**U.S. Department of Justice**
Office of Justice Programs
*National Institute of Justice*

# National Institute of Justice

Law Enforcement and Corrections Standards and Testing Program

## Users' Guide for Hand-Held and Walk-Through Metal Detectors

## NIJ Guide 600–00

# ABOUT THE LAW ENFORCEMENT AND CORRECTIONS STANDARDS AND TESTING PROGRAM

The Law Enforcement and Corrections Standards and Testing Program is sponsored by the Office of Science and Technology of the National Institute of Justice (NIJ), U.S. Department of Justice. The program responds to the mandate of the Justice System Improvement Act of 1979, which directed NIJ to encourage research and development to improve the criminal justice system and to disseminate the results to Federal, State, and local agencies.

The Law Enforcement and Corrections Standards and Testing Program is an applied research effort that determines the technological needs of justice system agencies, sets minimum performance standards for specific devices, tests commercially available equipment against those standards, and disseminates the standards and the test results to criminal justice agencies nationally and internationally.

The program operates through:

The *Law Enforcement and Corrections Technology Advisory Council* (LECTAC), consisting of nationally recognized criminal justice practitioners from Federal, State, and local agencies, which assesses technological needs and sets priorities for research programs and items to be evaluated and tested.

The *Office of Law Enforcement Standards* (OLES) at the National Institute of Standards and Technology, which develops voluntary national performance standards for compliance testing to ensure that individual items of equipment are suitable for use by criminal justice agencies. The standards are based upon laboratory testing and evaluation of representative samples of each item of equipment to determine the key attributes, develop test methods, and establish minimum performance requirements for each essential attribute. In addition to the highly technical standards, OLES also produces technical reports and user guidelines that explain in nontechnical terms the capabilities of available equipment.

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Publications are available at no charge through the National Law Enforcement and Corrections Technology Center. Some documents are also available online through the Internet/World Wide Web. To request a document or additional information, call 800–248–2742 or 301–519–5060, or write:

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# Users' Guide for Hand-Held and Walk-Through Metal Detectors

## NIJ Guide 600–00

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Prepared for:
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Office of Science and Technology.

# FOREWORD

The Office of Law Enforcement Standards (OLES) of the National Institute of Standards and Technology (NIST) furnishes technical support to the National Institute of Justice (NIJ) program to strengthen law enforcement and criminal justice in the United States. OLES's function is to conduct research that will assist law enforcement and criminal justice agencies in the selection and procurement of quality equipment.

OLES is: (1) subjecting existing equipment to laboratory testing and evaluation, and (2) conducting research leading to the development of several series of documents, including national standards, user guides, and technical reports.

This document covers research conducted by OLES under the sponsorship of the National Institute of Justice. Additional reports as well as other documents are being issued under the OLES program in the areas of protective clothing and equipment, communications systems, emergency equipment, investigative aids, security systems, vehicles, weapons, and analytical techniques and standard reference materials used by the forensic community.

Technical comments and suggestions concerning this guide are invited from all interested parties. They may be addressed to the Director, Office of Law Enforcement Standards, National Institute of Standards and Technology, Gaithersburg, MD 20899–8102.

Dr. David G. Boyd, Director
Office of Science and Technology
National Institute of Justice

# BACKGROUND

The Office of Law Enforcement Standards (OLES) was established by the National Institute of Justice (NIJ) to provide focus on two major objectives: (1) to find existing equipment that can be purchased today, and (2) to develop new law-enforcement equipment which can be made available as soon as possible. A part of OLES's mission is to become thoroughly familiar with existing equipment, to evaluate its performance by means of objective laboratory tests, to develop and improve these methods of test, to develop performance standards for selected equipment items, and to prepare guidelines for the selection and use of this equipment. All of these activities are directed toward providing law enforcement agencies with assistance in making good equipment selections and acquisitions in accordance with their own requirements.

As the OLES program has matured, there has been a gradual shift in the objectives of the OLES projects. The initial emphasis on the development of standards has decreased, and the emphasis on the development of guidelines has increased. For the significance of this shift in emphasis to be appreciated, the precise definitions of the words "standard" and "guideline" as used in this context must be clearly understood.

A "standard" for a particular item of equipment is understood to be a formal document, in a conventional format, that details the performance that the equipment is required to give and describes test methods by which its actual performance can be measured. These requirements are technical and are stated in terms directly related to the equipment's use. The basic purposes of a standard are (1) to be a reference in procurement documents created by purchasing officers who wish to specify equipment of the "standard" quality, and (2) to identify objectively equipment of acceptable performance.

Note that a standard is not intended to inform and guide the reader; that is the function of a "guideline." Guidelines are written in non-technical language and are addressed to the potential user of the equipment. They include a general discussion of the equipment, its important performance attributes, the various models currently on the market, objective test data where available, and any other information that might help the reader make a rational selection among the various options or alternatives available to him or her.

*A standard is not intended to inform and guide the reader; that is the function of a guideline*

This guide is provided to describe to the reader the technology used in hand-held and walk-through metal detectors that is pertinent for use in weapon and contraband detection.

Kathleen Higgins
*National Institute of Standards and Technology*
January 2001

## ACKNOWLEDGMENTS

This document is a result of inputs from the law enforcement and corrections (LEC) community regarding the contents for a users' guide for hand-held and walk-through detectors for use as metal weapon detectors. In particular, the following local and State LEC agencies have provided inputs that were used in writing the guide:

Allen County Sheriff's Department, Fort Wayne, IN
Arapahoe County Sheriff's Department, Littleton, CO
Buffalo Police Department, Buffalo, NY
California Department of Corrections, Sacramento, CA
Erie County Sheriff's Department, Erie County, NY
Fairfax County Sheriff's Department, Fairfax, VA
Frederick County Adult Detention Center, Frederick, MD
Los Angeles County Sheriff's Department, Monterey Park, CA
Montgomery County Police, Wheaton District Station, Silver Spring, MD
New Hampshire Department of Corrections, Concord, NH
New York State Department of Corrections, Buffalo, NY
Rhode Island Department of Corrections, Cranston, RI
Rome Police Department, Rome, NY

The following Federal LEC agencies provided comments and inputs regarding the contents of the guide:

Bureau of Alcohol, Tobacco, and Firearms, U.S. Department of Treasury
Bureau of Diplomatic Security, U.S. Department of State
Federal Aviation Administration, U.S. Department of Transportation
Federal Bureau of Investigation, U.S. Department of Justice
Federal Bureau of Prisons, U.S. Department of Justice
United States Secret Service, U.S. Department of Treasury

Others have contributed to the development of this document: M. Misakian of the National Institute of Standards and Technology (NIST), Gaithersburg, MD and G.A. Lieberman of the Office of Law Enforcement Standards (OLES) of NIST furnished technical comments and suggestions; J.L. Tierney and D.A. Abrahamson, both under contract with NIST during preparation of this document, provided technical and editorial comments and recommendations; and S.E. Lyles of OLES and B.A. Bell of NIST provided editorial and administrative support.

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## COMMONLY USED SYMBOLS AND ABBREVIATIONS

| | | | | | |
|---|---|---|---|---|---|
| A | ampere | H | henry | nm | nanometer |
| ac | alternating current | h | hour | No. | number |
| AM | amplitude modulation | hf | high frequency | o.d. | outside diameter |
| cd | candela | Hz | hertz (c/s) | O | ohm |
| cm | centimeter | i.d. | inside diameter | p. | page |
| CP | chemically pure | in | inch | Pa | pascal |
| c/s | cycle per second | IR | infrared | pe | probable error |
| d | day | J | joule | pp. | pages |
| dB | decibel | L | lambert | ppm | parts per million |
| dc | direct current | L | liter | qt | quart |
| EC | degree Celsius | lb | pound | rad | radian |
| EF | degree Fahrenheit | lbf | pound-force | rf | radio frequency |
| dia | diameter | lbf·in | pound-force inch | rh | relative humidity |
| emf | electromotive force | lm | lumen | s | second |
| eq | equation | ln | logarithm (base e) | SD | standard deviation |
| F | farad | log | logarithm (base 10) | sec. | section |
| fc | footcandle | M | molar | SWR | standing wave ratio |
| fig. | figure | m | meter | uhf | ultrahigh frequency |
| FM | frequency modulation | min | minute | UV | ultraviolet |
| ft | foot | mm | millimeter | V | volt |
| ft/s | foot per second | mph | miles per hour | vhf | very high frequency |
| g | acceleration | m/s | meter per second | W | watt |
| g | gram | N | newton | ? | wavelength |
| gr | grain | N·m | newton meter | wt | weight |

area=unit$^2$ (e.g., ft$^2$, in$^2$, etc.); volume=unit$^3$ (e.g., ft$^3$, m$^3$, etc.)

## PREFIXES

| | | | |
|---|---|---|---|
| d | deci ($10^{-1}$) | da | deka (10) |
| c | centi ($10^{-2}$) | h | hecto ($10^{2}$) |
| m | milli ($10^{-3}$) | k | kilo ($10^{3}$) |
| µ | micro ($10^{-6}$) | M | mega ($10^{6}$) |
| n | nano ($10^{-9}$) | G | giga ($10^{9}$) |
| p | pico ($10^{-12}$) | T | tera ($10^{12}$) |

## COMMON CONVERSIONS (See ASTM E380)

| | |
|---|---|
| 0.30480 m = 1ft | 4.448222 N = 1 lbf |
| 2.54 cm = 1 in | 1.355818 J = 1 ft·lbf |
| 0.4535924 kg = 1 lb | 0.1129848 N·m = 1 lbf·in |
| 0.06479891g = 1gr | 14.59390 N/m = 1 lbf/ft |
| 0.9463529 L = 1 qt | 6894.757 Pa = 1 lbf/in$^2$ |
| 3600000 J = 1 kW·hr | 1.609344 km/h = 1 mph |

Temperature: $T_{EC} = (T_{EF} ! 32) \times 5/9$

Temperature: $T_{EF} = (T_{EC} \times 9/5) + 32$

# USERS' GUIDE FOR HAND-HELD AND WALK-THROUGH METAL DETECTORS

# 1. INTRODUCTION

## 1.1 Purpose of the Guide

The guide provides the law enforcement and corrections (LEC) community with information concerning the theory and limits of operation of hand-held and walk-through metal weapon detectors. This guide is also intended to supplement National Institute of Justice (NIJ) standards for hand-held (HH) and walk-through (WT) metal weapon detectors (see sec. 6, refs. 1 and 2). It contains information to help the user better understand the standards and their specifications. The guide also includes general training instructions for metal detector operators and supervisors, and information on where to obtain more detailed training. A brief discussion of safety topics is also contained in the guide. A list of present suppliers of hand-held and walk-through metal detectors is also provided. Throughout this guide, the HH and WT metal detectors will be referred to as HH and WT units.

## 1.2 Information Source

The topics addressed in this guide were determined from interviews with a number of LEC agencies (see acknowledgment list on p. vii). Interviews were conducted in medium to large agencies because the majority of sworn officers are employed in medium to large agencies (see fig. 1). Furthermore, the civilian population served is represented by the number of sworn officers and not the number of agencies, although the majority of agencies are small (see fig. 2). The agencies that were selected for interview were either located near NIST in Gaithersburg, MD or had representatives on the Law Enforcement and Corrections Technology Advisory Council (LECTAC).

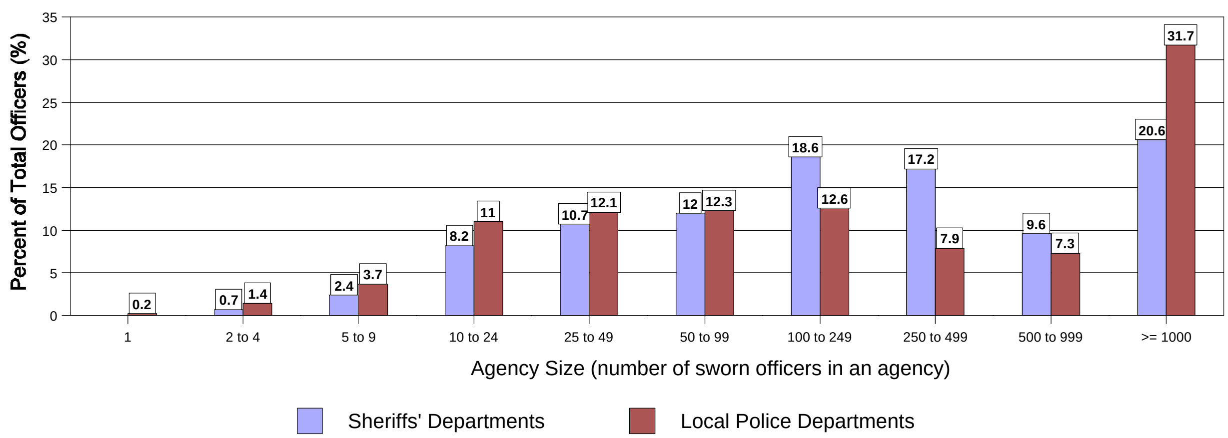


***Figure 1**. The percent of sworn officers vs agency size (given as number of sworn officers in the agency); see section 6, references 3 and 4*

### 1.3 Security Requirements and Applications

HH and WT units are used to control the type of objects allowed into restricted areas and to find objects hidden within these areas. Different users have different security requirements. For example, courthouse security requires preventing entry of firearms and large (greater than a few inches long) metal objects that can be used to injure another person. Corrections facilities, on the other hand, want to restrict penetration of even smaller metal objects into the secure areas; for example, objects that can be used to open handcuffs, such as paper clips. However, there is a limit to the smallest metal object that can be detected with present HH and WT metal weapon detector technology, and the LEC officer or agent must be aware of this. Therefore, realistic object size detection levels must be established based on the perceived threat for a given environment. In reality, HH and WT units can detect magnetizable materials and electrically conductive materials that are nonmetallic, such as conductive polymers and saline solutions (like human tissue). However, this discussion is limited to the detection of metal objects.

#### 1.3.1 Metal Object Sizes as Related to Security

According to interviews with representatives of many local, State, and Federal LEC agencies, there appear to be primarily three levels of practiced security that are based on the size of the metal object to be found. For purposes of this document, these shall be labeled large, medium, and small object sizes. The ability to find the smallest possible metal object is limited by detection technology. The requirement to find the smallest metal object is significant at corrections and detention facilities where even the smallest piece of metal can be used as a weapon or part of a weapon or to compromise (defeat) other safety devices and constraints. A pat-down search at the time of arrest also requires the ability to find small objects. Small-sized metal objects that can be a threat to security are paper clips, razor blades from disposable shaving razors, metal pen refills,

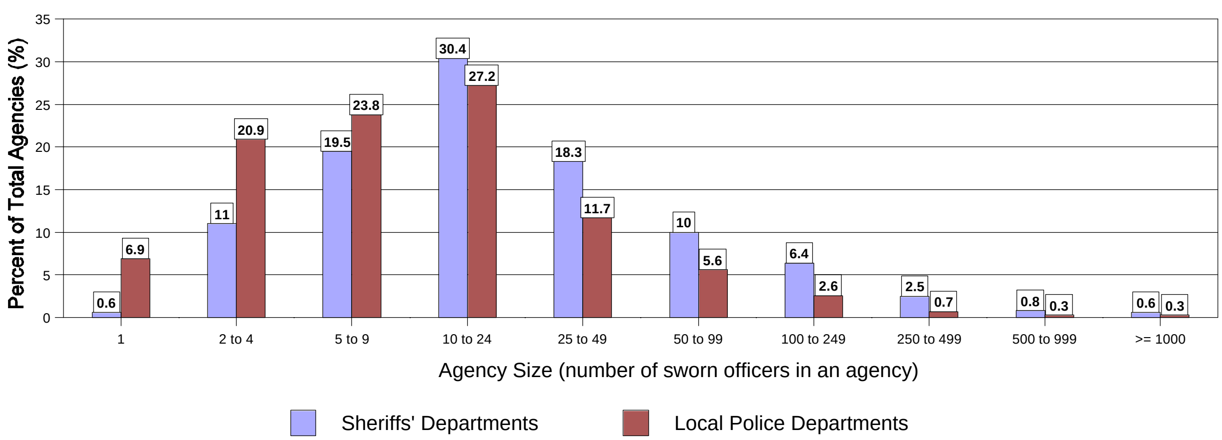


***Figure 2. The percent of agencies in a given size range where the agency size is determined by the number of sworn officers (see sec. 6, refs. 3 and 4)***

etc.  However, nonmetallic objects can also be used as weapons, and metal detectors cannot detect these nonmetallic weapons.

Medium-sized metal object detection is encountered in similar situations and environments where small-sized metal object detection is used.  The primary difference is that in certain instances the perceived threat of small-sized objects is small, or there is insufficient time to resolve potential alarms caused by small-sized metal objects.  Examples of medium-sized threat objects are short sections of hacksaw blades, blades from hand-held paint scrapers, small screwdriver bits, small caliber ammunition, handcuff keys, etc.

Detection of large-sized metal objects are primarily a concern at courthouses, for very-important-person (VIP) security, for event security, during a routine personal search, etc.  In these situations, all firearms and any knives with blades over 7.6 cm (3 in) long must be found.  However, when the HH or WT unit is operating in a mode for detection of large metal objects, these units must discriminate between large metal objects and small metal objects to reduce a large number of time-consuming secondary searches.

### 1.3.2  Environment and Conditions of Use

Corrections and detention facilities are primarily indoor environments where the HH and WT units are used at a fixed location and, therefore, are not typically subject to temperature and humidity changes.  However, in some situations the units may be used outside or at an entry port where exposure to varying (on a short-time scale) temperature and humidity is encountered.  A HH unit carried by law enforcement officers on patrol and used for a pat-down search at the time of arrest is a high-security application that requires environmental tolerance.  Therefore, the sensitivity of detection performance to environmental conditions is important.  Furthermore, the outdoor-use devices may be exposed to blowing sand/dust, blowing rain, spilled liquids, fungal growth (if stationary), solar radiation, etc.

Although the environmental conditions for most indoor applications are relatively constant, detection performance of HH and WT units can vary due to other conditions.  For example, low power or poor power quality may affect detection performance.  Furthermore, electromagnetic interference (EMI) or mechanical interference may cause the HH and WT unit to function improperly.  EMI can be caused by electric motors, radios, computers, etc.  Basically, almost anything that is electrically powered can be a source of EMI.  Mechanical interference can be caused by metal walls or moving metal doors.

There is also the issue of ruggedness, which describes the physical and mechanical abuse that the HH and WT units may be subject to and still be required to exhibit acceptable performance.  Hand-held units, during normal use, may be dropped, kicked, stepped upon, sat upon, etc.  Consequently, these HH units must tolerate mechanical abuse without breaking or affecting detection performance.  Furthermore, these HH units must not expose surfaces or edges that can be dangerous to the operator or allow the device to be used as a weapon.  Walk-through units also must tolerate some mechanical abuse. The abuse in this case may be from flying objects, hitting, kicking, bumping, etc. Walk-through units must also be resistant to sliding and tipping over.

### 1.4 Revised NIJ Standards

Revisions of the NIJ standards were implemented because of requests by HH and WT metal detector manufacturers and by LECTAC members. The LECTAC advised the NIJ concerning potential law enforcement and correction technology worthy of research and development support. The revised NIJ standards address the issues deemed important by the LECTAC. The revised NIJ standards not only address the above mentioned subjects, but also quality assurance, reliability, and maintainability.

## 2. THE NATIONAL INSTITUTE OF JUSTICE STANDARDS

The National Institute of Justice (NIJ) has developed two Standards pertaining to metal detectors for use as weapons detectors (see refs. 1 and 2 listed in sec. 6). One of these Standards is for HH units and the other is for WT units. Both of these Standards are somewhat technical in nature. To help the LEC community better understand these NIJ Standards, this section of this guide contains a brief section-by-section description of each Standard, with particular emphasis on detector performance requirements and specifications (found in sec. 2 of each Standard) and the rationale for these requirements and specifications in the Standards. Consequently, this section of the guide refers to sections in the Standards, and to simplify referencing this section of the guide to the Standards, the same numbering is used here as is used in the Standards with the exception of an additional “2" preceding each section title. The two NIJ Standards are almost identical except for specific parts that are unique to either the HH or WT units.

### 2.1 Introduction

#### 2.1.1 Purpose of the Standard

As mentioned in the corresponding section in the NIJ Standards, the purpose of the Standards is to establish performance requirements and methods of test for active hand-held and walk-through metal detectors used to find metal weapons and/or metal contraband concealed or carried on a person. The hand-held metal detectors can also be used to locate metal weapons and contraband hidden within or on the premises of a building or within a nonmetallic object or body (such as the ground, food, etc.).

#### 2.1.2 Definitions

The definition sections of the NIJ Standards are provided to facilitate the use and understanding of the standards. Since each defined term is italicized throughout the standards, it provides a useful cross reference tool. This section is intended to provide clear and identical interpretations of the standards, object size classes, test objects, and test methods by all parties.

### 2.2 Requirements for Acceptance

Section 2 of the Standards contains all the performance and system requirements and specifications required for acceptance. The performance requirements and specifications of the standards are primarily concerned with detection performance. System requirements and specifications refer to all other requirements and specifications and include power, battery back-up, safety, durability, interference, and many others. Furthermore, without some quality assurance program in place, a HH and WT unit that was safe at the time of purchase may fail to remain safe. These issues are covered in the revised NIJ standard.

### 2.2.1 Safety Specifications and Requirements

#### 2.2.1.1 Electrical

Physical contact to voltages exceeding a particular value can be dangerous. HH and WT units should not expose the user or public to high-voltage electrical signals or power. If high voltages do exist within or on these devices, then these devices must be enclosed so as to prevent user access to the high voltages. Underwriters' Laboratories (UL) provides a standard for exposure to voltages that is referenced in the NIJ standard.

#### 2.2.1.2 Mechanical

Another safety concern is more mechanical or physical in nature. The operator or another person coming into contact with the HH or WT unit should not be exposed to needless risk of injury. The HH and WT unit should not contain sharp edges, loose covers/cowlings, hanging wires, protruding surfaces, etc. To address this concern, the detector is required to have rounded corners, no external wires or cables to trip over, and no loose parts. Violations of these safety requirements would be obvious, but unless stated explicitly, manufacturer compliance cannot be assumed.

#### 2.2.1.3 Exposure

Magnetic fields are used by HH and WT units to sense the presence of metal objects. Scientific studies have raised the concern that exposure to magnetic fields may cause biological changes in living cells. The effect of exposure of biological tissue and systems (human bodies) to magnetic fields has been addressed by several standards-setting organizations, and these standards are used in the revised NIJ standard to limit human exposure to magnetic fields generated by HH and WT units.

In addition, certain types of personal medical electronic devices may be affected by these magnetic fields. However, the effect of magnetic fields on personal electronic medical devices has not been studied extensively. These devices may be implanted under the skin or attached to the surface of the skin and include cardiac defibrillators, pacemakers, infusion pumps, spinal cord stimulators, ventilators, etc. At the time of this writing, only a few manufacturers of HH and WT units have had the effect of their detectors on personal medical electronic devices tested; and this was only for cardiac pacemakers. The Center for Device and Radiation Health (CDRH) of the Food and Drug Administration (FDA) is the Federal organization responsible for determining safety of exposure to various types of radiation. The CDRH has defined exposure limits for laser sources, cabinet x-ray machines, microwave ovens, etc. At the time of this writing, however, the CDRH has not declared any formal opinions regarding the exposure of the various personal medical electronic devices to the magnetic fields generated by hand-held and walk-through metal detectors.

#### 2.2.1.4 Warning Labels

A warning label is required on HH and WT units until the FDA or a similar agency has determined that exposure to the magnetic fields generated by HH and WT units is not unsafe.

### 2.2.2 Electrical Requirements

#### 2.2.2.1 Power

The quality and condition of either ac (walk-through) or battery power (hand-held) may have an impact on detector performance. The quality and condition of the ac voltage level and battery level is addressed in the standard. In addition, both power sources are subjected to testing for any impact on detector performance, and a requirement is imposed for a visual indicator to alert the operator if a power problem exists.

#### 2.2.2.2 Burn-In

Users of hand-held and walk-through metal detectors are concerned with the reliability of the equipment. To ensure that each detector is capable of reliable performance without early burn-out, a statistical sample of each type of detector is subjected to a long period (160 consecutive hours) of cycle and performance testing.

#### 2.2.2.3 EEPROM Program Storage (WT only)

The EEPROM (electrically erasable programmable read-only memory) is required so that the programmed operating parameters of the walk-through metal detector are not lost during a power outage or interruption.

### 2.2.3 Detection Performance Specifications

The detection performance specifications of the Standards, excluding the magnetic field intensity distribution mapping, are based on the detection of specific metal test objects. These test objects are also used to define the level of security. There are three object size classes defined in the NIJ Standards for HH and WT metal detectors for use as weapons detectors. The three sizes are large, medium, and small. The large-sized object class includes test objects that are replicas of handguns and knives. The medium-sized object class includes handcuff keys, #2 Phillips screw driver bits, and 22 caliber long rifle rounds. The small-sized object class is applicable only for HH detectors and includes short sections of a pen refill and the blade from a disposable razor. In addition, for the HH detectors, there is an optional small-sized test object, the hypodermic needle from a disposable syringe. The reason that the hypodermic needle is an optional test object is that it is very difficult to find. The HH and WT units may be designed to find objects of more than one object size class, in which case the unit must be tested for each object size class.

#### 2.2.3.1 Detection Sensitivity

If the hand-held or walk-through metal detector fails to find metal weapons concealed or carried on a person, human safety is unknowingly at risk. This standard ensures that each test object, which is a replica of a threat item, appropriate for the object-size detection classification level of the detector unit is detected at specified orientations in the area around the HH unit and in the portal area of the WT unit.

#### 2.2.3.2 Speed

Users of hand-held and walk-through metal detectors require the detector to perform effectively whether the detector or the person being tested moves quickly or slowly. This specification and its associated test procedure assures proper detector performance for a reasonable speed range.

#### 2.2.3.3 Repeatability

If the HH or WT unit fails to find metal weapons concealed or carried on a person, human safety is unknowingly at risk. The HH and WT unit must detect each appropriate test object every time it is tested to assure user confidence in the ability of the HH and WT unit to properly perform. This specification requires that the HH and WT unit be tested at its weakest point for 50 consecutive trials and detect the appropriate test objects without failure.

#### 2.2.3.4 Discrimination

For the large-sized object class of a HH or WT unit, it is important that objects smaller than the large-sized test objects (which includes the medium-sized and small-sized test objects listed in sec. 5.2 of the Standards) do not cause the HH or WT unit to alarm, which could then produce unnecessary delays and reduce throughput. For HH and WT units designed to find large-sized objects, this specification requires that the HH or WT unit not alarm when metal objects that are smaller than the large-sized test objects pass through the portal of the WT unit or are brought near the HH unit.

#### 2.2.3.5 Body Concealment

If the HH or WT unit fails to find metal weapons concealed on a person, human safety is unknowingly at risk. This specification is designed to test whether a person can conceal objects from detection by placing them under the armpit or in other concealed areas of the body. However, body concealment is not likely to significantly effect detection performance, especially for the low operating frequencies used by WT units.

#### 2.2.3.6 Throughput (WT only)

Another specification requested by users of WT units is a maximum throughput rate, which describes a maximum number of persons that can pass through the WT unit per minute without reducing the probability of successful detection. This specification tests the WT unit's ability to properly detect a metal object on a person walking through the portal of the WT and then to reset (become ready) for the next person. Purchasers of detectors may use this specification to compute the number of detectors required for a given security application based on the expected total throughput rate for that application.

#### 2.2.3.7 Multiple Metal Objects (WT only)

Users of HH and WT units require the detector to perform effectively even if more than one metal object is present. This specification prevents one or more metal objects from affecting the detection of another metal object.

#### 2.2.3.8 Magnetic Field Mapping (HH only)

If the hand-held or walk-through detector fails to find metal weapons concealed or carried on a person, human safety is unknowingly at risk. To ensure that there are not any "weak spots" in the magnetic field that could enable a person to carry a prohibited object through a detector without detection, the magnetic field intensity in the portal area of the WT unit and around the HH unit is measured.

### 2.2.4 Operating Requirements

#### 2.2.4.1 Operator Controls

To prevent anyone from tampering with or inadvertently changing the detection parameters of the HH or WT unit, only those controls required to operate the HH or WT unit are accessible to the operator. Other controls are inaccessible to the operator. The Standards also lists the operator controls that must be provided.

#### 2.2.4.2 Control Panel Error Codes (WT only)

To assist an operator or a technician in servicing different models of WT units, a unit must provide a uniform two-digit error code to identify different types of system failures. The first digit of the code represents the general area of system failure and is specified. The second digit may be used by the manufacturer to provide additional information on the malfunction.

#### 2.2.4.3 Interference

There are primarily two types of interferences associated with HH and WT units: electromagnetic and mechanical. Electromagnetic interferences (EMI) can be conducted and/or radiated. The NIJ Standards address both EMI generated by HH and WT units and the EMI susceptibility of HH and WT units. To ensure proper detector performance, this requirement sets standards for both electromagnetic and mechanical interference, when applicable. This reduces the effect of external influences on HH and WT units, such as a voltage surge, a two-way radio, a metal wall, a moving door, etc.

#### 2.2.4.4 Environmental Ranges and Conditions

An HH unit typically is used in a variety of environmental conditions and can be used both indoors and outdoors. A WT unit may also be used indoors or outdoors, but because of its size and weight, a WT unit likely will not be moved as frequently as a HH unit. The Standards for HH and WT units require testing under various environmental conditions that include: temperature, relative humidity, salt mist, fungus, rain/wind, sand/dust, environmental corrosion, and solar radiation. Practical requirements are placed on the performance of the HH and WT units under these conditions to assure that detector performance is not compromised. Both HH and WT units may be provided as indoor-only or indoor/outdoor models.

### 2.2.5 Mechanical Specifications and Requirements

#### 2.2.5.1 Dimensions and Weight

Ergonomics of the HH units is also an issue. HH and WT units have weight requirements to reduce fatigue during long-term use (hand-held) and ease of relocation (walk-through). The Federal Aviation Administration (FAA) of the Department of Transportation published an ergonomic study of then-available (1995) HH units (see sec. 6, ref. 5). This document considers the effect of HH unit design and operating procedures on the effectiveness of operators using the HH units to find concealed objects. Some HH units exhibited an apparent advantage over others for long-term use because of reduced operator fatigue and greater comfort during use. Since ease-of-use and comfort affect operator performance, it is recommended that the FAA study be reviewed. Furthermore, incapacity by an ailment, such as carpel tunnel syndrome, will adversely affect the LEC agency operating budget and overall agency performance. The WT unit also has minimum dimensional requirements so persons can walk normally through the portal without undue restrictions.

#### 2.2.5.2 Durability/Ruggedness

An HH unit is subjected to a number of forms of abuse such as dropping and severe bumping. Therefore, the HH unit must be durable enough to withstand these forces and still operate properly. Similarly, a WT unit may be bumped, dropped during shipment or relocation, slid or tipped over. This specification requires that the HH and WT units perform properly after being exposed to normal and expected physical abuse.

### 2.2.6 Functional Requirements

#### 2.2.6.1 Audible Alarms

This provision requires a minimum sound level volume for audible alarms to assure that the audible alarm can be heard by the operator. This requirement also provides for a two-state or proportional alarm, depending on whether the detector is a walk-through or hand-held unit. The audible alarm requirement forces uniformity of alarm functions regardless of the detector manufacturer, thereby, making all detector units sound similar to the user. Other alarms are also required by the NIJ Standards to assure the operator that the detector unit is performing properly or to alert the operator in the event of any problem.

#### 2.2.6.2 Visual Indicators

Certain detector conditions also require a visible alarm indication. The NIJ Standard sets a minimum illumination level for visual indicators to ensure that the visual indicator can be seen by the operator. Visual indicators, with the audible alarm turned off, allow an operator to detect metal objects without necessarily alerting the person being scanned of an alarm indication. Visual indicators are also required to assure the operator that the detector unit is performing properly.

#### 2.2.6.3 Detection Signal Output Connector

For factory or laboratory testing, a detection signal output connector is required to extract the analog detector signal prior to the alarm. The connector also allows the HH and WT units to be monitored from a remote location. This connector can be used to assist the technician in servicing any detector problems.

#### 2.2.6.4 Interchangeability

Any given model of HH or WT unit is required to have interchangeable parts and components to facilitate maintenance.

#### 2.2.6.5 Field Servicing

The HH and WT units are required to be designed for ease of maintenance, and the electronics must be of modular design to provide ease in repair.

### 2.2.7 Detector Mount

The manufacturer is required to provide a detector holder for accurately positioning the detector unit with respect to the measurement system. The detector mount provides repeatability and comparability of measurements for each type of detector manufactured.

### 2.2.8 Quality Control and Assurance

If the HH or WT unit fails to find metal weapons concealed or carried on a person, human safety is unknowingly at risk. Accordingly, to assure that each HH and WT unit meets or exceeds the requirements of these standards and is highly dependable, the manufacturer must meet ISO 9001 quality assurance standards. These standards provide a model for quality assurance in design, development, production, installation, and servicing and are the same as those standards used for a variety of products such as automobiles, consumer electronics, etc.

### 2.2.9 Documentation

This section requires each manufacturer to provide a uniform list of deliverable items with each detector unit to assist the operators and technicians in the use and servicing of the detector. The following is a list of the required documentation: operating instructions, operator training instructions and videotape or CD ROM, technical specifications, waveform report, certification of inspection and conformance, certification of test procedures, suggested maintenance schedule, and installation instructions. This documentation is also required to assure that each detector unit (on the basis of statistical sampling) meets the requirements of the NIJ Standards. There is an equation given in sections 2.9.8 of the NIJ Standards that is used to determine the number of units to test. This equation (see sec. 6, ref. 6) is $m = \frac{0.1Mk_M}{0.1k_M + 0.01M}$, where m is the number of units that must be tested, M is the number of available units of the same type and model tested, and $k_M$ is the coverage factor for the 99 percent confidence interval (see table B.1 of ref. 7 of sec. 6 ). The value of 0.1 in the equation relates to the expected percentage of rejected units and a value typically found in manufacturing (see sec. 6, ref. 8). The value of 0.01 is the acceptable percentage of unit failures and is set by the NIJ Standards to balance production and test costs and subsequent cost to the LEC agency. Figure 3 shows how the value of the acceptable percentage of unit failures impacts the required number of tested units. In addition to the above documents, technical manuals and technical training manuals and videotapes (or CD ROM) are provided to the LEC agency upon request.

## 2.3 Performance Testing Procedures

This section describes all the test methods that are unique to measuring the detection performance of hand-held and walk-through metal detectors. All other tests, such as that for

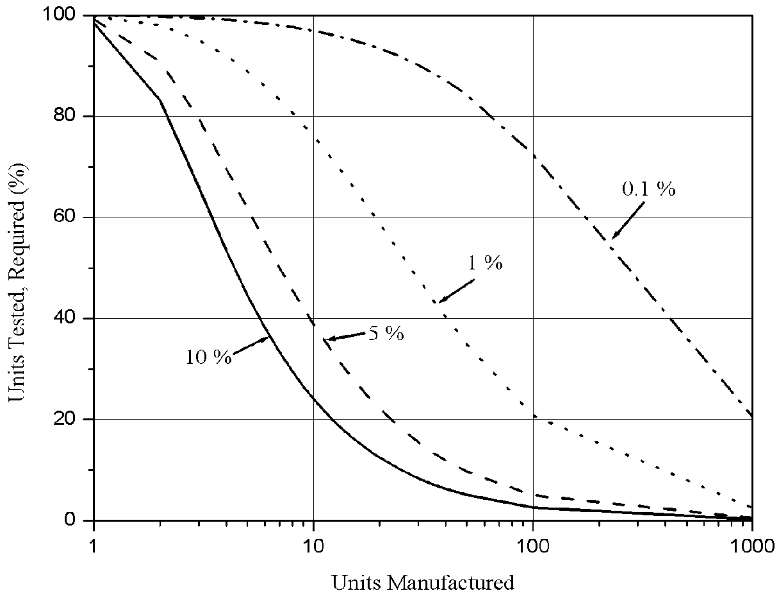


***Figure 3. The number of units that must be tested versus the number of units manufactured (the different curves represent different acceptable failure rates or percentages that must be satisfied; the NIJ Standards have this failure rate set to 0.1 %)***

environmental and mechanical tolerance, are performed in accordance with one of the standards referenced in section 1.2 of the NIJ Standards.

### 2.3.1 General Test Conditions

To compare the performance of HH and WT units from different manufacturers or of different models from a particular manufacturer, it is important that the test conditions be consistent. Consistent test conditions also enhance reproducibility of the measurement. Although the NIJ Standards require proper operation over a range of conditions, well-defined test conditions ensure that the performance data is reproducible.

#### 2.3.1.1 Test Location

The test location should be free from interferences of any type so that the metal detector performance can be properly assessed . Furthermore, if interferences are added to the performance tests, the number of different performance tests and their corresponding test conditions would increase to the point where the cost of testing becomes prohibitive. The effect of electromagnetic interferences is tested separately as per section 13 of the ASTM Designation F 1468–95, “Standard Practice for Evaluation of Metallic Weapons Detectors for Controlled Access

Search and Screening." The effect of metal walls, floors, doors, etc., are tested in accordance with the tests in section 3 of the NIJ Standards.

#### 2.3.1.2 Environment

Although the HH and WT units must function over a wide range of temperatures, humidities, and other environmental conditions, nominal environmental test conditions are specified in the NIJ Standard to enhance measurement reproducibility. Furthermore, performing the tests at only one temperature and relative humidity, instead of many or at any one arbitrary temperature and humidity within the operating ranges, reduces the number of required tests. However, the manufacturer must still show that the HH and WT units can operate normally under the environmental ranges and conditions specified in the NIJ Standards. The manufacturer may show that the WT unit complies with the environmental requirements by showing that all of the components and their interconnections comply with the environmental requirements. The advantage of environmental tests of the components of a WT unit instead of the entire WT system is that testing the entire WT unit for environmental effects would be much more costly than individually testing all of the components.

#### 2.3.1.3 Preparations

The HH and WT units must be properly installed, have fresh batteries, and be properly adjusted before any performance tests are done.

### 2.3.2 Detection Performance Tests

The group of tests described in section 3.2 of the NIJ Standards is required to assess detection performance. Tests to determine compliance with the other requirements stated in the NIJ Standards are referenced to other standards which, are listed in their order of appearance in section 1.2 of the NIJ Standards. The data format is specified to provide uniformity in the data presented to the LEC agencies.

#### 2.3.2.1 Object Size Classes

The impact of object size classes on performance testing is described in section 3.2.1 of the NIJ Standards. If the detection sensitivity of the HH or WT unit is adjustable, then these adjustments shall at least conform to the different object size levels defined in the NIJ Standards, and these units must be tested for each object size class.

#### 2.3.2.2 Equipment

The equipment required for the test is listed and their performance requirements described. This information assists the testing laboratory in selecting the appropriate instrumentation for performing the tests.

#### 2.3.2.3 Detection Sensitivity

The detection sensitivity test is used to determine the ability of the units to sense the test objects with several different orientations with respect to the HH and WT units. The appropriate test objects are used for this test; that is, if the unit is specified as being able to detect large-sized objects, then the medium-sized test objects are used. For the HH units, measurements are performed over each measurement plane. For the WT units, the measurements are performed at specific locations in the portal area that correspond to particular body locations. The weakest and strongest interactions are recorded for each test object, and this information is used for later tests. The measurement output is the detection signal obtained from the HH or WT unit's detector electronics.

#### 2.3.2.4 Speed

The speed test is used to evaluate detection performance for a range of speeds of an object moving through the portal of a WT unit or by a HH unit. The speed range and increment are specified in section 2, "Requirements for Acceptance," of the NIJ Standards. The appropriate test objects are used for this test; that is, if the unit is specified as being able to detect large-sized objects, then the large-sized test objects are used. For the HH units, measurements are performed through one location in each measurement plane. For the WT units, the measurements are performed at specific locations in the portal area that correspond to particular body locations. The measurement output is whether or not an alarm was produced.

#### 2.3.2.5 Body Concealment

The purpose of the concealed object test described in the revised NIJ Standards is to establish a test procedure for measuring the ability of the HH and WT units to sense a metal object concealed by the human body. As mentioned earlier (sec. 2.2.3.5), the effect of body concealment on detection performance is not significant. However, for very small objects, the detection signal from the human body maybe larger than that of the object (see sec. 3.2.6). The present test procedure is not intended to be the most scientific or reproducible test method possible. Using the armpit versus, for example, the crotch as test location is arbitrary. For practical reasons, a body cavity cannot be used as a place of concealment for this test. It is difficult to say which location, the armpit or crotch, would be a better location to test for body cavity concealment. The armpit may provide a continuous screen on both sides of the test object because people may keep their arm stationary while walking through the portal of a WT unit, whereas the object may become uncovered on one of its sides because legs move apart during walking. The thighs provide a larger mass to hide the test object than does an arm; the chest provides a larger mass than the thigh. The primary intention of this rudimentary procedure was to introduce the test into the standards, with the intention of subsequently developing a scientific test method that would supersede it. The measurement output is whether or not an alarm was produced.

#### 2.3.2.6 Throughput (WT Only)

This method measures the ability of the WT unit to sense two metal objects passing through the portal in succession. The test objects used for this test are derived from the detection sensitivity tests. The test objects are the ones that provided the largest and smallest sensitivity readings; therefore, there are two test objects for this test. The temporal profile of the response (response waveform) of the WT unit to the two test objects, as it is passed through the portal of the WT, is recorded. The minimum time allowed between two successive subjects walking through the portal is determined from these two waveforms. To calculate this minimum time, the person conducting the test (the tester) labels the waveform providing the larger response, $W_{big}$, and the waveform providing the smaller response $W_{small}$. The tester then finds the maximum signal from these two waveforms and calls these values $M_{big}$ and $M_{small}$ and also locates the time on $W_{big}$ where $M_{big}$ occurred and calls this time $t_{start}$. The next step is to locate the time on $W_{big}$ where the signal decreases to about half of $M_{small}$ and call this time $t_{stop}$. Subtracting $t_{start}$ from $t_{stop}$ provides the interval of time that you must wait before the WT unit is ready to scan the next person. The number of people that can pass through the WT unit per minute can be found by dividing 60 by the time interval (in seconds) just calculated: $60/(t_{stop}-t_{start})$. The measurement output is the time difference between the $t_{stop}$ and $t_{start}$.

### 2.3.3 Alarm Indication Tests

These tests are required to ensure that the alarms can provide an indication of sufficient intensity or loudness to attract the attention of the average user/operator. No matter how good the detection performance may be, if the operator is not aware that an object was sensed, the detector is useless.

### 2.3.4 Time-Varying Generated Magnetic Field Test

This test requires that the profile of the time-varying magnetic field be measured and recorded. Like the profile or contour of a landscape shows how structures or the land rises above the surface of the ground, the time (or temporal) profile of the magnetic field shows how the magnetic field intensity varies from low values to high values. The sinusoidal waveforms shown in section 3.2.1.1.2 are examples of the temporal profile of the ac power available at the electrical outlets in our homes. The time profile of the magnetic field, in conjunction with the maximum magnitude of the magnetic field, will be used to develop test methods to determine the susceptibility of personal medical electronic devices (like pacemakers) to the magnetic fields generated by HH and WT units.

### 2.3.5 Test for Operation Near a Metal Wall, Steel Reinforced Floor, or Moving Metal Door

The WT unit must function properly when placed over a steel reinforced floor or located near a metal wall and/or a moving metal door. Similarly, the HH unit must function normally near a metal wall. The HH and WT units are metal detectors and, therefore, will detect metal walls, doors, floors, etc.  However, the sensitivity to the objects should not affect HH and WT performance when there is sufficient spacing and the units have been properly adjusted.  The purpose of this test is to determine whether the HH and WT units perform properly when sufficiently separated from large metal objects such as walls, floors, and doors.

The metal wall test has been introduced into the revised NIJ Standard for WT detectors.  The purpose of this test is to assess HH and WT detector performance with a nearby metal wall.  For WT units, the detection performance is examined after the metal panel has been put in place and the WT unit adjusted to accommodate for the proximity of that panel.  The moving door test (WT only) has replaced the moving panel test of the old NIJ Standard.  The new method is more reproducible than the previous because:  the moving panel is now mounted with hinges to a stationary pivot, the moving panel is accurately aligned and positioned with respect to the WT unit, and the motion is completed in a defined time.  The metal floor test (WT only) has also been modified.  In this case, the steel reinforcing rods and wire mesh are replaced by a continuous metal sheet.  The thickness of the sheet has been adjusted to provide a signal comparable to the simulated reinforcement.  The purpose of using the sheet is to simplify the required test objects and enhance uniformity of the tests.

#### 2.3.6  Battery Life Test (HH Only)

The battery life test is used to ensure that the units will function properly for the entire period specified in the NIJ Standards.

#### 2.3.7  Burn-In Test

The burn-in test is to make sure the electronic systems are not going to fail after these systems are shipped by the manufacturer.  Typically, for electronic circuits, possible failure occurs early in the life cycle.  For comparison, mechanical systems typically experience the greatest failure rate after a long period of use.

### 2.4  Field Testing Procedures

These are test procedures to be performed by the LEC officer or agent to make sure the HH and WT units are performing properly both when received from the manufacturer and during subsequent periodic performance checks.

### 2.5  Test Objects Description

The purpose of the test objects is to provide exemplars for performance measurements and a basis for measurement comparison.  This allows all WT and HH units produced by manufacturers to be tested for compliance to the revised Standard and objectively compared.  The LEC agency can then select the best HH or WT unit based on accurate comparative data rather than speculative data.  The purpose of the exemplars is to make a better standard that will help the LEC agencies get a better device.  The Standard includes certain specifications and must have tests appropriate for checking adherence to those specifications.  Test objects are required for checking for adherence and, consequently, those objects must be well defined; that is, they must be standards. The test objects are replicas of the threat items.  Replicas are used because they are safer, in some cases, than the threat item but, moreover, because the dimensional tolerance and material properties of the replicas can be specified.  Furthermore, to enhance safety and allow for orientation-dependent performance measurements, the replicas are encased in plastic.

Not all threat items can have a replica that is used as a test object.  This is because there are many threat items and the cost of testing HH and WT units with all possible test objects would be prohibitive.  Consequently, we have examined the group of threat items for each object size class and have selected those objects that would give the smallest signal; that is, that would be the hardest to find.  The HH and WT units are used under different circumstances and, consequently, their corresponding test objects may be different.  For example, the requirements of courthouse and correction facility security are extremely different.  For correctional facility security of inmates,  the smallest metal object that can be found is important.  Because the body is, in some sense, a container of electrically conductive solution, finding hypodermic needles with a WT unit is extremely difficult.  However, the hypodermic needles may be found with a HH unit.  At a courthouse, on the other hand, the WT unit is used to find relatively large objects (handguns and knives) and unresolved items, which are still detectable by the WT unit, are resolved by a secondary search using HH units or other means.

### 2.5.1  Large-Sized Test Objects

The large-sized test objects are relatively large metal objects that can be sensed by most commercially available HH and WT metal detectors.  These objects are weapons and have been defined by the LEC agencies as a handgun and a knife and, accordingly, the two test objects are replicas of the handgun and knife.  The material that is used to make the replica is non-ferromagnetic stainless steel because stainless steel is less detectable than other possible metals that can be used for these items.  The shape of the handgun replica indicated in the NIJ Standard is not perfect and is a temporary design.  A design of a replica that more accurately represents the interaction of a handgun with HH and WT units will be determined in the future and incorporated in subsequent revisions of the NIJ Standards.  Because of the variation in handgun shape and metal composition, more than one replica may be required.  The large-sized test objects are the same for both the HH and WT units.

### 2.5.2  Medium-Sized Test Objects

The medium-sized test objects are small metal objects that can be sensed by most commercially available HH and WT metal detectors and represent objects defined as threat items by LEC agencies.  These threat items can be used to defeat security constraints or can be fashioned into or used as weapons and are the following: a handcuff key, a 38 mm long section of hacksaw blade, a razor blade from a paint scraper, nail clippers, a #2 Phillips screwdriver bit, and a

22-caliber long rifle round.  Finding the medium-sized test objects requires that the HH and WT units be adjusted to have sufficient sensitivity for finding these relatively small-sized objects. Although there are only five test objects, the number of tests required to assess HH and WT detection performance for these test objects and their unique orientations is large and, therefore, time consuming and costly.  To reduce the cost of testing, certain threat items are not used in the NIJ Standards.

The nail clipper is not used in the test because it is made of material with similar electrical and magnetic properties as the smaller and, therefore, harder to find scraper blade and hacksaw blade. The scraper blade is also not used in the test because it is easier to detect for all orientations than is the short section of hacksaw blade.  The handcuff key is made of a material with similar electrical properties as that of the hacksaw blade.  The handcuff key was also experimentally observed to be more difficult to find than the short section of hacksaw blade for the orientations tested.  Consequently, the short section of the hacksaw blade is not used in the test.  Depending on orientation, the handcuff key may give a smaller or larger detection response than either the 22-caliber round or the Phillips screwdriver bit.  Accordingly, both HH and WT units use a replica of the handcuff key as one of the medium-sized test objects.  To reduce the number of test objects further, the #2 Phillips screwdriver bit and the 22-caliber round were examined to see if both were necessary in the test.  The #2 Phillips screwdriver bit is about the same size as a 22-caliber long rifle round.  However, because of the electrical and magnetic properties of the material that make these two objects, the 22-caliber round is expected to be more difficult to find.  This expectation was verified experimentally in a laboratory using sensitivity-adjustable HH units.  However, according to conversations with LEC officers, it appears that finding the 22-caliber round is very difficult using a WT unit.  Consequently, a replica of the screwdriver bit will be used for one of the medium-sized test objects for WT units, and a replica of the 22-caliber long rifle round is used for one of the medium-sized test objects for the HH units.  Therefore, the medium-sized test objects for the HH units are the 22-caliber long rifle round and the handcuff  key, and for the WT units the medium-sized test objects are the #2 Phillips screwdriver bit and the handcuff key.

### 2.5.4  Small-Sized Test Objects (HH Only)

The small-sized test objects are the smallest metal objects that have been defined by the LEC agencies as security or safety threats.  These items include metal paper clips, metal pen clips, metal pen refills, metal blades from disposable razors, and hypodermic needles of disposal syringes.  As with the medium-sized test objects, the number of tests required to assess the HH detection performance using these test objects is costly.  Therefore, only the worst case threat items are used for the test method of the NIJ Standard.

The pen refill is typically made of brass and the pen clip of steel.  Since both objects are about the same width and thickness (when the refill is flattened) and both can be made to be the same length, the material properties dictate which object to use (see sec. 3.2.1).  The pen refill will be harder to detect than the pen clip because of its material properties; therefore, the pen clip is not used in the tests.  The paper clip, because of its mass and thickness, is expected to be more easily detected than is the blade from the disposable razor (materials of both objects have similar electric and magnetic properties); this expectation was verified experimentally in a laboratory using sensitivity-adjustable HH units.  Therefore, the paper clip is not used as a test object.  The relative detectability of the pen refill and razor blade varies with orientation of these objects within the magnetic field, so replicas of both of these objects are used as test objects.  In addition, the hypodermic needle from the disposable syringe is used as the ideal test object.  However, this item is not a mandatory small-sized test object but an optional one.

### 2.5.5  Innocuous Item Test Objects (Large-Sized and Medium-Sized Objects)

The innocuous items are defined in section 5.4 of the NIJ Standards as being reduced scale replicas of the test objects used for either medium-sized or large-sized object tests.  The purpose of the innocuous item test objects is to demonstrate discrimination.  For example, if the LEC agency is maintaining the security at a courthouse, large knives and handguns are forbidden but other metal objects, such as paper clips and pens, are not forbidden.  Discrimination allows the operator of the HH or WT to find the target items (handguns and knives) and not the innocuous items.  Without discrimination in this situation, the operator would have to address everyone entering a courthouse that carried any metal object on their person, and this would cause excessive delays.

To prevent providing information that can be useful to ill-intentioned people, the innocuous item devices will be limited.  Only one innocuous item each will be used for medium-sized and large-sized object tests.  For the medium-sized objects class, the innocuous item test object applies only to the HH units and is the replica of the brass refill, which is a small-sized test object.  For the large object size class, the innocuous item test object is a 0.75 scaled replica of the knife and is constructed of nonferromagnetic stainless steel.

## 2.6  References

The NIJ Standards include a number of references to other agency provisions, comprised of standards and test methods developed by other qualified scientific organizations, which are incorporated by reference into the Standards.  This eliminated the need to restate standards and test methods that have already been developed and adopted by the scientific community.

# 3. PRINCIPLES OF OPERATION

This section of the guide is intended to provide the reader with technical information on the operation of hand-held and walk-through metal detectors used in law enforcement and corrections applications. This section is written so that the reader can easily choose the amount of technical detail desired. The subsections, sub-subsections, etc., contain increasingly more detail. **Therefore, if just cursory information is desired or required, the reader should read only those sections labeled with single numeric characters in this section ("3.1," "3.2", "3.3," and "3.4").** The more interested reader can read sections labeled with multiple numeric characters ("3.2.3," "1.2.4.3," etc.). **Bolded text indicates important concepts.**

There are a number of commercially available hand-held (HH) and walk-through (WT) units that are used for concealed weapon detection (see list in sec. 7). There are also extended-arm type metal detectors that are used by correction agencies to find metal items buried under the ground or hidden around the grounds of a facility. The extended-arm metal detector is the same type of metal detector typically used in treasure hunting. These three different forms of metal detectors are shown in figure 4. For brevity and because the extended-arm and HH metal detectors function similarly, the extended-arm and HH detectors will be combined for this discussion and referred to as HH metal detectors. All of the HH units and all but one model of WT unit, at the time of this writing, use active-illumination techniques to detect a metal object. Active illumination means here that the detector sets up a field and this field is used to probe the environment. The HH and WT units create and detect magnetic fields and, therefore, contain

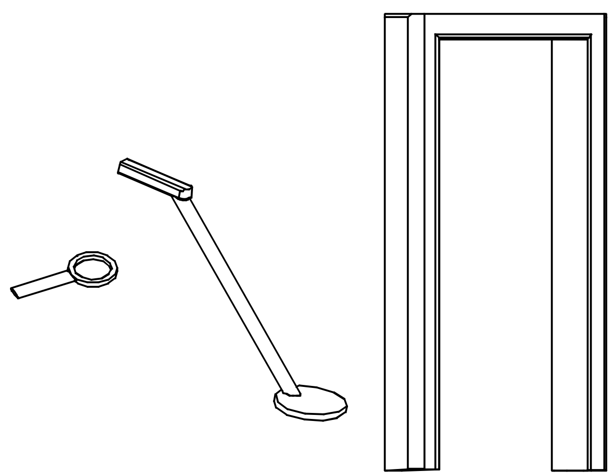

***Figure 4. Different forms of metal detectors (the form on the far left is a hand-held type device, the form in the middle is an extended-arm type device, and the form on the right is a walk-through type device*)**

subsystems for creating and detecting magnetic fields (see fig. 5). An object is detected if the magnetic field of the HH or WT unit interacts with the object and if the sensor part of the HH and WT units can then detect this interaction. **The object must be electrically conductive (see sec. 3.2.1.1) or magnetizable (see sec. 3.2.1.2.2) for the HH or WT unit to detect the object**. Other aspects of the object are also important to detection and will be discussed later.

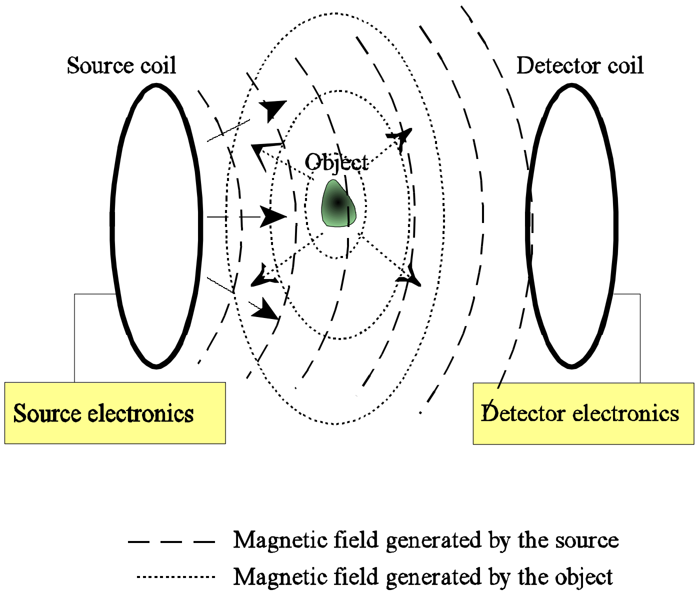


***Figure 5. Diagram of a metal detector with an object inside the detection space***

The purpose of this section is to describe, in general terms, how the HH and WT metal weapon detectors work. This section explains how a magnetic field is generated (see sec. 3.1), how an object interacts with the generated magnetic field (see sec. 3.2), how the object is then detected (see sec. 3.3), and how electromagnetic interference affects performance of the HH and WT units (see sec. 3.4).

### 3.1 Generation of a Magnetic Field

**There is a magnetic field associated with electrical current (flow of charge) in a wire. The magnetic field produced by the current in a straight wire exists in the space surrounding the wire and is represented graphically by the circular line as shown in fig. 6. Winding the wire into a coil concentrates the magnetic field produced by the current. The magnetic field of the HH and WT units is produced by passing an electrical current through a coil of wire. The circles (contour lines) that wrap around the wire represent the magnetic field intensity; the farther away these circles are from the wire, the weaker is the magnetic field.** The magnetic field does not change abruptly at these contour lines but varies gradually. These lines

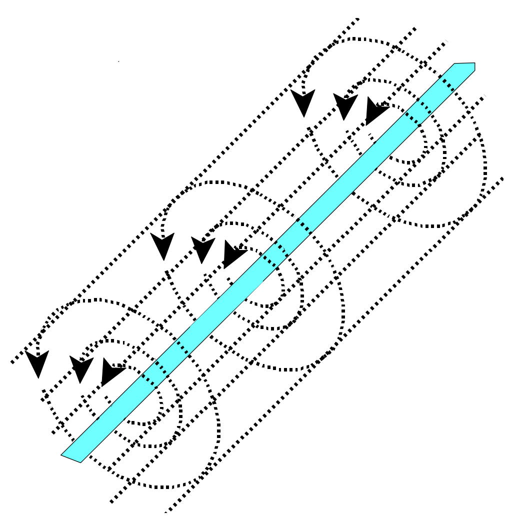

***Figure 6. Magnetic field lines around a current carrying wire wrap around the wire***

can also be  presented as shading (see fig. 7) and are similar to the lines on a topographical map that shows elevation variations.  The circuit and coil for generating the magnetic field is called the source.  Figure 8 shows how the intensity of the magnetic field drops off as you move away from the source coil.   We can see from figure 8 that the field strength drops off very quickly.  The direction and intensity of the magnetic fields around a circular loop of wire, similar to the source and sensor coils in WT and HH units, are shown in figures 9 and 7.  Note how the direction (from the arrows in fig. 9) and intensity (from the gray-scale plot in fig. 7) of the magnetic fields change with position between the source and detection coils.

### 3.2  Interaction of an Object With the Magnetic Field

**The magnetic field of an HH or WT unit varies with time, as described in section 3.3.1.  This time-varying magnetic field has associated with it an electric field (see sec. 6, refs. 9 and 10 for more information) and the magnitude of this accompanying electric field is proportional to the rate at which the magnetic field changes. The object may interact with the magnetic field directly or it may interact with the associated electric field.**

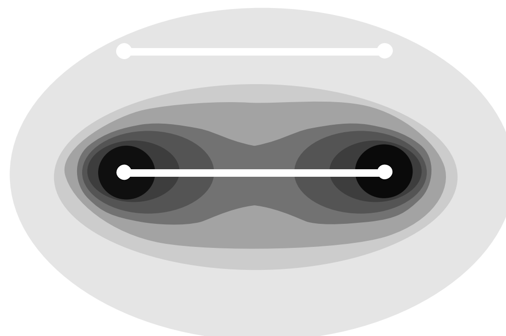

***Figure 7.  Intensity of the magnetic field between and around the source (depicted by the lower horizontal line) and sensor (upper line) coils; darker areas indicate higher magnetic field intensity.***

**The magnetic field produced by the source may interact with a nearby object.  The**

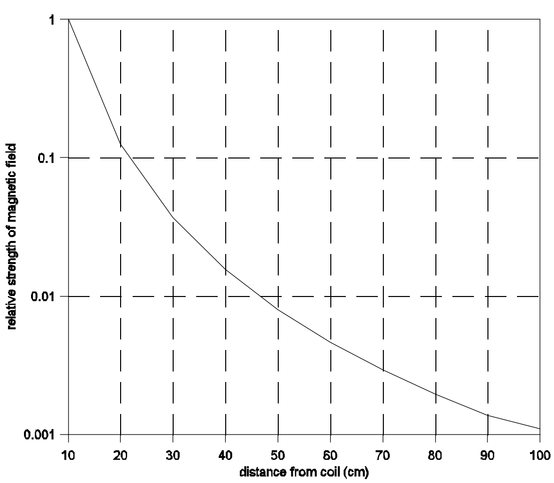


***Figure 8.  The intensity of the magnetic field at various distances from the source coil***

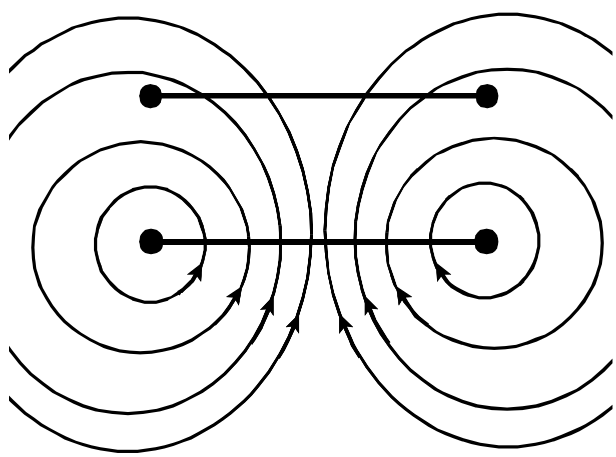

***Figure 9.  Direction of the magnetic field between the source and sensor coils (the source and sensor coils are depicted by the lower and upper horizontal lines)***

**type and strength of this interaction depends on the type of material that the object is made of (see sec. 3.2.1), the size (sec. 3.2.2) and shape (sec. 3.2.4) of the object, the orientation of the object in the magnetic field (sec. 3.2.3), the speed of the object through the magnetic field, etc.), and other less important factors. The sensor electronics of the HH or WT unit (see fig. 4) responds to the interaction of the object with the magnetic field and this provides a detection signal. This signal indicates whether an interaction took place. If the signal is large enough, it may cause the HH or WT unit to alarm. The strength of the interaction may be determined from the alarm if the HH or WT unit is equipped with a proportional alarm indicator.**

### 3.2.1 Object Material

Each material has a unique set of electromagnetic properties. Therefore, a group of objects that are identical (shape, size, etc.) except for their material composition will each have a unique signal. That is, the interaction between the object and the source magnetic field will be different for each object. Two characteristics of the material that will determine the strength of the interaction are the electrical conductivity (sec. 3.2.1.1) and the magnetic permeability (sec. 3.2.1.2) of that material. The electrical conductivity and magnetic permeability of an object allow two different paths for interactions with the magnetic field and these interactions may be sensed by the HH and WT units.

#### 3.2.1.1 Electrical Conductivity

The electrical conductivity describes the ease at which electrical charge can move (or flow) in a material. A material that allows electrical charge to flow is called a conductor. For metals, the electrical charge is carried by electrons. In certain solutions, like salt water, the electrical charge is carried by ions. To get an idea of the variation in the electrical conductivity of different materials, see table 1. The units of conductivity are Siemens per meter (S/m). The electrical conductivity of human tissue is about 0.5 S/m.

The flow of electrical charge in a conductor is analogous to water flow in a pipe: the higher the conductance of a pipe, the easier it is for water to flow in the pipe. It does require, however, a force to make the water flow. Similarly, for an electrical charge to flow in a conductor requires an external force. Again, a comparison can be made to water flow: water flows through a pipe because pressure is applied to one end of the pipe and not the other end; pressure exerts a force on water causing it to move. The analogous quantity to pressure for electric charge is voltage, such as the voltage at the ac outlets in our homes. The movement of electrical charge is called an electrical current. The time-varying magnetic field produced by the HH and WT units also exerts a force that can cause charge to flow. The flow of electrical charge caused by the magnetic field is called an eddy current (see sec. 3.2.1.1.1).

*Table 1. Electrical conductivity of some materials (see sec. 6, ref. 9)*

| Material | Conductivity (S/m) |
|---|---|
| copper | 57 000 000 |
| aluminum | 35 000 000 |
| brass | 11 000 000 |
| lead | 5 000 000 |
| stainless steel | 2 000 000 |
| cast iron | 1 000 000 |
| graphite | 100 000 |
| sea water | 4 |
| distilled water | - 0.0001 |
| bakelite | - 0.000 000 001 |
| glass | - 0.000 000 000 001 |
| diamond | - 0.000 000 000 000 1 |
| air | 0. |

#### 3.2.1.1.1 Induced Eddy Current

The magnetic field of the source may cause (or induce) charge to flow in a nearby conductive object; this induced current is called an eddy current. The magnitude of the induced current is dependent on the object's electrical conductivity (and other properties). However, not all magnetic fields can induce an eddy current; the magnetic field must be changing with time, similar to how the ac voltage in our homes changes with time (see fig. 10). (The reason the voltage in our homes is called ac, or alternating current, is because it alternates or changes with time). If the magnetic field did not change with time, no eddy currents would be induced in the object. The eddy currents induced in an object by the external magnetic field can themselves produce magnetic fields that can interact with other objects. **These eddy-current-induced magnetic fields are called secondary magnetic fields and may be detected by the HH and WT units (see sec. 3.2.1.1.2).** Furthermore, the process of inducing an eddy current in an electrically conductive object by the source magnetic field will affect the operation of the source electronics. **This source-circuit-related effect may also be used by the HH and WT units to detect the presence of an electrically conductive object** (see sec. 3.3.2.4).

The magnitude of the eddy current that is induced in the object by the source (or primary) magnetic field is dependent on the electrical conductivity of the object. A very poor conductor, such as graphite, will support only a very small eddy current. On the other hand, a very good conductor, such as gold, silver, aluminum, or copper, can support a much larger eddy current.

The magnetic permeability (see sec. 3.2.1.2) also affects the magnitude of the induced eddy current. The effect of the permeability, in this case, as compared to magnetizing the object (see sec. 3.2.1.2.2), is to alter the magnitudes of the magnetic field inside the object. Larger permeability values (see table 2) mean larger eddy currents.

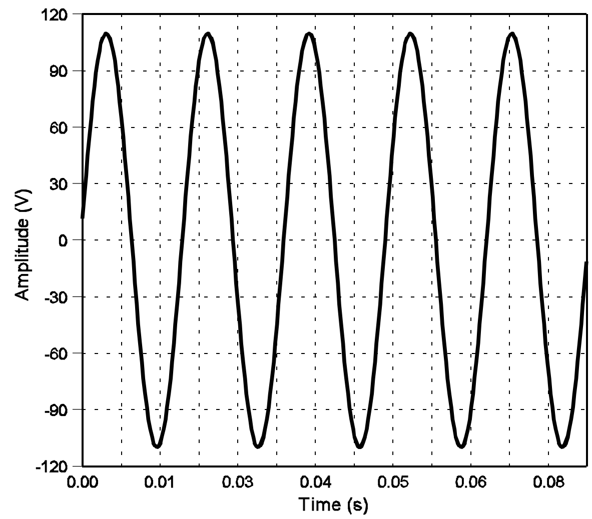


***Figure 10. 60 Hz ac voltage present at outlets***

#### 3.2.1.1.2 Secondary Magnetic Field

The magnetic field generated by the source is called the primary magnetic field, and the primary magnetic field can induce an eddy current in an electrically conductive object. The eddy currents that are induced in the object can also generate a magnetic field, and these magnetic fields are called secondary magnetic fields. These secondary magnetic fields also can induce currents in other electrically conductive objects, for example the sensor coils in a HH or WT unit. **Consequently, the secondary magnetic fields may be detected by the HH and WT units and this will provide an indication of the presence of a metal object.** The primary magnetic field and the change in the primary magnetic field due to the presence of a magnetizable and/or electrically conductive object may also be simultaneously detected by either a HH or WT unit (see sec. 3.3.2).

### 3.2.1.2 Magnetic Permeability

So far, we have seen how the object's electrical conductivity can affect the eddy current induced in the object. We have also noted that the magnetic permeability will affect eddy current generation. In addition to these eddy-current interactions, the magnetic field can also interact with an object by magnetizing the material that makes up the object (sec. 3.2.1.2.2). Magnetization may last only for as long as the object is in a magnetic field or it may last for a long time after being removed from the magnetic field (such as in permanent magnets, like the ones found on many refrigerator doors). How long a material stays magnetized depends on certain properties of the material (not discussed here). How an object gets magnetized is discussed in sec. 3.2.1.2.2. The degree to which a material can be magnetized is dependent on its permeability. A common way to compare the ease or strength of magnetization of a material is through a parameter called the relative permeability (sec. 3.2.1.2.1). The HH and WT units may sense the magnetic interaction of the object with the primary magnetic field (see sec. 3.2.1.2.4).

The magnetic properties of a material are dependent on moving electrical charges. Whereas the flow of electrical charge through an area is dependent on conductivity, the magnetization of an object is not dependent on charge flow. What is required is that the charge be moving and that this motion be rotation around another object and/or spinning on its own axis (see sec. 6, refs. 11, 12, and 13 for more detailed information).

### 3.2.1.2.1 Relative Permeability

The reference for relative permeability is a vacuum because a vacuum has no particles that can interact with the magnetic field: the relative permeability of a vacuum is 1. Air has a relative permeability of 1 because there are so few particles (molecules, atoms, etc.) that can interact with the magnetic field. Relative permeability values can be slightly less than 1 (for what is called diamagnetic materials), slightly more than 1 (for paramagnetic materials), and much greater than 1 (for ferromagnetic materials). For this application, if a material behaves like air in terms of its permeability, then a magnetic field will not measurably magnetize the material. Table 2 lists some materials and their relative permeability values. When the relative permeability of a material is much larger than 1, then the material will noticeably affect the generated magnetic field.

Common magnetic materials are metals or materials that contain metal atoms, and in these materials the magnetic properties are the result of electron interactions within the material. There are many different ways that the electrons may interact with each other in a material, and this is the basis for magnetic-based classification of materials (see far right column in table 2). Ferromagnetic materials possess domains (see sec. 3.2.1.2.2) that allow objects made from these materials to strongly interact with an externally-applied magnetic field (like those magnetic fields produced by HH and WT units). The other types of magnetic materials (see table 2) weakly interact with an applied magnetic field and, therefore, will not be discussed further.

### 3.2.1.2.2 Magnetizing an Object

The magnetization of a ferromagnetic object occurs because the object consists of very small (microscopic) magnetic domains that can be affected by the presence of a magnetic field. Think of these domains like miniature bar magnets suspended in a bowl (see fig. 11). In figure 11, the bowl plays the part of the object, and the black and white rectangles play the part of the magnetic domains (or mini-magnets). The poles of these mini-magnets are represented by the dark (north pole) and light (south pole) halves. If the orientation of all these mini-magnets is random, as is shown in figure 11, then the material is not magnetized. If the object (bowl) is placed in a magnetic field and the orientation of the mini-magnets is unchanged, then the permeability of the material is 1. On the other hand, if a few of the mini-magnets align so that the north poles point

***Table 2. Relative permeability and magnetic classification of some materials (see sec. 6, ref. 9)***

| Material | Relative Permeability | Classification |
|---|---|---|
| supermalloy | 1 000 000 | ferromagnetic |
| purified iron | 200 000 | ferromagnetic |
| iron ( 0.2 % impurities) | 5000 | ferromagnetic |
| mild steel (0.2 % carbon) | 2000 | ferromagnetic |
| nickel | 600 | ferromagnetic |
| cobalt | 250 | ferromagnetic |
| aluminum | 1.000 02 | paramagnetic |
| air | 1.000 000 4 | paramagnetic |
| vacuum | 1. | nonmagnetic |
| water | 0.999 991 | diamagnetic |
| copper | 0.999 991 | diamagnetic |
| lead | 0.999 983 | diamagnetic |
| silver | 0.999 83 | diamagnetic |

either up or down, then the material has a permeability close to 1. If the north poles of nearly all the mini-magnets point up, then the material has a very high permeability. The effect of high permeability is discussed in sec. 3.2.1.2.3.

Sometimes an object that has been exposed to a magnetic field will remain magnetized after being removed from the magnetic field or if the magnetic field is turned off. This happens, for example, when we place steel tools in contact with permanent magnets for a long time. We can reduce the magnetization of the tool if we disturb (rattle) the domains in the tool by, for

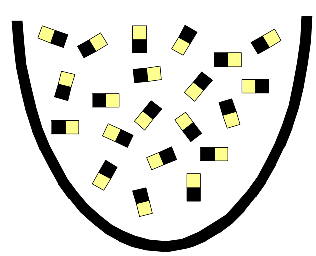

***Figure 11. Bowl of black and white rectangles where the bowl represents an object and the rectangles represent the magnetic domains within that object (which are shown to be randomly oriented)***

example, hitting the tool with a hammer. Materials in which the magnetic domains are always aligned are called permanent magnets.

#### 3.2.1.2.3 Effect of a High Permeability Object on a Magnetic Field

An object that has a relative permeability much greater than 1 can affect the source magnetic field in two ways. First, energy is required to align the magnetic domains of the object. This energy is taken from the source magnetic field and, therefore, less energy from the magnetic field is available to induce an eddy current in the object. However, a large relative permeability means that induced currents may be larger depending on the electrical conductivity of the object. An object made of a high permeability material will also distort the magnetic fields produced by the source, see figures 12 and 13.

#### 3.2.1.2.4 Secondary Magnetic Fields

Because the magnetic field from the source changes with time, the magnetic domains within the magnetized object can "relax" when the magnetic fields are turned off or reduced. Relax means that the domains return to the orientation they had before the magnetic field was turned on. In this process of relaxing, the magnetic field of the object gives rise to a secondary magnetic field. These relaxation-based secondary magnetic fields may be detected by HH and WT units just as the eddy-current-based secondary magnetic fields may be detected.

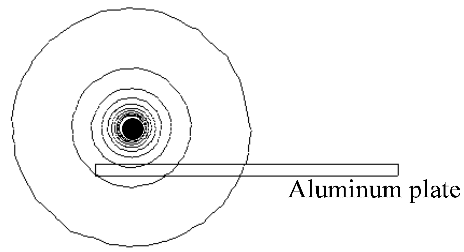


***Figure 12. Magnetic field lines around a wire conductor perpendicular to the page (dark circle) located next to an aluminum plate***

### 3.2.2 Object Mass

Each object, due to its mass alone, will have a unique signal. For example, a sugar-cube-sized or brick-sized piece of aluminum will not give the same signal. The brick-sized object will give a larger signal. However, two objects with the same mass and with the same material composition may cause different levels of response by a HH or WT unit because of structural or orientation differences (see sec. 3.2.3 and 3.2.4).

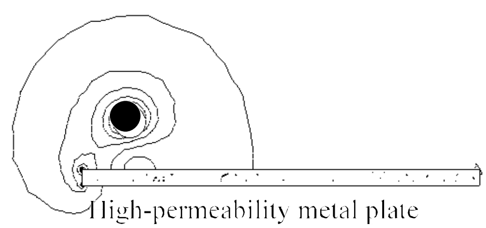


***Figure 13. Magnetic field lines around a wire conductor perpendicular to the page (dark circle) located next to a high-permeability metal plate***

### 3.2.3 Object Orientation With Respect to the Magnetic Field

Orientation of the object in the primary magnetic field has an effect on HH and WT detection performance because the source (primary) magnetic field is directional (see fig. 9). Directional means that the magnetic field at any selected location points in some specific direction. This direction is not necessarily up and down, or left and right. However, the direction can be broken up into up-down and left-right parts (or components). For example, pretend that the source was at the bottom left of a doorway and the field lines are pointing to the top right corner of the same doorway (see fig. 14). Although the field is directed diagonally, it can be described as first going over to the right and then going up. Breaking the field into vertical and horizontal components is important in understanding how the orientation of the object affects its interaction with the magnetic field.

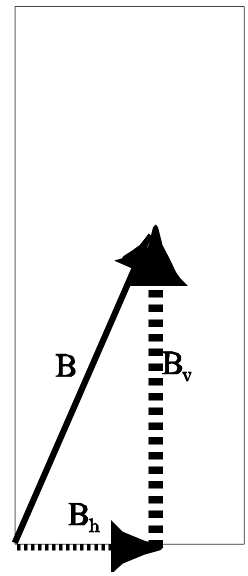


***Figure 14. Magnetic field (labeled by B) within a doorway where the source is at the bottom left corner, the magnetic field line is directed to the upper right corner, and the dotted lines represent the vertical ($B_v$) and horizontal ($B_h$) components of B***

The importance of object orientation in relation to the direction of the magnetic field is that, to induce a large eddy current, the magnetic field has to be perpendicular to a surface of the object. For example, if the magnetic field is directed into an edge of a metal plate, then the induced eddy current is small (see fig. 15). However, if the magnetic field is directed into the large surface of the metal plate, the induced eddy current will be large.

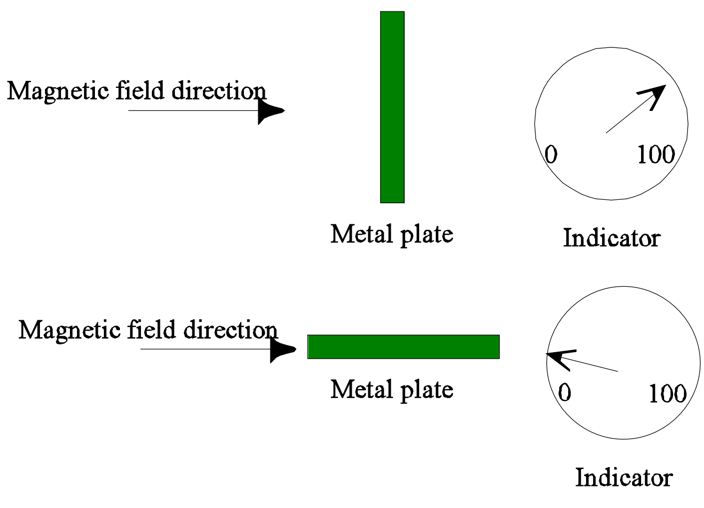


***Figure 15. Effect of object orientation and magnetic field on induced eddy current; the indicator shows how large is the induced eddy current***

### 3.2.4 Object Shape

The shape of an object will also affect detection. This is best described by using a few examples (secs. 3.2.4.1.1 and 3.2.4.1.2), but first we will show how the eddy current generation can be visualized (see fig. 16). In figure 16, the magnetic field lines are directed into the top of the plate (indicated by the crosses). Loops of eddy currents are generated around each cross and the direction of current flow is depicted by the arrows. The loops are square shaped to simplify this discussion. Imagine making these loops close, close enough so that the edges touch. Look at the squares labeled "a" and "b." The eddy currents on the right side of "a" are canceled by the eddy currents on the left side of "b" because the current charges are flowing in opposite directions. If we keep doing this cancellation of current for all loops, we find that only the currents around the edges of the plate will remain. The current that remains is the eddy current that is induced in the plate by the primary magnetic field. These eddy currents will generate secondary magnetic fields that may be detected by the HH and WT units. The magnitude of the eddy current that is generated will depend on the length of the eddy current path (sec. 3.2.4.1) and the conductivity of the material. It should be pointed out that this cancellation of current around the loops is a simplification. In reality, the current varies between the center of the plate and the edges of the plate, and this is dependent on the electrical conductivity of the objects and the frequency of the magnetic field.

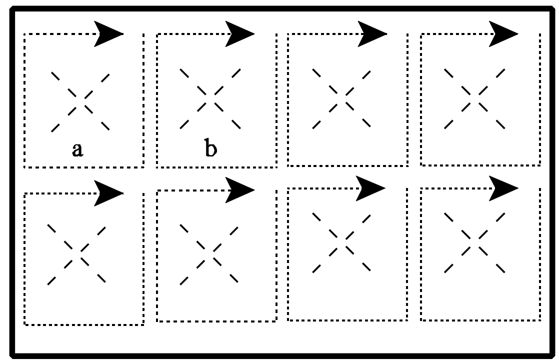


***Figure 16. Loops of eddy current generated in a plate of conductive material in the presence of a magnetic field. The magnetic field lines are directed into the block and are depicted by the "x"s, the plate is defined by the heavy solid line, and the eddy current directions are indicated by the dotted lines with arrows***

### 3.2.4.1 Eddy Current Path

The length of the eddy current path affects the magnitude of the observed eddy current because the eddy current loses power as it travels along its path. These losses are identical to losses caused by current flow through any resistive material. The greater the power losses, the smaller will be the eddy current. Two examples (secs. 3.2.4.1.1 and 3.2.4.1.2) will be given to help understand the effect of path length. The object shape also affects the magnitude of the induced eddy current through an effect called the "skin effect" (sec. 3.2.4.2).

#### 3.2.4.1.1 Example of Two Plates

Consider two plates that have the same thickness and area but one is a round plate and the other a square (all sides equal in length) plate (see fig. 17). Also assume the magnetic field is perpendicular to the large surfaces and not the edges. The areas of the plates determine the total amount of interaction between the plate and the magnetic field. For these two objects the total interaction is the same because the areas are the same. However, we know the perimeter of the square plate is about 1.13 times greater than the perimeter of the round plate. Because the total magnetic field interaction is the same for the two plates but the current path is longer for the square plate than for the round plate, the detection signal will be larger for the round plate. Remember, the longer path length will have more resistance than the shorter path length and, therefore, lose more power (see sec. 3.2.4.1).

#### 3.2.4.1.2 Example of a Length of Wire and a Loop of Wire

Consider a wire hanging in the magnetic field. The eddy current path length is approximately two times the length of the wire. Now connect the two ends of the wire to form a loop and let the magnetic field be perpendicular to the loop. We get two induced currents for the connected wire, one of which is an eddy current and would give a signal similar to that of the unconnected wire. However, the other current contribution is caused by the magnetic field through the center of the loop and will be large; the loop is acting as an antenna, just like the coils in the HH and WT units. Therefore, the connected wire (loop) will cause the HH and WT units to have a much larger response than will the dangling wire.

### 3.2.4.2 Skin Effect

The magnetic field must change with time (see fig. 10) to generate an eddy current. However, the speed at which this magnetic field changes will affect the magnitude of the induced eddy current. This speed-related effect, which also depends on the conductivity of the material, is called the skin effect. The skin effect describes how deep the electromagnetic energy will penetrate into a material. Slow variations (low frequency) give rise to large skin depths and fast variations (high frequency) to small skin depths; high conductivities give rise to small skin depths and low conductivities to large skin depths (see fig. 18). For example, at 60 Hz (typical frequency used in the U.S. for electrical power) the skin depth in a copper conductor is about 8.5 mm (1/3 in). Since household wiring has a much smaller diameter than 8.5 mm, the current is carried fairly uniformly throughout the volume of the wire (such as shown in the right side of fig. 18). If household wiring was about an inch in diameter, the current would be primarily carried on the outer 8.5 mm of the wire and not in the center of the wire (as shown in the left side of fig. 18).

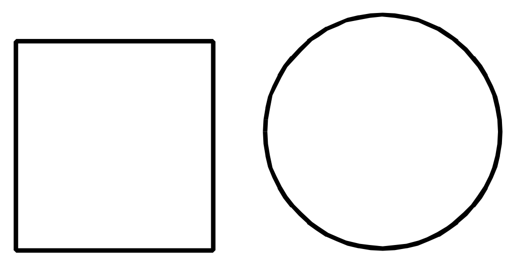

***Figure 17. A square plate and a round plate that have the same area***

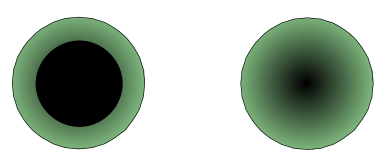

***Figure 18. Cross-sections of two identical conductive wires carrying current at two different frequencies where the conductor at the left is carrying the higher frequency (the density of the current is indicated by the shading: the lighter the shading, the higher is the current density)***

An eddy current at a given frequency and for a given material will be larger if the skin depth is less than the thickness of the object than if the skin depth is much greater than the object thickness. Smaller eddy currents mean less interaction of the generated magnetic field with the object and, therefore, lower detectability of the object. The skin depth in an electrically conductive material decreases as the operating frequency (see sec. 3.3.1) of the HH and WT increases, and for typical target items (handguns, knives, razor blades, handcuff keys) the magnitude of the induced eddy current will increase as the frequency increases. The increased eddy current will result in an increase in detectability of the object. Similarly, as the electrical conductivity of the object increases, the skin depth decreases, and the eddy currents increase. However, as the electrical conductivity increases beyond a certain value (dependent on many factors), the absorption of the primary field power caused by eddy current resistive losses (see sec. 3.2.4.1) will decrease. Consequently, the detectability of an object will first increase and then decrease as the electrical conductivity of the object increases. However, for most if not all the materials encountered by LEC officers, the increase in electrical conductivity of the object will result in an increased detectability of the object. To summarize, objects with high electrical conductivity will be easier to detect than objects with low electrical conductivity. Thin electrically-conductive objects are easier to find with HH and WT units operating at high frequencies than with units operating at low frequencies.

### 3.2.5 Effects of Other Metal Objects

The location of other metal objects, either innocuous items or other target items, near a target item (metal weapon or contraband item) may affect the detection of the target item. This effect will depend on the type of sensor circuitry (see sec. 3.3.2) and the type of source (see sec. 3.3.1) used by the HH and WT units. For example, the presence of a metal wall or metal floor (including steel reinforcing bars, or "rebar") will affect the ability to detect a target item. Metal walls and floors affect all HH and WT units. The effect of metal walls and floors is dependent on their proximity to the HH and WT units. A metal wall or floor may cause a very large response by the HH or WT unit if the wall or floor is nearby. If this large response is not compensated for by the HH or WT circuitry, this response will result in false-positives (or nuisance alarms, which causes an alarm even though there is no target item present). False-positives will reduce throughput. The sensor circuit may be designed to compensate for the presence of the large constant background level caused by the metal wall or floor. However, the sensor circuit must still possess appropriate characteristics that allow a very small object to be detected in the presence of the large background; otherwise, false-negatives (no alarm occurs even though there is a target item present) may occur, which would compromise security and the safety of the officers and others.

It is also possible for one (or more) metal object(s) to affect the detection of a target item by certain types of HH or WT units. The additional item (an innocuous item or another target item) may affect the detection of the target item either by absorbing the energy of the secondary magnetic field produced by the target item and/or by producing its own secondary magnetic field. However, the effect of absorption by one object, of the secondary magnetic fields generated by another object, will have a negligibly small effect on detection performance.

#### 3.2.5.1 Multiple Object Interference

Multiple object interference (also called metal cancellation) is the result of the detection method and the analysis used to obtain an alarm from the data. Metal cancellation may occur, for example, when two objects made of dissimilar metals are passed through the portal of a WT unit and are not detected. When this occurs, it is because the detection method or data analysis allows the unit to discriminate between metal types. Frequently this discrimination is adjustable so that manufacturers can calibrate their WT units to detect objects made of certain metals. This type of discrimination is used to reduce nuisance alarms (alarms caused by innocuous items) by focusing on objects made of materials that are typically used in the fabrication of threat items. However, this type of discrimination does allow the possibility that two threat items of dissimilar metals can pass through a WT unit undetected. Multiple object interference can also be caused when the secondary magnetic field that is induced by one object is masked by the presence of nearby objects. However, this effect on detection performance will be negligibly small.

### 3.2.6 Effects of the Human Body

The effect of the human body on the detectability of a target item is caused by the electrical conductivity of the human body (sec. 3.2.1.1). Because the human body (or any animal body) is electrically conductive, the magnetic field generated by the HH and WT device will interact with the human body just as it would any other electrically conductive object. This interaction will reduce the power of the magnetic field that actually reaches and can interact with the hidden target item and, therefore, reduce the detectability of such a hidden target item. Although some people may attempt to hide a target item from detection by placing the target item within a body cavity, under the arm, between the legs, etc., body concealment effects on detection performance will be small because of the relatively low electrical conductivity of the human body compared to that of metals. However, because of the body's electrical conductivity and size, the body may mask the presence of a small metal object, that is, the body may produce a detection signal larger than that from a very small metal object. The masking effect can be reduced by examining only a portion of the human body for the hidden or concealed object.

## 3.3 Detection

**As mentioned earlier, an object will be detected if the object interacts with the generated (primary) magnetic field and if the HH and WT unit can sense this interaction. The eddy currents induced in the electrically conductive object by the primary magnetic field will generate a secondary magnetic field that can be detected by the HH and WT units (sec. 3.2.1).** Similarly, the relaxation of the magnetization induced in the magnetizable object by the primary magnetic field will generate a secondary magnetic field that can also be detected by the HH and WT units (sec. 3.2.2). **Also, the operation of the source electronics may be**

**affected by the presence of an electrically conductive or magnetizable object, and this effect may be used to sense the presence of the object.**

**There are several methods of detecting an object, and these will be mentioned in sec. 3.3.2. These different methods are dependent on the types of sources and sensors that are used by the HH and WT units.**

The manufacturers of HH and WT metal detectors are sensitive about providing detailed information regarding the operation of their systems; therefore, this information will not be disclosed here. What is provided in this section is an informational overview.

### 3.3.1 Sources

The source may produce either continuous-wave (cw) or pulsed energy or power. A continuous wave source generates an unbroken repeating wave of electromagnetic energy (similar to that shown in fig. 10). The frequency of the repeats is called the information-carrying (or carrier) frequency. Continuous-wave (cw) sources can also be modulated; that is, some parameter of the cw signal can be forced to vary over time. A couple of examples of modulation are amplitude modulation (AM) and frequency modulation (FM). Modulation is accomplished using electronic circuits. In amplitude modulation, the amplitude of the cw signal is forced to vary with time. In frequency modulation, the carrier frequency is varied. Most modulation schemes were developed for communication and broadcast applications. The cw source can also be pulse modulated. In this case, the envelope looks like a rectangular pulse (see fig. 19). Pulse modulation is a type of amplitude modulation.

A pulse source generates pulses of electromagnetic energy. A pulse source should not be confused with a pulse-modulated cw source even though the pulse modulation envelope of a pulse-modulated cw source may look similar to the profile of the output of a pulse source. The output of a pulse source looks like that shown in figure 19.

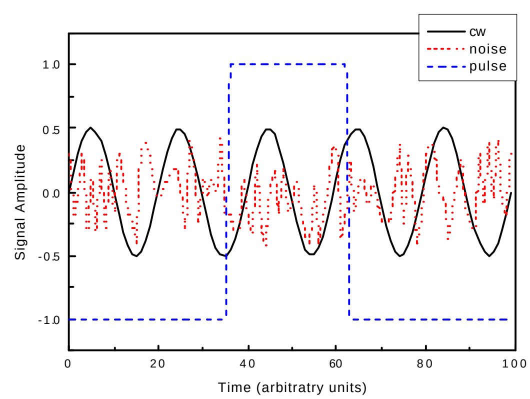


***Figure 19. The temporal (time) profiles of the output of three different sources: a pulse source, a continuous-wave (cw) source, and a noise source***

The type of source will affect the choice of circuitry that is used for metal object detection. To better understand and appreciate the differences between these different types of sources, the spectra of the output of these sources is required. A description of a spectrum is given in section 3.3.1.1.

#### 3.3.1.1 Spectrum

Everything we see occurs in the time domain. However, some things have a tendency to repeat themselves, such as sunrises and sunsets. Sunrises and sunsets are periodic events with a frequency of one occurrence per day. Periodic means that something is repeated at given intervals. The spectrum is a convenient tool that is used to examine the periodicity and consistency of a repeated event.

#### 3.3.1.1.1 Spectra of Pulse Source, CW Source, and Noise

The time history (or time record) of the outputs of pulse, cw, and noise sources are shown in figure 19. The noise source is shown because noise will have a bearing on the type of source to use. The spectra of these sources are shown in figure 20. What is important to note is the difference between the time records and frequency spectra of these different sources. The cw source has a very sharp line spectrum meaning that energy is available only at very distinct frequencies. Noise, on the other hand, has the same nominal energy for all the frequencies shown in figure 20. Pulse sources produce power over a band (range) of frequencies, somewhere between a line spectrum and a flat spectrum. The band of frequencies for the pulse spectrum is called the bandwidth.

### 3.3.1.2 Source Effects

The reason the source is important in the design of the HH and WT sensor circuits is because of the effects of noise. There are primarily two trade-offs when selecting a source: cost and noise immunity. For example, if a cw source is used and the sensor circuit does not restrict the input frequencies, then the signal contribution from the noise may dominate and the detection of a metal object will not be possible. Another way of saying this is that the input signal must be filtered tightly around the frequency of the cw source (see fig. 20) to reject the signal contribution from the noise. If the sensor circuit collected power from the entire frequency range indicated in figure 20, the total collected power would be dominated by the noise power. On the other hand, if the power was filtered around a frequency of 23 (units are not specified in the figure and for the purpose of this document are not necessary), then the dominant contributor to the total collected power would be the source and/or signal power. Filtering around a central frequency is called bandpass filtering. A pulse source produces a broad spectrum (see fig. 20) and a narrow bandpass filter may actually be detrimental. For the example in figure 20, with any bandpass filter centered around a frequency of about 18, the noise power would dominate the total collected

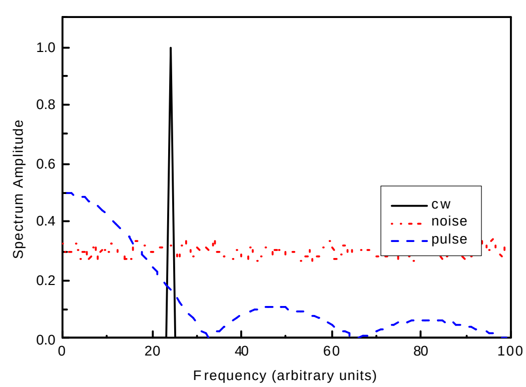


***Figure 20. The frequency spectra of three different sources: a pulse source, a continuous-wave (cw) source, and a noise source***

power.  The reason that a narrow bandpass filter may be detrimental when using a pulse source is that the energy of the pulse over a narrow frequency band may be less than that of the noise.  If the signal energy is less than the noise energy, an object will not be detected.  However, obtaining a very narrow bandpass filter is very difficult.

Typically, when a pulse source is used, the sensor is synchronously gated; that is, the sensor is turned off and on and this on-and-off operation is synchronized with the generated pulses.  The sensor is on just long enough to detect the response of any objects to the generated pulse.  Gating in the time domain is analogous to bandpass filtering in the frequency domain.  This will be discussed more in section 3.4.3.1.

### 3.3.2  Sensors

Sensors can be designed to detect changes in the following: a) the power of the primary magnetic field that arrives at the detection coil, b) the power of any secondary magnetic field that is generated and arrives at the detection coil, c) both (a) and (b), and d) any changes in the performance of the source electronics.  Detection methods (a), (b), and (c) are direct detection methods and (d) is an indirect method.  The sensor can detect these powers directly or indirectly. In the direct case, the sensor circuit contains a sensor that detects the magnetic field power and a circuit to analyze the sensor output.  In the indirect case, the sensor circuit and the source circuit make up a special type of circuit, and the properties of this special circuit are affected by the presence of an electrically conductive and/or magnetizable object.

#### 3.3.2.1  Primary Magnetic Field Power

The sensor can be designed so that it detects changes in the magnitude of the primary magnetic field that arrives at the detection coil.  Consequently, any object that affects the magnitude of the primary magnetic field may be detected, and it does not matter if the object interacted via its conductivity, permeability, or both.  However, the secondary magnetic field will also be detected by the sensor and this affects the quality of the signal.  If this type of sensing is used, it will probably be done with a continuous-wave source.

#### 3.3.2.2  Secondary Magnetic Field Power

The sensor may be designed to detect only the secondary magnetic fields produced by the object. This would typically be done in pulse systems because it is necessary to differentiate between the primary and secondary magnetic fields.  A rough description on how the HH and WT units can be made to differentiate between the primary and secondary magnetic fields depends on using gating as described in section 3.3.1.2.  A procedure that allows the primary magnetic field to be ignored is the following.  While a pulse is being generated from the source, the sensor is turned off. Recall, the pulse source generates pulses of magnetic fields at a given rate or frequency (see sec. 3.3.1).   After the pulse is over, the sensor is turned on and information (the signal) is collected by the sensor.  The sensor is then turned off before the source generates the next pulse.

This process, described very simply here, allows the HH and WT units to ignore the generated (primary) magnetic field pulse and sense only the secondary magnetic field pulse.  As mentioned earlier, the secondary magnetic fields are produced by the eddy currents in the object and by the relaxation of the induced magnetization of the object.

#### 3.3.2.3  Primary and Secondary Magnetic Field Power

The sensor of the HH and WT units can also be designed to detect both the primary and secondary magnetic fields.  This case is a bit more complicated than the other two methods, but it has greater potential for finding an object than using either the primary or secondary magnetic fields alone.

#### 3.3.2.4  Circuit Properties

As mentioned earlier, the sensor can be designed to provide indirect detection of an electrically conductive or magnetizable object placed in the primary magnetic field.  In this situation, the sensor and sensor circuits make up a special circuit, such as a resonant circuit, that is affected by electrically conductive or magnetizable objects.  A resonant circuit is a circuit that can either store or deliver energy over very narrow frequency ranges.  The frequency range has a central frequency, or resonant frequency, and upper and lower frequency bounds.  The amount of energy that can be stored and delivered is dependent on what is called the quality or “Q” factor of the circuit.   The presence of an electrically conductive or magnetizable object within the detection space of a HH or WT unit causes the resonant frequency to shift and the Q to change.  Sensor circuits can be designed to be very sensitive to changes in the resonant behavior of a resonant circuit.  Typically, this type of detection will be performed with a cw source.

## 3.4  Electromagnetic Interference

**Electromagnetic interference (EMI) will affect detection performance of a HH or WT unit. EMI can come from someone "keying" a walkie-talkie, an electric motor, fluorescent lighting, radios, other HH and WT units, etc.   Furthermore, HH and WT units also will affect the performance of other electronic devices, including each other, by generating electromagnetic radiation.  Therefore, it is necessary to know the sources of EMI that can affect HH and WT unit performance, how the HH and WT sensors and sources are affected by EMI, and how EMI effects can be reduced.  A definition and description of EMI is given in section 3.4.1.**

### 3.4.1  Definitions

Electromagnetic interference (EMI) is a term that is used to describe the following:  a) the effects that unwanted electromagnetic energy have on an electronic system, and b) the capability of an electronic system to generate electromagnetic energy that can affect the performance of other electronics.  When we are talking about the EMI generated by an electronic system (such as a HH or WT unit), we are talking about emissions; when we are talking about the effects that EMI can have on an electronic system (for example, HH or WT units), we are talking about susceptibility. EMI can also be radiated or conducted. Therefore, we can have conducted emissions, radiated emissions, conducted susceptibility, and radiated susceptibility. Conducted EMI is interference that travels along wires, such as power lines. For example, when a television is turned on it will generate EMI that is returned back along the power line. Radiated EMI is the interference that propagates through the air.

### 3.4.2 Sources of EMI

EMI can come from someone "keying" a walkie-talkie, an electric motor, fluorescent lighting, radios, other HH and WT units, etc. Basically, anything that can produce or use electromagnetic energy is a source of EMI. Whether or not the HH and WT unit is affected by (is susceptible to) the electromagnetic energy is dependent on the design of the HH and WT units, on the power of the EMI, etc. The HH and WT unit can also be a source of EMI for other electronics, such as a radio, a computer, etc.

### 3.4.3 HH and WT Units

**WT units generate and are susceptible to conducted and radiated EMI. HH units are susceptible to and generate radiated EMI.** Therefore, the emissions from the WT and HH units must be controlled, and this is accomplished by following established guidelines or standards. These standards and guidelines are usually written by international technical organizations and prescribe limitations on the energy that can be generated by an electronic system or device. Reduction of generated EMI can be accomplished through circuit design and shielding.

The performance of HH and WT units may also be affected by EMI. The EMI may result in false-positives, which result in additional traffic delays, and false-negatives, which result in unsafe situations and compromised security. The way to improve EMI resistance (or equivalently, to decrease EMI susceptibility) is to design EMI-resistant circuits. The susceptibility to EMI also has established standards and guidelines. The international technical guidelines prescribe EMI power thresholds below which the electronics system should not be affected.

Some WT units reduce the incidence of false-positive detection caused by EMI through the use of infrared sensors. These sensors detect the presence of an individual within the portal of a WT unit. The alarm circuitry is disabled unless someone is present within the portal. However, this does not reduce EMI-caused false-positive detection while an individual is present in the portal. Furthermore, the operator must be alert to attempts to pass contraband through the WT unit before the alarm circuitry is activated by the infrared sensor.

#### 3.4.3.1 EMI and Source/Sensor Considerations

Since EMI is a form of noise, it is best to reduce EMI generation and susceptibility. The optimal choice of a source/sensor pair for low EMI generation and susceptibility will be dependent on many factors, most importantly, on circuit design. A figure of merit for detectability is the signal-to-noise ratio (SNR). The SNR is the ratio of the power of the ideal noise-free signal to the power of the noise. The higher the SNR the more likely a signal will be detected.

The decision to choose between a pulse source or a cw source is affected by a number of parameters, including the SNR (see sec. 3.4.3.1.1). An advantage of using a pulse source instead of a cw source is that stable cw sources are typically more expensive than pulse sources, and stability of the output power and frequency is more important for cw sources than for pulse sources. However, depending on the circuit design, overall noise may be much lower in a narrowband cw system than in a broadband pulse system.

#### 3.4.3.1.1 Signal-to-Noise Ratio

The source affects the SNR of the HH and WT units because the power detected by the sensor (see sec. 3.4.3.1.1) is dependent on the power generated by the source. The more power generated by the source, the more power is available for interaction with objects in the detection space and, consequently, the larger the induced eddy current and/or magnetization. Pulse sources produce peak powers that are much greater than the average power of cw sources. However, the average power of the pulse source is typically much less than the average power of the cw source. So, if the sensor circuit is allowed to collect the signal continuously (the sensor is always on), then a cw source is preferred because the signal from HH or WT units using a pulse source will have a much lower SNR than the signal from HH or WT units using a cw source. However, if the sensor circuit is turned on only for a short duration (see sec. 3.3.1), then the HH or WT units using the pulse source will provide much larger SNR than the HH or WT units using a cw source.

# 4. USER TRAINING GUIDE

The following is a description of general training guidelines for both HH and WT unit operators (screeners) and screener supervisors. This section is intended only to be a guide to help define the information content of a formal training program that should be implemented by an LEC agency. Formal training is also available through the Air Transport Association of America (ATA) and is basically a training program that was developed for air carriers in conjunction with the Federal Aviation Administration (FAA). To obtain training from the ATA, a formal request (on agency letterhead) must be submitted to the ATA who will then obtain clearance from the FAA. According to both the FAA and the ATA, a request to obtain training by a valid LEC agency will not be denied. The ATA's address and phone number is:

Air Transport Association of America
1301 Pennsylvania Avenue, NW
Washington, DC 20004
Phone: 202–626–4000

The suggested training regime that will be described later in this section can be obtained through the ATA. These training recommendations are general and can be applied to both LEC personnel and contract personnel. Although cabinet x-ray systems are commonly found in LEC security checkpoints, x-ray systems are not mentioned in these recommendations because this guide is not intended to be a guide for cabinet x-ray machines.

The American Society for Testing and Materials (ASTM) has a published guide for the qualification, selection, etc., for personnel using hand-held and walk-through metal detectors that can be used to supplement formal training or to supplement the recommendations given here. The document is entitled *Standard Guide for Qualification, Selection, Training, Utilization, and Supervision of Security Screening Personnel*, Designation: F1532–94 and is available from the ASTM:

American Society for Testing and Materials
100 Barr Harbor Drive
West Conshohocken, Pennsylvania, USA 19428–2959
Phone: 610–832–9585

This ASTM guide provides suggestions regarding various personnel considerations, such as qualification, background, etc. In addition, factors that may affect job satisfaction and performance are also mentioned. These factors include training, comfort at station, compensation, recognition, supervision, recommended duty rotation, etc. It is recommended that the LEC agencies review this document, especially if an agency does not have a formal quality management structure in place.

### 4.1 General Considerations

All persons responsible for performing screening functions, including employees of companies under contract to furnish such services to LEC agencies, should be trained in proper screening techniques, physical inspection, and use of metal detectors. In addition to the primary security objectives, the training should emphasize the need for courteous, vigilant, and efficient application of screening procedures.

The training should be presented in a formal manner with ample opportunity for questions and answers. LEC agency supervisory personnel should, to the extent practical, monitor all training to assure the adequacy of such training, and, where practical, a senior management official should participate to emphasize management interest and concern.

Initial training for screeners of all levels is described in section 4.2, and topics pertinent for supervisory level screeners are given in section 4.3. Recommendations for course content for initial training of screeners are given in section 4.4, for refresher courses in section 4.5, and for supervisory screeners in section 4.6. The following are recommendations for training, and each LEC agency should tailor the training procedures for agency-specific requirements.

### 4.2 Initial Training

No person should be allowed to perform any screening function that requires the exercise of his/her independent judgment regarding access, by property or others, to any area beyond the screening point unless that person has received formal training and on-the-job training in the quantity and the manner described below, has satisfactorily demonstrated the ability to detect test objects under realistic conditions, and has the ability to explain the elements that resulted in such detection. Initial training includes the following:

1. Not less than 12 h of initial instruction covering the subjects listed in section 4.4 with emphasis on special screening situations and screening equipment operation. The instruction should include weapons and dangerous devices guidelines and person/property screening procedures.

2. Written testing to determine whether the trainee has assimilated the classroom portion of the initial training.

3. Following successful completion of the written testing, the trainee should undergo a formal on-the-job training (OJT) program, which should include the following:

    a. Work with and under the close supervision of fully qualified screeners to further familiarize themselves with screening equipment, procedures, and duties. During this OJT period, the trainee should not make independent judgments as to whether persons or property may enter a sterile area without further inspections.

b. The successful detection, individually, of each agency-approved test object (appropriate for the equipment in use at the checkpoints) at which the screener is to be employed, under realistic conditions as described below. The individual should explain the recognition factors applied in detecting the objects before he/she may be considered to have successfully completed this phase of initial training.

4. The LEC agency should ensure that the performance of new screening personnel is observed and checked during their first 40 h of duty by a supervisory-level individual to verify that each screener knows and understands the job requirements and procedures and to provide instruction and practical guidance to them as appropriate. The agency should annotate the screener's training and qualification records with significant observations made and deficiencies noted.

### 4.3 Selection, Training, Testing, and Certification of Screening Supervisors

1. No person should be used to perform the duties of a Screening Supervisor (SS) unless that person meets the basic requirements for screening personnel (sec. 4.2).

2. The LEC agency should first select, train, and test the prospective SS as a fully qualified screener as prescribed above. Following selection, the prospective SS should be trained in accordance with this program before commencing his or her duties.

3. The LEC agency should, on a timely basis, train the SS in all LEC agency procedural changes regarding screening requirements or systems.

4. The LEC agency should provide recurrent training as prescribed below to the SS that is, at a minimum, at least identical to and at the same frequency as that afforded nonsupervisory screeners.

5. The LEC agency should, as part of the SS initial training and every 12 months thereafter, test the SS using a written examination to verify his/her knowledge of SS duties and responsibilities; and screening requirements, equipment, and procedures.

6. The LEC agency should maintain records of the individual's qualifying education and employment, initial and recurrent training, and testing.

### 4.4 Recommended Content for Initial Screener Training Course

The following are recommendations regarding the information that should be contained in a course designed to train an LEC officer (or contracted personnel) for screening.

1. The reason for screening.
2. The legal basis for screening.

3. The effectiveness of screening.
4. How checkpoint screening works.
   a. Agency responsibilities.
   b. How screening works.
      i. The sterile area.
      ii. Screening checkpoint plans.
      iii. How a screening checkpoint works.
      iv. Screening tasks.
      v. Screening supervisor.
      vi. The subject's rights.
5. The importance of the screener.
   a. Screener attributes.
   b. Tact, courtesy, and caution.
6. Identifying the threat.
   a. Potential weapons.
   b. Obvious weapons.
      i. Firearms and knives.
      ii. Explosive devices.
      iii. Test objects.
   c. Hazardous materials.
7. Screening the person.
   a. The walk-through metal detector.
   b. The hand-held metal detector.
   c. The consent search.
8. Screening atypical persons.
   a. Private screening.
   b. Law enforcement and corrections officers.
   c. Nonambulatory and other physically impaired persons.
   d. Dignitaries, VIPs.
   e. NonEnglish speaking persons.
   f. Elderly persons.
   g. Children in strollers.
9. Special situations.
   a. Classified or legally privileged documents.
   b. Religious articles.
10. Checkpoint specific instruction.
    a. Alarm procedures.
    b. Equipment operation.
    c. Agency procedures.
11. Screener test and evaluation.
    a. Qualifying score:  review any incorrect responses.
    b. Partially qualifying score:  remedial instruction, retest where necessary.
    c. Disqualifying score:  repeat entire training program.

## 4.5 Recommended Content for Recurrent Screener Training Course

The following are recommendations regarding the information that should be contained in a refresher course designed to update and refresh an LEC officer's (or contracted personnel's) skill in screening functions.

1. Annual review.
2. Brief screeners on new threat information.
3. Review pertinent security experience and applicable security incidents.
4. Review basic screening procedures and techniques.

## 4.6 Recommended Content for Screener Supervisor Training Course

The following are recommendations regarding the information that should be contained in a course designed to teach an LEC officer (or contracted personnel) supervisory screening functions. This training program should encompass at least 8 h of classroom and on-site instruction in addition to the initial screener training specified in section 4.2.

1. The screener supervisor.
2. The supervisor's job responsibilities.
3. Exceptional screening and special situations.
   a. The subject's rights.
   b. The consent search.
   c. Authorized armed individuals.
   d. Private screening.
   e. Contraband.
4. Equipment testing responsibilities and techniques.
   a. The walk-through metal detector field test and calibration.
   b. The hand-held metal detector.
   c. Reporting equipment deficiencies.
5. Record keeping.
   a. Operator logs.
   b. Walk-through metal detector test logs.
   c. Incident logs.
   d. Screener training records.
6. Conflict avoidance and problem resolution.
7. Working with management.
   a. Knowing your responsibilities.
   b. The information chain.
8. Incident management.
   a. Detaining persons.
   b. Weapons guidelines.
   c. Interviewing witnesses.

    d. Collecting evidence.
    e. Incident reports.
9. Screening supervision.
    a. The team concept.
    b. Review of positions.
    c. Rotation of screeners.
    d. Supervision of OJT training.
    e. Observation of screeners.
10. Motivational techniques.
11. Station specific instruction.
    a. Alarm procedures.
    b. Station chain of command.
    c. OJT practices.
    d. Duty hours.
    e. Assignment rotation.
    f. Rest breaks.
    g. Scheduling practices.
    h. Inspection procedures.
12. Supervisor test and evaluation.
    a. Qualifying score: review any incorrect responses.
    b. Partial qualifying score: remedial instruction and retest where necessary.
    c. Disqualifying score: repeat entire training program.

# 5. GENERAL INSTALLATION PROCEDURES

The American Society for Testing and Materials (ASTM) has a published guide for the installation of walk-through metal detectors. The document is entitled *Standard Guide for Installation of Walk-through Metal Detectors*, Designation: C1238–93 and is available from the ASTM:


American Society for Testing and Materials
100 Barr Harbor Drive
West Conshohocken, PA 19428–2959
Phone: 610–832–9585


The general installation procedures should not supersede the specific installation procedures provided by the manufacturer. It should be used to supplement the manufacturer's procedures where they are lacking. Furthermore, certain sections of this ASTM guide, such as the appendices, may provide information about potential (yet avoidable) interference problems and also insight into the reason for specific installation considerations.

# 6. REFERENCES


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# 7. LIST OF DETECTOR MANUFACTURERS

The following is a list of manufacturers interested in selling to law enforcement and corrections agencies and that agreed to be listed herein. This list is arranged alphabetically and is based on the information available as of December 2000.

| MANUFACTURER* | HAND-HELD | WALK-THROUGH | STATE | PHONE NUMBER |
|---|---|---|---|---|
| Adams Electronics, Inc. | Y | N | OK | 580–233–6886 |
| CEIA | Y | Y | OH | 330–405–3190 |
| Control Screening, LLC | Y | Y | PA | 412–837–5411 |
| EG&G | Y | Y | CA | 310–816–1600 |
| Fisher Research Laboratory | Y | N | CA | 209–826–3292 |
| Garrett Metal Detectors | Y | Y | TX | 800–234–6151 |
| Heimann Systems | Y | Y | NJ | 908–603–5914 |
| Metorex | Y | Y | NJ | 609–406–9000 |
| Ranger | Y | Y | TX | 800–726–4388 |
| Rapiscan | Y | Y | CA | 310–978–1457 |
| Shielbel | Y | N | DC | 202–483–8311 |
| Sirchie Fingerprint Labs, Inc. | Y | Y | NC | 919–781–3120 |
| Torfino Enterprises, Inc. | Y | N | FL | 561–790–0111 |
| Vallon GmbH | Y | Y | CO | 303–933–7955 |
| White's Electronics, Inc. | Y | N | PA | 800–547–6911 |

*Identification of the companies in this table does not imply endorsement or recommendation of these companies or their products by the National Institute of Standards and Technology.

**U.S. Department of Justice**
**Office of Justice Programs**
810 Seventh Street N.W.
Washington, DC 20531

**Janet Reno**
*Attorney General*

**Daniel Marcus**
*Associate Attorney General*

**Mary Lou Leary**
*Acting Assistant Attorney General*

**Julie E. Samuels**
*Acting Director, National Institute of Justice*

**Office of Justice Programs**
**World Wide Web Site:**
*http://www.ojp.usdoj.gov*

**National Institute of Justice**
**World Wide Web Site:**
*http://www.ojp.usdoj.gov/nij*