

Electric and Magnetic Field (EMF) Analysis for Woburn-to-Wakefield Junction Underground 345-kV Transmission Line

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1 Introduction and Summary

NSTAR Electric Company *d/b/a* Eversource Energy (“Eversource”) and New England Power Company *d/b/a* National Grid (“NEP”) (together, “Proponents”) have proposed to install a 345-kV underground (UG) transmission line using 3,500-kcmil XLPE-insulated copper cables from Eversource’s Woburn (Pond Street) Substation to National Grid’s Wakefield Junction (Montrose Avenue) Substation, a distance of approximately 8 miles. Epsilon Associates is preparing the environmental assessments for this project, and Epsilon requested that Gradient perform an independent assessment of the electric and magnetic field (EMF) impacts associated with this proposed new transmission line.

For the majority of the route, individual phase conductors will be in a duct bank, with one phase per duct, and with the three conductors in an inverted-delta configuration (∇). The 2 uppermost conductors are nearest the ground surface and will be 40 inches (3.33 ft) below grade (See diagram in Appendix A). There will be a number of underground splice vaults along the route, associated with a different (vertical) spacing of the phase conductors, where the phase conductor nearest the ground surface will be 5½ feet below grade (See diagram in Appendix A). In year 2018, the peak load is anticipated to be 206 amperes and the annual average load is projected to be 64.4 amperes.

As described in this report, we found that magnetic field levels calculated to exist immediately above the underground cables (at a height of 3 ft [\sim 1 m] above ground) are well below the International Commission on Non-Ionizing Radiation Protection (ICNIRP) health-based guidelines for public exposure to EMF (2,000 mG). In addition, all field values are below the Massachusetts ROW-edge magnetic field guideline value of 85 mG (MAEFSB, 2010). Underground lines produce no above-ground electric fields, so these 345-kV conductors will not produce any above-ground post-project electric fields.

At peak loading, the maximum magnetic field values generated by the proposed underground line in an inverted-delta configuration will be 34 mG, and this will fall to 3.6 mG at a horizontal distance of \pm 20 feet away from the centerline of the conductors. At peak load, in the vicinity of the splice vaults, the maximum magnetic field values will be 44 mG, and this will fall to 9.1 mG at a horizontal distance of \pm 20 feet away from the centerline of the conductors.

At annual average load, these values will (for the ∇ configuration) be 10.5 mG, falling to 1.1 mG at \pm 20 feet for the majority of the line length, and (for the vertical configuration in the splice vaults) 13.6 mG, falling to 2.8 mG at \pm 20 feet from the centerline of the conductors. In all cases, field values decrease rapidly with lateral distance from the lines.

Section 2 of this report describes the nature of EMF, provides values for EMF levels from common sources, and reports on available EMF exposure guidelines. Section 3 outlines the EMF modeling procedures for calculating magnetic field strengths as a function of lateral distance from an electric transmission or distribution line, as well as providing graphical and tabular results. Section 4 summarizes the conclusions, and Section 5 lists the bibliographic references.

2 Nature of Electric and Magnetic Fields

All matter contains electrically charged particles. Most objects are electrically neutral because positive and negative charges are present in equal numbers. When the balance of electric charges is altered, we experience electrical effects, such as the static electricity attraction between a comb and our hair, or drawing sparks after walking on a synthetic rug in the wintertime. Electrical effects occur both in nature and through our society's use of electric power (generation, transmission, consumption).

2.1 Units for EMF Are Kilovolts per Meter (kV/m) and Milligauss (mG)

The electrical tension on utility power lines is expressed in volts or kilovolts (kV; 1 kV = 1,000 V). Voltage is the "pressure" of the electricity, and can be envisioned as analogous to the pressure of water in a plumbing system. The existence of a voltage difference between power lines and ground results in an "electric field," usually expressed in units of kilovolts per meter (kV/m). The size of the electric field depends on the voltage, the separation between lines and ground, and other factors.

Power lines also carry an electric current that creates a "magnetic field." The units for electric current are amperes (A) and are a measure of the "flow" of electricity. Electric current can be envisioned as analogous to the flow of water in a plumbing system. The magnetic field produced by an electric current is usually expressed in units of gauss (G) or milligauss (mG), where 1 G = 1,000 mG. Another unit for magnetic field levels is the microtesla (μT), where 1 μT = 10 mG. The size of the magnetic field depends on the electric current, the distance to the current-carrying conductor, and other factors.

2.2 There Are Many Natural and Man-made Sources of EMF

Everyone experiences a variety of natural and man-made electric and magnetic fields. Electric and magnetic field levels can be slowly varying or steady (often called "DC fields"), or can vary in time (often called "AC fields"). When the time variation of interest corresponds to that of power line currents, *i.e.*, 60 cycles per second, the fields are called "60-Hz" EMF. Man-made magnetic fields are common in everyday life. For example, many childhood toys contain magnets. Such permanent magnets generate strong, steady magnetic fields. Typical toy magnets (*e.g.*, "refrigerator door" magnets) have fields of 100,000 to 500,000 mG. On a larger scale, the earth's core creates a steady magnetic field that can be easily demonstrated with a compass needle. The size of the earth's magnetic field in the northern US is about 550 mG (over a hundred times smaller than fields generated by "refrigerator door" magnets). Knowing the strength of the earth's magnetic field provides a perspective on the size of power line magnetic fields. The earth's steady field does not have the 60-Hz time variation characteristic of power line EMF, but is experienced as a changing magnetic field as one moves around in it. Alternatively, moving magnets generate time-varying magnetic fields. For example, a magnet spinning at 60 times a second will produce a 60-Hz magnetic field indistinguishable from that found near electric power lines carrying the appropriate level of electric current. Even the rotating steel-belted radial tires on a car produce time-varying magnetic fields. And although magnetic resonance imaging (MRI) is a diagnostic procedure that puts humans in much larger, but steady, magnetic fields (*e.g.*, 20,000,000 mG), it is preferred over taking an X-ray picture. Contrary to X-rays, MRIs have no known health risks (other than the large forces exerted on nearby steel objects).

2.3 Power-frequency EMF Are Found Near Electric Lines and Appliances

Electric transmission lines, distribution lines, and electric wiring in buildings carry AC currents and voltages that change size and direction at a frequency of 60 Hz. These 60-Hz currents and voltages create 60-Hz EMF nearby. The size of the magnetic field is proportional to the line current, and the size of the electric field is proportional to the line voltage. The EMF associated with electrical wires and electrical equipment decrease rapidly with increasing distance away from the electrical wires.

When EMF derives from different sources (*e.g.*, adjacent wires), the size of the net EMF produced will be somewhere in the range between the sum of EMF from the individual sources and the difference of the EMF from the individual sources. Thus, EMF may partially add, or partially cancel, but generally, because adjacent wires are often carrying current in opposite directions, the EMF produced tends to be cancelled. Inside residences, typical baseline 60-Hz magnetic fields (far away from appliances) range from 0.5 to 5.0 mG. EMF in the home arise from electric appliances, indoor wiring, grounding currents on pipes and ground wires, and outdoor distribution or transmission circuits. All these separate power-line magnetic fields add or subtract from the steady field of the earth (570 mG), so that the sum total magnetic field in the home has both a steady part and a time-varying part.

Higher 60-Hz magnetic field levels are found near operating appliances. For example, can openers, mixers, blenders, refrigerators, fluorescent lamps, electric ranges, clothes washers, toasters, portable heaters, vacuum cleaners, electric tools, and many other appliances generate magnetic fields of 40 to 300 mG at distances of 1 foot (NIEHS, 2002). Magnetic fields from personal care appliances held within ½ foot (*e.g.*, shavers, hair dryers, massagers) can produce 600 to 700 mG. At school and in the workplace, lights, motors, copy machines, vending machines, video-display terminals, pencil sharpeners, electric tools, and electric heaters are all sources of 60-Hz magnetic fields.

2.4 State, National, and International Guidelines for EMF Are Available

The US has no federal standards limiting occupational or residential exposure to 60-Hz EMF. Table 2.1 shows guidelines suggested by national and world health organizations. The levels shown on Table 2.1 are designed to be protective against any adverse health effects. The limit values should not be viewed as demarcation lines between safe and dangerous levels of EMF, but rather, levels that assure safety with an adequate margin of safety to allow for uncertainties in the science. Table 2.2 lists guidelines that have been adopted by various states in the US. State guidelines are not health-effect based, and have been typically adopted to maintain the *status quo* for EMF on and near transmission line ROWs.

Table 2.1 60-Hz EMF Guidelines Established by Health and Safety Organizations

Organization	Magnetic Field	Electric Field
American Conference of Governmental and Industrial Hygienists (ACGIH) (occupational)	10,000 mG ^a 1,000 mG ^b	25 kV/m ^a 1 kV/m ^b
International Commission on Non-Ionizing Radiation Protection (ICNIRP) (general public, continuous exposure)	2,000 mG	4.2 kV/m
Non-Ionizing Radiation (NIR) Committee of the American Industrial Hygiene Assoc. (AIHA) endorsed (in 2003) ICNIRP's occupational EMF levels for workers	4,170 mG	8.3 kV/m
Institute of Electrical and Electronics Engineers (IEEE) Standard C95.6 (general public, continuous exposure)	9,040 mG	5.0 kV/m
UK, National Radiological Protection Board (NRPB) [now Health Protection Agency (HPA)]	2,000 mG	4.2 kV/m
Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), Draft Standard, Dec. 2006 ^c	3,000 mG	4.2 kV/m
<i>Comparison to steady [see text] (DC) EMF, encountered as EMF outside the 60-Hz frequency range:</i>		
Earth's magnetic field and atmospheric electric fields, steady levels, typical of environmental exposure ^d	550 mG	0.2 kV/m up to > 12 kV/m
Magnetic Resonance Imaging Scan, static magnetic field intensity ^d	20,000,000 mG	–

Notes:

- (a) The ACGIH (2010a) guidelines for the general worker (ACGIH, 2010b, p124-127).
- (b) The ACGIH (2010a) guideline for workers with cardiac pacemakers (ACGIH, 2010b, p 124-127).
- (c) ARPANSA (2006, 2008).
- (d) These EMF are steady fields, and do not vary in time at the characteristic 60 cycles-per-second that power-line fields do. However, if a person moves in the presence of these fields, the body experiences a time-varying field.

Table 2.2 State EMF Standards and Guidelines for Transmission Lines

State	Line Voltage (kV)	Electric Field (kV/m)		Magnetic Field (mG)	
		On ROW	Edge ROW	On ROW	Edge ROW
Florida ^a	69 – 230	8.0	2.0 ^b		150
	500	10.0			200, 250 ^c
Massachusetts			1.8		85
Minnesota		8.0			
Montana		7.0 ^d	1.0 ^e		
New Jersey			3.0		
New York ^c		11.8	1.6		200
		11.0 ^f			
		7.0 ^d			
Oregon		9.0			

Notes:

ROW = right of way; mG = milligauss; kV/m = kilovolts per meter.

- (a) Magnetic fields for winter-normal, *i.e.*, at maximum current-carrying capability of the conductors.
- (b) Includes the property boundary of a substation.
- (c) 500 kV double-circuit lines built on existing ROWs.
- (d) Maximum for highway crossings.
- (e) May be waived by the landowner.
- (f) Maximum for private road crossings.

Sources: NIEHS (2002); FLDEP (2008).

3 Modeled Magnetic Fields

3.1 Software Programs Used for Modeling EMF

We used the FIELDS computer program, designed by Southern California Edison, to calculate magnetic and electric field levels from the proposed underground transmission lines at cross-sections perpendicular to the lines as a function of current and distance. EMF modeling programs operate using Maxwell's equations, which accurately describe the laws of physics as they apply to electricity and magnetism. Modeled fields calculated using such programs are both precise and accurate for the input data utilized. Results of models have been cross-checked against each other and against other software (e.g., "CORONA" from the Bonneville Power Administration, US Dept. of Energy) to ensure that the implementation of the laws of physics are consistent. In validation tests, program results for EMF have been found to be in very good agreement with each other.

3.2 Power-Line Flow

Magnetic fields produced by the proposed lines were modeled using line loadings communicated by Eversource. The current per phase satisfies the relationship:

$$(Eq. 3.1) \quad S = \sqrt{3} \times V \times I_{phase}$$

where:

S	=	the power in kilovolt-amps (kVA)
V	=	the line voltage in kilovolts (kV)
I_{phase}	=	the current per phase in amps (A).

Thus, the current per phase conductor is:

$$(Eq. 3.2) \quad I_{phase} = \frac{S}{\sqrt{3} \times V}$$

Electric current values were provided by the Proponents and are listed in Table 3.1. The Proponents determined these currents using power-flow modeling for the future year 2018 assuming that all of the other Greater Boston solution projects were complete, that all lines are in service, and using the peak-load generation dispatch for the Greater Boston needs assessment studies that would produce the highest current flow on the proposed new line.

Table 3.1 Electric Currents for the Proposed Project, Estimated for Post-Project Year 2018

Transmission Line	Average Annual Load Current (Amps)	Peak Load Current (Amps)
345-kV, 3,500-kcmil, XPLE	64.4	206

3.3 EMF Model for the Proposed Transmission Line

EMF modeling of the proposed underground lines included calculation of magnetic fields levels expected to exist 3 feet (~1 meter) above the ground surface for the loading scenarios described above (IEEE, 1997 a,b).

Eversource provided Gradient with proposed conductor configuration schematics as well as circuit specifications (select drawings are included as Appendix A to this report). The 345-kV transmission line conductors are within 8" diameter ducts as shown in Figure 3.1, which shows them in an inverted-delta (∇) arrangement. The vertical and horizontal spacing between the centerline of the conductors is 14 inches (additional details are shown in Appendix A).

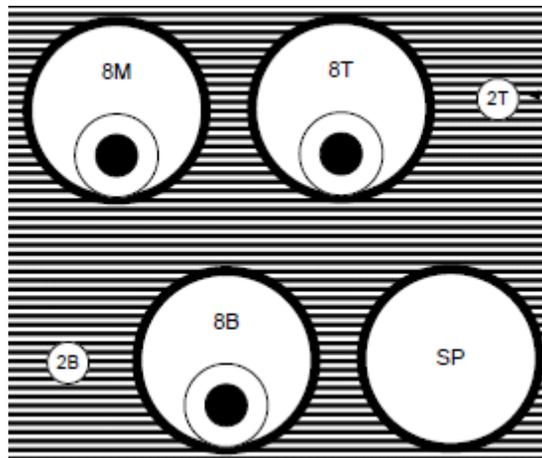


Figure 3.1 The Inverted-Delta Configuration of the Underground, 345-kV, 3,500-kcmil Copper Phase Conductors, Inside 8" ID, HDPE Pipes Having 1" Walls

The configuration of the phase conductors while passing through a splice vault is shown in Figure 3.2, which shows the conductors arranged vertically above each other, with a separation of 2 ft.

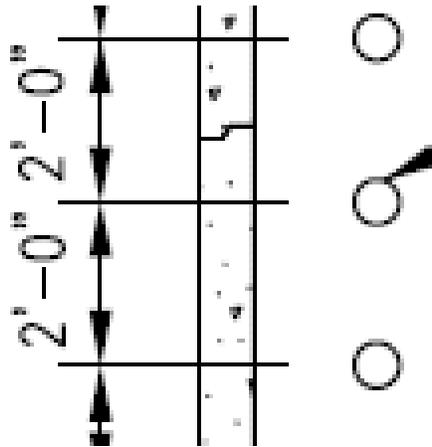


Figure 3.2 Vertical Configuration of the Individual Phase Conductors (circles on the right) During Their Travel Through the Splice Vault / Manhole Section

The future (2018) peak and average loadings on the 345-kV line conductors are 206 A and 64.4 A, respectively.

3.4 EMF Modeling Results

The graphs in Figures 3.3 and 3.4 plot the magnetic field *versus* horizontal distance from centerline, both for the typical underground conductor configuration (∇), and for the vertical conductor configuration in the splice vault / manhole section.

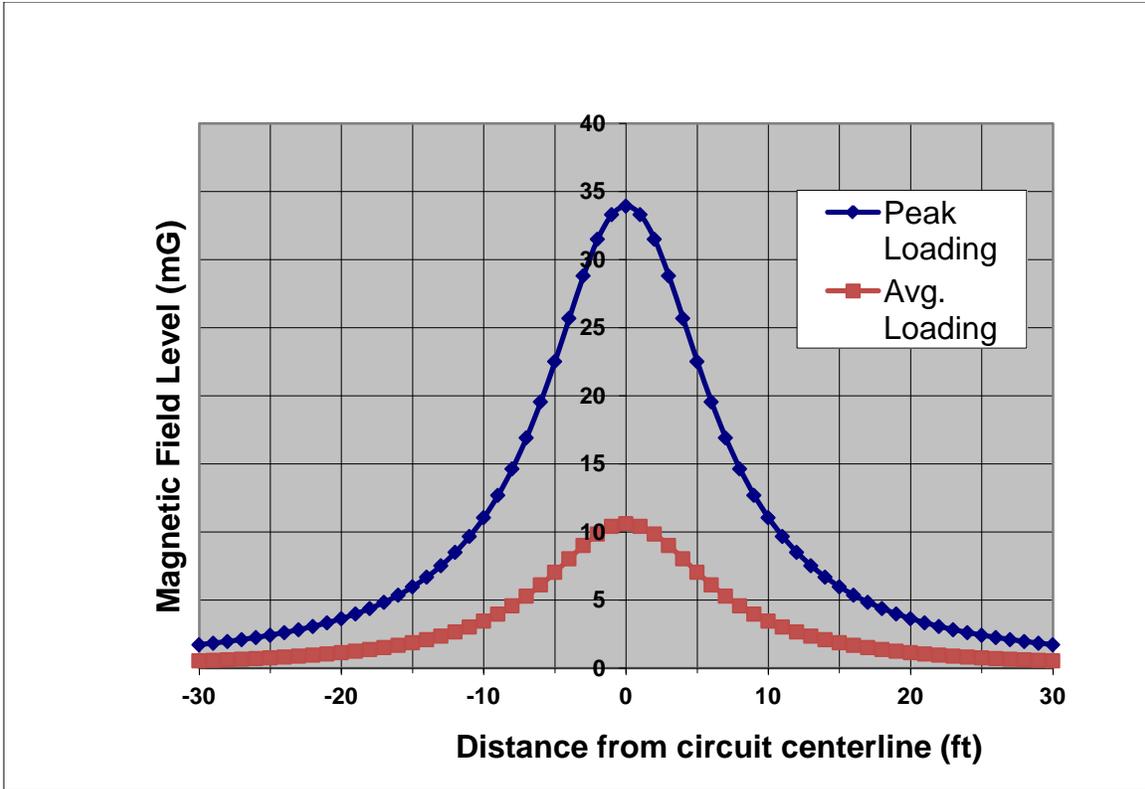


Figure 3.3 Magnetic Field *versus* Lateral Distance from the Centerline of the Conductors (x = 0 ft) for the Standard Inverted-Delta (∇) Configuration of the Underground Conductors

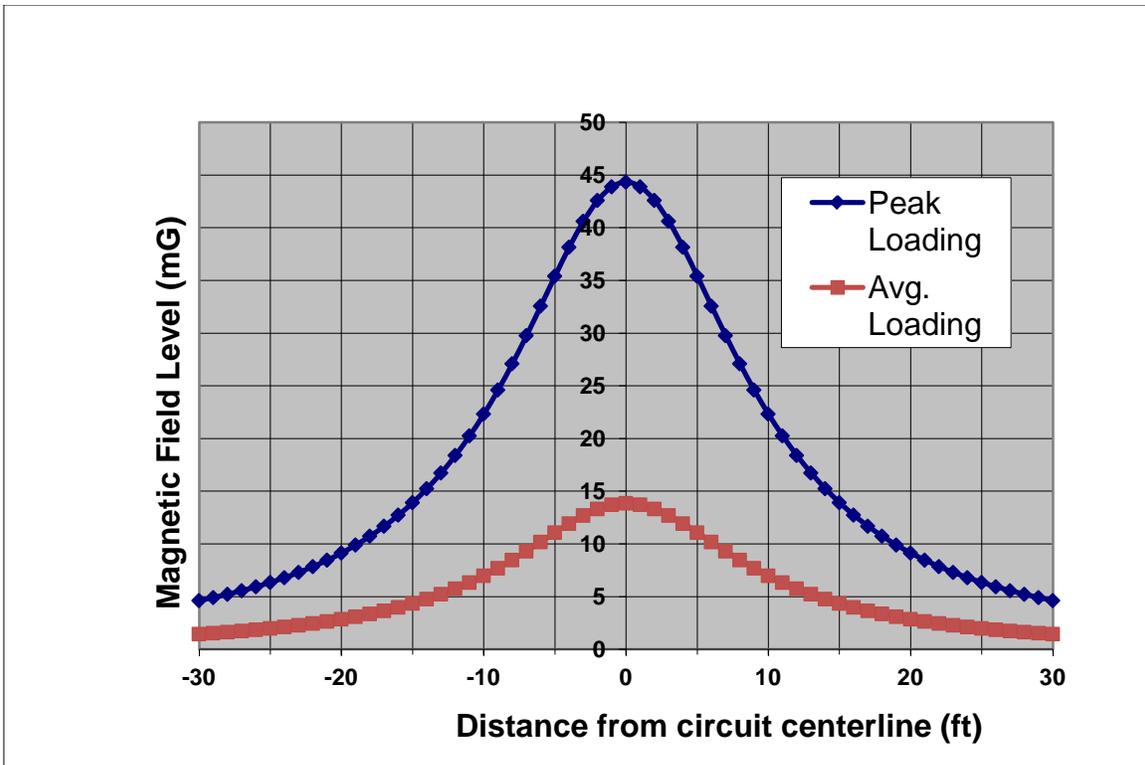


Figure 3.4 Magnetic Field versus Lateral Distance from the Centerline of the Conductors (x = 0 ft) for the Vertical Configuration of the Underground Conductors (Splice Vault / Manhole Section)

In all cases, even the peak modeled magnetic field values fall well below the Massachusetts guideline for magnetic field values (85 mG, see Section 2, Table 2.2). The peak values are also well below the International Commission on Non-Ionizing Radiation Protection (ICNIRP) health-based guidelines for public exposure to EMF (2,000 mG, see Section 2, Table 2.1).

4 Conclusions

Gradient calculated the magnetic field levels at 3 feet (~ 1 meter) above ground-surface (IEEE, 1997a,b), projected to exist in the vicinity of the proposed 345-kV underground lines for the Woburn-to-Wakefield Junction project. Table 4.1, below, summarizes the magnetic field results for the EMF modeling. All fields represent modeled values for the projected peak and average operational line loads (2018). Because all circuits are underground, the above-ground electric fields associated with the 345-kV line are zero.

Table 4.1 Modeled Magnetic Fields 3 Feet Above Ground Surface

Section of Line Being Modeled	Maximum Magnetic Field (mG), Directly Above Line	Magnetic Field (mG), 20 ft to Either Side of Centerline
2018 Peak Load, Typical Line Sections	34	3.6
2018 Avg. Load, Typical Line Sections	10.5	1.1
2018 Peak Load, Splice Vault Sections	44	9.1
2018 Avg. Load, Splice Vault Sections	13.6	2.8

Table 4.1 shows that the maximum magnetic field levels predicted along the underground routes of the proposed line fall well below accepted health-based guidelines for allowable public exposure to magnetic fields (2,000 mG) (ICNIRP, 2010). In addition, all field levels along the line routes fall below the Massachusetts ROW-edge magnetic-field guideline of 85 mG (MAEFSB, 2010). Overall, there is no expectation of adverse health effects due to the EMF impact from the proposed underground 345-kV transmission-line project.

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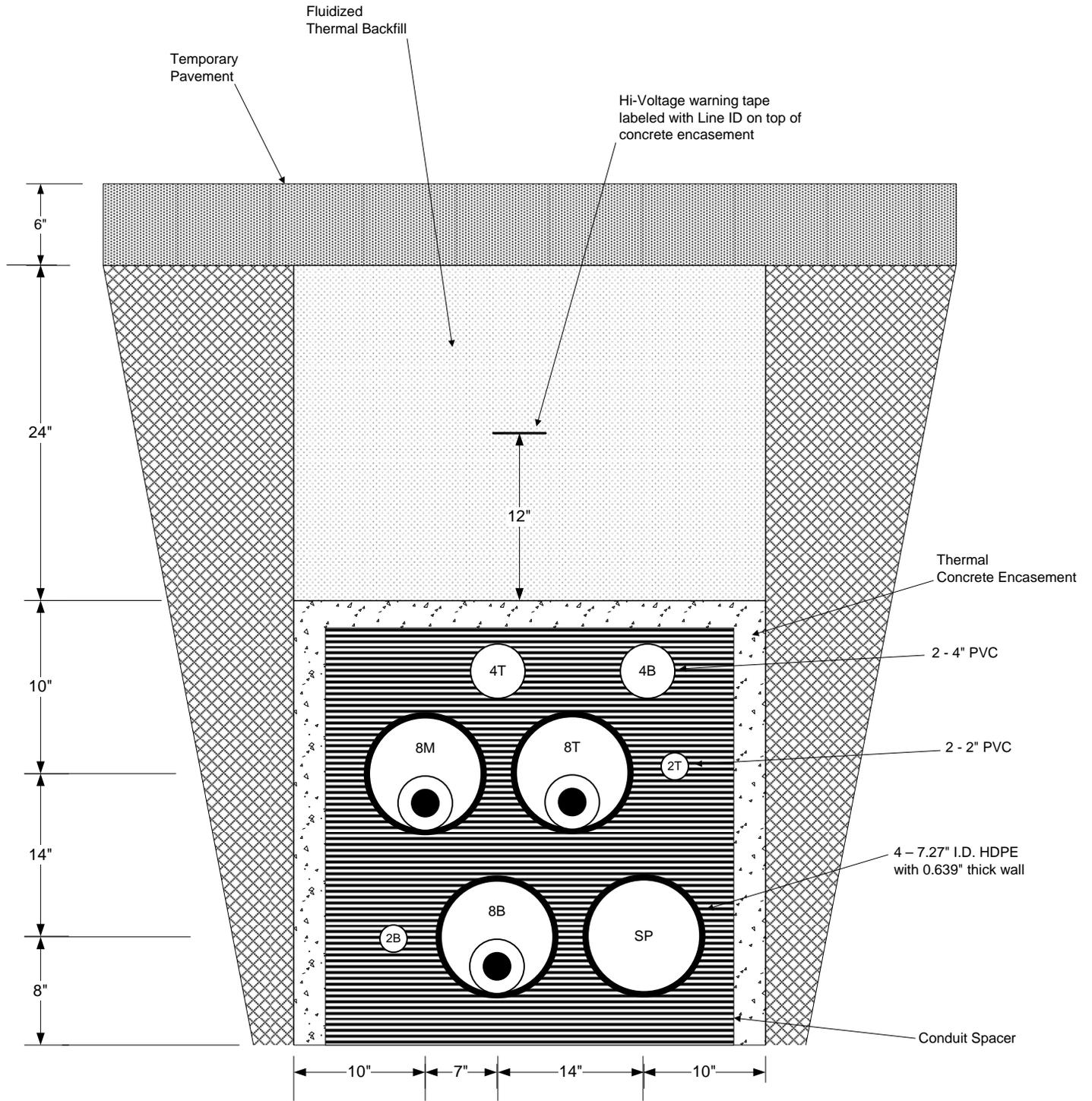
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Appendix A

**Cross Sections of Woburn-to-Wakefield Junction Line,
345-kV Transmission Duct Bank System**



NOTE: Not to Scale

0	XX/XX/XX	Issued
Rev.	Date	Description



115 KV / 345 KV XLPE Cross Section

Appendix XX
Rev 0
Sheet X of X

Woburn-to-Wakefield, 345-kV line, Schematic of splice vault location / manhole section

Demetrios Sakellaris (Eversource) E-mail of 3/2/2015 11:56 AM states top of manhole cover (at grade) is 3 feet above ceiling of vault. Thus, the 3 phase conductor depths are:

5 ½ feet

7 ½ feet

9 ½ feet

All arranged vertically from each other.

