October 2019

RHODE ISLAND ENERGY FACILITY SITING BOARD PROJECT SITING REPORT

Q-143 and R-144 115 kV Underground Transmission Line Reconductoring Project

Providence, Rhode Island

PREPARED FOR:

THE NARRAGANSETT ELECTRIC COMPANY D/B/A NATIONAL GRID
280 MELROSE STREET
PROVIDENCE, RI 02907

FOR SUBMITTAL TO:

STATE OF RHODE ISLAND ENERGY FACILITY SITING BOARD
89 JEFFERSON BOULEVARD
WARWICK, RI 02888

PREPARED BY:

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FOXBOROUGH, MA 02035

This document has been reviewed for Critical Energy Infrastructure Information (CEII).

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GLOSSARY OF TERMS

A	Amperes, a measure of electrical current.
ACI	American Concrete Institute
ANSI	American National Standards Institute
ASCE	American Society of Civil Engineers
BMPs	Best Management Practices
Cable	A fully insulated conductor usually installed underground, but in some circumstances can be installed overhead.
Cable Terminal	A riser structure that mechanically supports the cable and terminations.
Cable Terminations	The cable terminations allow transition from cables to other electrical components.
Circuit	A system of conductors (three conductors or three bundles of conductors) through which an electric current flows.
Conductor	A metallic wire which serves as a path for electric current to flow.
Conduit	Pipes, usually PVC plastic, typically encased in concrete to house and protect underground power cables or other subsurface utilities.
Demand	The total amount of electric power required at any given time by an electric supplier's customers.
Distribution Line or System	Power lines that operate under 69 kV.
DPW	Department of Public Works
Duct Bank	A group of ducts or conduit usually encased in concrete in a trench.
Duct	Pipe for underground power cables (see also Conduit).
EFSB	Rhode Island Energy Facility Siting Board
EFSB Rules	State of Rhode Island and Providence Plantations Energy Facility Siting Board Rules of Practice and Procedure, effective; April 11, 1996.
Electric Field	A field produced as a result of voltages applied to electrical conductors and equipment; usually measured in units of kilovolts per meter.
Electric Transmission	Facilities (≥ 69 kV) that transmit electrical energy from generating plants to substations, or from substation to substation.
ELUR	Environmental Land Use Restriction
EMF	Electric and magnetic fields
Environmental Monitor	Inspects environmental conditions within the construction site, reviews the contractors' compliance with environmental permit conditions during the construction phase of a project, and makes recommendations for corrective actions to protect sensitive environmental resources proximate to a construction site.

EPR	Ethylene Propylene Rubber, a type of cable insulation.
FWW Rules	Rhode Island Fresh Water Wetlands Rules
Hz	Hertz, a measure of the frequency of alternating current; expressed in units of cycles per second.
IEEE	Institute of Electrical and Electronic Engineers
I-95	Interstate Route 95
ISO-NE	ISO New England, Inc., the independent system operator of the New England electric transmission system.
kcmil	One thousand circular mils, approximately 0.0008 square inches, a measure of conductor cross-sectional area.
kV	Kilovolt - one kV equals 1,000 volts
Load	Amount of power delivered upon demand at any point or points in the electric system; load is created by the power demands of customers' equipment (residential, commercial and industrial).
M	million
Mandrel	A cylindrical rod used in proofing conduits after installation.
Megavolt Ampere	Measure of electrical capacity equal to the product of the line-to-line voltage, the current and the square root of 3 for three-phase systems; electrical equipment capacities are sometimes stated in MVA.
mG	milligauss, a measure of magnetic field intensity.
MODF	Mineral Oil Dielectric Fluid – An insulating fluid used in transformers and certain types of underground transmission cables.
NAAQS	National Ambient Air Quality Standards
NERC	North American Electric Reliability Corporation
NESC	National Electrical Safety Code. The NESC is an ANSI standard that covers basic provisions for safeguarding of persons from hazards arising from the installation, operation, or maintenance of 1) conductors and equipment in electrical supply stations, and 2) overhead and underground electric supply and communication lines. It also includes work rules for the construction, maintenance, and operation of electric supply and communication lines and equipment.
NOI	Notice of Intent
NPCC	Northeast Power Coordinating Council
NRCS	Natural Resource Conservation Service
NRHP	National Register of Historic Places
OSHA	Occupational Safety and Health Administration
Phase	Transmission and distribution AC circuits are comprised of three conductors or bundles of conductors that have voltage and angle differences between them; each of these conductors (or bundles) is referred to as a phase.

Project	Q-143 and R-144 115 kV Underground Cable Transmission Line Project
Project Area	The area immediately adjacent to the Project Route between Admiral Street Terminal and Dollar Street.
Proofing	Verifying a conduit internal diameter and integrity by pulling a device (mandrel) through it.
Report	Project Siting Report
PVC	Polyvinyl Chloride, a type of plastic.
Q-143 Line	Q-143 115 kV underground electrical transmission line
R-144 Line	R-144 115 kV underground electrical transmission line
Reactive Power	A component of power associated with capacitive or inductive circuit elements; its unit of measurement is the VAR (Volt-Ampere, Reactive).
Reconductor	Replacement of existing conductors with new conductors, and any necessary structure reinforcements or replacements.
RICRMC	Rhode Island Coastal Resources Management Council
RIDEM	Rhode Island Department of Environmental Management
RIDOT	Rhode Island Department of Transportation
RIGIS	Rhode Island Geographic Information System
RIGL	Rhode Island General Laws
RIHPHC	Rhode Island Historical Preservation & Heritage Commission
RIPDES	Rhode Island Pollutant Discharge Elimination System
RIPTA	Rhode Island Public Transportation Authority
ROW	Right-of-Way. Corridor of land within which a utility company holds legal rights necessary to build, operate, and maintain power lines.
SCFF	Self-Contained Fluid Filled, a type of underground transmission cable.
SESC	Soil Erosion and Sediment Control
SGMP	Soil and Groundwater Management Plan
Solid Dielectric	Cables having a rubber or polymeric insulating material that is extruded onto the conductor. This material is typically ethylene propylene rubber (EPR) or cross-linked polyethylene (XLPE).
Splices	A connection between two cable sections.
SR	State Route
Study Area	A 1,000-foot-wide corridor measured 500 feet on either side of the subject underground cables.
Substation	A fenced-in yard containing switches, circuit breakers, power transformers, line terminal structures, and other equipment enclosures and structures; voltage changes, adjustments of voltage, monitoring of circuits and other service functions take place in the substation.

Surge Arrester	A device attached to power lines to limit over voltages during switching surges or lightning events.
Switching Station	Same as Substation except with no power transformers; switching of circuits and other service functions take place in a switching station.
SWPPP	Storm Water Pollution Prevention Plan
TMDL	Total Maximum Daily Load
TMP	Traffic Management Plan
TNEC	The Narragansett Electric Company d/b/a National Grid
Transmission Line	An electric power line operating at 69,000 volts or more.
Trenwa© Trench	A precast concrete trough with removable covers set flush with the ground surface, used for routing of cable, typically used in Substations.
USGS	United States Geological Survey
Voltage	Electric potential difference between any two conductors or between a conductor and ground, typically measured in kilovolts (thousands of volts) for utility projects.
Watercourses	Rivers, streams, brooks, waterways, lakes, ponds, swamps, bogs and all other bodies of water, natural or artificial, public or private.
XLPE	Cross Linked Polyethylene, a type of underground cable insulation.

1.0 INTRODUCTION

1.1 Project Overview

This Project Siting Report ("Report") has been prepared in accordance with Rule 1.6(F) of the *Rhode Island Energy Facility Siting Board's* ("EFSB") *Rules of Practice and Procedure* ("EFSB Rules") to support a 90-day Notice of Intent ("NOI") for the proposed modification/reconductoring of the existing Q-143 and R-144 115 kilovolt (kV) underground electric transmission lines (the "Q-143 and R-144 Lines" or "Lines") (the "Project"), owned and operated by The Narragansett Electric Company d/b/a National Grid ("TNEC" or "the Company").

The Project involves reconductoring approximately two miles each of the Q-143 and R-144 Lines in Providence, Rhode Island within the existing route from the Admiral Street Cable Terminal to Manhole 31 on Dollar Street ("Project Route"). Refer to Volume II Mapping, Figure 1 for plans of the Project Route. The entire route is located within the limits of the existing roadway rights-of-way ("ROW"), which includes travel lanes and sidewalks.

In a previous proceeding, the EFSB approved TNEC's Providence River 115 kV Cable Relocation Project (Docket No. SB-2017-02) (Appendix C). The purpose of Docket No. SB-2017-02 was to resolve submarine cable failures, to return the R-144 Line to service, and to reduce the risk of failure of the Q-143 submarine cable. The cable relocation occurred between the existing Franklin Square Substation, crossed the Point Street Bridge over the Providence River, and terminated at Dollar Street. This construction is complete and roadway restoration is underway. The Project presented herein involves reconductoring the balance of the Q-143 and R-144 Lines from Dollar Street north to the Admiral Street Cable Terminal.

The Q-143 and R-144 Lines were installed in 1939 and 1946, respectively, and have experienced failures of various components with increasing frequency in recent years. The Project is proposed to maintain a reliable supply of electricity to TNEC's customers.

The purpose and need for the Project are detailed in Section 2.0 of this Report. Section 3.0 provides a detailed description of each of the components of the Project, and also discusses construction practices, safety and public health considerations, estimated costs for the Project, and anticipated Project schedule. An analysis of alternatives to the Project, together with reasons for the rejection of each alternative, is presented in Section 4.0 of this Report. Detailed descriptions of the characteristics of the natural and social environment within and immediately surrounding the Project location are included as Sections 5.0 and 6.0, respectively. Section 7.0 of this Report identifies the potential impacts of the Project on the natural and social environments. Finally, Section 8.0 summarizes proposed mitigation measures which are intended to offset or eliminate the potential impacts associated with the Project.

This Report is being submitted to satisfy the applicable requirements of Rhode Island General Laws (RIGL) 42-98-1 et seq., the Energy Facility Siting Act, and Rule 1.6(F) of the EFSB Rules. The Energy Facility Siting Act states that "[n]o person shall site, construct, or alter a major energy facility within the state without first obtaining a license from the siting board pursuant to this chapter." RIGL § 42-98-4. Transmission lines with a design rating equal to or greater than 69 kV are classified as major energy facilities. Rule 1.6(F) permits the filing of a Notice of Intent at least 90 days before commencement of modification (e.g. reconductoring) of an existing transmission line that is more than 6,000 feet in length. Pursuant to Rule 1.6(F) of the EFSB Rules, the EFSB must make a determination as to whether the Project "may have a significant impact on the environment or the

public health, safety and welfare" and, therefore, constitutes an alteration of a major energy facility. If the EFSB determines that the Project will not have such an impact, the Project may proceed without further review. As discussed in detail in this Report, the Project will not have a significant impact on the environment, public health, safety or welfare, and no further review is needed.

1.2 Project Team

This Report has been prepared by TNEC with contributions from numerous employees of and consultants retained by TNEC, including planners, engineers, and legal personnel. The description of the affected natural and social environments, and impact analyses were prepared by POWER Engineers, Inc. ("POWER"), and Exponent, Inc. ("Exponent") prepared the analysis of the health effects of Electric and Magnetic Fields ("EMF") and EMF modeling and calculations. POWER is also preparing the Project engineering and design documents.

1.3 Compliance with EFSB Requirements

Compliance with the EFSB Rules is addressed in the application which is filed under separate cover with the EFSB.

2.0 PROJECT NEED

2.1 Need

TNEC strives to provide its customers with high quality and reliable electric service at the lowest possible cost, while minimizing environmental and social impacts. Reliability is measured in terms of frequency and duration of power outages lasting one minute or more. The quality of electric service refers to voltage levels, variations in voltage frequency, harmonics, and outages lasting less than one minute.

The Project need is driven by the condition of and reliability concerns with the Q-143 and R-144 Lines. In recent years, the Q-143 and R-144 Lines have experienced an increasing number of splice and cable failures due to the gradual degradation of the cables and accessories, as well as the degradation of the associated fluid reservoirs, valve panels, and alarm system (collectively, the "hydraulic system"). Typical failures result in lengthy circuit outages and prolonged system operation in abnormal configurations. To eliminate these outages and improve circuit availability, TNEC proposes to reconductor the existing cables with solid dielectric cables.

The Project is needed to maintain firm and reliable electric supply to TNEC customers in Providence.

If the Project does not proceed, the electric supply to the Providence area load will continue to be at risk due to the condition of the cable system.

2.2 Benefits

Completing the Project will result in measurable benefits, including the following:

- Improve reliability to the 115-kV transmission system serving TNEC's Providence customers by replacing the existing fluid-filled cables that have surpassed their life expectancy;
- Increase capacity of the underground transmission lines which provides greater transmission flexibility in the Providence area; and
- Install solid dielectric cables that typically require less maintenance compared to the existing fluid-filled cables.

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3.0 PROJECT DESCRIPTION AND PROPOSED ACTION

3.1 Introduction

In this section of the Report, the overall scope of the Project is identified and the individual components and facilities comprising the Project are described. This section of the Report also details TNEC's construction practices, safety and public health considerations, traffic patterns and traffic management, estimated costs, the anticipated construction schedule and community outreach for the Project.

3.2 Description of the Existing Transmission Cables

The Q-143 and R-144 Lines are located in Providence, Rhode Island, and feed areas of the City of Providence, including commercial, residential, and industrial customers. The Q-143 and R-144 Lines were installed in 1939 and 1946, respectively, and connect the Admiral Street Cable Terminal located at the intersection of Admiral Street and Clarkson Street to the Franklin Square Substation located at 469 Eddy Street, both in Providence. Each Line consists of three single phase self-contained fluid-filled ("SCFF") cables and the Lines share 2.3 miles of common duct bank with separate manholes for each Line.

The two Lines between Admiral Street Cable Terminal and Manhole 31 on Dollar Street share a common duct bank primarily consisting of concrete encased four-inch fiber conduits. Fiber conduits are composed of a mixture of wood pulp and asphalt, and were widely used for electrical conduits until the 1960's. There are short sections of duct bank with concrete encased six-inch polyvinyl chloride ("PVC") conduit from past relocations. The majority of the duct bank has nine (9) conduits in a three (3) conduit wide x three (3) conduit high configuration (see Figure 3). The common duct bank includes six (6) cables to create the two Lines, an active fiber optic cable and a single ground continuity conductor that is shared between the two Lines. Although the duct bank is common between the two Lines, at the manhole locations, the duct bank splits to separate manholes for splicing. There is a total of 28 manhole pairs (56 manholes) along the Project Route from Manhole #1 to, and including, Manhole #31 on Dollar Street. At each pair, there is one manhole for the Q-143 Line and one manhole for the R-144 Line. The existing cables are single phase SCFF 500 kcmil (five hundred thousand circular mils) hollow-core copper conductor with several sections of 1,000 kcmil conductor.

3.3 Scope of the Project

The scope of the Project includes the following components.

- Remove existing cables and accessories, and re-use approximately 6,400 feet existing duct bank.
- Install short sections of new duct bank at 22 manhole pairs at 22 locations to bridge the existing duct bank sections through or around the existing manholes.
- Remove and replace six (6) manhole pairs at six (6) locations for splicing the power cables
- Install two (2) new manhole pairs at new locations along the existing duct bank alignment.

- Realign short sections of duct bank between new manholes and existing duct bank, as necessary.
- Rebuild remaining original portion of Manhole 31 on Dollar Street.
- Replace/repair existing ducts as needed after proofing of each conduit.
- Install six (6) 115 kV 1,500 kcmil copper conductor solid dielectric insulated cables in the existing/modified duct bank.
- Install two (2) new ground continuity conductors (500 kcmil copper, 600 Volt insulated) in the existing/modified duct bank.
- Install three (3) 115 kV splices in each splicing manhole.
- Install cable riser structures, three (3) outdoor cable terminations and three (3) surge arresters per Line within the Admiral Street Cable Terminal.
- Install one (1) fiber optic cable from Admiral Street Cable Terminal to Franklin Square Substation.

3.3.1 Project Route

The Project Route is approximately two miles long (see Figure 1) and is generally established in a north-south direction from the existing TNEC Admiral Street Cable Terminal to the existing Manhole 31 on Dollar Street. The proposed cable route is located within the limits of a public roadway ROW in a developed urban area in Providence.

The Project Route is as follows:

- Approximately 100 feet through the TNEC fee-owned property occupied by the Admiral Street Substation;
- Approximately 1,000 feet along Admiral Street from the TNEC fee-owned property occupied by the Admiral Street Substation to Route 146;
- Approximately 200 feet across Route 146 to the intersection of Admiral Street & Charles Street;
- Approximately 3,200 feet on Charles Street from Admiral Street to Mill Street;
- Approximately 900 feet on Mill Street from Charles Street to North Main Street;
- Approximately 2,250 feet on North Main Street from Mill Street to South Main Street;
- Approximately 2,675 feet on South Main Street from North Main Street to Dollar Street; and
- Approximately 25 feet on Dollar Street from South Main Street to Manhole 31.

3.3.2 Cable Rating

TNEC's Transmission Planning Group reviewed the future capacity needs of the cables. Upon completion of this Project, each of the Q-143 and R-144 Lines must meet the requirements of 130 Megavolt Ampere or 653 amps (A) summer normal. An ampacity study for the two Lines in the existing and proposed duct bank configurations determined that 1,500 kcmil copper 115 kV solid dielectric cables will satisfy this future requirement.

3.4 Construction Practices

3.4.1 Introduction

The Project is located within an urban environment and the cable system is located beneath paved roadways and sidewalks, with portions of the Project Route located adjacent to open green space/ landscaped areas along the roadways. Project construction will be sequenced in phases. Each of these steps is described in more detail below. The construction steps will be conducted in sequence at each location so that several phases of construction will be ongoing simultaneously in different sections of the route. The Company proposes to perform the construction in the following sequence:

- Install environmental controls.
- Remove all cables and accessories from the duct bank and manhole system.
- Modify the duct bank and manhole system to accept modern transmission cables.
- Install the new transmission cables.
- Restore pavement and other surfaces affected by construction.

Prior to construction, both Lines will be taken out of service. During the period of the Line outage, the electric load normally served by the Lines will be served by other overhead and/or underground transmission and distribution lines. This temporary outage plan is possible due to recent upgrades to the transmission system including the improvements to the Woonsocket Substation.

3.4.2 Installation of Environmental Controls

Prior to commencing underground construction, the contractor will install appropriate soil erosion and sediment controls (e.g., catch basin inlet protection, straw wattles, silt fence) at locations where the disturbance of pavement or soils have the potential to impact a natural resource. Storm water control measures will be installed in accordance with National Grid's standards and all applicable requirements, including design and manufacturer specifications.

Excess sediment generated by construction will be swept daily to minimize accumulation of sediment or dust within the construction work zone. During trenching for the duct bank and excavation for the manholes, TNEC and its contractors will first saw-cut the pavement and/or concrete, and then live-load the excavated soils and materials directly into awaiting transport that will be queued along the Project Route. This method of construction will allow for a "clean trench" which will significantly reduce any temporary stockpiling of excavated soils/materials and minimize the potential for the inadvertent release of soil and/or sediment onto the street or sidewalks.

Sediment control barriers will be installed along the perimeter of the Project that will receive storm water from disturbed areas. Installation and maintenance of sediment barriers must be completed in accordance with National Grid's *ROW Access, Maintenance, and Construction Best Management Practices (EG-303NE)* and the maintenance requirements specified by the product manufacturer or the *RI SESC Handbook*. The sediment control barriers will be included in the Soil Erosion and Sediment Control ("SESC") Plan.

Any in-water work performed in the Moshassuck River will be temporary and confined to the minimum space needed to work safely under the Mill Street Bridge. Appropriate measures will be implemented to confine the work space, and to contain construction materials and debris. For

purposes of response to an inadvertent release, an emergency spill kit, including surface oil booms, will be maintained on-site during construction.

3.4.3 Cable Removal

During the original construction, the splices and cables within the existing manholes were coated with an asbestos cement fireproofing compound. Although this material has been removed from many of the manholes during past repairs, approximately half of the remaining manholes will require abatement. Asbestos abatement will be performed by licensed asbestos abatement contractors in accordance with RI Department of Health requirements. Removed asbestos materials will be lawfully disposed of.

Once an abatement has been completed, removal of existing cables and accessories will commence. The existing power cables are filled with a mineral oil based dielectric fluid ("MODF"). Prior to cable removal, the free MODF in the hollow cable cores and accessories will be drained. Free MODF removal will occur at existing hydraulic isolation points, referred to as "stop joints."

Stop joint manholes are located at the following locations:

- Charles Street, north of the Interstate 95 crossing;
- North Main Street at Mill Street;
- South Main Street at Crawford Street; and
- Dollar Street at South Main Street.

Free MODF will be collected in DOT-approved containers and lawfully disposed of at a National Grid approved receiving facility. Once free MODF removal is completed, cable removal will begin at the manhole locations. Cable removal requires the use of winch trucks, reel handling equipment and support vehicles. Removed cable will be collected in oil tight DOT-approved containers or collected on reels and will ultimately be recycled. Reservoirs and other MODF handling equipment, which are located in the stop joint manholes and at Admiral Street Cable Terminal, will be drained, removed from the manholes, and recycled.

3.4.4 Manhole Installation and Modifications

From Admiral Street Cable Terminal to Manhole 31 on Dollar Street, there are a total of 56 manholes, arranged as 28 manhole pairs. At each manhole pair along the route, the Q-143 Line is spliced in one manhole, and the R-144 Line is spliced in the other. The average manhole to manhole spacing, as installed is 400 feet. Under modern underground transmission practice the spacing between manholes is generally 1,500 to 2,000 feet. In addition, the existing manholes, which are approximately 6 feet wide x 12 feet long x 6.5 feet tall (internal dimensions), are considered inadequately sized for modern transmission cable. Many of the existing manholes have poor duct alignment, where the conduits enter and exit the manholes in diagonally opposite corners.

As a result of the aforementioned factors, a majority of the existing manholes will be retired. Prior to retirement, manholes will be cleaned and residual debris and/or cable oil will be removed, if present. Residual debris and cable oil will be properly and lawfully disposed of or recycled. Twenty (20) of the existing manhole pairs will be replaced with short sections of duct bank within the footprint of the existing manholes. At two manhole pairs, the manholes will be bypassed with new duct bank.

Manholes that are to be bridged with new duct bank or bypassed will be retired. Access to retired manholes will be removed and the surface will be restored to surrounding grade. At six (6) manhole pair locations, the existing manholes will be replaced with new pre-cast concrete manholes to allow for cable pulling and splicing. An additional two (2) new pre-cast concrete manhole pairs will be installed along the existing duct bank outside of the footprint of existing manholes. In total, eight (8) new pre-cast manholes are proposed to be installed per line, a significant reduction from the current 28 manholes per line in this section. The new precast manholes will be approximately 18 feet long x 7 feet wide x 7 feet tall (internal dimensions). The Manhole 31 pair on Dollar Street is being expanded under the Providence River Cable Relocation Project and will require modifications to the original structure to accept the new cable system while leaving the expanded portion intact. The proposed construction at each manhole location is listed in Table 1 below:

TABLE 1 PROPOSED CONSTRUCTION AT EACH MANHOLE LOCATION

Manhole Pair Number	Individual Manhole Designation		Replace (R) Bridge (Br) Bypass (Bp)	Location	Figure 1 Sheet Number
	Q-143	R-144			
1	2011	2010	Br	Admiral St & Chad Brown St	1
2	2013	2012	Br	Approx. 90’ NW of Admiral St & Fillmore St	1
3	2015	2014	R	Admiral St & Whipple St	1
4	2498	2499	Bp	Charles St & Admiral St	1
5	2563	2564	R	Charles St & Admiral St	1
7	1989	2021	R	Charles St & Ashburton St	2
7.5	2023	2022	Br	Approx. 200’ NW of Charles St & Corliss St	2
8	1988	2024	Br	I-95N Exit 23 Off-Ramp	2
9	1987	2025	R	Charles St, Ashburton St & Randall St.	3
10	1986	2026	Br	Charles St & Stevens St	3
11	2027	1985	Br	Charles St & Orms St	3
12	2028	1984	Br	Western abutment of Mill Street Bridge	3/4
13	2029	2030	Br	Eastern abutment of Mill Street Bridge	4
13.5	(New)	(New)	(New)	Island between Mill St & Canal St	4

14	2031	2032	Bp	Mill St & Canal St	4
15	2033	2034	Br	North Main St & Church St	4
16	2036	2035	R	North Main St & Cady St	4/5
17	2038	2037	Br	Approx. 100' S of North Main St & Meeting St	5
17.5	(New)	(New)	(New)	North Main St. & Thomas St.	5
18	2039	2040	Br	Washington St & North Main St	5
20	2042	2041	Br	North Main St & Drowne St	5/6
22	2043	2044	Br	South Main St & Hopkins St.	6
23	2046	2045	Br	Approx. 170' S of South Main St. & Hopkins St.	6
24	2047	2048	Br	Approx. 260' N of South Main St. & Planet St.	6
25	2050	2049	R	South Main St. & Planet St.	6
26	2051	2052	Br	South Main St. & Power St.	6/7
27	2053	2054	Br	Approx. 250' S of South Main St. & Power St.	7
28	2056	2055	Br	South Main St & Williams St	7
29	2058	2057	Br	South Main St & James St	7
30	2060	2059	Br	South Main St & Transit St	7
Total					
28 Existing Manhole Pairs 8 Proposed New Manholes			Replace: 6 manhole pairs Bridge: 20 manhole pairs Bypass: 2 manhole pairs New: 2 manhole pairs		

Notes: The existing manholes for the Q-143 & R-144 circuits are referred to as either Manhole (MH) # or Manhole Q#### / R####. When referred to as a one- or two-digit number, ex. MH #2, this indicates both manholes for the Q-143 and R-144 circuit at this location. In this example, MH #2 consists of manholes Q2013 and R2012.
Replace (R): A removal of the existing manhole pair to allow the installation of new, pre-cast manholes.
Bridge (Br): A partial removal of the existing manhole pair to allow duct line to be installed in the footprint of the existing manhole pair. The existing access will be removed, and the surface restored to existing grade.
Bypass (Bp): Installation of new duct line around the existing manhole pair. Bypassed manholes will be retired, including removal of access and restoration of the surface to surrounding grade.

For safety purposes, the manhole and duct bank construction locations will be shored and barricaded. During construction, manhole and duct bank excavation sites may be protected by concrete (Jersey)

barriers on a case by case basis. Manhole modifications within roadways will require the temporary closure of a travel lane in the immediate vicinity of the manhole construction.

3.4.5 Trenching and Installation of Duct Bank

New conduit installations at the manhole retirement areas and conduit repair areas will be encased in 3,000 psi concrete to protect the conduits and cables from mechanical damage. New duct bank will be installed at a minimum depth of 30 inches below finish grade to the top of the concrete. If existing utility interference requires shallow burial of the duct bank, overlapping steel plates will be installed over new conduit installations to provide additional mechanical protection against third-party damage to the cables.

The primary method for constructing an underground duct bank is by open-cut trenching. In open-cut trenching, the width of the trench is established on the street via marking, DigSafe® is contacted, the location of existing utilities is confirmed, and the pavement is cut. The saw cutting provides a clean disturbance in the pavement and defines the trench for the next activity.

Following saw cutting, the existing pavement is removed by pneumatic hammers and loaded via a backhoe into awaiting transport. Pavement is handled separately from the soil due to its obvious recycling disposition.

The majority of new duct bank construction for the Project will occur at the manhole retirement areas. Once the manholes in a given area have been cleaned and retired, duct bank construction to “bridge” between the existing duct bank will commence. The new duct bank segments in the manhole retirement areas will be approximately 100 feet in length each, although this will vary somewhat based on the original manhole arrangement.

The trench will be excavated to the required depth by a backhoe. In pre-determined areas, some of the excavation will be done by hand to avoid disturbing existing utility lines and/or service connections. Within a public way, a “clean trench” method will be used where soil is loaded directly into awaiting transport (i.e., live-loading) for temporary off-site staging, recycling or disposal. Removal of the soil, rather than stockpiling, reduces the size of the required work area and minimizes the potential for sedimentation and nuisance dust. Any rock and concrete encountered during excavation will be removed by mechanical means.

The trench is shored as required by soil conditions and Occupational Safety and Health Administration (“OSHA”) safety rules. The shoring is designed to permit the passage of traffic adjacent to the trench and will allow for the trench to be covered with steel plating to permit unabated traffic over the trench during non-working hours.

The conduit will be replaced/installed in sections, connecting between the cut off existing duct bank sections. Special adapters will be used to provide a smooth transition between the existing fiber conduits and the modern PVC duct bank segments. Rebar doweling, or other means will be used to create a mechanical bond between new and old duct bank. After installation in the trench, the conduits will be encased with structural concrete (3000 psi). The duct bank will then be backfilled with native soil, select gravel backfill, or fluidized thermal material with suitable thermal characteristics to dissipate the heat generated by the cables.

If groundwater is encountered, dewatering will be performed in accordance with applicable regulatory requirements and in accordance with National Grid’s *EG-303NE*.

Upon completion of the manhole removals, new duct bank construction, and new manhole installation, each duct will be proofed to ascertain the acceptability of the conduit for cable installation. If an unusable duct is detected, TNEC will complete a localized duct replacement to repair the location. 'Blisters' or other defects of the fiber conduits that result in reduced internal diameter can generally be removed without the need for excavation by using special cutting equipment similar to a motorized sewer rooter. Broken or displaced conduits may require localized excavation and repair. Repaired conduits will be re-inspected and proofed.

Temporary paving will restore the roadway to use once the section of duct bank is completed. Permanent restoration is discussed in the restoration section below.

3.4.6 Installation and Testing of New Cable

After successful conduit inspection and "proofing," the transmission cables, ground-continuity conductors and fiber optic cables will be installed and spliced. Cable reels will be delivered to the manholes, where the cable will be pulled into the conduit using a truck-mounted winch and cable handling equipment. Once cable installation has progressed sufficiently, cable splicing in the manholes will commence. It takes approximately one to two weeks to complete the transmission cable splices in each manhole. A splicing van will be parked over or next to the manholes during this time.

Once the complete cable system has been installed, the cable system will be tested. At the completion of successful testing, the Lines will be energized.

3.4.7 Restoration of Project Route

After construction activities are completed, disturbed areas will be restored, and environmental controls will be removed. Some environmental controls may need to remain until the area is stabilized.

Disturbed pavement will be restored per the City of Providence Department of Public Works ("DPW") or Rhode Island Department of Transportation ("RIDOT") requirements.

3.4.8 Environmental Compliance Monitoring

TNEC will retain the services of an environmental monitor to oversee construction activities including the installation and maintenance of soil erosion and sediment controls on a routine basis to ensure compliance with all federal, state, and local permit requirements.

3.4.9 Construction Work Hours

Proposed construction work hours for the Project will be between 7:00 a.m. and 7:00 p.m. Monday through Friday when daylight permits and between 7:00 a.m. and 5:00 p.m. on Saturday. Some splicing activities, occurring at manhole locations, may require extended work hours. In addition, work hours may be altered or extended as directed or approved by DPW and RIDOT.

Prior to and during construction, TNEC will notify abutting property owners, municipal officials, DPW, and Police and Fire Chiefs of the details of planned construction including the normal work hours and any extended work hours.

3.4.10 Construction Traffic Management

TNEC's contractors will coordinate closely with the City of Providence, RIDOT and Rhode Island Public Transportation Authority ("RIPTA") to develop acceptable Traffic Management Plans ("TMPs") for work within state and local roads and sidewalks. At locations where construction equipment must be staged in the road, the contractors will follow a pre-approved work zone traffic control plan with appropriate police details.

During non-work hours, temporary cover (steel plates) will be installed over the trench locations within paved roads to maintain traffic flow over the work area if practical, or alternative traffic patterns will be established around the construction area (particularly at manhole construction areas).

Appropriate safety measures will be implemented to allow safe traffic patterns for vehicles, bicyclists and pedestrians.

3.4.11 Safety and Public Health Considerations

TNEC will design, install, and maintain the Project so that the health and safety of the public are protected. This will be accomplished through adherence to applicable regulations, and industry standards and guidelines established for the protection of the public. Specifically, the Project will be designed, built, and maintained in accordance with the National Electrical Safety Code ("NESC"). The facilities will be designed in accordance with sound engineering practices using established design codes and guidelines published by, among others, the Institute of Electrical and Electronic Engineers ("IEEE"), the American Society of Civil Engineers ("ASCE"), the American Concrete Institute ("ACI"), and the American National Standards Institute ("ANSI"). Practices that will be used to protect the public during construction will include, but not be limited to, establishing traffic control plans for construction traffic on busy streets to maintain safe driving conditions, restricting public access to potentially hazardous work areas, noise and dust control management, and coordination with the City of Providence and RIDOT during installation.

A discussion of the current status of the health research relevant to exposure to EMF is attached as Appendix A. This report was prepared by Exponent.

3.4.12 Estimated Project Costs

TNEC has estimated the cost for the reconductoring of the Q-143 and R-144 Lines between the Admiral Street Cable Terminal and Manhole 31 located on Dollar Street (Table 2). At the current conceptual level of design, the Project is anticipated to cost approximately $46.5M.

TABLE 2 ESTIMATED PROJECT COSTS

PROJECT COMPONENTS	ESTIMATED COST ($M)
Transmission Cable Facilities	$43.8M
Admiral Street Cable Terminal Termination Structures	$2.7M
Total	**$46.5M**

3.4.13 Preliminary Project Schedule

The Company expects the licensing and permitting process to continue through the fourth quarter 2019 with final engineering completed during the third quarter 2019. Construction is anticipated to begin in the first quarter 2020 with completion in the fourth quarter 2021.

TNEC has developed a preliminary schedule based on time estimates for planning and engineering, permitting and licensing, and construction (Table 3). The Project is expected to be completed and in-service by second quarter 2022.

TABLE 3 PRELIMINARY PROJECT SCHEDULE

ACTIVITY	ESTIMATED START DATE	ESTIMATED COMPLETION DATE
Planning and Engineering	2nd Q 2018	3rd Q 2019
Permitting and Licensing	1st Q 2019	4th Q 2019
Construction	1st Q 2020	4th Q 2021
Facilities In-Service	1st Q 2022	
Final Restoration	2nd Q 2022	

3.4.14 Public Outreach

TNEC has reached out to the City of Providence, RIDOT, and RIPTA to inform them of the proposed Project activities and will continue these relationships as the Project develops. TNEC representatives also met with the National Park Service at their Roger Williams National Memorial facility in Providence. TNEC will communicate with residents, businesses and others along the Project Route to provide information relative to the Project and its impact and will prepare and distribute Project-related materials containing relevant Project details and Company contact information. Project related outreach materials may reference the Project's brand name *Power4Tomorrow*.

The Company will also promote, advertise and host a community Open House at a location near the Project Route to provide the public with an opportunity interact with subject matter experts on the Project need, location, benefits and construction activities, as well as to respond to questions and/or share concerns.

The Company will notify abutters of its planned construction start and work schedule prior to commencing construction, with particular attention paid to businesses along the Project Route. Company representatives will meet individually with business owners prior to the start of construction to provide notification of the Project schedule and potential impact to their businesses.

The Company will also produce and publish construction notification advertising in relevant local newspapers to heighten awareness of Project construction activities. The Project team will also promote, establish and maintain a Twitter presence to provide impacted constituencies who engage in social media to interact with the Project team on that platform, providing an additional potential point of contact.

In addition, notifications will be made by mail, email and/or scheduled customer appointments to keep abutters and other members of the public apprised of Project schedules and material

developments. A Project website will be created and promoted through which abutters and interested parties can learn more about the Project and obtain the latest information on the construction schedule.

Lastly, a consumer hotline number will be established to provide 24-hour Project contact information. The Company is committed to responding promptly to any customer inquiry.

The full summary of Stakeholder Relations outreach efforts is summarized in the table below:

TABLE 4 SUMMARY OF PROJECT OUTREACH

PROJECT OUTREACH	ESTIMATED TIMELINE
Project Introduction/Fact Sheet	Fall 2019
Door-to-door outreach	Fall 2019
Community Open House	Fall 2019
Project website	Fall 2019
Media Relations	As needed throughout Project
Abutter construction notifications	As needed throughout construction
Construction signage	As needed throughout construction
Advertising	Throughout construction periods
Twitter feed	Launch with construction
Customer hotline phone number	Throughout Project

3.4.15 ISO-NE Approval of Project

The Q-143 and R-144 Lines are not defined as Pool Transmission Facilities by ISO-NE. A Level I Proposed Plan Application will be filed by TNEC with ISO-NE to ensure the proposed changes and upgrades to the transmission system will not have a significant impact on the bulk power transmission system.

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4.0 PROJECT AND ROUTE ALTERNATIVES

4.1 Introduction

This section describes the alternatives to the Project that were considered to address the condition and reliability issues with the Q-143 and R-144 Lines. TNEC's goal is to select the alternative that best meets the Project need, with a minimum impact on the natural resources and social environments, at the lowest possible cost. Alternatives to the Project have been evaluated to ensure that these objectives are met. Section 4.2 describes the no-action alternative, Section 4.3 describes the re-use of the existing duct bank with new manholes (preferred), Section 4.4 describes the re-use of existing duct bank system with manhole roof rebuilds, Section 4.5 describes a new manhole and duct bank system using the existing route and Section 4.6 describes the new route alternatives. Figure 4 illustrates the Alternatives.

4.2 No-Action Alternative

The Q-143 and R-144 Lines have experienced a series of splice and cable failures. The no-action alternative would leave the Q-143 and R-144 Lines in their current condition, exposing the Providence area to increased contingency risks from future failures. The potential for thermal overloads and the increased possibility of loss of load due to the long-term outage of the Q-143 and R-144 Lines is not an acceptable alternative for maintaining a firm and reliable electric supply for TNEC's Providence customers.

This alternative was dismissed as it would not address the need to resolve the condition and reliability issues with the Q-143 and R-144 Lines and would not provide a forecasted increase in capacity need over the existing cable ratings. The no-action alternative is not acceptable from either an operational or reliability perspective.

4.3 Re-use of Existing Duct Bank System with New Manholes (Preferred Plan)

This alternative involves the re-use of the existing manhole and duct bank system between the Admiral Street Cable Terminal and the existing Manhole 31 on Dollar Street.

The preferred plan will retire two-thirds of the existing manholes and replace the balance of the manholes to allow construction of solid dielectric cable and splices.

The primary advantage of this option is the limited need for linear trenching within the streets and sidewalks in a heavily congested area of Providence, in contrast to the other replacement options discussed below. The local impact is limited to retirement of 22 manhole pairs (converting them to duct bank), rebuilding six manhole pairs with new precast manholes and adding two new precast manhole pairs along the existing duct bank outside of the footprint of existing manholes. There may be limited areas of the duct bank requiring repairs based on field inspections. Reuse of substantial portions of the duct bank will reduce the cost and community impacts of the Project as compared to alternatives that require end to end duct bank and manhole construction.

The current cost estimate for the preferred plan is $46.5 million.

TABLE 5 PREFERRED ROUTE ESTIMATE

PROJECT COMPONENTS	ESTIMATED COST
Transmission Cable Facilities	$43.8M
Admiral Street Cable Terminal Termination Structures	$2.7M
Total	**$46.5M**

This alternative is the preferred plan (and consequently the proposed Project) as it will resolve the asset condition and reliability concerns for the Q-143 and R-144 Lines with the fewest environmental and social impacts at the lowest possible cost, and within the shortest Project schedule timeline.

4.4 Re-use of Existing Duct Bank System with Manhole Roof Rebuilds

This alternative would also re-use the existing manhole and duct bank system between the Admiral Street Cable Terminal and the existing Manhole 31 on Dollar Street, but in this case an attempt would be made to salvage the existing manholes as well as the duct bank.

This alternative would require modifications to the existing manholes in the form of roof replacements for most, if not all, along the route. The roof replacements would be needed to relocate manhole cover openings to provide access to the vaults. The existing cover openings would be obstructed under this plan, since it would be necessary to install and splice the cable diagonally across the manhole in order to gain additional cable length needed for splicing.

The primary advantage of this option is the limited need for linear trenching within the streets and sidewalks in a heavily congested area of Providence. Manhole roof rebuilds would require discrete construction at 28 manhole pair locations.

However, the major concerns with this alternative would be the non-standard cable racking in the undersized existing manholes, the need for special high stress cable splice designs, and significantly more splices than would be needed under the preferred plan. Further, recent investigations revealed that the concrete and rebar at existing manholes is beginning to deteriorate, jeopardizing their long-term viability. As a result, this alternative would not resolve long-term reliability concerns.

Moreover, community impacts and potentially adverse effects on the social/developed environment of this alternative plan are likely to be greater than the preferred plan. Construction of this alternative would require two separate civil construction activities at each manhole pair, resulting in repeated disruptions to abutters. Additional construction-related activities along the entire route would include increased cable pulling and splicing due to the significantly greater number of manholes in comparison to the preferred option.

Ultimately, the Company rejected this alternative because of the potential long-term reliability concerns and greater social impacts as compared with the preferred plan.

4.5 New Manhole and Duct Bank System Using Existing Route

This alternative would use the existing route with a new manhole and duct bank system. It would require the removal of the existing manholes and duct banks, followed by replacement with a new installation along the same route as the existing infrastructure.[1]

This alternative would commence with the removal of the existing power cables, control cable, splices and accessories from the existing manhole and duct bank system located within the public way. The next step would involve the removal of the existing duct bank and manholes between the Admiral Street Cable Terminal and the existing Manhole 31 located within Dollar Street. Excavation within the streets and travel lanes, some sidewalks and landscape medians would occur to install new precast manhole pairs located at approximately 1,500 linear foot intervals. Trenching and excavation along the existing route for two miles of city streets would be required to occur in order to install a new duct bank extending from the Admiral Street Cable Terminal to the existing Manhole 31 within Dollar Street. The new duct bank would consist of six (6) 6.0-inch Schedule 40 PVC conduits, two (2) 4.0-inch PVC conduits, and two (2) 2.0-inch Schedule 40 PVC conduits. The 2.0-inch conduits would be reserved for ground continuity conductors and the 4.0-inch conduits would be dedicated to communication cable. The PVC conduits would be encased in a common concrete envelope. One of the final phases of construction would involve installing new transmission cables in the duct bank and manhole system. Testing and commissioning of the new facilities would be completed prior to energization.

Following the existing cable route while removing and replacing existing underground structures would allow a more standard design to be implemented. The new manholes would not require special racking, pull-through, or splice designs. A standard system would simplify future upgrades and maintenance to the Lines. Most benefits of this plan would also be achieved under the preferred plan.

However, the existing route is heavily congested with existing utilities, some of which are installed directly on top of the existing manhole and duct bank system. This increases the difficulty of both removal and the new installation.

Removal and installation would heavily impact pedestrian and roadway traffic, existing road-side parking, and businesses along the route. This alternative would also create significantly more disruptive impacts associated with the installation of an entirely new duct bank and manhole system. In addition, the current conceptual level cost estimate for this alternative is approximately $73 million.

Ultimately, the Company dismissed this alternative because of said challenges and the estimated cost that exceeds the preferred plan by approximately $26 million.

4.6 New Route Alternatives

The final alternative considered would be to construct a new manhole and duct bank system along an entirely new route. Two new route options between the Admiral Street Cable Terminal and Franklin

[1] The duct banks must be removed and replaced in the same alignment due to the limited space within the roadway ROW from other existing utilities.

Square Substation have been assessed via desktop study.[2] The routes were chosen to limit the overall length of installation as well as to remain on existing roadways to the greatest extent possible.

The two new representative route alternatives (Route Alternative A and B) are shown on Figure 4 and are described as follows:

The first new route option, Route Alternative A, is 3.15 miles in length. It travels from Admiral Street to Whipple Street, and then crosses Douglas Avenue to connect to Candace Street. From Candace Street the route travels on Smith Street and crosses to Calverly Street. It then crosses the Kinsley Street Bridge over the Woonasquatucket River via Bath Street and continues onto Providence Place, turning onto Dean Street, which crosses Route 6. The route continues along Dean Street, crossing Interstate Route 95 (I-95) at Washington Street and continuing on Franklin / East Franklin Street until it reaches Point Street. From Point Street the route connects to Franklin Square Substation.

The second new route option, Route Alternative B, is 2.34 miles in length. It travels from Admiral Street to Whipple Street then crosses onto Douglas Avenue. From Douglas Avenue the cables travel over I-95 via the Orms Street Bridge to continue along Park Street. The route then crosses Smith Street to connect to Francis Street. The route remains on Francis Street then connects to Dorrance Street. At the intersection of Dorrance Street and Clifford Street, the cables turn onto Clifford Street then onto Richmond Street. From Richmond Street the cables connect to Point Street then terminate at Franklin Square Substation.

The conceptual level costs of these alternatives are approximately $79 million and $62 million, respectively.

These alternatives would allow a traditional underground solid dielectric cable system design to be implemented in an entirely new conduit and manhole system. The existing Q-143 and R-144 Lines could remain in-service during construction of the new route, therefore minimizing outages of the cables during construction. The existing cables would be removed after the new cables are in service.

These alternatives also present several challenges. Each of the new route alternatives is longer than the Project Route. A new route would require new engineering, a full route selection process and more extensive permitting and licensing, all of which would delay the replacement of the Lines. In addition, the existing utilities along the route options are not fully known so a thorough investigation of existing utilities along the route would be required for implementation of either new alternative. Use of a new route would also have a greater construction impacts because of the work associated with the construction of the new lines and the removal of the existing lines.

For these reasons, and the higher costs associated with both new routes, the Company dismissed these alternatives.

[2] The Company also considered whether an alternative route between the Admiral Street Cable Terminal and Manhole 31 could theoretically be used. However, the preferred route is the most direct and enables the Company to reuse a majority of its existing duct bank system, including the portion of the system between Franklin Square Substation and Manhole 31 that was recently permitted in Docket No. SB-2017-02. This significantly reduces costs and impacts associated with constructing a new duct bank and manhole system along new route segments. The Company therefore did not further consider route alternatives between the Admiral Street Cable Terminal and Manhole 31 other than the Project Route.

4.7 Conclusion

TNEC evaluated several alternatives in the development of the Project. These alternatives were evaluated based on their relative advantages and disadvantages. Ultimately, TNEC concluded that re-using the existing duct bank system with new manholes is significantly preferred to the other alternatives because it will: resolve the age, condition, and reliability concerns with the Q-143 and R-144 Lines meeting the need for the Project at the lowest possible cost; be constructed with the fewest environmental impacts; and be completed in the shortest timeframe.

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5.0 DESCRIPTION OF AFFECTED NATURAL ENVIRONMENT

5.1 Introduction

The Project area is the space immediately adjacent to the Project Route between the Admiral Street Cable Terminal and Dollar Street (Figure 1). According to the EFSB Rules, a detailed description of the environmental characteristics of the "Study Area" is required. As shown in Figure 2, the Study Area is the area within 500 feet on either side of the Project. As permitted by EFSB Rule 1.6(F)(3), several natural and environmental descriptions (climate and weather and geology) have not been addressed in this report, since the Project is located within a highly developed urbanized area and will not realize these impacts.

5.2 Soils

Soils along the proposed route primarily consist of urban fill materials. According to the Natural Resources Conservation Service ("NRCS") web soil survey, the entire upland route from the Dollar Street to the Admiral Street Cable Terminal is identified as urban land. Given the heavy, historical industrial usage of the Project Route, soil pre-characterization will take place in advance of construction, where feasible, in order to select an appropriate receiving facility for excess soils that cannot be reused as backfill. A Project-specific Soil and Groundwater Management Plan ("SGMP") will be developed for the entire route and will be implemented and adhered to during construction activities.

5.2.1 Admiral Street Cable Terminal

The Admiral Street Cable Terminal is identified as a state-listed site regulated by the Rhode Island Department of Environmental Management ("RIDEM") Office of Waste Management due to certain environmental impacts to soils and groundwater from historical operations. Environmental conditions at the Admiral Street Cable Terminal are currently being assessed; as such, soil-disturbing work within the Admiral Street Cable Terminal will be subject to the requirements of an Environmental Land Use Restriction (ELUR), site-specific environmental guidance, the SGMP and Health and Safety Plan.

5.2.2 Cable Route

Most of the proposed land cable route between the Dollar Street and the Admiral Street Cable Terminal consists of asphalt pavement and concrete sidewalk, underlain by presumed granular urban fill (resulting from the original Line construction and former land filling practices). The proposed cable route is expected to utilize existing subsurface conduit/duct bank systems. However, excess soil may be generated along the proposed route (within the roadways) as a result of the retirement and replacement of existing manholes, and repair and replacement of segments of the existing duct bank. Soil-disturbing work along this portion of the route is subject to the requirements of the Project-specific SGMP.

5.3 Groundwater

The RIDEM classifies all of the state's groundwater resources and establishes groundwater quality standards for each class. The four classes are designated GAA, GA, GB, and GC. Groundwater classified as GAA and GA is to be protected to maintain drinking water quality, whereas groundwater classified as GB and GC is known or presumed to be unsuitable for drinking water use without treatment. Most of the Study Area falls within a RIDEM designated GB groundwater resource area. The remaining portion of the Study Area consists of the Providence River.

Businesses and residences in the area are connected to the Providence municipal water supply. There are no known wellhead protection areas within the Study Area.

Based on previous investigations conducted near the Project Route, groundwater is expected to be present between approximately 8 and 11 feet below grade. Dewatering may be necessary due to groundwater infiltration or periodic stormwater run-off.

Groundwater will be managed in accordance with the SGMP.

5.4 Surface Water

The Project Route crosses over the Moshassuck River (waterbody identification No. RI0003008R-01C) via the Mills Street Bridge. Additionally, the southern portion of the Project is bordered to the west by the tidally influenced Providence River (waterbody identification No. RI0007020E-01B). The RIDEM List of Impaired Waters developed in response to the requirements of Section 303(d) of the federal Clean Water Act lists the Providence River as Category 5 Waters, which are waters that are impaired or threatened for one or more designated uses by a pollutant(s) and requires a Total Maximum Daily Load ("TMDL"). TMDL refers to the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards. The term also refers to the waterbody specific studies completed to determine the allowable pollutant levels and the pollution control activities needed to restore water quality. The Moshassuck River is listed as a B {a} water body that is impaired due to Benthic-Macroinvertebrate Bioassessments and Enterococcus. The section of the Providence River that abuts the Project is listed as a SB1 {a} water body that is impaired due to fecal coliform, total nitrogen, and dissolved oxygen. The use of the Providence River is limited because of poor water quality.

The Providence River does support populations of marine fisheries, such as Atlantic menhaden (*Brevoortia tyrannus*). The river also supports populations of crustaceans, such as blue crab (*Callinectes sapidus*). RIDEM has monitored hypoxic (low oxygen levels) conditions in the Providence River which has led to reported fish kills within the river.

Both the Moshassuck River and the Providence River are classified by the Rhode Island Coastal Resources Management Council ("RICRMC") as Type 5 Waters, Recreational and Commercial Harbor. Type 5 waters are defined as waters that are adjacent to waterfront areas that support a variety of tourist, recreational, and commercial activities.

5.5 Vegetation

The existing pervious areas predominantly consist of paved travel lanes and concrete and/or brick sidewalks. The Project Route does contain some areas of vegetation, landscaped medians and public

street trees. Portions of the Study Area include managed green spaces between Whipple Street and Route 246. Typically, these areas consist of a continuous grass cover and ornamental shrubs. An Urban Coastal Greenway creates a vegetated green space along the waterfront, north of Point Street, and across the Providence River from the Project Route. This area is currently a public access/boardwalk that consists of both a timber and brick boardwalk area with several bench and gazebo structures and is being further developed.

5.6 Wetland and Watercourses

Waterbodies and associated wetlands along the cable route were identified based on a desktop review of Rhode Island Geographic Information System ("RIGIS") wetlands data (RIGIS 1993).

Wetlands are resources which have ecological functions and societal values. Wetlands are characterized by three criteria: (i) the presence of undrained hydric soil, (ii) a prevalence (>50 percent) of hydrophytic vegetation, and (iii) wetland hydrology, where soils are saturated near the surface or flooded by shallow water during at least a portion of the growing season.

In accordance with the provisions of the Rhode Island Fresh Water Wetlands Act and Rules ("FWW Rules"), RIDEM regulates freshwater activities in and around streams and open water bodies which include rivers, streams, ponds, Areas Subject to Storm Flowage, Areas Subject to Flooding, and floodplains. A river is any perennial stream indicated by a blue line on a United Stated Geological Survey ("USGS") topographic map. If the stream or river is greater than 10 feet wide, the area within 200 feet of each bank is regulated as a 200-foot riverbank wetland.

The Project Route crosses the Moshassuck River using the existing conduit system attached to the underside of the Mill Street Bridge. The Moshassuck River is over 10 feet wide and has a regulated 200-foot riverbank wetland. The Project Route also crosses into the 200-foot river bank buffer zone of the Providence River near the intersection of Washington Place and South Main Street. The RICRMC consulted with the RIDEM and both agencies determined that a maintenance permit will be required from the RICRMC due to the Moshassuck River crossing and work within 200 feet of shoreline features. However, no RIDEM freshwater wetlands permitting is required for the Project. The RICRMC has the jurisdiction over freshwater wetlands in the vicinity of the coast, and the lower reaches of the Providence River and the Moshassuck River are tidally influenced.

Prior to reusing the conduit system, the existing Mill Street Bridge transmission line conduits will be repaired and retrofitted, as necessary. An existing, out-of-service distribution duct bank that is self-supporting underneath the Mill Street Bridge will be removed.

Working beneath the Mill Street Bridge will require the installation of temporary scaffolding and ladders. These temporary work platforms will be installed to avoid adverse effects to the river banks and river bed. The temporary work platforms will be secured in place so they are not washed downstream. The weather conditions and water levels in the river will be monitored during construction, and should weather conditions indicate inclement weather, the temporary platforms will be removed and later reinstalled. Signage/placards will be installed informing the public of the temporary restriction in the water. Netting or other appropriate measures will be used to prevent construction-related materials from falling into the water. An emergency spill response kit and an oil boom will be maintained at the work site.

5.7 Wildlife

5.7.1 Urban Wildlife

The Project Route is located within urbanized sections of the City of Providence. The major landscape features include paved roadways, developed lands and buildings, some city parks and recreational areas, a federal memorial park, interchanges and a railroad crossing. Vegetation is limited but the available green spaces and waterbodies (i.e., Providence River and Moshassuck River) do provide habitat for wildlife species that are better adapted to urban settings. Wildlife utilization of the habitat provided within this urban setting includes, but is not limited to, the following species.

TABLE 6 URBAN WILDLIFE SPECIES

Common Name	Scientific Nomenclature	Species Type
Gray Squirrel	*Sciurus carolinensis*	Mammal
Raccoon	*Procyon lotor*	Mammal
Striped Skunk	*Mephitis mephitis*	Mammal
Norway Rat	*Rattus norvegicus*	Mammal
Red-tailed Hawk	*Buteo jamaicensis*	Bird of Prey
Domestic Pigeon	*Columba livia domestica*	Bird
European Starling	*Sturnus vulgaris*	Bird
Mallard Duck	*Anas platyrhynchos*	Dabbling Duck
American Black Duck	*Anas rubripes*	Dabbling Duck
Double-crested Cormorant	*Phalacrocorax auritus*	Seabird
Canada Goose	*Branta canadensis*	Bird

5.7.2 State-Listed Species

Based on consultations with RIDEM and the Rhode Island Natural History Survey (RINHS), two avian species have been documented within the vicinity of the Project in downtown Providence. Correspondence with RIDEM and RINHS are not included in this report as they contain privileged information about the locations of state-listed species.

Peregrine Falcon (*Falco peregrinus*)

The peregrine falcon is a Rhode Island State Endangered Species (Enser 2006). These birds prefer open habitats which provide rocky cliffs with ledges overlooking rivers, streams, lakes, or coastal bays, with an abundance of birds for prey (DeGraaf and Yamasaki 2001). Peregrine falcons will also breed in cities on tall buildings, including a building in Providence, within proximity of the Study Area. Peregrine falcons will use the same nest in successive years and their nests are generally a scraped shallow depression in gravel or debris (DeGraaf and Yamasaki 2001).

Common Nighthawk (*Chordeiles minor*)

The Common nighthawk is a Rhode Island Species of Concern (Enser 2006). These birds prefer a variety of open habitats such as grasslands, cultivated fields, large woodland clearings, prairies, gravel beaches, coastal sand dunes, railroad rights-of-way, and flat gravel roofs (DeGraaf and Yamasaki 2001). Common nighthawks currently nest on the roofs including a roof on a building within proximity near the Study Area. Common nighthawks do not build nests but lay their eggs on bare ground, usually on gravel or partially vegetated soils and gravel roofs (DeGraaf and Yamasaki

2001). They are mainly crepuscular and nocturnal but will occasionally feed during the day. Common nighthawks feed on flying insects such as mosquitos, moths, grasshoppers, and flying ants (DeGraaf and Yamasaki 2001).

5.8 Air Quality

The Project Area is subject to the National Ambient Air Quality Standards ("NAAQS"). These standards were established by the federal Clean Air Act Amendments and are designed to protect public health and welfare. Air quality analyses for projects that may impact motor vehicle traffic are required to evaluate their impact on atmospheric ozone and carbon monoxide levels downwind of the Project Area. After considerable analysis and review, Rhode Island was able to demonstrate to the United States Environmental Protection Agency that Rhode Island sources do not significantly contribute to downwind ozone attainment and will not prevent downwind areas from attaining the NAAQS by required attainment dates. This Project will not require further evaluation of atmospheric emissions from vehicular sources.

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6.0 DESCRIPTION OF AFFECTED SOCIAL ENVIRONMENT

6.1 Introduction

According to the EFSB Rules, a detailed description of the social environmental characteristics of the Study Area is required. The Study Area is wholly within the City of Providence and is subject to the City of Providence Comprehensive Land Use Plan. Based on the nature of the Project (reconductoring of existing underground facilities) and the limited scope of the proposed work, information is not being provided on regional population trends, or employment conditions as permitted by EFSB Rule 1.6(F)(3), since the Project will not impact these resources.

6.2 Land Use

Land use near the Admiral Street Cable Terminal and along the existing cable route primarily consists of commercial, institutional, high density residential, and developed recreational uses (i.e., City of Providence Hopkins Park). The cable route is also adjacent to a smaller percentage of land uses including industrial, railroads and associated facilities, other transportation, transitional areas (open urban space), medium density residential, educational (Rhode Island School of Design), governmental (i.e., U.S. District Court for the District of Rhode Island, parks (i.e., Roger Williams National Memorial and City of Providence South Main Street Park) and vacant lands (i.e., Route I-195 Redevelopment District). Land use and zoning districts are shown in Figure 5 for Land Use/Zoning.

6.3 Visual Resources

The area is characterized by a mix of heavy commercial, industrial, open space, residential and mixed-use waterfront uses. The residential areas are densely clustered developments of single-family homes that generally range in age and character from early-twentieth century homes to contemporary-style townhomes. Major highways within the Study Area include Rhode Island State Routes ("SR") 1, 44, 122, 146, 246, and I-95. A significant portion of the Q-143 and R-144 Lines are within the roadways of SRs 1, 44, and 246 which feature dense commercial development, downtown businesses and Open Spaces along the Providence River. The northern portion of the Study Area also features clustered business parks with larger buildings occupied by both offices and light industrial facilities. However, the reconductoring of the Q-143 and R-144 Lines consists of replacing or eliminating manholes, rebuilding discrete segments of the duct bank, and installing new cable and other components within the roadway.

6.4 Noise

Noise in the vicinity of the Study Area is typical of a busy urban area with city traffic being the predominant source of noise. For the most part, the Study Area is characterized by commercial, institutional and high-density land uses. Ambient sound levels are influenced by diverse factors such as vehicular traffic, commercial and industrial activities, and outdoor activities typical of urban environments. Noise receptors include businesses, residences and designated recreational areas.

6.5 Historic and Cultural Resources

On behalf of TNEC, POWER Cultural Resources has performed a Phase 1a/b cultural investigation and are in consultation with the Rhode Island Historical Preservation and Heritage Commission ("RIHPHC"). There are 14 known archaeological resources on file at RIHPHC within 500 feet of the Project. These resources largely reflect Providence's significant early historical period activities, but also include a small number of sites dated to the period before European colonization of the area. Providence is a densely-settled urban area that experienced a significant level of historical period activity, and as such a number of National Register of Historic Places ("NRHP") listed above-ground properties are within the Study Area.

6.6 Transportation

The Project Route is located along city streets and SRs 1, 44, and 246. The transportation needs of the Project Area are served by a network of federal, state and local streets and highways. Major highways within and the along the Project Route include SRs 1, 44, 122, 146, 246; and Interstate Route 95 (I-95).

Additionally, two bridges are crossed by the cable route. The northern part of the cable route crosses over the AMTRAK northeast corridor rail tracks via the Charles Street Bridge. The cable route crosses over the Moshassuck River via the Mill Street Bridge. The conduits for the existing cable route are mounted to the bridge at the AMTRAK crossing, or are self-supporting in the case of the Moshassuck River crossing under the Mill Street Bridge.

6.7 Electric and Magnetic Fields

EMF is a term used to describe electric and magnetic fields that are created by voltage (electric field) and electric current (magnetic field). TNEC, like all North American electric utilities, supplies electricity at 60 Hertz (Hz). Therefore, the electric utility system and the equipment connected to it, produce 60-Hz (power-frequency) EMF. These fields can be measured using instruments and can be calculated using computer models.

Power frequency EMFs are present wherever electricity is used. Sources of these fields include utility transmission lines, distribution lines, substations, building wiring in homes, offices, and schools, and the appliances and machinery used in these locations.

Electric fields are present whenever voltage exists on a wire, and do not depend on the magnitude of the current flow. The magnitude of the electric field is primarily a function of the configuration and operating voltage of the line and decreases with the distance from the source (i.e., the transmission line). Electric fields are shielded (i.e., the strength is reduced) by conducting surfaces, including trees, fences, walls, buildings, and most types of structures. The strength of an electric field is measured in volts per meter (V/m) or kilovolts per meter (kV/m). In this Project, neither the existing Lines nor the rebuilt Lines produce an electric field above ground because of the shielding provided by the cable sheaths and the earth.

Magnetic fields are present whenever current flows in a conductor and are not dependent on the voltage present on the conductor. The magnetic field strength from a transmission line is a function of both the current flow on the conductor and the configuration of the transmission line. The strength of

these fields also decreases with distance from the source. However, unlike electric fields, most common materials have little shielding effect on magnetic fields.

Magnetic fields are measured in units called Gauss. However, for the low levels normally encountered during daily activities, the field strength is expressed in a much smaller unit, the milligauss (mG), which is one thousandth of a Gauss.

Magnetic fields from the transmission lines in the existing duct bank were calculated by Exponent using projected annual average and annual peak load levels for the year 2020. Calculations were performed at average loading to best predict the magnetic field that might occur on any randomly-selected day of the year for projected loadings on the transmission lines. Calculations also were performed for peak loading on the existing Lines to estimate the highest magnetic fields but which are expected to occur at most during a few hours on a few days of the year. The magnetic fields from the existing cable system were calculated to describe the historical normal operation of both Lines in service. Tables 7 and 8 show the magnetic field (Root Mean Square Resultant) levels produced by the transmission lines in the existing duct bank under average and peak loads, respectively.

TABLE 7 CALCULATED MAGNETIC FIELD LEVELS (MG) (ANNUAL AVERAGE LOAD) UNDER EXISTING CONDITIONS (2020 PRE-CONSTRUCTION)

DISTANCE FROM DUCT BANK CENTERLINE						
Configuration	**Loading (Year)**	**−50 feet**	**−25 feet**	**MAX**	**+ 25 feet**	**+50 feet**
Existing Lines	Existing (2020)	0.6	1.1	8.3	1.1	0.6

TABLE 8 CALCULATED MAGNETIC FIELD LEVELS (MG) (ANNUAL PEAK LOAD) UNDER EXISTING CONDITIONS (2020 PRE-CONSTRUCTION)

DISTANCE FROM DUCT BANK CENTERLINE						
Configuration	**Loading (Year)**	**−50 feet**	**−25 feet**	**MAX**	**+ 25 feet**	**+50 feet**
Existing Lines	Existing (2020)	0.5	1.0	6.7	1.0	0.5

The existing configuration allows for mutual cancellation of magnetic fields with an optimal phasing configuration. The magnetic fields decrease rapidly with distance. At ±25 feet from the duct bank, the magnetic-field level at average loading is 1.1 mG. At peak loading, the magnetic-field levels are slightly lower than for average loading directly over the duct bank, and similar to magnetic field levels under average loading at distances of ±25 feet from the duct bank centerline.

A discussion of the current status of the health research relevant to exposure to electric and magnetic fields is included in Appendix A. This report was prepared by Exponent.

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7.0 IMPACT ANALYSIS

This section presents an analysis of the potential impacts of the Project on the existing environmental and social surroundings within the Study Area.

The Project will be constructed in a manner that minimizes the potential for adverse environmental impacts. Utilizing the existing cable route along with the retirement and/or replacement of manholes will minimize the impacts to environmental and social resources. Any anticipated minor impacts are addressed within the following sections. There are no expected impacts to climate and weather or geology.

A monitoring program will be conducted by TNEC to verify that the Project is constructed in compliance with all relevant licenses and permits and all applicable federal, state and local laws and regulations. Design and construction mitigation measures will be implemented so that construction-related environmental impacts are minimized.

7.1 Soils

Soil within the proposed construction areas may be impacted by contaminants from former land uses and/or historic filling practices along the cable route. Given the industrial usage of the Project Route, soil pre-characterization will take place in advance of construction, where feasible, to identify management procedures for any excess soils that cannot be reused as backfill. Appropriate soil management procedures will be used for handling, managing and disposing or reusing of potentially impacted soil. Specifically, soil generated within the Admiral Street Cable Terminal will be managed in accordance with the applicable ELUR, site-specific environmental guidance, and/or SGMPs. Soil that may be generated along the proposed Project Route (beyond TNEC-owned properties) as a result of the repair and/or replacement of the conduit/duct bank system and/or manholes will be managed in accordance with the Project-specific SGMP and RIDEM regulations. Additionally, during trenching for the duct bank and excavation for the manholes, the excavated soils and materials will be live-loaded directly into awaiting transport that will be queued along the Project Route. This method of construction will allow for a “clean trench,” which will significantly reduce any temporary stockpiling of excavated materials and minimize the potential for the inadvertent discharge of soils into the Project Area.

During construction related activities, portions of the Project Area will be exposed to wind and precipitation that have the potential to increase erosion and sedimentation. As part of the permitting process, a Storm Water Pollution Prevention Plan (“SWPPP”) will be developed and an SESC Plan will also be developed and implemented during the construction phase of the Project. The SWPPP Plan will be maintained on-site and updated throughout the Project to reflect environmental inspection reporting and Best Management Practices (“BMPs”). Additionally, to minimize impacts, TNEC will adhere to National Grid’s *EG-303NE*. Typical BMPs include straw wattles, catch basin inserts and dust control measures, as well as other erosion and sedimentation control measures. These devices will be inspected by TNEC’s environmental monitor during construction and repaired or replaced if necessary. SESC measures will be selected to minimize the potential for soil erosion and sedimentation in areas where soils are disturbed.

In the vicinity of active construction sites within the road ROW, catch basins will have inserts of geotextile fabric or other equivalent controls. Dust monitoring and wet methods (e.g. water spraying) will take place to mitigate the potential for fugitive dust, as needed.

The Project construction contractors will be responsible for maintaining appropriate setback distances between the watercourses and work areas. Signs alerting the construction crews of sensitive resources will be installed, if necessary.

During periodic post-construction inspections, TNEC will determine the appropriate time frame for removing these temporary soil erosion controls. This determination will be made based on the effectiveness of restoration measures, such as percent vegetative cover achieved, and in accordance with applicable permit and certificate requirements.

7.2 Groundwater Resources

RIDEM designated the groundwater for the Study Area as GB, or water not suitable for human consumption without treatment. Project construction and operation is not expected to impact the groundwater quality. Groundwater within the proposed construction areas may be impacted by contaminants from former land uses.

If excavation dewatering is necessary along the Project Route, water will be containerized for off-Site disposal or properly treated on-site for subsequent discharge to the ground surface through an approved infiltration basin in accordance with the SGMP. If treatment and recharge is required, dewatering activities will comply with National Grid's *EG-303NE,* Rhode Island Storm Water Program and Rhode Island Pollutant Discharge Elimination System ("RIPDES") Regulations. Typical BMPs for treatment and recharge include dewatering basins, filter bags and filter socks. Water trucks may be utilized when site restrictions make it difficult to utilize other dewatering methods. Dewatering flow shall be controlled so that it does not cause scouring or erosion. Distance to sensitive areas, direction of flow (toward or away from protected or sensitive areas, such as wetlands, ponds, or streams), ground conditions, volume of water, and pump rate will be considered. Dewatering areas will be cleaned, and equipment removed as soon as dewatering is complete.

Water from within the excavations (e.g., trenches and manholes) will not be pumped or discharged to surface water, stormwater drainage systems, or publicly or privately-owned treatment works without obtaining applicable permits from federal, state, or local agencies. Dewatering methods will be conducted in conformance with National Grid's Environmental Guidance Document EG-701RI.

No significant groundwater impacts have been identified at the Admiral Street Cable Terminal. If dewatering occurs, the pumpate encountered may require treatment prior to discharge.

7.3 Wetland and Waterbodies

Any impact of the Project upon surface waters will be minor and temporary. Construction activities temporarily increase risks for soil erosion and sedimentation that may temporarily degrade existing water quality; however, appropriate BMPs will be implemented and maintained to effectively control sediment. The Project will span the Moshassuck River under the Mill Street Bridge with an existing duct bank. The analysis of the existing duct bank is included in the scope of this Project. The duct bank is anticipated to be confirmed acceptable for re-use by the contractor. Any structural repairs required to re-use it are expected to be minimal. In addition to this work, an existing out-of-service distribution duct bank underneath the Mill Street Bridge will be removed. Inspection of the transmission duct bank under the bridge and the removal of the distribution duct bank will involve similar setups to the inspection of the actual bridge structure, including personnel access to the waterway and temporary scaffolding erected. Appropriate boom setups and other measures will be

taken during any construction activity where there is a concern of foreign objects entering the waterway. The installation of temporary scaffolding would be installed and monitored to avoid adverse effects to the ambient flow and integrity of the river. The Providence River is the only other surface water feature within the Study Area but is not directly traversed by the Project Route.

Potential impacts to surface waters, if sediment transport is not controlled, include temporary increased turbidity and sedimentation (locally and downstream) and subsequent alterations of benthic substrates, decreases in primary production and dissolved oxygen concentrations, releases of toxic substances and/or nutrients from sediments, and destruction of benthic invertebrates. SESCs will effectively minimize the potential for this situation to occur. The implementation and maintenance of stringent SESC BMPs will limit the levels of Project related sedimentation and will minimize adverse impacts to surface waters.

The Project will not adversely impact recreational and commercial activities along the rivers during construction.

7.4 Vegetation

The Project Route contains some intermittent areas of vegetation, landscaped medians and public street trees. The construction along the Project Route will impact some landscaped areas and involve removal of some public street trees. TNEC will consult with the City Forester to appropriately restore disturbed areas and to replace public street trees.

7.5 Wildlife

The fairly limited tracts of contiguous habitat, lack of wildlife corridors, and anthropomorphic disturbances along the Project Route likely discourage significant wildlife utilization along the Project corridor, with the exception of species known to adapt to these environments. The Project construction may result in a temporary displacement of those localized species inhabiting these areas, however, there will be no permanent loss of available habitat along the Project Route.

No construction impacts are anticipated to directly occur to either peregrine falcons or common nighthawks in downtown Providence as a result of Project construction. The Study Area is located within an urban environment, including paved roadways, developed lands and buildings, some city parks and recreational areas, a federal memorial park, interchanges and a railroad crossing. The cable route itself is located within the public roadway, sidewalks and utility ROW. The identified nesting location for the peregrine falcon is outside of the 500-foot Study Area.

7.6 Air Quality

There are two potential sources of air quality impacts associated with the Project – dust and vehicle emissions – neither of which are expected to be significant. During earth disturbing activities, the contractor will deploy dust mitigation measures as described in National Grid's *EG-303NE* guidelines. Exposed soils will be wetted and stabilized as necessary to suppress dust generation. During trenching for the duct bank and excavation for the manholes, the excavated soils and materials will be live-loaded directly into dump trucks that will be queued along the Project Route. This method of construction will allow for a "clean trench" which will significantly reduce any temporary stockpiling of material and minimize the potential for the inadvertent discharge of soil onto the street or sidewalks. These measures will be designed to keep fugitive dust emissions low.

Emissions generated by the operation of construction machinery (carbon monoxide, nitrogen oxides, sulfur oxides, and particulate matter) are short in duration and generally not considered significant. TNEC requires the use of ultra-low sulfur diesel fuel exclusively in its contractor's diesel-powered construction equipment. Vehicle idling is to be minimized during the construction phase of the Project, in compliance with the Rhode Island Diesel Engine Anti-Idling Program, Air Pollution Control Regulation No. 45, authorized pursuant to RIGL § 31-16.1 and § 23-23-29. The contractor is responsible for complying with the state regulatory requirements along with TNEC Environmental Guidance (*EG-802RI*) Vehicle Idling – Rhode Island.

Upon completion of the installation of the proposed underground cables, the Project will not generate air emissions. Daily vehicle traffic patterns, characteristics, and volumes will not be permanently affected; therefore, no additional vehicular air emissions will be generated.

7.7 Land Use and Recreation

The Project will be constructed underground, in public streets and on existing TNEC property; therefore, it will not displace any existing land uses, nor will it affect any future development proposals that meet local zoning requirements. Short-term land use impacts may occur during the construction phase of the Project. Detours and other accommodations will be made to provide alternative access around the construction work site. Impacts associated with the construction phase of the Project will be temporary, and present land uses within the Study Area can continue during and following construction. TNEC will provide notification of the intended construction plan and schedule to affected businesses and other land owners so that the effect of any temporary disruptions may be minimized.

No existing recreational uses will be displaced long-term by the Project. TNEC has initiated consultation with the City of Providence to inform them of the construction-related disturbances that will occur adjacent to the southeast corner of the Hopkins Park. Construction should not affect access to Hopkins Park, South Main Street Park and Roger Williams National Memorial Park. However, detours will be established to maintain access to these public parks if necessary. Since the Project is located within existing public streets, potential long-term impacts will be avoided.

The Project will occupy areas dedicated to use for electrical facilities, it will not displace any existing residential or other uses, nor will it affect any future development proposals that meet local zoning requirements. Short-term land use impacts may occur during the construction phase of the Project. Impacts associated with the construction phase of the Project will be temporary, and most present land uses along the existing corridor could resume following construction. TNEC will provide notification of the intended construction plan and schedule to affected landowners and abutters so that the effect of any temporary disruptions may be minimized and those affected by the construction-phase of the Project may plan ahead.

7.8 Visual Resources

The only aboveground facilities associated with the Project will be upgrades at the existing Admiral Street Cable Terminal. Visual and aesthetic impacts from installation of replacement equipment will not substantially alter the overall visual setting of the existing Cable Terminal. The cable reconductoring will be completed using the existing cable route in public roadways and will not show additional visual changes. No long-term impacts to visual resources are anticipated as a result of the Project.

7.9 Noise

The Project is located entirely within urban portions of the City of Providence, where ambient sound levels are influenced by diverse factors including vehicular noise, commercial and industrial activities, and outdoor activities. Temporary construction noise may be generated by the Project. The generation of noise will result from the operation of construction equipment and vehicles such as trucks with diesel engines, excavators, jackhammers, drilling equipment, and cable installation rigs. Proper mufflers will be required to control noise levels generated by construction equipment.

7.10 Historic and Cultural Resources

Consultation with the RIHPHC about potential impacts to archaeological resources is ongoing. There are known archaeological areas of significance within the vicinity of the Project Area, but the area has been subject to extensive urbanization and soil disturbance.

Potential impacts to both known and unknown historic and archaeological resources continue to be addressed through consultation with the RIHPHC. TNEC will continue consultation with the RIHPHC. A letter from the RIHPHC dated April 8, 2019, stating that the RIHPHC continues to find that the Project will have no adverse effect on any above-ground historic properties is included in Appendix B. TNEC will consult with the RIHPHC as to monitoring requirements should any areas of elevated archaeological potential be subject to impacts.

No effects to above-ground historic resources are anticipated. NRHP listed or eligible properties that are in the immediate vicinity of proposed manhole or duct bank excavation will be subject to analysis by a structural engineer prior to the commencement of construction activities. If recommended by the structural engineer, vibratory monitoring will be conducted at these locations throughout the construction process. NRHP listed or eligible properties potentially subject to structural analysis are depicted in Figure 1.

All proposed impacts from this Project will occur within existing roadways or sidewalks in areas that are likely already extensively disturbed. Consultation with the RIHPHC indicates that no additional archaeological survey is warranted, based on the scope of the Project. Risks to above-ground resources often include indirect ones, such as loss of integrity in association or setting. However, this Project will be conducted within existing roadways, sidewalks and transmission infrastructure and neither direct nor indirect effects to historic above-ground resources are anticipated.

7.11 Transportation

The construction-related traffic increase will be small relative to total traffic volume on public streets in the area. In addition, it will be intermittent and temporary, and construction related traffic will cease once the Project is completed. Work on the underground transmission cables will involve temporary lane restrictions to some of the roads in the Project Area during certain times of the construction. Dollar Street may be temporarily closed to facilitate the work required within the two existing manholes. Detours are available on adjacent streets to allow for vehicular access around the construction zone. TNEC will coordinate closely with the City of Providence, RIDOT and RIPTA to develop acceptable TMPs for work within city and state streets and highways. No long-term impacts to traffic flow or roadways are expected.

7.12 Safety and Public Health

Because the proposed electrical facilities will be designed, built and maintained in accordance with the standards and codes as discussed in Section 3.4.11, public health and safety will be protected.

7.13 Electric and Magnetic Fields

The magnetic fields produced by the existing transmission lines in 2020 are compared here to the magnetic field levels after completion of the Project in 2022 and five years later.[3]

For projects involving construction of new or reconfigured transmission lines, it is TNEC's standard practice to evaluate low cost/no cost options for reducing magnetic field levels through optimization of phase configurations (Ref. Transmission Line Engineering Document GL.06.01.101), a practice consistent with recommendations of the World Health Organization ([WHO] 2007). Consistent with this practice, based upon Exponent's phasing analysis, TNEC has selected a phasing of the Lines that will minimize magnetic fields.

The magnetic fields were calculated for the proposed reconductored Lines (average annual and peak loads). The results are summarized in Tables 9 and 10 and compared to the magnetic fields from the existing configuration.

TABLE 9 CALCULATED MAGNETIC FIELDS (MG) PRE-CONSTRUCTION AND POST-CONSTRUCTION (ANNUAL AVERAGE LOAD)

DISTANCE FROM DUCT BANK CENTERLINE						
Configuration	**Loading (Year)**	**−50 feet**	**−25 feet**	**MAX**	**+ 25 feet**	**+50 feet**
Existing Lines	2020	0.6	1.1	8.3	1.1	0.6
Reconductored Lines	Proposed (2022)	0.4	0.8	6.2	0.8	0.4
	Proposed (2027)	0.4	0.9	8.1	0.8	0.4

TABLE 10 CALCULATED MAGNETIC FIELDS (MG) PRE-CONSTRUCTION AND POST-CONSTRUCTION (ANNUAL PEAK LOAD)

DISTANCE FROM DUCT BANK CENTERLINE						
Configuration	**Loading (Year)**	**−50 feet**	**−25 feet**	**MAX**	**+ 25 feet**	**+50 feet**
Existing Lines	2020	0.5	1.0	6.7	1.0	0.5
Reconductored Lines	Proposed (2022)	0.8	1.8	17	1.6	0.8
	Proposed (2027)	0.8	1.8	18	1.7	0.8

Calculated magnetic-field levels at average loading of the transmission lines in the proposed underground duct bank in both 2022 and 2027 are shown in Table 9. These calculations indicate that the magnetic field levels will be very similar to those from the original existing Line configuration. The highest magnetic field level is calculated to be approximately 8.1 mG using the annual average

[3] In this Project, neither the existing Lines nor the rebuilt Lines produce an electric field above ground because of the shielding provided by the cable sheaths and the earth, as discussed in Section 6.7.

load, decreasing to 0.4 mG at a distance of ±50 feet from the reconductored Lines. At peak loading, magnetic field levels are calculated to increase slightly.

As described above, TNEC has selected the phasing of the Lines to maximize the cancellation of the magnetic fields from the phase conductors.

The magnetic-field levels from all existing and proposed configurations are similar to the magnetic-field levels experienced on a ROW from distribution or sub-transmission lines and to more common intermittent exposure from appliances (Savitz et al. 1989; NIEHS 2002). At peak loading, expected to occur for a few hours on a few days per year, magnetic-field levels would be higher, but still similar to those within the ROW of typical distribution or sub-transmission lines (Savitz et al. 1989).

The magnetic field levels produced by the existing and proposed facilities are well below guidelines for public exposure recommended by the International Committee on Electromagnetic Safety and the International Committee on Nonionizing Radiation Protection. No national scientific or public health agency has determined that exposure to field levels below these guideline levels poses any health hazard. A discussion of the current state of the health research relevant to exposure to electric and magnetic fields that was prepared by Exponent is included in Appendix A.

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8.0 MITIGATION MEASURES

The Project is not anticipated to have any long-term impacts to the natural or social environment of the Study Area. Mitigation measures for this Project will be used to reduce the impacts of the construction work on the natural and social environment. There are no long-term impacts to mitigate as a result of this Project; therefore, mitigation efforts are focused on the construction phase.

8.1 Natural Environment

8.1.1 Soil Erosion and Sediment Controls and Street Sweeping

Soil erosion and sediment controls will be used during construction activities involving disturbance of soils. These will be installed and maintained to mitigate migration of sediment into the Moshassuck River and Providence River, catch basins along the roadway, and at the Admiral Street Cable Terminal. An SESC Plan and a SWPPP will be developed and implemented for the construction activities. Sediment control measures will include the installation and maintenance of silt fencing, straw bales, straw wattles, and silt sacks for dewatering. Street sweeping will occur along the Project Route daily, as needed, as the Project commences to avoid sedimentation in construction areas within roadways. Additionally, during trenching for the duct bank and excavation for the manholes, excavated soils and materials will be live-loaded directly into awaiting transport that will be queued along the Project Route. This allows for a “clean trench,” which will significantly reduce any temporary stockpiling of excavate and minimize the potential for the inadvertent discharge of dirt onto the street or sidewalks. These measures will be inspected regularly during construction and maintained as necessary in accordance with the RIPDES General Permit for Storm Water Discharge Associated with Construction Activity. Construction crews will be responsible for conducting daily inspections and identifying erosion controls that must be maintained or replaced, as necessary.

Upon completion of construction activities, pervious areas will be stabilized, revegetated and replanted, as necessary. TNEC will coordinate with the City of Providence arborist to develop an inventory of public street trees and other streetscape areas which may be affected by construction activities. Affected trees or areas will be replaced, restored, or otherwise mitigated for, as necessary, following completion of work activities.

8.1.2 Soil Management

Given the historical industrial usage of the Project Route, soil pre-characterization will take place in advance of construction, where feasible, to determine handling and management and disposal methods. Site specific handling and management of materials generated from the excavation of the duct bank trenches and manholes excavations will be developed and implemented, as appropriate. Prior to the initiation of construction within the Admiral Street Cable Terminal, soil management activities will be conducted in accordance with the ELUR, site-specific environmental guidance, and/or SGMP to select the appropriate re-use or disposal methods. Soil disturbed during construction activities will be properly handled, managed, and disposed or reused in accordance with the ELUR, SGMP, site-specific environmental guidance and/or RIDEM regulations. Following the completion of construction, disturbed areas will be restored to their original condition.

8.1.3 Dewatering

Dewatering BMPs (e.g., filter bags, absorbent materials, splash pads) will be implemented to treat pumpate prior to discharge where excavations (e.g., trenches and manholes) along the Project ROW require the need for dewatering of groundwater or accumulated storm water.

Alternatively, groundwater or accumulated storm water may be containerized for proper off-site disposal. Dewatering discharge water will not be released near wetlands, streams/rivers, other sensitive resource areas, directly into catch basins, other storm water devices, or substation *Trenwa* trenches, prior filtering the sediment from the dewatering pumpate. The contractor will implement measures to ensure construction dewatering is not directed toward historic structures to avoid potential flooding or water-related damages. If it is determined that the chosen controls are not appropriately filtering the fine sediment from the dewatering pumpate, then the controls shall be revised or supplemented. Dewatering methods will be conducted in conformance with Rhode Island Storm Water Program, RIPDES Regulations, National Grid's EG-303NE and National Grid's Environmental Guidance Document EG-701RI.

8.1.4 Dust and Vibration

Reasonable precautions will be taken to prevent the excessive generation of nuisance dust and vibration during pavement removal, manhole retirement, soil excavation, stockpiling, loading, and other soil handling activities for the underground cable and Admiral Cable Terminal upgrade. Dust control measures will be implemented, as required, to prevent airborne particulate matter. Exposed soils on access roads shall be wetted and stabilized as necessary to suppress dust generation. As required, enclosure systems will be installed around construction work zones to reduce the spread of construction dust. The Contractor will be responsible for routine sweeping of the streets where excess sediment may accumulate or may be tracked onto the paved surface by construction vehicles. Work along the Project Route will comply with all applicable federal, state, and local regulations, including the RIDEM's Air Pollution Control Regulations, and specifically Regulation No. 5 regarding control of fugitive dust.

TNEC will perform pre-and post-construction inspections at select locations, as warranted. Continued consultation with the RIHPHC will occur prior to construction to discuss individual historic buildings vulnerabilities to vibration. The Company will perform a structural analysis to assess the potential impacts of construction on certain structures. Based on the results of that analysis, TNEC will implement practical strategies to reduce vibration exposure to adjacent buildings and structures, if necessary. These measures may include (but are not limited to): arranging delivery locations and times to limit disruption and possible damage to a neighboring historic structure; exploring excavation and demolition methods that produce low vibration levels; limiting vibration of adjacent buildings with sufficient underpinning or reinforced excavation walls, if needed; and requiring the contractor to participate in a vibration monitoring program at historic sites to ensure that vibration levels or indications of movement are within established thresholds. If warranted, the Company will slightly shift the proposed route further into the public ROW and away from certain buildings.

8.2 Social Environment

8.2.1 Traffic

TNEC will develop TMPs, based on consultations with the City of Providence, RIDOT and RIPTA which will serve to minimize potential traffic congestion and access restrictions during the construction period. The TMPs will be submitted to the City of Providence and RIDOT as part of the utility permit review process. TNEC will also inform affected businesses and other landowners near the Project Route of the planned construction schedule.

Once the construction is complete, the roadways, sidewalks and other disturbed areas from the construction of the Project will be restored to their previously existing or improved condition. Repaving of the streets will be carried out in accordance with the City of Providence and RIDOT requirements.

The TMPs will also include a plan for managing vehicular and pedestrian traffic and detours around the active construction zone to maintain access to educational and governmental facilities, parks and other land uses along the Project Route.

8.2.2 Historic and Cultural Resources

Consultation with the RIHPHC has been initiated by TNEC. TNEC will assign archaeological monitors to observe the trenching of the duct bank and manhole excavation, should the RIHPHC make a final determination that archaeological monitoring is required. A cultural resource specialist will also be consulting with the structural engineers related to NRHP above-ground properties in the immediate vicinity of construction activities.

8.2.3 Supervision and Monitoring

Throughout the entire construction process, TNEC will retain the services of an environmental monitor. The primary responsibility of the monitor will be to oversee construction activities including the installation and maintenance of erosion and sedimentation controls. Environmental monitoring will be conducted on a routine basis to ensure compliance with all federal and state permit requirements, TNEC company policies, and other commitments. The environmental monitor will be a trained environmental scientist responsible for supervising construction activities relative to environmental issues. The environmental monitor will be experienced in the erosion and sedimentation control techniques described in this report and will have an understanding of watercourse resources to be protected.

During periods of prolonged precipitation, the monitor will inspect all locations to confirm that the environmental controls are functioning properly. In addition to retaining the services of an environmental monitor, TNEC will require the contractor to designate an individual to be responsible for the daily inspection and upkeep of environmental controls. This person will also be responsible for providing direction to the other members of the construction crew regarding matters of wetland access and appropriate work methods. Additionally, all construction personnel will be briefed on Project environmental compliance issues and obligations prior to the start of construction. Regular construction progress meetings will provide the opportunity to reinforce the contractor’s awareness of these issues.

8.2.4 Safety and Public Health

Practices to be used to protect the public during construction will include, but not be limited to, establishing TMPs for construction traffic on busy streets to maintain safe driving conditions, and restricting public access to potentially hazardous work areas. Following construction, all cable infrastructures and the cable termination facility will be clearly marked with warning signs to alert the public of potential hazards if entered.

Only 40-hour OSHA trained crews will perform construction in areas where there is known contamination. Personal protection equipment will be required for all on-site workers potentially exposed to impacted materials.

8.2.5 Noise

As discussed in Section 7.9, the Project is located within urban portions of the City of Providence, where ambient sound levels are influenced by vehicular traffic, commercial/residential construction, roadway construction, and highway and railroad transportation corridors. Construction-related noise will be intermittent and will occur throughout Project construction. TNEC will require its contractors to implement source controls to reduce noise emissions during the construction phase of the Project.

9.0 BIBLIOGRAPHY

DeGraaf, R.M. and M. Yamasaki. 2001. New England Wildlife: Habitat, Natural History, and Distribution. 2nd Edition. Hanover, NH: University Press of New England. 482 p.

Enser, R.W. 2006. *Rare Native Animals of Rhode Island*. Rhode Island Natural Heritage Program. Rhode Island Department of Environmental Management. Providence, RI.

_____. 2010. Division of Water Resources, June 2010. Groundwater Quality Rules. Retrieved July 24, 2017 from http://www.dem.ri.gov/pubs/regs/regs/water/gwqual10.pdf.

_____. 2011a. Division of Water Resources. July 2006, Amended December 2010. Water Quality Regulations. Retrieved August 2, 2017 from http://www.dem.ri.gov/pubs/regs/regs/water/h2oq10.pdf.

_____. 2011b. Lakes and Ponds (1:5000); Lakes5k10.zip. Rhode Island Geographic Information System Data Distribution System, URL: http://www.rigis.org/data/lakes5k, Environmental Data Center, University of Rhode Island, Kingston, Rhode Island (last date accessed: 21 April 2018).

National Grid. 2016. *Franklin Square Substation to South Street Substation 115 kV Underground Transmission Line Project.* Rhode Island Energy Facility Siting Board Environmental Report. Retrieved August 1, 2017.

National Park Service (NPS). 1990. *National Register Bulletin 15: How to Apply the National Register Criteria for Evaluation.* Accessed online on July 12, 2016.

Rhode Island Department of Transportation (RI DOT). 1990. Accessed from the RIHPHC website on August 11, 2017.

Rhode Island Geographic Information System (RIGIS). 1993. Wetlands 93; wetlands93.zip. Rhode Island Geographic Information System Data Distribution System, URL: http://www.rigis.org/data/wetlands93, Environmental Data Center, University of Rhode Island, Kingston, Rhode Island (last date accessed: 12 April 2018).

State of Rhode Island. 2018. 2016 Impaired Waters Report. Retrieved April 27, 2018 from http://dem.ri.gov/programs/benviron/water/quality/surfwq/pdfs/iwr16.pdf.

The Narragansett Electric Company d/b/a National Grid. 2016. *Providence River 115kV Cable Relocation Project.* Rhode Island Energy Facility Siting Board Environmental Report. Retrieved December 15, 2017.

United States Environmental Protection Agency (USEPA). 2008. Sole Source Aquifer Program. Retrieved October 24, 2016 from http://www.epa.gov/region1/eco/drinkwater/pc_solesource_aquifer.html

United States Geological Survey (USGS). 1989. Lakes and Ponds; ponds.zip. Rhode Island Geographic Information System Data Distribution System, URL: http://www.rigis.org/data/ponds, Environmental Data Center, University of Rhode Island, Kingston, Rhode Island (last date accessed: 27 April 2018).

FIGURES:

FIGURE 1 PROJECT ROUTE
FIGURE 2 STUDY AREA
FIGURE 3 ENGINEERING DETAIL SHEET
FIGURE 4 UNDERGROUND TRANSMISSION LINE ALTERNATIVE ROUTES
FIGURE 5 LAND USE/ZONING

APPENDIX A CURRENT STATUS OF RESEARCH ON EXTREMELY LOW FREQUENCY ELECTRIC AND MAGNETIC FIELDS AND HEALTH (FEBRUARY 22, 2019)

Health Sciences Practice

Exponent®

Current Status of Research on Extremely Low Frequency Electric and Magnetic Fields and Health

2014-2018

Current Status of Research on Extremely Low Frequency Electric and Magnetic Fields and Health

2014-2018

Prepared for:

Rhode Island
Energy Facility Siting Board
and
The Narragansett Electric Company d/b/a
National Grid

Prepared by:

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February 22, 2019

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Acronyms and Abbreviations

µT	Microtesla
AC	Alternating current
ALL	Acute lymphoblastic leukemia
ALS	Amyotrophic lateral sclerosis
ALT	Alanine aminotransferase
AMI	Acute myocardial infarction
AST	Aspartate aminotransferase
CI	Confidence interval
CNS	Central nervous system
DMBA	7,12-dimethylbenz[a]anthracene
DNA	Deoxyribonucleic acid
EHC	Environmental Health Criteria
ELF	Extremely low frequency
EMF	Electric and magnetic fields
EPA	Environmental Protection Agency
G	Gauss
HCN	Health Council of the Netherlands
HLRN	Hemolymphoreticular neoplasia
Hz	Hertz
IARC	International Agency for Research on Cancer
ICES	International Committee on Electromagnetic Safety
ICNIRP	International Commission on Non-Ionizing Radiation Protection
JEM	Job exposure matrix
kV	Kilovolt
kV/m	Kilovolts per meter
LSPC	Lotus seedpod procyanidins
MDA	Malondialdehyde
mG	Milligauss
mg/L	milligrams per liter
OR	Odds ratio

RR	Relative risk
SCENIHR	Scientific Committee on Emerging and Newly Identified Health Risks
SCHEER	Scientific Committee on Health, Environmental and Emerging Risks
SOD	Superoxide dismutase
TWA	Time weighted average
V/m	Volts per meter
WHO	World Health Organization

Limitations

At the request of the New England Power Company, d/b/a National Grid, Exponent, Inc., prepared this summary report on the status of research related to extremely low frequency electric- and magnetic-field exposure and health. The findings presented herein are made to a reasonable degree of scientific certainty. Exponent reserves the right to supplement this report and to expand or modify opinions based on review of additional material as it becomes available, through any additional work, or review of additional work performed by others.

The scope of services performed during this investigation may not adequately address the needs of other users of this report, and any re-use of this report or its findings, conclusions, or recommendations presented herein are at the sole risk of the user. The opinions and comments formulated during this assessment are based on observations and information available at the time of the investigation. No guarantee or warranty as to future life or performance of any reviewed condition is expressed or implied.

1 Executive Summary

This report was prepared to address the topic of extremely low frequency (ELF) electric and magnetic fields (EMF) and health for the Rhode Island Energy Facility Siting Board at the request of The Narragansett Electric Company d/b/a National Grid.

ELF EMF are invisible fields surrounding all objects that generate, use, or transmit electricity. There are also natural sources of ELF EMF, including the electric fields associated with the normal functioning of our circulatory and nervous systems. People living in developed countries are constantly exposed to ELF EMF in their environments, since electricity is a fundamental part of technologically-advanced societies. Sources of man-made ELF EMF include appliances, wiring, and motors, as well as distribution and transmission lines. Section 3 of this report provides information on the nature and sources of ELF EMF, as well as typical exposure levels.

Research on ELF EMF and health began with the goal of finding therapeutic applications and understanding biological electricity (i.e., the role of electrical potentials across cell membranes and current flows between cells in our bodies). Over the past 40 years, researchers have examined whether ELF EMF from man-made sources can cause short- or long-term health effects in humans using a variety of study designs and techniques. This research considered many aspects of physiology and diseases, including cancers in children and adults, neurodegenerative diseases, reproductive effects, and cardiovascular disease.

Guidance on the possible health risks of all types of exposures comes from health risk assessments or systematic weight-of-evidence evaluations of the cumulative literature on a particular topic conducted by expert panels organized by scientific organizations. Policy makers and the public should look to the conclusions of these reviews, since they are conducted using set scientific standards by scientists representing the various disciplines required to assess the topic at hand. In a health risk assessment of any exposure, it is essential that scientists evaluate the type and strength of research studies available. Human health studies vary in methodological rigor; therefore they vary in their capacity to extrapolate findings to the population at large. Furthermore, three types of studies—epidemiology, *in vivo*, and *in vitro*—

relevant to the particular research topic must be evaluated concurrently to understand possible health risks. Section 3 of this report provides a summary of the methods used to conduct a health risk assessment.

The World Health Organization (WHO) published a health risk assessment of ELF EMF in 2007 that critically reviewed the cumulative epidemiologic and laboratory research to date, taking into account the strength and quality of the individual research studies they evaluated. Section 5 provides a summary of the WHO's conclusions with regard to the major outcomes they evaluate. The WHO report provided the following overall conclusions:

> New human, animal, and in vitro studies published since the 2002 IARC Monograph, 2002 [*sic*] do not change the overall classification of ELF as a possible human carcinogen (WHO, 2007, p. 347).
>
> Acute biological effects [i.e., short-term, transient health effects such as a small shock] have been established for exposure to ELF electric and magnetic fields in the frequency range up to 100 kHz that may have adverse consequences on health. Therefore, exposure limits are needed. International guidelines exist that have addressed this issue. Compliance with these guidelines provides adequate protection. Consistent epidemiological evidence suggests that chronic low-intensity ELF magnetic field exposure is associated with an increased risk of childhood leukaemia [*sic*]. However, the evidence for a causal relationship is limited, therefore exposure limits based upon epidemiological evidence are not recommended, but some precautionary measures are warranted (WHO, 2007, p. 355).

Exponent's report provides a systematic literature review and a critical evaluation of relevant epidemiologic and *in vivo* studies published from December 2014 through December 2018. These recent studies did not provide sufficient evidence to alter the basic conclusion of the WHO—the research does not confirm that electric fields or magnetic fields are a cause of cancer or any other disease at the levels we encounter in our everyday environment. The current guidance from the WHO on its website states that "[b]ased on a recent in-depth review of the scientific literature, the WHO concluded that current evidence does not confirm the existence of any health consequences from exposure to low level electromagnetic fields."[1]

[1] https://www.who.int/peh-emf/about/WhatisEMF/en/index1.html. Accessed January 19, 2019.

There are no national recommendations, guidelines, or standards in the United States to regulate ELF EMF or to reduce public exposures, although the WHO recommends adherence to the exposure limits established by the International Commission on Non-Ionizing Radiation Protection or the International Committee for Electromagnetic Safety for the prevention of acute health effects at high exposure levels. In light of their assessments of the scientific research, some scientific organizations recommend low-cost interventions to reduce ELF EMF exposure. While the large body of existing research does not confirm any likely harm associated with ELF EMF exposure at low levels, research on this topic will continue to reduce remaining uncertainty.

Note that this Executive Summary provides only an outline of the material discussed in this report. Exponent's technical evaluations, analyses, conclusions, and recommendations are included in the main body of this report, which at all times is the controlling document.

2 Introduction

Questions about electric and magnetic fields (EMF) and health are commonly raised during the permitting of transmission lines. Numerous national and international scientific and health agencies have reviewed the research and evaluated potential health risks of exposure to extremely low frequency (ELF) EMF. The most comprehensive review of ELF EMF research was published by the World Health Organization (WHO) in 2007. The WHO's Task Group critically reviewed the cumulative epidemiologic and laboratory research through 2005, taking into account the strength and quality of the individual research studies they evaluated.

National Grid requested that Exponent provide an easily-referenced document that updates a report previously prepared for the Rhode Island Energy Facility Siting Board as part of its Applications for the 2015 Rhode Island Transmission Projects.[2] Exponent's 2015 report systematically evaluated peer-reviewed research and reviews by scientific panels published through November 2014. This current report updates this earlier report with a systematic evaluation of peer-reviewed research and reviews by scientific panels published from December 2014 through December 2018 and describes if and how these recent results affect conclusions reached by the WHO in 2007.

Nature of extremely low frequency electric and magnetic fields

Electricity is transmitted as current from generating sources to high-voltage transmission lines, substations, distribution lines, and then finally to our homes and workplaces for consumption. The vast majority of electricity in North America is transmitted as alternating current (AC), which changes direction 60 times per second (i.e., a frequency of 60 Hertz [Hz]).

Everything that is connected to our electrical system (i.e., power lines, wiring, appliances, and electronics) produces ELF EMF (Figure 1). Both electric fields and magnetic fields are properties of the space near these electrical sources. Forces are experienced by objects capable

[2] Exponent, Inc. *Current Status of Research on Extremely Low Frequency Electric and Magnetic Fields and Health: Rhode Island Transmission Projects – The Narragansett Electric Company d/b/a/ National Grid*. Prepared for the Rhode Island Energy Facility Siting Board. March 9, 2015.

of interacting with these fields; electric charges are subject to a force in an electric field, and moving charges experience a force in a magnetic field.

- **Electric fields** are the result of voltages applied to electrical conductors and equipment. The electric field is expressed in measurement units of volts per meter (V/m) or kilovolts per meter (kV/m); 1 kV/m is equal to 1,000 V/m. Conducting objects including fences, buildings, and our own skin and muscle easily block electric fields. Therefore, certain appliances within homes and workplaces are the major source of electric fields indoors, while transmission and distribution lines are the major source of electric fields outdoors.

- **Magnetic fields** are produced by the flow of electric currents; however, unlike electric fields, most materials do not readily block magnetic fields. The strength of a magnetic field is expressed as magnetic flux density in units of gauss (G) or milligauss (mG), where 1 G = 1,000 mG.[3] The strength of the magnetic field at any point depends on characteristics of the source; in the case of power lines, magnetic-field strength is dependent on the arrangement of conductors, the amount of current flow, and distance from the conductors.

[3] Scientists also refer to magnetic flux density at these levels in units of microtesla. Magnetic flux density in units of mG can be converted to microtesla by dividing by 10 (i.e., 1 mG = 0.1 microtesla).

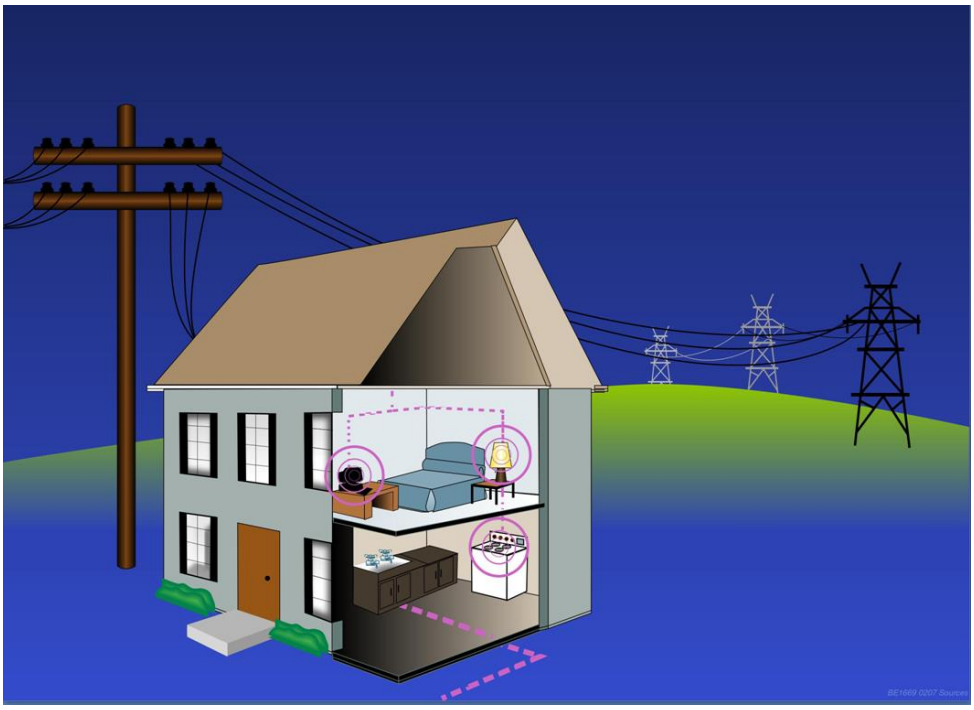


Figure 1. Numerous sources of ELF EMF in our homes (appliances, wiring, currents running on water pipes, and nearby distribution and transmission lines).

Sources and exposure

The intensity of both electric fields and magnetic fields diminishes with increasing distance from the source. Electric fields and magnetic fields from transmission lines generally decrease with distance from the conductors in proportion to the square of the distance, described as creating a bell-shaped curve of field strength around the lines.

Since electricity is such an integral part of our infrastructure and everyday life (e.g., transportation systems, homes, and businesses), people living in modern communities are surrounded by these fields. Figure 2 describes typical EMF levels measured in residential and occupational environments, compared to levels measured on or at the edge of transmission-line rights-of-way. While EMF levels decrease with distance from the source, any home, school, or office tends to have a background EMF level as a result of the combined effect of the numerous EMF sources. In general, the background magnetic-field level in a house away from appliances is typically less than 20 mG, while levels can be hundreds of mG in close proximity to

appliances. Background levels of electric fields range from 10 V/m to 20 V/m, while appliances produce levels up to several tens of V/m (WHO, 2007).

Experiments have yet to show which aspect of ELF EMF exposure, if any, may be relevant to biological systems. The current standard to evaluate EMF exposure for health research is long-term, average personal exposure, which is the average of all exposures to the varied electrical sources encountered in the many places we live, work, eat, and shop. As expected, this exposure is difficult to approximate, and exposure assessment is a major source of uncertainty in studies of ELF EMF and health (WHO, 2007).

Little research has been done to characterize the general public's exposure to magnetic fields, although some basic conclusions are available from the literature:

- *Personal magnetic-field exposure:*
    - The vast majority of persons in the United States have a time-weighted average (TWA) exposure to magnetic fields less than 2 mG (Zaffanella and Kalton, 1998).[4]
    - In general, personal magnetic-field exposure is greatest at work and during travel (Zaffanella and Kalton, 1998).
- *Residential magnetic-field exposure:*
    - The highest magnetic-field levels are typically found directly next to appliances (Zaffanella, 1993). For example, Gauger (1985) reported the maximum AC magnetic field at 3 centimeters from a sampling of appliances as 3,000 mG (can opener); 2,000 mG (hair dryer); 5 mG (oven); and 0.7 mG (refrigerator).
    - Several parameters affect the distribution of personal magnetic-field exposures at home: residence type, residence size, type of water line, and proximity to overhead power lines. Persons living in small homes, apartments, homes with metal piping, and homes close to

[4] TWA is the average exposure over a given specified time period (i.e., an 8-hour workday or 24 hours) of a person's exposure to a chemical or physical agent. The average is determined by sampling the exposure of interest throughout the time period.

three-phase electric power distribution and transmission lines tended to have higher at-home magnetic-field levels (Zaffanella and Kalton, 1998).

- Residential magnetic-field levels are caused by currents from nearby transmission and distribution systems, pipes or other conductive paths, and electrical appliances (Zaffanella, 1993).

- *Workplace magnetic-field exposure*
  - Some occupations (e.g., electric utility workers, sewing machine operators, telecommunication workers) have higher exposures due to work near equipment with high magnetic-field levels (NIEHS, 2002).

- *Power line magnetic-field exposure*
  - The magnetic-field levels associated with transmission and distribution lines vary substantially depending on their configuration, amount of current flow (load), and distance from conductors, among other parameters. At distances of approximately 300 feet from overhead transmission lines and during average electricity demand, the magnetic-field levels from many transmission lines are often similar to the background levels found in most homes, as illustrated in Figure 2, and as discussed in a National Institute of Environmental Health Sciences booklet on EMF (NIEHS, 2002).

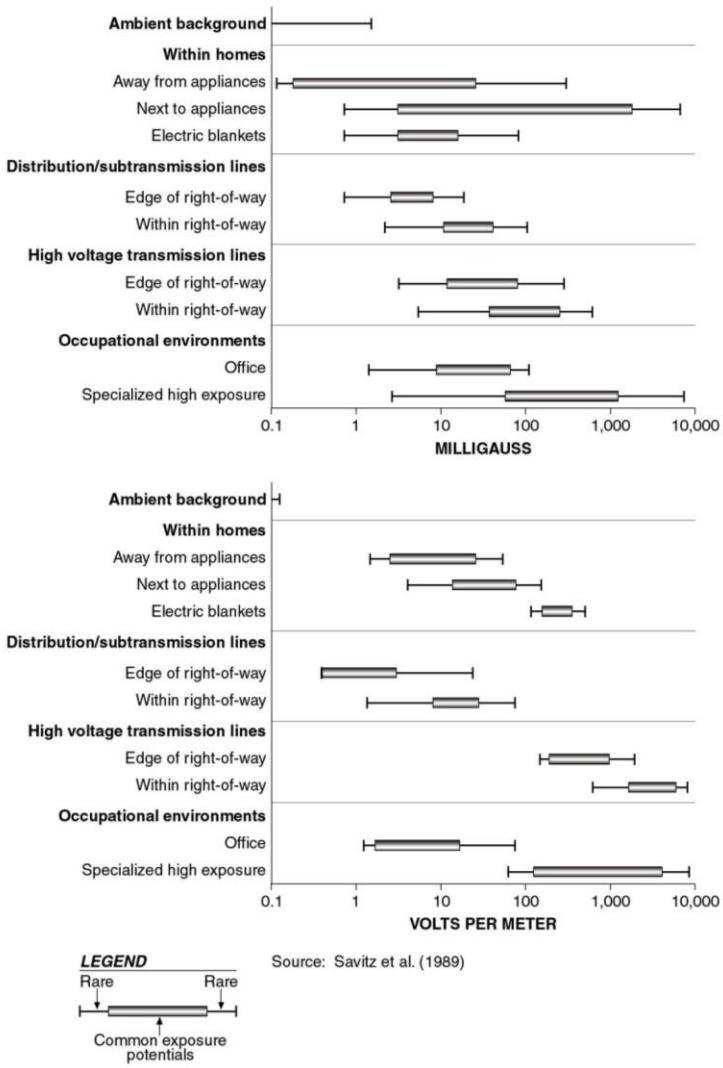


Figure 2. Electric- and magnetic-field strengths in the environment.

Known effects

Similar to virtually any exposure, adverse effects can be expected from exposure to very high levels of ELF EMF. If the current density or electric field induced by an extremely strong magnetic field exceeds a certain threshold, excitation of muscles and nerves is possible (ICNIRP, 2010). Also, strong electric fields can induce charges on the surface of the body that can lead to small shocks (i.e., micro shocks). These are acute and shock-like effects that cause no long-term damage or health consequences. Limits for the general public and workplace have been set to prevent these effects, but there are no real-life situations where these levels are exceeded on a regular basis. Standards and guidelines are discussed in more detail in Section 8.

3 Methods for Evaluating Scientific Research

Science is more than a collection of facts. It is a method of obtaining information and of reasoning to ensure that the information and conclusions are accurate and correctly describe physical and biological phenomena. Many misconceptions in human reasoning occur when people casually interpret their observations and experience. Therefore, scientists use systematic methods to conduct and evaluate scientific research and assess the potential impact of a specific agent on human health. This process is designed to ensure that more weight is given to those studies of better quality, and to ensure that studies with a given result are not selectively chosen from available studies to advocate or suppress a preconceived idea of an adverse effect. Scientists and scientific agencies and organizations use these standard methods to draw conclusions about the many exposures in our environment.

Weight-of-evidence reviews

The scientific process entails looking at *all* the evidence on a particular issue in a systematic and thorough manner to evaluate if the overall data present a logically coherent and consistent picture. This is often referred to as a weight-of-evidence review, in which all studies are considered together, giving more weight to studies of higher quality and using an established analytic framework to arrive at a conclusion about a possible causal relationship. Weight-of-evidence reviews typically are conducted within the larger framework of health risk assessments or evaluations of particular exposures or exposure circumstances that qualitatively and quantitatively define health risks. Several agencies have described weight-of-evidence and health risk assessment methods, including the International Agency for Research on Cancer (IARC), which routinely evaluates substances such as drugs, chemicals, and physical agents for their ability to cause cancer; the WHO International Programme for Chemical Safety; the United States Environmental Protection Agency (EPA), which sets guidance for public exposures; the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR); and the United States National Toxicology Program (USEPA, 1993, 1996; WHO, 1994; SCENIHR, 2012; NTP, 2015). Two steps precede a weight-of-evidence evaluation: a systematic review to

identify the relevant literature and an evaluation of each relevant study to determine its strengths and weaknesses.

The following sections discuss important considerations in the evaluation of human health studies of ELF EMF in a weight-of-evidence review, including exposure considerations, study design, and methods for estimating risk, bias, and the process of causal inference. The purpose of discussing these considerations here is to provide context for the later weight-of-evidence evaluations.

Exposure considerations

Methods to evaluate exposure range widely in studies of ELF EMF. They include the classification of residences based on the relative capacity of nearby power lines to produce magnetic fields (i.e., wire code categories); occupational titles; calculated magnetic-field levels based on job histories (i.e., a job-exposure matrix [JEM]); residential distance from nearby power lines; spot measurements of magnetic-field levels inside or outside residences; 24-hour and 48-hour measurements of magnetic fields in a particular location in a house (e.g., a child's bedroom); calculated magnetic-field levels based on the characteristics of nearby power installations; and personal measurements of magnetic fields for a 24-hour or 48-hour period.

Each of these methods has strengths and limitations (Kheifets and Oksuzyan, 2008). Magnetic-field exposure is ubiquitous, but it varies for each individual over a lifetime as the locations one frequents change and as the ELF EMF sources in those locations also change. This lack of consistency makes valid estimates of personal magnetic-field exposure challenging. Furthermore, without a biological basis to define a relevant exposure metric (average exposure or peak exposure) and a defined critical period for exposure (e.g., *in utero*, shortly before diagnosis), relevant and valid assessments of exposure are problematic. Exposure misclassification is one of the most significant concerns in studies of ELF EMF.

In general, long-term personal measurements are the metrics selected by epidemiologists. Other methods are generally weaker because they may not be strong predictors of long-term exposure and do not take into account all magnetic-field sources. ELF EMF can be estimated indirectly by assigning an estimated amount of exposure to an individual based on calculations considering

nearby power installations or a person's job title. For instance, a relative estimate of exposure could be assigned to all machine operators based on historical information on the magnitude of the magnetic field produced by the machine. Indirect measurements are not as accurate as direct measurements because they do not contain information specific to that person or the exposure situation. In the example of machine operators, the indirect measurement may not account for how much time any one individual spends working at that machine or any potential variability in magnetic fields produced by the machines over time. In addition, such occupational measurements do not take into account the worker's residential magnetic-field exposures.

While JEMs are an advancement over earlier methods, they still have some important limitations, as highlighted in a review by Kheifets et al. (2009) summarizing an expert panel's findings.[5] A person's occupation provides some relative indication of the overall magnitude of their occupational magnetic-field exposure, but it does not take into account the possible variation in exposure due to different job tasks within occupational titles, the frequency and intensity of contact to relevant exposure sources, or variation by calendar time. This was highlighted by a study of 48-hour magnetic-field measurements of 543 workers in Italy in a variety of occupational settings, including: ceramics, mechanical engineering, textiles, graphics, retail, food, wood, and biomedical industries (Gobba et al., 2011). There was significant variation in this study between the measured TWA magnetic-field levels for workers in many of the International Standard Classification of Occupations' job categories, which the authors attributed to variation in industry within these task-defined categories.

Types of health research studies

Research studies can be broadly classified into two groups: 1) epidemiologic observations of people and 2) experimental studies of humans, animals (*in vivo*), and cells and tissues (*in vitro*) conducted in laboratory settings. Epidemiologic studies investigate how disease is distributed in populations and what factors influence or determine this disease distribution (Gordis, 2000). Epidemiologic studies attempt to identify potential causes for human disease while observing

[5] Kheifets et al. (2009) reports on the conclusions of an independent panel organized by the Energy Networks Association in the United Kingdom in 2006 to review the current status of the science on occupational EMF exposure and identify the highest priority research needs.

people as they go about their daily lives. Such studies are designed to quantify and evaluate the associations between disease and reported exposures to environmental factors.

The most common types of epidemiologic studies in the ELF EMF literature are case-control and cohort studies. In case-control studies, people with and without the disease of interest are identified and the exposures of interest are evaluated. Often, people are interviewed or their personal records (e.g., medical records or employment records) are reviewed in order to establish the exposure history for each individual. The exposure histories are then compared between the diseased and non-diseased populations to determine whether any statistically significant differences in exposure histories exist. In cohort studies, on the other hand, individuals within a defined cohort of people (e.g., all persons working at a utility company) are classified as exposed or non-exposed and followed over time for the incidence of disease. Researchers then compare disease incidence in the exposed and non-exposed groups.

Experimental studies are designed to test specific hypotheses under controlled conditions and are vital to assessing cause-and-effect relationships. An example of a human experimental study relevant to this area of research would be studies that measure the impact of magnetic-field exposure on acute biological responses in humans, such as hormone levels. These studies are conducted in laboratories under controlled conditions. *In vivo* studies of animals and *in vitro* experimental studies also are conducted under controlled conditions in laboratories. *In vivo* studies expose laboratory animals to very high levels of a chemical or physical agent to determine whether exposed animals develop cancer or other effects at higher rates than unexposed animals, while attempting to control other factors that could possibly affect disease rates (e.g., diet, genetics). *In vitro* studies of isolated cells and tissues are important because they can help scientists understand biological mechanisms as they relate to the same exposure in intact humans and animals. The responses of cells and tissues outside the body, however, may not reflect the response of those same cells if maintained in a living system, so their relevance cannot be assumed. Therefore, it is both necessary and desirable to assess whether a particular agent could cause adverse health effects using both epidemiologic and experimental studies.

Both of these approaches—epidemiologic and experimental laboratory studies—have been used to evaluate whether exposure to ELF EMF has any adverse effects on human health.

Epidemiologic studies are valuable because they are conducted in human populations, but they are limited by their non-experimental design and typical retrospective nature. In epidemiologic studies of magnetic fields, for example, researchers cannot control the amount of individual exposure, how exposure occurs over time, the contribution of different field sources, or individual behaviors other than exposure that may affect disease risk, such as diet. In valid risk assessments of ELF EMF, epidemiologic studies are considered alongside experimental studies of laboratory animals, while studies of isolated tissues and cells are generally considered supplementary.

Estimating risk

Epidemiologists measure the statistical association between exposures and disease in order to estimate risk. This brief summary is included to provide a foundation for understanding and interpreting statistical associations in epidemiologic studies as risk estimates.

Two common types of risk estimates are absolute risk and relative risk (RR). Absolute risk, also known as incidence, is the amount of new disease that occurs in a given period. For example, the absolute risk of invasive childhood cancer in children 0 to 19 years of age for 2004 was 14.8 per 100,000 children (Reis et al., 2007). RRs are calculated to evaluate whether a particular exposure or inherent quality (e.g., EMF, diet, genetics, race) is associated with a disease outcome. This is calculated by looking at the absolute risk in one group relative to a comparison group. For example, white children 0 to 19 years of age had an estimated absolute risk of childhood cancer of 15.4 per 100,000 in 2004, and African American children in the same age range had an estimated absolute risk of 13.3 per 100,000 in the same year. By dividing the absolute risk of white children by the absolute risk of African American children, we obtain an RR of 1.16. This RR estimate can be interpreted to mean that white children have a risk of childhood cancer that is 16% greater than the risk of African American children. Additional statistical analysis is needed to evaluate whether this association is statistically significant, as defined in the following sub-section.

It is important to understand that risk is estimated differently in cohort and case-control studies because of the way the studies are designed. Traditional cohort studies provide a direct estimate of RR, while case-control studies only provide indirect estimates of RR, called odds ratios (OR).

For this reason, among others, cohort studies usually provide more reliable estimates of the risk associated with a particular exposure. Case-control studies are more common than cohort studies, however, because they are less costly and more time efficient.

Thus, the association between a particular disease and exposure is measured quantitatively in an epidemiologic study as either the RR (cohort studies) or OR (case-control studies) estimate. The general interpretation of a risk estimate equal to 1.0 is that the exposure is not associated with an increased incidence of the disease. If the risk estimate is greater than 1.0, the inference is that the exposure is associated with an increased incidence of the disease. On the other hand, if the risk estimate is less than 1.0, the inference is that the exposure is associated with a reduced incidence of the disease. The magnitude of the risk estimate is often referred to as its strength (i.e., strong versus weak). Stronger associations are given more weight because they are less susceptible to the effects of bias.

Statistical significance

Statistical significance testing provides an idea of whether or not a statistical association is a chance occurrence or whether the association is likely to be observed upon repeated testing. The terms statistically significant or statistically significant association are used in epidemiologic studies to describe the tendency of the level of exposure and the occurrence of disease to be linked, with chance as an unlikely explanation. Statistically significant associations, however, are not necessarily an indication of cause-and-effect because the interpretation of statistically significant associations depends on many other factors associated with the design and conduct of the study, including how the data were collected and the number of study participants.

Confidence intervals (CI), reported along with RR and OR values, indicate a range of values for an estimate of effect that has a specified probability (e.g., 95%) of including the true estimate of effect. CIs evaluate statistical significance, but do not address the role of bias, as described further below. A 95% CI indicates that if the study were conducted a very large number of times, 95% of the measured estimates would be within the upper and lower confidence limits.

The CI range is also important for interpreting estimated associations, including the precision and statistical significance of the association. A very wide CI indicates great uncertainty in the

value of the true risk estimate. This is usually due to a small number of observations. A narrow CI provides more certainty about the true RR estimate. If the 95% CI does not include 1.0, the probability that an association is due to chance alone is 5% or lower, and the result is considered statistically significant, as discussed above.

Meta-analysis and pooled analysis

In scientific research, the results of smaller studies may be difficult to distinguish from normal, random variation. This is also the case for sub-group analyses where few cases are estimated to have high exposure levels (e.g., in case-control studies of childhood leukemia and TWA magnetic-field exposure greater than 3 to 4 mG). Meta-analysis is an analytic technique that combines the published results from a group of studies into one summary result. A pooled analysis, on the other hand, combines the raw, individual-level data from the original studies and analyzes the data from the studies altogether. These methods are valuable because they increase the number of individuals in the analysis, which allows for a more robust and stable estimate of association. Meta- and pooled analyses are important tools for qualitatively synthesizing the results of a large group of studies.

The disadvantage of meta- and pooled analyses is that they can convey a false sense of consistency across studies if *only* the combined estimate of effect is considered (Rothman and Greenland, 1998). These analyses typically combine data from studies with different study populations, methods for measuring and defining exposure, and disease definitions. This is particularly true for analyses that combine data from case-control studies, which often use very different methods for the selection of cases and controls and exposure assessment (Linet, 2003). Therefore, meta- and pooled analyses are used not only to synthesize or combine data but also to understand which factors cause the results of the studies to vary (i.e., publication date, study design, possibility of selection bias), and how these factors affect the associations calculated from the data of all the studies combined (Rothman and Greenland, 1998).

Meta- and pooled analyses are a valuable technique in epidemiology; however, in addition to calculating a summary RR, they should follow standard techniques (Stroup et al., 2001) and analyze the factors that contribute to any heterogeneity between the studies.

Bias in epidemiologic studies

One key reason that the results of epidemiologic studies cannot directly provide evidence for cause-and-effect is the presence of bias. Bias is defined as "any systematic error in the design, conduct or analysis of a study that results in a mistaken estimate of an exposure's effect on the risk of disease" (Gordis, 2000, p. 204). In other words, sources of bias are factors or research situations that can mask a true association or cause an association that does not truly exist. As a result, the extent of bias, as well as its types and sources, is one of the most important considerations in the interpretation of epidemiologic studies. Since it is not possible to fully control human populations, perfectly measure their exposures, or control for the effects of all other risk factors, bias will exist in some form in all epidemiologic studies of human health. Laboratory studies, on the other hand, more effectively manage bias because of the tight control the researchers have over most study variables.

One important source of bias occurs in epidemiologic studies when a third variable confuses the relationship between the exposure and disease of interest because of its relationship to both. Consider an example of a researcher whose study finds that people who exercise have a lower risk of diabetes compared to people who do not exercise. It is known that people who exercise more also tend to consume healthier diets and healthier diets may lower the risk of diabetes. If the researcher does not control for the impact of diet, it is not possible to say with certainty that the lower risk of diabetes is due to exercise and not to a healthier diet. In this example, diet is the confounding variable.

Cause versus association and evaluating evidence regarding causal associations

Epidemiologic studies can help suggest factors that may contribute to the risk of disease, but they are not used as the sole basis for drawing inferences about cause-and-effect relationships. Since epidemiologists do not have control over the many other factors to which people in their studies are exposed, and diseases can be caused by a complex interaction of many factors, the results of epidemiologic studies must be interpreted with caution. A single epidemiologic study is rarely unequivocally supportive or non-supportive of causation; rather, a weight is assigned to the study based on the validity of its methods and all relevant studies (epidemiology, *in vivo*, and *in vitro*)

must be considered together in a weight-of-evidence review to arrive at a conclusion about possible causality between an exposure and disease.

In 1964, the Surgeon General of the United States published a landmark report on smoking-related diseases (HEW, 1964). As part of this report, the Surgeon General outlined nine criteria for evaluating epidemiologic studies (along with experimental data) for causality. In a more recent edition of this report, these criteria have been reorganized into seven criteria. In the earlier report, which was based on the commonly referenced Hill criteria (Hill, 1965), coherence, plausibility, and analogy were considered as distinct items, but are now summarized together because they have been treated in practice as essentially reflecting one concept (HHS, 2004). Table 1 provides a list and brief description of each criterion.

Table 1. Criteria for evaluating whether an association is causal

Criteria	Description
Consistency	Repeated observation of an association between exposure and disease in multiple studies of adequate statistical power, in different populations, and at different times.
Strength of the association	The larger (stronger) the magnitude and statistical strength of an association between exposure and disease, the less likely such an effect is the result of chance or unmeasured confounding.
Specificity	The exposure is the single cause or one of a few causes of disease.
Temporality	The exposure occurs prior to the onset of disease.
Coherence, plausibility, and analogy	The association cannot violate known scientific principles and the association must be consistent with experimentally demonstrated biologic mechanisms.
Biologic gradient	The observation that the stronger or greater the exposure, the stronger or greater the effect, also known as a dose-response relationship.
Experiment	Observations that result from situations in which natural conditions imitate experimental conditions. Also stated as a change in disease outcome in response to a non-experimental change in exposure patterns in populations.

Source: Department of Health and Human Services, 2004

The criteria were meant to be applied to statistically significant associations observed in the cumulative epidemiologic literature (i.e., if no statistically significant association is observed for an exposure then the criteria are not relevant). It is important to note that these criteria were not intended to serve as a checklist, but as guide to evaluate associations for causal inference. Theoretically, it is possible for an exposure to meet all seven criteria, but still not be deemed a causal factor. Also, no one criterion can provide indisputable evidence for causation, nor can any single criterion, except for temporality, rule out causation.

In summary, the judicious consideration of these criteria is useful in evaluating epidemiologic studies, but they cannot be used as the sole basis for drawing inferences about cause-and-effect relationships. In line with the criteria of coherence, plausibility, and analogy, epidemiologic studies are considered along with *in vivo* and *in vitro* studies in a comprehensive weight-of-evidence review. Epidemiologic support for causality is usually based on high-quality studies that report consistent results across many different populations and study designs and are supported by experimental data collected from *in vivo* and *in vitro* studies.

Biological response versus disease in human health

When interpreting research studies, it is important to distinguish between a reported biological response and an indicator of disease. This is relevant because exposure to ELF EMF may elicit a biological response that is simply a normal response to environmental conditions. This response, however, may not be a disease, cause a disease, or be otherwise harmful. There are many exposures or factors encountered in day-to-day life that elicit a biological response, but the response is neither harmful nor the cause of disease. For example, as a person walks from a dark room indoors to a sunny day outdoors, the pupils of the eye naturally constrict to limit the amount of light passing into the eye. This constriction of the pupil is a biological response to the change in light conditions. Pupil constriction, however, is neither a disease itself, nor is it known to cause disease.

4 The WHO 2007 Report: Methods and Conclusions

The WHO is a scientific organization within the United Nations system with the mandate to provide leadership on global health matters, shape health research agendas, and set norms and standards. The WHO established the International EMF Project in 1996, in response to public concern about exposure to ELF EMF and possible adverse health outcomes. The Project's membership includes 8 international organizations, 8 collaborating institutions, and over 54 national authorities. The overall purpose of the Project is to assess health and environmental effects of exposure to static and time-varying fields in the frequency range of 0 Hz to 300 gigahertz. A key objective of the Project is to evaluate the scientific literature and make periodic status reports on health effects to be used as the basis for a coherent international response, including the identification of important research gaps and the development of internationally acceptable standards for ELF EMF exposure.

In 2007, the WHO published their Environmental Health Criteria (EHC) 238 on EMF summarizing health research in the ELF range. The EHC used standard scientific procedures, as outlined in its Preamble and described above in Section 3, to conduct the review. The Task Group responsible for the report's overall conclusions consisted of 21 scientists from around the world with expertise in a wide range of scientific disciplines. They relied on the conclusions of previous weight-of-evidence reviews,[6] where possible, and mainly focused on evaluating studies published after an IARC review of ELF EMF and cancer in 2002.

The WHO Task Group and IARC use specific terms to describe the strength of the evidence in support of causality between specific agents and cancer. These categories are described here because, while they are meaningful to scientists who are familiar with the IARC process, they can create an undue level of concern with the general public. *Sufficient evidence of carcinogenicity* is assigned to a body of epidemiologic research if a positive association has been observed in studies in which chance, bias, and confounding can be ruled out with reasonable

[6] The term weight-of-evidence review is used in this report to denote a systematic review process by a multidisciplinary, scientific panel involving experimental and epidemiologic research to arrive at conclusions about possible health risks. The WHO EHC on EMF does not specifically describe their report as a weight-of-evidence review. Rather, they describe conducting a health risk assessment. A health risk assessment differs from a weight-of-evidence review in that it also incorporates an exposure and exposure-response assessment.

confidence. *Limited evidence of carcinogenicity* describes a body of epidemiologic research where the findings are inconsistent or there are outstanding questions about study design or other methodological issues that preclude making a conclusion. *Inadequate evidence of carcinogenicity* describes a body of epidemiologic research where it is unclear whether the data is supportive or unsupportive of causation because there is a lack of data or there are major quantitative or qualitative issues. A similar classification system is used for evaluating *in vivo* studies and mechanistic data for carcinogenicity.

Summary categories are assigned by considering the conclusions of each body of evidence (epidemiologic, *in vivo*, and *in vitro*) together. As identified in Figure 3, categories include (from highest to lowest risk): *carcinogenic to humans*; *probably carcinogenic to humans*; *possibly carcinogenic to humans*; *not classifiable as to its carcinogenicity to humans*; and *probably not carcinogenic to humans*. These categories are intentionally meant to err on the side of caution, giving more weight to the possibility that the exposure is truly carcinogenic and less weight to the possibility that the exposure is not carcinogenic. The category *possibly carcinogenic to humans* denotes exposures for which there is limited evidence of carcinogenicity in epidemiologic studies and less than sufficient evidence of carcinogenicity in studies of experimental animals. *In vitro* research is not described in Figure 3 because it provides ancillary information; it is used to a lesser degree in evaluating carcinogenicity and is classified simply as strong, moderate, or weak.

	Epidemiology Studies				Animal Studies			
	Sufficient evidence	Limited evidence	Inadequate evidence	Evidence suggesting lack of carcinogenicity	Sufficient evidence	Limited evidence	Inadequate evidence	Evidence suggesting lack of carcinogenicity
Known Carcinogen	✔							
Probable Carcinogen		✔			✔			
Possible Carcinogen		✔				✔	✔	
Not Classifiable			✔			✔	✔	
Probably not a Carcinogen				✔				✔

Sufficient evidence in epidemiology studies—A positive association is observed between the exposure and cancer in studies, in which chance, bias and confounding were ruled out with "reasonable confidence."

Limited evidence in epidemiology studies—A positive association has been observed between the exposure and cancer for which a causal interpretation is considered to be credible, but chance, bias or confounding could not be ruled out with "reasonable confidence."

Inadequate evidence in epidemiology studies—The available studies are of insufficient quality, consistency or statistical power to permit a conclusion regarding the presence or absence of a causal association between exposure and cancer, or no data on cancer in humans are available.

Evidence suggesting a lack of carcinogenicity in epidemiology studies—There are several adequate studies covering the full range of levels of exposure that humans are known to encounter, which are mutually consistent in not showing a positive association between exposure to the agent and any studied cancer at any observed level of exposure. The results from these studies alone or combined should have narrow confidence intervals with an upper limit close to the null value (e.g. a relative risk of 1.0). Bias and confounding should be ruled out with reasonable confidence, and the studies should have an adequate length of follow-up.

Sufficient evidence in animal studies—An increased incidence of malignant neoplasms is observed in (a) two or more species of animals or (b) two or more independent studies in one species carried out at different times or indifferent laboratories or under different protocols. An increased incidence of tumors in both sexes of a single species in a well-conducted study, ideally conducted under Good Laboratory Practices, can also provide sufficient evidence.

Limited evidence in animal studies—The data suggest a carcinogenic effect but are limited for making a definitive evaluation, e.g. (a) the evidence of carcinogenicity is restricted to a single experiment; (b) there are unresolved questions regarding the adequacy of the design, conduct or interpretation of the studies; etc.

Inadequate evidence in animal studies—The studies cannot be interpreted as showing either the presence or absence of a carcinogenic effect because of major qualitative or quantitative limitations, or no data on cancer in experimental animals are available

Evidence suggesting a lack of carcinogenicity in animal studies—Adequate studies involving at least two species are available which show that, within the limits of the tests used, the agent is not carcinogenic.

Figure 3. Basic IARC method for classifying exposures based on potential carcinogenicity.

The IARC has reviewed over 1,000 substances and exposure circumstances to evaluate their potential carcinogenicity. Eighty percent of exposures fall in the categories *possibly carcinogenic* (31 percent) or *not classifiable* (49 percent).[7] This occurs because it is nearly impossible to prove that something is completely safe, and few exposures show a clear-cut or probable risk, so most agents will end up in either of these two categories. Throughout the

[7] https://monographs.iarc.fr/agents-classified-by-the-iarc/. Accessed January 19, 2019.

history of the IARC, only one agent has been classified as *probably not carcinogenic*, which illustrates the conservatism of the evaluations and the difficulty in proving the absence of an effect beyond all doubt.

The WHO report provided the following overall conclusions with regard to ELF EMF:

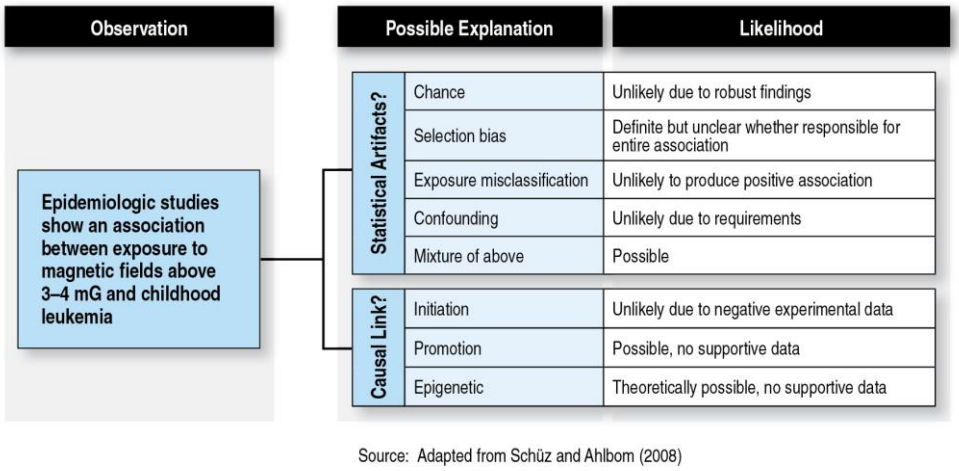
> New human, animal, and in vitro studies published since the 2002 IARC Monograph, 2002 [*sic*] do not change the overall classification of ELF as a possible human carcinogen (p. 347).
>
> Acute biological effects [i.e., short-term, transient health effects such as a small shock] have been established for exposure to ELF electric and magnetic fields in the frequency range up to 100 kHz that may have adverse consequences on health. Therefore, exposure limits are needed. International guidelines exist that have addressed this issue. Compliance with these guidelines provides adequate protection. Consistent epidemiological evidence suggests that chronic low-intensity ELF magnetic field exposure is associated with an increased risk of childhood leukaemia [*sic*]. However, the evidence for a causal relationship is limited, therefore exposure limits based upon epidemiological evidence are not recommended, but some precautionary measures are warranted (p. 355, WHO, 2007).

With regard to specific diseases, the WHO concluded the following:

Childhood cancers. The WHO report paid particular attention to childhood leukemia because the most consistent epidemiologic association in the area of ELF EMF and health research has been reported between this disease and TWA exposure to high magnetic-field levels. Two pooled analyses reported an association between childhood leukemia and TWA magnetic-field exposure >3 to 4 mG (Ahlbom et al., 2000; Greenland et al., 2000). These data, categorized as limited epidemiologic evidence, resulted in the classification of magnetic fields as possibly carcinogenic by the IARC in 2002.

The WHO report systematically evaluated several factors that might be partially, or fully, responsible for the consistent association, including: chance, misclassification of magnetic-field exposure, confounding from hypothesized or unknown risk factors, and selection bias. The authors concluded that chance is an unlikely explanation since the pooled analyses had a large sample size and decreased variability; control selection bias probably occurs to some extent in these studies and would result in an overestimate of the true association, but would not explain the entire observed association; it is less likely that confounding occurs, although the possibility

that some yet-to-be identified confounder is responsible for the association cannot be fully excluded; and, finally, exposure misclassification would likely result in an underestimate of the true association, although it is not entirely clear (see Figure 4 below). The WHO concluded that reconciling the epidemiologic data on childhood leukemia and the negative experimental findings (i.e., no hazard or risk observed) through innovative research is currently the highest priority in the field of ELF EMF research. Given that few children are expected to have long-term *average* magnetic-field exposures greater than 3 to 4 mG, however, the WHO stated that the public health impact of magnetic fields on childhood leukemia would likely be minimal, if the association was determined to be causal.



Source: Adapted from Schüz and Ahlbom (2008)

Figure 4. Possible explanations for the observed association between magnetic fields and childhood leukemia.

Fewer studies have been published on magnetic fields and childhood brain cancer compared to studies of childhood leukemia. The WHO Task Group described the results of these studies as inconsistent and limited by small sample sizes and recommended a meta-analysis to clarify the research findings.

Breast cancer. The WHO concluded that the more recent studies they reviewed on breast cancer and ELF EMF exposure were higher in quality compared with earlier studies, and for that reason, they provide strong support to previous consensus statements that magnetic-field exposure does not influence the risk of breast cancer. In summary, the WHO stated "[w]ith these [more recent] studies, the evidence for an association between ELF magnetic-field exposure and the risk of female breast cancer is weakened considerably and does not support an association of this kind"

(WHO, 2007, p. 9). The WHO recommended no further research with respect to breast cancer and magnetic-field exposure.

Adult leukemia and brain cancer. The WHO concluded, "In the case of adult brain cancer and leukaemia [*sic*], the new studies published after the IARC monograph do not change the conclusion that the overall evidence for an association between ELF [EMF] and the risk of these disease remains inadequate" (WHO, 2007, p. 307). The WHO panel recommended updating the existing European cohorts of occupationally-exposed individuals and pooling the epidemiologic data on brain cancer and adult leukemia to confirm the absence of an association.

In vivo research on carcinogenesis. The WHO concluded the following with respect to *in vivo* research: "[t]here is no evidence that ELF [EMF] exposure alone causes tumours [*sic*]. The evidence that ELF field exposure can enhance tumour [*sic*] development in combination with carcinogens is inadequate" (WHO, 2007, p. 10). Recommendations for future research included the development of a rodent model for childhood acute lymphoblastic leukemia (ALL) and the continued investigation of whether magnetic fields can act as a co-carcinogen.

Reproductive and developmental effects. The WHO concluded that, overall, the body of research does not suggest that maternal or paternal exposures to ELF EMF cause adverse reproductive or developmental outcomes. The evidence from epidemiologic studies on miscarriage was described as inadequate and further research on this possible association was recommended, although low priority was given to this recommendation.

Neurodegenerative diseases. The WHO reported that the majority of epidemiologic studies have reported associations between occupational magnetic-field exposure and mortality from Alzheimer's disease and amyotrophic lateral sclerosis (ALS), although the design and methods of these studies were relatively weak (e.g., disease status was based on death certificate data, exposure was based on incomplete occupational information from census data, and there was no control for confounding factors). The WHO concluded that there is inadequate data in support of an association between magnetic-field exposure and Alzheimer's disease or ALS. The panel highly recommended that further studies be conducted in this area, particularly studies where the association between magnetic fields and ALS is estimated while controlling for the possible confounding effect of electric shocks.

Cardiovascular disease. It has been hypothesized that magnetic-field exposure reduces heart rate variability, which in turn increases the risk for acute myocardial infarction (AMI). With one exception (Savitz et al., 1999), however, none of the studies of cardiovascular disease morbidity and mortality that were reviewed show an association with exposure. Whether a specific association exists between exposure and altered autonomic control of the heart remains speculative and overall the evidence does not support an association. Experimental studies of both short- and long-term exposure indicate that while electric shock is an obvious health hazard, other hazardous cardiovascular effects associated with ELF EMF are unlikely to occur at exposure levels commonly encountered environmentally or occupationally.

5 Current Scientific Consensus

The following sections identify and describe epidemiologic and *in vivo* studies related to ELF EMF and health published between December 2014 and December 2018. The purpose of this section is to evaluate whether the findings of these recent studies alter the conclusions published by the WHO in their 2007 report, as described in Section 4. A previous Exponent report summarized the literature through November 2014[8] and concluded that those results did not provide sufficient evidence to alter the basic conclusion of the WHO EHC published in 2007.

A structured literature search was conducted using PubMed, a search engine provided by the National Library of Medicine and the National Institutes of Health that includes over 15 million up-to-date citations from MEDLINE and other life science journals for biomedical articles (http://www.pubmed.gov). A well-defined search strategy was used to identify English language literature indexed between December 2014 and December 2018.[9] All fields (e.g., title, abstract, keywords) were searched with various search strings that referenced the exposure and disease of interest.[10] A researcher with experience in this area reviewed the titles and abstracts of these publications for inclusion in this evaluation. The following specific inclusion criteria were applied:

1. **Outcome**. Included studies evaluated one of the following diseases: cancer; reproductive or developmental effects; neurodegenerative diseases; or cardiovascular disease. Research on other outcomes was not included (e.g., psychological effects, behavioral effects, hypersensitivity). Few studies are available in these research areas, so research evolves more slowly.

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[8] Exponent, Inc. *Current Status of Research on Extremely Low Frequency Electric and Magnetic Fields and Health: Rhode Island Transmission Projects – The Narragansett Electric Company d/b/a/ National Grid*. Prepared for the Rhode Island Energy Facility Siting Board. March 9, 2015.

[9] Since there is sometimes a delay between the publication date of a study and the date it is indexed in PubMed, it is possible that some studies not yet indexed, but published prior to December 2018, are not included in this update.

[10] EMF OR magnetic fields OR electric fields OR electromagnetic OR power frequency OR transmission line AND cancer (cancer OR leukemia OR lymphoma OR carcinogenesis) OR neurodegenerative disease (neurodegenerative disease OR Alzheimer's disease OR amyotrophic lateral sclerosis OR Lou Gehrig's disease) OR cardiovascular effects (cardiovascular OR heart rate) OR reproductive outcomes (miscarriage OR reproduction OR developmental effects).

2. **Exposure**. The study must have evaluated 50/60-Hz AC ELF EMF.

3. **Exposure assessment methods**. Included studies evaluate exposure beyond self-report of an activity or occupation. Included studies estimated exposure through various methods including calculated EMF levels using distance from power lines; measured TWA exposure; and average exposure estimated from JEMs.

4. **Study design**. Study design includes epidemiologic studies, meta-analyses, pooled analyses, human experimental studies, and *in vivo* studies of carcinogenicity. The review relies on the conclusions of the WHO with regard to *in vivo* studies in the areas of reproduction, development, neurology, and cardiology. Further, this report relies on the conclusions of the WHO report (as described in Section 4) with regard to mechanistic data from *in vitro* studies since this field of study is less informative to the risk assessment process (IARC, 2002).

5. **Peer-review**. The study must have been peer-reviewed and published. Therefore, no conference proceedings, abstracts, or on-line material were included.

Epidemiologic studies are evaluated below first by outcome (childhood cancer; adult cancer; reproductive or developmental effects; neurodegenerative disease; and cardiovascular effects), followed by an evaluation of *in vivo* research on carcinogenesis. Tables 3 through 9 list the relevant studies that were published from December 2014 through December 2018 in these areas.

Childhood health outcomes

Childhood leukemia

In 2002, the IARC assembled and reviewed research related to ELF EMF to evaluate the strength of the evidence in support of carcinogenicity. The IARC expert panel noted that when studies with the relevant information were combined in a pooled analysis (Ahlbom et al., 2000; Greenland et al., 2000), a statistically significant two-fold association was observed between childhood leukemia and estimated average exposure to high levels of magnetic fields (i.e., greater than 3 to 4 mG of average 24- and 48-hour exposure). This evidence was classified as limited evidence in support of carcinogenicity, falling short of sufficient evidence because chance, bias, and confounding could not be ruled out with reasonable confidence. Largely as a

result of the findings related to childhood leukemia, the IARC classified magnetic fields as *possibly carcinogenic*, which as noted previously is a category that describes exposures with limited epidemiologic evidence and inadequate evidence from *in vivo* studies. The classification of *possibly carcinogenic* was confirmed by the WHO in their 2007 review.

Since the WHO conducted their review, childhood leukemia continues to be a main focus of ELF EMF epidemiologic research. Kheifets et al. (2010) provided an update to the analyses conducted by Ahlbom et al. (2000) and Greenland et al. (2000) by reporting the results of a pooled analysis of seven case-control studies of childhood leukemia and ELF EMF published between 2000 and 2010. Although the authors included a large number of cases (n=10,865) in this analysis, only 23 cases had measured fields and 3 cases had calculated fields in the highest exposure category (≥3 mG). A moderate and statistically not significant association was reported for the highest exposure category (OR 1.44, 95% CI 0.88-2.36), which was weaker than the association reported in the previous pooled analyses (Ahlbom et al., 2000; Greenland et al., 2000).

More recently, three large case-control studies from France (Sermage-Faure et al., 2013), Denmark (Pedersen et al., 2014a), and the United Kingdom (Bunch et al., 2014) assessed the risk of childhood leukemia in relation to residential proximity to high-voltage power lines. None of these studies reported consistent overall associations between childhood leukemia development and residential distance to high-voltage power lines. The largest of these studies (Bunch et al., 2014) was an update of an earlier study in the United Kingdom (Draper et al., 2005) and included over 53,000 childhood cancer cases diagnosed between 1962 and 2008 and over 66,000 healthy children as controls. Overall, the authors reported no association between childhood leukemia development and residential proximity to power lines with any of the voltage categories. The statistical association reported in the earlier study (Draper et al., 2005) was no longer apparent in the updated analysis (Bunch et al., 2014).

All three case-control studies had large sample sizes and were population-based studies requiring no subject participation, which minimizes the potential for selection bias. The main limitation of these studies was the reliance on distance to power lines as the main exposure metric, which is known to be a poor predictor of actual residential magnetic-field exposure. Several observers in

the scientific literature discussed the limitations of distance as an exposure proxy in the context of the French study by Sermage-Faure et al. (Bonnet-Belfais et al., 2013; Clavel et al., 2013). In addition, Chang et al. (2014) provided a detailed discussion of the limitations of exposure assessment methods based on geographical information systems. Swanson et al. (2014) also concluded, based on their analysis of data from the British study (Bunch et al., 2014), that geocoding information not based on exact address, but only on post code information, is "probably not acceptable for assessing magnetic-field effects" (Swanson et al., 2014a, p. N81).

Recent studies (December 2014 through December 2018)

Several recent studies analyzed the same populations used in two of the three case-control studies summarized above (Bunch et al., 2014; Pedersen et al., 2014a).

The authors of the previous Danish study (Pedersen et al., 2014a) also evaluated whether consideration of other potential risk factors for childhood leukemia may influence the results in relation to distance to power lines (Pedersen et al., 2014b). Adjustments for socioeconomic status, mother's age, birth order, domestic radon exposure, or traffic-related air pollution were reported not to affect associations relating to power lines. The authors reported a statistical interaction between distance to power lines and radon exposure; however, they attributed these findings to chance, as these results were based on a small number of cases. Pedersen et al. (2015) reported the results of another case-control study using a study population that mostly overlapped with the previous two papers (Pedersen et al., 2014a, 2014b). Pedersen et al. (2015) included all children in Denmark diagnosed before 15 years of age with a first primary leukemia (n=1,536), central nervous system (CNS) tumor (n=1,324), or malignant lymphoma (n=417) between 1968 and 2003. Cases were identified from the Danish Cancer Registry. Two to five controls (n=9,129) for each case were selected randomly from the Danish childhood population and were matched to cases based on their sex and year of birth. For all study subjects, average magnetic-field exposure levels were calculated from overhead 50- to 400- kilovolt (kV) power lines based on their residential addresses from 9 months before birth until the diagnosis. The authors reported no statistically significant associations between all cancers combined and the three types of cancers separately and estimated exposures ≥0.4 microtesla (μT) (4 mG) compared to <0.1 μT (1 mG). The large number of cases and controls in the study, the inclusion of

residential history and exposure assessment throughout the children's entire lifetime, control for some potential confounders (including radon exposure, traffic-related air pollution, and socioeconomic status) and the reliance on reliable population-based cancer and population registries in Denmark are among the strengths of the study. Reliance on calculated magnetic-field levels for exposure assessment and lack of details on the accuracy of the input data to these calculations, including historical line loading and distance to residence, and the small number of cases in the highest exposure categories despite that large study size, are among the limitations of the paper.

In a separate analysis of the previous study population in the United Kingdom (Bunch et al., 2014), the investigators also examined the distance of high-voltage underground cables (mostly AC 275 kV and 400 kV) to case and control residences (Bunch et al., 2015). Over 52,000 cases of childhood cancer occurring between 1962 and 2008 in England and Wales, along with their matched controls, were included in these analyses. The authors reported no statistically significant associations or exposure-response trends between childhood leukemia and distance to power lines or calculated magnetic-field levels from the underground cables. The authors concluded that their results further detract from the hypothesis that exposure to magnetic fields explains the associations observed in earlier studies.

Based on additional analyses of the data, Bunch et al. (2016) reported that the association with distance to power lines observed in earlier years, which was more pronounced among older children (10 to 14 years of age), and for myeloid leukemia, were linked to calendar year of birth or year of cancer diagnosis, rather than the age of the power lines. The authors noted this finding implies that whatever factor or factors might have resulted in the apparent risk increase in the earlier years of the study are less likely to be linked to the newly built or existing power lines and more likely to be related to a yet to be identified characteristic of the population (or chance variation) in those years. Analyses by regions of the country did not suggest any clear pattern. The authors concluded that their findings, overall, do not provide support for the etiologic role of magnetic fields in the reported associations. Furthermore, Swanson and Bunch (2018) reanalyzed the data in Bunch et al. (2014) by using finer distance categories with cut-points at every 50-meter distance from the power lines in various periods from 1962 to 2008. The authors reported that no overall associations between distance categories and childhood leukemia were

observed for the period including 1980 and later, and that associations for periods prior to 1980 showed no monotonic or consistent pattern with distance. Thus, Swanson and Bunch concluded that their finding "weakens the evidence that any elevated risks are related to magnetic fields" (Swanson and Bunch, 2018, p. N30).

Crespi et al. (2016) reported the results of a large, record-based, case-control study of childhood leukemia (n=5,788) and CNS tumors (n= 3,308) diagnosed between 1986 and 2008 and residential proximity to high-voltage overhead power lines (60 kV to 500 kV) in California. Cases were identified from the California Cancer Registry. Controls were selected from the California Birth Registry and matched to cases based on their age and sex; birth records were also obtained for cases. For all subjects, distance of the address at birth to the nearest power line was estimated using geographic information systems, aerial imaging from Google Earth, and site visits for a subset of subjects. Additional details on methods are presented in Kheifets et al. (2015). Crespi et al. (2016) reported no consistent overall associations between risk of leukemia or CNS tumor and residential distance to power lines with voltage of ≥200 kV. A statistically non-significant increase was reported for childhood leukemia among subjects with addresses closer than 50 meters to power lines at ≥200 kV. Analyses that also included lower voltage lines revealed no associations with either leukemia or CNS tumors.

Kheifets et al. (2017a) and Amoon et al. (2018a) conducted additional analyses using the same California study population as Crespi et al. (2016). Kheifets et al. (2017a) reported on childhood leukemia and calculated magnetic fields from California power lines. The authors calculated magnetic-field levels at birth address using geographic information systems, aerial imagery, historical information on load and phasing, and site visits; additional details on the magnetic-field calculations are presented in a separate publication (Vergara et al., 2015). In the main analyses by Kheifets et al. (2017a), which included all cases of leukemia and primary controls with geocode accuracy, the authors used unconditional logistic regression models that controlled for age, sex, race/ethnicity, and socioeconomic status. Overall, the authors reported no consistent pattern of association; they reported a slight, statistically non-significant, negative association in the intermediate exposure categories (1 to 2 mG and 2 to 4 mG) compared to the lowest exposure category (<1 mG), and a small, statistically non-significant, positive association in the highest exposure category (≥4 mG) (OR 1.5, 95% CI 0.7-3.2). The authors reported

similar results in subgroup and sensitivity analyses and commented that all estimates had wide CIs. The authors concluded that their study "does not in itself provide clear evidence for risk associated with greater exposure to magnetic fields from power lines, but could be viewed as consistent with previous findings of increased risk" (Kheifets et al., 2017a, p. 1117). Thomas (2018) commented that while the Kheifets et al. (2017a) study had low potential for selection bias due to its record-based methods, the study may be subject to exposure misclassification resulting in bias towards the null because the exposure assessment considered residential proximity only to high-voltage power lines and other sources, including distribution lines, were ignored.

Amoon et al. (2018a) assessed the potential impact of residential mobility of the study subjects (i.e., moving residences between birth and diagnosis) on the associations reported in Crespi et al. (2016). The authors reported that while children that moved tended to be older, lived in housing other than a single-family home, had younger mothers and fewer siblings, and were of lower socioeconomic status, changing residences was not associated with either calculated fields or proximity to ≥200-kV power lines. Thus, the authors concluded that "[m]obility appears to be an unlikely explanation for the associations observed between power lines [*sic*] exposure and childhood leukemia" in the California study (Amoon et al., 2018a, p. 459).

Epidemiologists from Italy published two papers that describe the methods (Magnani et al., 2014) and results (Salvan et al., 2015) of a case-control study of childhood leukemia and residential exposure to 50-Hz magnetic fields. The study included a total of 412 leukemia cases less than 10 years of age diagnosed between 1998 and 2001 and 587 controls matched to cases based on sex, date of birth, and geographic location. The authors assessed exposure to residential ELF magnetic fields by extended measurements (24 to 48 hours) in the children's bedroom. The authors used conditional logistic regression to calculate RR and adjust for potentially confounding variables. In their analyses, the researchers evaluated various exposure metrics (e.g., measures of central tendency or peak-exposure measures; continuous or categorical exposures based on measurements during nighttime, weekend, or entire measurement periods). The authors also assessed the potential role of residential mobility of the subjects in the observed associations. None of the analyses reported consistent exposure-response patterns. The main limitations of the study include the potential for differential participation of controls and cases

and differences in participation rates of the study subjects based on their socioeconomic status, which in combination may result in a reference group that is not fully representative of the underlying population at risk. In turn, this may bias the calculated effect estimates. The low prevalence of subjects with higher estimated average exposures (particularly exposure >3 mG) results in a limitation of the statistical power of the study.

Amoon et al. (2018b) conducted a meta-analysis of epidemiologic studies of residential distance to power lines and childhood leukemia. The authors pooled the data from 11 studies with record-based assessments of residential distance from high-voltage power lines from 10 countries (Australia, Brazil, Denmark, France, Italy, Norway, Sweden, Switzerland, the United Kingdom, and the United States); this included the previously mentioned studies by Pedersen et al. (2014a), Sermage-Faure et al. (2013), Bunch et al. (2014), and Crespi et al. (2016). In total, 29,049 cases and 68,231 controls were included in the analyses. The authors reported no association when proximity to transmission lines with any voltage was investigated; the adjusted OR for residential distance <50 meters, as compared to distances ≥300 meters, was 1.01 [95% CI, 0.85-1.21]). For power lines with voltages of ≥200 kV, the adjusted OR (1.13) for distances <50 meters also was not statistically significant (95% CI, 0.92-1.93). The reported associations were slightly stronger for leukemia case diagnoses before 5 years of age and in study periods prior to 1980. Adjustment for various potential confounders (e.g., socioeconomic status, dwelling type, residential mobility) had little effect on the estimated the associations.

Kheifets et al. (2017b) conducted a comparative analysis of epidemiologic studies of childhood leukemia that investigated the association between childhood leukemia and ionizing radiation (i.e., radon or gamma radiation) or non-ionizing radiation (i.e., ELF EMF), or both, in an attempt to evaluate to what extent bias, confounding, and other methodological issues might be responsible for the reported associations. The authors reported that while they found some indication of bias, they found little evidence that confounding has a substantial influence on results.

A small cross-sectional study of 22 cases of childhood ALL and 100 controls from Iran reported a statistically significant association with “prenatal and postnatal childhood exposure to high voltage power lines” (Tabrizi and Bigdoli, 2015, p. 2347). The study, however, would carry very

little weight, if any, in an overall evaluation, because of its cross-sectional study design, very small sample size, and a complete lack of information on exposure assessment in the study. Tabrizi and Hossein (2015) published an apparent duplication of the study with near identical results and limitations. A letter to the editor that highlighted major flaws in the study pointed out the apparent duplication and suggested retraction of the second publication (Dechent and Driessen, 2016).

A Greek case-control study examined the association between parental occupational exposures and childhood acute leukemia at a major pediatric hospital in Athens (Kyriakopoulou et al., 2018). The study included 108 cases of ALL or acute myeloid leukemia under the age of 15, and 108 controls matched on age, gender, and ethnicity. The parents' job titles held during four different exposure periods (1 year before conception, during pregnancy, during breastfeeding, and from birth until diagnosis) were evaluated for exposure (exposed versus unexposed) to four agents (high contact level, chemicals, electromagnetic fields, and ionizing radiation) based on the authors' review of literature and their professional judgment. A total of six cases (5.6%) and six controls (5.6%) were categorized as exposed to electromagnetic[11] fields. No statistically significant associations were observed between electromagnetic-field exposure and childhood acute leukemia for any of the four periods of exposure. No associations were observed between childhood acute leukemia and the remaining exposure categories; however, the authors did observe that high birth weight and family history of cancer were associated with the development of leukemia.

Chinese researchers have published several meta-analyses in recent years. Su et al. (2016) conducted a meta-analysis of 11 case-control studies and 1 cohort study that investigated the association between parental exposure to ELF magnetic fields and risk of childhood leukemia in the offspring. Overall, neither maternal nor paternal occupational ELF magnetic-field exposure was associated with childhood leukemia risk.

The authors noted, however, that they observed an association when they combined small and low-quality studies, but not when they combined larger and high-quality studies. This indicates

that sampling and other biases may contribute to the reported associations in small, low-quality studies.

Zhang et al. (2016) combined epidemiologic studies of all types of cancer in their meta-analyses, including studies of adult and childhood cancers. Since various adult and childhood cancers have very different etiologies and biological mechanisms, it is scientifically not defensible to expect that any specific exposure will have an identical effect on the risk of all types of cancers, which renders the study's main results mostly meaningless, or difficult to interpret at best.

Assessment of residential exposure to EMF among children also continues to be of interest. While not linked to any specific health outcomes, EMF exposure assessment studies of children were recently reported from Australia, Italy, Spain, and Switzerland (Karipidis, 2015; Struchen et al., 2016; Liorni et al., 2016; Gallastegi et al., 2016). Magne et al. (2017) conducted a national survey of ELF magnetic-field exposure in France, including a representative sample of close to 1,000 children 0 to 14 years of age. The study was purely an exposure assessment study and the authors did not investigate any health outcome in relation to magnetic-field exposure. The authors conducted 24-hour measurements of ELF magnetic-field exposure for the included children and reported that 3.1% of the study participants had a 24-hour average exposure >0.4 µT (4 mG). Only 0.8% of the children, however, had 24-hour average exposure >0.4 µT (>4 mG) when exposure from alarm clocks was excluded. The authors also reported that none of the children with 24-hour average exposure >0.4 µT (>4 mG) lived within 125 meters of a 225-kV transmission line or within 200 meters of a 400-kV transmission line.

Assessment

In summary, while most of the recently published large and methodologically advanced studies showed no statistically significant associations between estimates of exposures from power lines (e.g., Bunch et al., 2014, Pedersen et al., 2014a, 2014b, Pedersen et al., 2015; Crespi et al., 2016; Kheifets et al., 2017a), and the most recent pooled analyses indicated weaker and statistically non-significant associations (Amoon et al., 2018b), the association between childhood leukemia and magnetic fields observed in some earlier studies remains unexplained. Thus, the results of

[11] In this context, electromagnetic is used to refer to ELF magnetic fields.

recent studies do not change the classification of the epidemiologic data as limited. This is the assessment of the most recent weight-of-evidence review released in 2015 by SCENIHR,[12] which concluded that the epidemiologic studies on childhood leukemia and EMF exposure continued to "prevent a causal interpretation" (SCENIHR, 2015). A similar conclusion was reached in a recent assessment conducted by a research consortium funded by the European Union, which concluded that recent research results have not provided new evidence that would change the overall conclusion reached by IARC in 2002, and the current evidence is consistent with the *possibly carcinogenic* classification (Schüz et al., 2016).

Table 2. Relevant studies of childhood leukemia

Author	Year	Study Title
Amoon et al.	2018a	Residential mobility and childhood leukemia.
Amoon et al.	2018b	Proximity to overhead power lines and childhood leukaemia: an international pooled analysis.
Bunch et al.	2015	Magnetic fields and childhood cancer: an epidemiological investigation of the effects of high-voltage underground cables.
Bunch et al.	2016	Epidemiological study of power lines and childhood cancer in the UK: further analyses.
Chang et al.	2014	Validity of geographically modeled environmental exposure estimates.
Crespi et al.	2016	Childhood leukaemia and distance from power lines in California: a population-based case-control study.
Dechent and Driessen	2016	Re: Role of Electromagnetic Field Exposure in Childhood Acute Lymphoblastic Leukemia and No Impact of Urinary Alpha- Amylase - a Case Control Study in Tehran, Iran.
Gallastegi et al.	2016	Characterisation of exposure to non-ionising electromagnetic fields in the Spanish INMA birth cohort: study protocol.
Karipidis et al.	2015	Survey of residential power-frequency magnetic fields in Melbourne, Australia.
Kheifets et al.	2015	Epidemiologic study of residential proximity to transmission lines and childhood cancer in California: description of design, epidemiologic methods and study population.
Kheifets et al.	2017a	Residential magnetic fields exposure and childhood leukemia: a population-based case-control study in California.
Kheifets et al.	2017b	Comparative analyses of studies of childhood leukemia and magnetic fields, radon and gamma radiation.
Kyriakopoulou et al.	2018	Parental occupational exposures and risk of childhood acute leukemia.

[12] On July 8, 2015, SCENIHR was renamed the Scientific Committee on Health, Environment, and Emerging Risks (SCHEER). Since any publications by this body referenced in this report were published before the name was changed, all citations to their publications note SCENIHR rather than SCHEER.

Author	Year	Study Title
Liorni et al.	2016	Children's personal exposure measurements to extremely low frequency magnetic fields in Italy.
Magnani et al	2014	SETIL: Italian multicentric epidemiological case-control study on risk factors for childhood leukaemia, non hodgkin lymphoma and neuroblastoma: study population and prevalence of risk factors in Italy.
Magne et al.	2017	Exposure of children to extremely low frequency magnetic fields in France: Results of the EXPERS study.
Pedersen et al.	2014b	Distance to high-voltage power lines and risk of childhood leukemia – an analysis of confounding by and interaction with other potential risk factors.
Pedersen et al.	2015	Residential exposure to extremely low-frequency magnetic fields and risk of childhood leukemia, CNS tumour and lymphoma in Denmark.
Salvan et al.	2015	Childhood leukemia and 50 Hz magnetic fields: findings from the Italian SETIL case-control study.
Schüz et al.	2016	Extremely low-frequency magnetic fields and risk of childhood leukemia: A risk assessment by the ARIMMORA consortium.
Struchen et al.	2016	Analysis of personal and bedroom exposure to ELF-MFs in children in Italy and Switzerland.
Su et al.	2016	Associations of parental occupational exposure to extremely low-frequency magnetic fields with childhood leukemia risk.
Swanson and Bunch	2018	Reanalysis of risks of childhood leukaemia with distance from overhead power lines in the UK.
Tabrizi and Bidgoli	2015	Increased risk of childhood acute lymphoblastic leukemia (ALL) by prenatal and postnatal exposure to high voltage power lines: a case control study in Isfahan, Iran.
Tabrizi and Hosseini	2015	Role of Electromagnetic Field Exposure in Childhood Acute Lymphoblastic Leukemia and No Impact of Urinary Alpha- Amylase--a Case Control Study in Tehran, Iran.
Vergara et al.	2015	Case-control study of occupational exposure to electric shocks and magnetic fields and mortality from amyotrophic lateral sclerosis in the US, 1991-1999.
Zhang et al.	2016	Meta-analysis of extremely low frequency electromagnetic fields and cancer risk: a pooled analysis of epidemiologic studies.
Comment on Kheifets et al. (2017a)		
Thomas	2018	Re: Kheifets et al. (2017): Residential magnetic fields exposure and childhood leukemia: a population-based case-control study in California.

Childhood brain cancer

Compared to the research on magnetic fields and childhood leukemia, there have been fewer studies of childhood brain cancer. The data are less consistent and limited by even smaller numbers of exposed cases compared with studies of childhood leukemia. The WHO review recommended the following:

> As with childhood leukaemia [*sic*], a pooled analysis of childhood brain cancer studies should be very informative and is therefore recommended. A pooled analysis of this kind can inexpensively provide a greater and improved insight into the existing data, including the possibility of selection bias and, if the studies are sufficiently homogeneous, can offer the best estimate of risk (WHO 2007, p. 18).

Addressing these recommendations, researchers conducted both a meta-analysis (Mezei et al., 2008) and a pooled analysis (Kheifets et al., 2010b) of available studies. The meta-analysis by Mezei et al. (2008) reported no overall association but reported a statistically non-significant weak association with calculated or measured magnetic fields above 3 to 4 mG based on a sub-analysis of five studies. The pooled analysis by Kheifets et al. (2010b) included data from 10 studies of childhood brain cancer or CNS cancer with long-term measurements, calculated fields, or spot measurements of residential magnetic-field exposure published from 1979 to 2010. Similar to childhood leukemia, few cases of childhood brain cancer had estimated magnetic-field exposures greater than 3 to 4 mG. None of the analyses showed statistically significant increases, and while some categories of high exposure had an OR >1.0, the overall patterns were not consistent with an association and no dose-response trends were apparent. The authors concluded that their results provide little evidence for an association between magnetic fields and childhood brain tumors.

In addition, the childhood leukemia study by Bunch et al. (2014), described above, also included cases of brain cancer (n=11,968) and other solid tumors (n=21,985) among children in the United Kingdom between 1962 and 2008. No association was reported by the authors between brain cancer or other cancers and distance to transmission lines.

Recent studies (December 2014 through December 2018)

Several of the same epidemiologic studies discussed in the childhood leukemia section investigated the potential relationship between residential proximity to overhead and underground transmission lines and childhood brain cancer (Bunch et al., 2015; Bunch et al., 2016; Pedersen et al., 2015; Crespi et al., 2016). None of these studies reported any consistent association between distance to power lines and childhood brain cancer risk. In Bunch et al. (2015), the authors reported a statistical association for childhood brain cancer and an intermediate category of distance (20 to 49.9 meters), but noted that “such an elevation does not

form part of a coherent pattern with other studies" and thus they were "therefore inclined to regard this as a chance result" (Bunch et al., 2015, p. 695). The authors observed no statistically significant trend with distance. Follow-up analyses of the same population that investigated the occurrence of cancer separately among younger and older children (Bunch et al., 2016) identified no "persuasive or consistent pattern" for brain tumors. The epidemiologic studies of childhood cancer conducted in Denmark and California also included cases of CNS tumors (Pedersen et al., 2015; Crespi et al., 2016). Pedersen et al. (2015) reported a non-statistically significant association between CNS tumors and exposure, regardless of the period investigated. Crespi et al. (2016) reported no evidence of increased risk for CNS cancers (all types).

An Italian case-control study examined the risk of neuroblastoma among children 0 to 10 years of age in relation to maternal characteristics and perinatal exposures (Parodi et al., 2014). A total of 207 cases diagnosed between 1998 and 2001 and 1,475 controls were included in the study. Exposure to ELF magnetic fields was based on 48-hour measurements in the children's beds. The authors reported no associations either with measures of central tendency (arithmetic and geometric means) or with peak exposure measures (90th and 95th percentiles) of ELF magnetic fields. The authors did report statistically significant associations, however, with maternal exposure to hair dye and solvents.

Su et al. (2018) conducted a meta-analysis of epidemiologic studies that investigated the association between parental occupational exposure to ELF magnetic fields and childhood CNS tumors. The authors included a total of 22 case-control and cohort studies published as of December 2017 in their analysis. For CNS tumors, they reported no statistically significant associations for paternal exposure to ELF magnetic fields, but reported a weak statistically significant association (OR = 1.16, 95% CI 1.06, 1.26) for maternal exposure based on a subset of eight studies. The authors reported no association for neuroblastoma with either maternal or paternal exposure to ELF magnetic fields. Study quality, as assessed by the authors, had inconsistent effects on the associations reported for maternal and paternal exposure. The authors noted that, when based on higher quality studies, observed associations were stronger for maternal exposure but weaker for paternal exposure. It is noteworthy that associations were statistically significant only when studies using non-quantitative exposure methods (i.e., relying on job titles only) were pooled, but no associations were reported based on studies with a

quantitative exposure assessment. The authors also reported evidence for publication bias. While most of the included studies investigated cancer among children, some of the studies also included persons with tumors diagnosed up to 30 years of age, which is an additional limitation of the analysis.

Assessment

Overall, the weight-of-evidence does not support an association between magnetic-field exposures and the development of childhood brain cancer. The results of recent studies do not alter the classification of the epidemiologic data in this field as inadequate, as they did not report any consistent and convincing evidence for an association. This is in line with the 2015 SCENIHR review, which concluded that "no association has been observed for the risk of childhood brain tumours [*sic*]" (SCENIHR, 2015, p. 158).

Table 3. Relevant studies of childhood brain cancer

Authors	Year	Study
Bunch et al.	2015	Magnetic fields and childhood cancer: an epidemiological investigation of the effects of high-voltage underground cables.
Bunch et al.	2016	Epidemiological study of power lines and childhood cancer in the UK: further analyses.
Crespi et al.	2016	Childhood leukaemia and distance from power lines in California: a population-based case-control study.
Parodi et al.	2014	Risk of neuroblastoma, maternal characteristics and perinatal exposures: the SETIL study.
Pedersen et al.	2015	Residential exposure to extremely low-frequency magnetic fields and risk of childhood leukaemia, CNS tumour and lymphoma in Denmark.
Su et al.	2018	Association between parental occupational exposure to extremely low frequency magnetic fields and childhood nervous system tumors risk: A meta-analysis.

Adult health outcomes

Breast cancer

The WHO reviewed studies of breast cancer and residential magnetic-field exposure, electric blanket usage, and occupational magnetic-field exposure. These studies did not report consistent associations between magnetic-field exposure and breast cancer. The WHO concluded that the

recent body of research on this topic was less susceptible to bias compared with previous studies, and as a result, it provided strong support to previous consensus statements that magnetic-field exposure does not influence the risk of breast cancer. Specifically, the WHO stated:

> Subsequent to the IARC monograph a number of reports have been published concerning the risk of female breast cancer in adults associated with ELF magnetic field exposure. These studies are larger than the previous ones and less susceptible to bias, and overall are negative. With these studies, the evidence for an association between ELF exposure and the risk of breast cancer is weakened considerably and does not support an association of this kind (WHO 2007, p. 307).

The WHO recommended no specific research with respect to breast cancer and magnetic-field exposure. Research in this area provided additional support for the WHO's conclusion that there is no association between exposure to ELF EMF and breast cancer development. A large case-control study that investigated the risk of several types of adult cancers and residential distance to high-voltage power lines reported no association between female breast cancer and residential distance to power lines or estimated exposure to magnetic fields (Elliott et al., 2013). Several occupational epidemiologic studies of female and male breast cancers also provided no support for an association between ELF EMF exposure and breast cancer development (Sorahan, 2012; Li et al., 2013; Koeman et al., 2014)

Recent studies (December 2014 through December 2018)

Grundy et al. (2016) conducted a population-based case-control study of male breast cancer and occupational exposure to magnetic fields. The authors identified cases (n=115) from eight Canadian provinces through the provincial cancer registries between 1994 and 1998, and selected controls (n=570), matched on age and sex, from provincial health insurance plans or using random-digit dialing. The authors obtained information on demographic characteristics and occupational history through self-administered questionnaires. An expert review assessed occupational exposure to magnetic fields. Each occupation was assigned an average exposure value; these values were then grouped into three categories (<0.3 µT [<3 mG], 0.3 to <0.6 [3 to <6 mG], and ≥0.6 µT [≥6 mG]) using cut-points based on the distribution of residential exposures reported in a previous study (Green et al., 1999). The authors reported statistically non-significant risk increases with the highest average exposure ≥0.6 µT (≥6 mG) compared to

exposure <0.3 μT (<3 mG), and with having an exposed job (≥0.3 μT [≥3 mG]) for at least 30 years compared to never having an exposed job. The authors noted that the remaining results were "inconsistent" and thus the study provides "limited support" for the hypothesis that magnetic-field exposure increases the risk of breast cancer in men (Grundy et al., 2016, p. 586). Selection of a subset of the controls using random-digit dialing, and reliance on self-reported information for exposure assessment represent a limitation of the study.

As summarized in the section on childhood leukemia, Zhang et al. (2016) combined epidemiologic studies of all types of cancer in their meta-analysis, including studies of adult and childhood cancers. This renders their main conclusions mostly meaningless, or difficult to interpret at best. Based on a sub-analysis that included 23 epidemiologic studies, the authors reported no statistically significant associations for breast cancer.

Assessment

The conclusion that there is no association between ELF EMF and breast cancer, as also expressed by the WHO, continues to be valid. The most recent case-control study, which reported no statistically significant associations with male breast cancer, adds to the growing body of null evidence for a role for magnetic-field exposure in breast cancer development in either residential or occupational settings. The recent review by SCENIHR (2015) concluded that overall studies on "adult cancers show no consistent associations" (p. 158).

Table 4. Relevant studies of breast cancer

Authors	Year	Study
Grundy et al.	2016	Occupational exposure to magnetic fields and breast cancer among Canadian men.
Zhang et al.	2016	Meta-analysis of extremely low frequency electromagnetic fields and cancer risk: a pooled analysis of epidemiologic studies.

Adult brain cancer

Brain cancer was studied along with leukemia in many of the occupational studies of ELF EMF. The findings were inconsistent, and there was no pattern of stronger findings in studies with more advanced methods, although a small association could not be ruled out. The WHO classified the epidemiologic data on adult brain cancer as inadequate and recommended 1)

updating the existing cohorts of occupationally-exposed individuals in Europe, and 2) pooling the epidemiologic data on brain cancer and adult leukemia to confirm the absence of an association.

The WHO stated the following:

> In the case of adult brain cancer and leukaemia, the new studies published after the IARC monograph do not change the conclusion that the overall evidence for an association between ELF [EMF] and the risk of these disease remains inadequate (WHO 2007, p. 307).

Overall, the epidemiologic studies of ELF EMF and adult brain cancer that have been reviewed in our previous reports predominantly support no association with brain cancer in adults but remain limited due to the exposure assessment methods and insufficient data available on specific brain cancer subtypes.

Recent studies (December 2014 through December 2018)

Carlberg et al. (2017, 2018) published the results of two case-control epidemiologic studies of occupational exposure to ELF EMF and brain cancer. Both studies relied on data from previously published case-control studies in Sweden (Hardell et al., 2006, 2013; Carlberg et al., 2013, 2015). Carlberg et al. (2017) included 1,346 living glioma cases diagnosed between the periods of 1997 to 2003 and 2007 to 2009 and 3,485 controls, ascertained from the Swedish Population Registry, who were matched to cases on sex and 5-year age group. Occupational exposure to ELF EMF was assessed from self-reported questionnaires on lifetime occupational history and a previously developed JEM (Turner et al., 2014). Overall, the authors observed no association with cumulative exposure to ELF EMF. Statistically signification associations were reported for grade IV astrocytoma and cumulative and average exposure when restricted to exposure experienced during the more recent exposure periods (1 to 14 years prior to diagnosis). The authors reported no association, however, with more distant exposure periods (15 to 20+ years) and observed no associations for other tumor grades. The authors hypothesized that the observed association for grade IV astrocytoma in the recent exposure periods is the result of a potential effect on cancer promotion. Because deceased subjects were excluded from the

analyses, and the reported association was limited to tumors of the highest grade (with the highest mortality rate), there is a high likelihood that the reported pattern of results arose due to differential exclusion of rapidly fatal cases among patients with the highest-grade tumors.

Carlberg et al. (2018) included 1,592 meningioma cases and 3,485 controls. The investigators used a similar approach and methods as in the previous study (Carlberg et al., 2017). The authors reported no trend or association between meningioma development and any of the investigated metrics of occupational exposure to ELF EMF (i.e., average occupational exposure, highest exposed job, or cumulative exposure) regardless of the time windows investigated (i.e., exposure during 1 to 14 years prior to diagnosis, or exposure more than 15 years prior to diagnosis).

Turner et al. (2017) investigated the potential interaction between occupational exposure to ELF magnetic fields; various chemicals, including cadmium, chromium, iron, and nickel; solvents, benzo(a)pyrene, polycyclic aromatic hydrocarbons; and environmental tobacco smoke, on brain cancer development within the INTEROCC case-control study. The current study presented additional analyses to an earlier study that examined ELF magnetic fields and brain cancer (Turner et al., 2014), and included 1,939 glioma and 1,822 meningioma cases, along with 5,404 controls matched on sex and age. Occupational exposure to both ELF magnetic fields and the chemicals of interest were assessed using JEMs. While some of the sub-analyses in the earlier study (Turner et al., 2014) reported both positive and negative associations for brain cancer development, overall there was no association with lifetime cumulative or average exposure for either main type of brain cancer. In the Turner et al. (2017) follow-up analysis, the authors reported that there was “no clear evidence” for an interaction between occupational exposure to ELF magnetic fields and occupational exposure to any of the included chemicals for either glioma or meningioma (p. 802).

Assessment

Recent studies do not provide support for an association between exposure to magnetic fields and brain cancer development. As mentioned above, the most recent SCENIHR report states that, overall, studies on “adult cancers show no consistent associations” (SCENIHR, 2015, p. 158).

Table 5. Relevant studies of adult brain cancer

Authors	Year	Study
Carlberg et al.	2017	Case-control study on occupational exposure to extremely low-frequency electromagnetic fields and glioma risk.
Carlberg et al.	2018	Case-control study on occupational exposure to extremely low-frequency electromagnetic fields and the association with meningioma.
Turner et al.	2017	Occupational exposure to extremely low frequency magnetic fields and brain tumor risks in the INTEROCC study.

Adult leukemia and lymphoma

There is a vast literature on adult leukemia and ELF EMF, most of which is related to occupational exposure. Overall, the findings of these studies are inconsistent—some studies report a positive association between measures of ELF EMF and leukemia and other studies show no association. No pattern has been identified whereby studies of higher quality or design are more likely to produce positive or negative associations. The WHO subsequently classified the epidemiologic evidence for adult leukemia as inadequate. They recommended updating the existing European occupational cohorts and updating a meta-analysis on occupational magnetic-field exposure. Subsequently, Kheifets et al. (2008) provided an update to two meta-analyses they published in the 1990s. Their updated meta-analysis indicated that pooled risk estimates from more recent studies were lower than in past meta-analyses and that no consistent pattern was observed by leukemia subtypes. Thus, the combined results were not in support of a causal association between occupational EMF exposure and adult leukemia. Studies reviewed in the previous Exponent report did not change the WHO conclusion.

Recent studies (December 2014 through December 2018)

Talibov et al. (2015) conducted a study of acute myeloid leukemia and occupational exposure to ELF magnetic fields and electric shocks within the Nordic Occupational Cancer study population. The case-control study included 5,409 cases diagnosed between 1961 and 2005 in Finland, Iceland, Norway, and Sweden, and 27,045 controls matched on age, sex, and country. Lifetime occupational exposure to ELF magnetic fields and shocks were assessed with JEMs based on jobs reported on the censuses. Potential confounding variables, including work-related exposure to benzene and ionizing radiation, were adjusted for in the analyses. The authors

reported no associations between leukemia and exposure to ELF magnetic fields or electric shocks among either men or women, and the authors concluded that "the evidence base linking ELF-MF [magnetic fields] with AML [acute myeloid leukemia] risk remains weak" (Talibov et al., 2015, p. 1084).

Huss et al. (2018a) conducted a census-based retrospective cohort study examining exposure to ELF magnetic fields and death from several types of hematopoietic malignancies within the Swiss National Cohort. The authors included a total of 3.1 million economically active individuals between 30 and 65 years of age (for men) or 62 years of age (for women) who participated in the 1990 or 2000 census, or both, in Switzerland. Mortality from different malignant neoplasms of the lymphoid and hematopoietic tissue (i.e., various types of acute and chronic leukemias and lymphomas) was evaluated from 1990 to 2008. The authors included death due to lung cancer in the analyses as a "negative control outcome"—the authors hypothesized *a priori* that lung cancer was not associated with exposure to ELF magnetic fields (Huss et al., 2018a, p. 468). Occupational exposure to ELF magnetic fields was assessed based on the study subjects' job title as reported at the time of the census and a JEM developed for ELF magnetic fields. In addition, they assessed potential confounding by other occupational exposures, including solvents, pesticides, herbicides, metals, and electric shocks by applying corresponding JEMs to the study subjects' job titles and adjusting for the exposures in the main analyses.

None of the hematopoietic cancer types included in the main analyses was statistically associated with either exposure corresponding to a median intensity of 0.19 µT or a higher exposure of 0.52 µT in the fully-adjusted models. Adjustment for the other occupational exposures had a very small effect on the risk estimates. The authors reported statistically significant associations for myeloid leukemia among men who were ever highly exposed at the time of both censuses (n=6) and for acute myeloid leukemia among men who were ever highly exposed at the time of both censuses and additionally during their vocational training (n=5). As noted, both estimates were based on a very small number of cases. Lung cancer mortality, included as a negative control, showed statistically significant associations and a clear exposure-response pattern with exposure to ELF magnetic fields. This finding clearly indicates that confounding by smoking, which is a well-established cause of both lung cancer and leukemias/lymphomas, remains a major weakness

of the study, and may explain the association reported in some of the sub-analyses. The authors concluded that their analysis "provided no convincing evidence for an increased risk of death" from hematopoietic cancers in workers occupationally exposed to ELF magnetic fields (Huss et al., 2018a, p. 467).

In the same study, Huss et al. (2018a) also conducted a meta-analysis of 28 epidemiologic studies of occupational exposure to ELF magnetic fields and acute myeloid leukemia published until September 2017. The authors reported a weak overall association, with a summary RR of 1.21 (95% CI: 1.08, 1.37).

Assessment

Recent studies did not provide substantial evidence for an association between EMF and leukemia overall, leukemia sub-types, or lymphoma in adults. Thus, the previous conclusion that the evidence is inadequate for adult leukemia remains appropriate. While some scientific uncertainty remains on a potential relationship between adult lymphohematopoietic malignancies and magnetic-field exposure because of continued deficiencies in study methods, the current database of studies provides inadequate evidence for an association (EFHRAN, 2012; SCENIHR, 2015).

Table 6. Relevant studies of adult leukemia

Authors	Year	Study
Huss et al.	2018a	Occupational extremely low frequency magnetic fields (ELF-MF) exposure and hematolymphopoietic cancers - Swiss National Cohort analysis and updated meta-analysis.
Talibov et al.	2015	Occupational exposure to extremely low-frequency magnetic fields and electrical shocks and acute myeloid leukemia in four Nordic countries.

Reproductive and developmental effects

In 2002, two studies received considerable attention because of a reported association between peak magnetic-field exposure greater than approximately 16 mG and miscarriage: a prospective cohort study of women in early pregnancy (Li et al., 2002) and a nested case-control study of women who miscarried compared to their late-pregnancy counterparts (Lee et al., 2002). These two studies improved on the existing body of literature because average exposure also was

assessed using 24-hour personal magnetic-field measurements (earlier studies on miscarriage were limited because they used surrogate measures of exposure, including visual display terminal use, electric blanket use, or wire code data). The Li et al. (2002) study, however, was criticized by the National Radiological Protection Board *inter alia* because of the potential for selection bias, a low compliance rate, measurement of exposure after miscarriages, and apparent selection of exposure categories after inspection of the data (NRPB, 2002). The scientific panels that considered these two studies concluded that the possibility of this bias precludes making any conclusions about the effect of magnetic fields on miscarriage (NRPB, 2004; FPTRPC, 2005; WHO, 2007). The WHO concluded, "[t]here is some evidence for increased risk of miscarriage associated with measured maternal magnetic-field exposure, but this evidence is inadequate" and recommended further epidemiologic research (WHO, 2007, p. 254).

Following the publication of these two studies, a hypothesis was put forth that the observed association may be the result of behavioral differences between women with healthy pregnancies that went to term (i.e., less physically active) and women who miscarried (i.e., more physically active after miscarriage) (Savitz, 2002). It was proposed that physical activity is associated with an increased opportunity for peak magnetic-field exposure, and the nausea experienced in early, healthy pregnancies, and the cumbersomeness of late, healthy pregnancies, would reduce physical activity levels, thereby decreasing the opportunity for environmental exposure to peak magnetic fields while going about in the community. This hypothesis received empirical support from studies that reported consistent associations between activity (mobility during the day) and various metrics of peak magnetic-field exposure measurements (Mezei et al., 2006; Savitz et al., 2006; Lewis et al., 2015). These findings suggest that the association between maximum magnetic-field exposure and miscarriage was due to differing activity patterns of the cases and controls, not to a magnetic-field effect on embryonic development and viability.

Studies on ELF EMF exposure and reproductive or development effects published subsequent to the WHO 2007 report included ones focusing on miscarriage or stillbirth (Wang et al., 2013; Shamsi Mahmoudabadi et al., 2013; Auger et al., 2012) and birth outcomes (de Vocht et al., 2014; Mahram and Ghazavi, 2013). These additional publications provided little new insight on pregnancy and reproductive outcomes and did not change the classification of the data from earlier assessments as inadequate. These authors' recommendations for future studies included,

among others, the selection of appropriate study populations, the assessment and control for potential confounding by the mothers' physical activity, the careful characterization of exposure, and the analysis of various exposure metrics in the study.

Recent studies (December 2014 through December 2018)

Several epidemiologic studies investigated the potential association between ELF magnetic-field exposure and miscarriage (Li et al., 2017; Sadeghi et al., 2017) or birth outcomes (de Vocht et al., 2014; Eskelinen et al., 2016; Migault et al. 2018). Li et al. (2017) examined the association between magnetic-field exposure and miscarriage in a cohort of 913 pregnant women in California. Exposure was assessed using 24-hour personal magnetic-field measurements collected on a single day during pregnancy, and the 99th percentile value observed during the 24-hour measurement period was used as the exposure of interest by the authors. The authors reported an increased risk of miscarriage in women with higher magnetic-field exposure (i.e., the 99th percentile value during the 24-hour measurement of ≥2.5 mG) compared to women with lower magnetic-field exposure (<2.5 mG) when measurements were collected on a typical day (defined as a day reflecting participants' typical pattern of work and leisure activities during pregnancy). They reported no association, however, among those women whose magnetic-field exposure was measured on a non-typical day, and no trend was observed for miscarriage risk with increasing magnetic-field exposures >2.5 mG. The authors did not report the overall TWA for the 24-hours of exposure that could be compared to previous studies.

While personal exposure measurements are an improvement over some of the earlier studies, the collection of only one measurement over a single 24-hour period during pregnancy is a limitation of the Li et al. (2017) study, as day-to-day changes in exposure cannot be captured. No information was provided in the paper on the exact timing of the measurement (i.e., whether the measurement day preceded or followed the occurrence of miscarriage among cases); this is a substantial limitation as measurements taken following miscarriage in a substantial fraction of cases was a major criticism of the previous study by the same research team (Li et al., 2002). Li et al. (2017) also failed to measure mobility during the measurement day, a potential major source of confounding in the study (e.g., Savitz, 2002; Mezei et al., 2006; Savitz et al., 2006). Varying levels of mobility between women with healthy pregnancies and women who suffer a

miscarriage remain a viable alternative explanation for the findings in both the previous and the current studies.

Iranian scientists (Sadeghi et al., 2017) conducted a case-control analysis of preterm birth and residential distance to high-voltage overhead power lines. The researchers identified 135 cases of live spontaneous preterm birth in an Iranian hospital between 2013 and 2014 and compared their estimated exposure to 150 controls with term live births selected using randomized-digit dialing. Exposure was defined as maternal residence during pregnancy located within 600 meters of a high-voltage power line as determined by use of a geographical information system. The study reported no statistically significant association between preterm birth and the mothers' residential distance from power lines (<600 meters compared to ≥600 meters). The authors reported a similar absence of an association with birth defects, which were more common among children with preterm birth. One of the main limitations of the study is the reliance on maternal address within 600 meters to high-voltage power lines as a surrogate for exposure. No elevation of ELF EMF levels can be expected for distances from approximately 100 to 600 meters in that zone; thus, no valid conclusions can be drawn from the study with respect to exposure to EMF.

A study from the United Kingdom investigated birth outcomes in relation to residential proximity to power lines during pregnancy between 2004 and 2008 in Northwest England (de Vocht et al., 2014). The researchers examined hospital records of over 140,000 births; distance to the nearest power lines were determined using geographical information data. The authors reported moderately lower birth weight within 50 meters of power lines but observed no statistically significant increase in risk of any adverse clinical birth outcomes (e.g., preterm birth, small for gestational age, low birth weight). The limitations of the study include its reliance on distance for exposure assessment and the potential for confounding by socioeconomic status, which were discussed by the authors. A follow-up analysis of the same data suggested that the observed association in the de Vocht et al. (2014) study, at least partially, may be due to confounding and missing data (de Vocht and Lee, 2014).

Eskelinen et al. (2016) examined the potential association between residential exposure to magnetic fields and time to pregnancy, low birth weight, and being small for gestational age among 373 mothers who gave birth between 1990 and 1994 in Kuopio University Hospital,

Finland. The study population was selected from the birth registry of the hospital. To increase the prevalence of women with high exposure to EMF and the range of exposure levels in the study, the scientists selected mothers with residences in close proximity to nearby sources (e.g., transmission lines, underground cables, transformers). They assessed exposure to magnetic fields through spot measurements in the home and through a questionnaire that requested information on occupational and residential sources of EMF (e.g., electrical appliances and equipment). None of the exposure metrics used to assess EMF exposure in the study was statistically associated with measures of fetal growth or time to pregnancy. Consideration of various metrics, including residential measurements and availability of personal level information on potential confounders, were among the strengths of the study, while the relatively few subjects with higher estimated average exposures (>0.4 µT [>4 mG]) subjects limited the study's statistical precision, which was noted by de Vocht and Burstyn (2016).

Migault et al. (2018) studied the relationship between maternal cumulative exposure to ELF EMF and two pregnancy outcomes (moderate prematurity and being small for gestational age) within the Elfe study. The Elfe study is a prospective birth cohort that included 18,329 infants born at 33 weeks of gestation or more in France during 2011 and is designed to follow the children until 20 years of age. Cumulative exposure to both occupational and residential ELF EMF during pregnancy was assessed using the mothers' self-reported occupation and the INTEROCC JEM. The JEM also included exposure estimates for five non-professional categories, including housewife, student, and unemployed, that were used to estimate residential exposure. The authors observed no statistically significant association between maternal cumulative exposure and moderate prematurity or small for gestational age when they evaluated any of the exposure metrics (categorical, binary, or continuous). The authors noted that the ability to consider both occupational and residential exposures in their cumulative estimates is a strength of the study but suggested that the small sample size in the high exposure categories limited the study's power to detect a potential association.

Using data from the Danish National Birth Cohort, Sudan et al. (2017) conducted a follow-up study to a previously reported association between intrauterine exposure to magnetic fields and childhood asthma (Li et al., 2011). The researchers examined 92,675 children born to 91,661 mothers who were pregnant between 1996 and 2002 and assessed intrauterine exposure of the

children using distance from the residence of the mother during pregnancy to the nearest power line. They observed no association between magnetic-field exposure estimated by distance from power lines and asthma development, regardless of how the asthma diagnosis was defined. The authors noted, however, that the majority of mothers and children in the dataset had no residential exposure from power lines (i.e., lived in a home that was located outside a specified distance to the nearest power line), thus limiting the ability to make firm conclusions. In addition, potential errors in the estimation of distances to power lines, which were used in the calculations of magnetic-field levels, are a limitation of the study's exposure assessment (Chang et al., 2014).

Darbandi et al. (2017) reviewed some of the human and animal studies published between 1978 and June 2016 that assessed the effects of EMF on male reproductive functions. The authors noted that the studies "provided contradictory results that were highly dependent on the exposure parameters," including intensity and duration of exposure. The inconsistent findings summarized in this paper provide little new insight into this area of research.

Lewis et al. (2016) assessed the scientific literature on ELF EMF exposure and measures of infertility and adverse pregnancy outcomes published between 2002 and 2015. The authors reviewed the strengths and limitations of 13 published studies and concluded that design limitations in most studies may explain their inconsistent findings. The authors' recommendations for future studies included the selection of appropriate study populations, the assessment and control for potential confounding by the mothers' physical activity, the careful characterization of exposure to minimize measurement error, and the consideration of various exposure metrics within the study, among other recommendations.

Assessment

The recent epidemiologic studies evaluated do not provide substantial new evidence in support of an association between EMF and reproductive or developmental outcomes and thus the classification of the data as inadequate remains appropriate. Studies in this research area still suffer from limitations in study design, sample size, and exposure assessment method. The most recent review by SCENIHR concluded that "recent results do not show an effect of ELF MF [magnetic field] exposure on reproductive function in humans." (SCENIHR, 2015)

Table 7. Relevant studies of reproductive and developmental effects

Authors	Year	Study
Darbandi et al.	2017	The effects of exposure to low frequency electromagnetic fields on male fertility.
de Vocht et al.	2014	Maternal residential proximity to sources of extremely low frequency electromagnetic fields and adverse birth outcomes in a UK cohort.
de Vocht and Lee	2014	Residential proximity to electromagnetic field sources and birth weight: Minimizing residual confounding using multiple imputation and propensity score matching.
Eskelinen et al.	2016	Maternal exposure to extremely low frequency magnetic fields: Association with time to pregnancy and foetal growth.
Lewis et al.	2016	Exposure to Power-Frequency Magnetic Fields and the Risk of Infertility and Adverse Pregnancy Outcomes: Update on the Human Evidence and Recommendations for Future Study Designs.
Li et al.	2017	Exposure to magnetic field non-ionizing radiation and the risk of miscarriage: a prospective cohort study.
Migault et al.	2018	Maternal cumulative exposure to extremely low frequency electromagnetic fields and pregnancy outcomes in the Elfe cohort.
Sadeghi et al.	2017	Preterm birth among women living within 600 meters of high voltage overhead Power Lines: a case-control study.
Sudan et al.	2017	Re-examining the association between residential exposure to magnetic fields from power lines and childhood asthma in the Danish National Birth Cohort.
Comment on Eskelinen et al. (2016)		
de Vocht and Burstyn	2016	Comments on “Maternal exposure to extremely low frequency magnetic fields: Association with time to pregnancy and foetal growth.”

Neurodegenerative diseases

Research into the possible effect of magnetic fields on the development of neurodegenerative diseases began in 1995; the majority of research since then has focused on Alzheimer’s disease and a specific type of motor neuron disease called ALS, which is also known as Lou Gehrig’s disease. Early studies on ALS, which had no obvious biases and were well conducted, reported an association between ALS mortality and estimated occupational magnetic-field exposure. The scientific review panels, however, were hesitant to conclude that the associations provided strong support for a causal relationship. Rather, they felt that an alternative explanation (i.e., electric shocks received at work) may be the source of the observed association.

The majority of the studies reviewed by the WHO reported statistically significant associations

between occupational magnetic-field exposure and mortality from Alzheimer's disease and ALS, although the design and methods of these studies were relatively weak (e.g., disease status was based on death certificate data, exposure was based on incomplete occupational information from census data, and there was no control for confounding factors). Furthermore, there were no biological data to support an association between magnetic fields and neurodegenerative diseases. The WHO panel concluded that there are inadequate data in support of an association between magnetic fields and Alzheimer's disease or ALS, stating that, "[w]hen evaluated across all the studies, there is only very limited evidence of an association between estimated ELF exposure and [Alzheimer's] disease risk" (WHO 2007, p. 194). The panel recommended more research in this area using improved methods; in particular they recommended studies that enrolled incident Alzheimer's disease cases (rather than ascertaining cases from death certificates), as well as studies that estimated electrical shock history in ALS cases.

Following the research recommendations of the WHO, scientists conducted epidemiologic research that studied exposure to ELF EMF and development of neurodegenerative diseases. Overall, these studies did not provide consistent and convincing support for an association. Several meta-analyses of these studies reported weak to no evidence of an association between occupational exposure to ELF magnetic fields and neurodegenerative disease (Zhou et al., 2012; Vergara et al., 2013). The authors of these meta-analyses concluded that potential within-study biases, evidence of publication bias, and uncertainties in the various exposure assessments greatly limit the ability to infer an association, if any, between occupational exposure to magnetic fields and neurodegenerative disease.

Several studies have examined the potential role of electric shocks in occupational environments as a possible explanation for the weak and inconsistent association between ELF EMF and ALS. The studies that addressed the issue of electric shocks in the development of neurodegenerative and neurological diseases presented no convincing evidence for an association (Das et al., 2012; Grell et al., 2012; van der Mark et al., 2014; Vergara et al., 2015; Fischer et al., 2015).

Recent studies (December 2014 through December 2018)

Koeman et al. (2015) studied the relationship between various occupational exposures and non-vascular dementia-related mortality using data from the Netherlands Cohort Study, a longitudinal

follow-up study of approximately 120,000 men and women 55 to 69 years of age at enrollment. The study authors identified 798 male and 1,171 female cases in the cohort diagnosed between 1986 and 2003 and obtained their lifetime occupational history by questionnaire. Using various JEMs, they assessed occupational exposures to solvents, pesticides, metals, ELF magnetic fields, electric shocks, and diesel exhaust. The authors reported moderate, but statistically non-significant, associations for non-vascular dementia and the highest estimates of exposures to metals, chlorinated solvents, and ELF magnetic fields. The association for magnetic fields, however, showed no exposure-response relationship based on cumulative exposure, and the authors concluded that the association observed for ELF magnetic fields and solvents might be attributable to confounding by exposure to metals. They reported no association for non-vascular dementia and exposure to electric shock.

Koeman et al. (2017) conducted a nested case-control analysis within the Netherlands Cohort Study that again assessed various occupational exposures, including solvents, pesticides, metals, ELF magnetic fields and electric shocks, and ALS mortality. The analysis included ALS cases (n=136) and a random subset (n=4,344) of the cohort study population. The authors reported a statistically significant association among men with “ever high” exposure; however, this was based on a small number of cases (n=9) in the high exposure category. In addition, they reported a statistically significant association between the ALS mortality among men for those with the highest 30 percent or more of cumulative ELF magnetic-field exposure; this association was no longer statistically significant when adjusted for the effects of other occupational exposures, including insecticides. They reported no statistically significant associations for other occupational exposures investigated in the study and that due to the overall low number of exposed women, risk analyses for women were “largely uninformative.”

Additional case-control studies of EMF exposure and ALS were conducted by Fischer et al. (2015), Vinceti et al. (2017), and Yu et al. (2014). Fischer et al. (2015) conducted a population-based case-control study of occupational exposure to electric shocks and magnetic fields and ALS in Sweden. The base population of the study included all individuals born in Sweden between 1901 and 1970 who were enumerated during the 1990 Swedish census. All cases of ALS in the study population, newly diagnosed between 1990 and 2010, were identified by record linkages to the Swedish patient and death registries. Five controls, individually matched to cases

on birth year and sex, were selected for each case from the study base. A total of 4,709 cases and 23,335 controls were included in the study. Occupational exposures were assessed by linking census-based information on occupations to previously developed JEMs. Overall, neither magnetic fields nor electric shocks were related to ALS. Among subjects <65 years of age, the authors reported statistically significant associations between ALS and exposure to electric shocks; however, they also observed a statistically non-significant decrease among subjects 65 years of age and older. The study has a number of strengths, which include its large sample size, population-based design, inclusion of incidence cases, and the reliance on multiple JEMs (three for EMF and two for electric shocks) for the exposure assessment.

Vinceti et al. (2017) conducted a population-based, case-control study of magnetic fields from high-voltage power lines and ALS within two regions in Italy. The authors included 703 ALS cases, diagnosed between 1998 and 2011, and a sample of 2,737 randomly selected controls from the same provinces. Based on information on residential addresses of the cases and controls, and information on high-voltage power lines with voltages between 132 and 380 kV, the authors modeled magnetic-field exposure at the study subjects' residences. The authors reported no statistically significant associations between ALS and calculated magnetic-field levels, and they observed no exposure-response trend. The authors concluded that their findings "appear to confirm" that exposure to magnetic fields from power lines occurring in the general population is not associated with an increased risk of ALS (Vincente et al., 2017, p. 583).

Yu et al. (2014) reported the results of a small case-control study of ALS that included 66 cases and 66 controls, and examined various lifestyle, environmental, and work-related variables as potential risk factors. Their results on occupational exposure to EMF, however, cannot be interpreted because of a severe error of combining estimates of ionizing and non-ionizing radiation exposures in their analysis.

Researchers have conducted several meta-analyses that examined exposure to ELF magnetic fields and ALS. Capozzella et al. (2014) reported the results of a meta-analysis of occupational exposure to ELF magnetic fields and various chemical agents and ALS; the authors reported weak associations with ELF magnetic fields. Two meta-analyses were published in 2018—one reviewed studies of residential exposure (Röösli and Jalilian, 2018), and the other reviewed

studies of occupational exposures (Huss et al., 2018b). Röösli and Jalilian (2018) combined data from five epidemiologic studies that examined residential exposure to ELF magnetic fields from high-voltage power lines and ALS. The authors reported no statistically significant associations; the pooled RR for the most exposed populations (either <200 meters from high-voltage lines or >0.1 µT [>1 mG]) was 0.71 (95% CI, 0.48-1.07). Huss et al. (2018b) conducted a meta-analysis combining data from 20 studies of occupational exposure to ELF magnetic fields and ALS. Overall, the authors reported a weak association with borderline statistical significance for ALS and estimated ELF magnetic-field levels (summary RR 1.14; 95% CI, 1.00-1.30). The authors reported a somewhat stronger association in a subset of six studies with full occupational history compared to studies where occupation was available only at certain time points. The authors also reported substantial heterogeneity among studies, evidence for publication bias, and the lack of a clear exposure-response relationship between estimates of ELF magnetic fields and ALS.

Recent reviews of environmental, occupational, and intrinsic risk factors for ALS did not conclude that there is a clear relationship between ELF magnetic fields or electric shocks and ALS (Ingre et al., 2015; Bozzoni et al., 2016).

Pedersen et al. (2017) updated a prior cohort study (Johansen, 2000) of occupational exposure to ELF magnetic fields and CNS disease, including dementia, motor neuron disease, Parkinson's disease, multiple sclerosis, and epilepsy, among more than 32,000 male electric utility workers in Denmark. The authors identified cases within the occupational cohort of electric utility workers from the Danish National Patient Registry diagnosed from 1982 to 2010. They estimated exposure to ELF magnetic fields using a JEM and company records of job title and area of work and classified into three categories (<0.1 µT [<1 mG], 0.1-0.99 µT [1-9.9 mG], and ≥1.0 µT [≥10 mG]).

Both external and internal comparisons were conducted: 1) disease incidence within the cohort was compared to disease incidence in the general population of Danish men (external comparison); and 2) disease incidence within exposed workers was compared to disease incidence among unexposed workers to account for the potential healthy-worker effect (internal comparison). No consistent pattern of disease association was reported by the authors for any of the investigated outcomes. While the external comparison indicated statistically significant

associations for all types of dementia in the highest exposure category of ELF magnetic fields, the internal comparison, which is the more appropriate comparison, reported no such associations. The authors reported no statistically significant increases with exposure to ELF magnetic fields for motor neuron disease, Parkinson's disease, multiple sclerosis, or epilepsy in either external or internal comparisons.

Brouwer et al. (2015) identified cases of Parkinson's disease diagnosed between 1986 and 2003 in a cohort of approximately 120,000 adults (i.e., the Netherlands Cohort Study, noted above). They assessed occupational exposure to EMF and electric shocks among the study subjects using JEMs. Based on a total of 609 cases of Parkinson's disease, the authors concluded that their results generally do not provide strong support for an association with EMF or electric shocks. A hospital-based case-control study in the Netherlands included 444 cases of Parkinson's disease and 876 matched controls (van der Mark et al., 2014). The authors assessed occupational exposure to EMF and electric shocks using work history and a JEM, and they reported no associations between any of the exposure metrics and Parkinson's disease.

Checkoway et al. (2018) investigated the association between Parkinsonism[13] and occupational exposure to several agents, including endotoxin, solvents, shift work, and magnetic fields, among female Shanghai textile workers. The study included 537 retired cotton factory workers who were at least 50 years of age, and 286 age-matched controls who were retired cotton factory workers not exposed to cotton dust (which was used to define endotoxin exposure). Exposure to magnetic fields was assessed using a JEM. The authors reported no statistically significant associations between occupational exposure to magnetic fields and parkinsonism. They further did not observe statistically significant associations with endotoxin, shift work, or solvent exposure. Huss et al. (2015) conducted a meta-analysis of 11 studies of occupational exposure to ELF magnetic fields and Parkinson's disease. The authors observed no statistically significant association (summary RR 1.05, 95% CI 0.98-1.13) and they reported that overall, there was "no evidence that the exposure to ELF-MF [magnetic fields] increases the risk of Parkinson's disease" (Huss et al., 2015, p. 7348).

[13] Parkinsonism is defined by Checkoway et al. (2018) as "a syndrome whose cardinal clinical features are bradykinesia, rest tremor, muscle rigidity, and postural instability. Parkinson disease is the most common neurodegenerative form of parkinsonism" (p. 887).

Jalilian et al. (2018) conducted a meta-analysis of 20 epidemiologic studies of occupational exposure to ELF magnetic fields and Alzheimer's disease. The authors reported a moderate, but statistically significant overall association for Alzheimer's disease (summary RR 1.63; 95% CI, 1.35-1.96), with weaker associations in cohort studies than in case-control studies. The authors also reported substantial heterogeneity among studies, and evidence for publication bias. Pooling results from studies with "higher risk" of bias, as assessed by the authors, resulted in stronger associations, suggesting that bias in the studies likely contributed to the reported associations.

A review of environmental risk factors for dementia concluded that the evidence for an association with ELF EMF was "mixed" and "moderate" and that "this complicated exposure requires some unpicking" (Killin et al., 2016, pp. 5, 23).

Assessment

In recent years, multiple studies examined the potential relationship between EMF, electric shocks, and neurodegenerative diseases. Many of these studies represented methodological improvements (e.g., increased sample size, improved exposure assessment, inclusion of incidence cases) compared to previous studies. In spite of these methodological improvements, the overall evidence from these studies provided no consistent or convincing support for a causal association. The most recent SCENIHR report (2015) concluded that newly published studies "do not provide convincing evidence of an increased risk of neurodegenerative diseases, including dementia, related to ELF MF [magnetic field] exposure" (SCENIHR, 2015, p. 186). Results of recent studies have not materially changed this overall assessment.

Table 8. Relevant studies of neurodegenerative disease

Authors	Year	Study
Bozzoni et al.	2016	Amyotrophic lateral sclerosis and environmental factors.
Brouwer et al	2015	Occupational exposures and Parkinson's disease mortality in a prospective Dutch cohort.
Capozzella et al.	2014	Work related etiology of amyotrophic lateral sclerosis (ALS): a meta-analysis.
Checkoway et al.	2018	Occupational exposures and parkinsonism among Shanghai women textile workers.

Authors	Year	Study
Fischer et al.	2015	Occupational exposure to electric shocks and magnetic fields and amyotrophic lateral sclerosis in Sweden.
Huss et al.	2015	Extremely low frequency magnetic field exposure and parkinson's disease--a systematic review and meta-analysis of the data.
Huss et al.	2018b	Occupational exposure to extremely low-frequency magnetic fields and the risk of ALS: A systematic review and meta-analysis.
Ingre et al.	2015	Risk factors for amyotrophic lateral sclerosis.
Jalilian et al.	2018	Occupational exposure to extremely low frequency magnetic fields and risk of Alzheimer disease: A systematic review and meta-analysis.
Killin et al.	2016	Environmental risk factors for dementia: a systematic review.
Koeman et al.	2015	Occupational exposures and risk of dementia-related mortality in the prospective Netherlands Cohort Study.
Koeman et al.	2017	Occupational exposure and amyotrophic lateral sclerosis in a prospective cohort.
Pedersen et al.	2017	Occupational exposure to extremely low-frequency magnetic fields and risk for central nervous system disease: an update of a Danish cohort study among utility workers.
Röösli and Jalilian	2018	A meta-analysis on residential exposure to magnetic fields and the risk of amyotrophic lateral sclerosis.
Vinceti et al.	2017	Magnetic fields exposure from high-voltage power lines and risk of amyotrophic lateral sclerosis in two Italian populations.
Yu et al.	2014	Environmental risk factors and amyotrophic lateral sclerosis (ALS): a case-control study of ALS in Michigan.

Cardiovascular disease

A hypothesis asserts that magnetic-field exposure reduces heart rate variability, which in turn increases the risk for AMI. In a large cohort of utility workers, Savitz et al. (1999) reported an association with arrhythmia-related deaths and deaths due to AMI among workers with higher magnetic-field exposure. Previous and subsequent studies did not report a statistically significant increase in cardiovascular disease mortality or incidence related to occupational magnetic-field exposure (WHO, 2007).

The WHO concluded:

> Experimental studies of both short- and long-term exposure indicate that, while electric shock is an obvious health hazard, other hazardous cardiovascular effects associated with ELF fields are unlikely to occur at exposure levels commonly encountered environmentally or occupationally. Although various cardiovascular changes have been reported in the literature, the majority of effects are small and the results have not been consistent within and between studies. With one

> exception [Savitz et al., 1999], none of the studies of cardiovascular disease morbidity and mortality has shown an association with exposure. Whether a specific association exists between exposure and altered autonomic control of the heart remains speculative. Overall, the evidence does not support an association between ELF exposure and cardiovascular disease." (WHO, 2007, p. 220)

Recent studies (December 2014 through December 2018)

Elmas (2016) summarized some of the literature examining the effects of EMF exposure on the heart. The review included studies that assessed the relationship between long-term occupational exposure and heart rate, as well as several studies examining short-term exposure and various health impacts. The author concluded that "despite these studies, the effects of EMFs on the heart remain unclear" and that there is "not yet any consensus in these works about possible mechanisms by which effects of EMF exposure may occur" (Elmas, 2016, p. 80).

Assessment

The conclusion that there is no association between magnetic fields and cardiovascular diseases has not changed. No original research studies have been identified on EMF and cardiovascular disease since Exponent's previous report. Thus, earlier conclusions on the lack of an association between magnetic fields and cardiovascular disease remain relevant.

Table 9. Relevant studies of cardiovascular disease

Authors	Year	Study
Elmas	2016	Effects of electromagnetic field exposure on the heart: a systematic review.

In vivo studies related to carcinogenesis

In the field of ELF EMF research, a number of research laboratories have exposed rodents, including those with a particular genetic susceptibility to cancer, to high levels of magnetic fields over the course of the animals' lifetime and performed tissue evaluations to assess the incidence of tumors in many organs. These studies are known as chronic bioassays.

In some of these studies, magnetic-field exposure was administered alone (to test for the ability of magnetic fields to act as a complete carcinogen). Other studies exposed animals to magnetic fields at the same time that they were exposed to a known carcinogen to assess their cancer

promoting capability. A third type of study exposed animals to magnetic fields and examined biological processes of only indirect relevance to the development of cancer but are nonetheless of interest to scientists. These three types of studies were reviewed by the WHO.

Chronic bioassays

The WHO review described four large-scale, long-term studies of rodents exposed to magnetic fields over the course of their lifetime that did not report increases in any type of cancer (Mandeville et al., 1997; Yasui et al., 1997; Boorman et al., 1999a, 1999b; McCormick et al., 1999). No directly relevant animal model for childhood ALL existed at the time of the WHO review. Some animals, however, develop a type of lymphoma similar to childhood ALL and studies exposing these predisposed transgenic mice to ELF magnetic fields did not report an increased incidence of this lymphoma type (Harris et al., 1998; McCormick et al., 1998; Sommer and Lerchel, 2004). Following the release of the WHO review, Bernard et al. (2009) reported that magnetic-field exposure did not affect development of the most common form of childhood leukemia induced in a rat model by a chemical carcinogen.

Carcinogenic agents plus magnetic fields (combined)

Studies investigating whether exposure to magnetic fields can promote cancer or act as a co-carcinogen treated animals to magnetic fields in combination with known cancer-causing agents, such as ionizing radiation, ultraviolet radiation, or other chemicals. No effects were observed in these studies on chemically-induced pre-neoplastic liver lesions, leukemia or lymphoma, skin tumors, or brain tumors WHO, 2007, Tables 78-79). However, the WHO review did note that incidence of 7,12-dimethylbenz[a]anthracene (DMBA)-induced mammary tumors was increased with magnetic-field exposure in a series of experiments in Germany (Löscher et al., 1993, 1994, 1997; Mevissen et al., 1993a, 1993b, 1996a, 1996b, 1998; Baum et al., 1995; Löscher and Mevissen, 1995), suggesting that magnetic-field exposure increased the proliferation of mammary tumors initiated by this chemical carcinogen. These results were not replicated in a subsequent series of experiments in a laboratory in the United States (Anderson et al., 1999; Boorman et al., 1999a, 1999b), possibly due to differences in experimental protocol and the species strain. In Fedrowitz et al. (2004) and Fedrowitz and Löscher (2008), exposure enhanced mammary tumor development in one sub-strain (Fischer 344 rats), but not in another sub-strain that was obtained from the same breeder, which argues against a promotional effect of magnetic

fields.[14]

Magnetic-field effects on biological processes potentially relevant to cancer

Some studies reviewed by the WHO reported an increase in genotoxic effects among exposed animals (e.g., DNA strand breaks in the brains of mice [Lai and Singh, 2004]), although the results have not been replicated. More recent studies in which animals were exposed to higher levels of magnetic fields for longer exposure periods reported no increase in damage to DNA (Saha et al., 2014; Korr et al., 2014). Indicators of biological processes that might lead to DNA damage are being constantly investigated, but while short-term effects on indicators of oxidation in tissues show some effects at very high levels (100,000 mG), effects at lower (but still high) levels (1,000 mG) are inconsistent and longer exposures do not result in greater responses (Glinka et al., 2013; Hassan and Abdelkawai, 2014; Manikonda et al., 2014; Akdag et al., 2013).

In summary, the WHO concluded the following with respect to *in vivo* research related to cancer: "There is no evidence that ELF [EMF] exposure alone causes tumours [*sic*]. The evidence that ELF field exposure can enhance tumour [*sic*] development in combination with carcinogens is inadequate" (WHO, 2007, p. 322). Subsequent research, as reviewed below, has not provided any clear support for the idea that magnetic fields promote the development of tumors initiated by carcinogenic chemicals or that magnetic fields have any confirmed effect on oxidative processes that might damage DNA or other cellular components linked to cancer.

Recent in vivo studies of carcinogenesis (December 2014 through December 2018)

Cancer bioassays

As noted above, none of the past large-scale, long-term bioassays of magnetic-field exposures reported that lifetime exposure to magnetic fields initiate or promote tumor development in rodents. Several newer studies that examined the tumor incidence in animals exposed to magnetic fields compared to that of unexposed controls over short or long periods of time are reviewed below.

[14] The WHO concluded with respect to the German studies of mammary carcinogenesis, "Inconsistent results were obtained that may be due in whole or in part to differences in experimental protocols, such as the use of specific substrains" (WHO 2007, p. 321).

Qi et al. (2015) compared the development of tumors in mice that had been exposed to 50-Hz, 500-mG magnetic fields or control conditions for 12 hours per day beginning 1 week prenatally and continuing until 15.5 months after birth. The exposed mice had significantly reduced body weights compared to controls. Tumors were not increased in males, but chronic myeloid leukemias were significantly higher in exposed females compared to controls. Interpretation of these data is difficult because of the limited experimental detail provided and because the authors did not report data on overall survival or the expected background incidence of tumors in these mice. In addition, no details on how the mice were exposed to magnetic fields or controls for potential effects of important housing variables (noise vibration, light) were provided. The study also did not report whether the analyses of the data were performed by experimenters who were unaware of the exposure history of the mice.

The Ramazzini Institute in Italy measured the effects of 50-Hz magnetic fields (Experiment BT 1CEM) on the body weight, tumor incidence, and mortality of male and female rats exposed to 0 mG, 20 mG, 200 mG, 1,000 mG, 10,000 mG, or intermittent 1,000 mG magnetic fields (30 minutes on and 30 minutes off) for 19 hours per day from day 12 of gestation until death (Bua et al., 2018). Bua et al. (2018) reported no effect of magnetic-field exposure on the incidence of total tumors in any group exposed to magnetic fields or on food and water consumption, body weight, or survival. These results are not consistent with the Qi et al. (2015) study discussed above.

Bua et al (2018) reported a statistically significant 26.6% decrease in malignant tumors in male rats following lifelong exposure to a 1,000 mG magnetic field. Exposures of other groups of male or female rats to magnetic fields across a range from 200 mG to 10,000 mG did not affect the incidences of the specific types of malignancies reported, specifically mammary gland tumors, schwannomas of the heart, thyroid C-cell carcinomas, and hemolymphoreticular neoplasia (HLRN).

Bua et al. (2018) concluded that the study “provided no evidence of any carcinogenic effect related to the exposure of ELF EMF alone” (p. 274) This result is consistent with a previous report from this same laboratory (Soffritti, 2010) on Experiment BT 3CEM in which the incidence of benign or malignant mammary tumors or survival of female rats exposed to

10,000 mG magnetic fields for 19 hours per day beginning before birth and continuing for their remaining lifetime did not differ from unexposed controls. Contrary to good experimental practice, the control group in this study was the same as used in the other studies from this laboratory discussed below (Experiments BT2 CEM and BT3 CEM), and the 10,000 mG exposure group in the Bua et al. (2018) study is the same as in Experiment BT 3 CEM (Soffritti, 2010).

In Experiment BT 2 CEM, Soffritti et al. (2016a) reported that the incidences of benign and malignant tumors in male and female rats exposed to a 10,000 mG magnetic field over their lifetime were no different from those of control rats. Nor did they observe any differences between these groups with respect to C-cell tumors of the thyroid or HLRN.

These are only some of studies of EMF conducted by this laboratory and so their strengths and weaknesses will be discussed *in toto* in the next section.

Carcinogenic agents plus magnetic fields (combined)

The Ramazzini Institute reported two other studies in which rats were exposed to known carcinogenic agents combined with magnetic fields. Soffritti et al. (2016b) reported no effects of gamma radiation plus magnetic field treatment on the body weights or survival rates of male or female rats in Experiment BT3 CEM. The percent of animals with actual cancers of the mammary gland was slightly, but not significantly, greater in female rats exposed to radiation alone (7.6%) than radiation plus 200 mG magnetic fields (7.5%) but was significantly less than the percent of females with mammary tumors exposed to radiation plus 10,000 mG magnetic fields (16.1%). The incidence of mammary tumors in male rats exposed to radiation alone was no different from those exposed to radiation plus 200 mG magnetic fields or radiation plus 10,000 mG magnetic fields. The incidence of HLRN observed in the radiation group was not increased by the addition of 200 mG magnetic field but was increased by the addition of a10,000 mG magnetic field. The authors assessed the incidence of malignant schwannomas in the heart, but there was no statistical difference between male rats treated with radiation or radiation plus magnetic fields at either field level or between any groups of exposed or control female rats. This particular study is deficient because it did not include groups of rats exposed just to 200 mG or 10,000 mG magnetic fields without radiation.

Soffritti et al. (2016b) used the same exposure apparatus and general methods as in Experiment BT 2 CEM to examine the effects of oral exposure to 50 milligrams per liter (mg/L) of formaldehyde, a known carcinogen, in drinking water for two years in combination with 10,000 mG, 50-Hz magnetic-field exposure. Controls were either unexposed (the same control group as reported in Experiments BT 1CEM and BT 3CEM) or treated with formaldehyde in drinking water only.

None of the treatment groups differed with respect to body weight or survival. Exposure to either magnetic fields alone or formaldehyde alone did not increase the incidence of total benign or malignant tumors above that observed in the control group, but the authors did not disclose the distribution of tumors across the different tissues, including the mammary gland, to this total. The incidences of malignant tumors, including C-cell carcinomas of the thyroid and lymphatic tumors, in male rats exposed to both formaldehyde plus magnetic fields were significantly different than those seen with formaldehyde treatment alone. These results were confounded, however, by the substantially reduced water intake levels over the first year of the study in males receiving formaldehyde in the drinking water with or without magnetic-field exposure. No effects were seen in females, except for an increase in thyroid adenomas and carcinomas in groups exposed to formaldehyde alone.

The strengths of the studies reported from the Ramazzini Institute include the large numbers of rats in each group and exposures over the animals' lifespan. These strengths, however, are outweighed by gross limitations in the design of the experiments and data analyses. The rats do not appear to have been randomly allocated to exposure groups and no data were presented to confirm the absence of the potentially confounding effects of noise and vibration. Cage lighting within the exposure room was not uniform, and the authors did not describe taking any measures to control this confounder. More important, the statistical analysis incorrectly treated each rat as the unit of analysis; however, because the rats were exposed in groups, each cage should have been the unit of analysis (Festing and Altmann, 2002). For some tumor types, the authors based their conclusions on only a few animals. Additionally, the large number of statistical tests performed could be expected to lead to false positive results by chance alone, but the authors did not adjust the statistical criteria to correct for this.

An additional concern is that the incidence of mammary cancers in unexposed controls in the Soffritti et al. (2016b) study and the Soffritti et al. (2015) study differs by more than two-fold, as does the incidence of cancers in rats exposed to 0.1 Gray[15] of ionizing radiation. The large variation in the control incidence of mammary tumors across studies calls into question the biological relevance of the small differences in tumor incidences seen with and without different treatments within any single study.

Based on concerns about the ability of the Ramazzini scientists to properly distinguish between leukemias and lymphomas in certain tissues, the EPA has "decided not to rely on data from the RI [Ramazzini Institute] on lymphomas and leukemias in these IRIS [Integrated Risk Information System] assessments" (USEPA, 2017). Furthermore, scientists from EPA and the National Institute for Environmental Health Sciences have taken an unprecedented step to warn risk assessors about problems with cancer bioassays that have been conducted by the Ramazzini Institute, like those described above (Gift et al., 2013).

One other study investigated the therapeutic potential of high magnetic-field exposures in the treatment of tumors but it was conducted for a short duration only. Mahna et al. (2014), injected female mice with mouse mammary tumor cells, then exposed them to 150,000 mG, 50-Hz magnetic fields (10 minutes per day for 12 days). Other animal groups were exposed to magnetic fields and electrochemotherapy (a combination of chemotherapy with pulsed electric current applied to the skin to increase permeability of cancers cells to the drugs). A sham-exposed control group was included, but analyses were not conducted in a blinded manner. The authors reported that magnetic-field exposure alone or in combination with the other treatments reduced tumor volume. Although these studies suffer from various limitations, the results suggest that magnetic-field exposure may have therapeutic applications in the treatment of tumors. Field strengths, however, were relatively high, and it is possible that the observed responses were due to effects of an induced electric field, not the magnetic field per se.

[15] Gray is the unit in which the absorbed dose of ionizing radiation, e.g., x-rays, is measured.

Magnetic-field effects on biological processes potentially relevant to cancer

While the case could be made that almost any biochemical process might be related to cancer, historically, processes relating to damage to deoxyribonucleic acid (DNA) and chromosomes have been given most attention and weight (IARC, 1999).

Alcaraz et al. (2014) exposed male mice to 2,000 mG, 50-Hz magnetic fields for 7 to 28 days. The study included no sham-exposed controls. Mice exposed to 50 centi-Grays of X-rays, which are known for their ability to damage DNA, served as positive controls and the analyses were conducted blind. The authors reported an increase in micronuclei produced by double-strand breaks of chromosomes in bone marrow erythrocytes 24 hours after magnetic-field exposure. The increase was not duration-dependent, however, and was substantially lower than that induced by X-rays.

Wilson et al. (2015) examined the effect of exposure to 100 to 3,000 mG, 50-Hz magnetic fields for 2 or 15 hours on the gene mutation frequency in the sperm and blood cells of mice. Sham-exposed mice were included as negative controls; mice exposed to X-rays served as positive controls. Mutation frequencies in blood cells of magnetic-field exposed mice were similar to those of the negative controls at 12 weeks after exposure. Mutation frequencies in sperm cells were slightly, but significantly, increased among magnetic-field exposed mice, although not in a dose-related manner. In contrast, X-rays significantly increased the mutation frequency in both cell types.

In a follow-on study to the report by Wilson et al., the same research team using the same experimental system tested whether concomitant exposure to magnetic fields and X-rays had a greater effect than X-rays alone (Woodbine et al., 2015). Mouse embryos were exposed to 3,000 mG, 50-Hz magnetic fields for 3 hours before and up to 9 hours after X-ray treatment. Controls were X-irradiated- and sham-exposed to magnetic fields. Additional controls were unexposed, sham-exposed, exposed to X-rays only (with or without sham-exposure), or exposed only to magnetic-fields. X-rays significantly increased DNA double-strand breaks at 1 hour after exposure and the number of breaks decreased to control levels within 6 to 11 hours post-exposure as the cells detected and repaired the DNA breaks. Magnetic-field exposure did not increase the amount of DNA breaks produced by X-rays nor affect the repair of DNA damage

caused by X-rays. One weakness of these studies is that the number of maternal animals per group was relatively small (n=1 to 4 per group).

Two recent studies examined DNA damage in human subjects exposed to EMF. Tiwari et al. (2015) investigated DNA damage in peripheral blood lymphocytes among 293 subjects in a cross-sectional study.[16] The authors considered 142 subjects as "exposed to EMFs emitted from high-voltage (132-kV) substations for more than 2 years of occupational exposure" (Tiwari et al., 2015, p. 57). The authors provided no further details on how they determined exposure status. The exposed subjects were compared to 151 non-exposed individuals (controls) of similar socioeconomic status, but the authors did not indicate how they selected control subjects. The analyses did not consider nor control for the potential confounding effect of other occupational exposures, including chemicals. The authors assessed DNA damage using the alkaline Comet assay and coded examination of slides; they also assessed other parameters related to plasma epinephrine concentrations, lipid peroxidation, and nitric oxide expression levels. Although the Comet tail length exhibited a slightly larger range in the exposed group, there was no significant difference between the two groups in the degree of DNA damage observed. The levels of lipid peroxidation and nitric oxide, but not stress (as measured by epinephrine levels), increased in the substation group relative to the control group but, "[t]he oxidative stress markers showed no relationship with exposure variables as assessed from regression analysis" (Tiwari et al., 2015, p. 59).

Villarini et al. (2015) studied a group of 21 electric arc welders in a cross-sectional study**.** The authors used an alkaline Comet assay to assess DNA damage in the white blood cells of arc welders and controls. The occupational exposures of arc welders include various metal fumes, chemicals, and magnetic fields. The control group included non-exposed individuals (healthy blood donors) of similar age, residence, and smoking status. Exposed individuals wore personal dosimeters for a single work shift to measure magnetic fields, which averaged 78 mG. The study did not assess magnetic-field exposure (or other exposures such as to chemicals) in the non-exposed controls. Comet tail lengths were similar in both groups; however, the welders exhibited significantly lower tail intensity and tail moment values than did controls, suggesting

[16] In a cross-sectional study, the investigators determine the study subjects' exposure and outcome status at the same time, thus, these types of studies are not suitable to draw any conclusion on a potential causal association.

that they had a lower degree of DNA damage. The authors suggested that this unexpected finding may be related to the type of DNA damage that might occur with exposure to various metal fumes, including chromium and nickel; both may induce DNA-protein cross-links that would migrate to a lesser degree than non-cross-linked DNA in the assay. The absence of magnetic-field measurements of persons serving as controls precludes the drawing of any conclusions regarding the effects of EMF exposure on DNA damage.

Normal cellular processes produce reactive oxygen species, and while they are effectively managed by other cellular functions, when they are produced in great excess, they can be damaging to DNA and other cell components and may support some carcinogenic processes. Three studies investigated a variety of tissue indicators of oxidative stress. It is important, however, to not simply assume that substances that increase oxidative stress are harmful, and antioxidants, including some vitamins, are beneficial. For example, there are clinical trials and other studies which report that antioxidants may damage DNA (Fox et al., 2012), may not protect against cancer in humans (Goodman et al., 2011), and may increase cancer risk and tumor progression (Sayin et al., 2014).

Because most cancers elicit a response from the immune system, blood levels of certain chemokines (important to inducing immune system functions) are reported to increase when various types of cancer occur. Li et al. (2018) investigated the chemokine response of Balb/c mice (100 per group) exposed to 50-Hz magnetic fields at levels of 0 (sham controls), 1,000 mG, 5,000 mG, and 25,000 mG for <1, 1, 10, 30, or 90 days. The mice were not randomly allocated to these groups and were housed in groups of 10. The mice were, however, randomly selected for weighing on alternate days. At each time point, blood was drawn from four mice and the average value reported. The investigators analyzed the samples for nine different chemokines that affect the immune response by promoting pro-inflammatory functions and recruiting immune cells to sites of infection. The investigators reported that exposure to magnetic fields over 90 days did not affect the body weight of the mice. Nor did the level of magnetic-field exposure have a significant effect on the chemokine levels in blood measured by immunoassay, with two exceptions: MCP-1 and EOTAXIN-1. The change in these chemokines was confirmed by ELISA assay and the clearest increase in levels was at 5,000 mG; magnetic field exposure at

the higher level of 25,000 mG reduced the increase in these chemokines. The authors report that they did not see the expected dose-dependent rise in chemokines.

Given the large number of mice (n=900) exposed in total using an exposure system in which only 10 mice could be exposed at a time for 8 hours per day, data collection must have continued for many months; thus, variations in multiple environmental and experimental variables likely affected the results. The 10 exposed mice in each group should have been used as the experimental unit in the statistical analyses, not the individual animals, and the failure to do so overestimates the differences between exposure conditions. Despite the large number of animals used in this study, only a small number of mice were included in each group for the purposes of data analysis and the reported variability of the cytokine measurement suggests that the results may not be very reliable. Given the limitations in the design and analysis of the study and the lack of dose-response, it is not clear that the differences reported are attributable to magnetic-field exposure *per se*. Further, because chemokines are important in eliciting immune reactions, an increase in chemokine levels may be indicative of a protective effect rather than increased susceptibility to cancer.

Luo et al. (2016) investigated potential effects of magnetic-field exposure on a variety of physiologic measures related to cellular oxidative processes. This study was predicated upon the theory that prolonged, uncompensated, high levels of oxidative products might contribute to cancer and neurodegenerative disease. The WHO (2007) and SCENIHR (2015) previously reviewed similar studies. Luo et al. (2016) suggested that a decline in superoxide dismutase (SOD) and a rise in malondialdehyde (MDA) in blood and the brain cortex are indicative of oxidative stress in cells.

Luo et al. (2016) randomly assigned male ICR mice in groups of 12 to 50-Hz, 40,000 mG, 60,000 mG, 80,000 mG, 100,000 mG magnetic fields, or sham-exposure (control) conditions for 4 hours per day and assayed the blood and brain for SOD and MDA levels after 7, 14, and 21 days. The authors observed noticeable and statistically significant changes in these two indicators with exposures at or above 80,000 mG in the predicted directions. The design of the study and the effects reported are similar to those reported in a previous study from this laboratory (Duan et al., 2014).

In the Luo et al. (2016) study, other groups of mice exposed to 80,000 mG magnetic fields also were orally administered 60, 90, or 120 mg of an antioxidant (lotus seedpod procyanidins [LSPC]) for 15 days before magnetic-field exposure and daily thereafter with magnetic-field exposure for an additional 28 days. The highest LSPC dose reversed the changes in SOD activity and MDA levels in the blood and brain cortex compared to mice exposed to magnetic fields only; changes in other oxidative indicators, including catalase, glutathione peroxidase, glutathione reductase, and glutathione-S-transferase, were also reversed. A strength of the study is that the authors tested for effects of magnetic fields at multiple exposure levels and randomized the mice to the experimental groups, which minimizes systematic bias. Yet, while the study was reported in detail, the analysis of the data was not performed blind, the authors reported no controls on noise and vibration from the magnetic-field coils and power supply, and like Bua et al. (2018), the authors did not properly account for the multiple animals exposed in each cage in the statistical analyses.

Another study also reported that extremely high levels of magnetic fields affected oxidative stress marker levels in blood and tissue. Li et al. (2015)[17] randomly assigned eight male Wistar rats to each of the following groups: sham control and 50-Hz, 50,000 mG, 100,000 mG, or 200,000 mG magnetic fields for 10 weeks. At the conclusion of the experiment, the authors analyzed blood samples for indicators of liver damage (alanine aminotransferase [ALT] and aspartate aminotransferase [AST]) and oxidative stress indicators (SOD and MDA) in blood, liver, and spleen. In addition, immunoglobulin G, immunoglobulin A, and immunoglobulin M antibodies were measured in the blood as indicators of immune system function. The investigators report that magnetic-field exposure significantly increased ALT and AST levels in blood, which may reflect changes in liver function. The results also showed a dose-related decrease in SOD and an increase in MDA in blood, liver, and spleen, particularly at the 100,000 mG and 200,000 mG levels. All levels of magnetic-field exposure reportedly decreased antibody concentrations in blood. The design of this study was superior in a number of ways to those of the other studies reviewed above with respect to randomization. It is not clear, however, if the animals were exposed individually or in groups, the authors did not report if the analyses were performed in a blind fashion, and the exposure system that generated the extremely high

[17] This is not the same scientist as the lead author of Li et al. (2018).

levels of magnetic fields to which the mice were exposed likely would have produced considerable noise and vibration that was not controlled for.

Assessment

One animal bioassay reported increased chronic myeloid leukemia in female, but not in male, mice exposed to magnetic fields from prior to birth through 15.5 months of age—a finding that conflicts with those of the other large-scale rodent bioassays reviewed by the WHO in 2007. Three other animal bioassays of long-term magnetic-field exposure as a possible carcinogen were published between 2014 and 2018, and as in previous studies of similar design, they demonstrated that magnetic fields do not cause cancer even when the exposure is life-long. Despite these results, there are serious concerns about the methods utilized in two of these studies and in two additional studies from the Ramazzini Institute in which lifelong exposures of rats to magnetic fields were combined with exposures to known carcinogens—ionizing radiation and formaldehyde. Neither of these latter studies showed convincing evidence in light of the studies' limitations that exposure to magnetic field plus carcinogens increased the overall incidence of tumors in male or female rats above that produced by these carcinogens alone. In a third study, the authors reported that extraordinarily high magnetic-field exposure (150,000 mG) compared to ICNIRP or ICES guidelines for public or occupational exposure, either alone or in combination with chemical therapeutic agents, for 10 days decreased the volume of tumors initiated by injecting mice with mammary tumor cells.

Recent studies also investigated two potential mechanisms related to carcinogenesis: genotoxicity and oxidative stress. Two of three studies of magnetic fields on DNA or chromosomes in animals reported no effects and two studies on indicators of DNA damage in human subjects reported no relationship to magnetic fields. Three other animal studies reported that magnetic-field exposure increased indicators of oxidative stress in blood and other tissues. The clearest effects of magnetic fields were reported at magnetic-field levels between 80,000 mG and 200,000 mG. All these studies had methodological limitations and the relevance of animal studies at such high field levels to persons in communities with far lower exposures is uncertain. These studies do not change the WHO's conclusion that the overall evidence from *in vivo* studies does not support the role of EMF exposures in genotoxic effects.

Overall, the *in vivo* studies published since the last update do not alter the previous conclusion that there is inadequate evidence of carcinogenicity due to ELF EMF exposure, but there is growing evidence that single and double strand breaks in DNA do not occur as a result of magnetic-field exposure.

Table 10. Relevant *in vivo* studies related to carcinogenesis

Authors	Year	Study
Alcaraz et al.	2014	Effect of long-term 50 Hz magnetic field exposure on the micronucleated polychromatic erythrocytes of mice.
Bua et al.	2018	Results of lifespan exposure to continuous and intermittent extremely low frequency electromagnetic fields (ELFEMF) administered alone to Sprague Dawley rats
Li et al.	2015	Effect of long-term pulsed electromagnetic field exposure on hepatic and immunologic functions of rats
Li et al.	2018	Eotaxin-1 and MCP-1 serve as circulating indicators in response to power frequency electromagnetic field exposure in mice
Luo et al.	2016	Chemoprotective action of lotus seedpod procyanidins on oxidative stress in mice induced by extremely low-frequency electromagnetic field exposure
Mahna et al.	2014	The effect of ELF magnetic field on tumor growth after electrochemotherapy.
Qi et al.	2015	Effects of extremely low-frequency electromagnetic fields (ELF-EMF) exposure on B6C3F1 mice
Soffritti et al.	2015	Life-span carcinogenicity studies on Sprague-Dawley rats exposed to gamma-radiation: design of the project and report on the tumor occurrence after post-natal radiation exposure (6 weeks of age) delivered in a single acute exposure
Soffritti et al.	2016a	Life-span exposure to sinusoidal-50 Hz magnetic field and acute low-dose γ radiation induce carcinogenic effects in Sprague-Dawley rats
Soffritti et al.	2016b	Synergism between sinusoidal-50 Hz magnetic field and formaldehyde in triggering carcinogenic effects in male Sprague-Dawley Rats
Tiwari et al.	2015	Epinephrine, DNA integrity and oxidative stress in workers exposed to extremely low-frequency electromagnetic fields (ELF-EMFs) at 132 kV substations
Villarini et al.	2015	Primary DNA damage in welders occupational exposed to extremely-low-frequency magnetic fields (ELF-MF)
Wilson et al.	2015	The effects of extremely low frequency magnetic fields on mutation induction in mice.
Woodbine et al.	2015	The rate of X-ray-induced DNA double-strand break repair in the embryonic mouse brain is unaffected by exposure to 50 Hz magnetic fields

6 Reviews Published by Scientific Organizations

A number of national and international scientific organizations have published reports or scientific statements with regard to the possible health effects of ELF EMF since January 2006. Although none of these documents represents a cumulative weight-of-evidence review of the caliber of the WHO review published in June 2007, their conclusions are of relevance. In general, the conclusions of these reviews are consistent with the scientific consensus articulated in Section 5.

The following list indicates the scientific organization and a link to the online reports or statements.

- **The European Health Risk Assessment Network on Electromagnetic Fields Exposure**
    - http://efhran.polimi.it/docs/IMS-EFHRAN_09072010.pdf (EFHRAN, 2010 [*in vitro* and *in vivo* studies])
    - http://efhran.polimi.it/docs/D2_Finalversion_oct2012.pdf (EFHRAN, 2012 [human exposure])
- **The Health Council of Netherlands**
    - http://www.gezondheidsraad.nl/en/publications/bioinitiative-report-0 (HCN, 2008a)
    - http://www.gezondheidsraad.nl/en/publications/high-voltage-power-lines-0 (HCN, 2008b)
    - http://www.gezondheidsraad.nl/sites/default/files/200902.pdf (HCN, 2009a)
    - http://www.gezondheidsraad.nl/en/publications/advisory-letter-power-lines-and-alzheimer-s-disease (HCN, 2009b)
- **The Health Protection Agency (United Kingdom)**

- http://www.hpa.org.uk/Publications/Radiation/DocumentsOfTheHPA/RCE01PowerFrequencyElectromagneticFieldsRCE1/ (HPA, 2006)

- **The International Commission on Non-Ionizing Radiation Protection**
  - http://www.icnirp.de/documents/LFgdl.pdf (ICNIRP, 2010)

- **The Scientific Committee on Emerging and Newly Identified Health Risks (European Union)**
  - http://ec.europa.eu/health/ph_risk/committees/04_scenihr/docs/scenihr_o_007.pdf (SCENIHR, 2007)
  - http://ec.europa.eu/health/ph_risk/committees/04_scenihr/docs/scenihr_o_022.pdf (SCENIHR, 2009)
  - http://ec.europa.eu/health/scientific_committees/emerging/docs/scenihr_o_041.pdf (SCENIHR, 2015)

The Swedish Radiation Protection Authority

- http://www.who.int/peh-emf/publications/reports/SWEDENssi_rapp_2006.pdf (SSI, 2007)
- http://www.who.int/peh-emf/publications/reports/SWEDENssi_rapp_2007.pdf (SSI, 2008)

- **The Swedish Radiation Safety Authority**
  - http://www.stralsakerhetsmyndigheten.se/Publikationer/Rapport/Stralskydd/2013/201319/ (SSM, 2013)
  - https://www.stralsakerhetsmyndigheten.se/contentassets/08b2f497b3ad48cf9e29a1d0008e7d82/201416-recent-research-on-emf-and-health-risk-ninth-report-from-ssms-scientific-council-on-electromagnetic-fields-2014 (SSM, 2014)

- https://www.stralsakerhetsmyndigheten.se/contentassets/ee7b28e0fee04e80bcaf84c24663a004/201519-recent-research-on-emf-and-health-risk---tenth-report-from-ssms-scientific-council-on-electromagnetic-fields-2015 (SSM, 2015)

- https://www.stralsakerhetsmyndigheten.se/contentassets/98d67d9e3301450da4b8d2e0f6107313/201615-recent-research-on-emf-and-health-risk-eleventh-report-from-ssms-scientific-council-on-electromagnetic-fields-2016 (SSM, 2016)

- https://www.stralsakerhetsmyndigheten.se/contentassets/f34de8333acd4ac2b22a9b072d9b33f9/201809-recent-research-on-emf-and-health-risk (SSM, 2018)

7 Standards and Guidelines

Following a thorough review of the research, scientific agencies develop exposure standards to protect against known health effects. The major purpose of a weight-of-evidence review is to identify the lowest exposure level below which no health hazards have been found (i.e., a threshold). Exposure limits are then set well below the threshold level to account for any individual variability or sensitivities that may exist.

Several scientific organizations have published guidelines for exposure to ELF EMF based on acute health effects that can occur at very high field levels. The ICNIRP reviewed the epidemiologic and experimental evidence and concluded that there was insufficient evidence to warrant the development of standards or guidelines on the basis of hypothesized long-term adverse health effects such as cancer; rather, the guidelines put forth in their 2010 document set limits to protect against acute health effects (i.e., the stimulation of nerves and muscles) that occur at much higher field levels. The ICNIRP recommends a residential screening value of 2,000 mG and an occupational exposure screening value of 10,000 mG (ICNIRP, 2010). If exposure exceeds these screening values, then additional dosimetry evaluations are needed to determine whether basic restrictions on induced current densities are exceeded. For reference, in a national survey conducted by Zaffanella and Kalton (1998) for the National Institute for Environmental Health and Safety's EMF Research and Public Information Dissemination program, only about 1.6% of the general public in the United States experienced exposure to magnetic fields of at least 1,000 mG during a 24-hour period.

The ICES also recommends limiting magnetic-field exposures at high levels because of the risk of acute effects, although their guidelines are higher than ICNIRP's guidelines; the ICES recommends a residential exposure limit of 9,040 mG and an occupational exposure limit of 27,100 mG (ICES, 2002). Both guidelines incorporate large safety factors.

The ICNIRP and ICES guidelines provide guidance to national agencies and only become legally binding if a country adopts them into legislation. The WHO strongly recommends that countries

adopt the ICNIRP guidelines or use a scientifically sound framework for formulating any new guidelines (WHO, 2006).

There are no national or state standards in the United States limiting exposures to ELF EMF based on health effects. Two states, Florida and New York, have enacted standards to limit magnetic fields at the edge of the right-of-way from transmission lines (NYPSC, 1978, 1990; FDER, 1989; FDEP, 1996). The basis for these limits, however, was to maintain the status quo so that fields from new transmission lines would be no higher than those produced by existing transmission lines.

Rhode Island does not have an EMF standard for transmission lines but the Energy Facility Siting Board in Rhode Island has encouraged the use of practical and cost-effective designs to minimize magnetic-field levels along the edges of transmission line rights-of-way. This approach is consistent with recommendations of the WHO (2007) for addressing ELF EMF.

Table 11. Screening guidelines for EMF exposure

Organization	Exposure (60 Hz)	Magnetic field
ICNIRP	Occupational	10,000 mG
	General Public	2,000 mG
ICES	Occupational	27,100 mG
	General Public	9,040 mG

Sources: ICNIRP, 2010; ICES, 2002

8 Summary

A significant number of epidemiologic and *in vivo* studies have been published on ELF EMF and health since the WHO 2007 report was released. A suggested weak statistical association between high, average magnetic fields and childhood leukemia has not been appreciably strengthened or substantially diminished by subsequent research, although the most recent studies tend to show no overall associations. The previously reported association in some studies remains unexplained and unsupported by experimental studies. The recent *in vivo* experimental studies confirm the lack of experimental data supporting a leukemogenic or other cancer risk associated with magnetic-field exposure. Publications on other cancer and non-cancer outcomes provided no substantial new information to alter the previous conclusion that the evidence is inadequate to conclude that ELF EMF exposure is harmful at typical environmental levels.

In conclusion, when recent studies are considered in the context of previous research, they do not provide evidence to alter the conclusion that ELF EMF exposure at the levels we encounter in our everyday environment is not a cause of cancer or any other disease process.

9 References

Ahlbom A, Day N, Feychting M, Roman E, Skinner J, Dockerty J, Linet M, McBride M, Michaelis J, Olsen JH, Tynes T, Verkasalo PK. A pooled analysis of magnetic fields and childhood leukaemia. Br J Cancer 83: 692-698, 2000.

Akdag MZ, Dasdag S, Cakir DU, Yokus B, Kizil G, Kizil M. Do 100- and 500-muT ELF magnetic fields alter beta-amyloid protein, protein carbonyl and malondialdehyde in rat brains? Electromagn Biol Med 32: 363-372, 2013.

Alcaraz M, Olmos E, Alcaraz-Saura M, Achel DG, Castillo J. Effect of long-term 50 Hz magnetic field exposure on the micronucleated polychromatic erythrocytes of mice. Electromagn Biol Med 33: 51-47, 2014.

Amoon AT, Oksuzyan S, Crespi CM, Arah OA, Cockburn M, Vergara X, Kheifets L. Residential mobility and childhood leukemia. Environ Res 164: 459-466, 2018a.

Amoon AT, Crespi CM, Ahlbom A, Bhatnagar M, Bray I, Bunch KJ, Clavel J, Feychting M, Hemon D, Johansen C, Kreis C, Malagoli C, Marquant F, Pedersen C, Raaschou-Nielsen O, Röösli M, Spycher BD, Sudan M, Swanson J, Tittarelli A, Tuck DM, Tynes T, Vergara X, Vinceti M, Wunsch-Filho V, Kheifets L. Proximity to overhead power lines and childhood leukaemia: an international pooled analysis. Br J Cancer 119: 364-373, 2018b.

Anderson LE, Boorman GA, Morris JE, Sasser LB, Mann PC, Grumbein SL, Hailey JR, McNally A, Sills RC, Haseman JK. Effect of 13 week magnetic field exposures on DMBA-initiated mammary gland carcinomas in female Sprague-Dawley rats. Carcinogenesis 20: 1615-20, 1999.

Auger N, Park AL, Yacouba S, Goneau M, Zayed J Stillbirth and residential proximity to extremely low frequency power transmission lines: a retrospective cohort study. Occup Environ Med 69: 147-149, 2012.

Baum A, Mevissen M, Kamino K, Mohr U, Löscher W. A histopathological study on alterations in DMBA-induced mammary carcinogenesis in rats with 50 Hz, 100 muT magnetic field exposure. Carcinogenesis 16: 119-125, 1995.

Bonnet-Belfais M, Lambrozo J, Aurengo A. Comment: childhood leukaemia and power lines--the Geocap study: is proximity an appropriate MF exposure surrogate? Br J Cancer 109: 1382-1383, 2013.

Boorman GA, Anderson LE, Morris JE, Sasser LB, Mann PC, Grumbein SL, Hailey JR, McNally A, Sills RC, Haseman JK. Effect of 26 week magnetic field exposures in a DMBA initiation-promotion mammary gland model in Sprague-Dawley rats. Carcinogenesis 20: 899-904, 1999a.

Boorman GA, McCormick DL, Findlay JC, Hailey JR, Gauger JR, Johnson TR, Kovatch RM,

Sills RC, Haseman JK. Chronic toxicity/oncogenicity evaluation of 60 Hz (power frequency) magnetic fields in F344/N rats. Toxicol Pathol 27: 267-278, 1999b.

Bozzoni V, Pansarasa O, Diamanti L, Nosari G, Cereda C, Ceroni M. Amyotrophic lateral sclerosis and environmental factors. Funct Neurol 31: 7-19, 2016.

Brouwer M, Koeman T, van den Brandt PA, Kromhout H, Schouten LJ, Peters S, Huss A, Vermeulen R. Occupational exposures and Parkinson's disease mortality in a prospective Dutch cohort. Occup Environ Med 72: 448-455, 2015.

Bua L, Tibaldi E, Falcioni L, Lauriola M, De Angelis L, Gnudi F, Manservigi M, Manservisi F, Manzoli I, Menghetti I, Montella R, Panzacchi S, Sgargi D, Strollo V, Vornoli A, Mandrioli D, Belpoggi F. Results of lifespan exposure to continuous and intermittent extremely low frequency electromagnetic fields (ELFEMF) administered alone to Sprague Dawley rats. Environ Res 164: 271-279, 2018.

Bunch KJ, Keegan TJ, Swanson J, Vincent TJ, Murphy MF. Residential distance at birth from overhead high-voltage powerlines: childhood cancer risk in Britain 1962-2008. Br J Cancer 110: 1402-1408, 2014.

Bunch KJ, Swanson J, Vincent TJ, Murphy MF. Magnetic fields and childhood cancer: an epidemiological investigation of the effects of high-voltage underground cables. J Radiol Prot 35: 695-705, 2015.

Bunch KJ, Swanson J, Vincent TJ, Murphy MF. Epidemiological study of power lines and childhood cancer in the UK: further analyses. J Radiol Prot 36: 437-455, 2016.

Capozzella A, Sacco C, Chighine A, Loreti B, Scala B, Casale T, Sinibaldi F, Tomei G, Giubilati R, Tomei F, Rosati MV. Work related etiology of amyotrophic lateral sclerosis (ALS): a meta-analysis. Ann Ig 26: 456-472, 2014.

Carlberg M, Soderqvist F, Hansson Mild K, Hardell L. Meningioma patients diagnosed 2007-2009 and the association with use of mobile and cordless phones: a case-control study. Environ Health 12: 60, 2013.

Carlberg M, Koppel T, Ahonen M, Hardell L. Case-control study on occupational exposure to extremely low-frequency electromagnetic fields and glioma risk. Am J Ind Med 60: 494-503, 2017.

Carlberg M, Koppel T, Ahonen M, Hardell L. Case-Control Study on Occupational Exposure to Extremely Low-Frequency Electromagnetic Fields and the Association with Meningioma. Biomed Res Int 2018: 5912394, 2018.

Chang ET, Adami HO, Bailey WH, Boffetta P, Krieger RI, Moolgavkar SH, Mandel JS. Validity of geographically modeled environmental exposure estimates. Crit Rev Toxicol 44: 450-466, 2014.

Checkoway H, Ilango S, Li W, Ray RM, Tanner CM, Hu SC, Wang X, Nielsen S, Gao DL,

Thomas DB. Occupational exposures and parkinsonism among Shanghai women textile workers. Am J Ind Med 61: 886-892, 2018.

Clavel J, Sermage-Faure C, Demoury C, Rudant J, Goujon-Bellec S, Guyot-Goubin A, Deschamps F, Hemon D. Reply: comment on 'Childhood leukaemia close to high-voltage power lines--the Geocap study, 2002-2007'--is proximity an appropriate MF exposure surrogate? Br J Cancer 109: 1383-1384, 2013.

Crespi CM, Vergara XP, Hooper C, Oksuzyan S, Wu S, Cockburn M, Kheifets L. Childhood leukaemia and distance from power lines in California: a population-based case-control study. Br J Cancer 115: 122-128, 2016.

Darbandi M, Darbandi S, Agarwal A, Henkle R, Sadeghi MR. The Effects of Exposure to Low Frequency Electromagnetic Fields on Male Fertility. Altern Ther Health Med, 2017 [epub ahead of print].

Das K, Nag C, Ghosh M. Familial, environmental, and occupational risk factors in development of amyotrophic lateral sclerosis. N Am J Med Sci 4: 350-355, 2012.

de Vocht F, Hannam K, Baker P, Agius R. Maternal residential proximity to sources of extremely low frequency electromagnetic fields and adverse birth outcomes in a UK cohort. Bioelectromagnetics 35: 201-209, 2014.

de Vocht F and Lee B. Residential proximity to electromagnetic field sources and birth weight: Minimizing residual confounding using multiple imputation and propensity score matching. Environ Int 69: 51-57, 2014.

de Vocht F and Burstyn I. Comments on "Maternal exposure to extremely low frequency magnetic fields: Association with time to pregnancy and foetal growth". Environ Int 96: 190-191, 2016.

Dechent D and Driessen S. Re: Role of Electromagnetic Field Exposure in Childhood Acute Lymphoblastic Leukemia and No Impact of Urinary Alpha- Amylase - a Case Control Study in Tehran, Iran. Asian Pac J Cancer Prev 17: 877-878, 2016.

Draper G, Vincent T, Kroll ME, Swanson J. Childhood cancer in relation to distance from high voltage power lines in England and Wales: a case-control study. BMJ 330: 1290, 2005.

Duan W, Liu C, Wu H, Chen C, Zhang T, Gao P, Luo X, Yu Z, Zhou Z. Effects of exposure to extremely low frequency magnetic fields on spermatogenesis in adult rats. Bioelectromagnetics 35: 58-69, 2014.

Elliott P, Shaddick G, Douglass M, de Hoogh K, Briggs DJ, Toledano MB. Adult cancers near high-voltage overhead power lines. Epidemiology 24: 184-190, 2013.

Elmas O. Effects of electromagnetic field exposure on the heart: a systematic review. Toxicol Ind Health 32: 76-82, 2016.

Eskelinen T, Roivainen P, Makela P, Keinanen J, Kauhanen O, Saarikoski S, Juutilainen J. Maternal exposure to extremely low frequency magnetic fields: Association with time to pregnancy and foetal growth. Environ Int 94: 620-625, 2016.

European Health Risk Assessment Network on Electromagnetic Fields Exposure (EFHRAN). Report on the Analysis of Risks Associated to Exposure to EMF: *In Vitro* and *In Vivo* (Animals) Studies. Milan, Italy: EFHRAN, 2010.

European Health Risk Assessment Network on Electromagnetic Fields Exposure (EFHRAN). Risk Analysis of Human Exposure to Electromagnetic Fields (Revised). Report D2 of the EFHRAN Project. Milan, Italy: EFHRAN, 2012.

Federal-Provincial-Territorial Radiation Protection Committee (FPTRPC). Health Effects and Exposure Guidelines Related to Extremely Low Frequency Electric and Magnetic Fields - An Overview. Ottawa: Health Canada, 2005.

Fedrowitz M, Kamino K, Löscher W. Significant differences in the effects of magnetic field exposure on 7,12-dimethylbenz(a)anthracene-induced mammary carcinogenesis in two substrains of Sprague-Dawley rats. Cancer Res 64: 243-251, 2004.

Fedrowitz M and Loscher W. Exposure of Fischer 344 rats to a weak power frequency magnetic field facilitates mammary tumorigenesis in the DMBA model of breast cancer. Carcinogenesis 29: 186-193, 2008.

Festing MF and Altman DG. Guidelines for the design and statistical analysis of experiments using laboratory animals. ILAR J 43: 244-258, 2002.

Fischer H, Kheifets L, Huss A, Peters TL, Vermeulen R, Ye W, Fang F, Wiebert P, Vergara XP, Feychting M. Occupational Exposure to Electric Shocks and Magnetic Fields and Amyotrophic Lateral Sclerosis in Sweden. Epidemiology 26: 824-830, 2015.

Florida Department of Environmental Protection (FDEP). Electric and Magnetic Fields. Chapter 62-814. 1996.

Florida Department of Environmental Regulation (FDER). Electric and Magnetic Fields. Chapter 17-274. 1989.

Fox JT, Sakamuru S, Huang R, Teneva N, Simmons SO, Xia M, Tice RR, Austin CP, Myung K. High-throughput genotoxicity assay identifies antioxidants as inducers of DNA damage response and cell death. Proc Natl Acad Sci U S A 109: 5423-5428, 2012.

Gallastegi M, Guxens M, Jimenez-Zabala A, Calvente I, Fernandez M, Birks L, Struchen B, Vrijheid M, Estarlich M, Fernandez MF, Torrent M, Ballester F, Aurrekoetxea JJ, Ibarluzea J, Guerra D, Gonzalez J, Röösli M, Santa-Marina L. Characterisation of exposure to non-ionising electromagnetic fields in the Spanish INMA birth cohort: study protocol. BMC Public Health 16: 167, 2016.

Gauger JR. Household appliance magnetic field survey. IEEE Trans Power App Syst 104: 2436-

2444, 1985.

Gift JS, Caldwell JC, Jinot J, Evans MV, Cote I, Vandenberg JJ. Scientific considerations for evaluating cancer bioassays conducted by the Ramazzini Institute. Environ Health Perspect 121: 1253-1263, 2013.

Glinka M, Sieron A, Birkner E, Cieslar G. Influence of extremely low-frequency magnetic field on the activity of antioxidant enzymes during skin wound healing in rats. Electromagn Biol Med 32: 463-470, 2013.

Gobba F, Bravo G, Rossi P, Contessa GM, Scaringi M. Occupational and environmental exposure to extremely low frequency-magnetic fields: a personal monitoring study in a large group of workers in Italy. J Expo Sci Environ Epidemiol 21: 634-645, 2011

Goodman M, Bostick RM, Kucuk O, Jones DP. Clinical trials of antioxidants as cancer prevention agents: past, present, and future. Free Radic Biol Med 51: 1068-1084, 2011.

Gordis L. Epidemiology. Philadelphia: WB Saunders Company, 2000.

Green LM, Miller AB, Agnew DA, Greenberg ML, Li J, Villeneuve PJ, Tibshirani R. Childhood leukemia and personal monitoring of residential exposures to electric and magnetic fields in Ontario, Canada. Cancer Causes Control 10: 233-243, 1999.

Greenland S, Sheppard AR, Kaune WT, Poole C, Kelsh MA. A pooled analysis of magnetic fields, wire codes, and childhood leukemia. Childhood Leukemia-EMF Study Group. Epidemiology 11: 624-634, 2000.

Grell K, Meersohn A, Schüz J, Johansen C. Risk of neurological diseases among survivors of electric shocks: a nationwide cohort study, Denmark, 1968-2008. Bioelectromagnetics 33: 459-465, 2012.

Grundy A, Harris SA, Demers PA, Johnson KC, Agnew DA, Villeneuve PJ. Occupational exposure to magnetic fields and breast cancer among Canadian men. Cancer Med 5: 586-596, 2016.

Hardell L, Carlberg M, Mild KH. Case-control study of the association between the use of cellular and cordless telephones and malignant brain tumors diagnosed during 2000-2003. Environ Res 100: 232-241, 2006.

Harris AW, Basten A, Gebski V, Noonan D, Finnie J, Bath ML, Bangay MJ, Repacholi MH. A test of lymphoma induction by long-term exposure of E mu-Pim1 trangenic mice to 50 Hz magnetic fields. Radiat Res 149: 300-307, 1998.

Hassan NS and Abdelkawi SA. Assessing of plasma protein denaturation induced by exposure to cadmium, electromagnetic fields and their combined actions on rat. Electromagn Biol Med 33: 147-153, 2014.

Health Council of the Netherlands (HCN). BioInitiative Report. The Hague: Health Council of

the Netherlands, 2008a.

Health Council of the Netherlands (HCN). High-Voltage Power Lines. Publication Number: 2008/04E. The Hague: Health Council of the Netherlands, 2008b.

Health Council of the Netherlands (HCN). Electromagnetic Fields: Annual Update. Publication No. 2009/02. The Hague: Health Council of the Netherlands, 2009a.

Health Council of the Netherlands (HCN). Advisory letter - Power lines and Alzheimer's disease. The Hague: Health Council of the Netherlands, 2009b.

Health Protection Agency (HPA). Power frequency electromagnetic fields, melatonin and the risk of breast cancer: report of an independent advisory group on non-ionising radiation. Documents of the Health Protection Agency. Series B: Radiation, Chemical and Environmental Hazards. Oxfordshire: HPA, 2006.

Hill AB. The Environment and Disease: Association or Causation? Proc R Soc Med 58: 295-300, 1965.

Huss A, Koeman T, Kromhout H, Vermeulen R. Extremely Low Frequency Magnetic Field Exposure and Parkinson's Disease--A Systematic Review and Meta-Analysis of the Data. Int J Environ Res Public Health 12: 7348-56, 2015.

Huss A, Spoerri A, Egger M, Kromhout H, Vermeulen R. Occupational extremely low frequency magnetic fields (ELF-MF) exposure and hematolymphopoietic cancers - Swiss National Cohort analysis and updated meta-analysis. Environ Res 164: 467-474, 2018a.

Huss A, Peters S, Vermeulen R. Occupational exposure to extremely low-frequency magnetic fields and the risk of ALS: A systematic review and meta-analysis. Bioelectromagnetics 39: 156-163, 2018b.

Ingre C, Roos PM, Piehl F, Kamel F, Fang F. Risk factors for amyotrophic lateral sclerosis. Clin Epidemiol 7: 181-193, 2015.

International Agency for Research on Cancer (IARC). The Use of Short- and Medium-Term Tests for Carcinogens and Data on Genetic Effects in Carcinogenic Hazard Evaluation. Lyon, France: International Agency for Research on Cancer (IARC), 1999.

International Agency for Research on Cancer (IARC). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Volume 80: Static and Extremely Low-Frequency (ELF) Electric and Magnetic Fields. Lyon, France: IARC Press, 2002.

International Commission on Non-ionizing Radiation Protection (ICNIRP). Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz to 100 kHz). Health Phys 99: 818-836, 2010.

International Committee on Electromagnetic Safety (ICES). IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields 0 to 3 kHz. Piscataway, NJ: IEEE,

2002; Reaffirmed 2007.

Jalilian H, Teshnizi SH, Röösli M, Neghab M. Occupational exposure to extremely low frequency magnetic fields and risk of Alzheimer disease: A systematic review and meta-analysis. Neurotoxicology 69:242-252, 2018.

Johansen C. Exposure to electromagnetic fields and risk of central nervous system disease in utility workers. Epidemiology 11: 539-543, 2000.

Karipidis KK. Survey of residential power-frequency magnetic fields in Melbourne, Australia. Radiat Prot Dosimetry 163: 81-91, 2015.

Kheifets L, Monroe J, Vergara X, Mezei G, Afifi AA. Occupational electromagnetic fields and leukemia and brain cancer: an update to two meta-analyses. J Occup Environ Med 50: 677-688, 2008.

Kheifets L and Oksuzyan S. Exposure assessment and other challenges in non-ionizing radiation studies of childhood leukaemia. Radiat Prot Dosimetry 132: 139-147, 2008.

Kheifets L, Bowman JD, Checkoway H, Feychting M, Harrington JM, Kavet R, Marsh G, Mezei G, Renew DC, van Wijngaarden E. Future needs of occupational epidemiology of extremely low frequency electric and magnetic fields: review and recommendations. Occup Environ Med 66: 72-80, 2009.

Kheifets L, Ahlbom A, Crespi CM, Draper G, Hagihara J, Lowenthal RM, Mezei G, Oksuzyan S, Schüz J, Swanson J, Tittarelli A, Vinceti M, Wunsch Filho V. Pooled analysis of recent studies on magnetic fields and childhood leukaemia. Br J Cancer 103: 1128-1135, 2010a.

Kheifets L, Ahlbom A, Crespi CM, Feychting M, Johansen C, Monroe J, Murphy MF, Oksuzyan S, Preston-Martin S, Roman E, Saito T, Savitz D, Schüz J, Simpson J, Swanson J, Tynes T, Verkasalo P, Mezei G. A pooled analysis of extremely low-frequency magnetic fields and childhood brain tumors. Am J Epidemiol 172: 752-761, 2010b.

Kheifets L, Crespi CM, Hooper C, Oksuzyan S, Cockburn M, Ly T, Mezei G. Epidemiologic study of residential proximity to transmission lines and childhood cancer in California: description of design, epidemiologic methods and study population. J Expo Sci Environ Epidemiol 25: 45-52, 2015.

Kheifets L, Crespi CM, Hooper C, Cockburn M, Amoon AT, Vergara XP. Residential magnetic fields exposure and childhood leukemia: a population-based case-control study in California. Cancer Causes Control 28: 1117-1123, 2017a.

Kheifets L, Swanson J, Yuan Y, Kusters C, Vergara X. Comparative analyses of studies of childhood leukemia and magnetic fields, radon and gamma radiation. J Radiol Prot 37: 459-491, 2017b.

Killin LO, Starr JM, Shiue IJ, Russ TC. Environmental risk factors for dementia: a systematic review. BMC Geriatr 16: 175, 2016.

Koeman T, van den Brandt PA, Slottje P, Schouten LJ, Goldbohm RA, Kromhout H, Vermeulen R. Occupational extremely low-frequency magnetic field exposure and selected cancer outcomes in a prospective Dutch cohort. Cancer Causes Control 25: 203-214, 2014.

Koeman T, Schouten LJ, van den Brandt PA, Slottje P, Huss A, Peters S, Kromhout H, Vermeulen R. Occupational exposures and risk of dementia-related mortality in the prospective Netherlands Cohort Study. Am J Ind Med 58: 625-635, 2015.

Koeman T, Slottje P, Schouten LJ, Peters S, Huss A, Veldink JH, Kromhout H, van den Brandt PA, Vermeulen R. Occupational exposure and amyotrophic lateral sclerosis in a prospective cohort. Occup Environ Med 74: 578-585, 2017.

Korr H, Angstman NB, Born TB, Bosse K, Brauns B, Demmler M, Fueller K, Kantor O, Kever BM, Rahimyar N, Salimi S, Silny J, Schmitz C. No evidence of persisting unrepaired nuclear DNA single strand breaks in distinct types of cells in the brain, kidney, and liver of adult mice after continuous eight-week 50 Hz magnetic field exposure with flux density of 0.1 mT or 1.0 mT. PLoS One 9: e109774, 2014.

Kyriakopoulou A, Meimeti E, Moisoglou I, Psarrou A, Provatopoulou X, Dounias G. Parental Occupational Exposures and Risk of Childhood Acute Leukemia. Mater Sociomed 30: 209-214, 2018.

Lai H and Singh NP. Magnetic-field induced DNA strand breaks in brain cells of the rat. Environ Health Perspect 113: 687-694, 2004.

Lee GM, Neutra RR, Hristova L, Yost M, Hiatt RA. A nested case-control study of residential and personal magnetic field measures and miscarriages. Epidemiology 13: 21-31, 2002.

Lewis RC, Evenson KR, Savitz DA, Meeker JD. Temporal variability of daily personal magnetic field exposure metrics in pregnant women. J Expo Sci Environ Epidemiol 25: 58-64, 2015.

Lewis RC, Hauser R, Maynard AD, Neitzel RL, Wang L, Kavet R, Meeker JD. Exposure to Power-Frequency Magnetic Fields and the Risk of Infertility and Adverse Pregnancy Outcomes: Update on the Human Evidence and Recommendations for Future Study Designs. J Toxicol Environ Health B Crit Rev 19: 29-45, 2016.

Li DK, Odouli R, Wi S, Janevic T, Golditch I, Bracken TD, Senior R, Rankin R, Iriye R. A population-based prospective cohort study of personal exposure to magnetic fields during pregnancy and the risk of miscarriage. Epidemiology 13: 9-20, 2002.

Li DK, Chen H, Odouli R. Maternal Exposure to Magnetic Fields During Pregnancy in Relation to the Risk of Asthma in Offspring. Arch Pediatr Adolesc Med 165: 945-950, 2011.

Li W, Ray RM, Thomas DB, Yost M, Davis S, Breslow N, Gao DL, Fitzgibbons ED, Camp JE, Wong E, Wernli KJ, Checkoway H. Occupational exposure to magnetic fields and breast cancer among women textile workers in Shanghai, China. Am J Epidemiol 178: 1038-1045, 2013.

Li L, Xiong DF, Liu JW, Li ZX, Zeng GC, Li HL. A cross-sectional study on oxidative stress in

workers exposed to extremely low frequency electromagnetic fields. Int J Radiat Biol 91: 420-425, 2015.

Li DK, Chen H, Ferber JR, Odouli R, Quesenberry C. Exposure to Magnetic Field Non-Ionizing Radiation and the Risk of Miscarriage: A Prospective Cohort Study. Sci Rep 7: 17541, 2017.

Li H, Lin L, Li L, Zhou L, Hao S, Zhang Y, Ding Z. Eotaxin1 and MCP1 serve as circulating indicators in response to power frequency electromagnetic field exposure in mice. Mol Med Rep 18: 2832-2840, 2018.

Linet MS, Wacholder S, Zahm SH. Interpreting epidemiologic research: Lessons from studies of childhood cancer. Pediatrics 112: 218-232, 2003.

Liorni I, Parazzini M, Fiocchi S, Douglas M, Capstick M, Kuster N, Ravazzani P. Computational assessment of pregnant woman models exposed to uniform ELF-magnetic fields: Compliance with the European current exposure regulations for the general public and occupational exposures at 50 Hz. Radiat Prot Dosimetry 172: 382-392, 2016.

Löscher W, Wahnschaffe U, Mevissen M, Lerchl A, Stamm A. Effects of weak alternating magnetic fields on nocturnal melatonin production and mammary carcinogenesis in rats. Oncology 51: 288-295, 1994.

Löscher W, Mevissen M, Lehmacher W, Stamm A. Tumor promotion in a breast cancer model by exposure to a weak alternating magnetic field. Cancer Lett 71: 75-81, 1993.

Löscher W and Mevissen M. Linear relationship between flux density and tumor co-promoting effect of prolonged magnetic field exposure in a breast cancer model. Cancer Lett 96: 175-180, 1995.

Löscher W, Mevissen M, Haussler B. Seasonal influence on 7,12-dimethylbenz[a]anthracene-induced mammary carcinogenesis in Spague-Dawley rats under controlled laboratory conditions. Pharmacol Toxicol 81: 265-270, 1997.

Luo X, Chen M, Duan Y, Duan W, Zhang H, He Y, Yin C, Sun G, Sun X. Chemoprotective action of lotus seedpod procyanidins on oxidative stress in mice induced by extremely low-frequency electromagnetic field exposure. Biomed Pharmacother 82: 640-648, 2016.

Magnani A, Balbo P, Facchini E, Occhetta E, Marino P. Lack of interference of electromagnetic navigation bronchoscopy to implanted cardioverter-defibrillator: in-vivo study. Europace 16: 1767-1771, 2014.

Magne I, Souques M, Bureau I, Duburcq A, Remy E, Lambrozo J. Exposure of children to extremely low frequency magnetic fields in France: Results of the EXPERS study. J Expo Sci Environ Epidemiol 27: 505-512, 2017.

Mahna A, Firoozabadi SM, Shankayi Z. The effect of ELF magnetic field on tumor growth after electrochemotherapy. J Membr Biol 247: 9-15, 2014.

Mahram M and Ghazavi M. The effect of extremely low frequency electromagnetic fields on pregnancy and fetal growth, and development. Arch Iran Med 16: 221-224, 2013.

Mandeville R, Franco E, Sidrac-Ghall S, Paris-Nadon L, Rocheleau N, Mercier G, Desy M, Gaboury L. Evaluation of the potential carcinogenicity of 60 Hz linear sinusoidal continuous-wave magnetic fields in Fisher F344 rats. FAESB Journal 11: 1127-1136, 1997.

Manikonda PK, Rajendra P, Devendranath D, Gunasekaran B, Channakeshava, Aradhya SR, Sashidhar RB, Subramanyam C. Extremely low frequency magnetic fields induce oxidative stress in rat brain. Gen Physiol Biophys 33: 81-90, 2014.

McCormick DL, Ryan B, Findlay JC, Gauger JR, Johnson TR, Morrissey R, Boorman GA. Exposure to 60 Hz magnetic fields and risk of lymphoma in PIM transgenic and TSG-*p53* (*p53* knockout) mice. Carcinogenesis 19: 1649-1653, 1998.

McCormick DL, Boorman GA, Findlay JC, Hailey JR, Johnson TR, Gauger JR, Pletcher JM, Sills RC, Haseman JK. Chronic toxicity/oncogenicity evaluation of 60 Hz (power frequency) magnetic fields in B6C3F1 mice. Toxicol Pathol 27: 279-285, 1999.

Mevissen M, Stamm A, Buntenkotter S, Zwingleberg R, Wahnschaffe U, Löscher W. Effects of magnetic fields on mmmary tumor development induced by 7,12-dimethylbenz(a)anthracene in rats. Bioelectromagnetics 14: 131-143, 1993a.

Mevissen M, Stamm A, Buntenkotter S, Zwingleberg R, Wahnschaffe U, Löscher W. Effects of AC Magnetic Field on DMBA-induced Mammary Carcinogenesis in Sprague-Dawley Rats. In Electricity and Magnetism in Biology and Medicine, edited by M. Blank. San Francisco, CA: San Francisco Press, 1993b.

Mezei G, Bracken TD, Senior R, Kavet R. Analyses of magnetic-field peak-exposure summary measures. J Expo Sci Environ Epidemiol 16: 477-485, 2006.

Mezei G, Gadallah M, Kheifets L. Residential magnetic field exposure and childhood brain cancer: a meta-analysis. Epidemiology 19: 424-430, 2008.

Migault L, Piel C, Carles C, Delva F, Lacourt A, Cardis E, Zaros C, de Seze R, Baldi I, Bouvier G. Maternal cumulative exposure to extremely low frequency electromagnetic fields and pregnancy outcomes in the Elfe cohort. Environ Int 112: 165-173, 2018.

National Institute of Environmental Health Sciences (NIEHS). EMF Questions & Answsers (NIH Publication 02-4493). Research Triangle Park, NC: NIEHS, 2002.

National Radiological Protection Board (NRPB). Review of the Scientific Evidence for Limiting Exposure to Electromagnetic Fields (0-300 GHz), Volume 15, No. 3. Chilton, UK: National Radiological Protection Board (NRPB), 2004.

National Radiological Protection Board (NRPB). Magnetic fields and miscarriage. Radiol Prot Bull No 1 (The eBulliten), June 2002.

National Toxicology Program (NTP). 2015. "Descriptions of NTP Study Types." U.S. Department of Health and Human Services. https://ntp.niehs.nih.gov/testing/types/index.html.

New York Public Service Commission (NYPSC). Opinion No. 78-13. Opinion and Order Determining Health and Safety Issues, Imposing Operating Conditions, and Authorizing, in Case 26529, Operation Pursuant to those Conditions, 1978.

New York Public Service Commission (NYPSC). Statement of Interim Policy on Magnetic Fields of Major Transmission Facilities. Cases 26529 and 26559 Proceeding on Motion of the Commission, 1990.

Parodi S, Merlo DF, Ranucci A, Miligi L, Benvenuti A, Rondelli R, Magnani C, Haupt R. Risk of neuroblastoma, maternal characteristics and perinatal exposures: the SETIL study. Cancer Epidemiol 38: 686-694, 2014.

Pedersen C, Raaschou-Nielsen O, Rod NH, Frei P, Poulsen AH, Johansen C, Schüz J. Distance from residence to power line and risk of childhood leukemia: a population-based case-control study in Denmark. Cancer Causes Control 25: 171-177, 2014a.

Pedersen C, Brauner EV, Rod NH, Albieri V, Andersen CE, Ulbak K, Hertel O, Johansen C, Schüz J, Raaschou-Nielsen O. Distance to high-voltage power lines and risk of childhood leukemia - an analysis of confounding by and interaction with other potential risk factors. PLoS One 9: e107096, 2014b.

Pedersen C, Johansen C, Schüz J, Olsen JH, Raaschou-Nielsen O. Residential exposure to extremely low-frequency magnetic fields and risk of childhood leukaemia, CNS tumour and lymphoma in Denmark. Br J Cancer 113: 1370-1374, 2015.

Pedersen C, Poulsen AH, Rod NH, Frei P, Hansen J, Grell K, Raaschou-Nielsen O, Schüz J, Johansen C. Occupational exposure to extremely low-frequency magnetic fields and risk for central nervous system disease: an update of a Danish cohort study among utility workers. Int Arch Occup Environ Health 90: 619-628, 2017.

Qi G, Zuo X, Zhou L, Aoki E, Okamula A, Watanebe M, Wang H, Wu Q, Lu H, Tuncel H, Watanabe H, Zeng S, Shimamoto F. Effects of extremely low-frequency electromagnetic fields (ELF-EMF) exposure on B6C3F1 mice. Environ Health Prev Med 20: 287-293, 2015.

Ries L, Smith MA, Gurney JG, Linet M, Tamra T, Young JL, Bunin GR, eds. Cancer Incidence and Survival among Children and Adolescents: United States SEER Program 1975-1995 (NIH Publication No. 99-4649). Bethesda, MD: National Cancer Institute, 1999.

Röösli M and Jalilian H. A meta-analysis on residential exposure to magnetic fields and the risk of amyotrophic lateral sclerosis. Rev Environ Health 33: 295-299, 2018.

Rothman KJ and Greenland S. Modern Epidemiology. Philadelphia: Lippencott-Raven Publishers, 1998.

Sadeghi T, Ahmadi A, Javadian M, Gholamian SA, Delavar MA, Esmailzadeh S, Ahmadi B,

Hadighi MSH. Preterm birth among women living within 600 meters of high voltage overhead Power Lines: a case-control study. Rom J Intern Med 55: 145-150, 2017.

Saha S, Woodbine L, Haines J, Coster M, Ricket N, Barazzuol L, Ainsbury E, Sienkiewicz Z, Jeggo P. Increased apoptosis and DNA double-strand breaks in the embryonic mouse brain in response to very low-dose X-rays but not 50 Hz magnetic fields. J R Soc Interface 11: 20140783, 2014.

Salvan A, Ranucci A, Lagorio S, Magnani C. Childhood leukemia and 50 Hz magnetic fields: findings from the Italian SETIL case-control study. Int J Environ Res Public Health 12: 2184-2204, 2015.

Savitz DA, Liao D, Sastre A, Kleckner RC, Kavet R. Magnetic field exposure and cardiovascular disease mortality among electric utility workers. Am J Epidemiol 149: 135-142, 1999.

Savitz DA. Magnetic fields and miscarriage. Epidemiology 13: 1-4, 2002.

Savitz DA, Herring AH, Mezei G, Evenson KR, Terry JW, Jr., Kavet R. Physical activity and magnetic field exposure in pregnancy. Epidemiology 17: 222-225, 2006.

Sayin VI, Ibrahim MX, Larsson E, Nilsson JA, Lindahl P, Bergo MO. Antioxidants accelerate lung cancer progression in mice. Sci Transl Med 6: 221ra15, 2014.

Schüz J, Dasenbrock C, Ravazzani P, Röösli M, Schar P, Bounds PL, Erdmann F, Borkhardt A, Cobaleda C, Fedrowitz M, Hamnerius Y, Sanchez-Garcia I, Seger R, Schmiegelow K, Ziegelberger G, Capstick M, Manser M, Muller M, Schmid CD, Schurmann D, Struchen B, Kuster N. Extremely low-frequency magnetic fields and risk of childhood leukemia: A risk assessment by the ARIMMORA consortium. Bioelectromagnetics 37:183-189, 2016.

Scientific Committee of Emerging and Newly Identified Health Risks (SCENIHR) for the Directorate-General for Health & Consumers of the European Commission. Possible Effects of Electromagnetic Fields (EMF) on Human Health. Brussels, Belgium: European Commission, 2007.

Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR). Health Effects of Exposure to EMF. Brussels, Belgium: European Commission, 2009.

Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR). Opinion on Potential Health Effects of Exposure to Electromagnetic Fields (EMF). Brussels, Belgium: European Commission, 2015.

Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR). Memorandum on the use of the scientific literature for human risk assessment purposes – weighing of evidence and expression of uncertainty. Brussels, Belgium: European Commission, 2012.

Sermage-Faure C, Demoury C, Rudant J, Goujon-Bellec S, Guyot-Goubin A, Deschamps F, Hemon D, Clavel J. Childhood leukaemia close to high-voltage power lines--the Geocap study,

2002-2007. Br J Cancer 108: 1899-1906, 2013.

Shamsi Mahmoudabadi F, Ziaei S, Firoozabadi M, Kazemnejad A. Exposure to Extremely Low Frequency Electromagnetic Fields during Pregnancy and the Risk of Spontaneous Abortion: A Case-Control Study. J Res Health Sci 13: 131-134, 2013.

Soffritti M, Belpoggi F, Lauriola M, Tibaldi E, Manser M, Accurso D, Chiozzotto D, Giuliani L. Mega-experiments on the carcinogenicity of Extremely Low Frequency Magnetic Fields (ELFMF) on Sprague-Dawley rats exposed from fetal life until spontaneous death: plant of the project and early results on mammary carcinogenesis. In Non-Thermal Effects and Mechanisms of Interaction between Electromagnetic Fields and Living Matter-An ICEMS Monograph (Eur J Oncol - Library Vol 5), edited by L. Giuliani and M. Soffritti. Bologna, Italy: National Institute for the Study and Control of Cancer and Environmental Diseases "Bernardino Ramazzini," 2010.

Soffritti M, Tibaldi E, Bua L, Padovani M, Falcioni L, Lauriola M, Manservigi M, Manservisi F, Belpoggi F. Life-span carcinogenicity studies on Sprague-Dawley rats exposed to gamma-radiation: design of the project and report on the tumor occurrence after post-natal radiation exposure (6 weeks of age) delivered in a single acute exposure. Am J Ind Med 58: 46-60, 2015.

Soffritti M, Tibaldi E, Padovani M, Hoel DG, Giuliani L, Bua L, Lauriola M, Falcioni L, Manservigi M, Manservisi F, Panzacchi S, Belpoggi F. Life-span exposure to sinusoidal-50 Hz magnetic field and acute low-dose gamma radiation induce carcinogenic effects in Sprague-Dawley rats. Int J Radiat Biol 92: 202-14, 2016a.

Soffritti M, Tibaldi E, Padovani M, Hoel DG, Giuliani L, Bua L, Lauriola M, Falcioni L, Manservigi M, Manservisi F, Belpoggi F. Synergism between sinusoidal-50 Hz magnetic field and formaldehyde in triggering carcinogenic effects in male Sprague-Dawley rats. Am J Ind Med 59: 509-21, 2016b.

Sommer AM and Lerchl A. The risk of lymphoma in AKR/J mice does not rise with chronic exposure to 50 Hz magnetic fields (1 microT and 100 microT). Radiat Res 162: 194-200, 2004.

Sorahan T. Cancer incidence in UK electricity generation and transmission workers, 1973-2008. Occup Med (Lond) 62: 496-505, 2012.

Stroup DF, Thacker SB, Olson CM, Glass RM, Hutwagner L. Characteristics of meta-analyses related to acceptance for publication in a medical journal. J Clinical Epidemiol 54: 655-660, 2001.

Struchen B, Liorni I, Parazzini M, Gangler S, Ravazzani P, Röösli M. Analysis of personal and bedroom exposure to ELF-MFs in children in Italy and Switzerland. J Expo Sci Environ Epidemiol 26: 586-596, 2016.

Su L, Fei Y, Wei X, Guo J, Jiang X, Lu L, Chen G. Associations of parental occupational exposure to extremely low-frequency magnetic fields with childhood leukemia risk. Leuk Lymphoma 57: 2855-2862, 2016.

Su L, Zhao C, Jin Y, Lei Y, Lu L, Chen G. Association between parental occupational exposure

to extremely low frequency magnetic fields and childhood nervous system tumors risk: A meta-analysis. Sci Total Environ 642: 1406-1414, 2018.

Sudan M, Arah OA, Becker T, Levy Y, Sigsgaard T, Olsen J, Vergara X, Kheifets L. Re-examining the association between residential exposure to magnetic fields from power lines and childhood asthma in the Danish National Birth Cohort. PLoS One 12: e0177651, 2017.

Swanson J, Bunch KJ, Vincent TJ, Murphy MF. Childhood cancer and exposure to corona ions from power lines: an epidemiological test. J Radiol Prot 34: 873-889, 2014.

Swanson J and Bunch KJ. Reanalysis of risks of childhood leukaemia with distance from overhead power lines in the UK. J Radiol Prot 38: N30-N35, 2018.

Swedish Radiation Protection Authority (SSI). Fourth annual report from SSI's Independent Expert Group on Electromagnetic Fields, 2006: Recent Research on EMF and Health Risks. SSI Rapport 2007:04. Stockholm, Sweden: Swedish Radiation Protection Authority, 2007.

Swedish Radiation Protection Authority (SSI). Fifth annual report from SSI's Independent Expert Group on Electromagnetic Fields, 2007. SSI Rapport 2008:12. Stockholm, Sweden: Swedish Radiation Protection Authority, 2008.

Swedish Radiation Safety Authority (SSM). Research 2013:19. Eighth Report from SSM:s Scientific Council on Electromagnetic Fields. Stockholm, Sweden: Swedish Radiation Safety Authority (SSM), 2013.

Swedish Radiation Safety Authority (SSM). Research 2014:16. Recent Research on EMF and Health Risk. Ninth report from SSM's Scientific Council on Electromagnetic Fields. Stockholm, Sweden: Swedish Radiation Safety Authority (SSM), 2014.

Swedish Radiation Safety Authority (SSM). Research 2015:19. Recent Research on EMF and Health Risk - Tenth report from SSM's Scientific Council on Electromagnetic Fields. Stockholm, Sweden: Swedish Radiation Safety Authority (SSM), 2015.

Swedish Radiation Safety Authority (SSM). Research 2016:15. Recent Research on EMF and Health Risk - Eleventh report from SSM's Scientific Council on Electromagnetic Fields, 2016. Including Thirteen years of electromagnetic field research

monitored by SSM's Scientific Council on EMF and health: How has the evidence changed over time? Stockholm, Sweden: Swedish Radiation Safety Authority (SSM), 2016.

Swedish Radiation Safety Authority (SSM). Research 2018:09. Recent Research on EMF and Health Risk - Twelfth report from SSM's Scientific Council on Electromagnetic Fields, 2017. . Stockholm, Sweden: Swedish Radiation Safety Authority (SSM), 2018.

Tabrizi MM and Bidgoli SA. Increased risk of childhood acute lymphoblastic leukemia (ALL) by prenatal and postnatal exposure to high voltage power lines: a case control study in Isfahan, Iran. Asian Pac J Cancer Prev 16: 2347-2350, 2015.

Tabrizi MM and Hosseini SA. Role of Electromagnetic Field Exposure in Childhood Acute Lymphoblastic Leukemia and No Impact of Urinary Alpha- Amylase--a Case Control Study in Tehran, Iran. Asian Pac J Cancer Prev 16: 7613-7618, 2015.

Talibov M, Guxens M, Pukkala E, Huss A, Kromhout H, Slottje P, Martinsen JI, Kjaerheim K, Sparen P, Weiderpass E, Tryggvadottir L, Uuksulainen S, Vermeulen R. Occupational exposure to extremely low-frequency magnetic fields and electrical shocks and acute myeloid leukemia in four Nordic countries. Cancer Causes Control 26: 1079-1085, 2015.

Thomas DC. Re: Kheifets et al. (2017): Residential magnetic fields exposure and childhood leukemia: a population-based case-control study in California. Cancer Causes Control 2018 [epub ahead of print].

Tiwari R, Lakshmi NK, Bhargava SC, Ahuja YR. Epinephrine, DNA integrity and oxidative stress in workers exposed to extremely low-frequency electromagnetic fields (ELF-EMFs) at 132 kV substations. Electromagn Biol Med 34: 56-62, 2015.

Turner MC, Benke G, Bowman JD, Figuerola J, Fleming S, Hours M, Kincl L, Krewski D, McLean D, Parent ME, Richardson L, Sadetzki S, Schlaefer K, Schlehofer B, Schüz J, Siemiatycki J, Van Tongeren M, Cardis E. Occupational exposure to extremely low frequency magnetic fields and brain tumour risks in the INTEROCC study. Cancer Epidemiol Biomarkers Prev 23: 1863-1872, 2014.

Turner MC, Benke G, Bowman JD, Figuerola J, Fleming S, Hours M, Kincl L, Krewski D, McLean D, Parent ME, Richardson L, Sadetzki S, Schlaefer K, Schlehofer B, Schüz J, Siemiatycki J, Tongeren MV, Cardis E. Interactions between occupational exposure to extremely low frequency magnetic fields and chemicals for brain tumour risk in the INTEROCC study. Occup Environ Med 74: 802-809, 2017.

US Department of Health and Human Services (HHS). Health Consequences of Smoking: A Report to the Surgeon General. Washington, DC: US Department of Health and Human Services, 2004.

US Department of Health Education and Welfare (HEW). Smoking and Health: Report of the Advisory Committee to the Surgeon General of the Public Health Service. PHS Publication No. 1103. Washington, DC: US Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, 1964.

US Environmental Protection Agency (USEPA). Reference Dose (RfD): Description and Use in Health Risk Assessments. Washington, DC: USEPA, 1993.

US Environmental Protection Agency (USEPA). Proposed Guidelines for Carcinogen Risk Assessments. EPA/600/P-92/003C. Washington, DC: USEPA, 1996.

US Environmental Protection Agency (USEPA). Update on Ramazzini Institute Data in IRIS Assessments. https://www.epa.gov/iris/update-ramazzini-institute-data-iris-assessments. Last updated June 14, 2017.

van der Mark M, Vermeulen R, Nijssen PC, Mulleners WM, Sas AM, van Laar T, Kromhout H, Huss A. Extremely low-frequency magnetic field exposure, electrical shocks and risk of Parkinson's disease. Int Arch Occup Environ Health 88:227-234, 2014.

Vergara X, Kheifets L, Greenland S, Oksuzyan S, Cho YS, Mezei G. Occupational exposure to extremely low-frequency magnetic fields and neurodegenerative disease: a meta-analysis. J Occup Environ Med 55: 135-146, 2013.

Vergara X, Mezei G, Kheifets L. Case-control study of occupational exposure to electric shocks and magnetic fields and mortality from amyotrophic lateral sclerosis in the US, 1991-1999. J Expo Sci Environ Epidemiol 25: 65-71, 2015.

Villarini M, Dominici L, Fatigoni C, Levorato S, Vannini S, Monarca S, Moretti M. Primary DNA damage in welders occupationally exposed to extremely-low-frequency magnetic fields (ELF-MF). Ann Ig 27: 511-519, 2015.

Vinceti M, Malagoli C, Fabbi S, Kheifets L, Violi F, Poli M, Caldara S, Sesti D, Violanti S, Zanichelli P, Notari B, Fava R, Arena A, Calzolari R, Filippini T, Iacuzio L, Arcolin E, Mandrioli J, Fini N, Odone A, Signorelli C, Patti F, Zappia M, Pietrini V, Oleari P, Teggi S, Ghermandi G, Dimartino A, Ledda C, Mauceri C, Sciacca S, Fiore M, Ferrante M. Magnetic fields exposure from high-voltage power lines and risk of amyotrophic lateral sclerosis in two Italian populations. Amyotroph Lateral Scler Frontotemporal Degener 18: 583-589, 2017.

Wang X, Zhao K, Wang D, Adams W, Fu Y, Sun H, Liu X, Yu H, Ma Y. Effects of exposure to a 50 Hz sinusoidal magnetic field during the early adolescent period on spatial memory in mice. Bioelectromagnetics 34: 275-84, 2013.

Wilson JW, Haines J, Sienkiewicz Z, Dubrova YE. The effects of extremely low frequency magnetic fields on mutation induction in mice. Mutat Res 773: 22-26, 2015.

Woodbine L, Haines J, Coster M, Barazzuol L, Ainsbury E, Sienkiewicz Z, Jeggo P. The rate of X-ray-induced DNA double-strand break repair in the embryonic mouse brain is unaffected by exposure to 50 Hz magnetic fields. Int J Radiat Biol 91: 495-499, 2015.

World Health Organization (WHO). International Programme on Chemical Safety (IPCS). Environmental Health Criteria 170 Assessing Human Health Risks of Chemicals: Derivation of Guidance Values for Health-based Exposure Limits. Geneva, Switzerland: World Health Organization, 1994.

World Health Organization (WHO). Framework for Developing Health-Based Standards. Geneva, Switzerland: World Health Organization: World Health Organization, 2006.

World Health Organization (WHO). Environmental Health Criteria 238: Extremely Low Frequency (ELF) Fields. Geneva, Switzerland: World Health Organization, 2007.

Yasui M, Kikuchi T, Ogawa M, Otaka Y, Tsuchitani M, Iwata H. Carcinogenicity test of 50 H sinusoidal magnetic fields in rats. Leuk Lymphoma 49: 531-540, 1997.

Yu Y, Su FC, Callaghan BC, Goutman SA, Batterman SA, Feldman EL. Environmental risk factors and amyotrophic lateral sclerosis (ALS): a case-control study of ALS in Michigan. PLoS One 9: e101186, 2014.

Zaffanella LE. Survey of Residential Magnetic Field Sources. Volume 2: Protocol, Data Analysis, and Management. EPRI TR-102759-V2. Palo Alto, CA: EPRI, 1993.

Zaffanella LE and Kalton GW. Survey of Personal Magnetic Field Exposure Phase II: 1,000 Person Survey. EMF Rapid Program, Engineering Project #6. Lee, Massachusetts: Enertech Consultants, 1998.

Zhang Y, Lai J, Ruan G, Chen C, Wang DW. Meta-analysis of extremely low frequency electromagnetic fields and cancer risk: a pooled analysis of epidemiologic studies. Environ Int 88: 36-43, 2016.

Zhou H, Chen G, Chen C, Yu Y, Xu Z. Association between extremely low-frequency electromagnetic fields occupations and amyotrophic lateral sclerosis: a meta-analysis. PLoS One 7: e48354, 2012.

APPENDIX B AGENCY CORRESPONDENCE

STATE OF RHODE ISLAND AND PROVIDENCE PLANTATIONS

HISTORICAL PRESERVATION & HERITAGE COMMISSION

Old State House 150 Benefit Street Providence, RI 02903

Telephone 401-222-2678 Fax 401-222-2968
TTY 401-222-3700 www.preservation.ri.gov

RIHPHC No. 13665
190402.06

8 April 2019

Via email: Jaime M. Donta (via email)

Jamie M. Donta
Power Engineers
2 Hampshire Street
Foxborough, MA 02035

Re: Narragansett Electric Company-- Q143 and R144 Cable Reconductoring Project, Phase 2
Providence RI

Dear Ms. Donta,

Thank you for updating the Rhode Island Historical Preservation and Heritage Commission (RIHPHC) on the expansion in the scope of the above-referenced project.

We continue to find that this project will have no adverse effect on any above-ground historic properties, and that archaeological monitoring should be carried out for the area of the new duct bank.

These comments are provided in accordance with Section 106 of the National Historic Preservation Act. If you have any questions, please contact Glenn Modica, Senior Project Review Coordinator, at glenn.modica@preservation.ri.gov or 401-222-2671.

Sincerely,

FR J. Paul Loether
Executive Director and State Historic Preservation Officer

190408.01

APPENDIX C STATE OF RHODE ISLAND ENERGY FACILITY SITING BOARD DOCKET NO. SB-2017-02

STATE OF RHODE ISLAND AND PROVIDENCE PLANTATIONS
ENERGY FACILITY SITING BOARD

THE NARRAGANSETT ELECTRIC COMPANY d/b/a NATIONAL GRID NOTICE OF INTENT APPLICATION PROVIDENCE RIVER 115 kV CABLE RELOCATION PROJECT, PROVIDENCE, RHODE ISLAND	:	**DOCKET NO. SB-2017-02**

DECISION AND ORDER

On December 18, 2017, the Narragansett Electric Company d/b/a National Grid (National Grid or Company) filed a Notice of Intent Application with the Energy Facility Siting Board (EFSB or Board) pursuant to Rule 1.6(f) of the Board's Rules of Practice and Procedure (Rules).[1] The application proposes to relocate a portion of the existing Q-143 and R-144 115 kV underground electric transmission lines (lines) located in Providence, Rhode Island. The lines were installed in 1939 and 1943, respectively, and connect the Franklin Square Substation and the Admiral Street Cable Terminal in Providence. Consisting of three single-phase self-contained fluid-filled cables, the lines share 2.3 miles of common duct bank and manhole system as well as 700 feet of submarine cables installed under the Providence River.[2] This project will relocate 1,650 feet of the lines extending approximately 1,930 feet. National Grid has made the project a

[1] Rule 1.6(f) provides for an abbreviated review of an application for the construction of power lines of more than 1,000 feet, but less than 6,000 feet, or the modification or relocation of existing power lines. After the application is filed and a public hearing held in one or more of the cities or towns affected by the project, the Board must make a determination within sixty days of the filing as to whether the project "may result in a significant impact on the environment or the public health, safety and welfare." If the Board finds no significant impact, the project does not constitute a major alteration. The applicant will, accordingly, be licensed to proceed without further review.

[2] The application provides a detailed description of the work to be performed as well as an extensive analysis of the impacts upon the natural and social environments and electromagnetic field levels. At the public hearing, the Board admitted as full exhibits the application and the Environmental Report, National Grid Exhibits 1 and 2, respectively. The Board also admitted a slide presentation as Exhibit 3 and a fact sheet as Exhibit 4. The application and attachments, as well as the other exhibits, are available at the Public Utilities Commission located at 89 Jefferson Boulevard, Warwick, Rhode Island or on-line at http://www.ripuc.org/efsb/2017_SB_2.html.

priority because the R-144 line is currently out of service due to a recent submarine cable failure. Because there are no remaining spare submarine cables available to repair or replace the R-144 line, the line's failure puts at risk reliability for portions of the City of Providence. Additionally, the submarine portion of the Q-143 line experienced a failure in 2016 and remains vulnerable to additional failure. The gradual deterioration of both the cable and hydraulic system have caused cable failures in both lines.

In its application, National Grid further described the existing lines. When installed in 1939 and 1946, the lines included eight submarine cables, six active and two spares. Previous failures required the Company to use both spare cables. Accordingly, the company was unable to correct the April 2017 failure of the R-144 line. Moreover, although originally buried approximately six to ten feet under the riverbed, due to accumulated sedimentation over time, the cables are now approximately 25 feet below the riverbed.

The proposed project will include: 1) installation of approximately 1,410 feet of new duct bank; 2) installation of approximately 520 feet of a conduit system under the Point Street Bridge to carry the lines over the Providence River; and 3) installation of two manholes on the east side of the Point Street Bridge, approximately 1,930 feet of new cable and conductors in the new duct bank, and three new outdoor terminations and surge arresters per line. The project will also include modification of two existing manholes and replacement of the termination structures within the Franklin Square Substation. National Grid identified three measurable benefits of the project: 1) restoring and improving the reliability of the Company's transmission system serving its Providence customers; 2) reducing exposure to long-term submarine cable outages; and 3) installing new cables that typically require less maintenance than the original ones.

The application described the underground route and how the project will be conducted in a series of phases. The area is described by National Grid as an urban environment, including paved roadways, sidewalks, and the Point Street Bridge, and open green space along the Providence River. Appropriate environmental controls, including soil erosion, sediment, and storm water controls, will be installed. A barge will be used to install the conduit on the underside of the Point Street Bridge.

The Company will retain an environmental monitor to oversee all construction activities to ensure compliance with all permit requirements. Additionally, after the work is complete, National Grid will restore all disturbed areas. Construction will be between 7:00 a.m. and 7:00 p.m. Monday through Friday and 7:00 a.m. and 5:00 p.m. on Saturday. National Grid will coordinate with the City of Providence to manage traffic during construction. It estimates the cost of the project to be approximately $16.3 million. National Grid anticipates beginning construction in the summer of 2018 and completing it in the summer of 2019. It conducted public outreach to the Rhode Island Department of Transportation, Providence officials, and major employers in the immediate vicinity of the construction area.

National Grid considered four alternatives. The first, the no-action alternative, was dismissed on three grounds. It did not address the need to restore the R-144 line to service, would leave the Q-143 line vulnerable to failure, and would further compromise reliability in certain parts of Providence. The Submarine Cable Alternative was rejected for four reasons. First, it was approximately one and a half times more expensive than the Point Street Bridge alternative. Second, repair would require dredging, splicing on a barge, and reburial. Third, estimated completion time was significantly longer than that for the Point Street Bridge alternative. And fourth, the Company would have to obtain environmental licenses, permits, and

approval. Finally, the horizontal Directional Drilling alternative was rejected as presenting a higher risk than the Point Street Bridge option.

The Point Street Bridge alternative was the one chosen. National Grid selected the Point Street Bridge Alternative because it was the least expensive, presented the fewest environmental impacts, had the shortest schedule, and would be the easiest to access, inspect, operate, and maintain.

The project area is highly developed. The soils consist of urban fill materials. The little vegetation that exists is primarily grass with some shrubs and trees. There are no known wellhead protection areas. The project will cross the Providence River, use of which is limited because of poor water quality and not being considered a viable drinking water resource. The project will not require an emissions evaluation.

Describing the social environmental effects, National Grid indicated that the entire on-land cable route is either along an existing roadway or within a right-of-way owned by the Narragansett Electric Company. Two historic properties, the Davol Rubber Company and the South Street Station, and one archaeological resource lie within 1,000 feet of the project. Because of the cable sheaths, the project will contain no above-ground electric fields. The magnetic fields are well below guidelines for public health exposure.

National Grid contended that the project will have no more than negligible impact on climate, weather, wildlife, or geology. Construction will occur in a manner that minimizes the potential for adverse environmental impact. Soil impacts will be mitigated through soil erosion control methods. Surface water resource impacts will be minimized through best management practices. National Grid maintains that the recreational and commercial activities along the

Providence River will not be impacted. Because the area is urban it does not contain any significant vegetation.

Dust and vehicle emissions and impact on land use and recreation will be temporary. The overall visual impact will not be substantially altered by the installation of new equipment or the upgrades to existing equipment. The Company will take precautions to reduce dust and odor.

At the public hearing on February 6, 2018, the Company presented three witnesses to describe the project and its effects as set forth in the Application and the Environmental Report and to respond to inquiries by the Board: George Maximovich, the project manager for National Grid; Erin Whoriskey Cahill, a lead environmental scientist with National Grid; and David Campilli, an underground transmission engineer with National Grid.

Mr. Maximovich testified that the two underground transmission lines were installed in 1939 and 1946 and run between the Franklin Square Substation and Admiral Street for approximately 2.3 miles.[3] He stated that the proposed project extends from the Franklin Square Substation to the Dollar Street manhole.[4] He said that a submarine cable failure in 2017 left the R-144 line out of service.[5] He explained there is a need for the project because the Q-143 line has also experienced failures.[6] Currently, he stated, there are distribution lines on the underside of the south side of the Point Street Bridge.[7] When asked, he provided that the new conduits will only be visible to someone situated under the bridge.[8] Mr. Maximovich described the construction sequence and identified the additional permits National Grid will have to obtain.[9] He testified that

[3] Hr'g Tr. at 4.
[4] *Id.* at 4-5.
[5] *Id.* at 4, 6.
[6] *Id.* at 6.
[7] *Id.* at 7.
[8] *Id.* at 8.
[9] *Id.* at 8-9.

construction is scheduled to begin in the summer of 2018 and be complete by the summer of 2019.[10]

In response to a question from Board Member Agrawal, Mr. Campilli identified some of the distinctions between the instant cable relocation project and the E-183 line project at issue in SB-2003-01. He noted that National Grid had considered a number of bridges in the vicinity for a possible under-bridge alignment configuration of the E-183 line. Because of structural inability to bear the weight of the cables or incompatible geometry and/or physical restrictions, none were deemed suitable.[11]

The Point Street Bridge was one of those considered in SB-2003-01. It was rejected because, among other problems, the only usable areas of the bridge were already fully occupied by the existing Q-143 and R-144 lines. That same condition presents no concerns about attache the new Q-143 and R-144 lines, however, because they will replace old lines and the old lines will be removed.[12]

Ms. Cahill has responsibility for all environmental aspects of the proposed project.[13] She described the project area as having urban fill on both sides of the river.[14] She stated that soils and groundwater will be impacted.[15] She testified that the Providence River is an impacted waterway.[16] She identified a number of soil erosion and sediment control mitigation methods, i.e., bales and waddles, to keep soil from infiltrating into the Providence River. She stated that a management plan would mitigate traffic impacts.[17] Ms. Cahill noted that National Grid will apply

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[10] *Id.* at 10.
[11] *Id.* at 14-15.
[12] *Id.* at 15—16.
[13] *Id.* at 17.
[14] *Id.* at 18.
[15] *Id.*
[16] *Id.*
[17] *Id.* at 19.

for the requisite state permits and that an environmental monitor will be on site to oversee soil disturbance activities and to ensure compliance will all permits.[18] She contended that there will be no long term environmental impacts, only intermittent impacts on noise and traffic, and no visual or cultural resource impacts.[19]

After the Company's presentation ended, the Chairperson solicited public comment. None was offered.

Immediately upon conclusion of the public hearing, the Board conducted an Open Meeting which had been properly noticed. The Board found the relocation of the underground transmission lines to be a positive step in ensuring reliability to the area. The Board also found the project will have no significant impact to the environment or public health, safety, and welfare. The social and environmental impacts resulting from the construction will be temporary and minimal. Moreover, the Board is assured that National Grid will engage in appropriate mitigation measures to minimize any disturbances to vegetation and soil and to the social environment. By a unanimous vote, the Board voted to issue the license.

ACCORDINGLY, it is hereby

(133) ORDERED:

The Energy Facility Siting Board hereby grants to the Narragansett Electric Company d/b/a National Grid a license, under R.I. Gen. Laws § 42-98-11, to relocate a portion of the Q-143 and R-144 115 kV underground electrical transmission lines, as previously described, subject to the Narragansett Electric Company d/b/a National Grid's receipt of all other permits required for the project.

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[18] *Id.* at 19-20.
[19] *Id.* at 20-21.

DATED AND EFFECTIVE AT PROVIDENCE, RHODE ISLAND ON FEBRUARY 6, 2018, PURSUANT TO AN OPEN MEETING DECISION. WRITTEN ORDER ISSUED MARCH 27, 2018.

ENERGY FACILITY SITING BOARD

Margaret E. Curran, Chairperson

Janet Coit, Member

Parag Agrawal, Member

STATE OF RHODE ISLAND AND PROVIDENCE PLANTATIONS
ENERGY FACILITY SITING BOARD

THE NARRAGANSETT ELECTRIC COMPANY d/b/a NATIONAL GRID NOTICE OF INTENT APPLICATION PROVIDENCE RIVER 115 kV CABLE RELOCATION PROJECT, PROVIDENCE, RHODE ISLAND	:	**DOCKET NO. SB-2017-02**

ERRATA ORDER

Whereas, pursuant to Rule 1.32(a) of the Energy Facility Siting Board's (Board) Rules of Practice and Procedure, the Board through this notice of erratum corrects an inadvertence contained in Board Decision and Order No. 133, previously issued in this docket, on March 27, 2018; and

Whereas, On Page 5 which reads:

> She stated that soils and groundwater will be impacted.

is hereby corrected to read:

> She stated that soils and groundwater are impacted from historical use.

Accordingly, it is hereby

(134) ORDERED:

That the modification described herein is adopted by the Board and shall constitute a permanent amendment to Order 133 issued in Docket No. SB-2017-02.

DATED AND EFFECTIVE AT WARWICK, RHODE ISLAND ON MARCH 29, 2018 .

ENERGY FACILITY SITING BOARD

Margaret E. Curran, Chairperson

Janet Coit, Member

Parag Agrawal, Member*

*Member Agrawal was unavailable for signature.