GRADIENT

Memorandum

To: Scott Mallory, Senior Project Manager, VELCO **Date:** April 20, 2023

From: Christopher Long, ScD, DABT, Gradient

Subject: K42 Line Rebuild and Reconductoring Project, Summary of Potential Electric and Magnetic Field (EMF) Impacts

Summary of Potential Electric and Magnetic Field (EMF) Impacts, K42 Line Rebuild and Reconductoring Project

VELCO requested that Gradient review the EMF results for the 115-kV K42 Overhead Transmission Line Rebuild and Reconductoring Project, where VELCO has proposed to reconductor their 115-kV K42 overhead transmission line from Highgate Substation to Georgia Substation (the "Project"). As part of the Project, the existing single 1272 (45/7) ACSR conductors will be replaced with conductor bundles consisting of two 1272 (45/7) ACSR conductors, and thermal capacity will be increasing from 1,731 to 3,462 amperes. Jeff Carrara of VELCO performed EMF analyses for three representative cross sections across the transmission line right-of-way (ROW) along the Project route. Cross section 1 (CS1) covers the majority of the route length, with the CS2 and CS3 cross sections representing a two-pole vertical dead-end structure and a special two-pole angle structure, respectively, that will occur for 1-2 structures (each) along the route. Schematic views for these three cross sections are provided on the following pages (Figures 1-3).

As described in this memo, post-Project electric and magnetic field values, under system loads representative of the range of projected operation for the line[1], reached maximums of 2.17 kilovolts per meter (kV/m) and 194 milligauss (mG), respectively, at 1 meter (m) above the ground surface directly beneath the lines for the CS1 conductor arrangement that covers the majority of the route length; these compare to existing pre-Project maximum electric and magnetic field values of 1.54 kV/m and 305 mG, respectively. EMF levels decreased rapidly with distance to either side of the transmission-conductor centerline, with ROW-edge electric and magnetic fields, under system loads representative of the range of projected operation for the line, ranging between 0.12 – 0.38 kV/m and 8.4 – 55 mG, respectively, for the CS1 conductor arrangement; these compare to ranges of existing pre-Project ROW-edge electric and magnetic field values of 0.18 – 0.18 kV/m and 20.5 – 34.5 mG, respectively. All of the modeled electric and magnetic field values fall well below the health-based guidelines of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) for public exposure to EMF, namely, 4.2 kV/m and 2,000 mG (ICNIRP, 2010).

[1] EMF modeling was conducted by VELCO for system loads representative of the range of existing and projected operation for the line, more specifically for Peak Load Low Generation (PLLG) and Minimum Load High Generation (MLHG) loading cases that reflect the range in generation in the Sheffield-Highgate Export Interface (SHEI) area and imports from the Highgate Converter Station. For demonstration purposes, the magnetic fields based on the thermal capacity of the K42 phase conductors were also calculated, but this thermal capacity case does not reflect normal line loading. That is, while thermal capacity magnetic field levels were calculated, the focus here is on EMF values during normal operating conditions, because EMF exposure guidelines and research studies refer to time-weighted-average (TWA) exposure, to which there's unlikely any significant contribution from unexpected, infrequent, and short-duration excursions to “thermal capacity” levels.

One Beacon Street, 17th Floor, Boston, MA 02108 | 617-395-5000 | www.gradientcorp.com

The subsequent sections of this memo describe the ROW cross sections and tabulate the EMF modeling results. This memo also describes the nature of EMF and provides values for EMF levels from common sources as well as available EMF exposure guidelines. The final section of this memo summarizes the conclusions, and bibliographic references are listed at the end of the memo.

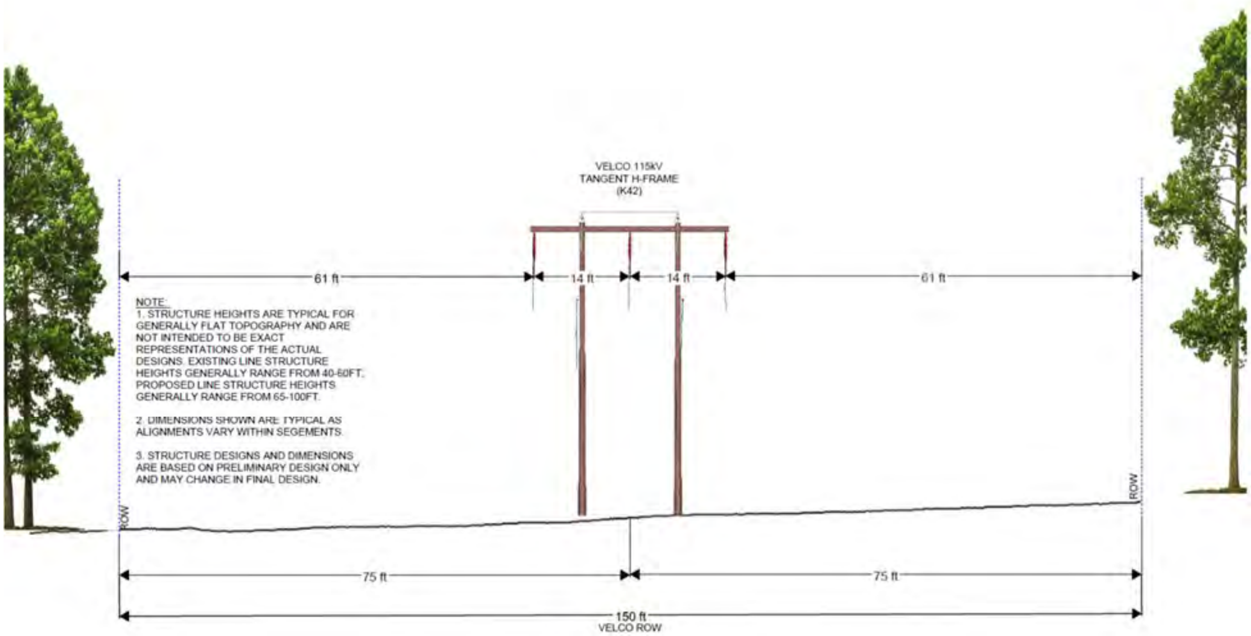

Figure 1a. Existing (Pre-Project) View for Cross Section 1 (CS1).

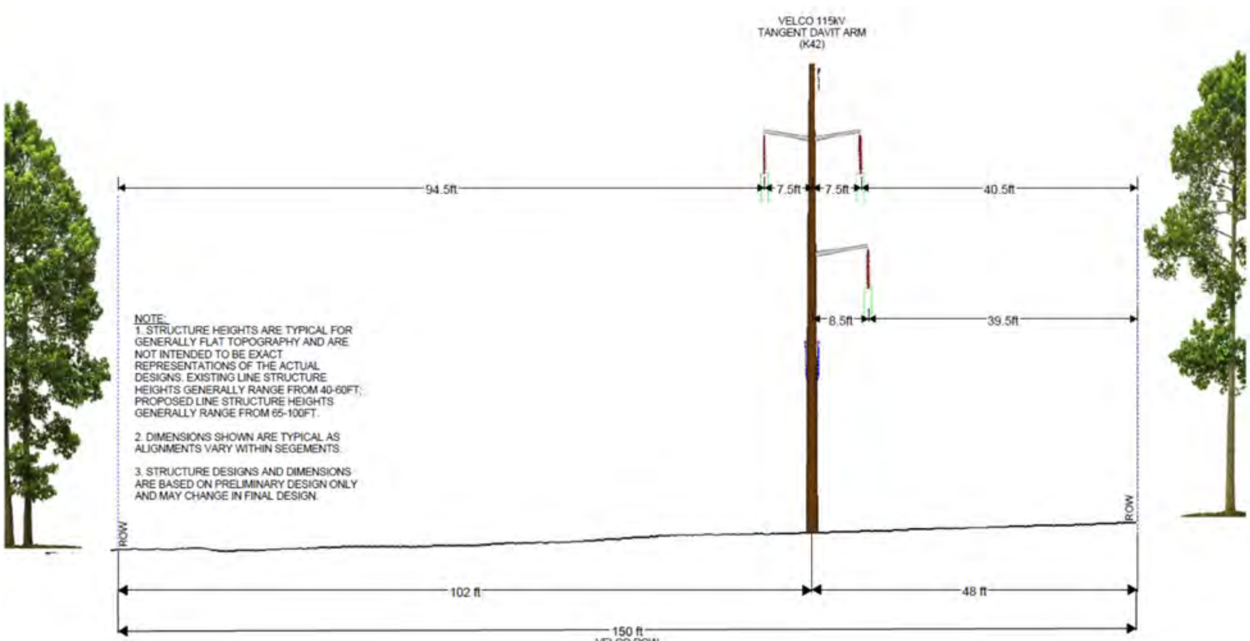

Figure 1b. Post-Project View for Cross Section 1 (CS1).

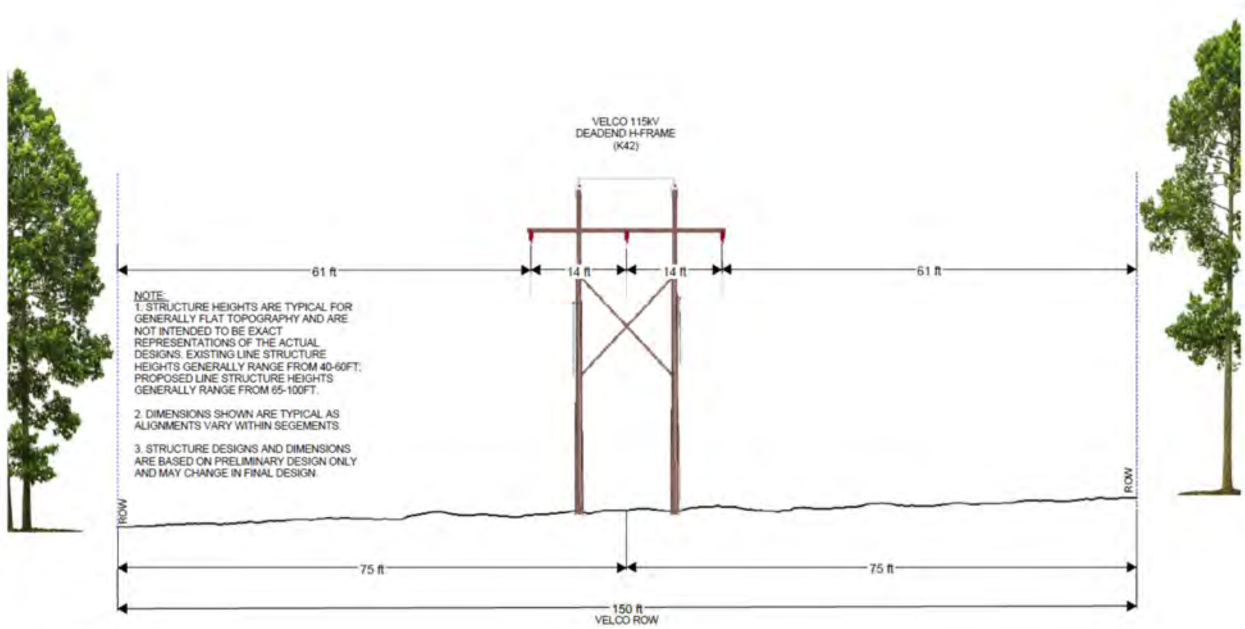

Figure 2a. Existing (Pre-Project) View for Cross Section 2 (CS2).

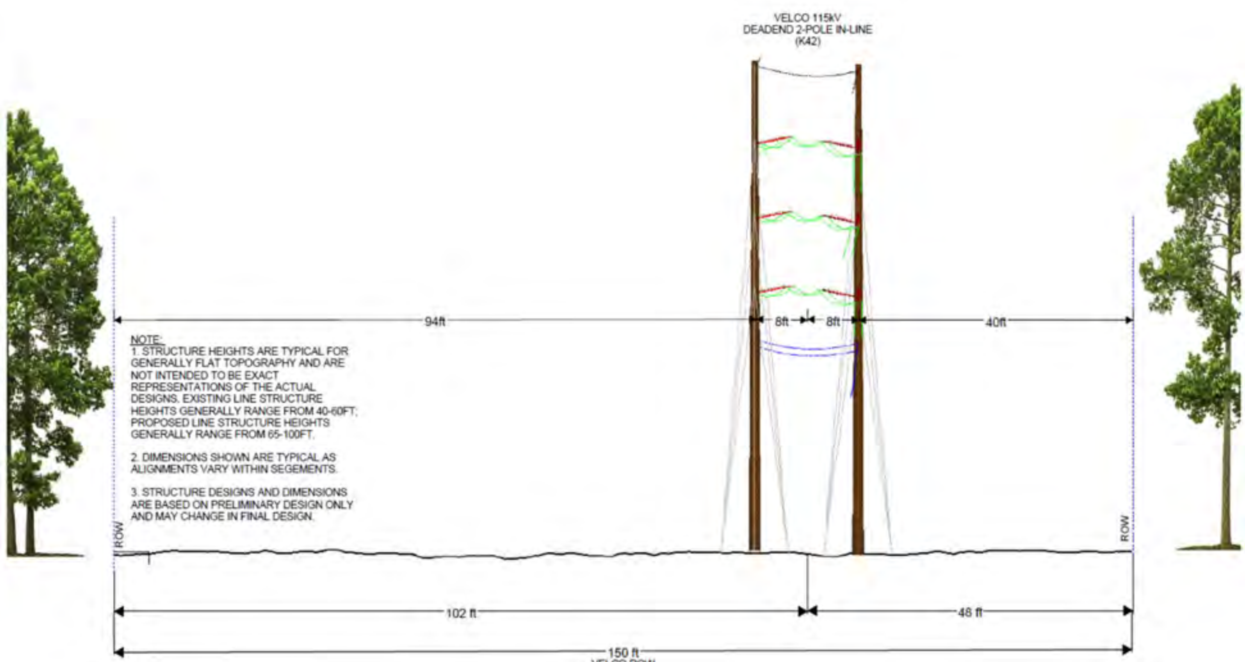

Figure 2b. Post-Project View for Cross Section 2 (CS2).

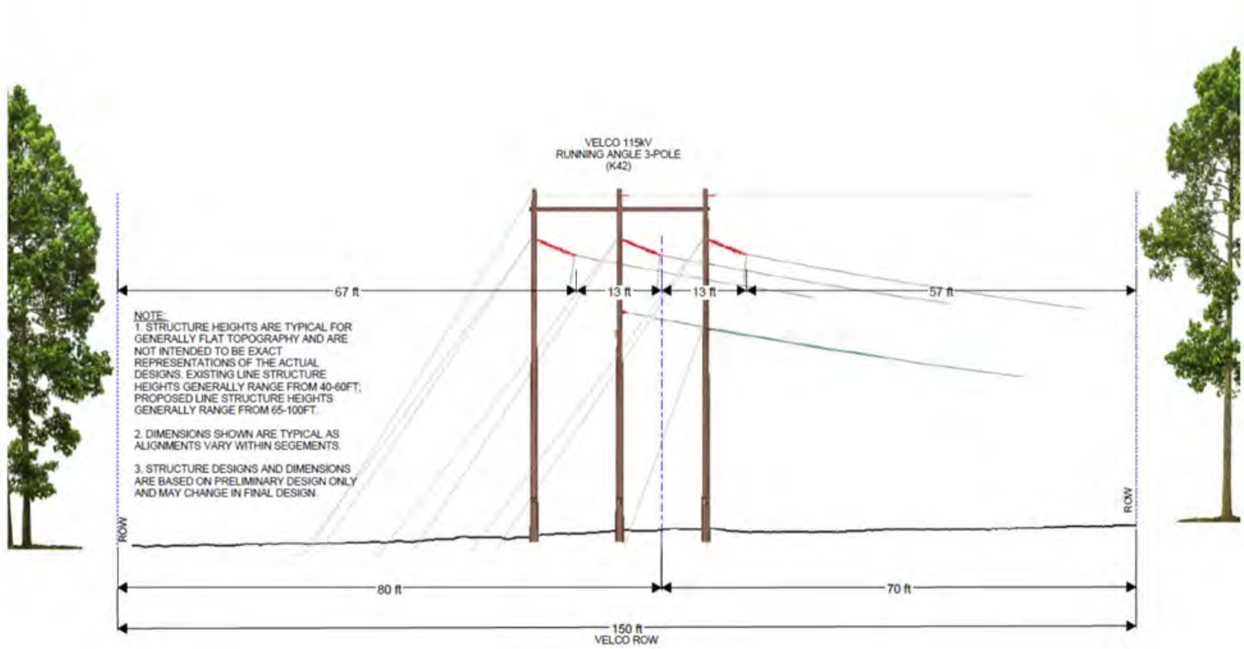

Figure 3a. Existing (Pre-Project) View for Cross Section 3 (CS3).

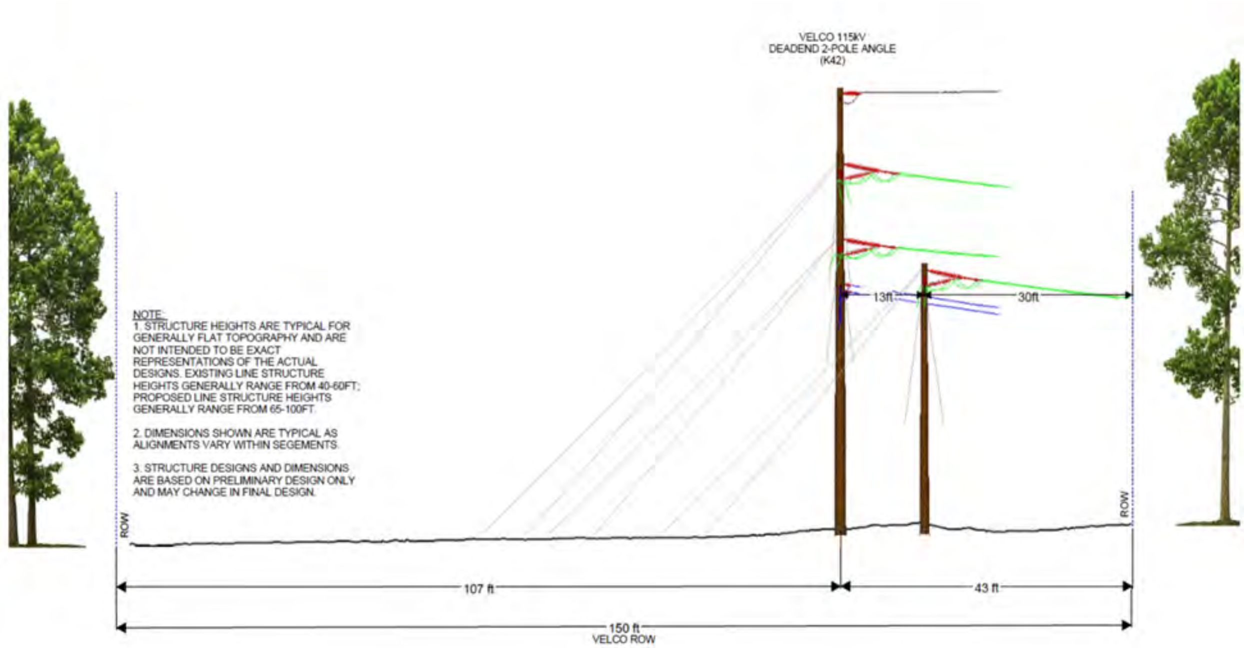

Figure 3b. Post-Project View for Cross Section 3 (CS3).

Software Program Used by VELCO for Modeling EMF

VELCO used a computer program to calculate magnetic and electric field levels from the transmission lines at cross sections perpendicular to the lines as a function of voltage, current, and distance. This program operates using Maxwell's equations, which accurately describe the laws of physics as they apply to electricity and magnetism. Modeled fields using this program are both precise and accurate for the input data utilized. Results of such modeling programs have been checked against each other to ensure that the implementation of the laws of physics are consistent. In these validation tests, EMF results have been found to be in very good agreement with each other (*e.g.*, Mamishev and Russell, 1995).

Basically, the electric and magnetic fields produced by transmission and distribution lines are a function of the voltages and currents present on each of the phase conductors, their relative spacing, and the height of the conductors above grade. For the CS1 cross section that is representative of the conductor arrangement for the majority of the Project route, the existing K42 phase-conductor configuration is flat horizontal, while the proposed phase-conductor configuration is delta. For the CS2 and CS3 cross sections that are for 1-2 structures each along the Project route, the existing flat horizontal arrangement of the K42 phase-conductors is being replaced with either a two-pole vertical dead-end structure or a special two-pole angle structure, respectively. Table 1 summarizes the input data for the proposed, reconductored K42 line for the typical CS1 cross section, including the PLLG, MLHG, and maximum thermal limit load currents that were used:

Table 1. Proposed K42 Transmission Line CS1 Phase-Conductor Configuration and Loadings

Conductor	Voltage	Conductor Diameter (inches)	Cond/ Bund	Height above grade, feet @ maximum sag	PLLG Loading	MLHG Loading	Max. Thermal Limit
Phase A conductor	121 kV	1.345	2	25	791 A	1331 A	3462 A
Phase B conductor	121 kV	1.345	2	40	791 A	1331 A	3462 A
Phase C conductor	121 kV	1.345	2	40	791 A	1331 A	3462 A
Grounding Wire	0	0.62	1	65	0 A	0 A	0 A

kV = kilovolt; A = ampere; PLLG = peak load low generation; MLHG = minimum load high generation, where the PLLG and MLHG loadings comprise the expected operating range.

EMF Modeling Results

VELCO modeled pre- and post-Project EMF values at 1 meter above grade for the 115-kV K42 overhead transmission line at the three representative cross sections. For each cross section, EMF modeling was conducted assuming full sag for the most conservative mid-span location of lowest conductor sag (*i.e.*, closest to the ground surface). Figures 4 through 6 (below and on the following pages) show the results of the EMF modeling for the three representative cross sections. Table 2 summarizes the maximum and ROW-edge field results for the pre- and post-Project EMF modeling across the cross sections and loading cases.

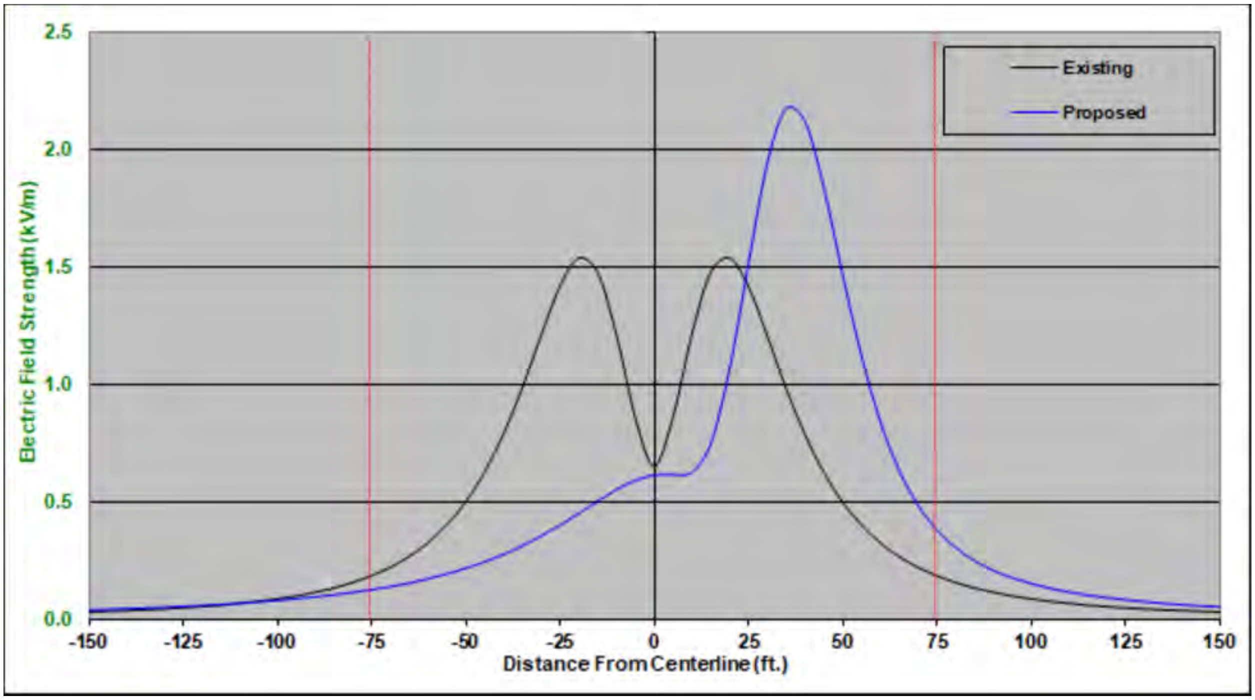

Figure 4a. Cross Section 1 (CS1): Electric Field Modeling Results in kV/m at 1 meter Above Ground. ROW edges are at ±75 feet. Since electric fields are dependent on voltage and the spatial configuration of the conductors, and have little dependence on conductor loads, there is just a single pre-Project electric field profile and a single post-Project electric field profile.

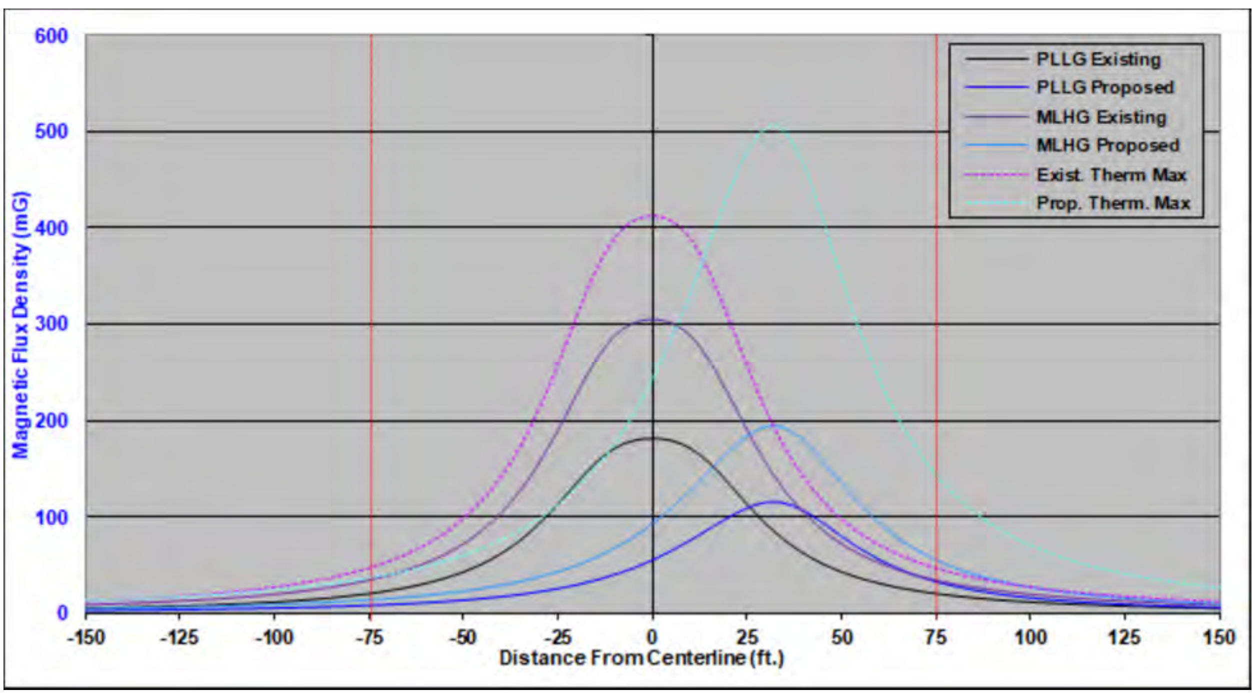

Figure 4b. Cross Section 1 (CS1): Magnetic Field Modeling Results in mG at 1 meter Above Ground. ROW edges are at ±75 feet.

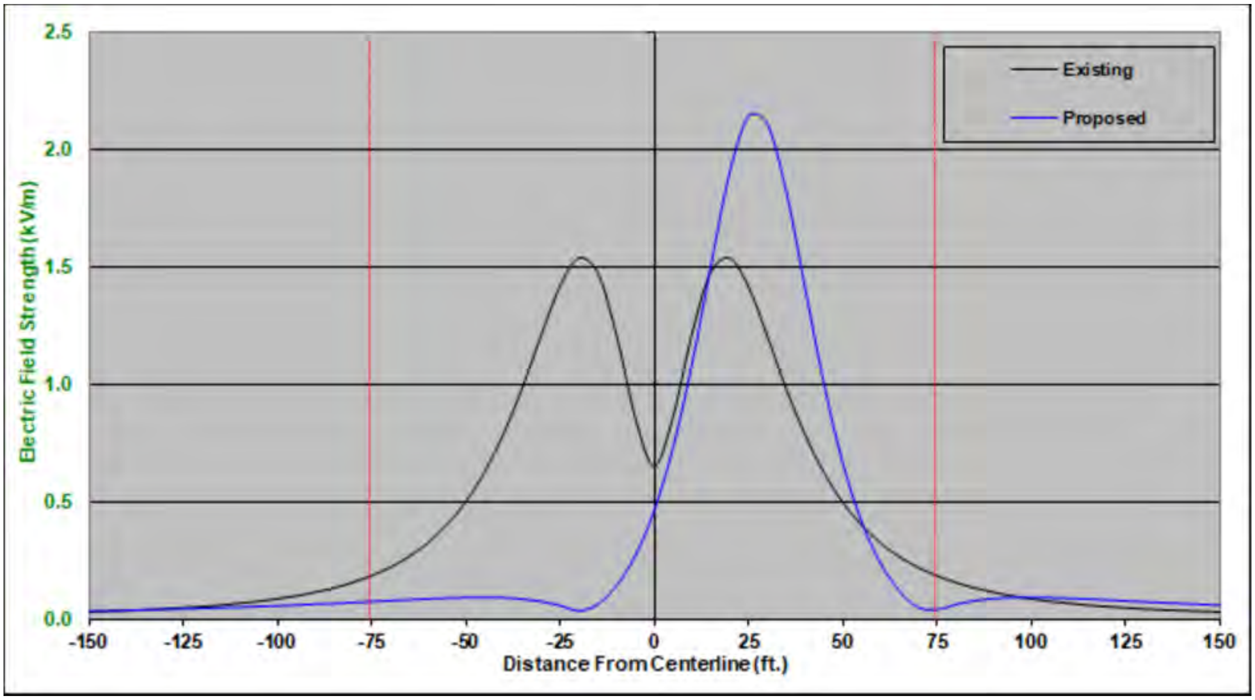

Figure 5a. Cross Section 2 (CS2): Electric Field Modeling Results in kV/m at 1 meter Above Ground. ROW edges are at ±75 feet. Since electric fields are dependent on voltage and the spatial configuration of the conductors, and have little dependence on conductor loads, there is just a single pre-Project electric field profile and a single post-Project electric field profile.

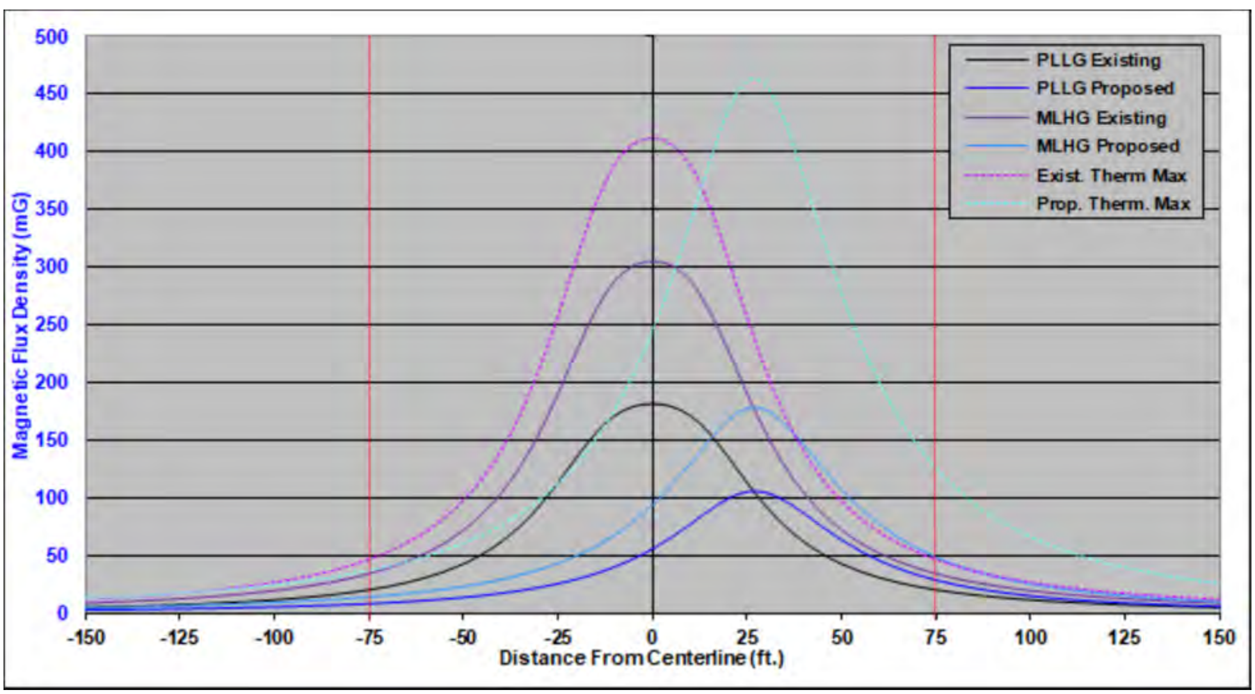

Figure 5b. Cross Section 2 (CS2): Magnetic Field Modeling Results in mG at 1 meter Above Ground. ROW edges are at ±75 feet.

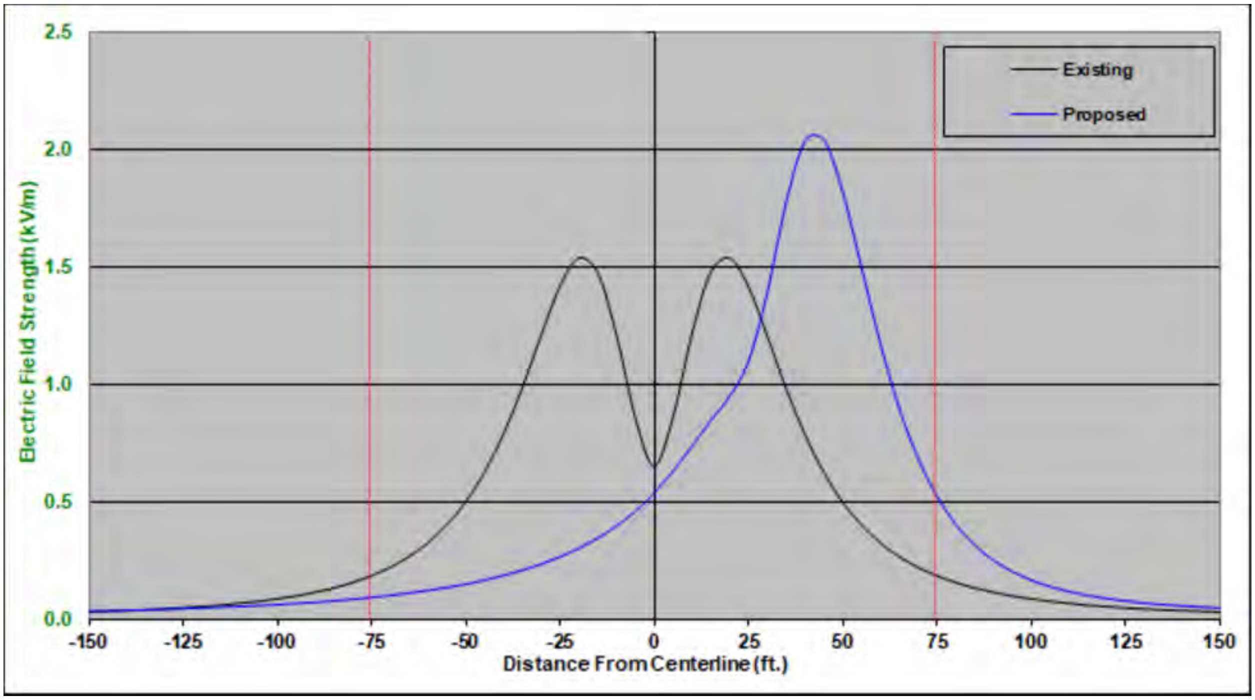

Figure 6a. Cross Section 3 (CS3): Electric Field Modeling Results in kV/m at 1 meter Above Ground. ROW edges are at ±75 feet. Since electric fields are dependent on voltage and the spatial configuration of the conductors, and have little dependence on conductor loads, there is just a single pre-Project electric field profile and a single post-Project electric field profile.

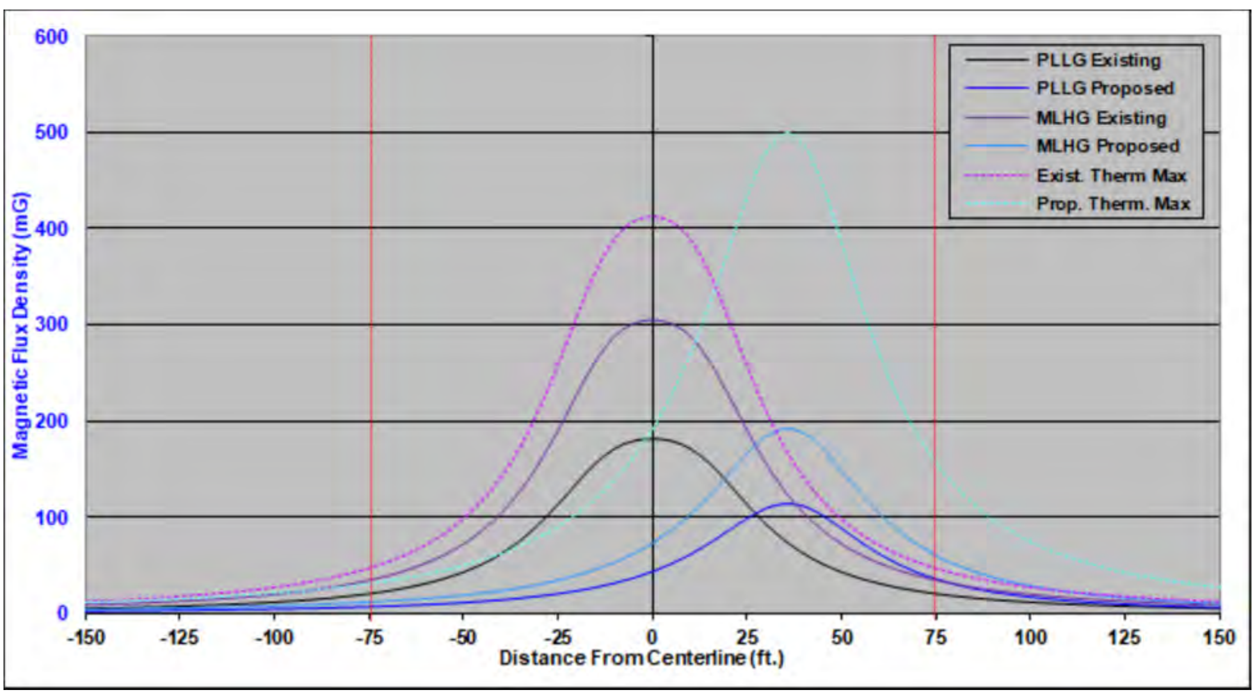

Figure 6b. Cross Section 3 (CS3): Magnetic Field Modeling Results in mG at 1 meter Above Ground. ROW edges are at ±75 feet.

Table 2. Modeled Project Maximum and ROW-edge EMF Values at Three Load Levels

Cross Section (CS) Location	Modeled Magnetic Field Values (mG)			Modeled Electric Field Values (kV/m)		
	PLLG Load	MLHG Load	Thermal Limit	PLLG Load	MLHG Load	Thermal Limit
CS1, CS2, CS3 – Pre-Project						
– 75 feet, ROW Edge	20.5	34.5	46.7	0.18	0.18	0.18
+ 75 feet, ROW Edge	20.5	34.5	46.7	0.18	0.18	0.18
Maximum Within the ROW	182	305	412	1.54	1.54	1.54
CS1 – Post-Project						
– 75 feet, ROW Edge	8.35	14.1	36.5	0.12	0.12	0.12
+ 75 feet, ROW Edge	33.0	55.5	144	0.38	0.38	0.38
Maximum Within the ROW	115	194	504	2.17	2.17	2.17
CS2 – Post-Project						
– 75 feet, ROW Edge	8.55	14.38	37.4	0.073	0.073	0.073
+ 75 feet, ROW Edge	29.0	48.7	127	0.04	0.04	0.04
Maximum Within the ROW	106	178	462	2.13	2.13	2.13
CS3 – Post-Project						
– 75 feet, ROW Edge	7.05	11.87	30.9	0.090	0.090	0.090
+ 75 feet, ROW Edge	35.9	60.4	157	0.52	0.52	0.52
Maximum Within the ROW	114	192	500	2.04	2.04	2.04

CS = cross section; ROW = right-of-way; mG = milligauss; kV/m = kilovolt/meter; PLLG = peak load low generation; MLHG = minimum load high generation.

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. Common examples are the static electricity attraction between a comb and our hair or a static electricity spark 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, and consumption).

Definition of Electric and Magnetic Fields (EMFs)

The electrical tension on utility power lines is expressed in volts or kilovolts (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 (EF), usually expressed in units of kilovolts per meter (kV/m). The size of the EF depends on the line voltage, the separation distance between lines and ground, and other factors.

Power lines also carry an electric current that creates a magnetic field (MF). The units for electric current are amperes (A), which is a measure of the "flow" of electricity. Electric current is analogous to the flow of water in a plumbing system. The MF produced by an electric current is usually expressed in units of gauss (G) or milligauss (mG) (1 G = 1,000 mG).[2] The size of the MF depends on the electric current, the distance to the current-carrying conductor, and other factors.

There Are Many Natural and Man-made Sources of EMFs

Everyone experiences a variety of natural and man-made EMFs. EMF levels can be steady or slowly varying (often called direct current [DC] fields), or EMF levels can vary in time (often called alternating current [AC] fields). When the time variation corresponds to that of standard North American power line currents (*i.e.*, 60 cycles per second), the fields are called 60-Hz EMFs, or power-frequency EMFs.

Man-made MFs are common in everyday life. For example, many childhood toys contain magnets. Such permanent magnets generate strong, steady (DC) MFs. Typical toy magnets (*e.g.*, refrigerator door magnets) have fields of 100,000-500,000 mG. On a larger scale, Earth's core also creates a steady DC MF that can be easily demonstrated with a compass needle. The size of the Earth's MF in the northern US is about 550 mG.

Power-frequency EMFs Are Found Near Electric Lines and Appliances

In North America, electric power 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 EMFs nearby. The size of the MF is proportional to the line current, while the size of the EF is proportional to the line voltage. The EMFs associated with electrical wires and electrical equipment decrease rapidly with increasing distance away from the electrical wires. Specifically, EMFs from three-phased, balanced conductors decrease in proportion to the square of the distance from the conductors (*i.e.*, $1/d^2$) (IEEE, 2014).

When EMF derives from different wires or conductors that are in close proximity, or adjacent to one another, the level 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. EMF may partially add, or partially cancel but, because adjacent wires are often carrying current in opposite directions, the EMF produced generally tends to cancel.

EMFs in the home arise from electric appliances, indoor wiring, grounding currents on pipes and ground wires, and outdoor distribution or transmission circuits. Inside residences, typical baseline 60-Hz MF levels (away from appliances) range from 0.5-5.0 mG.

Higher 60-Hz MF 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 MF levels in the range of 40-300 mG at distances of 1 foot (NIEHS, 2002). MF levels from personal care appliances held within half a foot (*e.g.*, shavers, hair dryers, massagers) can produce average fields of 600-700 mG. At school and in the workplace, lights, motors, copy machines, vending machines, video-display terminals, pencil sharpeners, electric tools, electric heaters, and building wiring are all sources of 60-Hz MFs.

Recognizing that magnetic resonance imaging (MRI) is a source of DC fields rather than 60-Hz fields, MRIs are a diagnostic procedure that puts humans in much larger, but steady, MF (*e.g.*, levels of 20,000,000

[2] Another unit for magnetic field (MF) levels is the microtesla (μT) (1 μT = 10 mG).

mG). The scanning MF superimposed on the large, steady static field (which is the source of the characteristic audio noise of MRI scans) exposes the body to time-varying MF similar to time-varying power-frequency MF.

State, National, and International Guidelines for Power-Frequency EMFs

Table 3 shows guidelines for 60-Hz AC EMFs from national and world health and safety organizations that are designed to be protective of workers and the general public against any adverse health effects. The limit values should not be viewed as demarcation lines between safe and dangerous levels of EMFs, but rather, levels that assure safety with an adequate margin to allow for uncertainties in the science. As part of its International EMF Project, the World Health Organization (WHO) has conducted comprehensive reviews of EMF health-effects research and existing standards and guidelines. The WHO website for the International EMF Project (WHO, 2023) notes: "*[T]he main conclusion from the WHO reviews is that EMF exposures below the limits recommended in the ICNIRP international guidelines do not appear to have any known consequence on health.*"

The US has no federal standards limiting either residential or occupational exposure to 60-Hz EMFs. Table 4 lists 60-Hz AC EMF guidelines that have been adopted by various states in the US. State guidelines are not generally health-effect-based and have typically been adopted to maintain the *status quo* for EMFs on and near a transmission line ROW.

Table 3 60-Hz AC EMF Guidelines Established by International Health and Safety Organizations

Organization	Electric Field	Magnetic Field
American Conference of Governmental and Industrial Hygienists (ACGIH) (occupational)	25 kV/m(1)	10,000 mG(1) 1,000 mG(2)
International Commission on Non-Ionizing Radiation Protection (ICNIRP) (general public)	4.2 kV/m(3)	2,000 mG(3)
International Commission on Non-Ionizing Radiation Protection (ICNIRP) (occupational)	8.3 kV/m(3)	10,000 mG(3)
Institute of Electrical and Electronics Engineers (IEEE) Standard C95.1™-2019 (general public)	5.0 kV/m(4)	9,040 mG(4)
Institute of Electrical and Electronics Engineers (IEEE) Standard C95.1™-2019 (occupational)	20.0 kV/m(4)	27,100 mG(4)

Notes:
AC = Alternating Current; EMF = Electric and Magnetic Field; Hz = Hertz; kV/m = Kilovolts Per Meter; mG = Milligauss.
(1) The ACGIH guidelines for the general worker (ACGIH, 2022).
(2) The ACGIH guideline for workers with cardiac pacemakers (ACGIH, 2022).
(3) ICNIRP (2010).
(4) IEEE (2019); developed by the IEEE International Committee on Electromagnetic Safety (ICES).

Table 4 State EMF Standards and Guidelines for Transmission Lines

State	Line Voltage (kV)	Electric Field (kV/m)		Magnetic Field (mG)	
		On ROW	Edge of ROW	On ROW	Edge of ROW
Florida[1]	69-230 >230-500 >500	8.0 10.0 15.0	2.0[2] 2.0[2] 5.5[2]		150[2] 200[2] 250[2,3]
Massachusetts			1.8		85
Minnesota		8.0			
Montana		7.0[4]	1.0[5]		
New Jersey			3.0		
New York[1]		11.8 11.0[6] 7.0[4]	1.6		200
Oregon		9.0			

Notes:

Blank = Not Applicable/Not Available; EMF = Electric and Magnetic Field; kV = Kilovolt; kV/m = Kilovolts Per Meter; mG = Milligauss; ROW = Right-of-Way.

Sources: NIEHS (2002); FLDEP (2008); MA EFSB (2009).

(1) Magnetic fields for winter-normal (*i.e.*, at maximum current-carrying capability of the conductors).
(2) Includes the property boundary of a substation.
(3) Also applies to 500-kV double-circuit lines built on existing ROWs.
(4) Maximum for highway crossings.
(5) May be waived by the landowner.
(6) Maximum for private road crossings.

Conclusions

All of the post-Project modeled electric and magnetic field values fall well below the ICNIRP 60-Hz EMF guideline limit values for public exposure (2,000 mG and 4.2 kV/m; ICNIRP, 2010). Overall, there is thus no expectation of adverse health effects due to the EMF changes caused by the K42 Line Rebuild and Reconductoring Project.

References

American Conference of Governmental Industrial Hygienists (ACGIH). 2022. "2022 TLVs and BEIs: Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices." American Conference of Governmental Industrial Hygienists (ACGIH), Cincinnati, OH, 307p.

Florida Dept. of Environmental Protection (FLDEP). 2008. "Electric and Magnetic Fields." Rule 62-814, F.S.C. 13p., June 1.

Institute of Electrical and Electronics Engineers, Inc. (IEEE). 2014. "IEEE Guide for the Design, Construction, and Operation of Electric Power Substations for Community Acceptance and Environmental Compatibility." IEEE 1127 - 2013. 50p.

Institute of Electrical and Electronics Engineers, Inc. (IEEE). 2019. "IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz." IEEE Std. C95.1-2019, 312p.

International Commission on Non-Ionizing Radiation Protection (ICNIRP). 2010. "ICNIRP Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz to 100 Hz)." *Health Phys*. 99(6):818-836. doi: 10.1097/HP.0b013e3181f06c86.

Mamishev, AV; Russell, BD. 1995. "Measurement of magnetic fields in the direct proximity of power line conductors." *IEEE Trans. Power Deliv*. 10(3):1211-1216. doi: 10.1109/61.400898.

Massachusetts Energy Facilities Siting Board (MA EFSB); Urman, S. 2009. "Final decision [In the Matter of the Petition of Pioneer Valley Energy Center, LLC for Approval to Construct a Generating Facility in the City of Westfield, Massachusetts and the Petition of Pioneer Valley Energy Center, LLC and Westfield Gas & Electric for Approval to Construct a Natural Gas Pipeline in the City of Westfield, Massachusetts]." EFSB 08-1. 80p., October 19.

National Institute of Environmental Health Sciences (NIEHS). 2002. "Questions and Answers about EMF Electric and Magnetic Fields Associated with the Use of Electric Power." 65p., June.

World Health Organization (WHO). 2023. "Radiation and health: Protection norms and standards." Accessed at https://www.who.int/teams/environment-climate-change-and-health/radiation-and-health/protection-norms.