BROOKHAVEN NATIONAL LABORATORY Safety & Health Services Division INDUSTRIAL HYGIENE GROUP Standard Operating Procedure: Field Procedure	NUMBER **IH99150** REVISION **FINAL rev 2**
SUBJECT: GENERAL PRINCIPLES: **Radio-frequency and Microwave Field Measurement Principles**	DATE **12/28/06** PAGE **1** OF 18

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1.0 Purpose/Scope

This procedure provides a standardized method for conducting area surveys with direct reading meters for radio frequencies. It should be used in conjunction with the SBMS Subject Area *Radio Frequencies (RF) and Microwaves* and an Instrument Operation procedure in the series such as IH SOP for the Narda Model 8718B Electromagnetic Radiation Survey Meter, Holaday HI–3702 Clamp on Induced Current Meter, or the HI4416 System readout.

An area survey meter should be used to determine baseline microwave field levels and area levels to evaluate the need for area warning posting, locate problem microwave sources, leaks, and measure the effectiveness of engineering controls. It can be used as a screening tool to determine the need for additional personal monitoring and to delineate controlled areas.

Time averaging dosimeters are not readily available for RF/microwave exposure determination. However, alarming monitors are available. They should be worn when it is not clear that the levels indicate that the exposure will exceed the OEL. This area survey meter can be used as a screening tool to identify those areas that may require a dosimeter alarm as well as identify the need for engineering controls, posting, as well as work practices and procedures. Documentation of the duration of the activity, and/or length of time in area is extremely important since the standards area based on exposure duration of 6 minutes except for frequencies from 15 GHz to 300 GHz where the duration is calculated.

2.0 Responsibilities

2.1 **Program Administration:** This procedure is administered through the SHSD Industrial Hygiene Group. Members of the SHSD Industrial Hygiene Group are required to follow this procedure. Other BNL organizations that provide BNL with field monitoring or other hazard assessment services are required to follow this SOP or an equivalent document that ensures an equal or superior method of assessment documentation and recordkeeping.

2.2 ***Industrial Hygiene Professional:*** The *Industrial Hygiene Professional* of SHSD and other BNL organizations are to be qualified by their supervision. These individuals will conduct or supervise industrial hygiene hazard assessments and personal exposure monitoring using this procedure. These *IH Professionals* are responsible for:

- Interpreting, reporting, and documenting personal exposure monitoring in accordance with the requirements of this procedure, other appropriate SOPs, and generally accepted professional standards and practices.
- Ensuring a quality report is prepared that documents the exposure, evaluates the relevance to exposure standards, and recommends protective and corrective actions.
- Ensuring the final report is provided in a timely manner to all appropriate parties.
- Ensuring that the appropriate data is correctly and completely entered into the BNL IH exposure monitoring database (i.e. *Compliance Suite*®).
- Ensuring that original records of sampling and analysis enter the SHSD *Record Custodian* filing system.

2.3 ***Industrial Hygiene Technician (Sampler)*:** The industrial hygiene technician is to be qualified by their supervision to conduct industrial hygiene personal exposure monitoring under the direction of his/her organization's *IH Professional.* The sampler is responsible for collecting personal exposure monitoring samples in accordance with the guidance of the *IH Professional* and the requirements of all SOP's pertinent to the particular monitoring requirements (i.e. Chain of custody, equipment check in/out, equipment operation, recordkeeping, etc.).

2.4 ***Compliance Suite® data entry:*** The management of the person conducting the sampling is responsible for entering complete and correct data into the BNL IH exposure monitoring database (i.e. *Compliance Suite*). This task may be assigned to one or more individuals who act as the data entry person for an organization, however, it remains the responsibility of the line management of the *Sampler* to ensure this task is fulfilled within 21 calendar days of the end of the sampling event.

3.0 Definitions

Averaging time (T_{avg}): The appropriate time period over which exposure is averaged for purposes of determining compliance with threshold limit values (TLVs).

Duty factor: The ratio of pulse duration to the pulse period of a periodic pulse train. A duty factor of 1.0 corresponds to continuous-wave (CW) operations.

Electric field (E): A field vector quantity that represents the force (f) on a positive test charge (q) at a point divided by the charge. $E = f/q$ Electric field strength is expressed in units of volts per meter (V/m).

Exposure: The subjection of a person to an electric or magnetic fields or to contact currents either than those originating from physiological processes in the body and other natural phenomena.

Exposure, partial-body: Exposure that results when RF fields are substantially non-uniform over the body. Fields that are non-uniform over volumes comparable to the human body may occur due to highly directional sources, standing waves, re-radiating sources, or exposure in a near field region of a radiating structure. See (RF "hot spot.)"

Far-field region: That region of the field of an antenna or source where the angular field distribution is essentially independent of the distance from the antenna. In this region, also called the free space region, the field has a predominantly plane-wave characteristic, i.e., locally uniform distributions of electric field strength and magnetic field strength in planes transverse to the direction of propagation.

Hertz (Hz): The unit for expressing frequency (f). One hertz equals one cycle per second.

Magnetic field strength (H): A vector that is equal to the magnetic flux density divided by the permeability of the medium. Magnetic field strength is expressed in units of amperes per meter (A/m).

Near-field region: A region generally in close proximity to a source or radiating structure, in which the electric and magnetic fields do not have a substantially plane-wave characteristic, but vary considerably from point to point. The near field is further divided into the reactive near field region, which is closest to the radiating structure and that contains most or nearly all of the stored energy, and the radiating near field region where the radiation field predominates over the reactive field, but lacks substantial plane-wave character and is complicated in structure. NOTE: For most antennas, the outer boundary of the reactive field region is commonly taken to exist at a distance of one-half wavelength from the antenna surface.

Occupational Exposure Limit: The maximum time weighted average (TWA) or ceiling value exposure permitted for employee exposure, based on the less of the OSHA Permissible Exposure Limits (PEL) or ACGIH Threshold Limit Value (TLV). OSHA does not have a RF/Microwave field standard for all wavelengths. BNL has adopted the guidelines that are found in the RF/Microwave subject area. The rms and peak electric and magnetic field strengths, their squares, or the plane-wave equivalent power densities associated with these fields and the induced and contact currents to which a person may be exposed without harmful effects for their working lifetime.

Power density (s) or electromagnetic power flux density: Power per unit area normal to the direction of propagation. This is usually expressed in units of watts per square meter (W/m^2) or microwatts per square centimeter (uW/cm^2). For plane wave power density, electric field strength (e) and magnetic field strength (H) are related by the impedance of free space, i.e., 377 ohms. $S= E^2/377$ $S=377H^2$ Where E and H are expressed in units of V/m and A/m respectively and S in units of W/m^2. Although many survey instruments indicate power density units, the actual quantities measured are E or E^2 or H or H^2.

Power density, average (temporal): The instantaneous power density integrated over a source repetition period.

RF Hotspots: A highly localized area of relatively more intense radio-frequency radiation that manifests itself in two principal ways: The presence of intense electric or magnetic fields immediately adjacent to conductive objects that are immersed in lower intensity ambient fields (often referred to as re-radiation), and Localized areas, not necessarily immediately close to conductive objects, in which there is a concentration of radio-frequency fields cause by reflections and/or narrow beams produced by high-gain radiating antennas or other highly directional sources. In both cases the fields are characterize by very rapid changes in field strength with distance. RF hot spots are normally associated with very non-uniform exposure of the body (partial body exposure). This is not to be confused with an actual thermal hot spot within the absorbing body.

Radio frequency (RF): A frequency that is used for radio transmission. Note: Although the RF spectrum is formally defined in terms of frequency from 0 to 3000 GHz, for purposes of this standard, the frequency range of interest is 30 KHz to 300 GHz.

Re-radiated field: An electromagnetic field resulting from currents induced in a secondary, predominantly conducting, object by electromagnetic waves incident on that object from one or more primary radiating structures or antennas. Re-radiated fields are sometimes called “reflected” or “scattered fields”. The scattering object is sometimes called a re-radiator or “secondary radiator. (See Scatter radiation).

Root-mean-square (rms): The effective value associated with joule heating, of a periodic electromagnetic wave. The rms value is obtained by taking the square root of the mean of the squared value of a function.

Spatial averaging: The rms of the field over an area equivalent to the vertical cross section of the adult human body, as applied to the measurement of electric or magnetic fields in the assessment of whole-body exposure. The spatial average is measured by scanning (with a suitable measurement probe) a planar area equivalent to the area occupied by a standing adult human (projected area). In most instances, a simple vertical, linear scan of the fields over a 2 meter height (approximately 6 feet), through the center of the projected area, will be sufficient for determining compliance with the threshold limit values.

Specific absorption: The quotient of the incremental energy (dW) absorbed by (dissipated in) an incremental mass (dm) contained in a volume (dV) of a given density.

Specific absorption rate (SAR): The time derivative of the incremental energy dW absorbed by (dissipated in) an incremental mass (dm) contained in a volume element (dV) of given density (ρ). SAR = d/dt(dW/dm) = d/dt(dW/ρdv)

SAR is expressed in units of watts per kilogram (W/kg).

Wavelength (λ): Of a monochromatic wave, the distance between two points of corresponding phase of two consecutive cycles in the direction of propagation. The wavelength (λ) of an electromagnetic wave is related to the frequency (f) and velocity (v) by the expression $v=f\lambda$. In free space the velocity of an electromagnetic wave is equal to the speed of light, i.e., approximately $3 \times 10^{8.}$

4.0 Prerequisites

4.1 Training prior to using this meter:

- Demonstration of proper operation of the instrument to the satisfaction of the SHSD IH Group Manager.
- Other appropriate training for the area to be entered (check with ESH coordinator or FR Representative for the facility).
- Review of the Radio Frequency /Microwave SBMS Subject Area.

4.2 Area Access:

- Contact the appropriate Facility Support Representative or FS Technician to obtain approval to enter radiological areas.
- Verify with the appropriate Facility Support Representative or FS Technician if a Work Permit or Radiological Permit is needed or is in effect. If so, review and sign the permit.
- Use appropriate PPE for area.

5.0 Precautions

5.1 Hazard Determination:

- The operation of an RF/microwave meter does not cause exposure to any chemical, physical, or radiological hazards. The meters do not generate Hazardous Waste. Use the meter to inform you of high non-ionizing radiation fields.
- The operation an area survey meter or use of this procedure does not cause exposure to any chemical, physical, or radiological hazards, or generate Hazardous Waste.
- The meters are very sensitive and can be burned by entry into fields above their capacity. Approach the source from a low background.
- The primary hazards from microwave are heating of the body. The eyes and genitals/reproductive organs are the most sensitive. Prolonged exposure to very high sources can result in death to the individual.

5.2 Personal Protective Equipment:

- If high fields are expected, the person doing monitoring should wear the Narda Alert® alarming meter.
- Microwave protective clothing is not available. Rely on engineering and administrative controls such as remaining a safe distance from the source as indicated by the direct reading meter.
- Additional PPE: Other appropriate PPE for hands, feet, skin, head, or eyes may be needed for the area being entered. Check with your ES&H representative.

5.3 **Job Risk Assessment:** Consult the *Job Risk Assessment* SHSD-JRA-05 for the risk analysis of this operation based on the hazards and controls of this SOP.

5.4 **Work Planning:** All requirements of work permits and work planning system reviews must be met in performing this procedure.

5.5 **Environmental Impact and Waste Disposal:** This sampling does not have adverse impact on the environment or create waste for disposal.

6.0 Procedure

6.1 Determine the need for sampling: A survey is performed for various reason:

- new or modified installations,

- changes in the previously surveyed environment,
- changes in the levels of emitted power or limits, and
- at a the request of personnel or management.

6.2 **O**btain information on the source and area prior to monitoring, such as appropriate information on:

- Emitters characteristics: Frequency, Power level, Modulation characteristics, Number of sources, Spurious Frequencies or harmonics, Intermittence of output, Antenna information (e.g., size, beam width, gain, orientation), and previous survey results.

- Site Characterization: Structures; Occupancy by people; Barriers, interlocks, signs, and visual or audible alarms; External areas (such as parking lots, residential areas or any other uncontrolled areas that may receive lower, but measurable emissions); Topographical information if applicable (for directional emitters like parabolic antennas, it is necessary to obtain beam elevation angles. This information is used to plot worst – case results of there are no mechanical means to stop the beam from illuminating people in the area.)

6.3 **Select the appropriate piece of equipment:** Determine if the known or predicted field strength is within the range of the equipment.

6.4 **Set up of the equipment prior to use:**

6.4.1 Verify the meter is calibrated as per the Instrument Operation SOP.

6.4.2 Check if the instrument can be zeroed. If the instrument does not read zero, then the probe must be zeroed. This must be done in an area without a microwave field or in a zero field chamber or bag.

6.4.3 Before beginning the survey, allow time to warm up and check the equipment. When using thermocouple-based probes, it is advisable to allow the probe to stabilize to the ambient temperature. Allowing the probe to raise or lower its temperature to the ambient temperature helps minimize "zero drift."

6.4.4 Ensure that the meter's batteries are charged enough to complete the survey.

6.5 **Measurement Principles:**

- Approach source from a low background. Begin the survey from a distance well beyond the calculated hazard distance.
- Always begin a survey with the meter set on its highest measurement range.

- Leave the area if the fields will cause exposure that exceeds the applicable standard.
- Keep the probe away from reflective surfaces.
- The operator should be further from the source than the probe and positioned to reduce reflection of the sound to the meter. Hold the probe at arms length, not close to the body.
- If the direction to the emitter is not known, or if there are multiple emitters, the probe should be held at a 45-degree angle. If there is a single emitter, the probe should be pointed directly at the source to minimize isotropic errors.
- Take spatially averaged levels.
- Take measurements at the employee's level (whether sitting, standing or bending) to estimate personal exposures and to locate isometric lines of RF field intensity on a sketch for defining area levels. Follow the flow chart in Attachment 9.1. Field levels are normally averaged over the whole body. The IEEE/ANSI C95.1 standard allows time averaging, but not whole body averaging, for exposures to the eyes and male testes' body areas.

6.6 **Start with the E field measurement:** If the frequency is less than 300 MHz, then an <u>H field measurement is required</u>.

- Non-uniform fields are commonly encountered in reflective conditions such as standing wave fields produced by reflection of fields from the earth or other reflective surfaces. Averaging may be accomplished through the use of real-time data-logging equipment or via manually obtained point measurements.
- For compliance with OEL standards – the average of a series of <u>ten</u> field strength measurements performed in a vertical line with uniform spacing starting at ground level up to a height of 2 m (~6 feet 8 inches) is sufficient. In practice, this means that field strength measurements should be made at heights above the ground separated by 20 cm (about 8 inches).
- Measurements should be taken at least 8 inches away from the surface of the source.
- If there is shielding, determine if there are any leaks in the barriers.
- Determine what typical operating positions are and where maximum exposures are possible. If personnel are never in close proximity to the instrument, then it is not necessary to measure surface levels.

6.7 **Radio Frequency Surveys (50 MHz to 300 MHz):** When surveying in this frequency range, readings may be affected by the distance between your body and the survey equipment. Specifically, your body becomes a large reflector increasingly affecting the probe as you move into the lower part of this frequency range. Maintain a distance of a few feet between your body and the probe.

- Both E-field and H-field readings will be made separately and compared with standard limits. **The IEEE/ANSI standard and ACGIH include limits for induced and contact currents, at frequencies below 100 MHz.**
- Once you are within a distance of λ/2Π to the antenna, the reactive field components may be greater than 10% of the radiating components, leading to errors of greater than 1 dB. Although the reactive components do not form part of the radiating field strength, they are real and can generate heating effects and/or induced currents.

6.8 **Radio Frequency Surveys (3 kHz to 50 MHz):** The problems with reflections off the body that begin to appear at 300 MHz become increasingly significant at lower frequencies. For accurate readings:

- Place the probe next to the meter, coiling up the probe's cable so that all components of the system are in the same strength field and put the entire assembly on a non-metallic stand <u>or</u> totally isolate the meter from the probe using a fiber optic link, which allows the meter to be located away from the probe without conducting the emission through a cable.
- For low frequency antennas that employ guy wires, there will normally be a field radiated from then that should be measured. The level of the reading will be greatly affected by the measurement distance you use. IEE/ANSI C95.1 standard recommends a minimum measurement distance of 20 cm from any passive re-radiator and 5 cm from an active radiator.
- Contact current hazards may be present when there are low (<100 MHz) frequency transmitters and conductive objects that may be touched by personnel. Ungrounded objects may store energy that will be discharged through a person's body when the object is touched. When in doubt, you should check the metallic objects near the antenna.
- Eliminate factors that result in erroneous measurements of field strength by maintaining an adequate separation distance between the probe elements and the field source.

6.9 **Recording readings:**

6.9.1 Plan and conduct hazard assessments and exposure monitoring using the procedure outlined in I*H 60500 Reporting Personnel Exposure Monitoring Results* for:

- Exposure Assessment Sampling Strategy,

- Initial Notification of Employee Monitoring Results, and
- Preparation of a formal report on the exposure monitoring or hazard assessment.

6.9.2 Use a Direct Reading Sampling Instrument Form *(*found in the Industrial Hygiene Laboratory) o*r equivalent* to record readings and additional required information. Return meter and original sampling form to the SHSD IH Laboratory. Copy goes to the ESH Coordinator.

6.9.3 Ensure that a copy of any hazard evaluation report written by a competent person on the survey is sent to the IH Laboratory and the Occupational Medicine Clinic, the department ESH coordinator, supervisor, and the individuals surveyed. The post-survey report should contain field readings, listing of steps taken before, during and after the survey, and the following: Emitter Information; Emitter Purpose; Site Map; Operational Procedures; Field Readings; Induced and/or Contact Current Hazards (if emissions are 100 MHz); Outline of Hazardous Areas; Existence of Ionizing Radiation; Control Procedures (Lockout-Tag out, Permit to Work, etc.); Existence of any other hazards (Fuel Storage, Ordinance, etc.); Hazard Areas; Field Readings at Areas Normally Accessible by People; Hot Spots; Existence and Adequacy of engineering Controls and Warning Signs; Use of and Operating Procedures to Control Exposures; Drawings, Sketches or Photographs of Area

6.9.4 Conclusions and Recommendations: If the survey uncovers potentially hazardous areas, the report should include information on the following as applicable: Placement of warning signs; Engineering controls; Antenna restriction devices; Use of terminations or dummy loads when testing; Use of barriers, interlocks and visual/audible alarms; Area or personal monitors that continually monitor for excessive fields (should any of the above measures fail).

7.0 Implementation and Training

Prior to using this procedure, the user:

7.1 Demonstrates proper operation of this instrument to the satisfaction of the SHSD IH Program Administrator.

7.2 Completes other appropriate training for the area to be entered (check with ESH

Coordinator or FS representative for the facility).

7.3 Completes OT&Q Training and a medical surveillance required for any PPE used on the job or for other hazards encountered in the work area.

7.4 Completes qualification on this procedure on at least a 3 year basis, providing the professional uses the equipment three times per year.

7.5 Personnel are to document their training using the Qualification Criteria listed in *IH50300 Industrial Hygiene Qualification Requirements.*

8.0 References

8.1 ACGIH Threshold Limit Values

8.2 IEEE C95.1: Standard for Safety Levels with Respect to Human Exposure to Radiofrequency Energy Electromagnetic Fields, 3kHz to 300 GHz

9.0 Attachments

9.1 **Monitoring Strategy Decision Logic**

9.2 **Non-ionizing Radiation General Information**

9.3 **Electromagnetic Radiation Spectrum**

9.4 **Job Performance Measure- Qualification Form**

10.0 Documentation

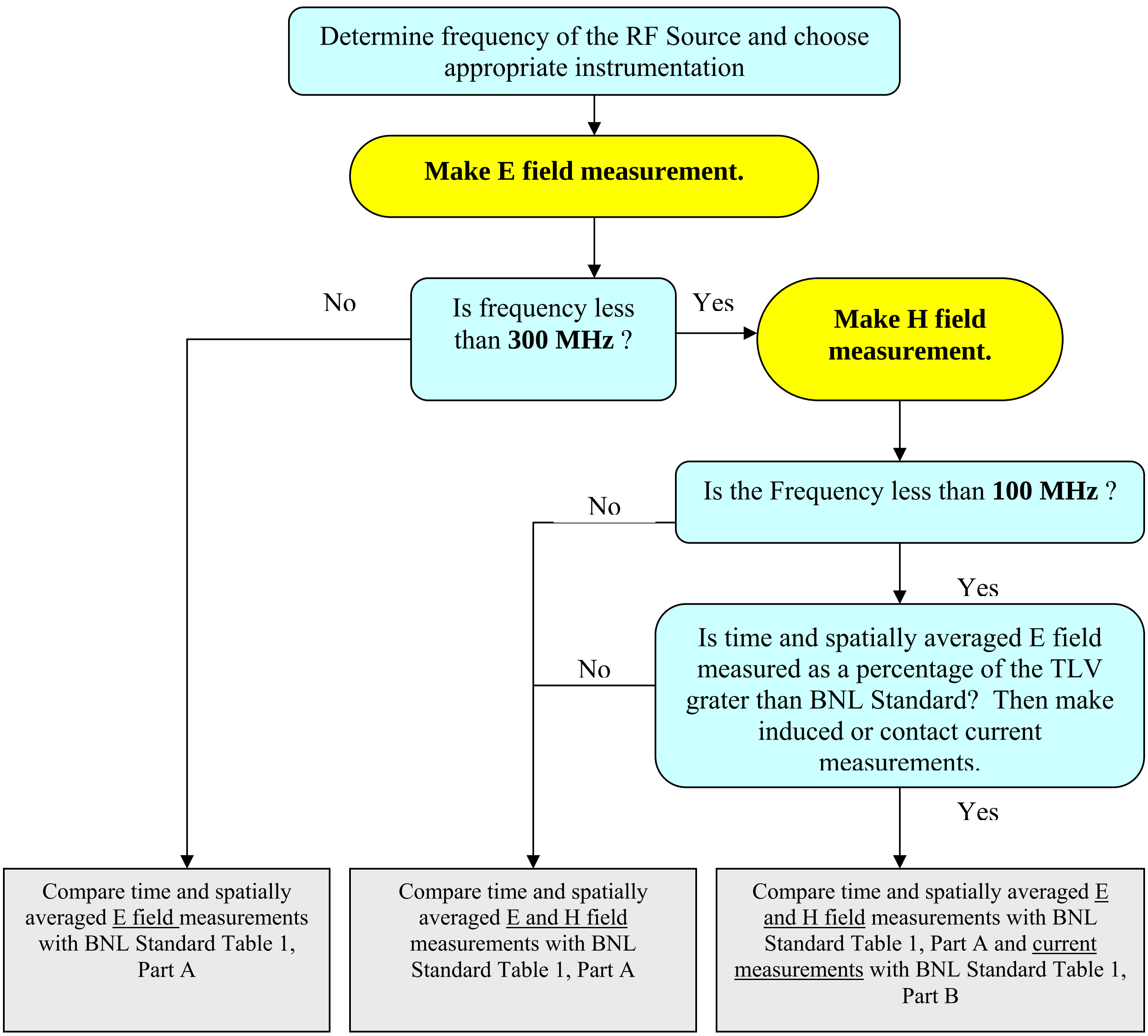
Document Development and Revision Control Tracking		
PREPARED BY: *(Signature and date on file)* **N. M. Bernholc** **Date 10/11/01**	**REVIEWED BY:** *(Signature and date on file)* **R. Selvey, SHSD IH Group** **Date 12/05/01**	**APPROVED BY:** *(Signature and date on file)* **R. Selvey, SHSD IH Group Leader** **Date 01/25/02**
ESH Coordinator/ Date: *none*	Work Coordinator/ Date: *none*	SHSD Manager / Date *none*
QA Representative / Date: *none*	Training Coordinator / Date: *none*	Filing Code: **IH52**
Facility Support Rep. / Date: *none*	Environ. Compliance Rep. / Date: *none*	Effective Date: **01/25/02**
ISM Review - Hazard Categorization ☐ High ☒ Moderate ☐ Low/Skill of the craft	Validation: ☐ Formal Walkthrough ☐ Desk Top Review ☐ SME Review Name / Date:	Implementation: Training Completed: Tracked in BTMS Procedure posted on Web: 12/28/06 Hard Copy files updated: 12/28/06

Revision Log

Purpose: ☐ Temporary Change ☐ Change in Scope ☒ Periodic review ☐ Clarify/enhance procedural controls Changed resulting from: ☐ Environmental impacts ☐ Federal, State and/or Local requirements ☐ Corrective/preventive actions to non-conformances ☒ none of the above Section/page and Description of change: Revised to include Section 7 Implementation and Training. Text added to Section 2, 4,5, 6, and 7. JRA added to Section 5.		
(signature on file) R. Selvey 03/29/05 SME Reviewer/Date:	Reviewer/Date:	Reviewer/Date:
Purpose: ☐ Temporary Change ☐ Change in Scope ☐ Periodic review ☒ Clarify/enhance procedural controls Changed resulting from: ☐ Environmental impacts ☐ Federal, State and/or Local requirements ☐ Corrective/preventive actions to non-conformances ☒ none of the above Section/page and Description of change: Changed SOP reference in Section 7. Removed JRA in Section 5 and added link to OHSAS web page. Corrected errors in text and numbers and combined Attachment 9.3 and 9.4. Correct errors in Attachment's numbers. Added references to Section 8. Minor modification to text in Section 6 for brevity and understanding. Streamlined some text in Attachment 9.2 to shorten and clarify. Added Job Performance Measure Attachment 9.4.		
(signature/date on file) R. Selvey 12/28/06 SME Reviewer/Date:	SME Reviewer/Date:	SME Reviewer/Date:

Attachment 9.1:

Monitoring Strategy Decision Logic



Attachment 9.2

Non-ionizing Radiation - General Information

1. ANTENNA CHARACTERISTICS

Antennas come in various shapes and sizes but they all operate in the same way. They receive electromagnetic energy from a transmitter through coaxial or wave-guide transmission line. Antenna design is dependent on the application frequency range of operation. The table below gives some of the characteristics of the two major types of antennas – wire and aperture.

ANTENNAS	
Wire Types	**Aperture Types**
Radiation from currents induced in conductors	Radiation from fields reflected off a surface
Static	Rotating
Low Directivity	High Directivity
Broad Beam width	Narrow Beam width
Dimensions on the order of one wavelength or less	Dimensions on the order of many wavelengths

Aperture antennas come in several forms. Examples include: arrays of low directivity elements, aperture horns, and a shaped reflector or lens illuminated by a broad beam radiator. There are three distinct areas in front of an antenna that you need to be familiar with. These areas are the reactive near field, the radiating near field, and the far field. All antennas operate as a point source once you are beyond the “Raleigh Distance.” The “Raleigh Distance” is that point where the field strength decreases inversely with the distance and the equivalent power density decreases with the square of the distance. The near field can extend to a distance of $D^2/4\gamma$ where D is the antenna diameter.

The power density in the radiating near field can be estimated to be 4P/A. In other words, the maximum power in the near field could be four times the average power over the nominal antenna area. This relationship is shown in the figure below.

2. INSTRUMENTATION CHARACTERISTICS: Instruments are available to cover from 3 kHz to over 100 GHz. ELF and VLF frequency bands are measured by other types of instruments, which are not covered in this Attachment. Different types of detectors are as follows:

1. General: A survey instrument usually contains three distinct parts: Meter, Probe and Cable (or leads). The meter displays the detected levels on an analog or digital display. Meters may include features such as storage of detected levels, audible alarms and built-in test sources. With few exceptions, meters do not form part of the measurement circuit, that is, they do not determine what frequencies or levels are detected. Probes, however, are part of the system that determines what may be measured. Probes are available in designs that detect from one direction (anisotropic) or from all directions (isotropic). Frequencies detected may be very few (narrow bandwidth) or very many (ultra broadband, e.g., 300 kHz to 50 GHz). Dynamic ranges average 30 dB or more and usually only one field component (electric or magnetic) is measured at a time. Cables transmit information from the probe to the meter assemblies. These cables are either shielded copper wires, or (at lower frequency ranges) fiber optic cables. Some low frequency designs exclude cables to maintain accurate readings. Before performing a survey, certain characteristics need consideration, including:

2. **Field Detection:** All probes available measure either the electric (E) or magnetic (H) fields. At high frequencies (300 MHz) some standards require that only one field component be measured (usually E) while at lower frequencies both field components might need to be measured. Additionally, you need to determine if surveys are to be performed with *isotopic or anistropic* probes. Isotropic probes are usually preferred because mistakes can be made when detecting fields from only one direction. Reflections are not as readily found and can result in considerable measurement errors. When measuring in the near field areas, an isotropic probe may be the only accurate solution because the phase relationship varies rapidly near the antenna.

3. **Frequency Range:** The instrument you choose must cover the frequency or frequencies of the emission. Some emissions may have large harmonics (or multiples) of the main signal, which a narrowband detector may not respond to.

4. **Measurement Range:** Calculations give you an estimate of the field strengths to expect. Most likely, you will want a probe that measures levels both above and below the calculated levels.

5. **Detection**: probes usually employ either diode-based or thermocouple-based detection. A diode is a non-linear device, which means that over its measurement range it may change from an average detector to a peak detector. As long as the emission is not modulated and it is a single-frequency emission there will not be a large error. If there is a compensating circuit that varies the detector's operation to maintain it in "square law," it will allow the diode to remain accurate in almost any environment. Thermocouple detection is also used to lower (<300 MHz) frequencies. Antenna arrays made up entirely of thermocouple junctions are available for use at higher (1 GHz) frequencies. Thermocouples are linear devices. This means that they will always give true RMS average results, even when used in multiple-emitter applications. Thermocouple array probes operate on energy deposition across their numerous junctions. In this way, they always generate an output that is proportional to the average energy, not mater how narrow the pulse's width is. This is why thermocouple detectors are usually used for measurements on pulse modulated emissions. The major drawback of thermocouples has been inefficiency when compared to diode detectors, meaning that the diode provides a larger output voltage for equivalent field strength. A thermocouple detector therefore exhibits "zero drift," which may be a significant part of a low level reading. Another consideration is that the diode can usually withstand a higher overload level than the thermocouple. This amplifies the need for performing pre-survey calculations, which helps guard against overloading either type of detector.

3. SURVEYING UNINTENTIONAL EMITTERS

Leakage surveys vary considerably from surveys involving known emitters such as antennas. In most cases there are no field calculations that can be performed before the survey.

A. MICROWAVE OVENS

Microwave oven standards regulate the permissible leakage around the perimeter of an oven door, not human exposure. This leads to a difference in the basic design of the survey equipment. The instruments required to measure this leakage are one-directional or anisotropic. This design helps ensure that only the oven is being tested, rather than having measurements potentially disturbed by other sources in the immediate area. The U.S. Code of Federal Regulation (CFR) 21 part 1030, specifies the maximum amount of leakage from the oven at distances of 5 cm – 1.0 mW/cm^2 before the oven is sold and 5.0 mW/cm^2 throughout its operating life.

Pre-survey Inspections

Microwave ovens have built-in safety features that should be checked before surveying for leakage. Visual inspections of the door hinges, door seals and latch mechanism should be performed. The latch mechanism can be checked by insuring that the oven stops operation when the door is opened. Excessive food around the door gasket can increase leakage, so ovens need to be kept clean.

Oven Surveys

Microwave ovens are normally tested when operating on their highest power level, and with a load of water (approximately 275 ml.). The test equipment is scanned about any surface of the oven, paying close attention to the area of the door seal while holding the probe horizontally. Most surveying equipment will have a 5 cm spacer to allow you to hold the probe against a surface. Response time for oven meters is usually around one second, but can be up to 3 seconds, so you need to scan the surface at an appropriate speed.

B. INDUSTRIAL EQUIPMENT

Industrial equipment that is used for heating, drying, and sealing is very common in the workplace. These systems can operate from a few Hertz, as in the case of induction heating at foundries, up to hundreds of kilohertz. Sputtering and plasma equipment usually operate at 13.56 MHz and heat sealing or vinyl welding devices usually operate at 27.12 MHz. Before beginning your survey, the emission frequency should be checked with a frequency counter, spectrum analyzer, or manufacturer-supplied data. Spectrum analysis is also useful for determining if equipment is generating multiple emissions, or harmonics, when operated at its highest power level.

With industrial surveys it is important to consider both whole-body averaging and time averaging. Most processes use high power for a short period, which allows for considerably lower averaged exposure levels. When surveying, it is normally beneficial to use a “story pole” that will allow you to mark various survey heights and repeatedly measure at the same point. High power handling is also worth mentioning here. When surveying a device that operates at 27.12 MHz, you will most likely be in the near field. The wavelength at this frequency is approximately 11 meters, which means that, because of the proximity to the source, power may vary greatly with only a slight change of probe position.

The United States has limitations on induced body currents. Such limitations should be considered when planning to perform low frequency (<100 MHz) surveys. In a document published in 1989, the U.S. National Institute of Occupational Safety and Health (NIOSH) stated that measuring the induced body current may provide the most direct indication of absorbed energy. Compliance measurements at frequencies below 100 MHz now include both field and current measurements. If field measurements approach standard or guidance limits, you should measure currents.

C. TRANSMISSION LINE LEAKAGE

A common example of leakage measurements is testing wave-guide flanges. Wave-guide flanges and bends are likely points of leakage in high power systems. Gaskets in flanges may deteriorate after cycled over temperature many times. Bends also tend to form stress cracks from temperature and mechanical stress. When testing wave-guide systems, most people will probe as closely as possible to the suspected areas. Normally, defective flanges can be tightened, while bends have to be removed from the system for repair or replacement.

Attachment 9.3

Electromagnetic Radiation Spectrum

Frequency			Wavelength	
0 Hz		Static		
1 Hz	1 Hz		186,280 miles	300,000 km
10 Hz			18,628 miles	30,000 km
3- 30 Hz		Extremely Low Frequency (ELF)	6212 miles	10,000 – 100,000 km
60Hz		Powerline	3105 miles	50,000 km
100 Hz			1862.8 miles	3,000 km
1000 Hz	1 kHz		186.3 miles	300 km
<3 kHz		**Sub-radio Frequency ↑**		>100 km
>10 kHz		**Radiofrequency ↓**		
10 kHz		**Very Low Frequency (VLF)**	18.6 miles	30 km
100 kHz			9836 ft (1.86 mi)	3000 meters
300 kHz		Low Frequency (LF)		1 km
1000 kHz	1MHz	AM radio	984 ft	300 meters
3 MHz		Medium (MF)		100 meters
10 MHz			98.4 ft	30 meters
27 MHz		RF heat Sealers	36.4 ft	11 meters
30 MHz		High Frequency (HF)	32.8 ft	10 meters
100 MHz		FM radio	9.8 ft	3 meters
300 MHz		**Very High Frequency (VHF)**	3.2 ft	1 m
>300 MHz		**Microwave ↓**	<3.28 ft	<1 meters
1000 MHz	1 GHz		11.8 inches	30 cm
2.45 GHz		Microwave ovens	4.8 inch	1.2 cm
3 GHz		**Ultra High Frequency (UHF)**	0.9 - 3.2 ft	10 cm
10 GHz		Satellite data links	1.18 inch	3 cm
30 GHz		Super High Frequency (SHF)	0.39 inch	10 mm
300 GHz		Extremely High Frequency (EHF)	0.039 inch	1 mm
1000 GHz	1 THz		0.012 inch	0.029 cm
10^{10} Hz		**Infrared**		1 mm (10 mm - 10 um)
400 THz		**Visible light, red**	0.03 inch	0.75 um (750 nm) (7500 Angstrom)
750 THz		**Visible light, purple**	0.017 mil	0.4 um (400 nm)
1000 THz ($10^{16\ Hz}$)		**Ultraviolet**		10 nm – 100 nm
3,000,000 THz		**X-Rays**		0.1 nm (0.01 – 10 nm)
50,000,000 THz		**Gamma Rays**		0.006 nm

Non-Ionizing Radiation Principle of Measurements
Job Performance Measure (JPM) Completion Certificate

Candidate's Name	Life Number:

Knowledge of the Principle of NIR Measurements

Criteria	Qualifying Standard	Unsatis-factory	Recov-ered	Satisf-.actory
Non-ionizing Radiation Principles	Understand the relationship of frequency and wavelength and near and far fields.			
	Understands the concepts of power density and E and H field strength.			
	Understands the differences and interrelationship of electric fields and magnetic fields.			
Hazard Analysis	Understands the basis of the need to perform field survey. i.e., the triggering events.			
Personal Protective Equipment	Understands the need to be aware of the potential hazards from NIR and to determine the needed controls			
Sampling Protocol	Understands the way to use meters to measure NIR- probe location and angles.			
	Understands the complications of reflective and reactive surfaces.			
Sampling Equipment	Knows the type of equipment needed for the procedure.			
Analysis of data	Knows the occupational exposure limits			
	Understands the concepts of spatial and time averaging.			
	Understands the need for induced and contact current measurements when applicable.			
	Understands the need to perform analysis on the data to assess potential exposure to the worker			
Record forms	Knows how to correctly and completely fill all forms associated with this SOP.			
Employee Notification	Knows how to timely and properly notify workers and management of problem areas.			

Employee: I accept the responsibility for performing this task as demonstrated within this JPM and the corresponding SOP.

Candidate Signature:	Date:

Evaluator: I certify the candidate has satisfactorily performed each of the above listed steps and is capable of performing the task unsupervised.

Evaluator Signature:	Date: