Energy Facility Siting Board Environmental Report

G-185S 115kV Transmission Line Reconductoring Project

Warwick, East Greenwich, and
North Kingstown
Rhode Island

Prepared for **The Narragansett Electric Company d/b/a National Grid**
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[1] Figures are included in a separate bound volume.

Glossary

AAL:	Annual Average Load.
AC:	Alternating Current. An electric current which reverses its direction of flow periodically. (In the United States this occurs 60 times a second -60 cycles or 60 Hertz). This is the type of current supplied to homes and businesses.
ACSR:	Aluminum Conductor Steel Reinforced wire
ACSS:	Aluminum Conductor Steel Supported wire
Ampere (Amp):	A unit of measure for the flow of electric current. A typical home service capability (i.e., size) is 100 amps. 200 amps or more is required for homes with electric heat.
ANSI:	American National Standards Institute
APL:	Annual Peak Load.
BMPs:	Best Management Practices
Bundle:	Two or more wires joined together to operate as a single phase.
Cable:	A fully insulated conductor usually installed underground but in some circumstances can be installed overhead.
Circuit:	A system of conductors (three conductors or three bundles of conductors) through which an electric current is intended to flow and which may be supported above ground by transmission structures or placed underground.
Conductor:	A metallic wire or cable 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.
Davit Arm Structure:	A single-shaft steel pole with an alternating arm configuration each of which supports a phase conductor.
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 between 4 kV and 35 kV that transport electricity to the customer.
Double-Circuit:	Two circuits on one structure.
Duct Bank:	A group of ducts or conduit usually encased in concrete in a trench.
Duct:	Pipe for underground power cables (see also Conduit).
EFI	Environmental Field Issue National Grid Guidance Document
EFSB:	Rhode Island Energy Facility Siting Board
Electric Field (EF):	A field produced as a result of voltages applied to electrical conductors and equipment; usually measured in units kilovolts per meter.

Electric Transmission:	The facilities (≥69 kV) that transmit electrical energy from generating plants to substations.
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.
Fault:	A failure or interruption in an electrical circuit (a.k.a. short circuit).
FEMA:	Federal Emergency Management Agency
Gauss (G):	A unit of measure for magnetic fields. 1G equals 1,000 milligauss (mG).
Gigawatt (GW):	One gigawatt equals 1,000 megawatts.
Glacial till:	Type of surficial geologic deposit that consists of boulders, gravel, sand silt, and clay mixed in various proportions. These deposits are predominantly nonsorted, nonstratified sediment and are deposited directly by glaciers.
H-frame Structure:	A wood or steel transmission line structure constructed of two upright poles with a horizontal cross-arm and diagonal bracings.
Hel:	Highly erodible land
ISO-NE:	ISO New England, Inc. The independent system operator of New England.
kcmil:	1,000 circular mils, approximately 0.0008 square inches. A measure of conductor cross-sectional area.
kV:	Kilovolt. 1 kV equals 1,000 volts.
kV/m:	Kilovolts per meter. A measurement of electric field strength.
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).
LTE:	Long-Term Emergency rating
mG:	milliGauss. Equals 1/1000 Gauss (see Magnetic Field).
Msl:	Mean sea level
NERC:	North American Electric Reliability Corporation
NESC:	National Electrical Safety Code
NPCC:	Northeast Power Coordinating Council
OPGW:	Optical ground wire
PAL:	Public Archaeological Laboratory, Inc.
Phase:	Transmission and distribution AC circuits are comprised of three conductors that have voltage and angle differences between them. Each of these conductors is referred to as a phase.

Phel:	Potentially highly erodible land
Power Transformer:	A device used to transform voltage levels to facilitate the efficient transfer of power from the generating plant to the customer. A step-up transformer increases the voltage while a step-down transformer decreases it. Power transformers have a high voltage and a low voltage winding for each phase (see also Auto Transformer).
PVC:	PolyVinyl Chloride
Reconductor:	Replacement of existing conductors with new conductors, and any necessary structure reinforcements or replacements.
Reinforcement:	Any of a number of approaches to improve the capacity of the transmission system, including rebuilding, reconductoring, uprating, conversion and conductor bundling methods.
RIDEM:	Rhode Island Department of Environmental Management
RIDOT:	Rhode Island Department of Transportation
RIGIS:	Rhode Island Geographic Information System
RIHPHC:	Rhode Island Historical Preservation & Heritage Commission.
RINHP:	Rhode Island Natural Heritage Program
Rip Rap:	A permanent erosion-resistant ground cover of large, loose, angular stone with filter fabric or granular underlining used to protect soil from the erosive forces of concentrated runoff.
RIPDES:	Rhode Island Pollutant Discharge Elimination System
ROW:	Right of way. Corridor of land within which a utility company holds legal rights necessary to build, operate and maintain power lines.
Shield Wire:	Wire strung at the top of transmission lines intended to prevent lightning from striking transmission circuit conductors. Sometimes referred to as static wire or aerial ground wire. May contain glass fibers for communication use. See also "OPGW".
Steel Pole Structure:	Transmission line structure consisting of tubular steel pole(s) with arms or other components to support insulators and conductors.
Step-down Transformer:	See Power Transformer.
Step-up Transformer:	See Power Transformer.
Substation:	A fenced-in yard containing switches, power transformers, line terminal structures, and other equipment enclosures and structures. Voltage change, adjustments of voltage, monitoring of circuits and other service functions take place in this installation.
Switching Station:	Same as Substation except with no power transformers. Switching of circuits and other service functions take place in this installation.
Terminal Points:	The substation or switching station at which a transmission line terminates.

Terminal Structure:	Structure typically within a substation that ends a section of transmission line.
Terminator:	An insulated fitting used to connect underground cables to overhead lines.
TMDL:	Total Maximum Daily Load, Maximum allowed pollutant load to a water body without exceeding water quality standards.
Transmission Line:	An electric power line operating at 69,000 volts or more.
USDA:	United States Department of Agriculture
USGS:	United States Geological Survey
V/m:	Volts per meter. A measure of electric field strength.
Voltage Collapse:	A condition where voltage drops to unacceptable levels and cascading interruptions of transmission system elements occur resulting in widespread blackouts.
Voltage:	A measure of the electrical pressure which transmits electricity. Usually given as the line-to-line root-mean square magnitude for three-phase systems.
Watercourse:	Rivers, streams, brooks, waterways, lakes, ponds, marshes, swamps, bogs, and all other bodies of water, natural or artificial, public or private.
Wetland:	Land, including submerged land, which consists of any of the soil types designated as poorly drained, very poorly drained, alluvial or flood plain by the U.S. Department of Agriculture, Natural Resources Conservation Service. Wetlands include federally jurisdictional wetlands of the U.S. and navigable waters, freshwater wetlands or coastal resources regulated by a state or local regulatory authority. Jurisdictional wetlands are classified based on a combination of soil type, wetland plants, and hydrologic regime, or state-defined wetland types.
Wire:	See Conductor.

1.0 Executive Summary

1.1 Introduction

This Environmental Report (the "ER" or "Report") has been prepared in accordance with Rule 1.6 (f) of the *EFSB Rules of Practice and Procedure* to support a Notice of Intent (NOI) for the reconductoring of the existing G-185S 115-kilovolt (kV) overhead electrical transmission line (G-185S Line), owned by The Narragansett Electric Company d/b/a National Grid ("National Grid") and located in Warwick, East Greenwich, and North Kingstown, Rhode Island (the "Project"). This report discusses the purpose of and need for the Project, the details of the work activities associated with the Project, Project alternatives, the existing natural and social environments that may be affected by the Project, an impact analysis, and proposed mitigation measures.

1.2 Proposed Action

National Grid is proposing to reconductor the G-185S Line which is situated within an approximately 300-foot wide right-of-way (ROW) in the City of Warwick, Town of East Greenwich, and Town of North Kingstown. Reconductoring involves replacing the conductors (wires) of an existing transmission line with new larger conductors which are capable of carrying more power. In many cases it is necessary to replace existing pole structures as part of a reconductoring project. The Project will include replacement of 19 of 62 existing wood pole and steel supporting structures, and the replacement of existing 795 kcmil conductors with larger 954 kcmil conductors. This work will occur within the ROW south of the Kent County Substation off Cowesett Road in Warwick and extend southward to the Old Baptist Road Tap Point[2] off South County Trail in the Town of East Greenwich, a distance of approximately 5.3 miles (see Figure 1-1[3]).

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[2] This is also known as the Davisville Tap Point.
[3] Figures are included in a separate bound volume.

1.3 Need for Project

The "ERO 2009 Compliance Southeast Massachusetts and Rhode Island (SEMARI) – Transmission Area Study" (December 2009) ("2009 ERO Report") identified thermal overloads on this section of the G-185S Line under contingency conditions. Subsequent annual studies have noted there have been only minor changes in load forecasts in this area, and hence the need for the reconductoring remains constant. Overload on the transmission line above applicable emergency ratings under contingency conditions does not meet the performance requirements set by North American Electric Reliability Corporation (NERC), ISO-New England (ISO-NE) and Northeast Power Coordinating Council Inc. (NPCC) planning standards and National Grid transmission guidelines. Reconductoring is also needed to maintain firm and reliable electric supply to National Grid customers.

1.4 Summary of Environmental Effects and Mitigation

The Project will occur within the existing ROW and will use existing access roads, thereby minimizing adverse environmental impacts. No long-term impacts to soil, bedrock, vegetation, surface water, groundwater, wetland resources or air quality will occur. Any potential sedimentation impacts and other short-term construction impacts to wetlands and surface waters will be mitigated by the use of soil erosion and sediment control best management practices (BMPs) and equipment access mats (swamp mats) to protect wetland soils, vegetation root stock, and streams. Minor, temporary disturbances of wildlife may result from equipment travel and construction crews working in the Project corridor. Any wildlife displacement will be negligible and temporary, since no permanent alteration of the existing habitat is proposed. As part of the Project, an environmental monitor will be part of the Project team to ensure compliance with all regulatory programs and permit conditions, and to oversee the proper installation and maintenance of the soil erosion and sediment control BMPs.

1.5 Summary of Social Effects and Mitigation

The Project will involve an existing transmission line within an existing ROW. No long-term impacts to residential, commercial or industrial land uses will occur as a result of the Project. Any construction noise impacts are expected to be brief and localized. No visual impacts will result from the reconductoring. The Project will improve the reliability of the electric supply and as such will have a positive effect for the area. Traffic controls plans will be employed as necessary at the ROW access points off local and state roads. The Project will not adversely impact the social and economic conditions in the Project area.

1.6 Conclusion

The reconductoring of the G-185S Line in its existing ROW is proposed to maintain a reliable supply of electricity to National Grid's customers in a cost effective manner. No significant environmental or social impacts will result from the Project.

2.0 Purpose and Need

2.1 Introduction

National Grid strives to provide its customers with high quality and reliable electric service at the lowest possible cost, while minimizing adverse environmental and social impacts. Reliability is measured in terms of the 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.

To reduce the chance of a long-term outage affecting large numbers of customers in one geographic area, National Grid, like other U.S. electric utilities, has developed design criteria, policies, and standards used both to assess the adequacy of the existing and future transmission system for all reasonably anticipated conditions and also to provide guidance in the design of future modifications or upgrades to the transmission system. These design criteria and standards are contained in the latest version of the National Grid Transmission Group Procedure 28 – Transmission Planning Guide ("Transmission Planning Guide").

Transmission planning studies are routinely completed to determine what facilities are needed to supply reliable electric power to specific geographic areas. The need to reconductor the G-185S Line was identified by a comprehensive transmission planning study.

The purpose of the G-185S Line improvements is to maintain firm and reliable electric supply to the loads of the southern Rhode Island area by avoiding overload of the transmission line conductors during certain contingency operating conditions. Overloading conductors can lead to annealing, loss of tensile strength, excessive conductor sag, possible loss of adequate clearances, and ultimately, failure. To avoid an overload, the system operator would be forced to drop customers to avoid damage to the conductors.

2.2 Purpose of Studies

The interconnected electric power system is a complex network of generation, transmission and distribution facilities which must reliably deliver electrical power to utility customers. To be reliable, the system must provide acceptable performance when components are out of service for maintenance or due to unexpected failures of equipment. Performance is typically measured in terms of transmission equipment thermal loading, nominal voltage and voltage variation, power transfers (transfers), generator stability response, and available short-circuit current.

To assess reliability, engineers study the system using a "what-if" approach that considers the operating states of each piece of equipment on the system and the range of possible customer demand for electric power. The operating states for equipment can be "in-service", "out-of-service," or for equipment such as generators, a variable range of power output. The number of possible combinations of operating states creates an almost infinite number of conditions in which the system could be operated. Some conditions are extremely unlikely, and design and operation of the system to such conditions would not be cost effective. As an example, if the system serving an area were built to withstand multiple transmission lines being out of service simultaneously, then a large number of redundant lines would be required to supply the load, which would not be cost effective. Other conditions, such as small changes in load or generation inputs, could be of little concern because they are trivial and well within the operating capability of the system.

It is therefore necessary to determine specific conditions that need to be studied which address the adequacy of the system. The identification of conditions which need to be considered is accomplished with design criteria and guidelines which generically define "deterministic conditions" that reasonably stress the system. Deterministic conditions recognize the state (i.e., in-service, out-of-service) of the equipment, but not the probability of the state. The capability of the system under these conditions is studied using computer simulations which model the electrical parameters of the system.

All National Grid transmission facilities in New England are designed in accordance with the reliability criteria contained in the Transmission Planning Guide, ISO-NE and New England Power Pool standards, the NPCC criteria, and the NERC Reliability Standards (collectively, the "Planning Documents").

In summary, the purpose of performing computer simulated studies is part of an effort to maintain reliable operation of the electric power system as the system continues to evolve and grow.

2.3 Process for Determining Need and Selecting a Solution

The study which supports this filing models the transfers over the transmission system and is known as a load flow (or power flow) study. Consequently, discussion of the process will be specific to the load flow study performed relative to this transmission line reconductoring proposal.

The first step in the process of determining need and selecting a solution is to establish reference points. The reference points, which are typically referred to as the base cases, simulate conditions with all system components operating as anticipated. Often times the base cases are projections of future conditions which include some proposed facilities. If the cases include proposed facilities, sensitivity analysis may be needed to evaluate the impact on the system of such proposed facilities being advanced, delayed, or cancelled.

The second step of this process is the contingency testing of the system. For the load flow analysis, testing the system involves taking components or lines out of service one at a time consistent with the design criteria and guidelines. The simulations of contingencies are run and compared against the base cases.

The third step in the process of determining need and selecting a solution is the analysis. If the system can withstand all of the separate contingencies while providing acceptable levels of performance and without exceeding the physical capabilities of the system's equipment, then the system is assumed to be reliable and additional equipment is not required. If the performance objectives are not met, but the loadings do not exceed emergency limits of the equipment, then there may be an opportunity to implement operating actions to mitigate the impacts of the stressed condition. If operating actions are available, simulations are run which model the operating actions. If operating actions are not available or are insufficient to adequately relieve the stressed condition in a timely manner, a determination of need has been established.

Once a need has been established, the fourth step in the process is to develop a list of possible alternatives that might address the problem(s). The base cases are modified to include each set of possible alternatives, one at a time. The previously described steps two and three are then repeated.

The fifth step repeats the first four steps based on cases which look further over time. The benefit of performing this longer term analysis is to identify any subsequent needs that should be considered in the economic evaluation of alternatives.

Following technical evaluation of alternatives, an engineering economic analysis may be performed. The economic analysis is designed to balance the cost of the capital investment, the annual operating and maintenance expenses, and the value of energy losses over the study period. These costs are represented as annual revenue requirements, and the present worth of the revenue requirements are summed to develop a cumulative present worth revenue requirement.

The process for determining and addressing need can be summarized as follows:

- Identify conditions during which the system response does not meet the design criteria and guidelines;
- Identify and evaluate alternatives; and
- Select the best economic and technical solution.

2.4 ISO-NE Approval of Project

National Grid filed the G-185S Reconductor Project – Level I Proposed Plan Application NEP-10-T02 on December 1, 2010 and ISO-NE approved the application on December 15, 2010. The ISO-NE approval is included in Appendix B.

2.5 Need for the Proposed Reconductoring

The transmission system is designed to avoid loading equipment above the Long-Term Emergency (LTE) rating. A recent review of the area load supply, as documented in the 2009 ERO Report, indicates that the section of the G-185S Line between the Kent County Substation and the Old Baptist Road Tap Point requires upgrade immediately. The 2009 ERO Report states that the G-185S Line could become loaded above its LTE rating under certain contingency conditions. As such, the need to reconductor the G-185S Line has been established. As further detailed in the 2009 ERO Report, the option to reconductor the G-185S Line has been recommended as the preferred alternative to address the potential overload condition, to comply with performance standards, and to maintain reliability of the transmission system.

2.6 Consequences of Not Reconductoring the G-185S Line

If the G-185S Line is not reconductored, the supply to the area load can no longer be maintained firm. As a result, it would be necessary to shed load under certain contingency conditions. Shedding load reduces reliability of service and is not an acceptable practice. Furthermore, it does not meet applicable transmission system design criteria.

3.0 Project Description and Proposed Action

3.1 Introduction

In this section of the Report, the scope of the Project is identified, the proposed facilities and National Grid's construction practices are described, estimated Project costs are identified, and the anticipated Project schedule is discussed.

3.2 Description of the Existing G-185S Line

The existing G-185S Line originates at National Grid's Kent County Substation located on Cowesett Road in Warwick, and extends a distance of approximately 15.5 miles to the West Kingston Substation, located off Great Neck Road in South Kingstown. From West Kingston Substation a 115kV transmission line extends into Connecticut. The G-185S Line is located in an existing approximately 300-foot wide ROW held by National Grid since the 1960s. The L-190 115kV transmission line and, in sections, the 3312 34.5 kV sub-transmission line, are also located within the cleared ROW. National Grid's rights to the ROW are by fee ownership or easement. The 5.3 mile portion of the G-185S Line which is proposed to be reconductored begins at the Kent County Substation in Warwick and extends south through Warwick, through East Greenwich, into North Kingstown, and then back into East Greenwich to the Project's southern terminus at the Old Baptist Road Tap Point located off South County Trail (see Figure 1-1). Figure 3-1, Sheets 1 through 6, is a detailed ROW site plan which shows the entire project route and all existing facilities.

For purpose of discussion, National Grid considered the portions of the ROW discussed in this Report to be divided into three segments. Segment 1 of the ROW extends from the Kent County Substation to the vicinity of Interstate 95 (see Figure 3-2). Segment 2 extends from the vicinity of Interstate 95 to the vicinity of Frenchtown Road (see Figure 3-3). Segment 3 extends from the vicinity of Frenchtown Road to the Project southern terminus at the Old Baptist Road Tap Point (see Figure 3-4).

The portion of the G-185S Line which is proposed to be reconductored contains approximately two miles of single-circuit structures and 3.3 miles of double-circuit steel pole davit arm structures, which support both the G-185S Line and the adjacent L-190 Transmission Line. The single-circuit segments of this transmission line are supported predominantly by wood pole structures with a few exceptions. The first two structures south of the Kent County Substation are single-circuit steel Y-Frame structures, Structures 3, 4, 8, and 54 are single-circuit steel pole davit arm structures. Single circuit structures are designed to support a single electrical circuit and double-circuit structures are designed to support two electrical circuits (see Figures 3-5 and 3-6). Structures 57, 58, and 59 are single circuit wood H-frame structures (see Figure 3-7).

The section of the G-185S Line between Kent County Substation and the Old Baptist Road Tap Point consists of 795 kcmil ASCR conductors. This portion of the line has now been identified as requiring reconductoring to meet expected load growth and to avoid thermal overload of the conductors under certain contingency conditions.

3.3 Scope of the Project

National Grid proposes to reconductor its existing G-185S Line between the Kent County Substation located on Cowesett Road in Warwick and the Old Baptist Road Tap Point located off South County Trail in East Greenwich, a distance of approximately 5.3 miles. An overview of the Project area is provided in Figure 1-1 and a more detailed overview is provided in Figure 3-1 (Sheets 1-6). Reconductoring involves replacing the conductors of existing electric transmission lines with new larger conductors (wires) which are capable of carrying more power. It is necessary to replace 19 of the 62 existing pole structures as part of the Project.

The scope of the Project involves replacing the existing 795 kcmil ACSR (Aluminum Conductor Steel Reinforced) conductors with new 954 kcmil ACSS (Aluminum Conductor Steel Supported) conductors. Existing insulator and hardware assemblies on all structures will be replaced with new equipment. Additionally, 1.5 miles of existing Optical Ground Wire (OPGW) will be replaced in kind.

To support the proposed reconductoring, it has been determined that all 14 existing single-circuit wood structures will need to be replaced with steel structures to provide the necessary strength and ground clearances required for the new larger conductors. All of the existing steel structures of the G-185S Line have been analyzed and five double-circuit structures were determined to require replacement. The remaining 43 existing steel structures were found to be sufficient to support the proposed new conductors, and will therefore remain in place. Each of the double-circuit structures being replaced will require new concrete foundations.

Tree trimming and select tree removal will be performed along the existing ROW in conjunction with the Project. The proposed modifications will not significantly change the appearance of the existing ROW or the G-185S Line.

In summary, the full scope of the Project consists of replacing a total of 19 structures with weathering steel structures, replacing the existing conductors of the transmission line with new conductors and associated insulators and hardware, replacing approximately 1.5 miles of OPGW, tree trimming and select tree removal along the 5.3 mile route.

3.4 Construction Practices

The reconductoring of the G-185S Line will be accomplished using conventional overhead electric power line construction techniques. Construction work hours will comply with local requirements. The proposed reconductoring will be carried out in a sequence of activities that will normally proceed as follows:

1. ROW vegetation maintenance/mowing and selective tree trimming/removal.
2. Installation of BMPs.
3. Access road maintenance.
4. Pole replacement and installation of foundations.
5. Conductor and OPGW removal and replacement.
6. Restoration of the ROW.

Each of these transmission line construction activities is described in the following sections.

National Grid will retain the services of an environmental monitor throughout the entire construction phase of the Project. The purpose of the environmental monitor will be to perform site inspections, ensure compliance with all applicable federal, state, and local permit conditions, maintain strict adherence to National Grid policies, and monitor effectiveness of and, if required, propose modifications to BMPs.

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3.4.1 ROW Vegetation Maintenance/Mowing and Selective Tree Trimming/Removal

To facilitate construction equipment access along the majority of the ROW and at structure sites, vegetation mowing and selective tree trimming and removal may be required in certain areas. This will be done to provide access to structure locations to facilitate safe equipment passage, to provide safe work sites for personnel within the ROW, and to maintain safe and reliable clearances between vegetation and transmission line conductors.

3.4.2 Installation of BMPs

Following the ROW mowing and vegetation maintenance activities, appropriate erosion control devices, such as straw bales, straw wattle, compost mulch tubes and siltation fencing, will be installed following the procedures identified in the Rhode Island Soil Erosion and Sediment Control Handbook, and in accordance with approved plans and permit requirements. The installation of these erosion control devices will be supervised by National Grid's environmental monitor. The devices will function to mitigate construction-related soil erosion and sedimentation, and will also serve as a physical boundary to separate construction activities from resource areas.

Access across wetland areas and streams, where upland access is not available, and work at structures within wetlands will be accomplished by the temporary placement of swamp mats. Swamp mats consist of timbers which are bolted together and temporarily placed over wetland areas to distribute equipment loads and minimize disturbance to the wetland and soil substrates. Swamp mats will be installed in a manner so as to not impede water flow. Such temporary swamp mat access roads and work pads will be removed following completion of construction, and any exposed soils will be seeded and mulched to promote vegetative growth and soil stabilization. Vegetation will not be permanently affected by the installation of these mats.

All work is to be in conformance with National Grid environmental guidance document EG-303NE, ROW Access, Maintenance and Construction Best Management Practices (EP No. 3 – Natural Resource Protection (Chapter 6), dated April 22, 2013).

3.4.3 Access Road Maintenance

Access roads are required along the ROW to provide the ability to construct, inspect, and maintain the transmission facilities. For the Project, existing access roads are suitable in a majority of the work areas. In some cases, existing access roads will require maintenance to support the proposed construction activities.

Access across wetland areas and streams, where upland access is not available, will be accomplished by the temporary placement of swamp mats and/or swamp mat bridges as described in Section 3.4.2.

Any access road maintenance will be carried out in compliance with the conditions and approvals of the appropriate federal and state regulatory agencies. Exposed soils on access roads will be wetted and stabilized as necessary to suppress dust generation. Crushed stone aprons (stabilized construction exits) will be used at all access road entrances at public roadways to minimize the amount of soil tracked onto paved roads by construction equipment. If necessary, public roads will be swept to remove any accumulation of Project related soil.

Equipment typically used during the maintenance of access roads will include dump trucks used to transport fill materials to work sites, and bulldozers, excavators, backhoes and graders which will be used to place fill materials or make cuts to achieve the proper access road profile. Cranes or log trucks will be used to place swamp mats in locations where temporary access across wetland areas is proposed. Throughout the Project, pick-up trucks will be used to transport crews and hand held equipment to work sites. Low-bed trailers will be used to transport tracked equipment which cannot be operated on public roadways to the work site.

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3.4.4 Pole Replacement and Installation of Foundations

As noted in the Project Description (Section 3.3) only 19 of the 62 transmission structures will be replaced. Poles will be replaced in close proximity to their existing locations. The process for replacing direct embedded structures and constructing new foundations required for five double-circuit structures are discussed in this section.

Excavation will be required to replace pole structures and install foundations. Grading may be required at some structure locations to provide a level work surface for construction equipment and crews.

If rock is encountered during excavation, rock removal can generally be accomplished by means of rock drilling.

Direct embedment structures will require excavations ranging from approximately 10 to 15 feet in depth and three to six feet in diameter. Excavated material will be temporarily stockpiled next to the excavation but will not be placed directly into resource areas. If a stockpile is located in close proximity to wetlands, it shall be enclosed by staked straw bales or another erosion and sediment control device. Steel casings may be used to support the sides of deeper excavations. Once the structure has been properly positioned and plumbed within the hole, the excavation will be backfilled with the native soil or clean gravel, and tamped to provide structural integrity. Following the backfilling operation, any remaining excavated material will be spread over adjacent upland areas or removed from the site.

Dewatering may be necessary during excavations for structures near wetland areas. The dewatering pumpate will be discharged into a straw bale and geotextile fabric settling basin or dewatering filter bag which will be located in an upland area. The pump intake will not be allowed to rest on the bottom of the excavation throughout dewatering. The basin and all accumulated sediment will be removed following dewatering operations and the area will be seeded and mulched.

As previously discussed, the five double-circuit transmission line structures to be replaced will require new reinforced concrete caisson foundations. These foundations will range from approximately 18 to 19 feet in depth, and six to seven feet in diameter. Installation of foundations will include foundation excavation, steel caisson installation, rebar work and concrete placement. Generally, steel casings will be used to support the sides of foundation excavations. Following the completion of foundation construction, excavated soil, clean gravel or concrete will be used to backfill around the foundation. The transmission structures are then erected upon the completed foundations. Any remaining excavated materials are then spread over upland areas or removed from the site. Old poles will be removed from the Project site and disposed of appropriately. The five old concrete caisson foundations will be cut off two feet below grade and the resulting void will be backfilled with topsoil.

Equipment typically used during the installation of foundations and pole structures will include excavating equipment such as backhoes and clam shell diggers, drill rigs, rock drills and concrete trucks. Cranes will be used to erect structures. Hand held equipment including shovels and vibratory tampers will be used during the backfilling of foundations and pole structures. Dump trucks will be used to remove excavated materials from the work site if necessary. Tracked equipment which cannot be operated on public roadways will be transported to the work site by means of a low-bed trailer.

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3.4.5 Conductor and OPGW Removal and Replacement

The existing conductors and certain sections of OPGW will be used to pull in the new conductors and OPGW. The new conductors will be installed using stringing blocks and tensioning equipment. The tensioning equipment is used to pull the conductors through the stringing blocks and to achieve the desired sag and tension condition. During the stringing operation, temporary guard structures or boom trucks will be placed at road and highway crossings and at crossings of existing utility lines to ensure the public safety and the continued operation of other utility equipment. To minimize any additional disturbance to soils and vegetation, existing access roads will be used to the fullest extent possible in the placement of pulling and tensioning equipment.

The equipment that will typically be used during the conductor installation operation includes puller-tensioners and conductor reel stands that will be located at the stringing sites. Bucket trucks and platform cranes will be used at non-wetland locations to mount stringing blocks on the structures. To avoid setting temporary poles as guard structures in environmentally sensitive areas, the booms of small cranes and bucket trucks will be used as guard structures in such areas during the stringing operation to prevent the conductors from falling across roads or other utility lines. Pickup trucks will be used to transport work crews and small materials to work sites. National Grid will coordinate work across state highways and Interstate 95 with the Rhode Island Department of Transportation (RIDOT).

3.4.6 Restoration of the ROW

Restoration efforts, including final grading and installation of permanent erosion control devices, will be completed following the reconductoring operation. All construction debris will be removed from the Project site and properly disposed. All disturbed areas around structures and other graded locations will be seeded with an appropriate conservation seed mixture and/or mulched to stabilize the soils in accordance with applicable regulations. Temporary erosion control devices will be removed following the stabilization of disturbed areas. Pre-existing drainage patterns, ditches, roads, walls, and fences will generally be restored to their former condition. Where authorized by property owners, permanent gates and access road blocks will be installed at key locations to inhibit access onto the ROW by unauthorized persons or vehicles.

3.4.7 Environmental Compliance and Monitoring

Throughout the entire construction process, National Grid will retain the services of an environmental monitor. The primary responsibility of the monitor will be to enforce compliance with all federal, state, and local permit requirements and National Grid company policies. At regular intervals and during periods of prolonged precipitation, the monitor will inspect all locations to determine that the environmental controls are functioning properly and to make recommendations for correction or maintenance, as necessary. In addition to retaining the services of an environmental monitor, National Grid will require the construction 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 such as wetland access and appropriate work methods. Installation and repair of BMPs and other compliance issues are tracked on an inspection form or action log that is updated and distributed weekly to appropriate personnel. Additionally, all construction personnel will be briefed on Project environmental issues and obligations prior to the start of construction. Regular construction progress meetings will reinforce the contractor's awareness of these issues.

3.4.8 Construction Traffic

Construction-related traffic will occur over the approximate four-month construction period. Access to the ROW for construction equipment will typically be gained from public roadways crossed by the ROW in various locations along the route. Because each of the construction tasks will occur at different times and locations over the course of the construction, traffic will be intermittent at these entry roadways. Traffic will consist of various vehicle types ranging from pick-up trucks to heavy construction equipment. Traffic impacts are expected to be negligible.

National Grid will coordinate closely with the RIDOT to develop acceptable traffic management plans for work within state highways and Interstate 95. National Grid will coordinate with local authorities for work on local streets and roads. At locations where construction equipment must be staged in a public way, the contractor will follow a pre-approved work zone traffic control plan.

3.5 Right-of-Way Maintenance

As is the present case, vegetation along the ROW will continue to be managed 1) to provide clearance between vegetation and electrical conductors and supporting structures so that safe, reliable delivery of power to consumers is assured, and 2) to provide access for necessary inspection, repair, and maintenance of the facility. All vegetation maintenance is carried out in strict accordance with National Grid's "ROW Vegetation Management Policies and Procedures," the requirements of the Rhode Island Department of Environmental Management (RIDEM) Division of Agriculture, and federal regulations as administered by the Environmental Protection Agency.

National Grid manages vegetation on its ROWs through integrated procedures combining removal of danger trees, hand cutting, targeted herbicide use, mowing, selective trimming and side trimming. Three methods of targeted herbicide treatments are utilized: basal application, cut stump treatment, and foliar application.

The appropriate method of vegetation management is chosen by a National Grid forester or arborist in accordance with National Grid's vegetation management policy. The long-term vegetation maintenance of the ROW will continue to be accomplished by hand and mechanical cutting and the selective application of herbicides where necessary. Herbicides will be applied by licensed applicators to select target species. Herbicides are never applied in areas of standing water or within designated protective buffer areas associated with wells, surface waters, and agricultural areas.

3.6 Safety and Public Health Considerations

National Grid will design, build, and maintain the reconductored G-185S Line so that the health and safety of the public are protected. This will be accomplished through adherence to all 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[4] (NESC). The facilities will be designed in accordance with sound engineering practices using established design codes and guides 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 ANSI. Practices which 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, and use of temporary guard structures at road and electric line crossings to prevent accidental contact with conductors during installation.

Following construction of the facilities, all transmission structures will be clearly marked with warning signs to alert the public of potential hazards if climbed or entered. Trespassing on the ROW will be inhibited by the installation of gates and/or barriers at entrances from public roads.

A discussion of the current status of the health research relevant to exposure to electric and magnetic fields (EMF) is attached as Appendix A. This report was prepared by Exponent.

3.7 Project Costs

National Grid prepared a planning grade estimate of the costs associated with the Project. Planning estimates are prepared prior to detailed engineering and are prepared in accordance with National Grid's estimating guidelines. Planning grade estimates are prepared using historical cost data, data from similar Projects, and other stated assumptions of the Project engineer. The accuracy of planning estimates is expected to be ± 25 percent. Estimated costs include costs of materials, labor and equipment, and escalation. The estimated capital costs associated with the Project is $4.6 million.

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[4] The NESC is an American National Standards Institute (ANSI) standard which covers basic provisions for the 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.

This estimate includes all materials, labor and equipment needed to:

- Remove and replace certain of the G-185S Line structures to adequately support and provide code clearances for new 954 kcmil ACSS conductors;
- Remove a 5.3-mile section of existing 795 kcmil ACSR conductors;
- Install a 5.3-mile section of new 954 kcmil ACSS transmission line conductor; and
- Remove and replace approximately 1.5 miles of OPGW.

Annual operation and maintenance activities for transmission lines include periodic ROW vegetation management, helicopter patrol, and miscellaneous route inspections. Since the ROW has an existing line on it, any increase in operation and maintenance costs will be nominal.

3.8 Project Schedule

It is necessary to take a transmission line out of service while it is being reconductored. National Grid anticipates starting the Project in January of 2015 with completion by the summer of 2015. This schedule is based on time duration estimates of Project permitting, detailed engineering, materials acquisition, scheduling of outages and construction. A schedule of major Project tasks is shown in Figure 3-8.

4.0 Alternatives to the Proposed Action

4.1 Introduction

Foremost in the development of the Project was to ensure that the plan selected to meet the electrical system needs is the most appropriate in terms of cost and reliability, and that environmental impacts are minimized to the fullest extent possible. Alternatives to the Project have been evaluated to ensure that these objectives are met.

In this section of the report, alternatives to the proposed action are discussed and analyzed, including the "Do Nothing" alternative, restoration of a removed Special Protection System (SPS), underground transmission line alternative, and the preferred "reconductoring of the existing G-185S Line".

4.2 "Do Nothing" Alternative

The "Do Nothing" option would be to continue operating the existing electrical transmission system without upgrading or relieving the G-185S Line. However, if the "Do Nothing" option is pursued, the G-185S Line could potentially become thermally overloaded under certain contingency scenarios during summer peak conditions.

If the "Do Nothing" option were to be pursued and there was such a contingency condition, the system operator would be forced to drop customers to avoid overloading conductors. Overloading conductors can lead to annealing, loss of tensile strength, excessive conductor sag, and possible loss of adequate clearances beneath the transmission line.

Because of the potential for a thermal overload, the alternative of continuing to operate the existing system without reconductoring the G-185S Line is not an acceptable alternative for maintaining a firm and reliable electric supply to our customers. If the capacity of this line is not increased, operational flexibility will continue to be limited.

4.3 Restore Wood River Special Protection System (SPS)

A Special Protection System (SPS) similar to one that existed at the Wood River Substation would protect the G-185S Line from the overload. An SPS is a protection system designed to detect abnormal system conditions and take corrective action other than the isolation of faulted elements. Such action may include changes in load, generation, or system configuration to maintain system stability, acceptable voltages or power flows.

SPS installation would cost less money and require less time to solve the overload issue for the G-185S Line. However, there were operational issues with the previous 1870 Line Overcurrent Trip SPS scheme and ISO-NE recommended removal of this SPS. Therefore, using an SPS to eliminate this overload would not align with ISO-NE's recommendations and therefore is not a viable option.

Additionally, the restoration of this SPS would reverse already completed upgrades on the transmission system as a result of the Southern Rhode Island Transmission Project which included the removal of the SPS in 2008.

Finally, an SPS would not provide relief for as long a period as the reconductoring proposal, and may lead to the need for additional facilities in the future. Because of these considerations, this alternative was not considered further.

4.4 Underground Transmission Line Alternative

National Grid examined an underground alternative to the proposed reconductoring of the G-185S Line. An underground alternative could address the thermal overloading of the G-185S Line. However, there would be significant cost, schedule, environmental, and operational disadvantages to an underground alternative.

An underground cable system consisting of two sets of 115 kV solid dielectric insulated cables utilizing 2,000 kcmil copper conductors will satisfy the ampacity requirements for the Project. The two sets of cable would be installed in a concrete encased duct bank, with manholes installed along the route at approximately 1,500 foot intervals. A transition station would be required at the Old Baptist Road Tap Point Site, and modifications would be required at Kent County Substation for an underground alternative.

National Grid examined use of the existing transmission ROW and use of the public roadway network for an underground transmission alternative. The existing roadway network does not easily connect between the Kent County Substation and the Old Baptist Road Tap Point location. Use of the roadway network for an underground alternative would add significant length and cost to the alternative, and would have potentially significant traffic impacts during construction. Use of the existing ROW was developed for the underground alternative for the Project. The length of this ROW alternative is approximately 5.3 miles.

There are several river crossings and wetlands along the ROW, and there would be limited access highway crossings of Interstate 95 and Route 403. These can be easily spanned by overhead transmission lines, but special construction techniques, such as horizontal directional drilling or pipe-jacking, would be needed to cross these obstructions with the Underground Alternative.

A Study Grade estimate was prepared for the underground alternative. This alternative would cost approximately $55 million, or more than ten (10) times the cost of the Project. In addition, the environmental impacts would be substantially increased, as construction of the underground line would require development of additional access roads and excavation along the full 5.3 miles of the ROW.

From a schedule perspective, the underground alternative would take several years to design, license and build and will not be available to address the potential overloading on a timely basis.

In addition to the significantly higher costs, environmental impacts, and schedule impacts, there are a number of system and operational issues associated with underground transmission lines. These include:

- Lengthy Outage Repair Times: When an overhead transmission line experiences an outage, it can typically be repaired within 24 to 48 hours. In the case of a failure of an underground transmission cable, repair times can be in the range of two weeks to a month or more. The extended outage times for underground cables expose the remainder of the transmission system to emergency loadings for longer periods of time. There is also increased exposure to loss of another transmission element, with possible loss of load, during the extended underground outage.
- Effect on Reclosing: Many faults on overhead lines are temporary in nature. Often it is possible to "reclose" (re-energize) an overhead line after a temporary fault, and return the line to service with only a brief interruption, measured in seconds. Faults on underground transmission cables are almost never temporary, and the cable must remain out of service until the problem is diagnosed and repairs can be completed.

- Ratings: It is often difficult to match overhead line ratings with underground cables. It is also much more difficult to upgrade ratings on underground lines should that become necessary in the future.

Due to the substantially higher costs, increased environmental impacts, and operational disadvantages the Underground Alternative was not considered further.

4.5 Parallel Transmission Line Alternative

A fourth alternative that was considered is the construction of a new electric transmission line parallel to the existing line on the existing ROW or a new ROW. Similar to the Underground Alternative, the Parallel Transmission Line Alternative would require the construction of new transmission infrastructure as opposed to upgrading existing infrastructure.

If the new line were constructed on the existing right-of-way, additional clearing would be required to make space on the ROW for the new line. Because of the time, cost, and permitting that would be associated with constructing a new transmission line on either the existing or a new ROW, it was concluded that a new parallel transmission line is not a viable alternative to the proposed action.

4.6 Reconductor the G-185S Line (Preferred)

For the reasons summarized in the previous sections, we concluded that the upgrading and reconductoring of the G-185S circuit on the existing ROW would be greatly preferred to the Do Nothing, Restore Wood River SPS, Underground, and Parallel Transmission Line Alternatives.

Project costs and environmental impacts would be significantly greater and permitting and implementation schedules would be substantially longer for the new transmission line alternatives in comparison to the proposed reconductoring alternative. Finally, the Do Nothing and Restore Wood River SPS alternatives are not acceptable from either an operational or reliability perspective, the Do Nothing alternative would not comply with ISO-NE standards, and the Restore Wood River SPS alternative would be contrary to ISO-NE recommendations.

The preferred option involves reconductoring the G-185S Line from Kent County substation to Davisville tap. The preferred option will solve the G-185S overload problem as well as resolve all asset concerns. More importantly, it complies with current ISO-NE standards.

5.0 Description of the Affected Natural Environment

5.1 Introduction

This section of the Report describes the existing natural environment that may be affected by the Project, both within and surrounding the existing transmission line ROW. As required by the Rules and Regulations of the EFSB, a detailed description of the environmental characteristics within and immediately surrounding the Project has been prepared. The following section describes the specific natural features which have been assessed for the evaluation of impacts and the preparation of mitigation measures. Information pertaining to existing site conditions has been obtained through available published resource information, the Rhode Island Geographic Information System (RIGIS) database, various state and local agencies, and field investigations of the ROW.

This chapter describes the existing environmental conditions in the Project corridor. The following sections describe the soils, surface waters, groundwater, plant communities, wetlands, and wildlife characterizing the Project area. These environmental features and how each will be potentially affected by the Project will be further discussed in the impact and mitigation sections of this Report. As permitted by EFSB Rule 1.6(f), several environmental factors (e.g., geology, air quality climate and weather) have not been addressed by this document, since the Project will have no potential to impact them.

5.2 Project Study Area

A Project Study Area was established to accurately assess the existing environment within and immediately surrounding the ROW. This Study Area consists of a 2,500 foot wide corridor centered on the existing ROW (see Figure 5-1). The boundaries of this corridor were determined to allow for a detailed inventory of existing conditions within and adjacent to the ROW.

The 5.3-mile long Project corridor is characterized by rolling, hilly topography. In the northern portion of the Project corridor, elevations of 150-200 feet mean sea level (msl) are present, as indicated by the United States Geological Survey (USGS) mapping[5] for this area. The highest lands (approximate elevation of 200 feet msl) in the Project corridor are in the vicinity of the Middle Road crossing in East Greenwich. The lowest elevations in the Project corridor (40 feet msl) are found in the area proximate to the Hunt River crossings.

Most of the Project corridor is characterized by a suburban land use with fragmented undeveloped forested and field land tracts. Transportation, institutional and, residential uses are the developed land uses in this area. State Route 4 is situated directly west of the Project corridor, and the ROW crosses Interstate 95 near the northern Project terminus and State Route 403 located near the southern Project terminus. East Greenwich High School, located off Avenger Drive, is also in the Study Area.

5.3 Soils

Detailed information concerning the physical properties, classification, agricultural suitability, and erodibility of soils in the vicinity of the ROW are presented in this section. Descriptions of soil types identified within the ROW and Study Area were obtained from the Natural Resources Conservation Service (NRCS) Web Soil Survey[6], the Soil Survey of Rhode Island (Rector, 1981), and from on-site investigations conducted by VHB. The Survey delineates map units that may consist of one or more soil series and/or miscellaneous non-soil areas that are closely and continuously associated on the landscape. In addition to the named series, map units include specific phase information that describes the texture and stoniness of the soil surface and the slope class. A total of 18 named soil series have been mapped within the Study Area. Table 5-1 lists the characteristics of the 24 soil phases (lower taxonomic units than series) found within the Study Area. Figure 5-2 depicts soil classes grouped by erodibility hazard as well as hydric soils.

5 http://store.usgs.gov/b2c_usgs/usgs/maplocator/(ctype=areaDetails&xcm=r3standardpitrex_prd&carea=%24ROOT&layout=6_1_61_48&uiarea=2)/.do

6 Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/. Accessed [July 25, 2013].

Table 5-1: Characteristics of Soil Phases within the ROW

Soil Map Unit Symbol	Soil Phase	Drainage Class	Percent Slope
BhA	Bridgehampton silt loam	mwd	0 to 3
BhB	Bridgehampton silt loam	mwd	3 to 8
BmA	Bridgehampton silt loam, till substratum	wd-mwd	0 to 3
BmB	Bridgehampton silt loam, till substratum	wd-mwd	3 to 8
BnB	Bridgehampton – Charlton complex	wd-mwd	0 to 8
BoC	Bridgehampton – Charlton complex	wd-mwd	3 to 15
CdB	Canton & Charlton fine sandy loam	wd	3 to 8
CeC	Canton & Charlton fine sandy loam	wd	3 to 15
ChB	Canton & Charlton very fine sandy loam	wd	3 to 8
ChC	Canton & Charlton very stony fine sandy loams	wd	8 to 15
EfA	Enfield silt loam	wd	0 to 3
FeA	Freetown mucky peat	vpd	0 to 2
HkC	Hinckley gravelly sandy loam	ed	3 to 15
HkD	Hinckley gravelly sandy loam	ed	15 to 35
MmA	Merrimac sandy loam	swed	0 to 3
Pg	Pits, gravel	ed-swed	Variable
QoC	Quonset gravelly sandy loam	ed	3 to 15
Rc	Raypol silt loam	pd	0 to 3
Rf	Ridgebury, Whitman & Leicester ex. stony fine sandy loam	pd-vpd	0 to 3
ScA	Scio silt loam	mwd	0 to 3
Ss	Sudbury sandy loam	mwd	0 to 3
SuB	Sutton very stony fine sandy loam	mwd	0 to 8
UD	Udorthents-Urban land complex	mwd-ed	0 to 15
WcB	Wapping, very stony silt loam	mwd	0 to 8

Notes:
ed = excessively drained
swed = somewhat excessively drained
wd = well drained
mwd = moderately well drained
pd = poorly drained (hydric)
vpd = very poorly drained (hydric)
8-15 percent slope = highly erodible
Source: NRCS Web Soil Survey.

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5.3.1 Prime Farmland Soils

Prime farmland, as defined by the United States Department of Agriculture (USDA), is the land that is best suited to producing food, feed, forage, fiber, and oilseed crops. It has the soil quality, growing season, and moisture supply needed to economically produce a sustained high yield of crops when it is treated and managed using acceptable farming methods.

Rhode Island recognizes 35 prime farmland soils. The ROW crosses seven prime farmland soil units as listed in Table 5-2.

Table 5-2: USDA Prime Farmland Soils within the ROW

Soil Map Unit Symbol	Name	Percent Slope
BhA	Bridgehampton silt loam	0 to 3
BmA	Bridgehampton silt loam, till substratum	0 to 3
CdB	Canton and Charlton fine sandy loams	3 to 8
EfA	Enfield silt loam	0 to 3
MmA	Merrimac sandy loam	0 to 3
ScA	Scio silt loam	0 to 3
Ss	Sudbury sandy loam	0 to 3

Prime farmland soils could be utilized as cropland, pastureland, rangeland, forestland, or other land. Urbanized land and water are exempt from consideration as prime farmland. Within the ROW and Study Area, prime farmland soils exist on land occupied by commercial, institutional, recreational, agricultural and residential land uses, cleared ROW, forestland, and roads.

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5.3.2 Farmland of Statewide Importance

Farmland of statewide importance is land that is designated by the Rhode Island Department of Administration Division of Planning to be of statewide importance for the production of food, feed, fiber, forage, and oilseed crops. Generally, farmlands of statewide importance include those lands that do not meet the requirements to be considered prime farmland, yet they economically produce high crop yields when treated and managed with modern farming methods. Some may produce as high a yield as prime farmland if conditions are favorable.

In order to extend the additional protection of state regulation to prime farmland, the State of Rhode Island has expanded its definition of farmland of statewide importance to include all prime farmland areas. Therefore, in Rhode Island, all USDA-designated prime farmland soils are also farmland of statewide importance.

Table 5-3 lists soil units designated as farmland soils of statewide importance that are found within the ROW.

Table 5-3: Farmland Soils of Statewide Importance within the ROW

Soil Map Unit Symbol	Name	Percent Slope
BhA	Bridgehampton silt loam	0 to 3
BhB	Bridgehampton silt loam	3 to 8
BmA	Bridgehampton silt loam, till substratum	0 to 3
BmB	Bridgehampton silt loam, till substratum	3 to 8
CdB	Canton and Charlton fine sandy loams	3 to 8
EfA	Enfield silt loam	0 to 3
HkC	Hinckley gravelly sandy loam	3 to 15
MmA	Merrimac sandy loam	0 to 3
Rc	Raypol silt loam	0 to 3
ScA	Scio silt loam	0 to 3
Ss	Sudbury sandy loam	0 to 3

Source: Soil Survey of Rhode Island (Rector, 1981).

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5.3.3 Potentially Erosive Soils

The erodibility of a soil is dependent upon the slope of the land occupied by the soil and the texture of the soil. NRCS has characterized soil map units, as "highly erodible", "potentially highly erodible" or “not highly erodible” due to sheet and rill erosion. This determination is done by using the Universal Soil Loss Equation (USLE). The USLE relates the effects of rainfall, soil characteristics, and the length and steepness of slope to the soil's tolerable sheet and rill erosion rate (see Figure 5-2).

Soils are applied an erodibility factor (K), which is a measure of the susceptibility of the soil to erosion by water. Soils having the highest K values are the most erodible. K values in Rhode Island range from 0.10 to 0.64 and vary throughout the depth of the soil profile with changes in soil texture. Very poorly drained soils and certain flood plain soils usually occupy areas with little or no slope. Therefore, these soils are not subject to erosion under normal conditions and are not given an erodibility factor. Soil map units described as strongly sloping or rolling may include areas with slopes greater than eight percent and soil map units with moderate erosion hazard are listed in Table 5-4.

Table 5-4: Soil Mapping Units with Potential Steep Slopes within the ROW

Soil Map Unit Symbol	Soil Phase	Percent Slope	Erodibility Hazard	Surface K Values
BoC	Bridgehampton – Charlton complex	3 to 15	Phel	
CeC	Canton & Charlton fine sandy loams	3 to 15	Phel	
ChC	Canton & Charlton v. stony fine sandy loams	8 to 15	Hel	0.20/0.24
HkC	Hinckley gravelly sandy loam	rolling	Phel	0.17
HkD	Hinckley gravelly sandy loam	hilly	Hel	0.17
QoC	Quonset gravelly sandy loam	3 to 15	Phel	0.20

Notes:
hel = highly erodible land
phel = potentially highly erodible land
Source: Soil Survey of Rhode Island (Rector, 1981) and United States Department of Agriculture, Natural Resources Conservation Service, Highly Erodible Soil Map Units of Rhode Island, Revised January 1993.

5.4 Surface Water

The Project lies within the Narragansett Bay drainage basin of Rhode Island.

A drainage basin is the area of land that drains water, sediment, and dissolved materials to a common outlet at some point along a stream channel (Dunne and Leopold, 1978), and is synonymous with watershed. Within the Narragansett Bay drainage basin are numerous subordinate watersheds associated with river systems. The Narragansett Bay Basin includes the system of waterways that discharge into the Atlantic Ocean between Point Judith in Narragansett and Sakonnet Point in Little Compton. The Narragansett Bay Basin also comprises the watershed tributaries to Narragansett Bay and the small waterways that flow into the Atlantic Ocean from Sakonnet Point east.

The waters of the State of Rhode Island (meaning all surface water and groundwater of the State) are assigned a Use Class which is defined by the most sensitive, and therefore governing, uses which it is intended to protect. Waters are classified according to specific physical, chemical and biological criteria which establish parameters of minimum water quality necessary to support the water Use Classification. The water quality classification of the major surface waters within the Study Area are identified in the descriptions of the water courses that follow. Classification and use of all water courses within the Study Area are presented in Table 5-5.

The ROW is drained by waterways which generally flow to the east and southeast into Narragansett Bay. Figure 5-3 depicts surface waters within the Study Area.

Pursuant to the requirements of Section 305(b) of the Federal Clean Water Act, water bodies which are determined to be not supporting their designated uses in whole or in part are considered impaired, and placed on the Clean Water Act, Section 303(d) List of Impaired Waters or have a total maximum daily load (TMDL) assessment where they are prioritized and scheduled for restoration. The causes of impairment are those pollutants or other stressors that contribute to the actual or threatened impairment of designated uses in a water body. Causes include chemical contaminants, physical parameters, and biological parameters. Sources of impairment are not determined until a TMDL assessment is conducted on a water body. Five impaired waters are located within the Study Area: Maskerchugg River, Saddle Brook, Fry Brook, Frenchtown Brook, and Hunt River. TMDLs have been approved for the pathogen and bacteria impairments within each of these impaired waters.

Table 5-5: Surface Water Resources within the Study Area

Water Body Name	Town	Approximate Location	Use Classification
Maskerchugg River	Warwick/E. Greenwich	5,200 feet north of Division Street	B
Saddle Brook (Tributary to the Maskerchugg River)	Warwick	1,300 feet north of Division Street	B
Tributary to the West Branch of the Maskerchugg River	East Greenwich	2,200 feet south of Division Street	B
Tributary to Hunt River	East Greenwich	2,150 feet north of Frenchtown Road	(A)
Fry Brook	E. Greenwich	1,320 feet north of Frenchtown Road	B
Frenchtown Brook	E. Greenwich	890 feet south of Frenchtown Road	A
Hunt River	E. Greenwich/ N. Kingstown	Headwaters to Frenchtown Road	A
Hunt River	E. Greenwich/N. Kingstown	Frenchtown Road to the Brown and Sharpe discharge outfall located approximately 0.55 miles downstream of Frenchtown Road.	B

Classification	Use
A	Public drinking water supply, no treatment.
B	Public drinking water supply with appropriate treatment; agricultural uses; bathing, other primary contact recreational activities; fish and wildlife habitat.
( )	Small streams tributary to Class A waters are considered Class A; small streams which are not otherwise designated are assumed to be Class B based on Rhode Island's Water Quality Standards criteria.

Source: R.I. Department of Environmental Management. Water Quality Regulations (December 2010).
R.I. Department of Environmental Management. State of Rhode Island 2012 303(d) List of Impaired Waters Final (August 2012)

Table 5-6: Impaired Surface Water Resources within the Study Area

Water Body	Impairment	Category
Maskerchugg River	Cadmium (Cd) levels	5
Maskerchugg River	Fecal coliform	TMDL
Saddle Brook	Fecal coliform	TMDL
Fry Brook	Pathogens	TMDL
Frenchtown Brook	Pathogens	TMDL
Hunt River	Pathogens	TMDL

Category	Explanation
TMDL	TMDL developed for pathogens/bacteria impairments and approved by EPA.
5	Impaired or threatened for one or more designated uses by a pollutant(s), and requires a TMDL. This Category constitutes the 303(d) List of waters impaired or threatened by a pollutant(s) for which one or more TMDL(s) are needed.

Source: R.I. Department of Environmental Management. State of Rhode Island 2012 303(d) List of Impaired Waters, Final August 2012.

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5.4.1 Maskerchugg River Watershed

The Maskerchugg River drains in an area of approximately six square miles and is located within portions of East Greenwich and Warwick. Although there are several unnamed intermittent and perennial streams within this watershed, there is only one named tributary, Dark Entry Brook, which lies outside of the Study Area. This watercourse originates on the west side of Drum Rock Hill, approximately one half mile east of the Kent County Substation, and flows south to its confluence with the Maskerchugg River at Bleachery Pond. Elevations within the Maskerchugg River watershed range from sea level at the drainage outlet at Greenwich Cove to 350 feet above sea level on Spencer Hill. The river has an average gradient of one percent, although the slope is greater near its headwaters along the south side of Cowesett Road. The Maskerchugg River is a RIDEM Use Class B waterway.

5.4.1.1 Saddle Brook

Saddle Brook originates approximately 1.5 miles west of Interstate 95 in the Town of West Warwick and passes through a variety of land uses including woodlands, residential, commercial/industrial, and transportation areas. For part of its approximately 2.4-mile length, Saddle Brook flows adjacent to Interstate 95. The portion of Saddle Brook which crosses the Study Area is classified by the RIDEM as a Class B water.

5.4.2 Hunt River Watershed

The Hunt River Basin is centrally located in Rhode Island on the westerly side of Narragansett Bay. The watershed drains approximately 25 square miles (15,445 acres) and includes parts of seven Rhode Island communities: Exeter, North Kingstown, East Greenwich, West Greenwich, Coventry, West Warwick, and Warwick. The watershed includes Hunt River, Potowomut River, and four major tributaries. The major tributary sub-watersheds are Sandhill Brook (2,352 acres), Frenchtown Brook (4,487 acres), Scrabbletown Brook (1,653 acres), and Fry Brook (1,986 acres) (see Figure 5-3).

With an average gradient of nine feet per mile, the main stream of the Hunt River slowly meanders through coastal lowlands to the dam at Forge Road where it meets tidal water approximately four river miles downstream from the ROW. The major tributaries to the Hunt River include Sandhill Brook, Scrabbletown Brook, Mawney Brook, Frenchtown Brook, and Fry Brook. Of these, only Frenchtown Brook and Fry Brook are located within the ROW.

With the exception of Sandhill Brook, these tributaries originate in the hilly and forested glacial till uplands. Sandhill Brook, like the Hunt River, has little gradient and runs northeasterly through coastal lowlands.

Elevations within the Hunt River watershed begin at sea level at Forge Road in North Kingstown and extend to more than 470 feet above sea level near the headwaters of Frenchtown Brook at Hopkins Hill in West Greenwich. All of the ponds on the Hunt River appear to be man-made, although small natural ponded areas may have existed before alterations. The average annual runoff, as measured at the Forge Road USGS gauging station, is about 27 million gallons a day, however, the river may discharge as little as eight million gallons a day for extended periods. The Hunt River is identified by the RIDEM as a Class A water body from its head waters to Frenchtown Road. From this point to Forge Road the river has a Class B use designation.

The two major tributaries to the Hunt River located within the ROW are Frenchtown Brook and Fry Brook. The following is a brief description of the characteristics of each tributary.

5.4.2.1 Frenchtown Brook

Frenchtown Brook originates within hilly glacial till in the eastern portion of West Greenwich and meanders eastward for approximately five miles before reaching the Hunt River approximately 600 feet north of Frenchtown Road. The RIDEM has classified Frenchtown Brook as a Use Class A water body. Class A waters are suitable for public water supply without any prior treatment. Frenchtown Brook is used for fishing and is periodically stocked. A fish ladder has been constructed within the brook west of State Route 4 to promote access to spawning areas by alewife and other anadromous fish.

5.4.2.2 Fry Brook

Fry Brook originates approximately 4,000 feet west of Bartons Corner in the Town of East Greenwich and passes through a variety of land uses including woodlands, agriculture fields, and transportation areas. For part of its three-mile length, Fry Brook flows adjacent to Route 2, receiving additional input from several small tributaries which originate west of Route 2. Fry Brook provides habitat for brook trout and is considered a valuable tributary to the Hunt River. The portion of Fry Brook which crosses the Study Area is classified by the RIDEM as a Class B water.

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5.4.3 Flood plain

The 100-year flood plain represents the extent of flooding that would result during a storm event having a one percent chance of occurring per year. Based on available Federal Emergency Management Agency (FEMA) mapping for the towns within the Study Area, the ROW crosses several areas of designated 100-year (Zone A) frequency flood plain. These areas include the flood plain of the Hunt River, Frenchtown Brook, Fry Brook, and Maskerchugg River. The unnamed watercourses may also contain 100-year flood plain though not mapped by FEMA.

5.5 Groundwater

The presence and availability of groundwater resources is a direct function of the geologic deposits in the area. Within the portion of the Study Area overlying deep stratified drift deposits, groundwater resources have the highest potential yield and quality, and thus are given the highest classification (Class GAA). These groundwater resources are presumed suitable for public drinking water use without prior treatment. Approximately 40 percent of the ROW is located within areas classified as GAA by the RIDEM, Groundwater Division. The remaining 60 percent of the ROW is located within areas classified as GA. Groundwater classified GA is also presumed suitable for public or private drinking water use without prior treatment, however, the potential yield of this resource is less than that of Class GAA due to the nature of the surrounding geologic deposits (glacial till and bedrock). Both GAA and GA classes are subject to the same groundwater quality standards and preventative action limits for organic and inorganic chemicals, microbiological substances and radionuclides. Groundwater resources within the Study Area are depicted in Figure 5-3.

Groundwater classified GB are those groundwater resources which may not be suitable for public or private drinking water use without treatment due to known or presumed degradation resulting from overlying land uses. Class GC groundwater is known to be unsuitable for drinking water use due to waste disposal practices such as landfills. Class GB and GC areas are served by a public water supply. These groundwater classifications do not occur within the Study Area.

5.5.1 Sole Source Aquifers

The major groundwater resource identified within the Study Area is the Hunt-Annaquatucket/Pettaquamscutt (HAP) Aquifer System. The United States Environmental Protection Agency has designated the HAP as a Sole Source Aquifer. The HAP Aquifer is the primary source of groundwater for public use in portions of Warwick, East Greenwich and North Kingstown. The purpose of sole source aquifer designation is to manage land use practices within the aquifer recharge area to protect groundwater quality. The entire ROW lies within the HAP recharge area. The location of the sole source aquifer is depicted on Figure 5-3.

5.6 Vegetation

The Study Area contains a variety of vegetative cover types typical of southern New England. These types include oak/pine forest, old field and managed lawn. This section of the report focuses on upland communities. Wetland communities are discussed in Section 5.7 of this report.

5.6.1 Oak/Pine Forest Community

The forested habitats located within the Study Area are dominated by an oak/pine canopy. Although these woodlands appear similar throughout, differences in the tree and shrub communities occur between sites. Precipitation and aspect are important factors in determining what vegetation a particular site will support. Hilltops and south facing slopes are often deficient in the amount of soil moisture available to the plant community. In summer, when the moisture requirements of plants are highest, hilltops become substantially drier than sites farther down slope. The trees growing on hilltops, therefore, are more tolerant of dry conditions, smaller, more widely spaced and are a different species composition than those on more favorable sites. Red oak (with mixtures of other oaks) and white pine generally occur on outwash soils and sandy till hills in the Study Area. Oak/pine forest also occurs on shallow-to-bedrock nutrient poor soils in the vicinity of the ROW.

Common associates of the hilltop oak/pine forests in the vicinity of the transmission line ROW include black (*Quercus velutina*) scarlet (*Q. coccinea*), and white (*Q. alba*) oaks as well as aspen (*Populus sp*.) and gray birch (*Betula populifolia*). The shrub/sapling understory includes such species as black cherry (*Prunus serotina*), lowbush blueberry (*Vaccinium angustifolium*) and greenbrier (*Smilax rotundifolia*). Sheep laurel (*Kalmia angustifolia*) and sweet fern (*Comptonia peregrina*) occasionally occur under oak stands with canopy openings on rocky slopes. Herbaceous species include bracken fern (*Pteridium aquilinum*), tree clubmoss (*Lycopodium obscurum*) and hay-scented fern (*Dennstaedtia punctilobula*). These hilltop communities occur where excessively drained soils predominate, and on hilltops throughout the Study Area.

There is an increase in the diversity within plant communities on midslopes compared with dry hilltops. The increase in soil moisture produces this greater diversity in trees, shrubs and herbs. Midslope tree species in addition to oaks include black birch (*Betula lenta*), white ash (*Fraxinus americana*), American beech (*Fagus grandifolia*) and several species of hickory (*Carya* sp.). Shrubs include witch hazel (*Hamamelis virginiana*), sassafras (*Sassafras albidum*) and ironwood (*Carpinus caroliniana*). Greenbrier and poison ivy (*Toxicodendron radicans*) are also common in this community. Common groundcover species include tree clubmoss and wintergreen (*Gaultheria procumbens*). Midslope oak/pine communities occur on cool north facing slopes and adjacent to forested wetlands on the uncleared portion of the ROW.

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5.6.2 Old Field Community

Vegetation within the cleared portions of the ROW is typically representative of an old field successional community. Old field communities are established through the process of natural succession from cleared land to mature forest. Within the cleared ROW, periodic vegetation management has favored the establishment and persistence of grasses and herbs. Over time, pioneer woody plant species including gray birch, black cherry, sumac (*Rhus* sp.) and eastern red cedar (*Juniperus virginiana*) have become established.

Within the cleared portions of the ROW, vegetation varies considerably. On dry hilltops, little bluestem (*Schizachyrium scoparium*), round-head bushclover (*Lespedeza capitata*), staghorn sumac (*Rhus typhina*) and eastern red cedar are common. On the mid-slope, greenbrier and blackberry (*Rubus* sp.) form dense, impenetrable thickets. Numerous herbs including goldenrod (*Solidago* sp.), aster (*Aster* sp.), pokeweed (*Phytolacca americana*), and mullein (*Verbascum thapsus*) are also common.

5.6.3 Managed Lawn

Portions of the cleared ROW are managed residential lawn. Typically these areas consist of a continuous grass cover which may include Kentucky bluegrass, red fescue, clover, and plaintains. Ornamental shrubs may also occur within these areas.

5.6.4 Agricultural Areas

Based on the existing land use mapping obtained from the RIGIS, the G-185S Line crosses an area of agricultural use. This agricultural use area appears to be an open field located immediately north of East Greenwich High School adjacent to Avenger Drive.

5.7 Wetlands

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

5.7.1 Study Area Wetlands

State-regulated freshwater wetlands and/or streams have been identified and delineated within the ROW. Figure 5-4 depicts wetland resources based on available RIGIS data within the Study Area. Field methodology for the delineation of State-regulated resource areas was based upon vegetative composition, presence of hydric soils and evidence of wetland hydrology. Based on the provisions of the Rhode Island Fresh Water Wetlands Act and Rules and Regulations Governing the Administration and Enforcement of the Freshwater Wetlands Act (RIDEM 2010) (the "Rules"), state-regulated fresh water wetlands include swamps, marshes, bogs, forested or shrub wetlands, emergent plant communities and other areas dominated by wetland vegetation and showing wetland hydrology. Swamps are defined as wetlands dominated by woody species and are three acres in size, or greater. Marshes are wetlands dominated by emergent species and are one acre or greater in size. Bogs are wetlands dominated by "bog" species and generally support sphagnum moss. Bogs have no minimum size criteria. Emergent plant communities are areas similar to marshes in vegetation composition; however, there is no size criterion. Forested and shrub wetlands are similar to swamps, but do not meet the three acre size criteria.

The upland area within 50 feet of the edge of a swamp, marsh or bog is regulated as the 50-foot Perimeter Wetland under the Rules. Emergent plant communities, forested wetlands and shrub wetlands do not merit a 50-foot Perimeter Wetland.

In addition to these vegetated wetland communities, Rhode Island also regulates activities in and around streams and open waterbodies which include Rivers, Streams, Ponds, Areas Subject to Storm Flowage (ASSF), Areas Subject to Flooding (ASF) and Flood Plain. A river is any perennial stream indicated as a blue line on a USGS topographic map. If the river is less than 10 feet wide, the area within 100 feet of each bank is regulated as 100 foot Riverbank Wetland. If the river is greater than 10 feet wide, the area within 200 feet of each bank is regulated as 200 foot Riverbank Wetland.

A pond is an area of open standing or slow moving water present for six or more months during the year and at least one quarter acre in size. Ponds have a 50 foot Perimeter Wetland associated with the boundary. An ASSF is defined as any body of flowing water as identified by a scoured channel or change in vegetative composition or density that conveys storm runoff into or out of a wetland.

Wetland types and their dominant plant species located within the ROW are described below.

5.7.1.1 Pond

A pond is a water body that is at least one-quarter acre in size, with open standing or slowly moving water present for at least six months a year. The boundary of a pond is determined by the extent of water which is delineated and surveyed. No ponds are located within the ROW.

5.7.1.2 Swamp

Swamps are defined as areas at least three acres in size, dominated by woody vegetation, where groundwater is at or near the ground surface for a significant part of the growing season. A 50-foot perimeter wetland is applied to swamps. Shrub swamps are areas dominated by broad-leaved deciduous shrubs and have an emergent herbaceous layer. Dominant species include sweet pepperbush (*Clethra alnifolia*), highbush blueberry (*Vaccinium corymbosum*), winterberry (*Ilex verticillata*), and swamp azalea (*Rhododendron viscosum*). Other species occurring in these swamps include arrowwood (*Viburnum dentatum*), and silky dogwood (C*ornus amomum*). Drier portions of shrub swamps are often densely overgrown with wild grape (*Vitus labrusca*) and greenbrier. Common species in the herbaceous layer include cinnamon fern, sensitive fern (*Onoclea sensibilis*), poison ivy (*Toxicodendron radicans*), and dewberry (*Rubus hispidus*). Although some wetlands on the ROW are composed entirely of shrub swamp, in most wetlands the shrub swamp occurs in areas where the wetland crosses the managed portion of the ROW.

Forested swamps mainly occur on the edges of the managed ROW where the shrub swamps are present. Vegetation in a forested swamp is comprised of red maple, willow (*Salix* sp.), black gum (*Nyssa sylvatica*), alder (*Alnus* sp.), silky dogwood, sweet pepperbush, winterberry, swamp azalea, cinnamon fern (*Osmunda cinnamomea*), common reed (*Phragmites australis*), and peat moss (*Sphagnum* sp.).

5.7.1.3 Marsh

Marshes are wetlands at least one acre in size where water is generally above the surface of the substrate and where the vegetation is dominated by emergent herbaceous species. Marsh is the dominant cover type in the large wetland system associated with the Hunt River within the ROW. Marsh vegetation is typically dominated by broad-leaved cattail (*Typha latifolia*) and tussock sedge (*Carex stricta*), with lesser amounts of common reed, sensitive fern, marsh fern (*Thelypteris palustris*), soft rush (*Juncus effusus*), and woolgrass (*Scirpus cyperinus*). One marsh is present within the ROW.

5.7.1.4 River

A River is a body of water designated as a perennial stream by the US Geologic Survey (a blue line stream on a USGS topographic map). Rivers located within the Study Area are the Maskerchugg River and Hunt River.

5.7.1.5 Stream/Intermittent Stream

A stream is any flowing body of water or watercourse other than a river which flows during sufficient periods of the year to develop and maintain defined channels. Such watercourses carry groundwater discharge and/or surface runoff. Such watercourses may not have flowing water during extended dry periods but may contain isolated pools or standing water. Streams and intermittent streams within the Study Area include Saddle Brook, Fry Brook, Frenchtown Brook, and other unnamed tributaries associated with these waterways. The ROW crosses seven streams/intermittent streams.

5.7.1.6 Emergent Plant Communities

Emergent plant communities within the ROW wetlands are characterized by cattail, bulrush (*Scirpus pungens*), blue joint (*Calamagrostis canadensis*), woolgrass (*Scirpus* *cyperinus*), meadowsweet, Joe-Pye weed (*Eupatorium dubium*), sensitive fern (*Onoclea sensibilis*), soft rush, and reed canary grass (*Phalaris arundinacea*).

5.7.1.7 Shrub/Forested Wetland

Shrub wetlands in the transmission line ROW are dominated by highbush blueberry, sweet pepper bush, arrowwood, spicebush, winterberry, greenbrier and cinnamon fern with minor amounts of skunk cabbage and poison ivy. Some wetlands on the ROW are composed entirely of shrub wetland.

Forested wetlands occur at the edge of the maintained ROW where most shrub wetlands are present. Vegetation includes red maple, yellow birch (*Betula alleghaniensis*) and ash with an understory generally consisting of vegetation mentioned previously in the shrub wetland.

5.7.1.8 Flood Plain

A flood plain is the land area adjacent to a river or stream or other body of flowing water which is, on the average, likely to be covered with flood waters resulting from a 100-year frequency storm event as mapped by FEMA. The flood plain areas within the ROW were described in Section 5.4.3.

5.7.1.9 Area Subject to Storm Flowage

ASSFs are channel areas and water courses which carry storm, surface, groundwater discharge or drainage waters out of, into, and/or connect freshwater wetlands or coastal wetlands. ASSFs are recognized by evidence of scouring and/or a marked change in vegetative density and/or composition.

5.7.1.10 Special Aquatic Site

A Special Aquatic Site (vernal pool) is a contained basin that lacks a permanent above ground outlet. It fills with water with the rising water table of fall and winter or with the meltwater and runoff of winter and spring snow and rain. Special aquatic sites contain water for a few months in the spring and early summer.

5.8 Wildlife

As previously described, the ROW passes through a variety of aquatic and terrestrial habitats. The wildlife assemblages present within the Study Area vary according to habitat characteristics. An overall list of wildlife species expected to occur within the transmission line ROW was compiled. This list encompasses the major habitats encountered within the ROW. It should be noted that individual species may not occur in one particular area as opposed to another, but may be found in the general area of the transmission line. A list of amphibian, reptiles, birds and mammals expected to occur within a given habitat are provided in Table 5-7. This information is based on geographical distribution and habitat preferences as described in New England Wildlife: Habitat, Natural History and Distribution (DeGraaf and Yamasaki, 2001).

Table 5-7: Expected and Observed Wildlife Species

	Terrestrial Habitats		Aquatic Habitats					
	Oak/Pine Forest	Old Field	Bog	Shallow Marsh	Shrub Swamp	Forested Wetland	River	Stream
AMPHIBIANS AND REPTILES								
Spotted Salamander	X				X	X		
Red Spotted Newt	X				X			
Northern Dusky Salamander	X							
Redback Salamander	X		X			X		
Northern Two-Lined Salamander	X		X			X	X	X
Eastern American Toad	X	X		X	X	X		
Fowler's Toad	X					X		
Northern Spring Peeper				X	X	X		
Gray Tree Frog	X		X		X	X		
Bullfrog				X	X	X		
Green Frog				X	X	X	X	X
Wood Frog	X		X	X	X	X		X
Pickerel Frog	X		X			X		X
Common Snapping Turtle	X	X	X	X		X	X	X
Stinkpot		X						
Spotted Turtle		X	X	X	X			
Eastern Box Turtle	X	X				X		
Eastern Painted Turtle						X		
Northern Water Snake			X		X	X	X	
Northern Brown Snake	X				X	X		
Eastern Garter Snake	X	O	X		X	X		
Northern Ringneck Snake	X					X		
Northern Black Racer	X	X			X	X		
Eastern Smooth Green Snake		X			X			
Eastern Milk Snake	X		X			X		
BIRDS								
Green Backed Heron				X		X	X	X
Wood Duck				X		X	X	
American Black Duck			X	X		X		
Sharp-shinned Hawk	X	X				X		
Red-shouldered Hawk	X				X			
Red-tailed Hawk	O	O				X		
Rough-legged Hawk		X	X					
American Kestrel		X						
Ring-necked Pheasant		X						
Ruffed Grouse	X	X				X		

	Terrestrial Habitats		Aquatic Habitats					
	Oak/Pine Forest	Old Field	Bog	Shallow Marsh	Shrub Swamp	Forested Wetland	River	Stream
American Woodcock	X	X			O			
Morning Dove	X	X						
Eastern Screech-Owl	X			X		X		
Great Horned Owl	X	X				X		
Barred Owl	X					X	X	X
Whip-poor-will	X	X				X		
Ruby-throated Hummingbird		X				X		
Downy Woodpecker	X					X		
Hairy Woodpecker	X					X		
Northern Flicker	X					X		
Eastern Wood-Pewee	X					X		
Alder Flycatcher				X				
Willow Flycatcher		X						
Least Flycatcher	X					X		
Eastern Phoebe	X					X		
Great Crested Flycatcher	X							
Eastern Kingbird		X				X		
Tree Swallow		X		X				
Blue Jay	O	O				O		
American Crow	X	X						
Black-capped Chickadee	O	O						
Tufted Titmouse	O					X		
Red-breasted Nuthatch	X		X			X		
White-breasted Nuthatch	X					X		
Brown Creeper	X		X			X		
Carolina Wren	X	X						
House Wren	X	X				X		
Blue-gray Gnatcatcher	X	X			X	X		
Eastern Bluebird	X	X						
Veery	X					X		
Hermit Thrush	X	X	X		X	X		
Wood Thrush	X					X		
American Robin	O	O	X		X	X		
Gray Catbird		O	X		O			
Northern Mockingbird		X						
Brown Thrasher	X	X						
Cedar Waxwing	X	X			X			
Northern Shrike		X						
European Starling		X						
Yellow-throated Vireo	X					X		
Warbling Vireo	X					X		
Red-eyed Vireo	X					X		
Blue-winged Warbler		X			X			
Nashville Warbler	X		X		X			
Yellow Warbler	X	X			X			
Chestnut-sided Warbler		X			X			
Yellow-rumped Warbler	X	X			X	X		
Black-throated Green Warbler	X					X		
Pine Warbler	X							
Prairie Warbler		X						
Black & White Warbler	X		X			X		
American Redstart	X					X		

	Terrestrial Habitats		Aquatic Habitats					
	Oak/Pine Forest	Old Field	Bog	Shallow Marsh	Shrub Swamp	Forested Wetland	River	Stream
Ovenbird	X					X		
Northern Waterthrush	X		X		X	X	X	X
Common Yellowthroat	X	X	X	X	X	X		
Canada Warbler	X		X		X	X		
Scarlet Tanager	X					X		
Northern Cardinal		O			X		X	X
Rose-breasted Grosbeak	X	X				X		
Indigo Bunting	X	X						
Rufous-sided Towhee	X	X						
Chipping Sparrow	X							
Fox Sparrow	X	X			X			
Song Sparrow	X	X			X			
Tree Sparrow		X			X			
Swamp Sparrow			X	X	X			
Field Sparrow		X						
Red-winged Blackbird			X	X	X			
Common Grackle	X		X	X	X			
Brown-headed Cowbird	X					X		
Northern Oriole	X					X		
Purple Finch	X							
House Finch	X							
American Goldfinch			X	X	X	X		
House Sparrow		X						
MAMMALS								
Virginia Opossum	X	X		X	X	X		
Masked Shrew	X	X	X	X	X	X		
Northern Short-tailed Shrew	X	X	X	X	X	X		
Hairy-tailed Mole	X	X				X		
Eastern Mole		X				X		
Star-nosed Mole			X	X	X		X	X
Little Brown Myotis	X	X	X	X	X	X	X	X
Keen's Myotis	X	X	X	X	X	X	X	X
Silver-haired Bat		X	X	X	X		X	X
Eastern Pipistrelle	X	X	X	X	X	X	X	X
Big Brown Bat	X	X	X	X	X	X	X	X
Eastern Cottontail		O		X				
Snowshoe Hare	X		X			X		
Eastern Chipmunk	O	O				X		
Woodchuck	X	X						
Gray Squirrel	X	O				X		
Red Squirrel						X		
Southern Flying Squirrel	X							
White-footed Mouse	X	X	X		X	X		
Southern Red-backed Vole	X	X	X		X	X		
Meadow Vole		X	X	X	X			
Woodland Vole	X	X				X		
Muskrat			X	X	X		X	X
House Mouse		X						
Meadow Jumping Mouse		X	X	X				
Red Fox	X	X			X	X		
Gray Fox	X	X			X	X		

	Terrestrial Habitats		Aquatic Habitats					
	Oak/Pine Forest	Old Field	Bog	Shallow Marsh	Shrub Swamp	Forested Wetland	River	Stream
Raccoon	X	X	X	X	X	X		
Ermine	X	X			X	X		
Mink	X	X	X	X	X	X	X	X
Striped Skunk	X	X			X	X		
White-tailed Deer	O	O			X	X		

Legend:

X = expected to occur

O = observed by VHB. Spring 2005/Fall 2013

Source: New England Wildlife: Habitat, Natural History and Distribution (DeGraaf and Yamasaki, 2001

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5.8.1 Rare and Endangered Species

The Rhode Island Natural Heritage Program (RINHP) database hosted on the RIDEM Environmental Resource Mapping website[7] as the "Regulatory Overlays: Natural Heritage Areas" does not identify any rare species habitat polygons within the ROW. There are no known state or federally listed rare, threatened or endangered (RTE) species within the ROW.

7 http://www.dem.ri.gov/maps/index.htm

6.0 Description of Affected Social Environment

6.1 Introduction

As part of this application, National Grid is providing information on the land uses within and proximate to the ROW, visual resources in vicinity of the Project, and the public roadway systems in the area. Based on the nature of the Project (reconductoring of existing 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).

6.2 Land Use

This section describes existing and future land use within the Study Area. The scope of this discussion will address those features which might be affected by the Project.

Land use along the ROW includes a mix of residential, commercial, institutional, transportation, industrial, and agricultural land uses as shown in Figure 6-1. The only natural open-water areas in the ROW are the Hunt River and its associated backwater areas located near the southern terminus of the Project.

6.2.1 Land Use Along the Transmission Line Corridor

The northern terminus of the Project is located south of Cowesett Road at the Kent County Substation in the City of Warwick. From the Kent County Substation, the Warwick section of the ROW runs south and generally parallel to and west of Interstate 95. The route crosses the Maskerchugg River and continues south through woodlands until reaching the intersection of Major Potter and Green Bush Roads. The ROW crosses over Major Potter Road and turns southwest, crossing woodlands before reaching Interstate 95. Continuing southwest, the ROW crosses Interstate 95, and runs for approximately 1,500 feet through forested, residential and wetland areas before reaching Division Street, the boundary between Warwick and East Greenwich.

After crossing Division Street into East Greenwich, the ROW heads south paralleling Route 4 on the east for approximately 2.8 miles, crosses Middle Road, and continues south, passing residential areas and the East Greenwich High School. Continuing south and paralleling Route 4, the ROW crosses a former gravel operation and a new Route 403 interchange before reaching Frenchtown Road.

After crossing over Frenchtown Road, the ROW continues south, paralleling Route 4 for approximately 1,000 feet, crossing Davisville Road and entering the Audubon Davis Memorial Wildlife Refuge property ("Audubon Property") associated with the Hunt River. The Audubon Property, located in the Towns of East Greenwich and North Kingstown, comprises over 100 acres of wildlife preserve. The ROW runs south through the Audubon property for approximately 5,400 feet to the Old Baptist Road Tap Point in the Town of East Greenwich. This portion of the ROW crosses forested upland areas and the Hunt River wetland complex.

6.2.2 Open Space and Recreation

Several areas of open space, including recreational areas, are present within the Study Area. These include the Audubon Property off Davisville Road, and the Hunt River Glen Conservation Easement off South County Trail. These open space resources provide year round opportunities for hiking, canoeing, and nature study.

The East Greenwich High School Athletic Complex is an established recreational area within the Study Area. This facility includes running tracks, football, soccer, and baseball fields.

6.2.3 Future Land Use

In order to assess future land use, an analysis of current zoning was undertaken. Typically, towns and cities manage future growth through zoning regulations which provide a degree of control over a community. The majority of the Study Area is zoned farming, industrial or residential in varying densities. High density residential areas within the Study Area include the City of Warwick and the Town of East Greenwich. More specifically, these areas are located northwest of Cowesett Road in Warwick and west of Route 4 south of Division Street in East Greenwich. The existing G-185S Line does not cross any areas currently zoned as high density residential.

Agricultural land within the ROW consists of an open field located immediately north of East Greenwich High School.

The only mention of electric transmission lines in the City of Warwick Draft Comprehensive Plan dated June 2013 is within Chapter 11 "Sustainability and Resilience" which notes that new transmission lines were being constructed as part of the Rhode Island Reliability Project.

The Town of East Greenwich Comprehensive Plan was adopted by the Town Council on August 26, 2013, but does not specifically address transmission lines.

There is no mention of electric transmission facilities in the Comprehensive Plan adopted by North Kingstown Town Council on October 20, 2008.

6.3 Visual Resources

The Rhode Island Department of Administration has not designated any areas within or immediately adjacent to the Project corridor as scenic areas of statewide importance. The undeveloped Audubon Property is located within a portion of the ROW off Davisville Road. Users of the Hunt River and East Greenwich High School have a viewscape of the existing transmission lines within the ROW.

6.4 Historic and Cultural Resources

The Public Archaeology Laboratory, Inc. (PAL) completed a Phase I(c) archaeological survey within the G-185S Line ROW. The locations of 16 of 19 structures planned for removal and replacement were given a rating of high to moderate sensitivity for intensive level subsurface testing.

Sixty-Six 50-x-50-cm shovel test pits, one array, and one judgmentally located test pit, were excavated within the area of potential effect at the high and moderate locations.

Archaeological investigations by PAL have identified two sites on this ROW, the previously documented Hunt River Site and the Maskerchugg South Site, discovered during the G-185S survey. Results of the testing support the previous determination that the Hunt River Site does not represent a significant archaeological resource in accordance with National Register eligibility criteria. Based on the results of the G-185S Project survey, PAL recommends that the Maskerchugg South Site does not represent a significant archaeological resource. Accordingly, no further archaeological investigation of either site is recommended as a planning element of structure replacements for the Project.

6.5 Transportation

The transportation needs of the Project are served by a network of federal, state and local roads and highways. The ROW crosses three town roads, three state routes, and Interstate 95 (Table 6-1) which will be utilized to access the G-185S Line.

Table 6-1 Right-of-Way Road Crossings

Road Name	Type
Interstate 95	Interstate
Division Street (Route 401)	State
Middle Road	Town
Avenger Drive	Town
Route 403	State
Frenchtown Road (Route 402)	State
Davisville Road	Town

6.6 Electric and Magnetic Fields

Electric and magnetic fields are present whenever electricity is used. The voltage causes an electric field which is usually measured in kilovolts per meter (kV/m). The current causes a magnetic field which is usually measured in milligauss (mG). Electric and magnetic fields were modeled and calculated to determine the edge of ROW field strengths with the existing conductors. These calculations were made based upon pre-Project Projected Summer 2015 annual average load (AAL) and annual peak load (APL). For the purpose of EMF modeling the Project is divided into five separate cross sections where the transmission lines change configuration. The cross-sections are shown on Figure 6-2. The electric fields for these cross sections are listed in Table 6-2 and the magnetic fields for the cross sections listed in Tables 6-3 and 6-4.

Table 6-2 Calculated Electric Field for Cross Sections XS-1 through XS-5

			Location[1] Electric field (kV/m)	
Cross Section	Description	Configuration	−ROW edge	+ROW edge
XS-1	Kent County to Structure #12	Pre-Project (2015)	0.47	0.01
XS-2	Structure #13 to Structure #45	Pre-Project (2015)	0.00	0.21
XS-3	Structure #46 to Structure #49	Pre-Project (2015)	0.27	0.21
XS-4	Structure #51 to Structure #54	Pre-Project (2015)	0.02	0.01
XS-5	Structure #54 to Structure #59	Pre-Project (2015)	0.22	0.01

[1] "- ROW edge" is the east side of the ROW. "+ ROW edge" is the west side of the ROW.

Table 6-3 Calculated Magnetic Field at AAL for Cross Sections XS-1 through XS-5

Cross section	Description	Configuration	Location[1] Magnetic Field (mG) −ROW edge	+ROW edge
XS-1	Kent County to Structure #12	Pre-Project (2015)	23.3	1.4
XS-2	Structure #13 to Structure #45	Pre-Project (2015)	0.1	19.5
XS-3	Structure #46 to Structure #49	Pre-Project (2015)	19.8	19.7
XS-4	Structure #51 to Structure #54	Pre-Project (2015)	8.4	1.1
XS-5	Structure #54 to Structure #59	Pre-Project (2015)	47.9	1.7

[1] "- ROW edge" is the east side of the ROW. "+ ROW edge" is the west side of the ROW.

Table 6-4 Calculated Magnetic Field at APL for Cross Sections XS-1 through XS-5

Cross section	Description	Configuration	Location[1] Magnetic Field (mG) −ROW edge	+ROW edge
XS-1	Kent County to Structure #12	Pre-Project (2015)	31.0	1.8
XS-2	Structure #13 to Structure #45	Pre-Project (2015)	0.1	26.0
XS-3	Structure #46 to Structure #49	Pre-Project (2015)	19.8	26.2
XS-4	Structure #51 to Structure #54	Pre-Project (2015)	9.9	1.5
XS-5	Structure #54 to Structure #59	Pre-Project (2015)	55.3	2.2

[1] "- ROW edge" is the east side of the ROW. "+ ROW edge" is the west side of the ROW.

7.0 Impact Analysis

7.1 Introduction

The Project will include reconductoring 5.3 miles of the G-185S Line extending from Kent County Substation in Warwick south to the Old Baptist Road Tap Point in East Greenwich, and will include the replacement of 19 of 62 structures. Impacts to environmental resources and the social environment will be negligible, and any anticipated minor impacts are addressed in the following sections. No impacts to bedrock, flood plain, groundwater, farmland soils, or air quality are expected.

7.2 Soils

Construction activities which disturb soil have the potential to increase the rates of erosion and sedimentation. Vehicle travel within the ROW may result in soil compaction and decreased infiltration rates. To minimize these potential impacts, standard construction techniques and BMPs, in accordance with the Rhode Island Soil Erosion and Sediment Control Handbook, will be installed and routinely maintained throughout the construction period. BMPs including the installation of erosion control barriers and swamp mats; the re-establishment of vegetation; and dust control measures will be employed to minimize any short- or long-term effects due to construction activity. These devices will be inspected by National Grid's environmental monitor frequently during construction and supplemented, repaired or replaced when needed. National Grid will develop and implement an Environmental Field Issue (EFI) document which will detail the BMPs and inspection protocols to guide the construction contractor and their personnel.

Excess soil from excavation at pole structures in uplands will be spread around the poles and stabilized to prevent migration to wetland areas or removed from the ROW. Wetland topsoil from exaction for pole structures in wetlands will be segregated and preserved for use during site restoration. Excess material excavated from pole structure locations in wetlands will be disposed of at upland sites or removed from the ROW. Topsoil will be spread over any excess excavated subsoil material which will then be seeded and mulched to promote rapid revegetation.

Highly erodible and potentially highly erodible soils are present within the ROW. Generally these areas include sloping till dominated uplands in the northern portion of the Project and the steeply sloping outwash terrace faces associated with the Hunt River. Any soils disturbed by construction activity within these areas will be stabilized with straw mulch or an erosion control blanket to minimize the off-site migration of sediments.

The ROW crosses mapped areas of prime farmland soils. The majority of these areas are currently developed as the East Greenwich High School complex. Both residential and transportation land uses also occupy a portion of these areas throughout the ROW. The Project will not displace any prime farmland soils.

Once work activities are completed, disturbed soils will be stabilized with seed and mulch to promote establishment of vegetative cover.

7.3 Surface Waters

Any impact of the Project upon surface watercourses will be minor and temporary. Construction activities temporarily increase risks for erosion and sedimentation that may temporarily degrade existing water quality; however, appropriate BMPs will be implemented and maintained to effectively control sediment. In addition, construction equipment will not cross rivers and streams along the construction corridor without the use of temporary mat bridges or other crossing structures. Swamp mats will be installed so as to not impede water flow. Emphasis has been placed on utilizing existing gravel roadways within the ROW and seeking access points that avoid crossing wetlands and surface waters.

The major surface water features within the transmission line ROW include the Maskerchugg River, Saddle Brook, Fry Brook, Frenchtown Brook, and the Hunt River. Swamp mats will be used to access structure locations within or adjacent to surface water features as conditions warrant. Access to most structure locations adjacent to these watercourses will be provided without impacting the channels either by using alternate upland access on the ROW or by spanning the areas using temporary wooden mats during construction. Sedimentation and erosion within these watercourses will be minimized through the implementation of BMPs prior to construction activities.

Potential impacts to surface waters if sediment transport is not controlled include increased 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. Erosion and sedimentation controls will effectively minimize the potential for this situation to occur. The implementation and maintenance of stringent erosion and sedimentation control BMPs will limit the levels of Project related sedimentation and will minimize adverse impacts to surface waters.

7.4 Groundwater

Potential impacts to groundwater resources within the transmission line ROW as a result of construction activity will be negligible. Equipment used for the construction of the transmission line will be properly maintained and operated to reduce the chances of spills of petroleum products and antifreeze. Refueling of equipment will be conducted in upland areas. Within primary groundwater recharge areas, special safeguards will be implemented to assure the protection of groundwater resources. Refueling equipment will be required to carry spill containment and prevention devices (i.e., absorbent pads, clean up rags, five gallon containers, absorbent material, etc.) at all times. In addition, maintenance equipment and replacement parts for construction equipment will be on hand to repair failures and stop a spill in the event of equipment malfunction. In some scenarios, refueling in place will be allowed for equipment that cannot be moved from a fixed location. Appropriate precautions must be utilized and National Grid Environmental representatives must be consulted prior to initiating the refueling.

Following construction, the normal operation and maintenance of the transmission line facility will pose no threat to groundwater resources.

7.5 Vegetation

The Project will occur within an existing ROW that has been managed to maintain vegetation at a height that does not interfere with the existing power lines. The Project will require mowing of vegetation in and along the ROW access roads and near structures that are to be replaced or accessed. Selective tree removal and trimming will be required for the Project. Management of the ROW vegetation will continue after the Project is completed to ensure continued access to the transmission line structures. ROW vegetation management will be completed in accordance with the National Grid Five Year Vegetation Management Plan 2009-2013 and the Rules and Regulations Governing the Administration and Enforcement of the Freshwater Wetlands Act (Rules).

7.6 Wetlands

The Project will result in some minor temporary wetland impacts at wetlands south of Kent County Substation, north of Frenchtown Road, and east of South County Trail near the southern Project terminus. Access road locations have been chosen to avoid wetlands completely where possible. Where unavoidable, wetland crossings were chosen to cross at previously impacted locations or at narrow points of the wetland. Swamp mats will be used at all unavoidable wetland crossings. The remaining structures are located in upland and have upland access resulting in no wetland impact. Where structures are located in or near wetland areas, erosion control measures in addition to swamp mats, will be employed as needed to reduce sedimentation impacts on the wetland. No long-term impacts to wetlands in the Project corridor will result from the proposed reconductoring.

7.7 Wildlife

Minor, temporary disturbances of wildlife may result from equipment travel and construction crews working in the Project corridor. During construction, displacement of wildlife may occur due to disturbance associated with ROW mowing and the operation of construction equipment. Wildlife currently utilizing the forested edge of the cleared ROW may be affected by the construction of the Project. Larger, more mobile species, such as eastern white tailed deer or red fox, will leave the construction area. Individuals of some bird species will also be temporarily displaced. Depending on the time of year of these operations, this displacement could impact breeding and nesting activities.

Smaller and less mobile animals such as small mammals, reptiles, and amphibians may be affected during vegetation mowing and the transmission line construction. The species impacted during the reconductoring of the transmission line are expected to be limited in number. Effects will be localized to the immediate area of construction around structure locations and along existing access roads. However, this is anticipated to be a temporary effect as it is expected that existing wildlife utilization patterns will resume and population sizes will recover once work activities are completed. Any wildlife displacement will be negligible and temporary, since no permanent alteration of the existing habitat is proposed. No long-term impacts to wildlife are expected to result from the Project.

7.8 Land Use and Recreation

Since the Project involves the reconductoring of existing facilities within an existing cleared ROW, there will be no permanent, long-term impacts to the existing residential, commercial, institutional, or recreational land uses in the ROW as outlined in the following sections.

7.8.1 Residential

A number of residential areas are located in proximity to the ROW. In most locations, existing vegetation will continue to provide visual screening of the facilities from residences. Because the Project occurs within an area dedicated to use for electrical facilities, the Project will not displace any existing residential uses, nor will it affect any future development proposals.

7.8.2 Commercial

The proposed route will cross a business area near Frenchtown Road. These businesses include commercial and retail uses. Normal operations will not be adversely affected by the Project. No displacement of business will result from the Project.

7.8.3 Institutions

East Greenwich High School is the only public institutional facility located along the Project route. The school is located approximately midway between Frenchtown Road and Middle Road. The existing transmission lines are visible from the high school. The proposed reconductoring work in this location will have no impact on existing land uses in the vicinity of the high school.

7.8.4 Recreation

The Project route passes through the Audubon Property and the Hunt River Glen Conservation Easement. These existing recreational uses will not be displaced by the Project.

Impacts to these existing parks and recreational areas from the Project will be minimal and short-term. Since the Project is located within an existing electric transmission line ROW, potential long-term impacts will be avoided.

7.8.5 Consistency with Local Planning

As documented in Section 2 of this Report, there is a clear need for improving the electrical reliability to the area. The City of Warwick, Town of East Greenwich, and Town of North Kingstown have Comprehensive Plans which describe the local direction regarding future development and growth in each community. Each municipality's Comprehensive Plan was evaluated with regard to expressed town-wide goals. The Project was then evaluated for consistency with the local planning initiatives in each community.

Because the Project will use existing ROW, it will not alter existing land use patterns and will not adversely impact future planned development. The Project will provide an adequate supply of electricity for the growth and development envisioned by the Comprehensive Plans of the host communities.

7.9 Visual Resources

Reconductoring consists of replacing existing conductors with new conductors. The Project will also require 19 structures to be replaced. Structures will be replaced along the same alignment and in roughly the same locations. Of the 19 structures to be replaced, five are existing double circuit steel davit arm structures that will be replaced with structures of the same type, 11 are existing wood pole davit arm structures that will be replaced with steel davit arm structures, and three are existing wood pole H-frame structures that will be replaced with steel H-frame structures. Following completion of the Project, the portion of the G-185S Line north of Interstate 95 will be comprised of structures with a uniform type which may result in some visual improvement from the current line configuration. No significant impacts to visual resources are anticipated as a result of the Project.

7.10 Noise

Temporary, minor construction noise may be generated by the reconductoring work that will occur during normal daytime working hours. Proper mufflers will be required to control noise levels generated by construction equipment. Noise impacts are expected to be negligible. Hours of construction will comply with applicable local requirements.

7.11 Transportation

The construction related traffic increase will be small relative to total traffic volume on public roads in the area. In addition, it will be intermittent and temporary, and construction related traffic will cease once the Project is completed. The addition of this traffic for the limited periods of time is not expected to result in any additional congestion or change in operating conditions along any of the roadways along the ROW.

National Grid will coordinate closely with RIDOT to develop acceptable traffic management plans for work within state highway ROWs. At all locations where access to the ROW intersects a public way, the contractor will follow a pre-approved work zone traffic control plan. Although traffic entering and exiting the ROW at these locations is expected to be small, vehicles entering and exiting the site will do so safely and with minimal disruption to traffic along the public way. Following construction, traffic activity will be minimal and will occur only when the ROW or transmission lines have to be maintained. As a result, the construction and operation of the transmission line will have minimal impact on the traffic of the surrounding area roadways. No long-term impacts to traffic flow or roadways are expected.

7.12 Historic and Cultural Resources

The PAL completed a Phase I(c) survey within the G-185S Line ROW. Of the 19 structure replacement and removals, the locations of 16 of the structures were given a rating of high to moderate sensitivity for intensive level subsurface testing.

As noted in Section 6.4, results of the testing to date support that the Hunt River and Maskerchugg South Sites do not represent significant archaeological resources in accordance with National Register eligibility criteria. Accordingly, no further archaeological investigation of either site is recommended prior to the structure replacements for the Project.

In the event National Grid plans any additional work bordering the Maskerchugg River and related wetlands north of the Maskerchugg River beyond the present Project, this area should continue to be considered sensitive for pre-contact components in meaningful contexts.

National Grid will work closely with the Rhode Island Historic Preservation and Heritage Commission (RIHPHC) to develop a strategy of mitigation if archaeological materials or potential historic properties are discovered during construction.

7.13 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 3.6, public health and safety will be protected.

7.14 Electric and Magnetic Fields

Electric field levels are a function of the voltage of transmission lines and other factors such as the phasing and configuration of the lines. Since the voltage will not change with the reconductoring, the electric field levels will not change from those shown in Table 6-2. The magnetic field levels at the edges of the ROW associated with the Project have been modeled and calculated. These calculations were also based upon Projected Summer 2015 and 2020 AAL and APL loads. The calculated magnetic field levels for the five cross-sections at AAL and APL are shown on Tables 7-1 and 7-2, respectively.

Magnetic field levels are a function of the current (load) on transmission lines and other factors such as the phasing and configuration of the lines. The Project will not change phasing or configurations of the lines. The magnetic field levels will not change as a result of the Project. A comparison of Table 6-3 and 6-4 with 7-1 and 7-2, respectively, shows small differences between existing and proposed conditions which are attributable to the change in projected loading of the parallel 3312 sub-transmission line.

A discussion of the current status of the health research relevant to exposure to electric and magnetic fields (EMF) is attached as Appendix A.

Table 7-1 Calculated Magnetic Field at AAL for Cross Sections XS-1 through XS-5

Cross Section	Description	Configuration	Location[1] Magnetic Field (mG) −ROW edge	+ROW edge
XS-1	Kent County to Structure #12	Pre-Project (2015)	23.3	1.4
		Post- Project (2015)	23.3	1.4
		Post- Project (2020)	23.3	1.4
XS-2	Structure #13 to Structure #45	Pre- Project (2015)	0.1	19.5
		Post-Project (2015)	0.1	19.5
		Post-Project (2020)	0.1	19.5
XS-3	Structure #46 to Structure #49	Pre-Project (2015)	19.8	19.7
		Post-Project (2015)	19.8	19.7
		Post-Project (2020)	20.4	19.7
XS-4	Structure #51 to Structure #54	Pre-Project (2015)	8.4	1.1
		Post-Project (2015)	8.4	1.1
		Post-Project (2020)	8.5	1.1
XS-5	Structure #54 to Structure #59	Pre-Project (2015)	47.9	1.7
		Post-Project (2015)	47.9	1.7
		Post-Project (2020)	48.6	1.7

[1] "- ROW edge" is the east side of the ROW. "+ ROW edge" is the west side of the ROW.

Table 7-2 Calculated Magnetic Field at APL for Cross Sections XS-1 through XS-5

Cross Section	Description	Configuration	Location[1] Magnetic Field (mG) −ROW edge	+ROW edge
XS-1	Kent County to Structure #12	Pre-Project (2015)	31.0	1.8
		Post-Project (2015)	31.0	1.8
		Post-Project (2020)	31.0	1.8
XS-2	Structure #13 to Structure #45	Pre-Project (2015)	0.1	26.0
		Post-Project (2015)	0.1	26.0
		Post-Project (2020)	0.1	26.0
XS-3	Structure #46 to Structure #49	Pre-Project (2015)	19.8	26.2
		Post-Project (2015)	19.8	26.2
		Post-Project (2020)	20.4	26.2
XS-4	Structure #51 to Structure #54	Pre-Project (2015)	9.9	1.5
		Post-Project (2015)	9.9	1.5
		Post-Project (2020)	10.0	1.5
XS-5	Structure #54 to Structure #59	Pre-Project (2015)	55.3	2.2
		Post-Project (2015)	55.3	2.2
		Post-Project (2020)	56.1	2.2

[1] "- ROW edge" is the east side of the ROW. "+ ROW edge" is the west side of the ROW.

8.0 Mitigation Measures

8.1 Introduction

Mitigation measures for this Project will be used to reduce the impacts of the work on the natural and social environment. The Project consists of the reconductoring of an existing transmission line in an existing ROW. As described in Chapter 7, there are no long-term impacts to mitigate as a result of this Project. Therefore, mitigation efforts are focused on the construction phase.

8.2 Construction Phase

The construction phase of the Project will include the replacement of poles and conductors of the G-185S Line. This work will require only minor disturbances to the surrounding natural environment. The use of existing access roads and erosion and sedimentation controls will mitigate possible disturbances to soils, wetlands, and other water resources. Straw wattles or compost mulch tubes will be placed around existing poles as needed where the poles are to be replaced near wetland or surface water resources. Stabilization of soil will occur when areas are disturbed.

National Grid will implement several measures during construction which will minimize impacts to the environment. These include the use of existing access roads and structure pads where possible, installation of erosion and sedimentation controls, supervision and inspection of construction activities within resource areas by an environmental monitor and minimization of disturbed areas. The following section details various mitigation measures which will be implemented to minimize construction related impacts.

8.2.1 Mitigation of Natural Resource Impacts

When the existing transmission lines were constructed, access roads were established within most portions of the ROW. During construction of the Project, vehicles will utilize these existing access roads where practical to minimize disturbance within the ROW.

Access through wetlands to the existing structure locations will be provided by utilizing swamp mats from the existing maintained portion of the ROW. Construction access will be limited to the existing structure locations and proposed access routes, and will be lined with erosion and sedimentation control BMPs where needed. Following erection of the structures, each area will be restored.

Vegetation management operations will be confined to the ROW. Vegetation mowing adjacent to wetland areas is of particular concern due to the potential for erosion, and therefore, specific mitigation measures will be implemented to minimize this potential where needed. These measures will include the installation of straw wattle or compost mulch tube diversion berms across the slope to intercept storm water runoff which will be directed through straw wattle or silt fence to remove suspended sediment. These structures will be maintained until vegetative cover is re-established. In addition, straw wattle and/or erosion control blankets will be installed across disturbed slopes adjacent to wetland areas in accordance with an erosion and sediment control plan. Excavated soils will be stockpiled and spread in approved soil areas well outside all biological wetland areas in such a manner that general drainage patterns will not be affected.

Where possible, existing vegetation will be retained at all road crossings and areas subject to public view to maintain a visual buffer to the ROW.

Stream crossings will be located perpendicular to the channel to the extent possible to reduce the crossing length and reduce the potential for disturbance to the water body. Design and implementation of all stream crossing structures (i.e., temporary mat bridges) will comply with standards and specifications as outlined in the "Rhode Island Soil Erosion and Sediment Control Handbook." Temporary access is used where the substrate is sufficiently firm or level to support equipment without creating a disturbance to the soil substrate.

8.2.1.1 Erosion and Sedimentation Control

Erosion and sediment control devices will be installed along the perimeter of identified wetland resource areas prior to the onset of soil disturbance activities to ensure that soil stockpiles and other disturbed soil areas are confined and do not result in downslope sedimentation of sensitive areas. Low growing tree species, shrubs and grasses will only be mowed along access roads and at pole locations. Construction crews will be responsible for conducting daily inspections and identifying erosion controls that must be maintained or replaced as necessary.

Dewatering may be necessary during excavations for pole structures adjacent to wetland areas. Water will be pumped into hay bale or silt fence settling basins or dewatering filter bags which will be located in approved areas outside wetland resource areas. The pump intake hose will not be allowed to set on the bottom of the excavation throughout dewatering. The basins or bags and all accumulated sediment will be removed following dewatering operations and the areas will be seeded and mulched.

8.2.1.2 Supervision and Monitoring

Throughout the entire construction process, National Grid 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, on a routine basis to ensure compliance with all federal and state permit requirements, National Grid 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 control techniques described in this report and will have an understanding of wetland 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, National Grid 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.

8.2.2 Mitigation of Social Resource Impacts

National Grid will minimize social resource impacts during construction by incorporating several standard mitigation measures. By use of an established transmission line ROW rather than creating a new ROW, the potential for disruption due to construction activities will be limited to an area already dedicated to transmission line uses. Construction generated noise will be limited by the use of mufflers on all construction equipment and by limiting construction activities to the hours specified in the local ordinances. Dust will be controlled by wetting and stabilizing access road surfaces, as necessary, and by maintaining crushed stone aprons at the intersections of access roads with paved roads. National Grid will minimize the potential for disturbance from the construction by notifying abutters of planned construction activities before and during construction of the line.

Some short term impacts are unavoidable, even though they have been minimized. By carrying out the reconductoring of the line in a timely fashion, National Grid will keep these impacts to a minimum.

National Grid will prepare a traffic management plan which will minimize impacts associated with increased construction traffic on local roadways.

8.3 Post-Construction Phase

Following the completion of construction, National Grid uses standard mitigation measures on all transmission line construction projects to minimize the impacts of projects on the natural and social environment. These measures include revegetation and stabilization of disturbed soils, ROW vegetation management practices and vegetation screening maintenance at road crossings and in sensitive areas. Other measures are used on a site specific basis. National Grid will implement the following standard and site specific mitigation measures for the Project.

8.3.1 Mitigation of Natural Resource Impacts

Restoration efforts, including final grading and installation of permanent erosion control devices, and seeding of disturbed areas, will be completed following construction. Construction debris will be removed from the Project site and disposed of at an appropriate landfill. Pre-existing drainage patterns, ditches, roads, fences, and stone walls will be restored to their former condition, where appropriate. Permanent slope breakers and erosion control devices will be installed in areas where the disturbed soil has the potential to impact wetland resource areas.

Vegetation maintenance of the ROW will be accomplished with methods identical to those currently used in maintaining the existing ROW. National Grid's ROW vegetation maintenance practices encourage the growth of low-growing shrubs and other vegetation which provides a degree of natural vegetation control. In addition to reducing the need to remove tall growing tree species from the ROW, the vegetation maintained on the ROW inhibits erosion.

8.3.2 Mitigation of Social Resource Impacts

Upon completion of the Project, magnetic field levels at the edges of the ROW will not significantly change from the existing condition.

Where possible, National Grid will limit access to the ROW by installing permanent gates and barriers where access roads enter the ROW from public ways. Select areas, may be visually screened with landscaping and/or grading.

Appendix A: Assessment of Electric and Magnetic Fields (EMF) and Health (October 2013)

Health Sciences Practice

Exponent®

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

G-185S 115-kV Transmission Line

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

G-185S 115-kV Transmission Line

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October 31, 2013

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Acronyms and Abbreviations

AC	Alternating current
ALL	Acute lymphoblastic leukemia
ALS	Amyotrophic lateral sclerosis
AMI	Acute myocardial infarction
CI	Confidence interval
CVD	Cardiovascular disease
DMBA	7,12-dimethylbenz[a]anthracene
ELF	Extremely low frequency
EMF	Electric and magnetic fields (or electromagnetic fields)
G	Gauss
HCN	Health Council of the Netherlands
HR	Hazard ratio
Hz	Hertz
IARC	International Agency for Research on Cancer
ICES	International Commission on Electromagnetic Safety
ICNIRP	International Committee on Non-Ionizing Radiation Protection
ISCO	International Standard Classification of Occupations
JEM	Job exposure matrix
kV	Kilovolt
kV/m	Kilovolts per meter
mG	Milligauss
MPE	Maximum permissible exposure
NIEHS	National Institute for Environmental and Health Sciences
OR	Odds ratio
RR	Relative Risk
SCENIHR	Scientific Committee on Emerging and Newly Identified Health Risks

SRR	Standardized Rate Ratio
SSI	Swedish Radiation Protection Authority
SSM	Swedish Radiation Safety Authority
TWA	Time weighted average
V/m	Volts per meter
WHO	World Health Organization

Limitations

At the request of National Grid, Exponent 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 health and extremely low frequency (ELF) electric and magnetic fields (EMF) at the request of National Grid as part of its Application for the G-185S 115-kV transmission line reconductoring project in portions of the City of Warwick, Town of East Greenwich, and Town of North Kingstown, Rhode Island.

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 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 application 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 30 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. Research on ELF EMF and long-term human health effects was prompted by an epidemiology study conducted in 1979 of children in Denver, Colorado, which studied the relationship of their cancers with the potential for ELF EMF exposure from nearby distribution and transmission lines. The results of that study prompted further research on childhood leukemia and other cancers. Childhood leukemia has remained the focus of EMF and health research, although many other diseases have been studied, including other cancers in children and adults, neurodegenerative diseases, reproductive effects, and cardiovascular disease, among others.

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. The public and policy makers should look to the conclusions of these reviews, since the reviews are conducted using set scientific standards by scientists representing the various disciplines required to understand the topic at hand. In a health risk assessment of any exposure, it is essential to consider the type and strength of research studies available for evaluation. Human health studies vary in methodological rigor and, therefore, in their capacity to extrapolate findings to the population at large. Furthermore, relevant studies in three areas of research (epidemiologic, *in vivo,* and *in vitro* research) must be evaluated to understand possible health risks. Section 4 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. 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. 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).

This report provides a systematic literature review and a critical evaluation of relevant epidemiology and *in vivo* studies published from May 2011 to July 1, 2013. These recent studies did not provide sufficient evidence to alter the basic conclusion of the WHO: the research does not suggest that electric fields or magnetic fields are a cause of cancer or any other disease at the levels we encounter in our everyday environment.

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 International Commission on Non-Ionizing Radiation Protection's or the International Committee for Electromagnetic Safety's exposure limits for the prevention of acute health effects at high exposure levels. In light of the epidemiologic data on childhood leukemia, scientific organizations are still in agreement that only low-cost interventions to reduce ELF EMF exposure are appropriate; the state of Massachusetts has approved transmission projects that have proposed effective no-cost and low-cost technologies to reduce magnetic-field exposure to the public. While the large body of existing research does not indicate any harm associated with ELF EMF, 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 of these reviews 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.

National Grid requested that Exponent provide an easily-referenced document to bring the WHO report's conclusions up to date. This report systematically evaluates peer-reviewed research and reviews by scientific panels published between May 1, 2011 and July 1, 2013 and also describes if and how these recent results affect conclusions reached by the WHO in 2007.

3 Extremely Low Frequency Electric and Magnetic Fields: Nature, Sources, Exposure, and Known Effects

Nature of ELF EMF

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 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); one 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 called gauss (G), or in milligauss (mG), where 1 G = 1,000 mG.[1] The strength of the magnetic field at any point depends on characteristics of the source; in the case of power lines, strength is dependent on the arrangement of conductors, the amount of current flow, and distance from the conductors.

[1] 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.

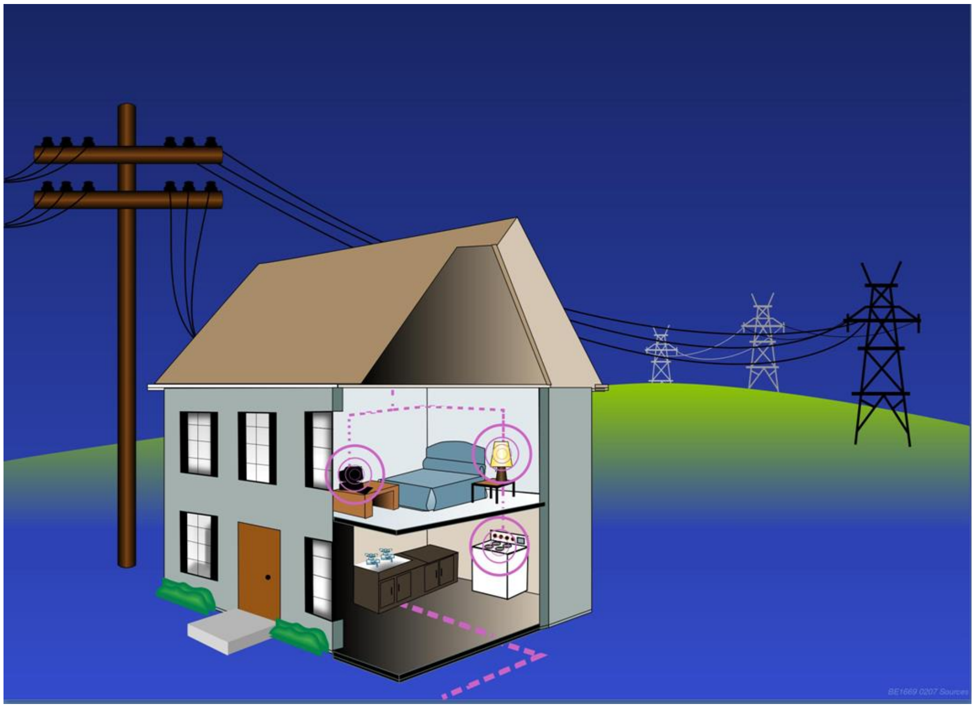

Figure 1. Numerous sources of ELF EMF in our homes (appliances, wiring, currents running on water pipes, and nearby distribution and transmission lines).

Sources and exposure

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

Since electricity is such an integral part of our infrastructure (e.g., transportation systems, homes, and businesses), people living in modern communities literally 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 0.01-0.02 kV/m, while appliances produce levels up to several tens of kV/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 of 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).[2]
    - 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).
    - The following 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 metallic piping, and homes close to 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.[3]

[2] TWA is the average exposure over a given specified time period (i.e., an 8-hour workday or a 24-hour day) 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.

[3] http://www.niehs.nih.gov/health/assets/docs_p_z/emf-02.pdf

- *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 (NIEHS, 2002) (Figure 2). The magnetic-field levels from underground transmission lines diminish much more quickly with distance than for overhead transmission lines because of the closer spacing of the conductors of underground transmission lines.

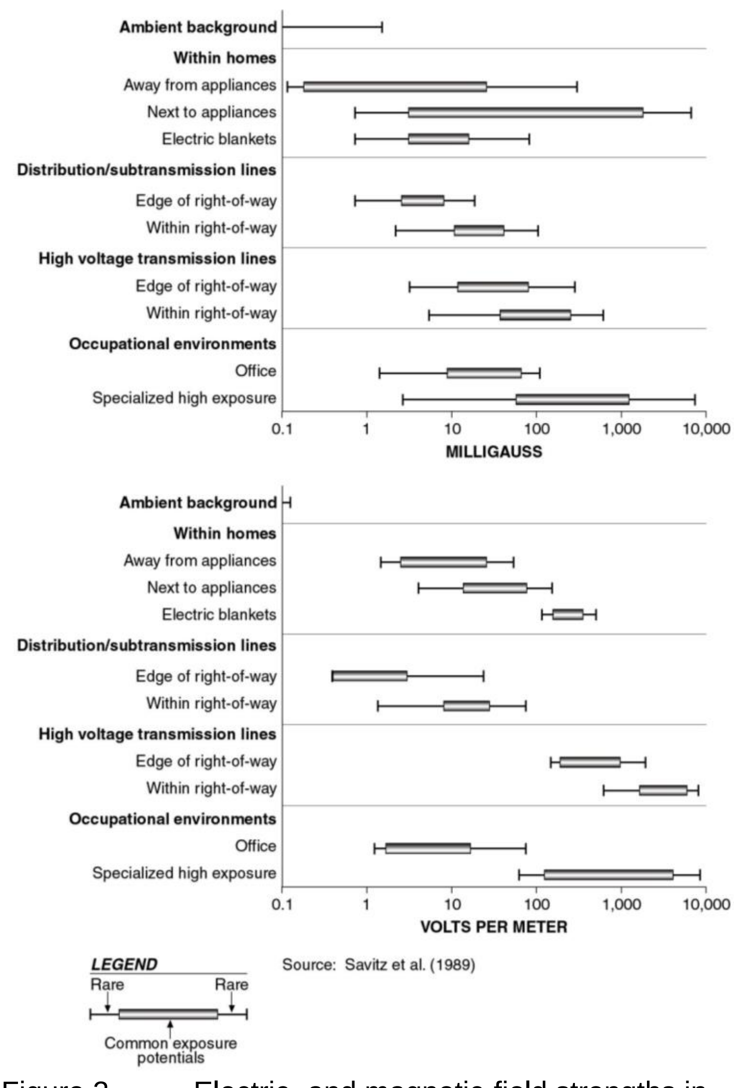

Figure 2. Electric- and magnetic-field strengths in the environment.

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. 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.

4 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 studies with a given result are not selected out from all of the studies available 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 presents 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 are typically conducted within the larger framework of health risk assessments or evaluations of particular exposures or exposure circumstances that qualitatively and quantitatively define health risks. Weight-of-evidence and health risk assessment methods have been described by several agencies, 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; and the US Environmental Protection Agency, which set guidance for public exposures (WHO, 1994; USEPA, 1993; USEPA, 1996). 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 EMF in a weight-of-evidence review, including exposure considerations, study design, 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

Exposure methods range widely in studies of ELF EMF, including: 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 the house (e.g., a child's bedroom); calculated magnetic-field levels based on the characteristics of nearby power installations; and, finally, personal 24-hour and 48-hour magnetic-field measurements.

Each of these methods has strengths and limitations (Kheifets and Oksuzyan, 2008). Since magnetic-field exposures are ubiquitous and vary over a lifetime as the places we frequent and the sources of ELF EMF in those places change, making 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.[4] 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 recent 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' (ISCO) job categories, which the authors attributed to variation in industry within the task-defined ISCO categories.

Types of health research studies

Research studies can be broadly classified into two groups: 1) epidemiologic observations of people and 2) experimental studies on animals, humans, cells, and tissues conducted in laboratory settings. Epidemiology studies investigate how disease is distributed in populations

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[4] 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.

and what factors influence or determine this disease distribution (Gordis, 2000). Epidemiology studies attempt to identify potential causes for human disease while observing people as they go about their normal, 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 epidemiology 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 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* and *in vitro* experimental studies are also 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. In the case of *in vitro* studies, the responses of cells and tissues outside the body 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 that agents that could present a potential health threat be explored by both epidemiology and experimental studies.

Both of these approaches—epidemiology and experimental laboratory studies—have been used to evaluate whether exposure to ELF EMF has any adverse effects on human health. Epidemiology studies are valuable because they are conducted in human populations, but they are limited by their non-experimental design and typical retrospective nature. In epidemiology 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, epidemiology 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 of risk is included to provide a foundation for understanding and interpreting statistical associations in epidemiology 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 of time. For example, the absolute risk of invasive childhood cancer in children ages 0 to 19 years for 2004 was 14.8 per 100,000 children (Ries 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 in the 0 to 19 year age range had an estimated absolute risk of childhood cancer of 15.4 per 100,000 in 2004, and African American children 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 a 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 of they are less costly and more time efficient.

Thus, the association between a particular disease and exposure is measured quantitatively in an epidemiology 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 vs. 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 epidemiology 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 range of the CI 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 where the “true” RR estimate lies. If the 95% CI does not include 1.0, the probability of an association being 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 3-4 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 an important tool 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. Therefore, in addition to the synthesis or combining of data, meta- and pooled analyses should be used to understand what 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 epidemiology studies

One key reason that results of epidemiology 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 epidemiology 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 epidemiology 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 epidemiology 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 tend to also 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 vs. association and evaluating evidence regarding causal associations

Epidemiology 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 are exposed in their studies, and diseases can be caused by a complex interaction of many factors, the results of epidemiology studies must be interpreted with caution. A single epidemiology 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, nine criteria for evaluating epidemiology studies (along with experimental data) for causality were outlined. In a more recent version of this report, these criteria have been reorganized into seven criteria. In the earlier version, 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 listing 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 is between exposure and disease, the less likely such an effect is the result of chance or unmeasured confounding.
Specificity	The exposure is the single (or one of a few) cause 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	This is also known as a dose-response relationship, i.e., the observation that the stronger or greater the exposure is, the stronger or greater the effect.
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 population.

Source: Department of Health and Human Services, 2004

The criteria were meant to be applied to statistically significant associations that have been observed in the cumulative epidemiologic literature (i.e., if no statistically significant association has been 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, aside from temporality, rule out causation.

In summary, the judicious consideration of these criteria is useful in evaluating epidemiology 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," epidemiology 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 reporting consistent results across many different populations and study designs that are supported by the experimental data collected from *in vivo* and *in vitro* studies.

Biological response vs. 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 a cause of disease. For example, when an individual 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 considered a biological response to the change in light conditions. Pupil constriction, however, is neither a disease itself, nor is it known to cause disease.

5 The WHO 2007 Report: Methods and Conclusions

The WHO is a scientific organization within the United Nations system whose mandate includes providing leadership on global health matters, shaping health research agendas, and setting 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 0-300 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.

The WHO published a Monograph on EMF in June 2007 as part of their Environmental Health Criteria Programme summarizing health research in the ELF range. The Monograph used standard scientific procedures, as outlined in its Preamble and described above in Section 4, 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,[5] 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 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 (see Figure 3). *In vitro* research is not described in Figure 3 because it provides ancillary information and, therefore, is used to a lesser degree in

[5] 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 Monograph 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.

evaluating carcinogenicity and is classified simply as strong, moderate, or weak. Categories include (from highest to lowest risk): carcinogenic to humans, probably carcinogenic to humans, possibly carcinogenic to humans, unclassifiable, 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 epidemiology studies and less than sufficient evidence of carcinogenicity in studies of experimental animals.

	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 900 substances and exposure circumstances to evaluate their potential carcinogenicity. Over 80% of exposures fall in the categories possible carcinogen (27%) or non-classifiable (55%). This occurs because, as described above, 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 history of the IARC, only one agent has been classified as probably not a carcinogen, which illustrates the conservatism of the evaluations and the difficulty in proving the absence of an effect beyond all doubt.

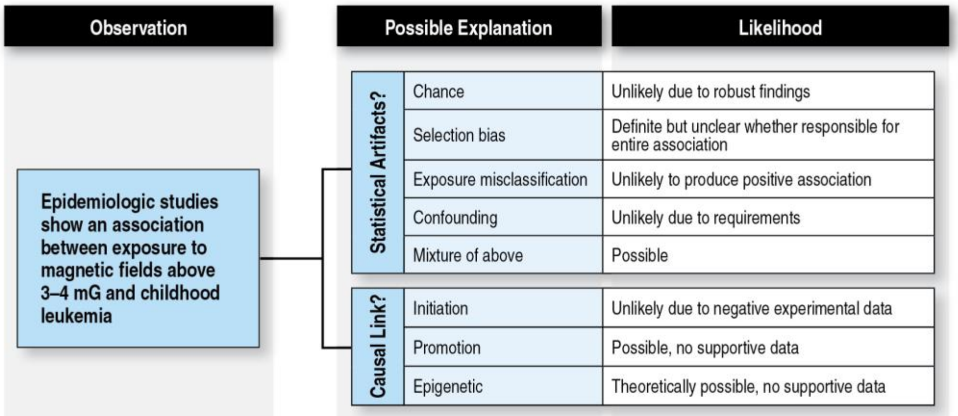
The WHO report provided the following overall conclusions with regard to ELF EMF:

> 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. 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 >3-4 mG (Ahlbom et al., 2000; Greenland et al., 2000); it is this data, categorized as limited epidemiologic evidence, that 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 larger 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 (i.e., no hazard or risk observed) experimental findings 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 3-4 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, 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 in 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. The evidence that ELF field exposure can enhance tumour 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.

In vitro research on carcinogenesis. The WHO concluded that magnetic-field exposure below 50,000 mG was not associated with genotoxicity *in vitro*. There was some evidence, however, to suggest that magnetic fields above these levels might interact with other genotoxic agents to induce damage. Evidence for an association between magnetic fields and altered apoptosis or expression of genes controlling cell cycle progression was considered inadequate.

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 epidemiology studies on miscarriage was described as inadequate and further research on this possible association was recommended, although low priority was given to this recommendation.

In vivo research on reproductive and developmental effects. The WHO concluded that the available *in vivo* studies were inadequate for drawing conclusions regarding the potential effects of magnetic fields on the reproductive system. Furthermore, they concluded that studies conducted in mammalian models showed no adverse developmental effects associated with magnetic-field exposure.

Neurodegenerative diseases. The WHO reported that the majority of epidemiology 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.

In vivo research on neurological effects. The WHO stated that various animal models were used to investigate possible field-induced effects on brain function and behavior. Few brief, transient responses had been identified.

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.

6 Current Scientific Consensus

The following sections identify and describe epidemiology and *in vivo* studies related to ELF EMF and health published from May 1, 2011 through July 1, 2013. 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 5.

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 literature indexed between May 1, 2011 and July 1, 2013.[6] All fields (e.g., title, abstract, keywords) were searched with various search strings that referenced the exposure and disease of interest,[7] as well as authors that regularly publish in this field. A scientist with experience in this area reviewed the titles and abstracts of these publications for inclusion in this evaluation. Only peer-reviewed, epidemiology studies, meta-analyses, human experimental studies, and whole animal *in vivo* studies of 50/60-Hz AC ELF EMF and recognized disease entities were included. The following specific inclusion criteria were applied:

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

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

3. **Exposure assessment methods**. Exposure must have been evaluated beyond self-report of an activity or occupation. Included studies estimated exposure through various methods including calculated EMF levels using distance from power lines; time-weighted average EMF exposures; and average exposure estimated from JEMs.

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6 While extensive efforts were made to identify relevant studies, it is possible that some studies reporting on the association between a disease and some measure of ELF EMF exposure were missed. Many occupational and environmental case-control studies of cancer are published, some of which examine a large number of possible exposures; if no reference to ELF EMF is made in the abstract, title, or keywords, for example, these studies may not have been identified using our search strategy. The most informative studies in this field, however, will be identified by our search strategy. In addition, 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 July 1, 2013, are not included in this update.

7 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).

4. **Study design**. Epidemiology, human experimental, and *in vivo* studies were included. A short section of recent *in vitro* studies on carcinogenesis was included for reference event though the previous updates did not systematically evaluate *in vitro* studies. For the most part, we rely on the conclusions of the WHO report (as described in Section 5) with regard to mechanistic data from *in vitro* studies since this field of study is less informative to the risk assessment process (IARC, 2002). Furthermore, only *in vivo* studies of carcinogenicity were evaluated in this review; the review relies on the conclusions of the WHO with regard to *in vivo* studies in the areas of reproduction, development, neurology, and cardiology.

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

Methodological research is now being pursued in many areas of ELF EMF research to identify the possible impact of certain aspects of study design or biases on the studies' results. Therefore, articles evaluating the impact of methodological aspects of epidemiology studies in this field are discussed, where appropriate. Systematic review articles of relevant topics are also noted, where appropriate. Articles published prior to the scope of this update are noted in certain circumstances to provide context.

Epidemiology 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 and *in vitro* research on carcinogenesis. Tables 3 through 12 list the relevant studies that were published May 1, 2011 through July 1, 2013 in these areas.[8]

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, a statistically significant two-fold association was observed between childhood leukemia and estimated exposure to high, average levels of magnetic fields (i.e., greater than 3-4 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," 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 June 2007.

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[8] Several studies are included that were published prior to May 1, 2011. These studies were not included in the previous update because they had not yet been indexed by Pub Med, so they are included in this current review.

Recent studies (2011 to July 1, 2013)

Eight studies have evaluated the association between childhood leukemia and magnetic fields since our previous review—five case-control studies, two pooled analyses, and one quantitative evaluation of the dose-response risk threshold of magnetic-field exposure levels (Table 2).

Wünsch-Filho et al. (2011) conducted a case-control study in the State of São Paolo, Brazil, which included 162 cases of childhood ALL recruited from eight hospitals between 2003 and 2009. Controls (n=565) were selected from the São Paolo birth registry and matched to cases by gender, age, and city of birth.

A methodological strength of this study was its exposure assessment that utilized two approaches to estimate ELF magnetic field exposure. First, the researchers took 3-minute magnetic field measurements in every room in the house and outside the door to the home, although the authors do not indicate at what time of day or year these outdoor measurements were taken.[9] They also took a 24-hour measurement in the child's bedroom. These measurements were categorized into four groups: < 1 mG, 1 mG to ≤ 3 mG, ≥ 3 mG to 4 mG, and > 4 mG. Second, the distance between each household to the closest power line of various voltages (88 kV, 138 kV, 230 kV, 345 kV, and 440 kV) was determined for cases and controls in the Metropolitan Region, which is the only area in the state where electric grid maps are available.

In addition to the exposure assessment methods, the study by Wünsch-Filho et al. (2011) is noteworthy because of the relatively large proportion of cases with estimated exposure greater than 3 mG (11 cases, i.e., 7%). Prior to publication of this study, a pooled analysis (Kheifets et al., 2010a, discussed in a previous update) used their raw data to calculate an OR of 1.26 (95% CI=0.61-2.62) for 24-hour residential exposure > 3 mG, but Wünsch-Filho et al. (2011) reported a lower OR of 1.09 (95% CI: 0.33-3.61) for exposure at this level. The authors concluded that although their results do not support an association between childhood leukemia and magnetic fields, this null finding should be interpreted with caution due to poor participation rates, small sample sizes, and a hospital-based design. The most important limitation was selection bias, which may have artificially reduced the estimated magnitude of association (i.e., there were low participation rates and evidence that excluded controls had greater levels of magnetic-field exposure).

Jirik et al. (2012) conducted a matched case-control study of 79 cases with leukemia (mainly ALL) and 79 controls without leukemia in the Czech Republic. The authors reported statistically non-significant decreased magnitudes of association for leukemia ranging between 7% and 22% for exposures >0.2 µT (2 mG), >0.3 µT (3 mG), and >0.4 µT (4 mg). No evidence of a linear trend was observed. Controls were matched to cases by age, sex, and permanent residence (participant age range <15 years, which acted as a proxy for exposure duration). A detailed assessment of exposure was conducted, as described in an earlier publication by Jirik et al. (2011), and included spot measurements lasting between 15 and 45 minutes within a 1 to 5 meter distance from children's homes (measurements were repeated to account for short-term variability and also repeated in different seasons to account for seasonal variability);

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9 Since loads on power lines vary throughout the day and at different times of the year, spot measurements around the perimeter of a home are only a moderately good proxy for actual magnetic-field exposure levels (Armstrong et al., 2001).

measurements directly outside and inside children's homes; and measurements near high-voltage cables (220 kV and 440 kV).[10] Personal, 24-hour (h) exposure measurements were also collected and characterized in two ways, namely, via stationary measured values in different locations of children's typical surroundings (e.g., at home or in the classroom) and by three personal measurements "carried out on a 12 years [*sic*] old school boy under [the] assumption that a school child spends 18 h at home (spot measurement 0.072 µT [0.72 mG]) or around the house (spot measurement 0.075 µT [0.75 mG]) and 6 h at school (spot measurement 0.181 µT [1.8 mG])" (Jirik et al., 2011).

Although the research by Jirik et al. (2012) was strengthened by the multiple exposure measurements in various locations, some major limitations, in line with those observed in the Wünsch-Filho et al. (2011) study, warrant mention. For example, small sample sizes by exposure category, particularly at the highest levels of exposure (>0.4 µT (4 mG); 13 cases and 14 controls), may have limited the study power and consequently hindered the ability to detect a statistically significant association, if present. Unmeasured confounding by socioeconomic position, a potential risk factor for childhood leukemia (Borugian et al., 2005; Poole et al., 2006; Smith et al., 2006), may have masked the true magnitude of association. Potential selection bias due to the refusal of some hospitals to participate also presents a significant limitation. In particular, no mention was made regarding the number of hospitals that refused to participate in the identification of cases, and only two of five university hospitals in the region provided medical data for the control subjects. Hence, the number of eligible hospitals overall that refused to participate may be substantial and could have biased the selection of both cases and controls.

In a population-based case-control study by Sermage-Faure et al. (2013), 2,779 cases of childhood acute leukemia diagnosed before the age of 15 years in France from 2002 through 2007 and 30,000 randomly sampled controls were analyzed in relation to their residential distance from high- and very high-voltage power lines (63 kV to 150 kV and 225 kV to 400 kV, respectively). Control subjects were comparable to the cases in age, the number of children living in the household, and several demographic and socioeconomic attributes. Residential addresses at the time of diagnosis or control selection were geocoded blind to case/control status, and distance was categorized as follows: 0 to 49 meters, 50 to 99 meters, 100 to 199 meters, 200 to 599 meters, and ≥600 meters. The study showed no significantly elevated magnitudes of association for childhood leukemia in analyses stratified by high- and very high-voltage power lines or overall. Specifically, within 0 to 49 meters of a high-voltage line or very-high voltage line, the ORs were 1.0 (95% CI: 0.6-1.7) and 1.7 (95% CI: 0.9-3.6), respectively, adjusted for age and administrative area of residence. Sensitivity analyses using data from the most accurately geocoded residences (uncertainty ≤20 meters) did not alter the findings of no association for either type of power line. When restricted in a sensitivity analysis to age at diagnosis of 0 to 4 years and the most accurately coded addresses, however, a statistically significant association for childhood leukemia was observed in relation to very high-voltage power lines at a distance of 0 to 49 meters (OR=4.1, 95% CI: 1.3–13.3; based on five cases). An association was not reported in the same type of analysis restricted to power lines of 63 kV to 150 kV (OR=0.6, 95% CI: 0.2–1.8; based on four cases). A methodological strength of the study

[10] ELF-magnetic field values were 2.46 µT (20.4 mG) and 3.33 µT (33.3 mG) from the 220 kV and 440 kV cables, respectively, and 0.89 µT (8.9 mG) and 1.13 µT (10.1 mG) within 30 meters from the 220 kV and 440 kV cables, respectively (Jirik et al., 2011).

is that the design precluded participation bias in the assessment of exposure and subject characteristics. This study, however, was limited by uncertainty in the exposure metric and because residential histories, particularly at the time of birth, were unavailable, which makes unmeasured confounding by residential mobility a concern (Swanson, 2013). The study was further limited by small sample sizes in strata confined to the nearest residential locations and an assessment of exposure based on current residence only (i.e., exposures at previous residences and latency relationships could not be assessed).

Studies have also investigated if magnetic-field exposure of parents either prior to conception or during pregnancy may be relevant to the risk of childhood leukemia. A small body of literature is available on this topic with inconsistent findings, including a study by Hug et al. (2010) that was discussed in the previous update and two new case-control studies discussed here.

Reid et al. (2011) used advanced JEMs to compare the occupational exposure of the parents of children with leukemia to the exposure of parents of children without leukemia. As with the earlier study (Hug et al., 2010), Reid et al. (2011) found no statistically significant association with maternal or paternal magnetic-field exposure measured in several time periods, which included any time before birth, up to 2 years before birth, up to 1 year before birth, and 1 year after birth. Similarly, a matched case-control study conducted by Keegan et al. (2012) of paternal ELF EMF exposure based on occupational classification and childhood leukemia (16,764 ascertained cases) in Great Britain from 1962 to 2006 reported no statistically significant association between ELF EMF exposure and total leukemia, lymphoid leukemia, and acute myeloid leukemia. In this study, only "other leukemia" was associated with paternal magnetic field exposure (OR=1.64, 95% CI: 1.14–2.38). All models in this study (Keegan et al., 2012) were adjusted for paternal social class only.

Recent research has evaluated the possible confounding effects of contact currents and investigations of childhood leukemia (Does et al., 2011, discussed in the previous update). Contact currents occur when the water line provides the ground for the home's electrical system. The hypothesis is that a child may experience a contact current from touching surfaces at different potentials while bathing, and these contact currents may be responsible for the association between magnetic fields and childhood leukemia. Two criteria must be fulfilled for contact currents to have this confounding effect. First, there must be an independent causal relationship between contact currents and childhood leukemia, and second, there must be a strong association between residential magnetic fields and the voltage between bathtub plumbing fixtures and drains.

A pooled-analysis by Kavet et al. (2011) suggests that the second criterion is met. The authors combined data from the Northern California Childhood Leukemia Study for over 500 case and control residences (n≥500) with data from other measurement studies conducted in Pittsfield, Massachusetts (n=22 residences), Denver, Colorado (n=191 residences), and San Jose, California (n=15 residences). The authors reported an OR of 15.1 (95% CI 3.6-61.0) for the association between contact currents and magnetic fields and concluded that the data could "support the possibility that contact current could be responsible for the association of childhood leukemia with magnetic fields." Since only one epidemiology study has been conducted on this subject (Does et al., 2011), further research is warranted in study populations with a greater potential for elevated contact current and magnetic-field exposure and with information available on the frequency of contact-current exposure. The prevalence of contact currents in buildings, however, is declining rapidly with the increased use of non-conductive plastic plumbing.

Kheifets et al. (2011) conducted a quantitative analysis based on meta- and pooled analyses to examine the WHO's conclusion that statistically significant associations between exposure to magnetic fields and childhood leukemia are observed at exposure levels >3 mG to 4, The authors suggest that the data best fits a model assuming an association with childhood leukemia could occur below the 3 mG to 4 mG range if a true relationship existed, although there were many limitations to their analysis.

In a pooled analysis conducted by Schüz et al. (2012), overall and event-free survival up to 10 years from diagnosis of childhood ALL was assessed using population-based data involving 3,073 cases across Canada, Denmark, Germany, Japan, the United Kingdom, and the United States (age range at diagnosis 1 to 14 years). All studies included in the analysis required having long-term exposure measurements (≥24 h) of residential ELF magnetic fields or calculated ELF magnetic fields based on historical power load data from power lines and their distance to residences in the vicinity. Exposure data were categorized as follows in survival analyses: ≤0.1 µT (1 mG), n=2,703 cases; 0.1 µT (1 mG) to 0.2 µT (2 mG), n=234 cases; 0.2 µT (2 mG) to 0.3 µT (3 mG), n=68 cases; and >0.3 µT (3 mG), n=68 cases. The results showed that there were no statistically significant associations between residential ELF magnetic fields and overall survival or the risk of relapse. Compared with exposure levels ≤0.1 µT (1 mG), the hazard ratios (HR) among children with ALL for overall survival were 1.42 (95% CI: 0.99–2.05) at 0.1 µT (1 mG) to 0.2 µT (2 mG), 1.27 (95% CI: 0.65–2.50) at 0.2 µT (2 mG) to 0.3 µT (3 mG), and 0.96 (95% CI: 0.49–1.89) at >0.3 µT (3 mG). Similarly, the HRs for event-free survival were 1.10 (95% CI: 0.82–1.46) at 0.1 µT (1 mG) to 0.2 µT (2 mG), 1.14 (95% CI: 0.69–1.89) at 0.2 µT (2 mG) to 0.3 µT (3 mG), and 0.76 (95% CI: 0.44–1.33) at >0.3 µT (3 mG) compared with exposure levels ≤0.1 µT (1 mG).

Noted strengths of the study by Schüz et al. (2012) are the inclusion of more than 3,000 cases, the systematic and cumulative follow-up for vital status, and the adjustment of important prognostic risk factors.[11] Limitations included a relatively small sample size at exposures >0.3 µT (3 mG), n=68, i.e., 2.2%, and a limited number of events particularly at exposure levels ≥0.2 µT (2 mG), i.e., 18 and 29 for overall and event-free survival analyses, respectively. Furthermore, uncertainties in the exposure assessment is evident since some children only had spot measurements or calculated magnetic fields, and the measurements of long-term exposure varied between studies. Schüz et al. (2012) further note that participation bias may have been introduced due to nonparticipation among cases with poorer survival; however, whether nonparticipation was associated with exposure remains unclear.

In addition to these new studies, several other publications on magnetic fields and childhood leukemia are noteworthy. One editorial questioned whether studies of childhood leukemia and magnetic fields have exhausted the methods available to this field and stated that "better insights into this association cannot be expected" (Schmiedel and Blettner, 2010). Several areas of

[11] A prognostic risk designation was used, as defined by the US National Cancer Institute, with the low risk group including children aged <10 years and diagnostic white blood cell count <50,000/µl, and the high risk group including children aged ≥10 years and with a white blood cell count ≥50,000/ µl.

inquiry, however, may provide additional clarity. For example, an ongoing international epidemiology study is being conducted on children with high magnetic-field exposure from residence above internal transformer stations in apartment buildings, which provides a more stable estimate of the association in upper exposure categories with less concerns of selection bias (Hareuveny et al., 2011). Agreement on the relevant exposure metric and window has not been reached. In addition, further work on prenatal environmental exposures will continue since research suggests that the first genetic changes linked to leukemia occur as part of fetal development (Eden, 2010).

Recent methodological work (2011 to July 1, 2013)

A statistical association can represent a true causal relationship between the identified exposure and disease, or it may be an artifact attributed to study design or methodological conduct. In the absence of experimental data to support a causal relationship, the WHO identified several possible errors that may explain the reported statistical association between childhood leukemia and magnetic-field exposure in some studies, including chance, misclassification of the true magnetic-field exposure due to poor exposure assessment methods, uncontrolled confounding of hypothesized or unknown risk factors, and control selection bias.

ELF EMF presents unique challenges in exposure assessment because it is ubiquitous, imperceptible, and has many sources (Kheifets and Oksuzyan, 2008). No target exposure parameter or exposure window has been identified, and the numerous methods of estimating exposure (personal measurements, calculations, spot measurements, and distance from power lines, among other methods) likely result in a different degree of error within and between studies. In the Schüz et al. (2012) study, the effects of magnetic-field exposure on overall and event-free survival were not materially different when excluding children who, prior to their date of diagnosis, had moved from the home where the exposure measurements were collected, thus confirming the robustness of their findings. Future studies also should report findings from these types of sensitivity analyses, and should further aim to account for residential mobility, if possible, due to the potential confounding effect of in- and out-migration patterns on reported associations between residential magnetic-field exposure and childhood leukemia (Swanson, 2013).

Erroneous conclusions can be made when distance from power lines is considered a valid proxy for magnetic-field exposure. For example, Maslanyj et al. (2009) (discussed in our previous review) reported that only 23% of homes in a 200 meter corridor and 19% of homes in a 50 meter corridor of 220-kV and 440-kV transmission lines had a residential magnetic-field level above 2 mG. The study suggests that distance is not a sensitive or specific proxy of residential magnetic-field exposure and calls into question the relevance of the associations reported in such studies (e.g., Draper et al., 2005).

Previous work has confirmed that exposure misclassification is not due to the time of day when magnetic-field measurements are made. Schüz et al. (2007) (discussed in our previous review) reported no difference in the magnitude or pattern of results for nighttime vs. 24-hour or 48-hour magnetic-field measurements. This study refutes the hypothesis that nighttime exposures are more strongly associated with childhood leukemia because magnetic fields might affect carcinogenesis through a melatonin-driven pathway.

Recent studies confirmed suggestions from previous research (Mezei and Kheifets, 2006; Mezei et al., 2008a, 2008b) that control selection bias appears to be operating in case-control studies of childhood leukemia and magnetic fields, although the exact degree of its influence is still unknown (Wünsch-Filho et al., 2011; Jirik et al., 2012).

Assessment

Recent studies continue to support a weak, if not null, association between elevated magnetic-field levels and childhood leukemia, but they lack the methodological improvements required to advance this field. A recent review by Swanson and Kheifets (2012) investigated if geomagnetic fields modify the association between magnetic-field exposure and childhood leukemia, but only identified limited and statistically non-significant evidence for this association based on individual studies included in one of two pooled analyses (Ahlbom et al., 2000; Kheifets et al., 2010). Hence, the epidemiologic evidence remains limited and any observed statistical association between magnetic-field exposure and childhood leukemia remains unexplained.

Wünsch-Filho et al. (2011) has provided some evidence of an association with elevated magnetic-field levels, but the results are undermined by several limitations, the most significant of which was selection bias. Although Reid et al. (2011) used advanced JEM methods, Jirik et al. (2012) utilized multiple methods for repeated exposure assessment, and Schüz et al. (2012) pooled data from several studies conducted in multiple countries, resulting in an assessment of residential exposure in association with survival among more than 3,000 cases of ALL, small sample sizes (particularly at higher exposure levels), exposure uncertainties (e.g., based on residence, lack of complete data on residential history), and potential confounding with electromagnetic energy of different frequencies prevent firm conclusions from being drawn.

One of the major limitations of recent work is the validity of the exposure assessment. Magnetic-field estimates have largely been based on calculated levels from nearby power lines, distance from nearby power lines, and measured, short-term residential levels. Some scientists have opined that epidemiology has reached its limits in this area and any future research must demonstrate a significant methodological advancement (e.g., an improved exposure metric or a large sample size in high exposure categories) to be justified (Savitz, 2010; Schmiedel and Blettner, 2010).

The findings from the recent literature do not alter previous conclusions of the WHO and other reviews, including ours, that the epidemiologic evidence on magnetic fields and childhood leukemia is “limited” from the perspective of the IARC classification. Chance, confounding, and several sources of bias still cannot be ruled out. Conclusions from several published reviews (Kheifets and Oksuzyan, 2008; Pelissari et al., 2009; Schüz and Ahlbom, 2008; Calvente et al., 2010; Eden, 2010; Schüz, 2011) and scientific organizations (SSI, 2007; SSI, 2008; HCN, 2009a; SCENIHR, 2009; EFHRAN, 2012; SSM, 2013) support this conclusion.

Researchers will continue to investigate the association between exposure to magnetic fields and childhood leukemia. In a recent assessment of the epidemiologic evidence of magnetic-field exposure and childhood leukemia, Schüz (2011) suggested that, because of scientific uncertainty, only 1% to 3% of all childhood leukemia cases in Europe and North America could be due to magnetic-field exposure, should a causal relationship exist. This assessment also provides additional support of the conclusions made by the WHO that a causal relationship between magnetic-field exposure and childhood leukemia risk has not yet been demonstrated.

It is important to note that magnetic fields are just one area of study in the extensive body of research on the possible causes of childhood leukemia. There are several other hypotheses under investigation that point to possible genetic, environmental, and infectious explanations for childhood leukemia (e.g., McNally and Parker, 2006; Belson et al., 2007; Rossig and Juergens, 2008; Bartley et al., 2010 [diagnostic x-rays]; Amigou et al., 2011 [road traffic]; Swanson, 2013).

Table 2. Relevant studies of childhood leukemia

Author	Year	Study Title
Jirik et al.	2012	Association between childhood leukaemia and exposure to power-frequency magnetic fields in middle Europe
Kavet et al.	2011	The relationship between residential magnetic fields and contact voltage: a pooled analysis
Keegan et al.	2012	Case–control study of paternal occupation and childhood leukaemia in Great Britain, 1962–2006
Kheifets et al.	2011	Exploring exposure-response for magnetic fields and childhood leukemia
Reid et al.	2011	Risk of childhood lymphoblastic leukaemia following parental occupational exposure to extremely low frequency electromagnetic fields
Sermage-Faure et al.	2013	Childhood leukaemia close to high-voltage power lines – the Geocap study, 2002–2007
Schüz et al.	2012	Extremely low-frequency magnetic fields and survival from childhood acute lymphoblastic leukemia: an international follow-up study
Wünsch-Filho et al.	2011	Exposure to magnetic fields and acute lymphocytic leukemia in São Paulo, Brazil

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, 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).

Recent studies (2011 to July 1, 2013)

No new studies on childhood brain cancer have been published since the last update; hence, we have included the discussion of childhood brain cancer and magnetic-field exposure from the June, 2011 update.

Table 3 below provides a list of the studies of childhood brain cancer and magnetic-field exposure published since the WHO report. In response to the WHO recommendation above, both a meta- and pooled analysis of studies on childhood brain tumors and residential magnetic-field exposure were conducted by Mezei et al. (2008b) and Kheifets et al. (2010b), respectively.[12] In Mezei et al. (2008b), 13 epidemiologic studies were identified that used various proxies of residential magnetic-field exposure (distance, wire codes, calculated magnetic fields, and measured magnetic fields). The combined effect estimate was close to 1.0 and not statistically significant, indicating no association between magnetic-field exposure and childhood brain tumors. A sub-group of five studies, however, with information on childhood brain tumors and calculated or measured magnetic fields greater than 3-4 mG reported a combined OR that was elevated but not statistically significant (OR=1.68, 95% CI=0.83-3.43). The authors suggested two explanations for this elevated OR. First, they stated an increased risk of childhood brain tumors could not be excluded at high exposure levels (i.e., >3-4 mG). Second, they stated that the similarity of this result to the findings of the pooled analyses of childhood leukemia suggests that control selection bias is operating in both analyses. Overall, the authors concluded that the analysis did not find a significant increase in childhood brain cancer risk using various proxies of residential exposure to magnetic fields.

The pooled analysis by Kheifets et al. (2010b) provides stronger data compared to the meta-analysis described above because original data were used, various sub-group analyses were conducted, and there was adjustment for possible confounding variables (e.g., socioeconomic status and mobility). The pooled analysis included data from 10 studies published from 1979-2010 of childhood brain or central nervous system cancer with long-term measurements, calculated fields, or spot measurements of residential magnetic-field exposure. Similar to childhood leukemia, few cases of childhood brain cancer had estimated magnetic-field exposures greater than 3-4 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 patterns were apparent. The authors concluded that their results provide little evidence for an association between magnetic fields and childhood brain tumors.

The pooled analysis included two case-control studies published after the WHO 2007 review (Kroll et al., 2010; Saito et al., 2010). Nearly 80% of the childhood brain cancer cases in the pooled analysis were contributed by Kroll et al. (2010), which evaluated 47 childhood brain cancer cases diagnosed over a 33-year period in the United Kingdom with their birth address within 400 m of a high-voltage transmission line. No associations with calculated magnetic-field exposure from nearby transmission lines were reported in any analysis of brain cancer in this large study, including calculated magnetic fields ≥1-2 mG, 2-4 mG, and 4mG.

[12] Both Mezei et al. (2008b) and Kheifets et al. (2010b) were discussed by Schüz (2011), and reported to provide little support for an association between ELF EMF exposure and brain cancer in children.

In a case-control study of 55 cases of childhood brain cancer, Saito et al. (2010) reported that children with brain cancer were more likely to have average magnetic-field exposure levels greater than 4 mG, compared to children without brain cancer.[13] The association was based on three cases and one control; interpretations of the data were, therefore, limited by small numbers in the upper exposure category. The study was also limited by very poor participation rates among study subjects; poor participation rates introduce the possibility of selection bias, among other biases. The strength of this study was its exposure assessment. Measurements were taken continuously over a weeklong period in the child's bedroom approximately 1 year post-diagnosis.

In a recent pooled analysis of two Canadian case-control studies, Li et al. (2009) calculated individual maternal occupational magnetic-field exposure pre- and post-conception and analyzed these estimates in relation to brain cancer in offspring. Associations were reported between childhood brain cancer and average magnetic-field exposures greater than approximately 3 mG for exposure during the 2 years prior to conception and during conception; no associations were found using the cumulative and peak exposure metrics. Previous studies of parental occupational magnetic-field exposure and childhood brain tumors have produced inconsistent results. More research is required in this area.

Assessment

Overall, recent studies were inconsistent, but the weight-of-evidence does not support an association between magnetic-field exposures and the development of childhood brain cancer. The larger and more methodologically advanced work (Kheifets et al., 2010b; Kroll et al., 2010) does not support an association. The recent data do not alter the classification of the epidemiologic data in this field as "inadequate."

Table 3. Relevant studies of childhood brain cancer

Authors	Year	Study
Kheifets et al.	2010b	A pooled analysis of extremely low-frequency magnetic fields and childhood brain tumors
Kroll et al.	2010	Childhood cancer and magnetic fields from high-voltage power lines in England and Wales: A case-control study
Li et al.	2009	Maternal occupational exposure to extremely low frequency magnetic fields and the risk of brain cancer in the offspring
Mezei et al.	2008b	Residential magnetic field exposure and childhood brain cancer: A meta-analysis
Saito et al.	2010	Power frequency magnetic fields and childhood brain tumors: A case-control study in Japan

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

[13] The unpublished results of this study were included in Mezei et al. (2008b).

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.

Recent studies (2011 to July 1, 2013)

Recent literature includes one case-control study of female breast cancer, a meta-analysis of 18 studies of male breast cancer, a second meta-analysis of 23 case-control studies of female breast cancer, and one cohort study of male and female breast cancer and magnetic-field exposure.

Sun et al. (2013) meta-analyzed 18 studies published from 1979 to December 2012 that examined the association between residential (n=2 studies) or occupational (n=16 studies) magnetic-field exposure and breast cancer among males. Among the 18 studies, 7 were of case-control design (n=57 cases and n=223 controls) and 11 were cohort studies (n=299 cases in a total population of 7,486,643). The authors crudely re-categorized data from the original studies by study design (case-control vs. cohort), exposure level (<2 mG vs. ≥2 mG vs. not provided), method of exposure assessment (job title vs. other), whether age was adjusted for (yes vs. no), and by occupational and residential exposure status. An overall OR of 1.32 (95% CI: 1.14-1.52) was reported. The pooled OR among the 7 case-control and 11 cohort studies was 1.39 (95% CI: 0.95-2.04) and 1.31 (95% CI: 1.12-1.53), respectively. Although this meta-analysis included a large sample size overall, data from a wide range of exposure definitions and cut-points were crudely combined. Hence, within-study bias and between-study heterogeneity may have severely distorted the reported findings. The case-control studies that were included in the meta-analysis were clearly limited by small sample sizes (range of case counts from 1 to 33), resulting in unstable study-level ORs (as evident from the reported 95% CIs). A review of study quality by the authors also revealed that 9 of the 11 cohort studies failed to confirm that participants did not have breast cancer at the beginning of the study (an important criterion for cohort studies). Similarly, a majority of the included cohort studies, if not all, may have suffered from attrition bias due to the lack of transparent reporting regarding follow-up. The extent of this bias is unknown, and could have erroneously led to a statistically significant pooled OR for these data despite 8 of the 11 studies reporting statistically non-significant associations.

Chen et al. (2013) summarized the results from 23 case-control studies on ELF EMF exposure and female breast cancer published between 1990 and 2010 in a meta-analysis. Various exposure assessments were evaluated including occupational exposure (7 studies), residential exposure (5 studies), blanket exposure (8 studies), and multiple exposures (2 studies). No statistically significant associations were reported for breast cancer among females with either exposure category (occupational exposure OR=1.08, 95% CI: 1.00–1.15; residential exposure OR=1.09, 95% CI: 0.97–1.22; blanket exposure OR=1.03, 95% CI: 0.95–1.12; multiple exposures OR=1.35, 95% CI: 0.97–1.89). In this meta-analysis, the numbers of exposed cases were not reported, and limitations inherent to case-control studies of magnetic-field exposure and cancer (e.g., differential misclassification of exposure, possible selection bias) are also inherent within the individual studies that were included. Furthermore, methodological weaknesses in the various exposure assessments were evident and subject to inaccuracies (e.g., several occupational exposure studies were based on job title only, use of electric blankets was based on self-report, residential proximity was used as an exposure surrogate).

Elliott et al. (2013) conducted a case-control study of adults between the ages of 15 to 74 years who were diagnosed with leukemia, brain or central nervous system cancer, malignant melanoma, or breast cancer (female only) and who were identified in the National Cancer Registry of the United Kingdom. Subjects with addresses within 1,000 meters of a high-voltage overhead transmission line were identified and comprised the case groups. Control groups for each of these types of cancer were selected from persons in the National Cancer Registry with other types of cancer that had not been associated with magnetic-field exposure in past research and were frequency-matched to the cases (1:1 in the case of breast cancer). The exposures of the cases and the controls were compared by calculating the magnetic field in units of nanotesla (nT) (100 nT = 1 mG) at the residence address for each case and control.

Potential confounders in the statistical models included age, sex, year of diagnosis/region, and measures of rurality and deprivation (a measure of socioeconomic status). The calculated magnetic fields at the addresses of the cases and controls did not differ and ORs showed no statistically significant trend with distance or calculated magnetic field, which led to the investigators concluding that, "After adjustment for deprivation and other confounders, we found no excess risks or trends for leukemia, brain/central nervous system cancers, malignant melanoma, or female breast cancer in relation to distance or magnetic fields from high-voltage overhead power lines in England and Wales" (Elliot et al., 2013, p. 4).

Strengths of this study include population-based data with 35 years of observation, a large sample size of subjects with calculated average magnetic-field exposures ≥ 1,000 nT (10 mG), the use of magnetic-field estimates in the year of diagnosis and for the 5 years prior to diagnosis based on proximity to power lines and case/control addresses, the use of a Geographical Information System (GIS) to capture exposure variation, the availability of individual addresses within the cancer registry with an approximate 0.1 meter accuracy, the use of cancer controls (i.e., high level of ascertainment), and the statistical control of important confounders like deprivation, which in part would account for potential differences in social class and access to screening programs for breast cancer cases.

The use of cancer controls in the study by Elliott et al. (2013) also presents some disadvantages particularly if there were to be an association between magnetic-field exposure and the control cancers, which would bias the reported risk estimates toward the null (in the presence of a positive association). Data on the migration of cases and controls was also lacking, therefore prohibiting an assessment of cumulative exposure or latency. Finally, only exposure from overhead power lines was evaluated, with no measurements within subjects' homes available for analysis.

Only one cohort study (Sorahan, 2012) of breast cancer was identified for this updated review. This study evaluated the incidence of breast cancer from 1973 to 2008 in a cohort of 71,360 male and 10,482 female employees of the former Central Electricity Generating Board of England and Wales. All employees were employed for at least 6 months and had worked for some time between 1973 and 1982. Exposure was defined by industry sector (power stations, transmission, non-operational, unclassifiable, no work history) and type of work (managers, engineers, administrative/clerical, industrial, building/construction, unknown). Year of job commencement (1926 to 1982), period from hire (0 to ≥40 years), and period when employment was left (<5 to ≥25 years) were also evaluated with respect to breast cancer incidence. No statistically significant association with male or female breast cancer was reported by known/classifiable industry sectors and work types, nor were significant associations reported by sex overall. Similarly, no linear trends in breast cancer risk were reported by sex for year of hire, period from first employment, and period from leaving employment. Methodological strengths of this study included the long-term follow-up, which is especially ideal for rare cancer sites (i.e., male breast cancer), and the overall sample size. The study was limited, however, because industry sector and work type were based on the first recorded job, and approximately 55% of the entire cohort was employed in the industry prior to when employment records were computerized. Therefore, nondifferential exposure misclassification is of concern, particularly given that women with "no work history" and who had an unknown type of work had significantly elevated, and comparable, magnitudes of association with breast cancer—n=39 cases in each category; standardized rate ratio (SRR) =1.43 (95% CI: 1.02-1.95) and SRR=1.42 (95% CI: 1.01-1.95) for no work history and unknown work type, respectively).

Recent methodological work for adult cancers (2011 to July 1, 2013)

Much of the research on ELF EMF and adult cancers is related to occupational exposures due to the higher range of exposures encountered in the occupational environment. The main limitation of these studies, however, has been the methods used to assess exposure, with early studies relying simply on a person's occupational title (often taken from a death certificate) and later studies linking a person's full or partial occupational history to representative average exposures for each occupation (i.e., a JEM). Furthermore, confounding by other risk factors such as occupational exposure to chemicals is possible but rarely is ever examined in the epidemiologic literature (Baldi et al., 2011). JEMs, while advanced, still have some notable limitations, as highlighted in a review by Kheifets et al. (2009) summarizing an expert panel's findings.[14] While a person's occupation may provide some indication of the overall magnitude of their occupational magnetic-field exposure, 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. Furthermore, since no biological mechanisms acting as potential mediators of the relationship between magnetic-field

[14] Kheifets et al. (2009) reported 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.

exposures and adult cancers have been established, an appropriate exposure metric is unknown. The expert panel concluded the following:

> Inconsistent results for many of the outcomes [related to occupational EMF exposure] may be attributable to numerous shortcomings in the studies, most notably in exposure assessment. There is, however, no obvious correlation between exposure assessment quality and observed associations … To better assess exposure, we call for the development of a more complete job-exposure matrix that combines job title, work environment and task, and an index of exposure to electric fields, magnetic fields, spark discharge, contact current, and other chemical and physical agents (quoted in Kheifets et al., 2009)

A study by Mee et al., (2009) included in our previous update confirmed that JEMs could be improved by linking occupational classifications with industry or information on participation in certain tasks of interest (e.g., use of welding equipment or work near power lines). Similarly, a study of the 48-hour exposure of 543 workers in Italy found that JEMs were a poor indicator of actual occupational, magnetic-field exposure levels (discussed in the previous update); half of the occupations classified in the same JEM categories included significantly different individual TWAs (Gobba et al., 2011).

Assessment

These studies support the growing body of scientific evidence against a causal role for magnetic fields in breast cancer. The meta-analyses by Sun et al. (2013) and Chen et al. (2013) include numerous limitations and therefore should be interpreted with great caution due to flaws within the individual studies and the crude pooling of data with a vast range of exposure definitions and cut-points. These studies should receive weight in the overall assessment because of their large size, but are still limited by deficiencies in exposure measures and potential sources of bias. Several review papers (Feychting and Forssén 2006; Hulka and Moorman, 2008) and expert groups (SCENIHR, 2009) support the conclusion that magnetic-field exposure does not influence the risk of breast cancer.

Table 4. Relevant studies of breast cancer

Authors	Year	Study
Chen et al.	2013	A meta-analysis on the relationship between exposure to ELF-EMFs and the risk of female breast cancer
Elliott et al.	2013	Adult cancers near high-voltage overhead power lines
Sorahan et al.	2012	Cancer incidence in UK electricity generation and transmission workers, 1973–2008
Sun et al.	2013	Electromagnetic field exposure and male breast cancer risk: a meta-analysis of 18 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).

Recent studies (2011 to July 1, 2013)

Epidemiology studies published since our last review on adult brain cancer and ELF EMF exposure are listed in Table 5 and include three case-control studies and one cohort study.

The work by Elliott et al. (2013), which was discussed in length as a recent breast cancer study, reported no elevated magnitude of association or trends for brain/central nervous system cancers in association with distance or estimated magnetic fields from high-voltage overhead power lines in England and Wales. No analyses were conducted by brain cancer subtypes.

A group of researchers from the University of São Paulo in Brazil conducted a case-control study based on death certificate data from two different databases (both the city and State of São Paolo's official mortality databases) for deaths between 2002 and 2005 in the Metropolitan Region of São Paulo (Marcilio et al., 2011). They identified deaths from brain cancer among adults in this large, urban area (population of approximately 20 million) that has a high demographic density and extensive overhead high-voltage power lines throughout the area. The researchers found no association between brain cancer mortality and living near a transmission line at death or calculated magnetic-field levels from these transmission lines. Their analyses were not conducted by brain cancer subtypes.

The strengths of this study include the relatively large sample size (n=2,357). In addition, the assessment of distance from transmission lines to the residence was performed without knowledge of subjects' case or control status and the selection of cases and controls did not entail voluntary participation, so there was no possibility of selection or recall bias.

Limitations of this study include the use of cancer deaths rather than incident cases, which limits generalizations to subtypes with a higher mortality rate. In addition, the authors only evaluated exposure at the address where participants lived at their time of death and did not evaluate information on occupational exposures, both of which preclude an accurate assessment of overall

TWA exposure. Finally, proximity to transmission lines appears to be a poor surrogate of magnetic-field exposure (Maslanyj et al., 2009).

In contrast to the studies by Elliott et al. (2013) and Marcilio et al. (2011), Baldi et al. (2011) examined the relationship between residential and occupational exposure to ELF EMF and brain cancer histology in a population-based case-control study based in Gironde, France between May 1999 and April 2001. Eligible cases were all subjects greater than 15 years of age and newly diagnosed with a brain tumor during the study period living in Gironde. Controls were selected randomly from the local electoral rolls. In total, 221 brain cancer cases (95 males and 126 females; 105 gliomas, 67 meningiomas, 33 acoustic neurinomas, 7 brain lymphomas, 9 others) and 442 individually age- and sex-matched controls identified in the general population were included. Occupational exposure was assessed by two industrial hygienists blinded to case and control status who determined the EMF type (ELF, radiofrequency), exposure duration based on the number of years EMF exposure was classified as present for each job, and the exposure probability (i.e., possibly exposed, probably exposed, and certainly exposed). A cumulative lifetime occupational exposure was calculated for each individual based on probability and duration and was analyzed by quartiles in (secondary) statistical analyses. Primary analyses examined occupational exposure by crudely dichotomizing it as present vs. absent (i.e., yes vs. no).

Baldi et al. (2011) also evaluated residential exposure, which was based on the distance between high power lines and residence at the time of diagnosis among cases and at the time of in-person interview for controls. High (90 kV and 63 kV) and very high (400 kV and 225 kV) power lines were evaluated as being overhead or underground. Case and control residences were geocoded by investigators who were blinded to both the disease status and the position of the power lines. Distance to the power line was then estimated for each study participant living within 100 meters from a high power line. During participants' interview, information on cell phone and radio use was also collected.

The authors reported statistically non-significant associations overall for brain cancer and occupational exposure (adjusted EMF OR=1.52, 95% CI: 0.92–2.51 and adjusted ELF OR=1.59, 95% CI: 0.97–2.61). Statistically non-significant ORs were reported for occupational exposure to EMF and glioma (OR= 1.64, 95% CI: 0.78–3.48), acoustic neurinoma (OR=0.84, 95% CI: 0.20–3.49), and meningioma (OR= 2.19, 95% CI 0.76–6.31). The only statistically significant positive association with occupational exposure to ELF was reported for meningioma (OR= 3.02, 95% CI: 1.10–8.25). Regarding cumulative occupational exposure, no linear trends were observed and the results were statistically non-significant within the majority of quartiles.

No statistically significant associations were reported by the authors for living ≤100 meters vs. >100 meters to power lines for brain cancer overall and by histology (glioma OR=0.66, 95% CI: 0.21–2.07; meningioma OR=2.99, 95% CI: 0.86–10.40; acoustic neurinoma OR=3.23, 95% CI: 0.28–36.62).

Despite several of the findings being statistically non-significant (i.e., there was no material difference in exposure between cases and controls), the authors concluded that "our results suggest an association between EMF exposure, in particular ELF, and meningiomas" (p. 1482). Strengths of this study include its population-based nature and an evaluation stratified by histology.

This study included few cases, however, with exposure to ELF EMF both overall and by brain cancer subtype, and is subject to an unknown amount of exposure misclassification, lacks direct measurement of exposure, and is limited by the number of exposed cases. Participation bias among controls is probable given that 31% of eligible participants refused to participate for health or other reasons.[15]

In addition to breast cancer, Sorahan et al. (2012) also evaluated the incidence of malignant brain cancer from 1973 to 2008 in their cohort of 71,360 male and 10,482 female employees of the former Central Electricity Generating Board of England and Wales. No statistically significant risk of brain cancer was reported for any industry sector or work type (including those that were unclassifiable or unknown), nor was a significant association reported overall (SRR=1.00, 95% CI: 0.88-1.12). Similarly, no linear trends in brain cancer risk were reported for year of hire, period from first employment, and period from leaving employment. Methodological strengths and limitations of this study were previously discussed. No analysis by sex or histology was presented.

Assessment

Findings from the recent literature predominantly support no association between exposure to ELF EMF and brain cancer in adults, but remain limited due to the exposure assessment methods and insufficient data on specific brain cancer subtypes. Currently, the literature provides very weak evidence of an association in some studies, if any, between magnetic fields and brain cancer.[16] The recent report by the SCENIHR described the data on brain cancers as "uncertain" (SCENIHR 2009, p. 43), and the current literature supports this judgment.

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[15] Morgan (2011) wrote a letter to the editor regarding the Baldi et al. (2011) study stating that the authors should have reported the risk of meningioma by sex due to a greater frequency of the disease in women compared with men, and that the significant risk reported may have been largely driven by the number of female cases. Only 13 exposed cases, however, were reported for occupational exposure to EMF and ELF, separately, and only 7 exposed cases were reported for residential exposure. Therefore, stratification by gender would produce a great amount of variability in the observed risk estimate. Furthermore, the authors matched cases and controls by sex, among other factors; therefore, sex was controlled for in the analysis and stratification by this risk factor would result in an over-adjustment of the results.

[16] A consensus statement by the National Cancer Institute's Brain Tumor Epidemiology Consortium confirms this statement. They classified residential power frequency EMF in the category "probably not risk factors" and described the epidemiologic data as "unresolved" (Bondy et al., 2008, p. 1958).

Table 5. Relevant studies of adult brain cancer

Authors	Year	Study
Baldi et al.	2011	Occupational and residential exposure to electromagnetic fields and risk of brain tumors in adults: a case–control study in Gironde, France
Elliott et al.	2013	Adult cancers near high-voltage overhead power lines
Marcilio et al.	2011	Adult mortality from leukemia, brain cancer, amyotrophic lateral sclerosis and magnetic fields from power lines: a case-control study in Brazil
Sorahan et al.	2012	Cancer incidence in UK electricity generation and transmission workers, 1973–2008

Adult leukemia and lymphoma

There is a vast amount of literature on adult leukemia and ELF EMF, most of which is related to occupational exposure. Overall, the findings of these studies are inconsistent—with some studies reporting a positive association between measures of ELF EMF and leukemia and other studies showing 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 occupation cohorts and updating a meta-analysis on occupational magnetic-field exposure.

Recent studies (2011 to July 1, 2013)

Three studies (two case-control and one cohort), all of which have already been described, and one cohort study in Spain reported on the possible association of exposure to magnetic fields and adult leukemia. Five additional studies (two of which were conducted by the same research team) examined biological responses to magnetic fields including immune and hematological responses, genotoxicity, and changes in blood chemistry parameters.

The Brazilian case-control study previously discussed also evaluated adult leukemia deaths (Marcilio et al., 2011). A statistically significant association was reported between residence at the time of death within 50 meters of a transmission line; however, the interpretation of this finding is unclear since it was restricted to lower voltage transmission lines. In addition, proximity is a poor predictor of magnetic-field exposure. A statistically non-significant positive association was also reported with calculated exposures greater than 3 mG from these transmission lines (OR=1.61, 95% CI=0.91-2.86). No analyses were conducted by leukemia subtypes.

Elliott et al. (2013) (already discussed) reported no elevated risk or trends for adult leukemia in association with distance or estimated magnetic fields from high-voltage overhead power lines in England and Wales. No analyses were conducted by leukemia subtypes.

In the cohort study of former employees of the Central Electricity Generating Board of England and Wales, Sorahan et al. (2012) found no statistically significant association with leukemia by industry sector or overall (SRR=0.94, 95% CI: 0.84-1.04). With the exception of engineers (SRR=0.72, 95% CI: 0.56-0.92), most types of work were not associated with adult leukemia. A positive linear trend for leukemia risk was reported in association with the time period of hire, but the individual categories for hire period (i.e., 1926 to 1939; 1940 to 1949; 1950 to 1959; 1960 to 1969; 1970 to 1982) were not significantly associated with risk of disease (SRRs ranged from 0.68 in the 1926 to 1939 hire period to 1.08 in the 1970 to 1982 hire period). No analysis by sex or histology was presented.

Rodriguez-Garcia et al. (2012) reported on the incidence of acute myeloid leukemia and ALL from 2000 to 2005 in El Bierzo, one of the most industrialized regions in northwestern Spain. All cases of acute leukemia diagnosed at one of two hospitals specializing in hematologic disorders in the region were identified. Information collected from medical records included family history of hematopoietic cancer, place of residence, occupational history, lifestyle risk factors, and clinical data. The air distance from the main village in each of 39 municipalities in El Bierzo to primary high power lines or power plants in the region including a high power line network, the point of maximal density of high power lines, or to the vicinity of thermoelectric power plants was calculated and evaluated in a correlational analysis with the estimated incidence of leukemia.

The authors observed 54 cases of acute leukemia over the 6-year study period, with an annual incidence rate of 3.06 and 1.59 per 100,000 persons for acute myeloid leukemia and ALL, respectively (standardized to the world population). Inverse correlations between both types of leukemia and the distance to thermoelectric power plants and high power lines network were reported (Pearson's correlation coefficient was statistically significant at $P<0.05$ for acute myeloid leukemia only).

Although Rodriguez-Garcia et al. (2012) claim that the case ascertainment rate was high, the exact number of cases among all eligible leukemia cases in the region was not reported. Limitations of this study include the use of aggregated data (vs. individual-level information), uncertainties in the exposure assessment including the mistaken assumption that generating plants *per se* are important sources of EMF, inadequate collection of data regarding occupational history (i.e., only the job description was captured), and the lack of a comparison group for conducting a more rigorous assessment of leukemia risk (i.e., RRs and ORs could not be estimated because there was no control group). Hence, the relative contribution of this hypothesis-generating study to the overall assessment of the literature is small.

The recent literature also includes one experimental study of the biological response in healthy men occupationally exposed to magnetic fields for up to 20 years compared with healthy men who were not occupationally exposed based on their profession. Touitou et al. (2013) examined whether there were differences in the activity of immune and hematologic biomarkers[17] known to play a role in the development of brain cancer and leukemia between 15 chronically exposed volunteers who worked in operating and maintaining extra high-voltage substations in the Paris metropolitan region, and 15 unexposed men recruited by the Centre d'Investigation Clinique of Pitié-Salpêtrière Hospital or who were white-collar workers at Electricité de France.

[17] Biomarkers included red blood cells, hemoglobin, hematocrit, platelets, mean platelet volume, total white blood cells, lymphocytes, monocytes, eosinophils, basophils, neutrophils, Ig (Immunoglobulin) A, IgM, IgG, CD (cluster of differentiation) 3, CD4, CD8, natural killer cells, B cells, total CD28, CD8+ CD28+, activated T cells, interleukin (IL)-2, IL-6, and IL-2 receptor.

Personal exposure measurements of magnetic fields recorded every 30 seconds were collected for all participants during a 7-day period (daytime and nighttime), and the biomarker profile was assessed nightly.[18] The results indicated no effect of 50-Hz magnetic fields on immune and hematologic parameters among participants. The authors further reported no association with field intensity ranging from 0.1 µT (1 mG) to >0.3 µT (3 mG). In both groups of men, all hematologic and immune system biomarkers were reported to be within normal ranges. Interestingly, this same research team found biological changes in serum sodium, chloride, phosphorus, and glucose in the exposed group >0.3 µT (3 mG) in the same experimental setting (Touitou et al., 2012). The clinical significance of these findings requires further evaluation.

A third study of biological responses to ELF EMF exposure was performed in male workers in the automotive industry, whereby 229 welders classified as having high exposure (median magnetic field = 0.51 µT [5 mG]) and 123 stampers classified as having low exposure (median magnetic field = 0.07 µT 7mG]) were selected (Liu et al., 2013).[19] Subjects were identified from two workshops within the automotive industry, however, no other details on subject identification were provided. All men included in the study were aged between 20 and 40 years and worked in the industry for more than 2 years. Although the laboratory results indicated statistically significant differences between the study groups in all hematological parameters under study, all values were within the normal range in the high exposure group. Among the low exposure group, however, the percentage of lymphocytes was outside the normal range (i.e., 57.69% vs. a normal range of 20% to 40%, as reported by the authors). This study, although interesting, is limited in several ways. All hematological parameters were measured only once per individual, participation bias is possible, no confounders were controlled for, and data on occupational history was not examined. Overall, this study lacked transparency in the methodology presented, particularly in the identification of participants.

Since damage to cellular DNA is thought to be necessary for tumor initiation, various studies have been conducted in humans and animals to examine whether magnetic-field exposure can induce DNA damage. One population group with relatively high exposure to ELF EMF is electric arc welders. For this reason, Dominici et al. (2011) conducted a study in 21 male welders looking for micronuclei and sister chromatid exchanges (SCE)—two markers of DNA damage—in peripheral blood leukocytes. The study group was matched based on age, residence, and smoking habit with 21 male controls working at other, unidentified occupations. Exposures were measured in the welders using personal dosimeters (but not in controls) and analyses were conducted in a blinded manner. The study authors reported inconsistent findings: increased micronuclei, but reduced SCE, in the electric arc welders compared to controls. It should be noted, however, that welders are also exposed to various metal fumes generated during the welding process, which include compounds previously characterized by IARC as carcinogenic or possibly carcinogenic, and exposures in the control group were not assessed; thus, it is difficult to attribute the findings of this limited study to ELF EMF exposure.

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[18] The subjects arrived at the testing facility between 18:00 hours and 18:30 hours. The study extended over a 12-hour period. Subjects were not allowed to watch television or to play video games in order to avoid any magnetic-field exposure that may produce bias. Since the testing facility could house only two volunteers per night, the study was staggered over 5 weeks for the exposed and over 7 weeks for the control subjects.

[19] The intensity of ELF EMF was detected with an EFA-300 Field Analyzer with a bandwidth of 5Hz-32 kilohertz.

Balamuralikrishnan et al. (2012) conducted an evaluation of chromosomal alteration in 50 electrical workers occupationally exposed to ELF EMF frequencies of 50 to 60 Hz in electrical substations and transmission work (180 kV to 420 kV energy transmission lines). The exposed study population was divided into two sub-groups, namely, those with direct exposure (28 transformer and power line workers) and those with indirect exposures (22 Electricity Board office workers). Controls consisted of 20 subjects with no previous occupational exposure to ELF EMF; from whence this population was derived, however, was not reported. Peripheral blood leukocytes were evaluated for chromosomal aberrations and micronuclei. Those with direct exposure to ELF EMF were reported to have statistically increased frequencies of both markers of DNA damage, independent of the smoking status of study subjects.

The existing literature related to immunology includes other human experimental and observational studies, *in vivo* studies, and *in vitro* studies. The WHO noted the inconsistency of these studies:

> Evidence for the effects of ELF electric or magnetic fields on components of the immune system is generally inconsistent. Many of the cell populations and functional markers were unaffected by exposure. However, in some human studies with fields from 10 μT to 2 mT, changes were observed in natural killer cells, which showed both increased and decreased cell numbers … In animal studies reduced natural killer cell activity was seen in female, but not male mice or in rats of either sex … Overall therefore, the evidence for effects of ELF electric or magnetic fields on the immune system and haematological system is considered inadequate (WHO, 2007, p. 237).

Thus, the recent studies by Touitou et al. (2013) and Liu et al. (2013), and the new literature with respect to DNA damage, merely add to the existing database of inconsistent findings. Future studies are required to replicate these findings.

Assessment

Recent studies of adult leukemia have attempted to clarify previously reported associations with magnetic field exposure; however, there remains no clear or statistically significant relationship observed. Currently, the recent literature provides weak evidence of a potential association between magnetic fields and adult leukemia overall or by subtype. The recent scientific evidence pertaining to magnetic field exposure and various immune and hematological responses provides no support for an association. The recent literature on genotoxic effects from occupational exposure to ELF EMF remains inconsistent.

Table 6. Relevant studies of adult leukemia/lymphoma

Authors	Year	Study
Balamuralikrishnan et al.	2012	Evaluation of chromosomal alteration in electrical workers occupationally exposed to low frequency of electro magnetic field (EMFs) in Coimbatore population, India
Dominici et al.	2011	Genotoxic hazard evaluation in welders occupationally exposed to extremely low-frequency magnetic fields (ELF-MF)
Elliott et al.	2013	Adult cancers near high-voltage overhead power lines
Liu et al.	2013	Effects of extremely low frequency electromagnetic field on the health of workers in automotive industry
Marcilio et al.	2011	Adult mortality from leukemia, brain cancer, amyotrophic lateral sclerosis and magnetic fields from power lines: a case-control study in Brazil
Rodriguez-Garcia et al.	2012	High incidence of acute leukemia in the proximity of some industrial facilities in El Bierzo, northwestern Spain
Sorahan et al.	2012	Cancer incidence in UK electricity generation and transmission workers, 1973–2008
Touitou et al.	2012	Long-term (up to 20 years) effects of 50-Hz magnetic field exposure on blood chemistry parameters in healthy men
Touitou et al.	2013	Long-term (up to 20 years) effects of 50-Hz magnetic field exposure on immune system and hematological parameters in healthy men

Reproductive/developmental effects

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 was assessed using 24-hour personal magnetic-field measurements (early studies on miscarriage were limited because they used surrogate measures of exposure, including visual display terminal use, electric blanket use, or wire code data). Following the publication of these two studies, however, 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 (less physically active) and women who miscarried (more physically active) (Savitz, 2002). It was proposed that physical activity is associated with an increased opportunity for peak magnetic-field exposures, 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 exposure to peak magnetic fields. Furthermore, nearly half of women who had miscarriages reported in the cohort by Li et al. (2002) had magnetic-field measurements taken after miscarriage occurred, when changes in physical activity may have already occurred, and all measurements in Lee et al. (2002) occurred post-miscarriage.

The scientific panels that have 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, "There is some evidence for increased risk of miscarriage associated with measured maternal magnetic-field exposure, but this evidence is inadequate" (WHO 2007, p. 254). The WHO stated that, given the potentially high public health impact of such an association, further epidemiologic research is recommended.

Recent studies (2011 to July 1, 2013)

While no new original research on magnetic-field exposure and miscarriage has been conducted, eight studies have recently been published on reproductive and developmental effects (Table 7). Three of these studies were conducted by the same lead investigator, and considered novel hypotheses regarding magnetic-field exposure and reproductive and developmental effects in the areas of sperm quality, asthma in offspring, and childhood obesity (Li et al., 2010; Li et al., 2011; Li et al., 2012).

Li et al. (2010) conducted the first investigation of measured magnetic-field levels and semen abnormalities in a population-based case-control study derived from healthy sperm donors in Shanghai, China. A two-fold, statistically significant association was reported between high magnetic-field exposure (90th percentile of 24-hour measurements $\geq$ 1.6 mG) and poor sperm quality. The relationship exhibited a dose-response pattern (i.e., the association increased in strength as estimated exposure increased) and other features associated with a valid relationship. The main strength of the study was the use of actual personal magnetic-field measurements. The authors note, however, that their study had limitations. They were able to measure magnetic-field exposure for one 24-hour time period only for each participant, and it is unclear how this 24-hour measurement reflects true magnetic-field exposure during spermatogenesis. In addition, except for a control for occupation, no control for chemical exposures (e.g., smoking) were considered (Fariello et al., 2012).

Li et al. (2011) also were the first to evaluate the association between magnetic-field exposure *in utero* and subsequent asthma in offspring using data from a prospective cohort study of 626 pregnant women collected a decade earlier in the San Francisco area (Li et al., 2002). In this study, the authors found that asthmatic children were more likely to have mothers with median, personally-recorded exposures to magnetic fields >2 mG during pregnancy, compared with the magnetic-field exposures of mothers of healthy children (HR=3.52, 95% CI: 1.68-7.35). The association was strong and indicated a dose-response pattern.

The design and methods of this study (Li et al., 2011) appear relatively strong, although similar to their study of sperm quality, the participants wore a magnetic-field meter for only one 24-hour period during the first or second trimester. In addition, it is possible that an unknown confounder is responsible for the observed association. The authors did not adjust for family income in their analysis, although family income of subjects with medium and high magnetic-field exposure was significantly below that of subjects with low magnetic-field exposure. This association of an indicator of low socioeconomic status with higher magnetic-field exposure suggests the possibility that the association is confounded by socioeconomic factors that play a role in the development of childhood asthma directly or as a surrogate of environmental risk factors such as indoor mold/allergen exposure and outdoor pollution (Rona, 2000). Additional limitations of this study (including residual confounding from indoor air quality and other risk factors for asthma) and comments on the authors' interpretation of the results have been published by other scientists (Brain et al., 2012; Villeneuve, 2012). Further studies on this topic with more detailed information on risk factors for childhood asthma are required.

Using the same cohort of pregnant women as in their previous studies, Li et al. (2012) published another analysis of *in utero* magnetic-field exposure, in this case, on the risk of childhood obesity. The magnetic-field exposure of the mothers during pregnancy was related to the weight of their children up to 13 years of age. The children of mothers with TWA magnetic-field exposures >1.5 mG were significantly more likely to be over the 97.5 percentile of age-specific weight than children of mothers with exposures ≤ 1.5 mG. A significant trend for higher weight with increasing magnetic-field exposure was also reported.

In both of the recent Li et al. studies (2011, 2012), mothers with higher magnetic-field exposures had significantly lower family incomes. Given this association and the complicated interrelationships between socioeconomic status and risk factors for childhood obesity, residual confounding is a distinct possibility (Brain et al., 2012; Villeneuve, 2012). Although adjustment was carried out for some socioeconomic risk factors and eight other potential confounding variables, income itself was not included as an adjustment factor. Curiously, pre-existing diabetes and gestational diabetes were treated as a single risk factor although each deserves separate treatment. By not characterizing the exposure groups by the prevalence of pre-existing diabetes of the mothers, one does not know whether the reported results are related to magnetic-field exposure or simply to more persons in the higher exposure group with a possibility of hereditary risk factors for diabetes.

Most of the same concerns raised during the original publication of this cohort apply to both the Li et al. (2011) and Li et al. (2012) studies, including the potential for selection bias, a low compliance rate, and the apparent selection of exposure categories after inspection of the data (NRPB, 2002). In the original Li et al. (2002) study of miscarriage, exposure was defined *a priori* as the average magnetic-field level recorded over 24 hours, for which no significant association with miscarriage was reported. The authors reported an association with magnetic-field exposures above a peak value of 16 mG; however, this was based on apparent *post hoc* inspection of the data. In the study of asthma, magnetic-field exposures were categorized into three groups, all apparently set *post hoc* as < 10 percentile, > 10 to 90^{th} percentile, and > 90^{th} percentile. In the study of obesity, on the other hand, only exposures in the 90^{th} percentile were considered. No explanation was provided by the authors for the differing exposure categories between studies. This raises the question as to whether different exposure categories were chosen after review of the results to maximize the strength of the reported association. This and the other limitations of the study diminish the weight of the reported results.

Malagoli et al. (2012) investigated maternal exposure to magnetic fields from high-voltage power lines in a population-based case-control study of birth defects in northern Italy between 1998 and 2006. The authors matched 228 newborns with congenital malformations with a control group of healthy newborns by year of birth, the mothers' age, and hospital of birth. Maternal residence during the first trimester was identified using GIS to determine if the residence was within a "geocoded" exposure corridor near high-voltage power lines (≥ 132 kV) with calculated magnetic-field levels > 1 mG. Only one case and five controls resided within the exposure corridor, and the study did not find an association between birth defects and magnetic-field exposure (RR = 0.7, 95% CI: 0.1-8.1) in the highest exposure category (≥ 4 μT). The authors concluded that the results do not support the hypothesis that *in utero* exposure to magnetic fields are related to birth defects, although the study is limited by the small number of participants and low statistical power.

Dimbylow and Findlay (2010) modeled internal electric fields and current density as a function of electric- and magnetic-field exposure in pregnant women and fetuses at different stages of gestation. The modeled internal fields indicate that compliance with the Reference Levels for public exposure determined by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) will produce internal electric fields and current densities in the mother and fetus substantially below the Basic Restriction values.

Auger et al. (2012) retrospectively evaluated if residential proximity to transmission lines was associated with stillbirth in a large population-based study of singleton stillbirths and live births from 1998 to 2007 in the entire Quebec metropolitan region. Based on maps of power transmission lines for 2008 from the Public Health Agency of Canada, distances (<25 meters, 25 to 49.9 meters, 50 to 74.9 meters, 75 to 99.9 meters, ≥100 meters) between lines and residential six-digit postal codes (n=89,473) were estimated and assessed in association with the presence or absence of stillbirth. The results demonstrated that residential proximity to transmission lines was not associated with the likelihood of stillbirth overall and stratified by early preterm (<28 weeks) and late preterm (28-36 weeks), adjusted for maternal age, education, civil status, language, immigration, previous deliveries, period, and neighborhood deprivation (i.e., an indicator of socioeconomic position). In a stratified model of term stillbirth, a statistically significant association was reported at a distance <25 meters (OR = 2.25, 95% CI: 1.14-4.45), but not at distances ≥25 meters. No dose-response pattern was evident overall and by term of stillbirth. The use of distance as a proxy for ELF EMF exposure weakens the value of this study, and may lead to misclassification due to in- and out-migration patterns.

Bellieni et al. (2012) examined if melatonin production as measured by urine levels of 6-hydroxymelatonin-sulfate normalized to creatinine (6OHMS/cr) in newborns was affected by magnetic fields emitted from incubators. A comparison of 6OHMS/cr levels among 28 babies who had spent at least 48 h in their incubator with documented magnetic fields was performed between measurements made on the last day of incubation and data collected two days following removal from the incubator (i.e., pre and post). Magnetic field levels in the incubators of exposed subjects were between 4.5 mG and 45.8 mG at the lowest motor power of the air ventilation system, and between 9.7 mG and 88.4 mG at the highest motor power. A control group of 27 babies also had pre- and post-measurements of their levels of 6OHMS/cr taken in a 48 h interval (i.e., babies in both study groups had two measurements taken). The findings showed that exposed babies' levels of 6OHMS/cr increased from an average of 5.34 to 7.68 ng 6OHMS/mg cr (p=0.026). Among control babies, levels of 6OHMS increased from an average of 5.91 to 6.17 ng 6OHMS/mg cr (p=0.679). No between group differences were observed. The authors reported that their study demonstrates a potential effect of magnetic fields on the melatonin production of newborns, although it is limited by the possible influence of prematurity and extraneous factors including the influence from other tissues and cells.

In a study of residential exposure to ELF EMF and pregnancy, fetal growth, and development, 222 women living in close proximity to high-voltage electric towers and cables during pregnancy (i.e., exposed) were compared with 158 women with "no exposure" during pregnancy (i.e., no exposure based on living in residences located two to three streets away from the exposed residences) (Mahram and Ghazavi, 2013). GIS mapping was used to identify regions with high-voltage towers and cables, and intensity measurements under and around these towers and cables were collected using a device with sensitivity in the span of 1 V/m to 199 kV/m for electric fields and within 0.1 mG to 20 G for magnetic fields. The authors reported that inclusion criteria required that the women lived "continuously" in the exposed or non-exposed residences before pregnancy (but no time period for residence was stated).

The results showed no significant differences between the exposed and non-exposed women with regard to their pregnancy duration, newborn birth weight, birth length, and head circumference. The authors also reported that exposure did not result in preterm labor or congenital anomalies based on a descriptive analysis. Although the authors collected magnetic field measurements for exposure characterization, several uncertainties remain in their assessment. In particular, multiple sources other than residential exposure were not considered, residential history was ill-defined, and no personal measurements were performed. Additionally, this study did not control for important confounders and the authors limited their findings to a descriptive analysis of residential exposure and reproductive effects, which were largely self-reported and not systematically collected through medical records for data validation.

Recent methodological work (2011 to July 1, 2013)

While there were no new methodological studies published between May 1, 2011 and July 1, 2013, two previous studies reviewed in the previous update should be mentioned. Although it is impossible to directly test for the effects of activity bias in the original studies of miscarriage, Mezei et al. (2006) and Savitz et al. (2006) evaluated if reduced physical activity was associated with a lower likelihood of encountering peak magnetic fields. In a 7-day study of personal magnetic-field measurements in 100 pregnant women, Savitz et al. (2006) reported that active pregnant women were more likely to encounter peak magnetic fields. In addition, a secondary analysis by Mezei et al. (2006) of pre-existing databases of magnetic-field measurements among pregnant and non-pregnant women found that increased physical activity levels were associated with peak magnetic fields. These findings are broadly supportive of the hypothesis that reduced activity among women (in early pregnancies because of nausea and in later pregnancies because of cumbersomeness) may explain the observed association between peak magnetic fields and miscarriage. As noted in a commentary on this issue, however, the possibility that there is a relationship between peak magnetic-field exposure and miscarriage still cannot be excluded and further research that accounts for this possible bias should be conducted (Neutra and Li, 2008; Mezei et al., 2006). There remains no biological basis, however, to indicate that magnetic-field exposure increases the risk of miscarriage (WHO, 2007).

Assessment

The recent epidemiologic research does not provide sufficient evidence to alter the conclusion that the evidence for reproductive or developmental effects is inadequate. The three studies by Li et al. (2010, 2011, 2012) report associations between various personal magnetic-field exposure categories and semen abnormalities, childhood asthma, and childhood obesity, respectively, but further research is required to address the limitations of these studies and to establish consistency.

Table 7. Relevant studies of reproductive and developmental effects

Authors	Year	Study
Auger et al.	2012	Stillbirth and residential proximity to extremely low frequency power transmission lines: a retrospective cohort study
Bellieni et al.	2012	Is newborn melatonin production influenced by magnetic fields produced by incubators?
Dimbylow and Findlay	2010	The effects of body posture, anatomy, age, and pregnancy on the calculation of induced current densities at 50 Hz
Li et al.	2010	Exposure to magnetic fields and the risk of poor sperm quality
Li et al.	2011	Maternal exposure to magnetic fields during pregnancy in relation to the risk of asthma in offspring
Li et al.	2012	A prospective study of in-utero exposure to magnetic fields and the risk of childhood obesity
Malagoli et al	2012	Maternal exposure to magnetic fields from high-voltage power lines and the risk of birth defects
Mahram and Ghazavi	2013	The effect of extremely low frequency electromagnetic fields on pregnancy and fetal growth, and development

Neurodegenerative diseases

Research into the possible effect of magnetic fields on the development of neurodegenerative diseases began in 1995, and 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 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 more recent studies discussed 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 is "inadequate" data in support of an association between magnetic fields and Alzheimer's disease or ALS. The panel recommended more research in this area using better methods; in particular, studies that enrolled incident Alzheimer's disease cases (rather than ascertaining cases from death certificates) and studies that estimated electrical shock history in ALS cases were recommended. Specifically, the WHO concluded, "When 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).

Recent studies (2011 to July 1, 2013)

Three epidemiology studies of motor neuron disease, including one of Alzheimer's disease and other forms of dementia, have been published recently (Table 8). The researchers who investigated adult mortality from leukemia and brain cancer (already discussed) also investigated the association between magnetic-field exposure from overhead transmission lines and ALS (Marcilio et al., 2011). Their study included 367 adult cases (≥40 years of age) of ALS and 308 controls. The authors estimated risk for four different distances from power lines and found no increase in risk in any of the categories adjusting for race, education, and marital status.

A large cohort study of the general population in the United States that assembled data from five census surveys also did not provide evidence that mortality from motor neuron disease (ALS makes up 90% of all motor neuron disease) is associated with occupational magnetic-field exposure (Parlett et al., 2011). The cohort of nearly 300,000 persons was followed for a maximum of 9 years, and 40 deaths due to motor neuron disease were identified. The incidence of mortality from motor neuron disease was compared for different magnetic-field exposure categories based on the job reported at the time of the census. The population-based nature and large size of the study adds strength to the conclusions, but the analysis is limited by the generic JEM that did not allow for direct or individual measurement of occupational exposure to magnetic fields, did not take into account variability of exposure within job categories and between census years, and did not consider specific job tasks within categories.

The previous review evaluated the first study on the relationship between residing in the vicinity of transmission lines and mortality from Alzheimer's disease (Huss et al., 2009). That study reported some associations between Alzheimer's disease and residential distances less than 50 meters. A recent population-based case-control study conducted by Frei et al. (2013) was identified for the present review and included significant improvements over the previous study (Huss et al., 2009). This recent case-control study (Frei et al., 2013) included all adults (≥20 years of age) hospitalized for the first time with any two or more of Alzheimer's disease, vascular dementia, other dementia, Parkinson's disease, multiple sclerosis, or motor neuron disease in Denmark between 1994 and 2010.[20] For each case identified in the general population through the Danish hospital registry, six controls with valid personal identification numbers[21] were randomly selected and individually matched by age and sex. Controls were required to be disease-free and alive at the time of case diagnosis. An evaluation of neurodegenerative disease risk among cases and controls in association with distance (<50 meters , 50 to 200 meters, 200 to <600 meters, ≥600 meters) from high-voltage power lines (132 kV to 400 kV) was performed among individuals with consistently geocoded residential history up to 20 years prior to case diagnosis (94.2% of eligible cases, 89.1% of eligible controls). Hazard ratios were estimated for having ever lived near a power line in the 5 to 20 years prior to diagnosis. The results showed no statistically significant elevated risk of neurodegenerative disease for any one of the outcomes under study in analyses of exposure defined by residential distance or by cumulative duration of residency (≥10 y, 5 to 9 y, <5 y, always lived ≥600 meters away). For Alzheimer's disease and motor neuron disease specifically, the magnitude of association among those living closest to

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[20] Cases with Alzheimer's disease, vascular dementia, or other dementia were included only if their first diagnosis was made at ≥65 years of age.

[21] Since 1968, the Central Population Register has assigned each Danish resident a personal identification number at birth or on the date of immigration, making it possible to track every resident in and across all Danish registers.

high-voltage power lines (<50 meters) was HR=1.04 (95% CI: 0.69-1.56) and HR=0.80 (95% CI: 0.34-1.89), respectively. Stratifying by age of diagnosis for Alzheimer's disease only, persons diagnosed at 65 to 75 years of age who lived within 50 meters of a power line had a statistically non-significant increased risk of disease (HR=1.92, 95% CI: 0.95-3.87), but those diagnosed at age >75 years had a statistically non-significant decreased risk (HR=0.81, 95% CI: 0.48-1.34). In conclusion, the authors reported that "[o]verall, there was little support for an association between neurodegenerative disease and living close to power lines."

The case-control study by Frei et al. (2013) had several strengths including: the use of registry data that covered the entire Danish population (approximately 5.5 million persons) and provided more accurate diagnoses than mortality records; no indication that selection bias had occurred (i.e., the exposure distribution for cases/controls with partial address information was comparable to that of those with complete data on residential history); accurate data on in- and out-migration patterns through the Central Population Register; very accurate data for power line and residence locations (3 to 5 meters); and individual-level socioeconomic data for all addresses. Limitations include potential misclassification of disease (particularly for dementia), the use of residential distance for the exposure assessment (i.e., no information on personal measurements or occupational exposure was included), and the exclusion of other sources of magnetic fields (e.g., underground transmission cables) from the exposure assessment. Some analyses of Alzheimer's disease were also limited by sample size.

Two recent meta-analyses of occupational exposure to ELF magnetic fields and neurodegenerative disease have been conducted and provide unconvincing evidence of a relationship (Zhou et al., 2012; Vergara et al., 2013). Zhou et al. (2012) conducted a meta-analysis of 17 studies (9 case-control, 8 cohort) of magnetic-field exposure and ALS published up to April 2012. The authors reported that 7 studies assessed exposure based on job title, 5 used a JEM, and 5 others used both job titles and JEMs. Additionally, 6 studies used clinical criteria to diagnose ALS and 11 used death certificates. Thus, misclassification bias in both the exposure and outcome assessments is of concern. This study found that occupational exposure to magnetic fields was weakly associated with ALS overall (RR=1.29, 95% CI = 1.02–1.62) and among the case-control studies (OR=1.39, 95% CI: 1.05–1.84). No significantly elevated association was observed among cohort studies (RR = 1.16, 95% CI: 0.80–1.69). An evaluation of data based on job title resulted in an association between ALS and magnetic field exposure in case-control studies (OR=1.76, 95% CI: 1.27–2.44), but not in the cohort studies (OR=1.16, 95% CI: 0.83–1.61). No statistically significant associations were observed among studies reporting exposure based on JEM by study design. Subgroup analyses based on outcome ascertainment revealed that occupational magnetic-field exposure was associated with ALS based on clinical diagnosis overall (RR=2.31, 95% CI: 1.34–3.99), but not in studies using death certificate data (RR = 1.11, 95% CI: 0.88–1.39). The authors reported that evidence of heterogeneity was observed in all analyses, thus making the results difficult to interpret and extrapolate.

A second meta-analysis (Vergara et al., 2013) identified 42 papers published up to January 12, 2012, on occupational exposure to ELF EMF, Alzheimer's disease, and motor neuron disease (1 publication was considered as 3 different studies due to different study populations included, therefore 44 studies were reported). Exposure metrics included well-defined occupation and job titles or tasks, JEMs, industrial hygiene assessments, historic measurements, or personal exposure measurements. Outcomes were evaluated based on the death certificate or by clinical pathology/diagnostic information.

Vergara et al. (2013) found that among the case-control studies, there were associations with both motor neuron disease and Alzheimer's disease (RR=1.38, 95% CI: 1.13–1.68 and RR=1.29, 95% CI: 1.11–1.50, respectively). Among the cohort studies, no significantly elevated magnitude of association was reported for motor neuron disease (RR=1.14, 95% CI: 0.92–1.42), but weak evidence of an association was observed for Alzheimer's disease (RR=1.39, 95% CI: 1.10–1.75). Significant heterogeneity was observed for all analyses by study design. Weak evidence of an association among Alzheimer's disease studies using occupational classification/JEMs or industrial hygiene measurements was reported, but no statistically significant association was reported for motor neuron disease (*p*-heterogeneity <0.0001 in both evaluations). No association was observed for either motor neuron disease or Alzheimer's disease in studies with either historic or personal exposure measurements (RR=1.53, 95% CI: 0.78–3.04 and RR=1.44, 95% CI: 0.94–2.23, respectively; no statistical heterogeneity was observed for either model). Weakly elevated associations were reported for both disease outcomes by source (motor neuron disease determined by death certificate vs. clinical pathology/diagnostic information: RR=1.20, 95% CI: 1.02–1.49 and RR=1.49, 95% CI: 1.10–2.02, respectively; Alzheimer's disease determined by death certificate vs. clinical pathology/diagnostic information: RR= 1.25, 95% CI: 1.08–1.44 and RR= 1.64, 95% CI: 1.24–2.18, respectively). Significant heterogeneity for both outcomes by death certificate was reported (*p*-heterogeneity <0.0001), but this was not the case for both endpoints based on clinical pathology/diagnostic information (*P*-heterogeneity >0.05).

In its 2007 review, the WHO recommended that studies of the effects of magnetic fields on the performance of mentally demanding tasks by human volunteers be conducted. One meta-analysis and two human experimental studies of magnetic-field exposure in relation to neurological endpoints are included in the recent body of research on neurodegenerative disease (Table 8). The meta-analysis quantitatively summarized the results of seven human experimental studies on the cognitive performance of 445 subjects (Barth et al., 2010). The authors concluded that, in aggregate, the studies provided little evidence for any effects of magnetic fields on cognitive function.

In an attempt to add to the sparse research on the effects of exposure to high-level magnetic fields in occupations such as power line worker and industrial welder, Corbacio et al. (2011) evaluated the impact of a 60 Hz, 30,000 mG magnetic field on cognitive function. The researchers found that magnetic-field exposure at such a high level had no effect on the speed and accuracy of performance on 9 cognitive tasks in 99 healthy human subjects (Corbacio et al., 2011). Volunteer adult participants (mean age 23.5) were assigned to two consecutive exposure conditions: sham/sham, exposure/sham, or sham/exposure, and also blinded to the examiners. This study does not support the notion that magnetic-field exposure affects cognitive functions.

Another study examined the effects of magnetic-field exposure on electrical activity of the brain. Carrubba et al. (2010) reported that 60-Hz magnetic fields of 10 and 50 mG did not produce delayed evoked potentials in human subjects, as recorded from the scalp with onset or offset of the field. Magnetic-field stimuli, however, produced changes in brain electrical activity, suggesting that the fields were detected in a manner similar to that of other sensory events. This study was not reported to have implemented methods to ensure that the analyses were conducted in a blinded manner.

A final study addressed the WHO's recommendation that additional dosimetry to better estimate the electric-field levels induced in tissues is needed. Hirata et al. (2011) used an advanced numerical dosimetry method to calculate the levels of electric fields produced in the brain and retina of human subjects exposed to an 81,000 mG, 20-Hz magnetic field, an exposure reported to stimulate visual phosphenes. The induced electric-field levels were similar to those assumed by International Commission on Electromagnetic Safety (ICES) and ICNIRP in previous modeling as a threshold for stimulation of the central nervous system. It should be noted, however, that both ICES and ICNIRP estimate that the threshold for stimulation would be considerably higher at 50-Hz or 60-Hz power frequencies.

Recent methodological work (2011 to July 1, 2013)

The majority of the research on EMF in relation to Alzheimer's disease and motor neuron disease, including ALS, pertains to occupational and residential exposures, with an emphasis given to the potentially higher range of exposures encountered in the occupational environment and in close proximity of a transmission line. The primary limitation of these studies, however, stems from the exposure assessment methods. For example, early studies of occupational exposure depend predominantly on a person's occupational title and more current studies tend to use JEMs. Very few studies use personal measurements of exposure, as evidenced by the most recent meta-analysis published (Vergara et al., 2013). Current methods of evaluating occupational exposure fail to take into account the intensity, frequency, and duration of exposure, all factors which are critically important especially for assessing dose-response trends. Additionally, the use of residential distance as a proxy for exposure produces uncertainty in this metric, as discussed previously.

The lack of population-based registries for evaluating incident dementia or ALS, as is available in Italy and Denmark (Vincenti et al., 2012; Frei et al., 2013), and a reliance on death certificate data, which is subject to misclassification and underreporting, greatly limit the ability to examine risk factors for disease and mortality attributed to neurodegenerative disease. Vergara et al., (2013) report that only severe Alzheimer's disease is likely to be listed on a death certificate, the distinction between this form of dementia and other forms potentially varies between clinical studies, and that misclassification of dementia relative to motor neuron disease occurs more frequently in practice. Hence, the epidemiologic results for studies of Alzheimer's disease should be viewed with greater caution than for studies of motor neuron disease, although both are subject to limited internal validity. In case-control studies in particular, control selection may include individuals with vascular or senile dementia (Vergara et al., 2013), thus potentially diluting the reported associations.

Maes and Verschaeve (2012) recently published their review examining if cytogenetics mediate the potential association between ELF EMF exposures and Alzheimer's disease. Implicated biological pathways include a potential increase in amyloid-β production following exposure (Noonan et al., 2002; Del et al., 2007; Davanipour and Sobel, 2009), a possible decreased production of melatonin induced by exposure (Kato and Shigemitsu, 1997; Davanipour and

Sobel, 2009), ELF EMF effects on oxidative stress (Wolf et al., 2005; Akdag et al., 2010; El-Helaly and Abu-Hashem, 2010; Goraca et al., 2010; Emre et al., 2011), and the possible contribution of exposure to aneuploidy (i.e., chromosomal instability) (Udroiu et al., 2006). Future studies are needed to provide insight into the potential mechanisms, particularly aneuploidy of chromosomes 17 and 21, which may explain a heightened risk of Alzheimer's disease attributed to ELF EMF exposures (Maes and Verschaeve, 2012).

Assessment

The recent literature does not alter the conclusion that there are "inadequate" data on motor neuron disease and Alzheimer's disease. In addition, no recent work has addressed the possible confounding effect of electrical shocks on motor neuron disease. Uncertainties in the estimates of occupational magnetic-field exposure persist—for example, both Marcilio et al. (2011) and Parlett et al. (2011) relied on generic JEMs that did not incorporate job tasks or reflect cumulative occupational magnetic-field exposure, and Frei et al. (2013) relied on residential distance. Further research in this area will be needed to address the limitations of research to date on neurodegenerative disease (Kheifets et al., 2009; EFHRAN, 2012; SSM, 2010).

Recent meta-analyses are severely limited by the presence of heterogeneity across studies, therefore making it very difficult to reach sound conclusions. Additionally, weak to no evidence of an association was presented in the meta-analyses discussed (Zhou et al., 2012; Vergara et al., 2013), leading the authors to conclude 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.

Overall, the main limitations of the recent literature include the difficulty in diagnosing Alzheimer's disease; the difficulty of identifying a relevant exposure window given the long and nebulous course of this disease; the difficulty of estimating magnetic-field exposure prior to the appearance of the disease; the under-reporting of Alzheimer's disease on death certificates; crude exposure evaluations that are often based on the recollection of occupational histories by friends and family given the cognitive impairment of the study participants; and the lack of consideration of both residential and occupational exposures or confounding variables.

Table 8. Relevant studies of neurodegenerative disease

Authors	Year	Study
Barth et al.	2010	Effects of extremely low frequency magnetic field exposure on cognitive functions: results of a meta-analysis
Carrubba et al.	2010	Numerical analysis of recurrence plots to detect effect of environmental strength magnetic fields on human brain electrical activity
Corbacio et al.	2011	Human cognitive performance in a 3 mT power-line frequency magnetic field
Frei et al.	2013	Residential distance to high-voltage power lines and risk of neurodegenerative diseases: a Danish population-based case-control study
Hirata et al.	2011	An electric field induced in the retina and brain at threshold magnetic flux density causing magnetophosphenes
Maes and Verschaeve	2012	Can cytogenetics explain the possible association between exposure to extreme low-frequency magnetic fields and Alzheimer's disease?
Marcilio et al.	2011	Adult mortality from leukemia, brain cancer, amyotrophic lateral sclerosis and magnetic fields from power lines: a case-control study in Brazil
Parlett et al.	2011	Evaluation of occupational exposure to magnetic fields and motor neuron disease mortality in a population-based cohort
Vergara et al.	2013	Occupational exposure to extremely low-frequency magnetic fields and neurodegenerative disease: A meta-analysis
Vinceti et al.	2012	Environmental risk factors for amyotrophic lateral sclerosis: methodological issues in epidemiologic studies
Zhou et al.	2012	Association between extremely low-frequency electromagnetic fields occupations and amyotrophic lateral sclerosis: A meta-analysis

Cardiovascular disease

It has been hypothesized 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 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 (CVD) 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 (2011 to July 1, 2013)

Since our last review in June 2011, only one occupational cohort study of CVD mortality has been conducted. A second study, which was previously discussed, examined cardiovascular biomarkers in relation to ELF EMF exposure among male workers in the automotive industry.

Koeman et al. (2013) evaluated data from the Netherlands Cohort Study on diet and cancer, which included 120,852 men and women between the ages of 55 and 69 years at baseline. Subjects filled out a baseline questionnaire on their occupational history, dietary habits, and various risk factors for cancer. Subjects were then followed for a period of 10 years.

At baseline, participants reported their job title, company name and industry, products manufactured, and the time period for each job ever performed. These data were then job-coded and converted into ISCO-88 job codes. Exposure to magnetic fields was determined by linking these job codes to a JEM that accounted for both the intensity and probability of exposure. The median intensity of the background, low, and high exposure categories were 0.11 μT (1.1 mG), 0.19 μT (1.9 mG), and 0.52 μT (5.2 mG), respectively, and the following exposure metrics were assessed: ever 'low or high exposure' vs. 'background exposure'; exposure duration in years, and cumulative exposure that spanned the job history up to baseline.

Overall, 8,200 deaths from CVD, either as primary or secondary causes, took place during the follow-up. In analyses of cumulative exposure adjusted for age at baseline, sex, smoking, attained education level, alcohol consumption, and body mass index, no statistically significant associations were reported by sex for all-cause CVD mortality or death by classification of CVD (e.g., ischemic heart disease, AMI, cerebrovascular disease). Ever exposure to low or high ELF magnetic fields also demonstrated no association with all-cause CVD mortality by sex or overall. For every 10-year increment in the exposure duration, no association with all-cause CVD mortality overall or among men was reported; however, a weak inverse association was observed in women (HR=0.87, 95% CI: 0.77-0.98).

This study is strengthened by the use of a large, population-based prospective cohort with long-term follow-up, a detailed baseline questionnaire on confounding risk factors, and complete occupational history information at baseline for 75% of all cases (n=6,151). Limitations include the use of death certificates, which likely resulted in non-differential misclassification of the underlying causes of death and therefore biased the findings toward the null. Additional limitations include the lack of exposure data during follow-up, the lack of exposure measurements, and a limited number of highly exposed cases relative to industry-based cohorts.

The Liu et al. (2013) study of 229 welders classified as having high exposure (median magnetic field = 0.51 µT [5.1 mG]) and 123 stampers classified as having low exposure (median magnetic field = 0.07 µT [7 mG]), which was discussed previously in relation to hematological parameters, found no statistically significant differences in the prevalence of self-reported hyperlipidemia or CVD between study groups. The authors additionally reported that the proportion of men with abnormal homocysteine, alanine aminotransferase, aspartate aminotransferase, glutamyl transpeptidase, and electrocardiogram values or signals was significantly higher in the high exposure group compared with the low exposure group. Noted methodological limitations (previously discussed) and the potential for outcome misclassification render a cautious interpretation of these latter findings. Although these parameters have been implicated in the CVD process, the clinical significance of these findings remains to be determined and could not be separated from potential effects of ubiquitous exposure to welding fumes that may be correlated to work in higher magnetic field exposure jobs. Hence, generalization of these results is very limited and future study with repeated outcome measurements collected in a controlled study setting is necessary.

Assessment

The recent literature, although limited, is consistent with the conclusion that there is no association between magnetic fields and CVD or cardiovascular parameters related to CVD.

Table 9. Relevant studies of cardiovascular disease

Authors	Year	Study title
Koeman et al.	2013	Occupational exposure to extremely low-frequency magnetic fields and cardiovascular disease mortality in a prospective cohort study
Liu et al.	2013	Effects of extremely low frequency electromagnetic field on the health of workers in automotive industry

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 cancer in many organs. In these studies, magnetic-field exposure has been administered alone (to test for the ability of magnetic fields to act as a complete carcinogen), in combination with a known carcinogen (to test for a promotional or co-carcinogenetic effect), or in combination with a known carcinogen and a known promoter (to test for a co-promotional effect).

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 report. Some animals, however, develop a type of lymphoma similar to childhood ALL and studies exposing 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).

Studies investigating whether exposure to magnetic fields can promote cancer or act as a co-carcinogen used known cancer-causing agents, such as ionizing radiation, ultraviolet radiation, or other chemicals. No effects were observed for studies on chemically-induced preneoplastic liver lesions, leukemia or lymphoma, skin tumors, or brain tumors; however, the 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 tumor cells. 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), 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.[22]

Some studies have 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.

In summary, the WHO concluded the following with respect to *in vivo* research: "There is no evidence that ELF [EMF] exposure alone causes tumours. The evidence that ELF field exposure can enhance tumour development in combination with carcinogens is inadequate" (WHO, 2007, p. 322). Recommendations for future research included the development of a rodent model for childhood ALL and the continued investigation of whether magnetic fields can act as a promoter or co-carcinogen.

Recent studies (2011-July 1, 2013)

No new animal bioassays of tumor development due to magnetic-field exposure alone or in combination with known cancer initiators have been conducted since the study by Bernard et al. (2008) that was the first study to use an animal model of ALL, the most common leukemia type in children, reviewed in the previous update. Instead, four studies have been published that investigate the therapeutic potential of magnetic-field exposures in the treatment of cancers. Additionally, numerous *in vivo* studies examining potential mechanisms that could precipitate cancer development have been conducted. These studies are listed in Table 10.

The vast majority of past large-scale, long-term bioassays of magnetic-field exposures have reported that lifetime exposure to magnetic fields do not initiate or promote tumor development in rodents. More recent studies have evaluated whether much higher strength magnetic-field exposures could be used therapeutically in the treatment of tumors. Berg et al. (2010) conducted a series of *in vitro* and *in vivo* studies using both sinusoidal and pulsed EMF exposures to look at the effects on tumor cell survival and molecular pathways. For the purposes of this review, only the results using sinusoidal EMF exposures are discussed, since pulsed fields are not relevant to the types of exposure associated with electrical transmission equipment. In the *in vivo* experiments, male SCID mice were inoculated with MX-1 tumor cells, then injected into the tumor site with 0.1 mg bleomycin, exposed to 200,000 mG, 50-Hz magnetic fields for 8 days (3 hours per day), or both. Sham exposures and blinded analyses were not reported; study details were also limited. Tumor growth was reduced by both treatments, either alone or in combination.

[22] 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).

In another study, Jiménez-Garcia et al. (2010) pretreated rats with diethylnitrosamine and 2-acetylaminofluorene and then subjected them to partial hepatectomy to induce preneoplastic lesions of the liver before exposing the rats to 45,000 mG, 120-Hz magnetic fields for 32 days, 50 minutes per day. For comparison purposes, both an untreated control group and a sham-treated control group were included; however, analyses were not reported to have been conducted in a blinded manner. The study investigators reported that magnetic-field exposures were associated with a reduction in both the number and area of liver preneoplastic lesions. These findings did not appear to be related to an effect on apoptosis, but rather, a possible reduction in cell proliferation.

El-Bialy and Rageh (2013) reported similar findings in female mice that had been previously injected with Ehrlich ascites carcinoma cells. In this study, the mice were treated with 3 mg/kg cisplatin on days 1, 4 and 7 or exposed to 100,000 mG, 50-Hz magnetic fields for 14 days (1 hour per day), or both. A control group was saline-treated, but not sham exposed to magnetic fields, and analyses were not reported to have been conducted in a blinded manner. Both magnetic-field exposure and cisplatin treatment, alone or in combination, were associated with reduced tumor volume and the strongest effect was noted with the combination treatment. This response appeared to be associated with reduced cell proliferation, but also increased DNA damage (as assessed using the Comet and micronucleus assays). In a similar study (Wen et al., 2011), mice that had been previously inoculated with H22 hepatocellular carcinoma cells received five 60-minute exposures to 7,000 mG, 100-Hz magnetic fields either alone or in combination with X-ray exposure (4 or 8 Gray). In other experiments, the mice were exposed to 1, 3, or 5 periods of magnetic-field exposure in combination with 4 Gray X-rays. Unexposed mice were sham-treated (with the exposure system turned off) and analyses were conducted in a blinded manner. Both X-rays and magnetic-field exposure, alone or in combination, inhibited tumor growth. X-rays alone, however, seemed to shorten overall survival duration. Magnetic-field exposure, on the other hand, had a beneficial effect in extending overall survival days. In summary, the results of these studies suggest that magnetic-field exposure may have therapeutic applications in the treatment of tumors; however, because the field strengths were relatively high in most of these studies, it is possible that the observed responses were due to electric fields induced in tissues by strong magnetic fields.

Fedrowitz and Löscher (2012) further investigated their previously reported differences in rat strain susceptibility to DMBA-induced mammary tumor development in response to magnetic-field exposure. Gene expression was evaluated in pooled samples of mammary tissue from both Fischer 344 rats (F344; magnetic-field susceptible)[23] and Lewis rats (magnetic-field insensitive) following two-weeks of continuous exposure to 1,000 mG, 50-Hz magnetic fields. Control rats of both strains were sham exposed (with the exposure system turned off) for the same duration. Analyses were conducted in a blinded manner and a 2.5-fold change in gene expression was established as the cut-off for establishing a magnetic-field exposure-related response. Only 22 out of a possible 31,100 gene transcripts were found to be altered with magnetic-field exposure in the two rat strains combined. Genes showing the greatest change in expression in response to magnetic-field exposure in F344 rats (with no effect observed in Lewis rats) were α-amylase

[23] This designation of 'susceptibility' to magnetic fields is not borne out in other studies of Fisher 344 rats (Boorman et al., 1999b).

(832-fold decrease), parotid secretory protein (662-fold decrease), and carbonic anhydrase 6 (39-fold decrease).

To follow-up on these findings, Fedrowitz et al. (2012) examined α-amylase activity in mammary tissues collected from previous experiments in which either F344 rats or Lewis rats were exposed to 1,000 mG, 50-Hz magnetic fields for 14 days; additional mammary tissues from F344 rats exposed for 1, 7, or 28 days were also examined. In initial experiments using tissues collected in 2005 through 2006, magnetic-field exposure was associated with increased α-amylase activity in cranial mammary tissues, but not caudal mammary tissues, from both F344 and Lewis rats. Thus, the response did not appear to correlate with their claims for rat strain susceptibility to magnetic-field exposure. In later experiments using tissues collected in 2007 through 2008, α-amylase activity in the cranial tissues was unaffected by magnetic-field exposure, but increased in the caudal tissues of F344 rats (and not the tissues of Lewis rats) in response to magnetic-field treatment. Additional experiments looked at α-amylase protein expression and its correlation with tissue differentiation following treatment with diethylstilbestrol. Overall, the findings of this study are contradictory, making interpretation difficult regarding the potential role of α-amylase expression in the observed sensitivity of F344 rats to magnetic-field exposure.

It has been hypothesized that exposure to ELF EMF may inhibit melatonin production, which in turn, could affect susceptibility to developing certain cancers, including breast cancer. A number of reviews have been published recently addressing this hypothesis (Touitou and Selmaoui, 2012; Naziroğlu et al., 2012; Halgamuge, 2013), with conflicting conclusions. These reviews summarize the animal and human data on EMF exposures and melatonin levels to varying extents. Many of these data were available at the time of the WHO's comprehensive health review, which concluded that the available evidence was inadequate to show an adverse effect of ELF EMF exposures on melatonin secretion or other parameters of neuroendocrine function (WHO, 2007).

Okudan et al. (2010) looked for DNA damage markers (micronuclei) in peripheral blood leukocytes derived from mice that were continuously exposed to 10, 20, 30, 40 or 50 mG, 50-Hz magnetic fields for 40 days. A control group was reported to have been sham-exposed and at least some of the analyses were conducted in a blinded manner. Based on a lack of dose-response, the study authors concluded that exposures at 50 mG and lower did not cause DNA damage. In a similar study, Mariucci et al. (2010) exposed mice to a much higher 50-Hz magnetic field at 10,000 mG, but for a shorter duration of 1 or 7 days. The study included an untreated control group, a sham exposure group (with the exposure system turned off), and a positive control exposed to X-ray irradiation (although results from the positive control were not shown), and analyses were conducted in a blinded manner. In this study, DNA damage, as measured by the Comet assay, was increased in the brain tissues of magnetic-field exposed mice at both 1 and 7 days; however, by 24 hours after the 7-day exposure, the DNA damage was no longer evident, suggesting rapid repair. Heat shock protein expression was unaffected by magnetic-field exposure.[24] In another study (Miyakoshi et al., 2012), 3-day old rats were continuously exposed to 100,000 mG, 50-Hz magnetic fields for 72 hours, or treated with 5 or 10

[24] The WHO report described the results of *in vitro* studies of the expression of heat shock genes as "inconsistent or inconclusive results" (WHO, 2007, p. 347).

mg/kg bleomycin, or both, and then brain astrocytes were examined in culture for the presence of micronuclei. Control animals were sham exposed (with the exposure system turned off). In other experiments, the animals were treated as above but also administered tempol, an antioxidant. The analyses in this study were not reported to have been conducted in a blinded manner. Magnetic-field exposure alone or in combination with 5 mg/kg bleomycin appeared to have no effect on micronuclei formation, but was reported to increase the frequency of micronuclei resulting from co-treatment with 10 mg/kg bleomycin. Tempol co-exposure was reported to reduce micronuclei formation, suggesting a role for activated oxygen species in their formation.

Oxidative stress is a condition in which oxygen free radical levels in the body are elevated and is one mechanism by which DNA damage, as well as other forms of cellular damage, may occur. Numerous recent *in vivo* studies have evaluated whether magnetic-field exposure may be associated with oxidative stress, with mixed results. To examine the possible acute effects of magnetic-field exposure, Martínez-Sámano et al. (2010, 2012) exposed rats that were either restrained or unrestrained to a 24,000 mG, 60-Hz magnetic field for 2 hours only. None of the examined markers of oxidative stress were affected by magnetic-field exposure in the liver. Kidney and heart tissues showed decreases in glutathione levels; plasma and brain exhibited reduced superoxide dismutase activity. Catalase activity was also reduced and lipid peroxidation increased in the brain following magnetic-field exposure. No effects on brain nitric oxide, lipid content or plasma corticosterone levels were observed. In a similar study (Chu et al., 2011), mice were exposed to a 23,000 mG, 60- Hz magnetic field for 3 hours. In the brain, hydroxyl radicals and superoxide dismutase activity were increased, ascorbic acid concentrations were reduced, and glutathione and glutathione peroxidase activity were unaffected. In these studies, control animals were sham-exposed (with the exposure system turned off), but analyses were not reported to have been conducted in a blinded manner.

Goraca et al. (2010) exposed rats to a 70,000 mG, 40-Hz magnetic field for either 30 or 60 minutes per day for a total of 14 days. The study investigators observed no effect of a 30 minute per day magnetic-field exposure on oxidative stress markers in the heart or plasma. In contrast, exposure for 60 minutes per day was reported to increase lipid peroxidation and hydrogen peroxide concentrations in the heart, reduced glutathione and free sulfhydryl concentrations in the same tissue, and to reduce the total antioxidant capacity of the plasma. In a related study, Ciejka et al. (2011) exposed rats in the same manner (to a 70,000 mG, 40-Hz magnetic field for 30 or 60 minutes per day), but for a slightly shorter duration of 10 days only. In this case, an increase in lipid peroxidation markers and sulfhydryl groups in the brain at the higher exposure level (60 minutes per day) was reported; hydrogen peroxide concentrations were unaffected. It is unclear, however, if these changes may be related to an increase in the noted sample protein levels. In both of these studies, controls were not reported to have been sham exposed and analyses were not reported to have been conducted in a blinded manner.

Akdag et al. (2010) examined the effects of more long-term magnetic-field exposure. Rats were continuously exposed to a 1,000 or 5,000 mG, 50-Hz magnetic field for 2 hours per day for 10 months. Control rats were sham exposed (with the exposure system turned off) and analyses were reported to have been conducted in a blinded manner. Although no morphological changes were noted in the brain tissues, at the highest exposure level various markers of oxidative stress (lipid peroxidation, total oxidant status, the oxidative stress index) were increased and antioxidant measures (catalase activity, total antioxidant capacity) were reduced. Kiray et al. (2012) conducted a similar study in which rats were exposed to a 30,000 mG, 50-Hz magnetic field 4 hours per day for 2 months. From the study report, it is not clear if control rats were sham-exposed and blinded analyses were not reported. In this study, morphological changes were noted in the hearts of exposed rats. Lipid peroxidation was reported to be increased and levels of anti-oxidative enzymes (superoxide dismutase and glutathione peroxidase) decreased.

Overall, it is hard to draw any conclusions from these studies of oxidative stress markers because the numbers of animals per group were generally low, the exposure parameters and oxidative stress markers examined varied across the studies, reported effects were contradictory across studies in some cases, and none of the analyses (with the exception of that by Akdag et al., 2010) were reported to have been conducted in a blinded manner. Independent replication of findings in studies with greater sample sizes and blinded analyses is needed.

The immune system is thought to play an important role in the immunosurveillance against cancer cells. Further, ALL, one of the cancers of concern for EMF exposures in children, arises in cells of the immune system. Thus, there is an interest in the potential effects of EMF exposures on immune function. To address this, Salehi et al. (2012) examined the effects of long-term magnetic-field exposure on the expression of various cytokines (including certain interleukins and interferon-γ [IFN-γ]), which are important factors in regulating immune function. Male rats were exposed to a 100 mG, 50-Hz magnetic field for 2 hours per day for 3 months. Control rats were sham exposed (with the exposure system turned off), but analyses were not reported to have been conducted in a blinded manner. No differences in body weight, or weights of the spleen and thymus (two important immune organs) were noted between the two groups. Serum concentrations of interleukin (IL)-12 were reduced with exposure, but levels of IFN-γ, IL-4 and IL-6 were unaffected. Spleen and blood cells were also collected from the animals after exposure to measure *in vitro* production. IL-6 production, but not production of the other cytokines, was increased in both cell types in response to phytohemagglutinin stimulation. In another study, Selmeoui et al. (2011) examined the effects of both continuous and intermittent exposure to a 100 mG, 50-Hz magnetic field on interleukins in human subjects. The control subjects were sham exposed, but in a separate room from that of the exposed group. In the intermittent condition, the exposure apparatus was 1 hour 'on' and 1 hour 'off', with the magnetic field switched on and off over a 15-second cycle during the 'on' operation. No exposure-related changes were observed with continuous exposure. In the intermittent condition, IL-6 expression was increased while the expression of four other interleukins (IL-1β, IL-1RA, IL-2 and IL-2R) was unaffected. The study authors cautioned that further study was required before any firm conclusions could be drawn from these findings.

A well-designed double-blind study (Kirschenlohr et al., 2012) examined gene expression in the white blood cells of 17 pairs of human subjects following exposure to a 620 mG, 50-Hz magnetic field on four different days (2 hours per day) over two weeks. On each exposure day, one member of each pair was exposed to the magnetic field and the other either exposed to sham conditions (with the current passing through the two coils of the exposure apparatus in opposing directions so that the magnetic field was cancelled, but the total current remained the same) or not exposed. On the next day, the exposures were reversed (the previously exposed subject was sham exposed or not exposed, and vice-versa). Blood samples were collected just prior to and following exposures, as well as at multiple times throughout the exposure period. Gene expression in one set of the collected blood samples (collected in week 1) was determined via microarray analysis with an emphasis on genes previously reported to respond to EMF exposure (i.e., immediate early genes involved in stress, inflammatory and proliferative and apoptotic responses). The samples collected just prior to exposure were used as reference samples. Any indications of a possible positive finding were verified using the second set of collected blood samples. The study investigators reported that no genes showed a consistent response to magnetic-field exposure.

In a similarly well-conducted study, Kabacik et al. (2013) looked for changes in the expression of genes in the bone marrow of juvenile mice exposed to a 1,000 mG, 50-Hz magnetic field for 2 hours. The premise for conducting this research was that many leukemias are derived from cells in the bone marrow; thus, changes in gene expression in the bone marrow may relate to the development of these cancers. Control mice were sham-exposed and the experiment repeated in multiple groups of exposed and unexposed mice. In order to confirm consistent changes with exposure, gene expression in these replicate samples was analyzed in a blinded manner using multiple methods and in different laboratories. Again, no consistent changes in gene expression in response to magnetic field exposure were found.

Assessment

As previously noted, no new animal bioassays of long-term magnetic-field exposure as a possible carcinogen or co-carcinogen have been conducted since the last update. Rather, a few studies have examined the potential of magnetic-field exposure to be used in the therapeutic treatment of tumors. Since these studies were generally conducted at relatively high magnetic-field strengths, however, it is unclear if the observed therapeutic potential might be due to tissue stimulation by induced electric fields; more study in this arena is warranted.

Various other studies investigated potential mechanisms related to carcinogenesis, including genotoxicity, oxidative stress, alterations in gene expression, and immune functional changes. Many of these studies suffer from various methodological deficiencies, including small samples sizes, the absence of sham-exposure treatment groups, and analyses that were not conducted in a blinded manner. Further, the results are generally inconsistent across the body of studies, with some studies reporting effects and other studies showing no change. Even in the studies showing alterations, these changes are not necessarily consistent from one study to the next. Two particularly well-conducted studies evaluated potential differences in gene expression resulting from magnetic-field exposure. These studies employed sham exposures, replicate samples, and blinded analyses using multiple experimental methods of measuring gene expression in multiple laboratories; they also took into consideration the potential statistical power of the studies. Neither of these studies reported consistent changes in gene expression due to magnetic-field exposure. 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.

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

Authors	Year	Study
Akdag et al.	2010	Effects of extremely low-frequency magnetic field on caspase activities and oxidative stress values in rat brain
Berg et al.	2010	Bioelectromagnetic field effects on cancer cells and mice tumors
Chu et al.	2011	Extremely low frequency magnetic field induces oxidative stress in mouse cerebellum
Ciejka et al.	2011	Effects of extremely low frequency magnetic field on oxidative balance in brain of rats
El-Bialy and Rageh	2013	Extremely low-frequency magnetic field enhances the therapeutic efficacy of low-dose cisplatin in the treatment of Ehrlich carcinoma
Fedrowitz and Löscher	2012	Gene expression in the mammary gland tissue of female Fischer 344 and Lewis rats after magnetic field exposure (50 Hz, 100 μT) for 2 weeks
Fedrowitz et al.	2012	Effects of 50 Hz magnetic field exposure on the stress marker α-amylase in the rat mammary gland
Goraca et al.	2010	Effects of extremely low frequency magnetic field on the parameters of oxidative stress in heart
Jiménez-Garcia et al.	2010	Anti-proliferative effect of extremely low frequency electromagnetic field on preneoplastic lesions formation in the rat liver
Kabacik et al.	2013	Investigation of transcriptional responses of juvenile mouse bone marrow to power frequency magnetic fields
Kiray et al.	2012	The effects of exposure to electromagnetic field on rat myocardium.
Kirschenlohr et al.	2012	Gene expression profiles in white blood cells of volunteers exposed to a 50 Hz electromagnetic field
Mariucci et al.	2010	Brain DNA damage and 70-kDa heat shock protein expression in CD1 mice exposed to extremely low frequency magnetic fields
Martínez-Sámano et al.	2010	Effects of acute electromagnetic field exposure and movement restraint on antioxidant system in liver, heart, kidney and plasma of Wistar rats: A preliminary report
Martínez-Sámano et al.	2012	Effect of acute extremely low frequency electromagnetic field exposure on the antioxidant status and lipid levels in rat brain
Miyakoshi et al.	2012	Tempol suppresses micronuclei formation in astrocytes of newborn rats exposed to 50-Hz, 10-mT electromagnetic fields under bleomycin administration
Okudan et al.	2010	Effects of long-term 50 Hz magnetic field exposure on the micro nucleated polychromatic erythrocyte and blood lymphocyte frequency and argyrophilic nucleolar organizer regions in lymphocytes of mice
Salehi et al.	2012	Exposure of rats to extremely low-frequency electromagnetic fields (ELF-EMF) alters cytokines production
Selmaoui et al.	2011	Acute exposure to 50-Hz magnetic fields increases interleukin-6 in young healthy men
Wen et al.	2011	The effect of 100 Hz magnetic field combined with X-ray on hepatoma-implanted mice

In vitro studies related to carcinogenesis

In its review of the available *in vitro* research on potential mechanisms of carcinogenesis, the WHO concluded that these studies generally fail to show genotoxicity at magnetic-field exposures below 500,000 mG. They further noted that studies of other potential carcinogenic mechanisms (e.g., cell proliferation, malignant transformation, altered gene expression) were inconsistent or inconclusive.

Since the last update, 26 new *in vitro* studies of ELF EMF exposures related to carcinogenesis were published (May 2011-June 2013). These studies are listed in Table 11. The majority of these studies have investigated cellular processes and mechanisms of relevance to carcinogenesis, including genotoxicity, proliferation, oxidative stress and immune responses. A few other studies, in contrast, investigated the therapeutic potential of magnetic-field exposure for tumor treatment (Berg et al., 2010; Karbowski et al., 2012). Overall, the results across this body of studies are inconsistent. Further, these studies generally suffer from various experimental deficiencies, including small sample sizes, the absence of sham-exposure conditions, a lack of control for various confounding variables (e.g., temperature, vibration), and analyses that have not been conducted in a blinded manner. These studies do not add significantly to the body of evidence available regarding ELF EMF exposure and carcinogenesis because of the limitations of *in vitro* studies for human risk assessment and because of these various deficiencies and the inconsistency of study results. This assessment of *in vitro* studies is consistent with the review by EFHRAN (2010a) that considered *in vitro* studies of cellular functions as providing "inadequate" evidence of cancer processes and "limited" evidence for other select cellular functions.

Table 11. Relevant *in vitro* studies of carcinogenesis

Authors	Year	Study
Basile et al.	2011	Exposure to 50 Hz electromagnetic field raises the levels of the anti-apoptotic protein BAG3 in melanoma cells
Batcioglu et al.	2011	Investigation of a weak magnetic field effect on the *in vitro* catalytic activity of adenosine deaminase and xanthine oxidase
Berg et al.	2010	Bioelectromagnetic field effects on cancer cells and mice tumors
Bouwens et al.	2012	Low-frequency electromagnetic fields do not alter responses of inflammatory genes and proteins in human monocytes and immune cell lines
Buldak et al.	2012	Short-term exposure to 50 Hz ELF-EMF alters the cisplatin-induced oxidative response in AT478 murine squamous cell carcinoma cells
Cho et al.	2012	Neural stimulation on human bone marrow-derived mesenchymal stem cells by extremely low frequency electromagnetic fields.
Cid et al.	2012	Antagonistic effects of a 50 Hz magnetic field and melatonin in the proliferation and differentiation of hepatocarcinoma cells
Coček et al.	2012	The impact of lower induction values of 50 Hz external electromagnetic fields on in vitro T lymphocyte adherence capabilities.
Fox et al.	2011	Macrophages under low oxygen culture conditions response to ion parametric resonance magnetic fields
Hong et al.	2012	Extremely low frequency magnetic fields do not elicit oxidative stress in MCF10A cells

Authors	Year	Study
Jin et al.	2012	Effects on micronuclei formation of 60-Hz electromagnetic field exposure with ionizing radiation, hydrogen peroxide, or c-Myc overexpression
Karbowski et al.	2012	Digitized quantitative electroencephalographic patterns applied as magnetic fields inhibit melanoma cell proliferation in culture
Kim et al.	2012	Time-varying magnetic fields of 60 Hz at 7 mT induce DNA double-strand breaks and activate DNA damage checkpoints without apoptosis
Lee et al.	2012	Combined effects of 60 Hz electromagnetic field exposure with various stress factors on cellular transformation in NIH3T3 cells
Luukkonen et al.	2011	Pre-exposure to 50 Hz magnetic fields modifies menadione-induced genotoxic effects in human SH-SY5Y neuroblastoma cells
Martinez et al.	2012	The proliferative response of NB69 human neuroblastoma cells to a 50 Hz magnetic field is mediated by ERK1/2 signaling
Park et al.	2013	Electromagnetic fields induce neural differentiation of human bone marrow derived mesenchymal stem cells via ROS mediated EGFR activation
Patruno et al.	2011	Kinetic study on the effects of extremely low frequency electromagnetic field on catalase, cytochrome P450 and inducible nitric oxide synthase in human HaCaT and THP-1 cell lines
Patruno et al.	2012	Activity of matrix metallo proteinases (MMPs) and the tissue inhibitor of MMP (TIMP)-1 in electromagnetic field-exposed THP-1 cells
Ross and Harrison	2013	Effect of time-varied magnetic field on inflammatory response in macrophage cell line RAW 264.7
Sarimov et al.	2011	Fifty Hertz magnetic fields individually affect chromatin conformation in human lymphocytes: Dependence on amplitude, temperature, and initial chromatin state
Sulpizio et al.	2011	Molecular basis underlying the biological effects elicited by extremely low-frequency magnetic field (ELF-MF) on neuroblastoma cells
Trillo et al.	2012	Influence of a 50 Hz magnetic field and of all-trans-retinol on the proliferation of human cell lines
Zhang et al.	2013	Effects of low frequency electromagnetic field on proliferation of human epidermal stem cells: An in vitro study
Zhou et al.	2011	Effects of 50 Hz sinusoidal electromagnetic fields of different intensities on proliferation, differentiation and mineralization potentials of rat osteoblasts
Zhou et al.	2013	Different electromagnetic field waveforms have different effects on proliferation, differentiation and mineralization of osteoblasts in vitro

7 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 6.

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/D2_Finalversion_oct2012.pdf (EFHRAN, 2012 [human exposure])
  - http://efhran.polimi.it/docs/IMS-EFHRAN_09072010.pdf (EFHRAN, 2010 [*in vitro* and *in vivo* [animal] studies)
- **The Health Council of Netherlands**
  - 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)
  - http://www.gezondheidsraad.nl/en/publications/bioinitiative-report-0 (HCN, 2008a)
  - http://www.gezondheidsraad.nl/en/publications/high-voltage-power-lines-0 (HCN, 2008b)
- **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)

  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/Global/Publikationer/Rapport/Stralskydd/2009/SSM-Rapport-2009-36.pdf (SSM, 2009)
  - http://www.stralsakerhetsmyndigheten.se/Global/Publikationer/Rapport/Stralskydd/2010/SSM-Rapport-2010-44.pdf (SSM, 2010)
  - http://www.stralsakerhetsmyndigheten.se/Publikationer/Rapport/Stralskydd/2013/201319/ (SSM, 2013)

8 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.[25] 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; FDER, 1989; NYPSC, 1990; FDEP, 1996), however, the basis for these limits was to maintain the "status quo" so that fields from new transmission lines would be no higher than those produced by existing transmission lines.

[25] Valberg et al. (2011) provides a listing of guidelines provided by health and safety organizations.

Table 12. 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

9 Summary

A significant number of epidemiology and *in vivo* studies have been published on ELF EMF and health since the WHO 2007 report was released in June 2007. The weak statistical association between high, average magnetic fields and childhood leukemia has not been appreciably strengthened or diminished by subsequent research and remains unexplained and unsupported by the experimental data. The recent *in vivo* studies confirm the lack of experimental data supporting a leukemogenic risk associated with magnetic-field exposure.

Overall, the current body of research supports the conclusion that there is no association between magnetic fields and adult cancer or cardiovascular disease, although future research is needed that improves upon exposure estimations. Recent literature suggested an association with magnetic fields and Alzheimer's disease, but no firm conclusions can be drawn from this literature set regarding causation.

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

10 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, Ulukaya E, Uzunlar AK, Kurt MA, Taskin A. Effects of extremely low-frequency magnetic field on caspase activities and oxidative stress values in rat brain. Biol Trace Elem Res 138: 238-249, 2010.

Amigou A, Sermage-Faure C, Orsi L, Leverger G, Baruchel A, Bertrand Y, Nelken B, Robert A, Michel G, Margueritte G, Perel Y, Mechinaud F, Bordigoni P, Hemon D, Clavel J. Road traffic and childhood leukemia: The ESCALE Study (SFCE). Environ Health Perspect 119: 566-572, 2011.

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: 1615-1620, 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.

Balamuralikrishnan B, Balachandar V, Kumar SS, Stalin N, Varsha P, Devi SM, Arun M, Manikantan P, Venkatesan C, Sasikala K, Dharwadkar SN. Evaluation of chromosomal alteration in electrical workers occupationally exposed to low frequency of electro magnetic field (EMFs) in Coimbatore population, India. Asian Pac J Cancer Prev 13: 2961-2966, 2012.

Baldi I, Coureau G, Jaffre A, Gruber A, Ducamp S, Provost D, Lebailly P, Vital A, Loiseau H, Salamon R. Occupational and residential exposure to electromagnetic fields and risk of brain tumors in adults: a case-control study in Gironde, France. Int J Cancer 129: 1477-1484, 2011.

Barsam T, Monazzam MR, Haghdoost AA, Ghotbi MR, Dehghan SF. Effect of extremely low frequency electromagnetic field exposure on sleep quality in high voltage substations. Iranian J Environ Health Sci Eng 9: 15, 2012.

Barth A, Ponocny I, Ponocny-Seliger E, Vana N, Winker R. Effects of extremely low-frequency magnetic field exposure on cognitive functions: results of a meta-analysis. Bioelectromagnetics 31: 173-179, 2010.

Bartley K, Metayer C, Selvin S, Ducore J, Buffler P. Diagnostic x-rays and risk of childhood leukaemia. . Int J Epidemiol 39: 1628-1637, 2010.

Basile A, Zeppa R, Pasquino N, Arra C, Ammirante M, Festa M, Barbieri A, Giudice A, Pascale M, Turco MC, Rosati A. Exposure to 50 Hz electromagnetic field raises the levels of the anti-apoptotic protein BAG3 in melanoma cells. J Cell Physiol 226: 2901-2907, 2011.

Batcioglu K, Dogan M, Uyumlu AB, Satilmis B, Bayri N, Atalay S, Demirtas H. Investigation of a weak magnetic field effect on the in vitro catalytic activity of adenosine deaminase and xanthine oxidase. Gen Physiol Biophys 30: 410-414, 2011.

Baum A, Mevissen M, Kamino K, Mohr U, Loscher 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.

Bellieni CV, Tei M, Iacoponi F, Tataranno ML, Negro S, Proietti F, Longini M, Perrone S, Buonocore G. Is newborn melatonin production influenced by magnetic fields produced by incubators? Early Hum Dev 88: 707-710, 2012.

Belson M, Kingsley B, Holmes A. Risk factors for acute leukemia in children: a review. Environ Health Perspect 115: 138-145, 2007.

Berg H, Gunther B, Hilger I, Radeva M, Traitcheva N, Wollweber L. Bioelectromagnetic field effects on cancer cells and mice tumors. Electromagn Biol Med 29: 132-143, 2010.

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.

Borhani N, Rajaei F, Salehi Z, Javadi A. Analysis of DNA fragmentation in mouse embryos exposed to an extremely low-frequency electromagnetic field. Electromagn Biol Med 30: 246-252, 2011.

Borugian MJ, Spinelli JJ, Mezei G, Wilkins R, Abanto Z, McBride ML. Childhood leukemia and socioeconomic status in Canada. Epidemiology 16: 526-531, 2005.

Bouwens M, de Kleijn S, Ferwerda G, Cuppen JJ, Savelkoul HF, Kemenade BM. Low-frequency electromagnetic fields do not alter responses of inflammatory genes and proteins in human monocytes and immune cell lines. Bioelectromagnetics 33: 226-237, 2012.

Brain JD, Kavet R, Valberg PA. Observations on power-line magnetic fields associated with asthma in children. Arch Pediatr Adolesc Med 155: 97-98, 2012.

Buldak RJ, Polaniak R, Buldak L, Zwirska-Korczala K, Skonieczna M, Monsiol A, Kukla M, Dulawa-Buldak A, Birkner E. Short-term exposure to 50 Hz ELF-EMF alters the cisplatin-induced oxidative response in AT478 murine squamous cell carcinoma cells. Bioelectromagnetics 33: 641-651, 2012.

Calvente I, Fernandez MF, Villalba J, Olea N, Nunez MI. Exposure to electromagnetic fields (non-ionizing radiation) and its relationship with childhood leukemia: a systematic review. Sci Total Environ 408: 3062-3069, 2010.

Carrubba S, Frilot C, 2nd, Chesson AL, Jr., Marino AA. Numerical analysis of recurrence plots to detect effect of environmental-strength magnetic fields on human brain electrical activity. Med Eng Phys 32: 898-907, 2010.

Chen Q, Lang L, Wu W, Xu G, Zhang X, Li T, Huang H. A Meta-Analysis on the Relationship between Exposure to ELF-EMFs and the Risk of Female Breast Cancer. PLoS One 8: e69272, 2013.

Cho H, Seo YK, Yoon HH, Kim SC, Kim SM, Song KY, Park JK. Neural stimulation on human bone marrow-derived mesenchymal stem cells by extremely low frequency electromagnetic fields. Biotechnol Prog 28: 1329-1335, 2012.

Chu LY, Lee JH, Nam YS, Lee YJ, Park WH, Lee BC, Kim D, Chung YH, Jeong JH. Extremely low frequency magnetic field induces oxidative stress in mouse cerebellum. Gen Physiol Biophys 30: 415-421, 2011.

Cid MA, Ubeda A, Hernandez-Bule ML, Martinez MA, Trillo MA. Antagonistic effects of a 50 Hz magnetic field and melatonin in the proliferation and differentiation of hepatocarcinoma cells. Cell Physiol Biochem 30: 1502-1516, 2012.

Ciejka E, Kleniewska P, Skibska B, Goraca A. Effects of extremely low frequency magnetic field on oxidative balance in brain of rats. J Physiol Pharmacol 62: 657-661, 2011.

Cocek A, Hahn A, Martonova J, Ambrus M, Dohnalova A, Nedbalova M, Jandova A. The impact of lower induction values of 50 Hz external electromagnetic fields on in vitro T lymphocyte adherence capabilities. Electromagn Biol Med 31: 166-177, 2012.

Consales C, Merla C, Marino C, Benassi B. Electromagnetic fields, oxidative stress, and neurodegeneration. Int J Cell Biol 2012: 683897, 2012.

Contessa GM, Falsaperla R, Brugaletta V, Rossi P. Exposure to magnetic fields of railway engine drivers: a case study in Italy. Radiat Prot Dosimetry 142: 160-167, 2010.

Corbacio M, Brown S, Dubois S, Goulet D, Prato FS, Thomas AW, Legros A. Human cognitive performance in a 3 mT power-line frequency magnetic field. Bioelectromagnetics 32: 620-633, 2011.

Davanipour Z and Sobel E. Long-term exposure to magnetic fields and the risks of Alzheimer's disease and breast cancer: Further biological research. Pathophysiology 16: 149-156, 2009.

de Jong A, Wardekker J, van de Sluijs J. Assumptions in quantitative analyses of health risks of overhead power lines. Environ Sci Pol 16: 114-121, 2012.

de Vocht F, Hannam K, Buchan I. Environmental risk factors for cancers of the brain and nervous system: the use of ecological data to generate hypotheses. Occup Environ Med 70: 349-356, 2013.

Del GE, Facchinetti F, Nofrate V, Boccaccio P, Minelli T, Dam M, Leon A, Moschini G. Fifty hertz electromagnetic field exposure stimulates secretion of beta-amyloid peptide in cultured human neuroglioma. Neurosci Lett 418: 9-12, 2007.

Dimbylow P and Findlay R. The effects of body posture, anatomy, age and pregnancy on the calculation of induced current densities at 50 Hz. Radiat Prot Dosimetry 139: 532-538, 2010.

Does M, Scelo G, Metayer C, Selvin S, Kavet R, Buffler P. Exposure to electrical contact currents and the risk of childhood leukemia. Radiat Res 175: 390-396, 2011.

Dominici L, Villarini M, Fatigoni C, Monarca S, Moretti M. Genotoxic hazard evaluation in welders occupationally exposed to extremely low-frequency magnetic fields (ELF-MF). Int J Hyg Environ Health 215: 68-75, 2011.

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.

Eden T. Aetiology of childhood leukaemia. Cancer Treat Rev 36: 286-297, 2010.

El-Bialy NS and Rageh MM. Extremely low-frequency magnetic field enhances the therapeutic efficacy of low-dose cisplatin in the treatment of Ehrlich carcinoma. Biomed Res Int 2013: 189352, 2013.

El-Helaly M and Abu-Hashem E. Oxidative stress, melatonin level, and sleep insufficiency among electronic equipment repairers. Indian J Occup Environ Med 14: 66-70, 2010.

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.

Emre M, Cetiner S, Zencir S, Unlukurt I, Kahraman I, Topcu Z. Oxidative stress and apoptosis in relation to exposure to magnetic fields. Cell Biochem Biophys 59: 71-77, 2011.

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. Report D3 of the EFHRAN Project, 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, 2012.

Fariello RM, Pariz JR, Spaine DM, Gozzo FC, Pilau EJ, Fraietta R, Bertolla RP, Andreoni C, Cedenho AP. The effect of smoking on the functional aspects of sperm and seminal plasma protein profiles in patients with varicocele. Hum Reprod 27: 3140-3149, 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, Hass R, Löscher W. Effects of 50 Hz mangetic field exposure on the stress marker α-amylase in the rat mammary gland. Int J Radiat Biol 88: 556-564, 2012.

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 Löscher W. Gene expression in the mammary gland tissue of female Fischer 344 and Lewis rats after magnetic field exposure (50 Hz, 100 muT) for 2 weeks. Int J Radiat Biol 88: 425-429, 2012.

Feychting M and Forssen U. Electromagnetic fields and female breast cancer. Cancer Causes Control 17: 553-558, 2006.

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

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

Fox SJ, Owegi HO, Egot-Lemaire SJ, Waite LR, Blackman CF, Page JK, Waite GN. Macrophages under low oxygen culture conditions respond to ion parametric resonance magnetic fields Biomed Sci Instrum 47: 52-57, 2011.

Frei P, Poulsen AH, Mezei G, Pedersen C, Cronberg Salem L, Johansen C, Roosli M, Schuz J. Residential distance to high-voltage power lines and risk of neurodegenerative diseases: a Danish population-based case-control study. Am J Epidemiol, 2013.

Gauger JR. Household appliance magnetic field survey. IEEE Trans Power App Syst 104: 2436-2444, 1985.

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.

Goraca A, Ciejka E, Piechota A. Effects of extremely low frequency magnetic field on the parameters of oxidative stress in heart. J Physiol Pharmacol 61: 333-338, 2010.

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

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.

Halgamuge MN. Pineal melatonin level disruption in humans due to electromagnetic fields and ICNIRP limits. Radiat Prot Dosimetry 154: 405-416, 2013.

Hareuveny R, Kandel S, Yitzhak NM, Kheifets L, Mezei G. Exposure to 50 Hz magnatic fieds in apartment buildings with indoor transformer stations in Israel. J Expo Sci Environ Epidemiol 21: 365-371, 2011.

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.

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. Report No. 2009/02. The Hague: HCN, 2009.

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: Health Protection Agency, 2006.

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

Hirata A, Takano Y, Fujiwara O, Dovan T, Kavet R. An electric field induced in the retina and brain at threshold magnetic flux density causing magnetophosphenes. Phys Med Biol 56: 4091-4101, 2011.

Hong MN, Han NK, Lee HC, Ko YK, Chi SG, Lee YS, Gimm YM, Myung SH, Lee JS. Extremely low frequency magnetic fields do not elicit oxidative stress in MCF10A cells. J Radiat Res 53: 79-86, 2012.

Huang SM, Lin YW, Sung FC, Li CY, Chang MF, Chen PC. Occupational exposure of dentists to extremely-low-frequency magnetic field. J Occup Health 53: 130-136, 2011.

Hug K, Grize L, Seidler A, Kaatsch P, Schuz J. Parental occupational exposure to extremely low frequency magnetic fields and childhood cancer: a German case-control study. Am J Epidemiol 171: 27-35, 2010.

Hulka BS and Moorman PG. Breast cancer: hormones and other risk factors. Maturitas 61: 203-213, 2008.

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

Jiménez-Garcia MN, Arellanes-Robledo J, Aparicio-Bautista DI, Rodriguez-Segura MA, Villa-Trevino S, Godina-Nava JJ. Anti-proliferative effect of extremely low frequency electromagnetic field on preneoplastic lesions formation in the rat liver. BMC Cancer 10: 159, 2010.

Jin YB, Kang GY, Lee JS, Choi JI, Lee JW, Hong SC, Myung SH, Lee YS. Effects on micronuclei formation of 60-Hz electromagnetic field exposure with ionizing radiation, hydrogen peroxide, or c-Myc overexpression. Int J Radiat Biol 88: 374-380, 2012.

Jirik V, Pekarek L, Janout V. Assessment of population exposure to extremely low freuency magnetic fields and its possible childhood health risk in the Czech Republic. Indoor Built Environ 20: 362-368, 2011.

Jirik V, Pekarek L, Janout V, Tomaskova H. Assocation between childhood leukaemia and exposure to power-frequency magnetic fields in Middle Europe. Biomed Environ Sci 25: 597-601, 2012.

Kabacik S, Kirschenlohr H, Raffy C, Whitehill K, Coster M, Abe M, Brindle K, Badie C, Sienkiewicz Z, Bouffler S. Investigation of transcriptional responses of juvenile mouse bone marrow to power frequency magnetic fields. Mutat Res 745-746: 40-45, 2013.

Karbowski LM, Harribance SL, Buckner CA, Mulligan BP, Koren SA, Lafrenie RM, Persinger MA. Digitized quantitative electroencephalographic patterns applied as magnetic fields inhibit melanoma cell proliferation in culture. Neurosci Lett 523: 131-134, 2012.

Kato M and Sheigemitsu T. Effect of 50 Hz Magnetic Fields on Pineal Function in the Rat. In The Melatonin Hypothesis, Breast Cancer and Use of Electric Power, edited by Stevens RG, Wilson BW,Anderson LE. Richland: Batelle Press, 1997.

Kavet R, Hooper C, Buffler P, Does M. The relationship between residential magnetic fields and contact voltage: a pooled analysis. Radiat Res 176: 807-815, 2011.

Keegan TJ, Bunch KJ, Vincent TJ, King JC, O'Neill KA, Kendall GM, MacCarthy A, Fear NT, Murphy MF. Case-control study of paternal occupation and childhood leukaemia in Great Britain, 1962-2006. Br J Cancer 107: 1652-1659, 2012.

Kheifets L, Afifi A, Monroe J, Swanson J. Exploring exposure--response for magnetic fields and childhood leukemia. J Expo Sci Environ Epidemiol 21: 625-633, 2011.

Kheifets L, Ahlbom A, Crespi CM, Draper G, Hagihara J, Lowenthal RM, Mezei G, Oksuzyan S, Schuz 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, Schuz 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, 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 and Oksuzyan S. Exposure assessment and other challenges in non-ionising radiation studies of childhood leukemia. . Radiat Prot Dosimetry 132: 139-147, 2008.

Kim J, Yoon Y, Yun S, Park GS, Lee HJ, Song K. Time-varying magnetic fields of 60 Hz at 7 mT induce DNA double-strand breaks and activate DNA damage checkpoints without apoptosis. Bioelectromagnetics 33: 383-393, 2012.

Kim SK, Choi JL, Kwon MK, Choi JY, Kim DW. Effects of 60 Hz magnetic fields on teenagers and adults. Environ Health 12: 42, 2013.

Kiray A, Tayefi H, Kiray M, Bagriyanik HA, Pekcetin C, Ergur BU, Ozogul C. The effects of exposure to electromagnetic field on rat myocardium. Toxicol Ind Health 29: 418-425, 2013.

Kirschenlohr H, Ellis P, Hesketh R, Metcalfe J. Gene expression profiles in white blood cells of volunteers exposed to a 50 Hz electromagnetic field. Radiat Res 178: 138-149, 2012.

Koeman T, Slottje P, Kromhout H, Schouten LJ, Goldbohm RA, van den Brandt PA, Vermeulen R. Occupational exposure to extremely low-frequency magnetic fields and cardiovascular disease mortality in a prospective cohort study. Occup Environ Med 70: 402-407, 2013.

Korpinen LH, Elovaara JA, Kuisti HA. Occupational exposure to electric fields and induced currents associated with 400 kV substation tasks from different service platforms. Bioelectromagnetics 32: 79-83, 2011b.

Korpinen LH, Kuisti HA, Paakkonen R, Vanhala P, Elovaara JA. Occupational exposure to electric and magnetic fields while working at switching and transforming stations of 110 kV. Ann Occup Hyg 55: 526-536, 2011a.

Kroll ME, Swanson J, Vincent TJ, Draper GJ. Childhood cancer and magnetic fields from high-voltage power lines in England and Wales: a case-control study. Br J Cancer 103: 1122-1127, 2010.

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.

Lee HJ, Jin YB, Lee JS, Choi JI, Lee JW, Myung SH, Lee YS. Combined effects of 60 Hz electromagnetic field exposure with various stress factors on cellular transformation in NIH3T3 cells. Bioelectromagnetics 33: 207-214, 2012.

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 DK, Ferber JR, Odouli R, Quesenberry CP, Jr. A prospective study of in-utero exposure to magnetic fields and the risk of childhood obesity. Sci Rep 2: 540, 2012.

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 23: 9-20, 2002.

Li DK, Yan B, Li Z, Gao E, Miao M, Gong D, Weng X, Ferber JR, Yuan W. Exposure to magnetic fields and the risk of poor sperm quality. Reprod Toxicol 29: 86-92, 2010.

Li P, McLaughlin J, Infante-Rivard C. Maternal occupational exposure to extremely low frequency magnetic fields and the risk of brain cancer in the offspring. Cancer Causes Control 20: 945-955, 2009.

Liu X, Zhao L, Yu D, Ma S, Liu X. Effects of extremely low frequency electromagnetic field on the health of workers in automotive industry. Electromagn Biol Med doi:10.3109/15368378.013.773909, Early Online, 2013.

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.

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, 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.

Luukkonen J, Liimatainen A, Hoyto A, Juutilainen J, Naarala J. Pre-exposure to 50 Hz magnetic fields modifies menadione-induced genotoxic effects in human SH-SY5Y neuroblastoma cells. PLoS One 6: e18021, 2011.

Maes A and Verschaeve L. Can cytogenetics explain the possible association between exposure to extreme low-frequency magnetic fields and Alzheimer's disease? J Appl Toxicol 32: 81-87, 2012.

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.

Malagoli C, Crespi CM, Rodolfi R, Signorelli C, Poli M, Zanichelli P, Fabbi S, Teggi S, Garavelli L, Astolfi G, Calzolari E, Lucenti C, Vinceti M. Maternal exposure to magnetic fields from high-voltage power lines and the risk of birth defects. Bioelectromagnetics 33: 405-409, 2012.

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.

Marcilio I, Gouveia N, Pereira Filho ML, Kheifets L. Adult mortality from leukemia, brain cancer, amyotrophic lateral sclerosis and magnetic fields from power lines: a case-control study in Brazil. Rev Bras Epidemiol 14: 580-588, 2011.

Mariucci G, Villarini M, Moretti M, Taha E, Conte C, Minelli A, Aristei C, Ambrosini MV. Brain DNA damage and 70-kDa heat shock protein expression in CD1 mice exposed to extremely low frequency magnetic fields. Int J Radiat Biol 86: 701-710, 2010.

Martinez MA, Ubeda A, Cid MA, Trillo MA. The proliferative response of NB69 human neuroblastoma cells to a 50 Hz magnetic field is mediated by ERK1/2 signaling. Cell Physiol Biochem 29: 675-686, 2012.

Martinez-Samano J, Torres-Duran PV, Juarez-Oropeza MA, Elias-Vinas D, Verdugo-Diaz L. Effects of acute electromagnetic field exposure and movement restraint on antioxidant system in liver, heart, kidney and plasma of Wistar rats: a preliminary report. Int J Radiat Biol 86: 1088-1094, 2010.

Martinez-Samano J, Torres-Duran PV, Juarez-Oropeza MA, Verdugo-Diaz L. Effect of acute extremely low frequency electromagnetic field exposure on the antioxidant status and lipid levels in rat brain. Arch Med Res 43: 183-189, 2012.

Maslanyj M, Simpson J, Roman E, Schuz J. Power frequency magnetic fields and risk of childhood leukaemia: misclassification of exposure from the use of the 'distance from power line' exposure surrogate. Bioelectromagnetics 30: 183-188, 2009.

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.

McNally RJ and Parker L. Environmental factors and childhood acute leukemias and lymphomas. Leuk Lymphoma 47: 583-598, 2006.

Mee T, Whatmough P, Broad L, Dunn C, Maslanyj M, Allen S, Muir K, McKinney PA, van Tongeren M. Occupational exposure of UK adults to extremely low frequency magnetic fields.

Occup Environ Med 66: 619-627, 2009.

Mevissen M, Lerchl A, Löscher W. Study on pineal function and DMBA-induced breast cancer formation in rats during exposure to a 100-mg, 50-Hz magnetic field. J Toxicol Environ Health 48: 169-185, 1996a.

Mevissen M, Lerchl A, Szamel M, Loscher W. Exposure of DMBA-treated female rats in a 50-Hz, 50 microTesla magnetic field: effects on mammary tumor growth, melatonin levels, and T lymphocyte activation. Carcinogenesis 17: 903-910, 1996b.

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 Blank M. 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.

Miyakoshi Y, Kajihara C, Shimizu H, Ynagisawa H. Tempol suppresses micronuclei formation in astrocytes of newborn rats exposed to 50-Hz, 10-mT electromagnetic fields under bleomycin administration. Mut Res Gen Toxicol Environ Mutagen 747: 183-141, 2012.

Morgan LL. Author's reply to: Occupational and residential exposure to electromagnetic fields and risk of brain tumours in adults: a case-control study in Gironde, France. Int J Cancer 130: 743; author reply 744, 2012.

National Radiological Protection Board (NRPB). Review of the Scientific Evidence for Limiting Exposure to Electromagnetic Fields (0-300 GHz). Chilton: NRPB, 2004.

National Radiological Protection Board (NRPB). Magnetic fields and miscarriage. Radiol Prot Bull No 1 (The eBulliten), June 2002, http://www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1211528166233.

Naziroğlu M, Tokat S, Demirci S. Role of melatonin on electromagnetic radiation-induced oxidative stress and Ca2+ signaling molecular pathways in breast cancer. J Recept Signal Transduct Res 32: 290-297, 2012.

Neutra RR and Li DK. Magnetic fields and miscarriage: a commentary on Mezei et al., JESEE 2006. J Expo Sci Environ Epidemiol 18: 537-538, 2008.

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: NYPSC, 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: NYPSC, 1990.

Noonan CW, Reif JS, Burch JB, Ichinose TY, Yost M, Magnusson K. Relationship between amyloid beta protein and melatonin metabolite in a study of electric utility workers. J Occup Environ Med 44: 769-775, 2002.

Okudan N, Celik I, Salbacak A, Cicekcibasi AE, Buyukmumcu M, Gokbel H. Effects of long-term 50 Hz magnetic field exposure on the micro nucleated polychromatic erythrocyte and blood lymphocyte frequency and argyrophilic nucleolar organizer regions in lymphocytes of mice. Neuro Endocrinol Lett 31: 208-214, 2010.

Park JE, Seo YK, Yoon HH, Kim CW, Park JK, Jeon S. Electromagnetic fields induce neural differentiation of human bone marrow derived mesenchymal stem cells via ROS mediated EGFR activation. Neurochem Int 62: 418-424, 2013.

Parlett LE, Bowman JD, van Wijngaarden E. Evaluation of occupational exposure to magnetic fields and motor neuron disease mortality in a population-based cohort. J Occup Environ Med 53: 1447-1451, 2011.

Patruno A, Pesce M, Marrone A, Speranza L, Grilli A, De Lutiis MA, Felaco M, Reale M. Activity of matrix metallo proteinases (MMPs) and the tissue inhibitor of MMP (TIMP)-1 in electromagnetic field-exposed THP-1 cells. J Cell Physiol 227: 2767-2774, 2012.

Patruno A, Tabrez S, Amerio P, Pesce M, Vianale G, Franceschelli S, Grilli A, Kamal MA, Reale M. Kinetic study on the effects of extremely low frequency electromagnetic field on catalase, cytochrome P450 and inducible nitric oxide synthase in human HaCaT and THP-1 cell lines. CNS Neurol Disord Drug Targets 10: 936-944, 2011.

Pelissari DM, Barbieri FE, Wunsch Filho V. Magnetic fields and acute lymphoblastic leukemia in children: a systematic review of case-control studies. Cad Saude Publica 25 Suppl 3: S441-452, 2009.

Poole C, Greenland S, Luetters C, Kelsey JL, Mezei G. Socioeconomic status and childhood leukaemia: a review. Int J Epidemiol 35: 370-384, 2006.

Reid A, Glass DC, Bailey HD, Milne E, de Klerk NH, Downie P, Fritschi L. Risk of childhood acute lymphoblastic leukaemia following parental occupational exposure to extremely low frequency electromagnetic fields. Br J Cancer 105: 1409-1413, 2011.

Reis L, Melbert D, Krapcho M, Mariotto A, Miller BA, Feuer EJ, Clegg L, Horner MJ, Howlander N, Eisner MP, Reichman M, Edwards BK, eds. SEER Cancer Statistics Review. Bethesda, MD: National Cancer Institute, 2007.

Rodriguez-Garcia JA and Ramos F. High incidence of acute leukemia in the proximity of some industrial facilities in El Bierzo, northwestern Spain. Int J Occup Med Environ Health 25: 22-30, 2012.

Rona RJ. Asthma and poverty. Thorax 55: 239-244, 2000.

Ross CL and Harrison BS. Effect of time-varied magnetic field on inflammatory response in macrophage cell line RAW 264.7. Electromagn Biol Med 32: 59-69, 2013.

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

Saito T, Nitta H, Kubo O, Yamamoto S, Yamaguchi N, Akiba S, Honda Y, Hagihara J, Isaka K, Ojima T, Nakamura Y, Mizoue T, Ito S, Eboshida A, Yamazaki S, Sokejima S, Kurokawa Y, Kabuto M. Power-frequency magnetic fields and childhood brain tumors: a case-control study in Japan. J Epidemiol 20: 54-61, 2010.

Salehi I, Sani KG, Zamani A. Exposure of rats to extremely low-frequency electromagnetic fields (ELF-EMF) alters cytokines production. Electromagn Biol Med 32: 1-8, 2013.

Sarimov R, Alipov ED, Belyaev IY. Fifty hertz magnetic fields individually affect chromatin conformation in human lymphocytes: dependence on amplitude, temperature, and initial chromatin state. Bioelectromagnetics 32: 570-579, 2011.

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

Savitz DA. The etiology of epidemiologic perseveration: when enough is enough. Epidemiology 21: 281-283, 2010.

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.

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.

Schmiedel S and Blettner M. The association between extremely low-frequency electromagnetic fields and childhood leukaemia in epidemiology: enough is enough? Br J Cancer 103: 931-932, 2010.

Schüz J. Exposure to extremely low-frequency magnetic fields and the risk of childhood cancer: update of the epidemiological evidence. Prog Biophys Mol Biol 107: 339-342, 2011.

Schüz J and Ahlbom A. Exposure to electromagnetic fields and the risk of childhood leukaemia: a review. Radiat Prot Dosimetry 132: 202-211, 2008.

Schüz J and Ahlbom A. Exposure to electromagnetic fields and the risk of childhood leukaemia: a review. Radiat Prot Dosimetry 132: 202-211, 2008.

Schüz J, Grell K, Kinsey S, Linet MS, Link MP, Mezei G, Pollock BH, Roman E, Zhang Y, McBride ML, Johansen C, Spix C, Hagihara J, Saito AM, Simpson J, Robison LL, Dockerty JD, Feychting M, Kheifets L, Frederiksen K. Extremely low-frequency magnetic fields and survival from childhood acute lymphoblastic leukemia: an international follow-up study. Blood Cancer J 2: e98, 2012.

Schüz J, Svendsen AL, Linet MS, McBride ML, Roman E, Feychting M, Kheifets L, Lightfoot T, Mezei G, Simpson J, Ahlbom A. Nighttime exposure to electromagnetic fields and childhood leukemia: an extended pooled analysis. Am J Epidemiol 166: 263-269, 2007.

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: European Commission, 2007.

Scientific Committee of Emerging and Newly Identified Health Risks (SCENIHR) for the Directorate-General for Health & Consumers of the European Commission. Health Effects of Exposure to EMF. Brussels: European Commission, 2009.

Selmaoui B, Lambrozo J, Sackett-Lundeen L, Haus E, Touitou Y. Acute exposure to 50-Hz magnetic fields increases interleukin-6 in young healthy men. J Clin Immunol 31: 1105-1111, 2011.

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.

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.

Sulpizio M, Falone S, Amicarelli F, Marchisio M, Di Giuseppe F, Eleuterio E, Di Ilio C, Angelucci S. Molecular basis underlying the biological effects elicited by extremely low-frequency magnetic field (ELF-MF) on neuroblastoma cells. J Cell Biochem 112: 3797-3806, 2011.

Sun JW, Li XR, Gao HY, Yin JY, Qin Q, Nie SF, Wei S. Electromagnetic field exposure and male breast cancer risk: a meta-analysis of 18 studies. Asian Pac J Cancer Prev 14: 523-528, 2013.

Swanson J. Residential mobility of populations near UK power lines and implications for childhood leukaemia. J Radiol Prot 33: N9-N14, 2013.

Swanson J and Kheifets L. Could the geomagnetic field be an effect modifier for studies of power-frequency magnetic fields and childhood leukaemia? J Radiol Prot 32: 413-418, 2012.

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: SSI, 2007.

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

Swedish Radiation Safety Authority (SSM). Recent Research on EMF and Health Risks: Sixth Annual Report from SSM's independent Expert Group on Electromagnetic Fields 2009. Report Number: 2009:36: SSM, 2009.

Swedish Radiation Safety Authority (SSM). Recent Research on EMF and Health Risks: Seventh Annual Report from SSM's independent Expert Group on Electromagnetic Fields 2010. Report Number: 2010:44: SSM, 2010.

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

Touitou Y, Djeridane Y, Lambrozo J, Camus F. Long-term (up to 20 years) effects of 50-Hz magnetic field exposure on blood chemistry parameters in healthy men. Clin Biochem 45: 425-428, 2012.

Touitou Y, Djeridane Y, Lambrozo J, Camus F, Selmaoui B. Long-term (up to 20 years) effects of 50-Hz magnetic field exposure on immune system and hematological parameters in healthy men. Clin Biochem 46: 59-63, 2013.

Touitou Y and Selmaoui B. The effects of extremely low-frequency magnetic fields on melatonin and cortisol, two marker rhythms of the circadian system. Dialogues Clin Neurosci 14: 381-399, 2012.

Trillo MA, Martinez MA, Cid MA, Leal J, Ubeda A. Influence of a 50 Hz magnetic field and of all-transretinol on the proliferation of human cancer cell lines. Int J Oncol 40: 1405-1413, 2012.

Ubeda A, Martinez MA, Cid MA, Chacon L, Trillo MA, Leal J. Assessment of occupational exposure to extremely low frequency magnetic fields in hospital personnel. Bioelectromagnetics 32: 378-387, 2011.

Udroiu I, Cristaldi M, Ieradi LA, Bedini A, Giuliani L, Tanzarella C. Castogenicity and aneuploidy in newborn and adult mice exposed to 50 Hz magnetic fields. Int J Radiat Biol 82: 561-567, 2006.

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 (EPA). Reference Dose (RfD): Description and Use in Health Risk Assessments. Washington, DC: USEPA, 1993.

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

Valberg PA. Magnetic Fields: Possible Environmental Health Effects. In Encyclopedia of Environmental Health, edited by Nriagu J. Amsterdam: Elsevier Science, 2011.

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.

Villeneuve PJ. Exposure to magnetic fields during pregnancy and asthma in offspring. Arch Pediatr Adolesc Med 166: 97, 2012.

Vinceti M, Fiore M, Signorelli C, Ondone A, Tesauro M, Consonni M, Arolin E, Malagoli C, Mandrioli J, Marmiroli S, Sciacca S, Ferrante M. Environmental risk factors for amyotrophic lateral sclerosis: methodological issues in epidemiologic studies. Ann Ig 24: 407-415, 2012.

Wen J, Jiang S, Chen B. The effect of 100 Hz magnetic field combined with X-ray on hepatoma-implanted mice. Bioelectromagnetics 32: 322-324, 2011.

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

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

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

Wunsch-Filho V, Pelissari DM, Barbieri FE, Sant'Anna L, de Oliveira CT, de Mata JF, Tone LG, Lee ML, de Andrea ML, Bruniera P, Epelman S, Filho VO, Kheifets L. Exposure to magnetic fields and childhood acute lymphocytic leukemia in Sao Paulo, Brazil. Cancer Epidemiol 35: 534-539, 2011.

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.

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, MA: Entertech Consultants, 1998.

Zhang M, Li X, Bai L, Uchida K, Bai W, Wu B, Xu W, Zhu H, Huang H. Effects of low frequency electromagnetic field on proliferation of human epidermal stem cells: An in vitro study. Bioelectromagnetics 34: 74-80, 2013.

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 doi: 10.1371/journal.pone.0048354, 2012.

Zhou J, Ming LG, Ge BF, Wang JQ, Zhu RQ, Wei Z, Ma HP, Xian CJ, Chen KM. Effects of 50 Hz sinusoidal electromagnetic fields of different intensities on proliferation, differentiation and mineralization potentials of rat osteoblasts. Bone 49: 753-761, 2011.

Zhou J, Wang JQ, Ge BF, Ma XN, Ma HP, Xian CJ, Chen KM. Different electromagnetic field waveforms have different effects on proliferation, differentiation and mineralization of osteoblasts in vitro. Bioelectromagnetics [Epub ahead of print], 2013.

Appendix B: Agency Coordination Documentation

ISO new england

Stephen J. Rourke
Vice President, System Planning

December 27, 2010

Mr. Yunzhe Liu
New England Power Company
40 Sylvan Road
Waltham, MA 02451

Subject: G-185S Reconductor Project – Level I Proposed Plan Application (PPA) NEP-10-T02

Dear Mr. Liu:

On December 15, 2010, it was voted by the Reliability Committee to recommend approval to ISO New England Inc. ("ISO") that no significant adverse impacts will result from New England Power Company's ("NGRID") PPA NEP-10-T02 to perform the following as detailed in Mr. Yunzhe Liu's December 1, 2010 transmittal to Mr. Don Gates, Chair, Reliability Committee:

> **NEP-10-T02 –** Transmission notification from NGRID for the upgrade of the existing 115 kV transmission line from Kent County substation to Davisville tap. In addition, replace 5.3 miles of ACSR conductor to 954 ACSS.

The in-service date of NEP-10-T02 is October 2013. It is recommended that the Project would not have a significant adverse effect on the reliability or operating characteristics of the transmission facilities of New England Power Company, the transmission facilities of another Transmission Owner or the system of a Market Participant. A determination under Section I.3.9 of the ISO Tariff is limited to a review of the reliability impacts of a proposed project as submitted by Participants and does not constitute an approval of a proposed project under any other provisions of the ISO Tariff.

Sincerely,

Stephen J. Rourke
Vice President, System Planning

cc: Proposed Plan Applications

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