

**LIBBY TO TROY REBUILD PROJECT**

***APPENDIX H***  
***ELECTRICAL EFFECTS***

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Prepared by  
**T. Dan Bracken, Inc.**

for  
**Bonneville Power Administration**



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# ELECTRICAL EFFECTS FROM THE BPA LIBBY TO TROY TRANSMISSION LINE REBUILD PROJECT

## 1.0 Introduction

The Bonneville Power Administration (BPA) is proposing to rebuild an approximately 17-mile (mi.) (27.4-kilometer [km]) 115-kilovolt (kV) single-circuit transmission line from the existing Libby Flathead Electric Cooperative (FEC) Substation near Libby, Montana to the existing BPA Troy substation near Troy, Montana. The proposed line is designated the Libby to Troy Transmission Line Rebuild. The proposed line would be built on existing and new right-of-way entirely within the state of Montana as either a single-circuit 115-kV line or as a double-circuit line operated at 115-kV. In the latter case, the line would be constructed to specifications for a 230-kV line but would be operated at 115-kV. It is unlikely that the double-circuit line would be operated as a 230-kV line in the intermediate future (10 – 20 years), if ever. Therefore this alternative was analyzed with an operating voltage of 115 kV.

Most of the proposed line would be located on the right-of-way of the existing Libby to Troy 115-kV line. Along some portions of the route, the existing right-of-way would have to be widened to accommodate the proposed line. Where the proposed line deviates from the existing right-of-way, new right-of-way would be acquired. New rights-of-way would be required for three possible realignments: the Pipe Creek Realignment, the Quartz Creek Realignment, and the Kootenai River Crossing Realignment (Table 1). There are no existing high-voltage transmission lines that parallel the existing route or the proposed realignments. However, there are distribution lines underbuilt on some of the poles of the existing 115-kV transmission line. In locations where there are existing underbuilt distribution lines, they would be accommodated either by placing them on new poles of the proposed line or by leaving them on existing poles that had been cut off.

The purpose of this report is to describe and quantify the electrical effects of the proposed Libby to Troy Transmission Line Rebuild project. These effects include the following:

- the levels of 60-hertz (Hz; cycles per second) electric and magnetic fields (EMF) at 3.28 feet (ft.) or 1 meter (m) above the ground,
- the effects associated with those fields,
- the levels of audible noise produced by the line, and
- electromagnetic interference associated with the line.

Electrical effects occur near all transmission lines, including the existing 115-kV line and other lines with voltages up to 500-kV in Montana. The levels of these quantities for the proposed line are computed and compared with those from the existing 115-kV line.

The voltage on the conductors of transmission lines generates an *electric field* in the space between the conductors and the ground. The electric field is calculated or measured in units of volts-per-meter (V/m) or kilovolts-per-meter (kV/m) at a height of 3.28 ft. (1 m) above the ground. The current flowing in the conductors of the transmission line generates a *magnetic field* in the air and earth near the transmission line; current is expressed in units of amperes (A). The magnetic field is expressed in milligauss (mG), and is also usually measured or calculated at a height of 3.28 ft. (1 m) above the ground. The electric field at the surface of the conductors causes the phenomenon of *corona*. Corona is the electrical breakdown or ionization of air in very strong electric fields, and is the source of audible noise, electromagnetic

radiation, and visible light. Corona is primarily of concern for transmission lines operating at 230 kV or higher and generally not a concern for 115-kV lines.

To quantify EMF levels along the route, the electric and magnetic fields from the proposed transmission line were calculated using the BPA Corona and Field Effects Program (USDOE, undated). In this program, the calculation of 60-Hz fields uses standard superposition techniques for vector fields from several line sources: in this case, the line sources are transmission-line conductors. (Vector fields have both magnitude and direction: these must be taken into account when combining fields from different sources.) Important input parameters to the computer program are voltage, current, and geometric configuration of the line. The transmission-line conductors are assumed to be straight, parallel to each other, and located above and parallel to an infinite flat ground plane. Although such conditions do not occur under real lines because of conductor sag and variable terrain, the validity and limitations of calculations using these assumptions have been well verified by comparisons with measurements. This approach was used to estimate fields for the proposed Libby to Troy Rebuild line, where minimum clearances were assumed to provide worst-case (highest) estimates for the fields.

Electric fields are calculated using an imaging method. Fields from the conductors and their images in the ground plane are superimposed with the proper magnitude and phase to produce the total field at a selected location.

The total magnetic field is calculated from the vector summation of the fields from currents in all the transmission-line conductors. Balanced (equal) currents are assumed for each three-phase circuit; the contribution of induced image currents in the conductive earth is not included.

Electric and magnetic fields for the proposed line were calculated at the standard height (3.28 ft. or 1 m) above the ground (IEEE, 1994). Calculations were performed out to 150 ft. (46 m) from the centerline of the existing corridor. The validity and limitations of such calculations have been well verified by measurements. Because maximum voltage, maximum current, and minimum conductor height above-ground are used, **the calculated values given here represent worst-case conditions:** i.e., the calculated fields are higher than they would be in practice. Such worst-case conditions would seldom occur.

The corona performance of the proposed line was also predicted using the BPA Corona and Field Effects Program (USDOE, undated). Corona performance is calculated using empirical equations that have been developed over several years from the results of measurements on numerous high-voltage lines (Chartier and Stearns, 1981; Chartier, 1983). The validity of this approach for corona-generated audible noise has been demonstrated through comparisons with measurements on other lines all over the United States (IEEE Committee Report, 1982). The accuracy of this method for predicting corona-generated radio and television interference from transmission lines has also been established (Olsen et al., 1992). Important input parameters to the computer program are voltage, current, conductor size, and geometric configuration of the line.

Corona is a highly variable phenomenon that depends on conditions along a length of line. Predictions of the levels of corona effects are reported in statistical terms to account for this variability. Calculations of audible noise and electromagnetic interference levels were made under conditions of an estimated average operating voltage of 118.5 kV and with the average line height along a span of 30 to 40 ft. (9.1 to 12.2 m), depending on the line configuration and location. Levels of audible noise, radio interference, and television interference are predicted for both fair and foul weather; however, corona is basically a foul-weather phenomenon. Wet conductors can occur during periods of rain, fog, snow, or icing. In the Libby-Troy area, such conditions are expected to occur about 6.2% of the time during a year based on hourly precipitation records from Libby during 2000 – 2004 (NOAA, 2005). Corona activity also increases with

altitude. For purposes of evaluating corona effects from the proposed line, an altitude of 2000 ft. (610 m) was assumed.

## **2.0 Physical Description**

### **2.1 Proposed Line**

BPA provided the physical and operating characteristics of the proposed line. The proposed 115-kV single-circuit transmission line would consist of three phase wires placed on mostly H-frame wood or steel structures (Figure 1a). Along short portions of the route the proposed 115-kV line conductors would be held on stand-off insulators on single wood poles with underbuilt distribution lines (Figure 1b). For the single-circuit alternative the proposed 115-kV structures would be similar in appearance to those of the existing line. The single-pole configuration for the Kootenai River Crossing realignment would not have underbuilt distribution lines and the minimum clearance would be the same as for the H-frame configuration, 24 ft.

The proposed double-circuit line alternative would be placed on tubular steel pole structures (Figure 1c). The double-circuit towers would have two sets of three phase wires arranged vertically on either side of the structure. Each set of three phase wires comprises a circuit. Initially, the two circuits would be tied together and operate as one circuit at 115-kV.

Voltage and current waves are displaced by 120° in time (one-third of a cycle) on each electrical phase. The maximum phase-to-phase voltage for both alternatives would be 121 kV; the average voltage would be 118.5 kV.

The 2002 - 2004 peak load for the existing Libby to Troy 115-kV line was 61.3 megawatts (MW), corresponding to currents of 301 amperes (A) per phase. The projected peak loads in 10 years for the proposed line rebuild are: 60.3 MW for the 115-kV single-circuit alternative and 65.3 MW for the double-circuit alternative. These loads correspond to a projected maximum current per phase of 296 A on the 115-kV single-circuit alternative and 160 A on the double-circuit alternative operated at 115-kV. The peak current is projected to remain relatively constant over the next 10 years and beyond.

The load factor for the existing and proposed lines is 0.43 (average load = peak load x load factor). Thus, the average currents on each circuit would be 43% of the maximum projected values.

The electrical characteristics and physical dimensions for the proposed line configuration are shown in Figure 1, and summarized in Table 2. Each phase of the proposed 115-kV single-circuit line would have one 0.95-inch (in.) (2.4-centimeter [cm]) diameter conductors (ACSR: aluminum conductor, steel reinforced). The proposed double-circuit alternative would use a single 1.30-in. (3.30-cm) conductor for each phase.

The horizontal phase spacing between the conductors of the 115-kV H-frame configuration would be 12.0 ft. (3.6 m), compared with 11.5 ft (3.5 m) for the existing H-frame configuration.

For the double-circuit configuration the horizontal spacing between lower and upper conductor positions would be about 20 ft. (6.1 m). Between the middle conductors, the horizontal spacing would be 30.0 ft. (9.15 m). The vertical spacing between the conductor positions would be 18.0 ft. (5.49 m). The spacing between conductor locations would vary slightly where special towers are used, such as at angle points along the line. Short sections of the proposed line where conductor locations would change, such as in

transitions between H-frame and single-pole configurations and upon entry to a substation, were not analyzed.

For the 115-kV H-frame configuration minimum conductor-to-ground clearance would be 24 ft. (7.3 m) at a conductor temperature of 212°F (100°C); clearances above ground would be greater under normal operating temperatures. The average clearance above ground along a span would be approximately 30 ft. (9.1 m); this latter value was used for corona calculations. At road crossings, the ground clearance would be at least 35 ft. (10.7 m). The final design of the proposed H-frame line could entail larger clearances. Clearances above ground and road crossings for the single wood pole structures would depend on the clearance required for the underbuilt communications and/or distribution lines. With underbuilt lines present, the 115-kV conductors would be higher than for the H-frame configuration (Figure 2).

Conductor-to-ground clearances for the 230-kV double circuit configuration would be 26.5 ft. (8.0 m), or greater, above ground. The average conductor-to-ground clearance along a span would be about 37.5 ft. (11.4 m). At road crossings minimum conductor clearance would be increased to 37.5 ft. (11.4 m) or greater.

The right-of-way width for the proposed 115-kV single-circuit alternative would vary from 60 (18.3 m) to 100 feet (30.5 m), with 80 feet (24.4 m) being the most prevalent width. The proposed right-of-width for the 230-kV alternative is 100 feet (30.5 m) over all but a few hundred feet of the proposed route. These right-of-way widths represent similar or increased widths from those of the existing line.

The electrical phasing of the proposed double-circuit line would be selected to ensure that BPA criteria for electric-field and audible-noise levels are met and to minimize electric and magnetic fields to the extent practical. The results reported here for fields and corona effects assume that the electrical phasing of the two circuits on the double-circuit line would be such as to place different electrical phases on the lower conductors of each circuit and on the upper conductors of each circuit. This phasing configuration tends to minimize the fields at ground level. During the design process, BPA will verify that any changes from the phasing described here continue to meet BPA design criteria. The choice of electrical phasing does not affect the performance of the single circuit line.

## **2.2 Existing Lines**

There are no existing transmission lines parallel to the existing or proposed alternative routes.

## **3.0 Electric Field**

### **3.1 Basic Concepts**

An electric field is said to exist in a region of space if an electrical charge, at rest in that space, experiences a force of electrical origin (i.e., electric fields cause free charges to move). Electric field is a vector quantity: that is, it has both magnitude and direction. The direction corresponds to the direction that a positive charge would move in the field. Sources of electric fields are unbalanced electrical charges (positive or negative) and time-varying magnetic fields. Transmission lines, distribution lines, house wiring, and appliances generate electric fields in their vicinity because of unbalanced electrical charge on energized conductors. The unbalanced charge is associated with the voltage on the energized system. On the power system in North America, the voltage and charge on the energized conductors are cyclic (plus to minus to plus) at a rate of 60 times per second. This changing voltage results in electric fields near sources that are also time-varying at a frequency of 60 hertz (Hz; a frequency unit equivalent to cycles per second).



As noted earlier, electric fields are expressed in units of volts per meter (V/m) or kilovolts (thousands of volts) per meter (kV/m). Electric- and magnetic-field magnitudes in this report are expressed in root-mean-square (rms) units. For sinusoidal waves, the rms amplitude is given as the peak amplitude divided by the square root of two.

The spatial uniformity of an electric field depends on the source of the field and the distance from that source. On the ground, under a transmission line, the electric field is nearly constant in magnitude and direction over distances of several feet (1 meter). However, close to transmission- or distribution-line conductors, the field decreases rapidly with distance from the conductors. Similarly, near small sources such as appliances, the field is not uniform and falls off even more rapidly with distance from the device. If an energized conductor (source) is inside a grounded conducting enclosure, then the electric field outside the enclosure is zero, and the source is said to be shielded.

Electric fields interact with the charges in all matter, including living systems. When a conducting object, such as a vehicle or person, is located in a time-varying electric field near a transmission line, the external electric field exerts forces on the charges in the object, and electric fields and currents are induced in the object. If the object is grounded, then the total current induced in the body (the "short-circuit current") flows to earth. The distribution of the currents within, say, the human body, depends on the electrical conductivities of various parts of the body: for example, muscle and blood have higher conductivity than bone and would therefore experience higher currents.

### **3.2 Transmission-line Electric Fields**

The electric field created by a high-voltage transmission line extends from the energized conductors to other conducting objects such as the ground, towers, vegetation, buildings, vehicles, and people. The calculated strength of the electric field at a height of 3.28 ft. (1 m) above an unvegetated, flat earth is frequently used to describe the electric field under straight, parallel transmission lines. The most important transmission-line parameters that determine the electric field at a 1-m height are conductor height above ground and line voltage.

Calculations of electric fields from transmission lines are performed with computer programs based on well-known physical principles (cf., Deno and Zaffanella, 1982). The calculated values under these conditions represent an ideal situation. When practical conditions approach this ideal model, measurements and calculations agree. Often, however, conditions are far from ideal because of variable terrain and vegetation. In these cases, fields are calculated for ideal conditions, with the lowest conductor clearances to provide upper bounds on the electric field under the transmission lines. With the use of more complex models or empirical results, it is also possible to account accurately for variations in conductor height, topography, and changes in line direction. Because the fields from different sources add vectorially, it is possible to compute the fields from several different lines if the electrical and geometrical properties of the lines are known. However, in general, electric fields near transmission lines with tall (> 1 m) vegetation below are highly complex and cannot be calculated. Measured fields in such situations are highly variable.

For evaluation of EMF from transmission lines, the fields must be calculated for a specific line condition. The NESC states the condition for evaluating electric-field-induced short-circuit current for lines with voltage above 98 kV, line-to-ground, as follows: conductors are at a minimum clearance from ground corresponding to a conductor temperature of 122°F (50°C), and at a maximum voltage (IEEE, 2002a). BPA has supplied the information for calculating electric and magnetic fields from the proposed transmission line: the maximum operating voltage, the estimated peak currents, and the minimum conductor clearances. The minimum clearances at 212°F (100°C) provided by BPA are lower than those

specified in the NESC (50°C). If the fields under the lower BPA conductor clearances meet the NESC criterion, they will also meet the criterion at clearances corresponding to the NESC conditions.

There are standard techniques for measuring transmission-line electric fields (IEEE, 1994). Provided that the conditions at a measurement site closely approximate those of the ideal situation assumed for calculations, measurements of electric fields agree well with the calculated values. If the ideal conditions are not approximated, the measured field can differ substantially from calculated values. Usually the actual electric field at ground level is reduced from the calculated values by various common objects that act as shields.

Maximum or peak field values occur over a small area at midspan, where conductors are closest to the ground. As the location of an electric-field profile approaches a tower, the conductor clearance increases, and the peak field decreases. A grounded tower will reduce the electric field considerably, by shielding. **Thus the assumption of minimum clearance results in peak (worst-case) fields that may be larger than what occur in practice.**

For traditional transmission lines, such as the proposed line, where the right-of-way extends laterally well beyond the conductors, electric fields at the edge of the right-of-way are not as sensitive as the peak field to conductor height. Computed values at the edge of the right-of-way for any line height are fairly representative of what can be expected all along the transmission-line corridor. However, the presence of vegetation on and at the edge of the right-of-way will reduce actual electric-field levels below calculated values.

### 3.3 Calculated Values of Electric Fields

Table 3 shows the calculated values of electric field at 3.28 ft. (1 m) above ground for the existing and proposed Libby to Troy Rebuild transmission lines operated at maximum voltage. The peak value on the right-of-way and the value at the edge of the right-of-way are given for the lines at minimum conductor clearance by configuration. Figure 2 shows lateral profiles for the electric field from the existing and proposed lines at the minimum line heights.

The calculated peak electric field expected on the right-of-way of the proposed H-frame line is 1.5 kV/m, which is the same as for the existing line. For average clearance, the peak field would be 1.0 kV/m or less. As shown in Figure 2, the peak values would be present only at locations directly under the 115-kV line, near mid-span, where the conductors are at the minimum clearance. The conditions of minimum conductor clearance at maximum current and maximum voltage occur very infrequently. The calculated peak levels are rarely reached under real-life conditions, because the actual line height is generally above the minimum value used in the computer model, because the actual voltage is below the maximum value used in the model, and because vegetation within and near the edge of the right-of-way tends to shield the field at ground level. Maximum electric fields on existing 115-kV corridors are typically the same as would occur under the proposed line. On 230-kV corridors peak fields are typically 2.5 to 3 kV/m and on 500-kV transmission line corridors, the maximum electric fields range from 7 to 9 kV/m.

The largest value expected at the edge of the right-of-way of the proposed H-frame line is 1.1 kV/m for the 60-foot right-of-way, decreasing to 0.4 kV/m for the 100-foot right-of-way.

Electric fields under the proposed single-pole configuration with an underbuild would be less than those under the H-frame configuration because of the increased height of the conductors. Peak fields would be 0.3 kV/m or less on the right-of-way and 0.1 to 0.2 kV/m at the edge of the right-of-way depending on the width. These field levels are comparable with those found for the single-pole sections of the existing line.

For the Kootenai River Crossing realignment the single-pole configuration without underbuild would have a peak field of 1.3 kV/m and the field at the edge of a an 80-foot right-of-way would be 0.2 kV/m.

Peak fields from the proposed double-circuit line operated at 115-kV would be 1.2 kV/m on the right-of-way and 0.2 kV/m at the edge of the right-of-way. These values are less than those for the existing and proposed 115-kV H-frame lines.

### **3.4 Environmental Electric Fields**

The electric fields associated with the Libby to Troy Rebuild line can be compared with those found in other environments. Sources of 60-Hz electric (and magnetic) fields exist everywhere electricity is used; levels of these fields in the modern environment vary over a wide range. Electric-field levels associated with the use of electrical energy are orders of magnitude greater than naturally occurring 60-Hz fields of about 0.0001 V/m, which stem from atmospheric and extraterrestrial sources.

Electric fields in outdoor, publicly accessible places range from less than 1 V/m to 12 kV/m; the large fields exist close to high-voltage transmission lines of 230 kV or higher. In remote areas without electrical service, 60-Hz field levels can be much lower than 1 V/m. Electric fields in home and work environments generally are not spatially uniform like those of transmission lines; therefore, care must be taken when making comparisons between fields from different sources such as appliances and electric lines. In addition, fields from all sources can be strongly modified by the presence of conducting objects. However, it is helpful to know the levels of electric fields generated in domestic and office environments in order to compare commonly experienced field levels with those near transmission lines.

Numerous measurements of residential electric fields have been reported for various parts of the United States, Canada, and Europe. Although there have been no large studies of residential electric fields, sufficient data are available to indicate field levels and characteristics. Measurements of domestic 60-Hz electric fields indicate that levels are highly variable and source-dependent. Electric-field levels are not easily predicted because walls and other objects act as shields, because conducting objects perturb the field, and because homes contain numerous localized sources. Internal sources (wiring, fixtures, and appliances) seem to predominate in producing electric fields inside houses. Average measured electric fields in residences are generally in the range of 5 to 20 V/m. Electric-field levels in public buildings such as shops, offices, and malls appear to be comparable with levels in residences.

Electric fields from household appliances are localized and decrease rapidly with distance from the source. Local electric fields measured at 1 ft. (0.3 m) from small household appliances are typically in the range of 30 to 60 V/m. Stopps and Janischewskyj (1979) reported electric-field measurements near 20 different appliances; at a 1-ft. (0.3-m) distance, fields ranged from 1 to 150 V/m, with a mean of 33 V/m. In another survey, reported by Deno and Zaffanella (1982), field measurements at a 1-ft. (0.3-m) distance from common domestic and workshop sources were found to range from 3 to 70 V/m. The localized fields from appliances are not uniform, and care should be taken in comparing them with transmission-line fields.

Electric blankets can generate higher localized electric fields. Sheppard and Eisenbud (1977) reported fields of 250 V/m at a distance of approximately 1 ft. (0.3 m). Florig et al. (1987) carried out extensive empirical and theoretical analysis of electric-field exposure from electric blankets and presented results in terms of uniform equivalent fields such as those near transmission lines. Depending on what parameter was chosen to represent intensity of exposure and the grounding status of the subject, the equivalent vertical 60-Hz electric-field exposure ranged from 20 to over 3500 V/m. The largest equivalent field corresponds to the measured field on the chest with the blanket-user grounded. The average field on the chest of an ungrounded blanket-user yields an equivalent vertical field of 960 V/m. As manufacturers

have become aware of the controversy surrounding EMF exposures, electric blankets have been redesigned to reduce *magnetic* fields. However, electric fields from these “low field” blankets are still comparable with those from older designs (Bassen et al., 1991).

Generally, people in occupations not directly related to high-voltage equipment are exposed to electric fields comparable with those of residential exposures. In a survey of 1,882 volunteers from utilities, electric-field exposures were measured for 2,082 work days and 657 non-work days (Bracken, 1990). Electric-field exposures for occupations other than those directly related to high-voltage equipment were equivalent to those for non-work exposure. Even in electric-utility occupations where high field sources are present, exposures to high fields are limited on average to minutes per day.

Electric fields found in publicly accessible areas near high-voltage transmission lines can typically range up to 3 kV/m for 230-kV lines, to 10 kV/m for 500-kV lines, and to 12 kV/m for 765-kV lines. Although these peak levels are considerably higher than the levels found in other public areas, they are present only in limited areas on rights-of-way.

The calculated electric fields for the proposed Libby to Troy Rebuild transmission line are consistent with the levels computed for the existing 115-kV transmission lines and for similar lines in Montana and elsewhere. The electric fields on the right-of-way of the proposed transmission line, as calculated, would be higher than levels normally encountered in residences and offices.

## **4.0 Magnetic Field**

### **4.1 Basic Concepts**

Magnetic fields can be characterized by the force they exert on a moving charge or on an electrical current. As with the electric field, the magnetic field is a vector quantity characterized by both magnitude and direction. Electrical currents generate magnetic fields. In the case of transmission lines, distribution lines, house wiring, and appliances, the 60-Hz electric current flowing in the conductors generates a time-varying, 60-Hz magnetic field in the vicinity of these sources. The strength of a magnetic field is measured in terms of magnetic lines of force per unit area, or magnetic flux density. The term “magnetic field,” as used here, is synonymous with magnetic flux density and is expressed in units of Gauss (G) or milligauss (mG).

The uniformity of a magnetic field depends on the nature and proximity of the source, just as the uniformity of an electric field does. Transmission-line-generated magnetic fields are quite uniform over horizontal and vertical distances of several feet near the ground. However, for small sources such as appliances, the magnetic field decreases rapidly over distances comparable with the size of the device.

The interaction of a time-varying magnetic field with conducting objects results in induced electric field and currents in the object. A changing magnetic field through an area generates a voltage around any conducting loop enclosing the area (Faraday's law). This is the physical basis for the operation of an electrical transformer. For a time-varying sinusoidal magnetic field, the magnitude of the induced voltage around the loop is proportional to the area of the loop, the frequency of the field, and the magnitude of the field. The induced voltage around the loop results in an induced electric field and current flow in the loop material. The induced current that flows in the loop depends on the conductivity of the loop.

## **4.2 Transmission-line Magnetic Fields**

The magnetic field generated by currents on transmission-line conductors extends from the conductors through the air and into the ground. The magnitude of the field at a height of 3.28 ft. (1 m) is frequently used to describe the magnetic field under transmission lines. Because the magnetic field is not affected by non-ferrous materials, the field is not influenced by normal objects on the ground under the line. The direction of the maximum field varies with location. (The electric field, by contrast, is essentially vertical near the ground.) The most important transmission-line parameters that determine the magnetic field at 3.28 ft. (1 m) height are conductor height above ground and magnitude of the currents flowing in the conductors. As distance from the transmission-line conductors increases, the magnetic field decreases.

Calculations of magnetic fields from transmission lines are performed using well-known physical principles (cf., Deno and Zaffanella, 1982). The calculated values usually represent the ideal straight parallel-conductor configuration. For simplicity, a flat earth is usually assumed. Balanced currents (currents of the same magnitude for each phase) are also assumed. This is usually valid for transmission lines, where loads on all three phases are maintained in balance during operation. The clearance for magnetic-field calculations for the proposed line was the same as that used for electric-field evaluations.

Standard techniques for measuring magnetic fields near transmission lines are described in ANSI IEEE Standard No. 644-1994 (IEEE, 1994). Measured magnetic fields agree well with calculated values, provided the currents and line heights that go into the calculation correspond to the actual values for the line. To realize such agreement, it is necessary to get accurate current readings during field measurements (because currents on transmission lines can vary considerably over short periods of time) and also to account for all field sources in the vicinity of the measurements.

As with electric fields, the maximum or peak magnetic fields occur in areas near the centerline and at midspan where the conductors are the lowest. The magnetic field at the edge of the right-of-way is not very dependent on line height. For a double-circuit line or if more than one line is present, the peak field will depend on the relative electrical phasing of the conductors and the direction of power flow.

## **4.3 Calculated Values for Magnetic Fields**

Table 4 gives the calculated values of the magnetic field at 3.28 ft. (1 m) height for the proposed Libby to Troy transmission line rebuild. Field values on the right-of-way and at the edge of the right-of-way are given for projected maximum currents and minimum conductor clearances. The maximum currents for the proposed single-circuit 115-kV alternatives and the double-circuit alternative are given in Table 2. The maximum current projected in 10 years for the single-circuit alternative is 301 A per phase and for the double-circuit alternative operated at 115 kV is 160 A per phase. The maximum current on the existing Libby to Troy single-circuit line is 301 A.

The actual magnetic-field levels would vary, as currents on the lines change daily and seasonally and as ambient temperature changes. Average currents over the year would be about 43% of the maximum values. The levels shown in the figures represent the highest magnetic fields expected for the proposed Libby to Troy Rebuild transmission line. Average fields over a year would be considerably reduced from the peak values, as a result of reduced average currents and increased clearances above the minimum value due to conductor temperatures less than the design value of 100 C°.

Figure 3 shows lateral profiles of the magnetic field under maximum current and minimum clearance conditions for the proposed 115-kV transmission line alternatives. Field profile for average height under maximum current conditions for the H-frame and double-circuit configurations are also included in Figure 3.

For the proposed 115-kV H-frame line, the maximum calculated 60-Hz magnetic field on the right-of-way at 3.28 ft. (1 m) above ground is 71 mG for a minimum conductor height of 24 ft. (7.3 m) and a maximum current of 296 A for the proposed action. The maximum field would decrease for increased conductor clearance. For the average conductor height over a span of 30 ft. (9.1 m), the maximum field would be 47 mG.

The calculated maximum magnetic fields is 32 mG at the edges of the 60-foot right-of-way, 21 mG at the edges of the 80-foot right-of-way, and 14 mG at the edges of the 100-foot right-of-way. Averaged over a year these maximum field levels would be about 43 percent of the above values. Thus, the average levels at the edges of the most prevalent 80-foot right-of-way for the H-frame configuration would be 9 mG or less. The maximum and average fields for the proposed H-frame configuration are very comparable with the fields from the existing H-frame configuration (Table 4).

Magnetic fields for the single-pole configuration with underbuild are reduced from those of the H-frame configuration because of the increased height of the conductors. The maximum magnetic field on the right-of-way for the single-pole configuration would be 10 mG compared to 71 for the H-frame. Fields at the edge of the single-pole right-of-way would be 10 mG for a 60-foot right-of-way width, 8 mG for an 80-foot width, and 6 mG for a 100-foot width. For the single-pole configuration without underbuild the maximum magnetic field on the right-of-way would be 34 mG.

The double-circuit configuration would have a maximum magnetic field on the right-of-way of 24 mG. The maximum field at the edge of the 100-foot right-of-way would be 5 mG.

#### **4.4 Environmental Magnetic Fields**

Transmission lines are not the only source of magnetic fields; as with 60-Hz electric fields, 60-Hz magnetic fields are present throughout the environment of a society that relies on electricity as a principal energy source. The magnetic fields associated with the proposed Libby to Troy Rebuild line can be compared with fields from other sources. The range of 60-Hz magnetic-field exposures in publicly accessible locations such as open spaces, transmission-line rights-of-way, streets, pedestrian walkways, parks, shopping malls, parking lots, shops, hotels, public transportation, and so on range from less than 0.1 mG to about 1 G, with the highest values occurring near small appliances with electric motors. In occupational settings in electric utilities, where high currents are present, magnetic-field exposures for workers can be above 1 G. At 60 Hz, the magnitude of the natural magnetic field is approximately 0.0005 mG.

Several investigations of residential fields have been conducted. In a large study to identify and quantify significant sources of 60-Hz magnetic fields in residences, measurements were made in 996 houses, randomly selected throughout the country (Zaffanella, 1993). The most common sources of residential fields were power lines, the grounding system of residences, and appliances. Field levels were characterized by both point-in-time (spot) measurements and 24-hour measurements. Spot measurements averaged over all rooms in a house exceeded 0.6 mG in 50% of the houses and 2.9 mG in 5% of houses. Power lines generally produced the largest average fields in a house over a 24-hour period. On the other hand, grounding system currents proved to be a more significant source of the highest fields in a house. Appliances were found to produce the highest local fields; however, fields fell off rapidly with increased distance. For example, the median field near microwave ovens was 36.9 mG at a distance of 10.5 in. (0.27 m) and 2.1 mG at 46 in. (1.17 m). Across the entire sample of 996 houses, higher magnetic fields were found in, among others, urban areas (vs. rural); multi-unit dwellings (vs. single-family); old houses (vs. new); and houses with grounding to a municipal water system.

In an extensive measurement project to characterize the magnetic-field exposure of the general population, over 1000 randomly selected persons in the United States wore a personal exposure meter for 24 hours and recorded their location in a simple diary (Zaffanella and Kalton, 1998). Based on the measurements of 853 persons, the estimated 24-hour average exposure for the general population is 1.24 mG and the estimated median exposure is 0.88 mG. The average field “at home, not in bed” is 1.27 mG and “at home, in bed” is 1.11 mG. Average personal exposures were found to be highest “at work” (mean of 1.79 mG and median of 1.01 mG) and lowest “at home, in bed” (mean of 1.11 mG and median of 0.49 mG). Average fields in school were also low (mean of 0.88 mG and median of 0.69 mG). Factors associated with higher exposures at home were smaller residences, duplexes and apartments, metallic rather than plastic water pipes, and nearby overhead distribution lines.

As noted above, magnetic fields from appliances are localized and decrease rapidly with distance from the source. Localized 60-Hz magnetic fields have been measured near about 100 household appliances such as ranges, refrigerators, electric drills, food mixers, and shavers (Gauger, 1985). At a distance of 1 ft. (0.3 m), the maximum magnetic field ranged from 0.3 to 270 mG, with 95% of the measurements below 100 mG. Ninety-five percent of the levels at a distance of 4.9 ft. (1.5 m) were less than 1 mG. Devices that use light-weight, high-torque motors with little magnetic shielding exhibited the largest fields. These included vacuum cleaners and small hand-held appliances and tools. Microwave ovens with large power transformers also exhibited relatively large fields. Electric blankets have been a much-studied source of magnetic-field exposure because of the length of time they are used and because of the close proximity to the body. Florig and Hoburg (1988) estimated that the average magnetic field in a person using an electric blanket was 15 mG, and that the maximum field could be 100 mG. New "low-field" blankets have magnetic fields at least 10 times lower than those from conventional blankets (Bassen et al., 1991).

In a domestic magnetic-field survey, Silva et al. (1989) measured fields near different appliances at locations typifying normal use (e.g., sitting at an electric typewriter or standing at a stove). Specific appliances with relatively large fields included can openers (n = 9), with typical fields ranging from 30 to 225 mG and a maximum value up to 2.7 G; shavers (n = 4), with typical fields from 50 to 300 mG and maximum fields up to 6.9 G; and electric drills (n = 2), with typical fields from 56 to 190 mG and maximum fields up to 1.5 G. The fields from such appliances fall off very rapidly with distance and are only present for short periods. Thus, although instantaneous magnetic-field levels close to small hand-held appliances can be quite large, they do not contribute to average area levels in residences.

In a study with 162 subjects, Mezei et al. (2001) employed magnetic-field exposure measurements, simultaneous record-keeping of appliance proximity, and an appliance-use questionnaire to investigate the contributions of appliances to overall exposure. They found that individual appliance use did not contribute significantly to time-weighted-average exposure, unless the use was prolonged during the day of measurements. For example, approximately 16% of exposure accumulated during periods when a subject was using a computer. For all subjects exposure during computer use accounted for on-average 9% of total exposure. Cell phones were identified as another source of relatively low fields and long use times that could contribute to overall exposure. Use of other small appliances did not contribute significantly to accumulated exposure but did contribute to the relatively short periods when high-field exposures were observed.

Although studies of residential magnetic fields have not all considered the same independent parameters, the following consistent characterization of residential magnetic fields emerges from the data:

- (1) External sources play a large role in determining residential magnetic-field levels. Transmission lines, when nearby, are an important external source. Unbalanced ground currents on neutral conductors and other conductors, such as water pipes in and near a house,

can represent a significant source of magnetic field. Distribution lines per se, unless they are quite close to a residence, do not appear to be a traditional distance-dependent source.

- (2) Homes with overhead electrical service appear to have higher average fields than those with underground service.
- (3) Appliances represent a localized source of magnetic fields that can be much higher than average or area fields. However, fields from appliances approach area levels at distances greater than 3.28 ft. (1 m) from the device.

Although important variables in determining residential magnetic fields have been identified, quantification and modeling of their influence on fields at specific locations is not yet possible. However, a general characterization of residential magnetic-field level is possible: average levels in the United States are in the range of 0.5 to 1.0 mG, with the average field in a small number of homes exceeding this range by as much as a factor of 10 or more. Average personal exposure levels are slightly higher, possibly due to use of appliances and varying distances to other sources. Maximum fields can be much higher.

Magnetic fields in commercial and retail locations are comparable with those in residences. As with appliances, certain equipment or machines can be a local source of higher magnetic fields. Utility workers who work close to transformers, generators, cables, transmission lines, and distribution systems clearly experience high-level fields. Other sources of fields in the workplace include motors, welding machines, computers, and video display terminals (VDTs). In publicly accessible indoor areas, such as offices and stores, field levels are generally comparable with residential levels, unless a high-current source is nearby.

Measurements of personal exposure to magnetic fields were made for 1,882 volunteer utility workers for a total of 4,411 workdays (Bracken, 1990). Median workday mean exposures ranged from 0.5 mG for clerical workers without computers to 7.2 mG for substation operators. Occupations not specifically associated with transmission and distribution facilities had median workday exposures less than 1.5 mG, while those associated with such facilities had median exposures above 2.3 mG. Magnetic-field exposures measured in homes during this study were comparable with those recorded in offices.

Magnetic fields in publicly accessible outdoor areas seem to be, as expected, directly related to proximity to electric-power transmission and distribution facilities. Near such facilities, magnetic fields are generally higher than indoors (residential). Higher-voltage facilities tend to have higher fields. Typical maximum magnetic fields in publicly accessible areas near transmission facilities can range from less than a few milligauss up to 300 mG or more, near heavily loaded lines operated at 230 to 765 kV. The levels depend on the line load, conductor height, and location on the right-of-way. Because magnetic fields near high-voltage transmission lines depend on the current in the line, they can vary daily and seasonally.

To characterize fields from the distribution system, Heroux (1987) measured 60-Hz magnetic fields with a mobile platform along 140 mi. (223 km) of roads in Montreal. The median field level averaged over nine different routes was 1.6 mG, with 90% of the measurements less than about 5.1 mG. Spot measurements indicated that typical fields directly above underground distribution systems were 5 to 19 mG. Beneath overhead distribution lines, typical fields were 1.5 to 5 mG on the primary side of the transformer, and 4 to 10 mG on the secondary side. Near ground-based transformers used in residential areas, fields were 80 to 1000 mG at the surface and 10 to 100 mG at a distance of 1 ft. (0.3 m).

The magnetic fields from the proposed line would be comparable to or less than those from the existing 115-kV line and other similar lines in Montana and elsewhere. On and very near the right-of-way of the proposed line, magnetic fields would be above average residential levels. However, the fields from the proposed H-frame transmission line would decrease rapidly and approach common ambient levels (1 mG) at a distance of about 200 feet from the centerline under maximum current conditions and at about 130



feet under average current conditions. The maximum fields from the other configurations would reach the 1 mG level closer to the line: at 145 feet from the single-pole line and at 100 feet from the double circuit line. Furthermore, the fields at the edge of the right-of-way for all configurations would not be above those encountered during normal activities near common sources such as hand-held appliances.

## **5.0 Electric and Magnetic Field (EMF) Effects**

Possible effects associated with the interaction of EMF from transmission lines with people on and near a right-of-way fall into two categories: short-term effects that can be perceived and may represent a nuisance, and possible long-term health effects. Only short-term effects are discussed here. The issue of whether there are long-term health effects associated with transmission-line fields is controversial. In recent years, considerable research on possible biological effects of EMF has been conducted. A review of these studies and their implications for health-related effects is provided in a separate technical appendix for the environmental assessment of the proposed Libby to Troy Rebuild transmission line.

### **5.1 Electric Fields: Short-term Effects**

Short-term effects from transmission-line electric fields are associated with perception of induced currents and voltages or perception of the field. Induced current or spark discharge shocks can be experienced under certain conditions when a person contacts objects in an electric field. Such effects occur in the fields associated with transmission lines that have voltages of 230-kV or higher. These effects are unlikely to occur under the proposed Libby to Troy Rebuild line.

Steady-state currents are those that flow continuously after a person contacts an object and provides a path to ground for the induced current. The amplitude of the steady-state current depends on the induced current to the object in question and on the grounding path. The magnitude of the induced current to vehicles and objects under the proposed line will depend on the electric-field strength and the size and shape of the object. When an object is electrically grounded, the voltage on the object is reduced to zero, and it is not a source of current or voltage shocks. If the object is poorly grounded or not grounded at all, then it acquires some voltage relative to earth and is a possible source of current or voltage shocks.

The responses of persons to steady-state current shocks have been extensively studied, and levels of response documented (Keesey and Letcher, 1969; IEEE, 1978). Primary shocks are those that can result in direct physiological harm. Such shocks will not be possible from induced currents under the existing or proposed lines, because clearances above ground required by the NESC preclude such shocks from large vehicles and grounding practices eliminate large stationary objects as sources of such shocks.

Secondary shocks are defined as those that could cause an involuntary and potentially harmful movement, but no direct physiological harm. Secondary shocks could occur under the proposed 115-kV line when making contact with ungrounded conducting objects such as large vehicles or equipment. However, such occurrences are anticipated to be very infrequent. Shocks, when they occur under the 115-kV line, are most likely to be barely perceptible and below the nuisance level. Induced currents would not be perceived off the right-of-way.

Induced currents are always present in electric fields under transmission lines and will be present near the proposed line. However, the fields from the proposed line would be below levels that normally cause perceivable currents. Furthermore during initial construction, it is BPA policy to ground metal objects, such as fences, that are located on the right-of-way. The grounding eliminates these objects as sources of induced current and voltage shocks. Multiple grounding points are used to provide redundant paths for

induced current flow. After construction, BPA would respond to any complaints and install or repair grounding to mitigate nuisance shocks.

Unlike fences or buildings, mobile objects such as vehicles and farm machinery cannot be grounded permanently. However, the likelihood of perceivable induced currents from such objects to persons under the proposed line is minimal. Limiting the possibility of induced currents from such objects to persons is accomplished in several ways.

First, required clearances for above-ground conductors tend to limit field strengths to levels that do not represent a hazard or nuisance. BPA and other utilities design and operate lines to be in compliance with the National Electrical Safety Code (NESC). Montana requires that transmission lines adhere to the NESC (Montana, 2005).

In addition to maintaining distances from lines, the NESC (IEEE, 2002a) requires that, for lines with voltage exceeding 98 kV line-to-ground (170 kV line-to-line), sufficient conductor clearance be maintained to limit the induced short-circuit current in the largest anticipated vehicle under the line to 5 milliamperes (mA) or less. This requirement would not apply to the 115-kV single-circuit alternatives, but would apply to the double-circuit configuration designed for operation at 230 kV. The line height of the double-circuit configuration over major road crossings would be increased to at least 37.5 ft (11.4 m). For 230-kV operation the electric fields at this clearance would be 2.4 kV/m. The largest vehicle allowed on highways in Montana (other than Interstate highways) is 88x14x8.5 feet (FMCSA, 2006). The induced current to this largest vehicle anticipated under the proposed double-circuit line at 230-kV would be less than 2.2 mA and easily meet the NESC 5 mA criterion (Reilly, 1979). In accordance with the NESC, line clearances would also be increased over other areas, such as over railroads, orchards and water areas to ensure safety.

Induced voltages occur on objects, such as vehicles, in an electric field where there is an inadequate electrical ground. If the voltage is sufficiently high, then a spark discharge shock can occur as contact is made with the object. Such shocks are similar to "carpet" shocks that occur, for example, when a person touches a doorknob after walking across a carpet on a dry day. The number and severity of spark discharge shocks depend on electric-field strength and generally of concern under lines with voltages of 345-kV or higher. Nuisance shocks, which are primarily spark discharges, are anticipated to occur very infrequently under the proposed line.

In electric fields higher than those that would occur under the proposed line, it is theoretically possible for a spark discharge from the induced voltage on a large vehicle to ignite gasoline vapor during refueling. The probability for exactly the right conditions for ignition to occur is extremely remote. The additional clearance of conductors provided at road crossings reduces the electric field in areas where vehicles are prevalent and reduces the chances for such events. Even so, BPA recommends that vehicles should not be refueled under the proposed line unless specific precautions are taken to ground the vehicle and the fueling source (USDOE, 1995).

Under certain conditions, the electric field can be perceived through hair movement on an upraised hand or arm of a person standing on the ground under high-voltage transmission lines. The median field for perception in this manner was 7 kV/m for 136 persons; only about 12% could perceive fields of 2 kV/m or less (Deno and Zaffanella, 1982). However it is very unlikely that field perception would occur under the proposed 115-kV line because even the maximum 1.5-kV/m field is below levels where most people experience perception (Deno and Zaffanella, 1982). Where vegetation provides shielding, the field would not be perceived.

Conductive shielding reduces both the electric field and induced effects such as shocks. Persons inside a vehicle cab or canopy are shielded from the electric field. Similarly, a row of trees or a lower-voltage distribution line reduces the field on the ground in the vicinity. Metal pipes, wiring, and other conductors in a residence or building shield the interior from transmission-line electric fields.

The electric fields from the proposed 115-kV line would be comparable to or less than those from existing 115-kV lines in Montana and elsewhere. Potential impacts of electric fields can be mitigated through grounding policies and adherence to the NESC. Worst-case levels are used for safety analyses but, in practice, induced currents and voltages are reduced considerably by unintentional grounding. Shielding by conducting objects, such as vehicles and vegetation, also reduces the potential for electric-field effects.

## **5.2 Magnetic Field: Short-term Effects**

Magnetic fields associated with transmission and distribution systems can induce voltage and current in long conducting objects that are parallel to the transmission line. As with electric-field induction, these induced voltages and currents are a potential source of shocks. A fence, irrigation pipe, pipeline, electrical distribution line, or telephone line forms a conducting loop when it is grounded at both ends. The earth forms the other portion of the loop. The magnetic field from a transmission line can induce a current to flow in such a loop if it is oriented parallel to the line. If only one end of the fence is grounded, then an induced voltage appears across the open end of the loop. The possibility for a shock exists if a person closes the loop at the open end by contacting both the ground and the conductor. The magnitude of this potential shock depends on the following factors: the magnitude of the field; the length of the object (the longer the object, the larger the induced voltage); the orientation of the object with respect to the transmission line (parallel as opposed to perpendicular, where no induction would occur); and the amount of electrical resistance in the loop (high resistance limits the current flow).

Magnetically induced currents from power lines have been investigated for many years; calculation methods and mitigating measures are available. A comprehensive study of gas pipelines near transmission lines developed prediction methods and mitigation techniques specifically for induced voltages on pipelines (Dabkowski and Taflove, 1979; Taflove and Dabkowski, 1979). Similar techniques and procedures are available for irrigation pipes and fences. Grounding policies employed by utilities for long fences reduce the potential magnitude of induced voltage.

The magnitude of the coupling with both pipes and fences is very dependent on the electrical unbalance (unequal currents) among the three phases of the line. Thus, a distribution line where a phase outage may go unnoticed for long periods of time can represent a larger source of induced currents than a transmission line where the loads are well-balanced (Jaffa and Stewart, 1981).

Knowledge of the phenomenon, grounding practices, and the availability of mitigation measures mean that magnetic-induction effects from the proposed 115-kV transmission line would be minimal.

Magnetic fields from transmission and distribution facilities can interfere with certain electronic equipment. Magnetic fields can cause distortion of the image on older style video display terminals (VDTs) and computer monitors (cathode-ray tubes). The threshold field for interference depends on the type and size of monitor and the frequency of the field. Interference has been observed for certain monitors at fields at or below 10 mG (Baishiki et al., 1990; Banfai et al., 2000). The problem typically arises when computer monitors are in use near electrical distribution or transmission facilities or near the distribution system in large office buildings.

Under maximum current conditions magnetic fields from the proposed line would fall below 10 mg at about 60 ft. from the centerline of the H-frame configuration. Under average current conditions, the field would be less than 10 mG at distances greater than 40 ft. from centerline. For maximum current conditions, the field at the edge of the right-of-way and beyond for the other proposed configurations would be less than 10 mG.

Interference from magnetic fields does not occur for flat-screen monitors, such as used in laptop computers. If interference does occur for an older monitor, it can be eliminated by shielding the affected monitor or moving it to an area with lower fields. Similar mitigation methods could be applied to other sensitive electronics, if necessary. Interference from 60-Hz fields with computers and control circuits in vehicles and other equipment is not anticipated at the field levels found under and near the proposed 115-kV transmission line.

The magnetic fields from the proposed line would be comparable to those from the existing line. It is anticipated that the impacts from magnetic fields would be unchanged from those present on and near the existing line.

## 6.0 Regulations

Regulations that apply to transmission-line electric and magnetic fields fall into two categories. Safety standards or codes are intended to limit or eliminate electric shocks that could seriously injure or kill persons. Field limits or guidelines are intended to limit electric- and magnetic-field exposures that can cause nuisance shocks or that might cause health effects. In no case has a limit or standard been established because of a known or demonstrated health effect.

The proposed line would be designed to meet the NESC (IEEE, 2002a), which specifies how far transmission-line conductors must be from the ground and other objects. The clearances specified in the code provide safe distances that prevent harmful shocks to workers and the public. In addition, people who live and work near transmission lines must be aware of safety precautions to avoid electrical (which is not necessarily physical) contact with the conductors. For example, farmers should not up-end irrigation pipes under a transmission or other electrical line or direct the water stream from an irrigation system into or near the conductors. BPA publishes and distributes a brochure that describes safe practices to protect against shock hazards around power lines (USDOE, 1995).

In addition, as a matter of safety, the NESC specifies that electric-field-induced currents from transmission lines must be below the 5 mA (“let go”) threshold deemed a lower limit for primary shock. This de-facto limit on electric fields does not apply to 115-kV lines because the electric fields under 115-kV lines are too low to produce such currents.

Field limits or guidelines have been adopted in several states and countries and by national and international organizations. Electric-field limits have generally been based on minimizing nuisance shocks or field perception. In some cases, such as the state limits in Table 5, the intent of magnetic-field limits has been to limit exposures to existing levels, given the uncertainty of their potential for health effects. In the case of international standard or guideline setting organizations, magnetic field limits have been based on thresholds for possible effects from induced internal currents or electric fields (ICNIRP, 1998; IEEE, 2002b).

There are currently no national standards in the United States for 60-Hz electric and magnetic fields. Montana has a regulation for electric fields from new transmission lines that restricts electric fields at road crossings to 7 kV/m and at the edge of the right-of-way in residential and subdivided areas to 1.0

kV/m (Montana, 2005). The edge of right-of-way restriction can be waived by the affected land-owner. For the proposed line, this regulation would possibly affect only sections where the proposed H-frame configuration is on a 60-foot wide right-of-way (Table 3). The one section of the route where this occurs is a 360 feet long section centered on a tower. In this area the conductors would be above the minimum clearance by at least 2.4 ft. and the field would be 1.0 kV/m or less. Montana does not have a limit for magnetic fields from transmission lines.

Besides Montana, several states have established mandatory or suggested limits on 60-Hz electric and (in two cases) magnetic fields. Five other states have specific electric-field limits that apply to transmission lines: Florida, Minnesota, New Jersey, New York and Oregon. Florida and New York have established regulations for magnetic fields. These regulations are summarized in Table 5, adapted from TDHS Report (1989; 1990). The estimated electric fields on and at the edge of the right-of-way of the proposed transmission line would meet the limits of all states.

Government agencies and utilities operating transmission systems have established design criteria that include EMF levels. BPA has maximum allowable electric fields of 9 and 5 kV/m on and at the edge of the right-of-way, respectively (USDOE, 1996). BPA also has maximum-allowable electric-field strengths of 5 kV/m, 3.5 kV/m, and 2.5 kV/m for road crossings. The proposed line would meet all BPA design criteria.

Electric-field limits for overhead power lines have also been established in other countries (Maddock, 1992). Limits for magnetic fields from overhead power lines have not been explicitly established anywhere except in Florida and New York (see Table 5). However, general guidelines and limits on EMF have been established for occupational and public exposure in several countries and by national and international organizations. The public exposure limits are lower than the occupational limits.

The American Conference of Governmental Industrial Hygienists (ACGIH) sets guidelines (Threshold Limit Values® or TLV®) for occupational exposures to environmental agents (ACGIH, 2005). In general, a TLV represents the level below which it is believed that nearly all workers may be exposed repeatedly without adverse health effects. For EMF, the TLVs represent ceiling levels. For 60-Hz electric fields, occupational exposures should not exceed the TLV of 25 kV/m. However, the ACGIH also recognizes the potential for startle reactions from spark discharges and short-circuit currents in fields greater than 5-7 kV/m, and recommends implementing grounding practices. They recommend the use of conductive clothing for work in fields exceeding 15 kV/m. The TLV for occupational exposure to 60-Hz magnetic fields is a ceiling level of 10 G (10,000 mG) (ACGIH, 2005). The ACGIH does not make recommendations for public exposures.

Electric and magnetic fields from various sources (including automobile ignitions, appliances and, possibly, transmission lines) can interfere with implanted cardiac pacemakers. In light of this potential problem, manufacturers design devices to be immune from such interference. However, research has shown that these efforts have not been completely successful and that a few older models of pacemakers could be affected by 60-Hz fields from transmission lines. There were also numerous models of pacemakers that were not affected by fields even larger than those found under transmission lines. Because of the known potential for interference with pacemakers by 60-Hz fields, field limits for pacemaker wearers have been established by the ACGIH. They recommend that wearers of pacemakers and similar medical-assist devices limit their occupational exposure to electric fields of 1 kV/m or less and to magnetic fields to 1 G (1,000 mG) or less (ACGIH, 2005).

The International Committee on Non-ionizing Radiation Protection (ICNIRP), working in cooperation with the World Health Organization (WHO), has developed guidelines for occupational and public

exposures to EMF (ICNIRP, 1998). For the general public, the ICNIRP guidelines recommend exposure limits of 4.2 kV/m for electric fields and 0.83 G (830 mG) for magnetic fields (ICNIRP, 1998).

ICNIRP has also established guidelines for contact currents, which could occur when a grounded person contacts an ungrounded object in an electric field. The guideline levels are 1.0 mA for occupational exposure and 0.5 mA for public exposure.

The Institute of Electrical and Electronic Engineers (IEEE, 2002b) has also set limits for occupational and public exposure to electric and magnetic fields and to contact currents. The IEEE electric-field limits are based on thresholds for possible reactions to perceivable spark discharges that occur in electric fields. The limits for public exposure to electric fields are 5 kV/m except on power line rights-of-way, where the limit is 10 kV/m. The magnetic-field limits are based on an extensive assessment of possible neurological responses to magnetic field exposures. The limit for public exposure to 60-Hz magnetic fields is 9,040 mG. The current limit for the general public is 0.5 mA for a touch contact.

The electric fields from the proposed 115-kV transmission line would meet the ACGIH, ICNIRP, and IEEE standards, provided wearers of pacemakers and similar medical-assist devices are discouraged from unshielded use of the right-of-way directly under the conductors at midspan – a relatively small area. (A passenger in an automobile under the line would be shielded from the electric field.) The magnetic fields from the proposed line would be well below the ACGIH occupational limits, and well below those of ICNIRP and IEEE for occupational and public exposures. The electric fields present on the right-of-way could induce currents in ungrounded large vehicles that exceeded the ICNIRP and IEEE levels of 0.5 mA.

## **7.0 Audible Noise**

### **7.1 Basic Concepts**

Audible noise (AN), as defined here, represents an unwanted sound, as from a transmission line, transformer, airport, or vehicle traffic. Sound is a pressure wave caused by a sound source vibrating or displacing air. The ear converts the pressure fluctuations into auditory sensations. AN from a source is superimposed on the background or ambient noise that is present before the source is introduced.

The amplitude of a sound wave is the incremental pressure resulting from sound above atmospheric pressure. The sound-pressure level is the fundamental measure of AN; it is generally measured on a logarithmic scale with respect to a reference pressure. The sound-pressure level (SPL) in decibels (dB) is given by:

$$\text{SPL} = 20 \log (P/P_0)\text{dB}$$

where P is the effective rms (root-mean-square) sound pressure,  $P_0$  is the reference pressure, and the logarithm (log) is to the base 10. The reference pressure for measurements concerned with hearing is usually taken as 20 micropascals (Pa), which is the approximate threshold of hearing for the human ear. A logarithmic scale is used to encompass the wide range of sound levels present in the environment. The range of human hearing is from 0 dB up to about 140 dB, a ratio of 10 million in pressure (EPA, 1978).

Logarithmic scales, such as the decibel scale, are not directly additive: to combine decibel levels, the dB values must be converted back to their respective equivalent pressure values, the total rms pressure level found, and the dB value of the total recalculated. For example, adding two sounds of equal level on the dB scale results in a 3 dB increase in sound level. Such an increase in sound pressure level of 3 dB, which corresponds to a doubling of the energy in the sound wave, is barely discernible by the human ear.

It requires an increase of about 10 dB in SPL to produce a subjective doubling of sound level for humans. The upper range of hearing for humans (140 dB) corresponds to a sharply painful response (EPA, 1978).

Humans respond to sounds in the frequency range of 16 to 20,000 Hz. The human response depends on frequency, with the most sensitive range roughly between 2000 and 4000 Hz. The frequency-dependent sensitivity is reflected in various weighting scales for measuring audible noise. The A-weighted scale weights the various frequency components of a noise in approximately the same way that the human ear responds. This scale is generally used to measure and describe levels of environmental sounds such as those from vehicles or occupational sources. The A-weighted scale is also used to characterize transmission-line noise. Sound levels measured on the A-scale are expressed in units of dB(A) or dBA.

AN levels and, in particular, corona-generated audible noise (see below) vary in time. In order to account for fluctuating sound levels, statistical descriptors have been developed for environmental noise. Exceedence levels (L levels) refer to the A-weighted sound level that is exceeded for a specified percentage of the time. Thus, the  $L_5$  level refers to the noise level that is exceeded only 5% of the time.  $L_{50}$  refers to the sound level exceeded 50% of the time. Sound-level measurements and predictions for transmission lines are often expressed in terms of exceedence levels, with the  $L_5$  level representing the maximum level and the  $L_{50}$  level representing a median level.

Table 6 shows AN levels from various common sources. Clearly, there is wide variation. Noise exposure depends on how much time an individual spends in different locations. Outdoor noise generally does not contribute to indoor levels (EPA, 1974). Activities in a building or residence generally dominate interior AN levels.

The EPA has established a guideline of 55 dBA for the annual average day-night level ( $L_{dn}$ ) in outdoor areas (EPA, 1978). In computing this value, a 10 dB correction (penalty) is added to night-time noise between the hours of 10 p.m. and 7 a.m.

Montana regulations for transmission lines call for the average annual  $L_{dn}$  noise levels at the edge of the right-of-way not to exceed 50 dBA (Montana, 2005). This limit applies to residential and subdivided areas unless the affected landowner waives the condition.

The BPA transmission-line design criterion for corona-generated audible noise ( $L_{50}$ , foul weather) is 50 dBA at the edge of the ROW (USDOE, 2006). This criterion applies to new line construction and is under typical conditions of foul weather, altitude, and system voltage. It is generally a consideration only for 500-kV transmission lines.

## **7.2 Transmission-line Audible Noise**

Corona is the partial electrical breakdown of the insulating properties of air around the conductors of a transmission line. In a small volume near the surface of the conductors, energy and heat are dissipated. Part of this energy is in the form of small local pressure changes that result in audible noise. Corona-generated audible noise can be characterized as a hissing, crackling sound that, under certain conditions, is accompanied by a 120-Hz hum. Corona-generated audible noise is of concern primarily for contemporary lines operating at voltages of 345 kV and higher during foul weather. The proposed 115-kV line may produce some noise under foul weather conditions.

The conductors of high-voltage transmission lines are designed to be corona-free under ideal conditions. However, protrusions on the conductor surface—particularly water droplets on or dripping off the conductors—cause electric fields near the conductor surface to exceed corona onset levels, and corona occurs. Therefore, audible noise from transmission lines is generally a foul-weather (wet-conductor)

phenomenon. Wet conductors can occur during periods of rain, fog, snow, or icing. Based on meteorologic records near the route of the proposed transmission line, such conditions are expected to occur about 6.2% of the time during the year in the Libby area (NOAA, 2005).

For a few months after line construction, residual grease or oil on the conductors can cause water to bead up on the surface. This results in more corona sources and slightly higher levels of audible noise and electromagnetic interference if the line is energized. However, the new conductors "age" in a few months, and the level of corona activity decreases to the predicted equilibrium value. During fair weather, insects and dust on the conductor can also serve as sources of corona, especially on higher voltage lines.

### **7.3 Predicted Audible Noise Levels**

Corona-generated audible-noise levels are calculated for average voltage and average conductor heights for fair- and foul-weather conditions. The predicted levels of audible noise for the proposed line operated at a voltage of 118.5 kV are given in Table 7.

The calculated median level ( $L_{50}$ ) during foul weather at the edge of the proposed Libby to Troy Rebuild line right-of-way ranges from 11 dBA for the double-circuit configuration (100-foot right-of-way) to 20 dBA for the single-pole configuration (60-foot right-of-way). As shown in Table 6, these levels represent a very quiet condition. It is very likely they would be masked by the sound of wind and/or rain during foul weather. The calculated maximum noise levels ( $L_5$ ) during foul weather at the edge of the right-of-way are only a few dBA higher and still would be very low compared to ambient noise. During fair-weather conditions, which occur about 94% of the time in the Libby area, corona is not likely to occur on the proposed line and corona-generated noise would not occur.

### **7.4 Conclusion**

The calculated foul-weather corona noise levels for the proposed line would be comparable to or less than those from the existing line. During fair weather, noise from the conductors is unlikely to be perceived on the right-of-way even directly under the conductors. In fair weather it is unlikely there would be any noise from the transmission line, and, if there was, it would be masked or so low as not to be perceived beyond the right-of-way. During foul weather, when ambient noise is higher, it is also likely that corona-generated noise off the right-of-way would be masked.

On and off the right-of-way, the levels of audible noise from the proposed line during foul weather would be well below the 55-dBA level that can produce interference with speech outdoors. The computed annual  $L_{dn}$  level for transmission lines operating in areas with 6% foul weather is about  $L_{dn} = L_{50} - 3$  dBA (Bracken, 1987). Therefore, assuming such conditions in the area of the proposed Libby to Troy Rebuild line, the estimated  $L_{dn}$  at the edge of the right-of-way would be approximately 16 dBA or less, which is well below the EPA  $L_{dn}$  guideline of 55 dBA and also well below the Montana limit for  $L_{dn}$  of 50 dBA.

## **8.0 Electromagnetic Interference**

### **8.1 Basic Concepts**

Corona on transmission-line conductors can also generate electromagnetic noise in the frequency bands used for radio and television signals. The noise can cause radio and television interference (RI and TVI). In certain circumstances, corona-generated electromagnetic interference (EMI) can also affect communications systems and other sensitive receivers. Interference with electromagnetic signals by



corona-generated noise is generally associated with lines operating at voltages of 345 kV or higher. This is especially true of interference with television signals. The design of the proposed 115-kV line would mitigate corona generation and keep radio and television interference levels at acceptable levels comparable to those from the existing 115-kV line.

Spark gaps on distribution lines and on low-voltage wood-pole transmission lines are a more common source of RI/TVI than is corona from high-voltage electrical systems. This gap-type interference is primarily a fair-weather phenomenon caused by loose hardware and wires. The proposed transmission line and distribution-line underbuilds would be constructed with modern hardware that eliminates such problems and therefore minimizes gap noise. Consequently, this source of EMI is not anticipated for the proposed line.

No state has limits for either RI or TVI, although Montana (2005) does require as part of the permitting process that appropriate mitigation be identified to prevent unacceptable interference. In the United States, electromagnetic interference from power transmission systems is governed by the Federal Communications Commission (FCC) Rules and Regulations presently in existence (FCC, 1988). A power transmission system falls into the FCC category of "incidental radiation device," which is defined as "a device that radiates radio frequency energy during the course of its operation although the device is not intentionally designed to generate radio frequency energy." Such a device "shall be operated so that the radio frequency energy that is emitted does not cause harmful interference. In the event that harmful interference is caused, the operator of the device shall promptly take steps to eliminate the harmful interference." For purposes of these regulations, harmful interference is defined as: "any emission, radiation or induction which endangers the functioning of a radio navigation service or of other safety services or seriously degrades, obstructs or repeatedly interrupts a radio communication service operating in accordance with this chapter" (FCC, 1988: Vol II, part 15. 47CFR, Ch. 1).

Electric power companies have been able to work quite well under the present FCC rule because harmful interference can generally be eliminated. It has been estimated that more than 95% of power-line sources that cause interference are due to gap-type discharges. These can be found and completely eliminated, when required to prevent interference (USDOE, 1980). Complaints related to corona-generated interference occur infrequently. This is especially true with the advent of cable television and satellite television, which are not subject to corona-generated interference. Mitigation of corona-generated interference with conventional broadcast radio and television receivers can be accomplished in several ways, such as use of a directional antenna or relocation of an existing antenna (USDOE, 1977; USDOE, 1980; Loftness et al., 1981).

## **8.2 Radio Interference (RI)**

Radio reception in the AM broadcast band (535 to 1605 kilohertz (kHz)) is most often affected by corona-generated EMI. FM radio reception is rarely affected. Generally, only residences very near to transmission lines can be affected by RI. The IEEE Radio Noise Design Guide identifies an acceptable limit of fair-weather RI as expressed in decibels above 1 microvolt per meter (dB $\mu$ V/m) of about 40 dB $\mu$ V/m at 100 ft. (30 m) from the outside conductor (IEEE Committee Report, 1971). As a general rule, average levels during foul weather (when the conductors are wet) are 16 to 22 dB $\mu$ V/m higher than average fair-weather levels.

## **8.3 Predicted RI Levels**

The predicted median ( $L_{50}$ ) fair-weather RI level at 100 ft. (30 m) from the outside conductor for the proposed H-frame and single-pole configurations line operating at 118.5 kV are 3 and 9 dB $\mu$ V/m,

respectively. These predicted fair-weather  $L_{50}$  levels are comparable to those for the corresponding configurations of the existing 115-kV Libby to Troy line. The levels would be well below the IEEE 40 dB $\mu$ V/m criterion for fair weather levels at distances greater than 100 ft. (30 m) from the outside conductor.

#### **8.4 Television Interference (TVI)**

Corona-caused TVI occurs during foul weather and is generally of concern for transmission lines with voltages of 345 kV or above, and only for conventional broadcast receivers within about 600 ft. (183 m) of such a line. As is the case for RI, gap sources on distribution and low-voltage transmission lines are the principal observed sources of TVI. The use of modern hardware and construction practices for the proposed line would minimize such sources. Because of the low level of corona on the proposed line it would not produce TVI. Television systems that operate at higher frequencies, such as satellite receivers, are not affected by corona-generated TVI. Cable television systems are similarly unaffected.

Other forms of TVI from transmission lines are signal reflection (ghosting) and signal blocking caused by the relative locations of the transmission structure and the receiving antenna with respect to the incoming television signal. The wood and steel pole towers proposed for use in the design of the proposed line are less effective in causing this type of interference than are lattice steel towers. The low profiles and cross sections for the proposed towers makes this type of interference very unlikely for the proposed line.

Thus, corona-generated TVI, signal reflection or signal blocking are not anticipated to occur due to the proposed 115-kV line. In the unlikely event that RI or TVI is caused by the proposed line, BPA has a program to identify, investigate, and mitigate legitimate RI and TVI complaints. It is anticipated that any instances of EMI caused by the proposed line could be effectively mitigated.

#### **8.5 Interference with Other Devices**

Corona-generated interference can conceivably cause disruption on other communications bands such as the citizen's (CB) and mobile bands. However, mobile-radio communications are not susceptible to transmission-line interference because they are generally frequency modulated (FM). Similarly, cellular telephones operate at a frequency of 900 MHz or higher, which is above the frequency where corona-generated interference is prevalent. In the unlikely event that interference occurs with these or other communications, mitigation can be achieved with the same techniques used for television and AM radio interference. As digital signal processing has been integrated into communications the potential impact of corona-generated EMI has decreased substantially.

#### **8.6 Conclusion**

Predicted EMI levels for the proposed 115-kV transmission line are comparable to, or lower, than those that are present near the existing 115-kV line and no impacts of corona-generated interference on radio, television, or other receptors are anticipated. Furthermore, if interference should occur, there are various methods for correcting it: BPA has a program to respond to legitimate complaints.

### **9.0 Other Corona Effects**

Corona is sometimes visible as a bluish glow or as bluish plumes on higher voltage lines. On the proposed 115-kV line, corona levels would be very low, so it is very unlikely that it could be observed.

When corona is present, the air surrounding the conductors is ionized and many chemical reactions take place, producing small amounts of ozone and other oxidants. Ozone is approximately 90% of the oxidants, while the remaining 10% is composed principally of nitrogen oxides. The corona level predicted for the proposed line is much lower than that on 500-kV lines. The levels from 500-kV lines are significantly below natural levels and fluctuations in natural levels. Consequently, any production of ozone from the proposed 115-kV line would be essentially undetectable at ground level.

## **10.0 Summary**

Electric and magnetic fields from the proposed transmission line have been characterized using well-known techniques accepted within the scientific and engineering community. The expected electric-field levels from the proposed line at minimum design clearance would be comparable to those from the existing 115-kV Libby to Troy line from other 115-kV lines in Montana. The expected magnetic-field levels from the proposed line would be comparable to those from the existing and other 115-kV lines in Montana.

The peak electric field expected under the proposed line would be 1.5 kV/m; the maximum value at the edge of the right-of-way would be about 1.0 kV/m. Clearances at road crossings would be increased to reduce the peak electric-field value to 1.2 kV/m or less.

Under maximum current conditions on both circuits, the maximum magnetic fields under the proposed line would be 71 mG; at the edge of the right-of-way of the proposed line the maximum magnetic field would be 32 mG. Over a year, the magnetic field levels would average to be about 43% of the above levels.

The electric fields from the proposed line would meet regulatory limits for public exposure in Montana and all other states that have limits and would meet the regulatory limits or guidelines for peak fields established by national and international guideline setting organizations. The magnetic fields from the proposed line would be within the regulatory limits of the two states that have established them and within guidelines for public exposure established by ICNIRP and IEEE.

Short-term effects from transmission-line fields are well understood and can be mitigated. Nuisance shocks arising from electric-field induced currents and voltages would rarely be perceivable on the right-of-way of the proposed line. It is common practice to ground permanent conducting objects during and after construction to mitigate against such occurrences.

Corona-generated audible noise from the proposed line could be perceivable during foul weather at the edge of the right-of-way, but most likely would be masked by ambient noise. Corona noise would not be present during fair weather. The levels would be comparable with, or less than, those near the existing 115-kV transmission line, would be well below the noise limit specified by Montana siting regulations, and would be well below levels specified in EPA guidelines.

Corona-generated electromagnetic interference from the proposed line would be comparable to or less than that from the existing 115-kV line. Radio interference levels would be well below limits identified as acceptable. Television interference, a foul-weather phenomenon usually associated with higher voltage lines, is not anticipated to occur from the proposed 115-kV line.

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## **List of Preparers**

T. Dan Bracken was the principal author of this report. He received a B.S. degree in physics from Dartmouth College and M.S. and Ph.D. degrees in physics from Stanford University. Dr. Bracken has been involved with research on and characterization of electric- and magnetic-field effects from transmission lines for over 30 years, first as a physicist with the Bonneville Power Administration (BPA) (1973 - 1980) and since then as a consultant. His firm, T. Dan Bracken, Inc., offers technical expertise in areas of electric- and magnetic-field measurements, instrumentation, environmental effects of transmission lines, exposure assessment and project management. Joseph Dudman of T. Dan Bracken, Inc., provided data entry, graphics, and clerical support in the preparation of the report.



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**Table 1: Alternative Routes for Proposed Libby to Troy Transmission Line Rebuild**

<b>Route</b>	<b>Description</b>	<b>Length, miles</b>	<b>Possible Line Configurations</b>
<b>Existing Right-of-Way</b>	Travels west in the vicinity of Kootenai River Road from Libby (FEC) Substation to the end of Kootenai River Road on the west side of the Big Horn Terrace area; continues along the north side of the Kootenai River; crosses the river just east of Kootenai Falls; follows new Highway 2 for a short distance; ascends above the Historic Old Highway 2 and on to Troy Substation.	17	H-frame  Single-pole with underbuild  230-kV double-circuit line operated at 115 kV
<b>Pipe Creek Alternative</b>	Travels north from the existing right-of-way just east of Central Road; turns west to re-connect with the existing right-of way at the northern most point on Bothman Drive.	0.8	H-frame  230-kV double-circuit line operated at 115 kV
<b>Quartz Creek Alternative</b>	Turns north from the existing right-of-way just east of Quartz Creek Road for approximately 1.3 miles; turns west for about 1.6 miles to rejoin the existing right-of-way at the end of Kootenai River Road.	2.9	H-frame  230-kV double-circuit line operated at 115 kV
<b>Kootenai River Crossing</b>	Crosses the river just east of a road washout at China Creek, approximately three-quarter mile east of the present crossing of the Kootenai River; after crossing the river turns west and parallels the north side of Highway 2; rejoins the existing right-of-way at the point of the existing crossing.	0.9	Single pole without underbuild  230-kV double-circuit line operated at 115 kV

**Table 2: Physical and Electrical Characteristics by Configuration for the Proposed Libby to Troy Transmission Line Rebuild**  
 See Table 1 for descriptions of alternative routes and Figure 1 for physical layout of line configurations.

Configuration	Existing		Proposed		
	H-frame	Wishbone <sup>1</sup>	H-frame	Single-pole	Double-circuit <sup>2</sup>
Voltage, kV Maximum/Average <sup>3</sup>	118.5/121	118.5/121	118.5/121	118.5/121	118.5/121
Current, A per phase Peak/Average	301/128	301/128	296/127	296/127	160/69
Electric phasing	A B C	B A C	A B C	A B C	C A B B A C
Clearance, ft. Minimum/Average <sup>3</sup>	24/30	38.5 w/ underbuild	24/30	38/40 w/ underbuild  24/26 w/out underbuild	26.5/37.5
Phase spacing, ft. <sup>4</sup>	11.5	5.6/6.9H, 5.0V	12	6.2H/7.0V	20/30 H, 18 V
Conductor: diam., in	0.91	0.91	0.95	0.95	1.30
Right-of-way width, ft.	0, 60, 80	60, 80	80 <sup>5</sup> , 100	60, 80	100 <sup>5</sup>

<sup>1</sup> Existing Vertical and Ell single-pole configurations have similar clearance, phasing and conductors.

<sup>2</sup> 230-kV double-circuit line operated at 115 kV

<sup>3</sup> Average voltage and average clearance used for corona calculations.

<sup>4</sup> H = horizontal feet; V = vertical feet

<sup>5</sup> There is a 360-foot long section of right-of-way with 60-foot width between Hummingbird Way and Lake Creek Road near the Troy substation.

**Table 3: Calculated Peak and Edge-of-right-of-way Electric Fields by Configuration for the Proposed Libby to Troy Transmission Line Rebuild at Minimum Clearance and Maximum Voltage**

<u>Configuration</u>	Existing		Proposed		
	H-frame	Single-pole Wishbone/ Vertical	H-frame	Single-pole with/without underbuild	Double- circuit <sup>1</sup>
<b>Peak, kV/m</b>	1.5	0.4/0.3	1.5	0.3/1.3	1.2
<b>Edge-of-ROW, kV/m</b>					
<b>60-ft. ROW</b>	1.0	0.4/0.2	1.1	0.2	NA
<b>80-ft. ROW</b>	0.6	0.3/0.2	0.7	0.2/0.2	NA
<b>100-ft. ROW</b>	NA <sup>2</sup>	NA	0.4	0.1	0.2

<sup>1</sup> 230-kV double-circuit line operated at 115 kV

<sup>2</sup> Not Applicable

**Table 4: Calculated Peak and Edge-of-right-of-way Magnetic Fields by Configuration for the Proposed Libby to Troy Transmission Line Rebuild operated at Maximum Current**

Average fields would be 43% of table values.

<u>Configuration</u>	Existing		Proposed		
	H-frame	Single-pole Wishbone/ Vertical	H-frame	Single-pole with/without underbuild	Double- circuit <sup>1</sup>
<b>Peak, mG</b>	70	18/12	71	14/34	24
<b>Edge-of-ROW, mG</b>					
<b>60-ft. ROW</b>	31	11/8	32	10	NA
<b>80-ft. ROW</b>	20	9/6	21	8/11	NA
<b>100-ft. ROW</b>	NA	NA	14	NA	5

<sup>1</sup> 230-kV double-circuit line operated at 115 kV

**Table 5: States with Transmission-line Field Limits**

STATE AGENCY	WITHIN RIGHT-OF-WAY	AT EDGE OF RIGHT-OF-WAY	COMMENTS
<b>a. 60-Hz ELECTRIC-FIELD LIMIT, kV/m</b>			
Florida Department of Environmental Regulation	8 ( 230 kV) 10 (500 kV)	2	Codified regulation, adopted after a public rulemaking hearing in 1989.
Minnesota Environmental Quality Board	8	—	12-kV/m limit on the high-voltage direct-current (HVDC) nominal electric field.
Montana Department of Environmental Quality	7 <sup>1</sup>	1 <sup>2</sup>	Codified regulation, adopted after a public rulemaking hearing in 1984.
New Jersey Department of Environmental Protection	—	3	Used only as a guideline for evaluating complaints.
New York State Public Service Commission	11.8 (7,11) <sup>1</sup>	1.6	Explicitly implemented in terms of a specified right-of-way width.
Oregon Facility Siting Council	9	—	Codified regulation, adopted after a public rulemaking hearing in 1980.
<b>b. 60-Hz MAGNETIC-FIELD LIMIT, mG</b>			
Florida Department of Environmental Regulation	—	150 ( 230 kV) 200 (500 kV)	Codified regulations, adopted after a public rulemaking hearing in 1989.
New York State Public Service Commission	—	200	Adopted August 29, 1990.

<sup>1</sup> At road crossings

<sup>2</sup> Landowner may waive limit

Sources: TDHS Report, 1989; TDHS Report, 1990; Montana, 2005

**Table 6: Common Noise Levels**

Sound Level, dBA	Noise Source or Effect
128	Threshold of pain
108	Rock-and-roll band
80	Truck at 50 ft.
70	Gas lawnmower at 100 ft.
60	Normal conversation indoors
50	Moderate rainfall on foliage
49	Edge of 500-kV right-of-way during rain
40	Refrigerator
25	Bedroom at night
20	Edge of 115-kV right-of-way during rain
0	Hearing threshold

Adapted from: USDOE, 1996.

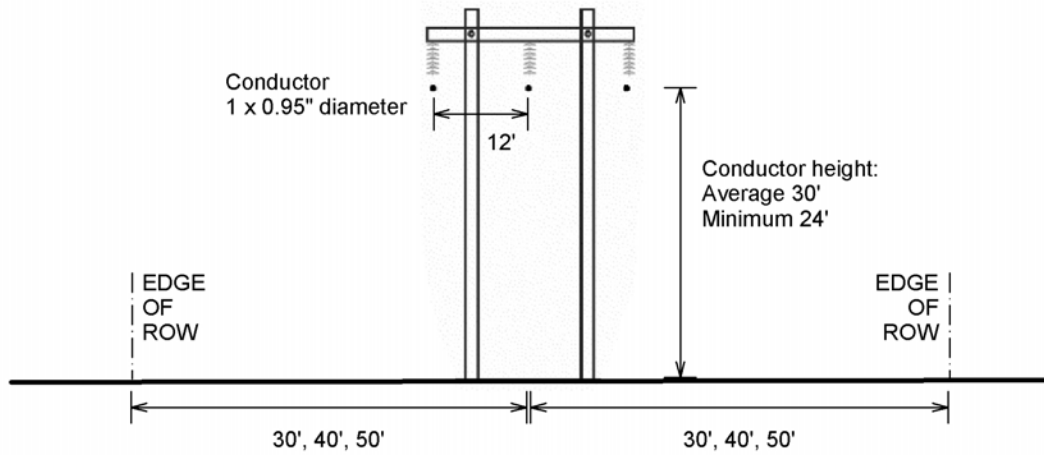
**Table 7: Predicted Foul-weather Audible Noise Levels at Edge of Right-of-way by Configuration for the Proposed Libby to Troy Transmission Line Rebuild**  
 AN levels expressed in decibels on the A-weighted scale (dBA). L<sub>50</sub> and L<sub>5</sub> denote the levels exceeded 50 and 5 percent of the time, respectively.

Configuration	Existing		Proposed		
	H-frame	Single-pole Vertical; Wishbone	H-frame	Single-pole	Double circuit <sup>1</sup>
<b>ROW Width, ft.</b>	80	60	80	60	100
<b>Foul weather: L<sub>50</sub>/L<sub>5</sub>, dBA</b>	19/23	22/26; 19/22	18/21	20/24	11/15
<b>Fair weather: L<sub>50</sub>/L<sub>5</sub>, dBA</b>	Not in corona	Not in corona	Not in corona	Not in corona	Not in corona

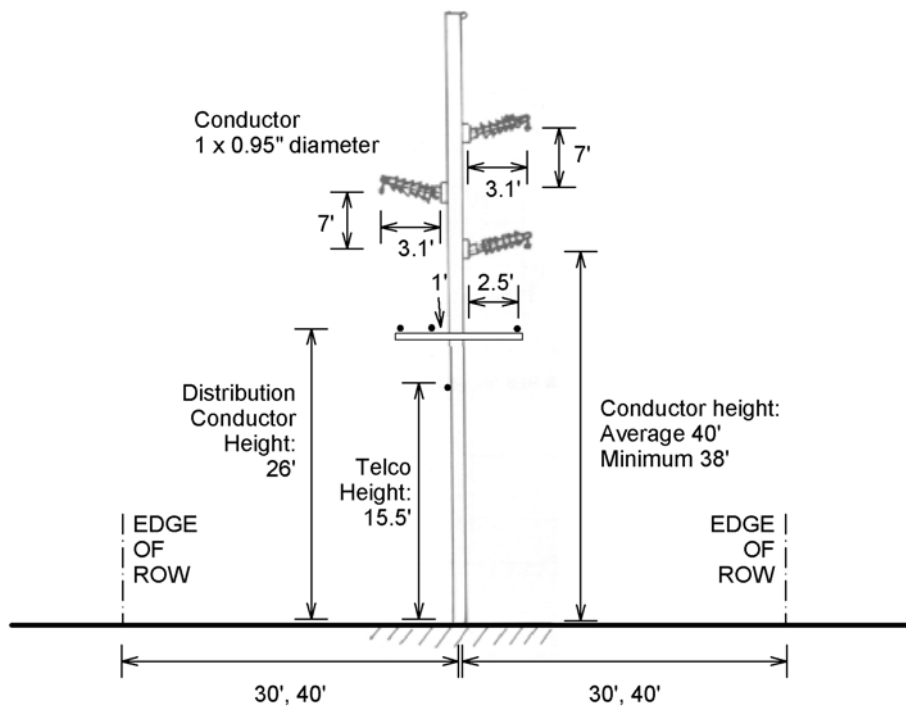
<sup>1</sup> 230-kV double-circuit line operated at 115 kV

**Figure 1: Configurations for the Proposed Libby to Troy Transmission Line Rebuild:**  
 a) 115-kV H-frame, b) 115-kV Single-pole with underbuild, and c) 230-kV double-circuit line operated at 115-kV  
 Routes and configuration are described in Tables 1 and 2.

a) 115-kV H-frame

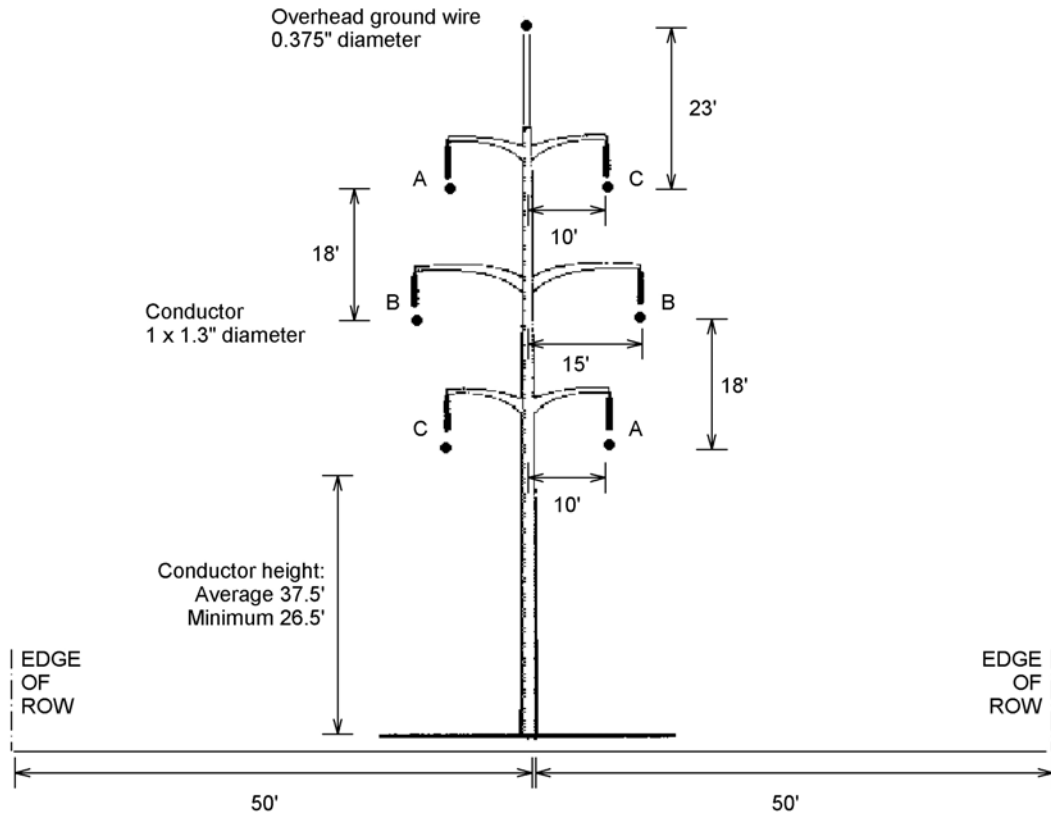


b) 115-kV Single-pole with underbuild



**Figure 1, continued**

c) 230-kV double-circuit line operated at 115-kV

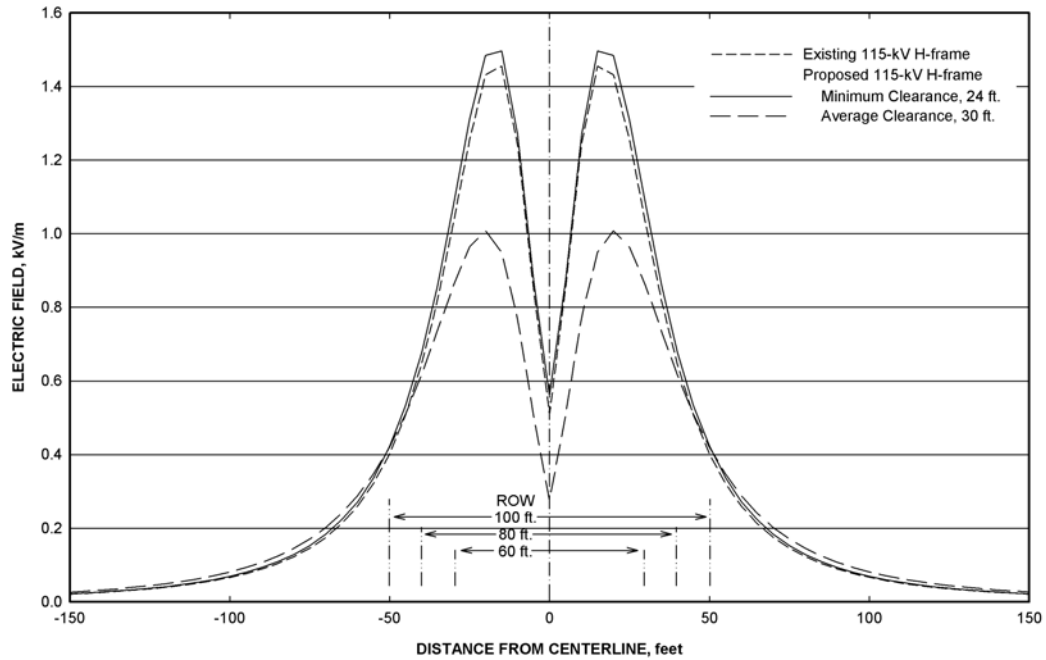




**Figure 2: Electric-field Profiles by Configuration for the Proposed Libby to Troy Transmission Line Rebuild under Maximum Voltage and Minimum Clearance Conditions:**

a) 115-kV H-frame, b) 115-kV Single-pole, and c) 230-kV Double-circuit line operated at 115-kV Configurations are described in Table 2.

a) 115-kV H-frame



b) 115-kV Single-pole

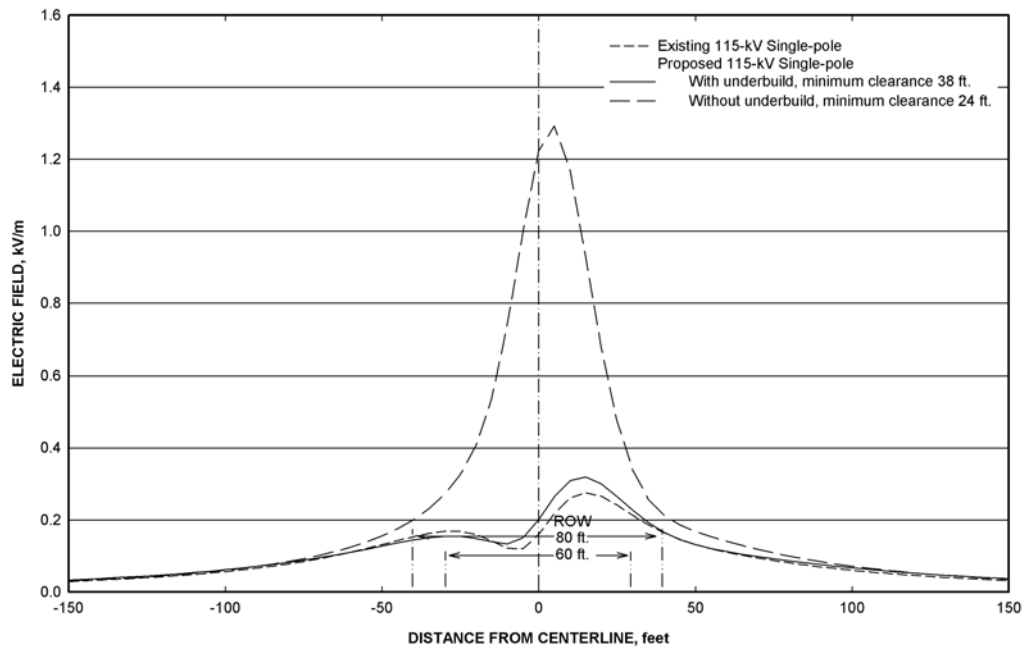


Figure 2, continued

c) 230-kV Double-circuit line operated at 115-kV

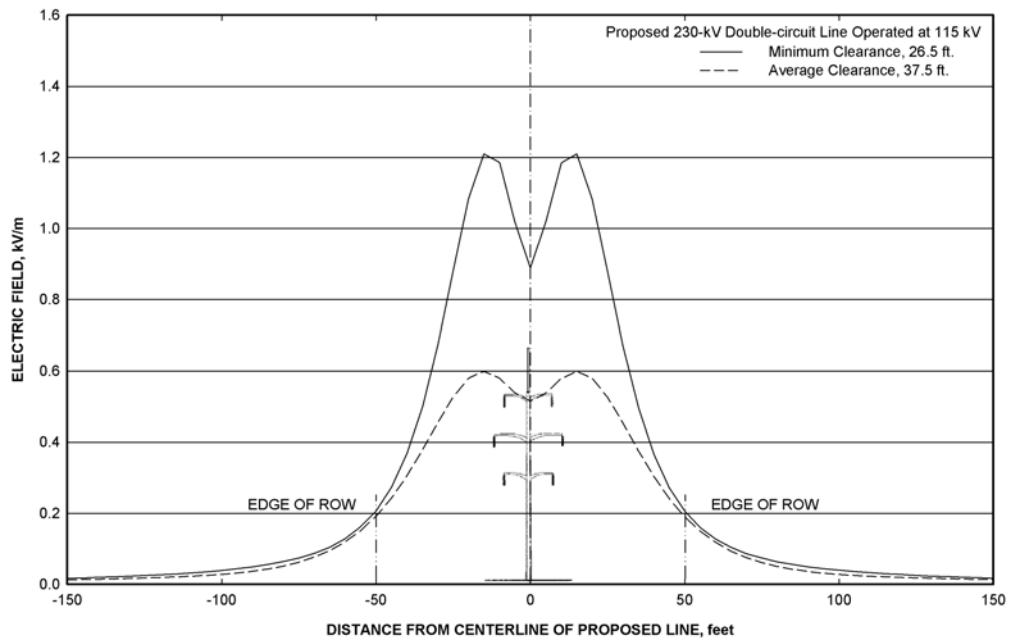
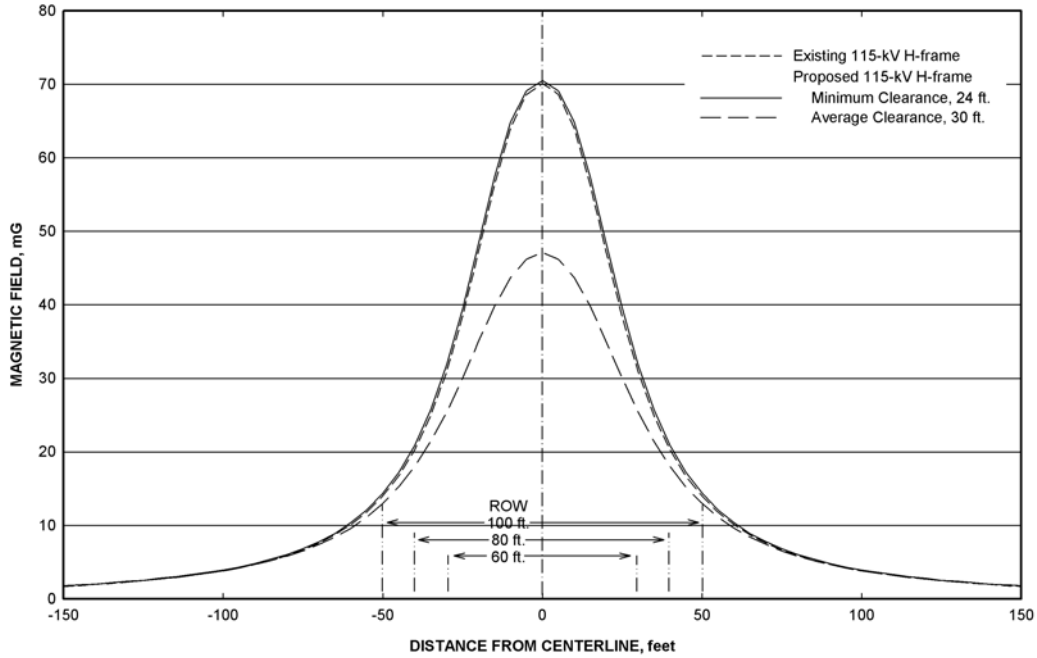


Figure 3: Magnetic-field Profiles by Configuration for the Proposed Libby to Troy Transmission Line Rebuild under Maximum Current and Minimum Clearance Conditions: a) 115-kV H-frame, b) 115-kV Single-pole, and c) 230-kV Double-circuit line operated at 115 kV. Configurations are described in Table 2.

a) 115-kV H-frame



b) 115-kV Single-pole

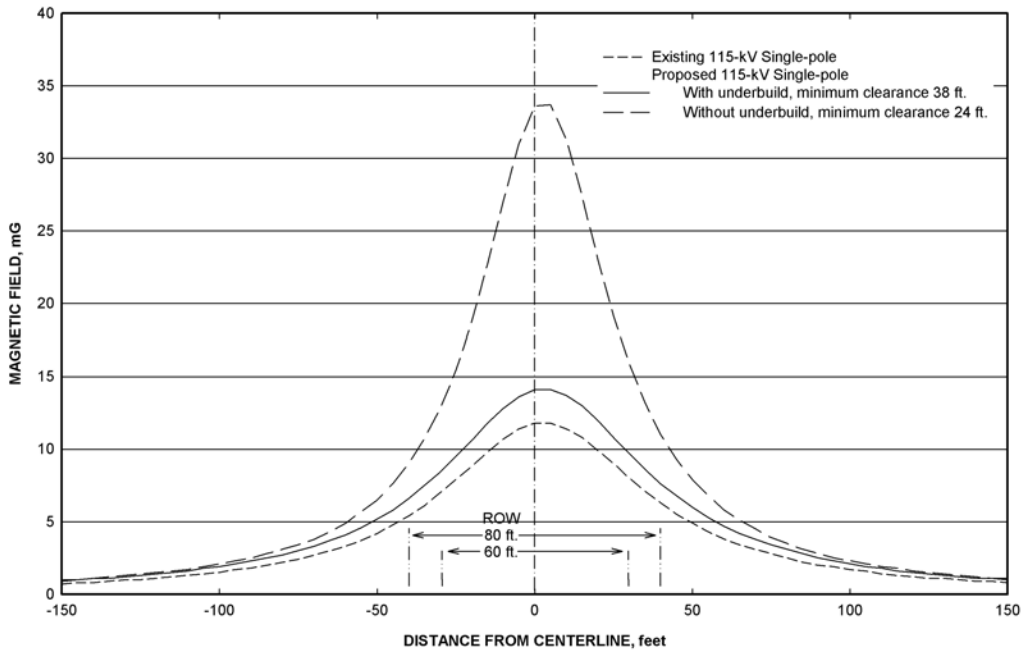


Figure 3, continued

c) 230-kV Double-circuit line operated at 115 kV

