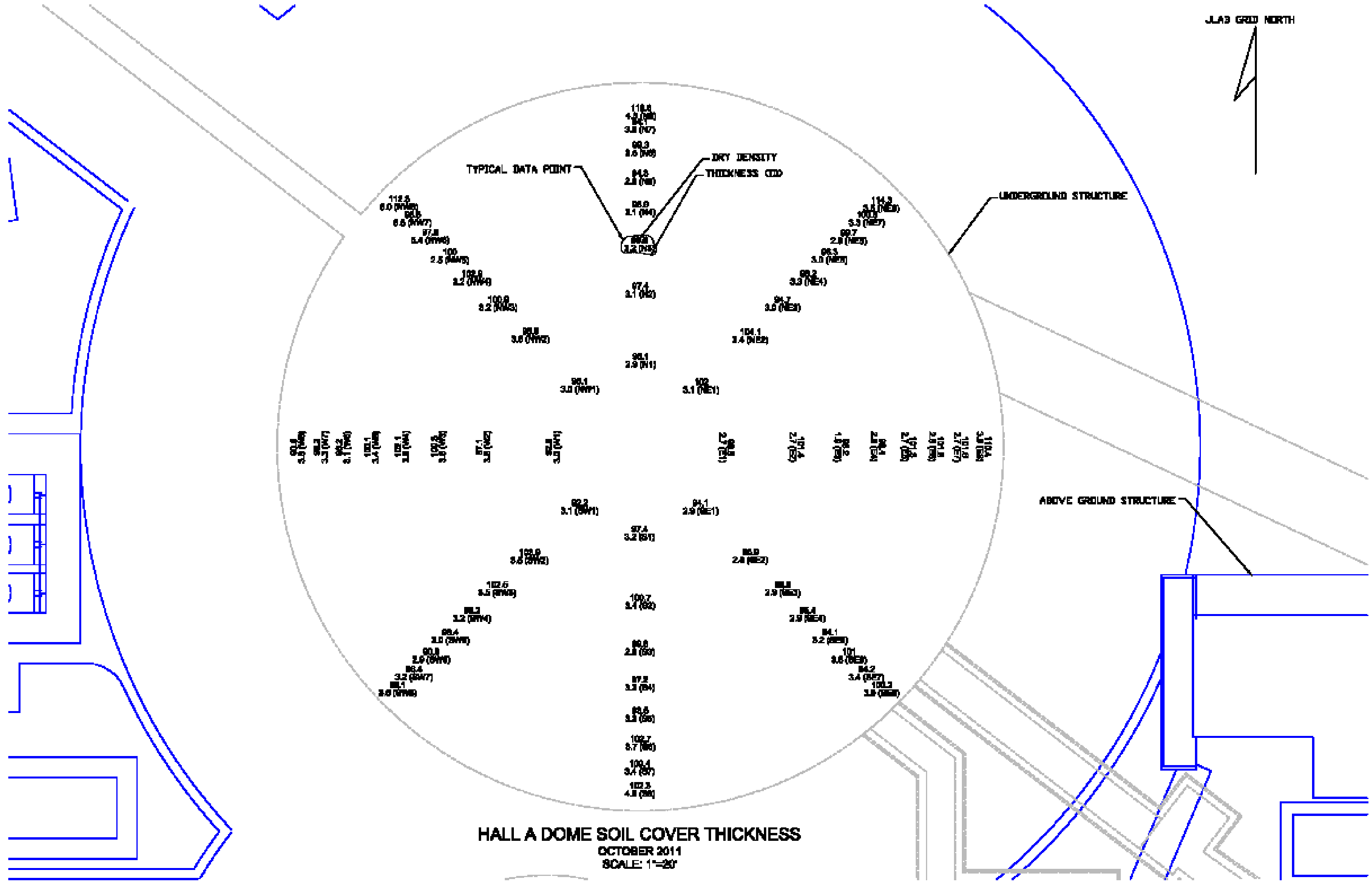
B. The discussions of berm shielding versus roof shielding associated with Table 4-6 of the FSAD are not completely transparent to the outside reviewer. Perhaps an additional drawing would be useful. A few “more words” would be helpful. Care should be taken to assure that the FSAD and ASE are aligned in this area.

C. In many documents including several of the references used in this review including the FSAD, there are many references to “dose”. From context, clearly absorbed dose is not the quantity of interest. However, it is not easy to infer what type of dose is meant in the context of the latest amendments to 10 CFR Part 835 “Occupational Radiation Protection” and in DOE Order 458.1 “Radiation Protection of the Public and the Environment”. One cannot tell if “equivalent dose”, “effective dose”, “ambient dose equivalent”, or other possible choices is meant. This should be clarified.

Attachment 1



Attachment 2



HALL A DOME SOIL COVER THICKNESS
OCTOBER 2011
SCALE: 1"=20'

Attachment 3

	JLAB Supplied Information for Hall A Dome					Reviewer Calculations						
Point Name	Dry Density	Wet Density	% Moisture	Normal Soil Thickness	Concrete Equivalent Thickness	ReCalculated Concrete Equivalent Thickness (dry density) based on JLAB Supplied Formula	Underling Concrete Thickness - Vashek's Notebook	Total Equivalwnt concrete thickness (dry density)	Delta, ft. Concrete equivalenmt average thickness vs value in TN97-017	Concrete Equivalent Thickness (wet density)	Total Equivalent concrete thickness (wet density)	Delta, ft. Concrete equivalent average thickness vs value in TN97-017
	lb/ft^3	lb/ft^3	Fraction	ft	ft	ft	ft	ft	ft	ft		
N1	96.1	113.4	0.181	2.9	1.9	**1.9**	1.1	3.0		2.3	3.4	
N2	97.4	111.5	0.145	3.1	2.0	**2.1**	1	3.1		2.4	3.4	
N3	89.6	106.5	0.188	3.2	1.9	**2.0**	1.1	3.1		2.4	3.5	
N4	98.9	115	0.163	3.1	2.0	**2.1**	1.2	3.3		2.5	3.7	
N5	94.3	108.7	0.153	2.8	1.8	**1.8**	1.3	3.1		2.1	3.4	
N6	99.3	114.6	0.155	3.5	2.3	**2.4**	1.4	3.8	-0.704	2.8	4.2	-0.369
N7												
N8												
NE1	102	114.4	0.122	3.1	2.1	**2.2**	1.1	3.3		2.4	3.5	
NE2	104.1	116.9	0.123	3.4	2.4	**2.4**	1	3.4		2.7	3.7	
NE3	94.7	113.5	0.199	3.0	1.9	**2.0**	1.1	3.1		2.3	3.4	
NE4	98.2	111	0.132	3.3	2.2	**2.2**	1.2	3.4		2.5	3.7	
NE5	96.3	111.1	0.153	3.0	1.9	**2.0**	1.3	3.3		2.3	3.6	
NE6	99.7	117.2	0.175	2.9	1.9	**2.0**	1.4	3.4	-0.623	2.3	3.7	-0.306
NE7												
NE8												
E1	99.5	114	0.157	2.7	1.8	**1.9**	1.1	3.0		2.1	3.2	
E2	101.4	116.5	0.149	2.7	1.8	**1.9**	1	2.9		2.2	3.2	
E3	98.2	112.2	0.142	1.9	1.3	**1.3**	1.1	2.4		1.5	2.6	
E4	96.4	110.9	0.150	2.8	1.8	**1.9**	1.2	3.1		2.1	3.3	
E5	101.3	115.6	0.141	2.7	1.8	**1.9**	1.3	3.2		2.2	3.5	
E6	101.8	116.2	0.141	2.5	1.7	**1.8**	1.4	3.2	-1.002	2.0	3.4	-0.747
E7												
E8												
SE1	94.1	107.8	0.146	2.9	1.8	**1.9**	1.1	3.0		2.2	3.3	
SE2	95.9	110.8	0.156	2.8	1.8	**1.9**	1	2.9		2.1	3.1	
SE3	99.9	114.5	0.146	2.9	1.9	**2.0**	1.1	3.1		2.3	3.4	
SE4	95.4	110.2	0.155	2.9	1.8	**1.9**	1.2	3.1		2.2	3.4	
SE5	94.1	108.6	0.153	3.2	2.0	**2.1**	1.3	3.4		2.4	3.7	
SE6	101	113.9	0.128	3.6	2.4	**2.5**	1.4	3.9	-0.719	2.8	4.2	-0.421
SE7												
SE8												
S1	97.4	111.6	0.145	3.2	2.1	**2.1**	1.1	3.2		2.5	3.6	
S2	100.7	113.4	0.127	3.4	2.3	**2.4**	1	3.4		2.7	3.7	
S3	99.6	118.9	0.124	2.8	1.8	**1.9**	1.1	3.0		2.3	3.4	
S4	97.2	109.6	0.128	3.3	2.1	**2.2**	1.2	3.4		2.5	3.7	
S5	93.5	104.6	0.118	3.3	2.1	**2.1**	1.3	3.4		2.4	3.7	
S6	102.7	110.8	0.079	3.7	2.5	**2.6**	1.4	4.0	-0.524	2.8	4.2	-0.237
S7												
S8												
SW1	92.2	111.6	0.210	3.1	1.9	**2.0**	1.1	3.1		2.4	3.5	
SW2	103.9	117.7	0.133	3.5	2.4	**2.5**	1	3.5		2.8	3.8	
SW3	102.5	116	0.132	3.5	2.4	**2.5**	1.1	3.6		2.8	3.9	
SW4	99.2	112.9	0.138	3.2	2.1	**2.2**	1.2	3.4		2.5	3.7	
SW5	98.4	112.9	0.147	3.0	2.0	**2.0**	1.3	3.3		2.3	3.6	
SW6	90.9	104.7	0.152	2.9	1.7	**1.8**	1.4	3.2	-0.591	2.1	3.5	-0.265
SW7												
SW8												
W1	92.8	109.3	0.177	3.0	1.9	**1.9**	1.1	3.0		2.3	3.4	
W2	97.1	112.5	0.159	3.6	2.3	**2.4**	1	3.4		2.8	3.8	
W3	100.3	114.6	0.143	3.8	2.6	**2.6**	1.1	3.7		3.0	4.1	
W4	102.1	114.3	0.119	3.6	2.5	**2.5**	1.2	3.7		2.8	4.0	
W5	100.1	113	0.129	3.4	2.3	**2.3**	1.3	3.6		2.6	3.9	
W6	96.2	109.8	0.141	3.1	2.0	**2.1**	1.4	3.5	-0.440	2.3	3.7	-0.108
W7												
W8												
NW1	96.1	111.9	0.165	3.0	1.9	**2.0**	1.1	3.1		2.3	3.4	
NW2	95.5	110.7	0.159	3.6	2.3	**2.4**	1	3.4		2.7	3.7	
NW3	100.9	116.2	0.152	3.2	2.2	**2.2**	1.1	3.3		2.6	3.7	
NW4	102.9	116.4	0.132	3.2	2.2	**2.3**	1.2	3.5		2.6	3.8	
NW5	100	116.8	0.169	2.5	1.7	**1.7**	1.3	3.0		2.0	3.3	
NW6	97.9	115.5	0.179	5.4	3.5	**3.6**	1.4	5.0	-0.385	4.3	5.7	-0.005
NW7												
NW8												
Max	104.1	118.9	0.21	5.4	3.5	3.6		5.0		4.3	5.7	
Min	89.6	104.6	0.079	1.9	1.3	1.3		2.4		1.5	2.6	
Avg	98.1	112.7	0.1	3.2	2.1	2.1		**3.3**		2.4	**3.6**	
Std Dev	3.4	3.3	0.0	0.5	0.3	0.4		**0.4**		0.4	**0.4**	

Attachment 4

JLAB Supplied Information for Hall A Dome						Reviewer Calculations						
Point Name	Dry Density	Wet Density	% Moisture	Normal Soil Thickness	Concrete Equivalent Thickness	ReCalculated Concrete Equivalent Thickness (dry density) based on JLAB Supplied Formula	Underling Concrete Thickness - Vashek's Notebook	Total Equivalwnt concrete thickness (dry density)	Delta, ft. Concrete equivalenmt average thickness vs value in TN97-017	Concrete Equivalent Thickness (wet density)	Total Equivalent concrete thickness (wet density)	Delta, ft. Concrete equivalenmt average thickness vs value in TN97-017
	lb/ft^3	lb/ft^3	Fraction	ft	ft	ft	ft	ft	ft	ft		
N1												
N2												
N3												
N4												
N5												
N6												
N7	94.1	107.4	0.141	3.8	2.4	**2.5**	1.45	3.9		2.8	4.3	
N8	119.6	125.5	0.049	4.8	3.8	**4.0**	1.5	5.5	-0.232	4.2	5.7	0.040
NE1												
NE2												
NE3												
NE4												
NE5												
NE6												
NE7	100.5	115.8	0.152	3.3	2.2	**2.3**	1.45	3.7		2.6	4.1	
NE8	114.3	123.3	0.078	3.5	2.7	**2.8**	1.5	4.3	-0.922	3.0	4.5	-0.639
E1												
E2												
E3												
E4												
E5												
E6												
E7	101.6	114.6	0.127	2.7	1.8	**1.9**	1.45	3.3				
E8	110.4	118.5	0.074	3.9	2.8	**3.0**	1.5	4.5	-1.014	3.2	4.7	-0.233
SE1												
SE2												
SE3												
SE4												
SE5												
SE6												
SE7	94.2	109.6	0.163	3.4	2.2	**2.2**	1.45	3.7		2.6	4.0	
SE8	100.2	119	0.187	3.9	2.6	**2.7**	1.5	4.2	-0.993	3.2	4.7	-0.560
S1												
S2												
S3												
S4												
S5												
S6												
S7	100.4	112.5	0.121	3.4	2.3	**2.4**	1.45	3.8				
S8	102.3	112.5	0.099	4.5	3.1	**3.2**	1.5	4.7	-0.680	3.5	5.0	0.071
SW1												
SW2												
SW3												
SW4												
SW5												
SW6												
SW7	96.4	109.2	0.133	3.2	2.1	**2.1**	1.45	3.6		2.4	3.9	
SW8	99.1	120.1	0.212	3.6	2.4	**2.5**	1.5	4.0	-1.151	3.0	4.5	-0.749
W1												
W2												
W3												
W4												
W5												
W6												
W7	99.2	114.9	0.159	3.3	2.2	**2.3**	1.45	3.7		2.6	4.1	
W8	90.6	113.5	0.253	3.8	2.3	**2.4**	1.5	3.9	-1.129	3.0	4.5	-0.650
NW1												
NW2												
NW3												
NW4												
NW5												
NW6												
NW7	98.8	114.3	0.157	5.5	3.6	**3.7**	1.45	5.2		4.3	5.8	
NW8	112.3	122	0.086	6.0	4.5	**4.6**	1.5	6.1	0.752	5.0	6.5	1.247
Max	119.6	125.5	0.253	6	4.5	4.6		6.1		5.0	6.5	
Min	90.6	107.4	0.049	2.7	1.8	1.9		3.3		2.4	3.9	
Avg	102.1	115.8	0.1	3.9	2.7	2.8		**4.2**		3.2	**4.7**	
Std Dev	8.0	5.2	0.1	0.9	0.7	0.8		**0.8**		0.8	**0.8**	

This note serves as an assessment of shielding on Hall A and also serves as the technical basis for the proper evaluation of effective soil thickness using wet density as applied to radiation shielding.

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[i] It should be noted that CEBAF DWG No 89-S-8-0648-038 Sheet No. S-201 (8/2/93), hereafter referred to as “drawing S-201” is apparently part of this set of “as built” drawings and was provided to the reviewer. “As built” drawings are available at M:\facilities\Projects\Completed Projects\Site\End Station Underground\Combined.

[ii] For smaller shields of localized sources, it is sometimes necessary to incorporate a geometrical correction (e.g., 1/r, $1/r^2$, etc.) to account for the somewhat larger radial distance embodied in a less dense soil equivalent to a denser concrete shield. For the conditions associated with the large TJNAF End Stations, such considerations are not significant.