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FY71 ENGINEERING REPORT ON SURVEILLANCE TECHNIQUES FOR CIVIL AVIATION SECURITY

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16. Abstract This document discusses the work performed by the TSC task group on surveillance techniques in FY71. The principal section is devoted to the technical description, classification and evaluation of commercial metal detectors for concealed weapons. It includes an outline of operating principles, test and evaluation procedures, detailed engineering data, and installation requirements. The evaluation is based on extensive laboratory tests at TSC and on tests at major airports by TSC and other government agencies. A briefer section deals with baggage inspection devices for weapons and explosives. The effort in this area was devoted to the identification of promising commercial X-ray systems and vapor detectors ('Sniffers') In an initial survey, several X-ray inspection systems were identified, using conventional high-dosage or recently developed low-dosage radiation sources, whose characteristics are described briefly herein. The discussion of vapor detectors is confined to three techniques: mass spectrometry, gas chromatography and bioluminescence. Principles of operation are outlined briefly and typical performance data are presented.

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INTRODUCTION

In FY71, TSC initiated a program to provide technological support to civil aviation security groups in the detection of concealed weapons and explosives. A task group was formed and a laboratory facility was established with the principal objective of performing evaluation of commercial equipment. As a secondary objective the group was to conduct feasibility studies of promising novel concepts. Ancillary activities of the task group included the following: tests of equipment installed at several major airports; observation of operational procedures at these installations; demonstration of detection equipment to representatives of government and industry; and participation in national and international security conferences. Specific accomplishments are discussed in the following sections.

EVALUATION OF SURVEILLANCE TECHNIQUES FOR CONCEALED WEAPONS ON PERSONNEL (METAL DETECTORS)

The detection of concealed metallic weapons is of primary concern in the screening of airline passengers. Many types of metal detectors are available commercially, in the price range from $135 to $8,000. For the guidance of potential users, an investigation was initiated to establish the performance characteristics of these detectors. For this purpose an extensive laboratory test procedure was developed and eleven commercial detectors were installed at TSC and evaluated; "Friskem" Night Stick Mark 3 and "Friskem" Walk-Through Station (Infinetics, Inc.), Squealer Model 15 (Rens Manufacturing Co.), Hand-Held Detector and SG-2C Metal Detector (Excelsior Electronics Corp.), Metal Detector Doorway (Rank Precision Industries, Ltd.), WD-4 Weapon Detector (Westinghouse Electric Corp.), Metor (Outokumpu Oy), "Magnetic Eye" Type MGG (Densok Measuring Instruments Works, Ltd.), Gamma 2WD Concealed Weapon Detector (SPS, Inc.), and Magnetic Surveillance (Schonstedt Instrument Co.). The following six detectors were evaluated in the field at Dulles, Kennedy, Los Angeles, O'Hare and Logan Airports: Model GB-3 Magnetic Detector (Schonstedt Instrument Co.), Transfrisker #6010 (Federal Laboratories, Inc.), "Squealer" (Riwosa S.A.), Active Walk-Through Doorway (Diver Detection Devices, Ltd.), Personnel Scanner PS-6 (Rens Manufacturing Co.), "Friskem" Type 3 Walk-Through Station (Infinetics, Inc.). The evaluations clearly indicated the necessity to separate the passenger from his hand-luggage in order to minimize the frequency of false alarms. The status, cost and technical performance rating of all the above detectors and of the Boekels metal detector (which was evaluated by personnel of the Federal Republic of Germany) have been presented in a summary report.(1) Eight of the above detectors detect the presence of conventional weapons with a high probability of success.

CLASSIFICATION OF METAL DETECTORS

Metal detectors fall into two major groups: small lightweight hand-held devices, and walk-through installations. Some detectors respond only to the presence of magnetic metals (iron and most steels), others respond to the presence of all metals, regardless of magnetic properties (stainless steel, brass, copper, aluminum, nickel, lead, zinc, tin, etc.), Hand-held devices intrinsically permit "frisking" of a subject without body contact; in this manner the location of concealed metal objects is readily determined. Walk-through devices, on the other hand, in their simplest configuration, respond to the presence of metal objects without indicating their location. It is more complicated (and more costly) to provide location discrimination. As shown in Figure 1, it is possible to distinguish six detector subgroups, depending on operating mode and performance characteristics. This classification scheme is helpful in comparing the performance of the various commercial models.

OPERATING PRINCIPLES OF METAL DETECTORS

DETECTORS OF MAGNETIC METALS ONLY

These devices measure disturbances in the Earth's magnetic field caused by objects which can be magnetized. The sensing element is a so-called "second harmonic flux gate magnetometer," extensively discussed in the literature(2). A typical configuration (Figure 2a) consists of an oscillator, a saturable core wound with two coils and a second-harmonic (synchronous) detector. The first (primary) coil is connected to an oscillator which drives the core into saturation magnetization during a portion of each half-cycle of the driving frequency f_o.

Voltage pulses are induced in the second (secondary) coil whose polarity and magnitude depend on the rate of change of the flux in the core. When no external magnetic field is applied, the flux versus applied field characteristic is symmetrical (Figure 2c); positive and negative pulses are evenly spaced in time and their frequency spectrum contains only odd harmonics. On application of an external field the magnetization characteristic becomes asymmetric (Figure 2d), positive and negative pulses are unevenly spaced in time and the frequency spectrum now contains a second harmonic, $2f_o$ which is detectable. As shown in Figure 2a, a synchronous detector may be employed and filters used to eliminate $2f_o$ from the primary coil and f_o from the secondary coil. Various configurations may be used to eliminate f_o from the secondary circuit and to enhance sensitivity. Typical of these are the double-core and toroidal arrangements shown in Figure 3. Another configuration used in a commercial second harmonic flux gate magnetometer is shown in Figure 4a. It consists of a ferrite toroid, T, wound with an excitation coil N_p. A secondary coil, N_s, is wound over the entire arrangement. An alternating current applied in N_p induces a flux in T. When saturation is reached in the core, the excess flux spreads beyond the toroid (Figure 4b). The flux in toroid T will expand beyond the core in symmetrical fashion when saturation magnetization is exceeded (Figure 4b). No voltage is induced in N_s in

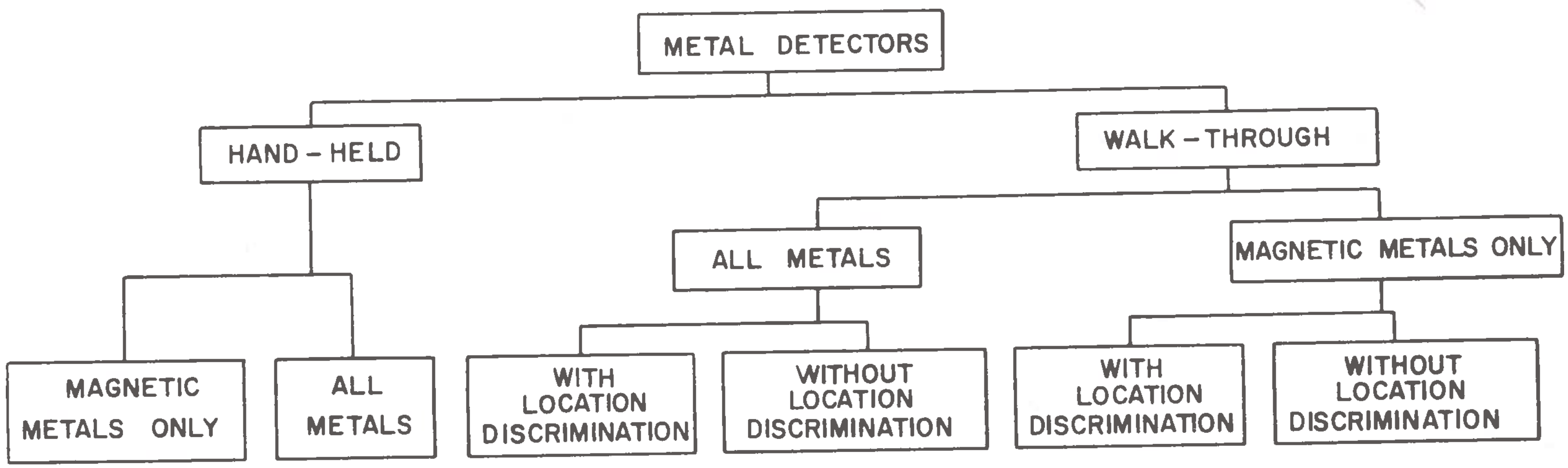

Figure 1. Classification of Metal Detectors

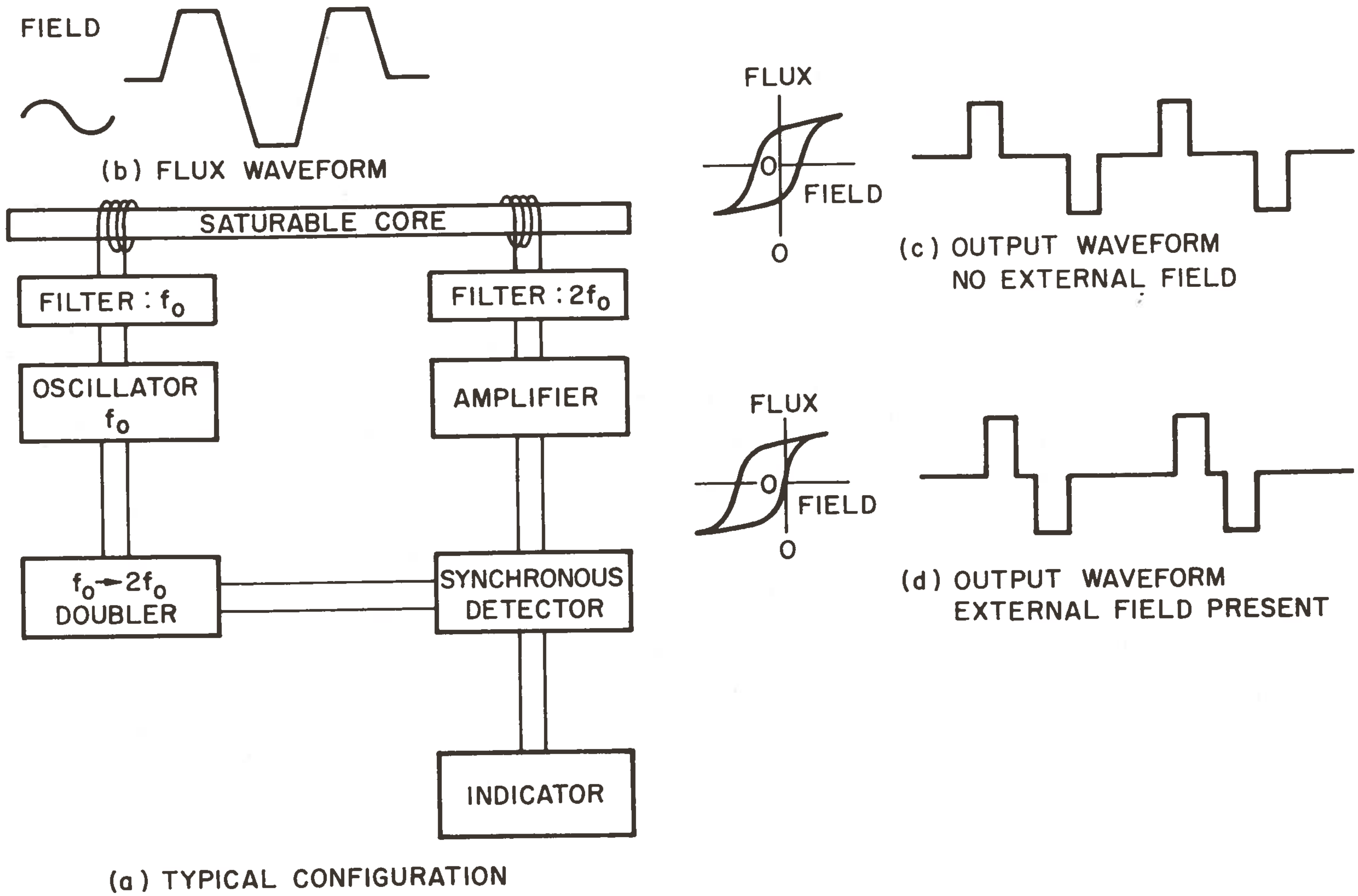

Figure 2. Principles of Second Harmonic Fluxgate Detector

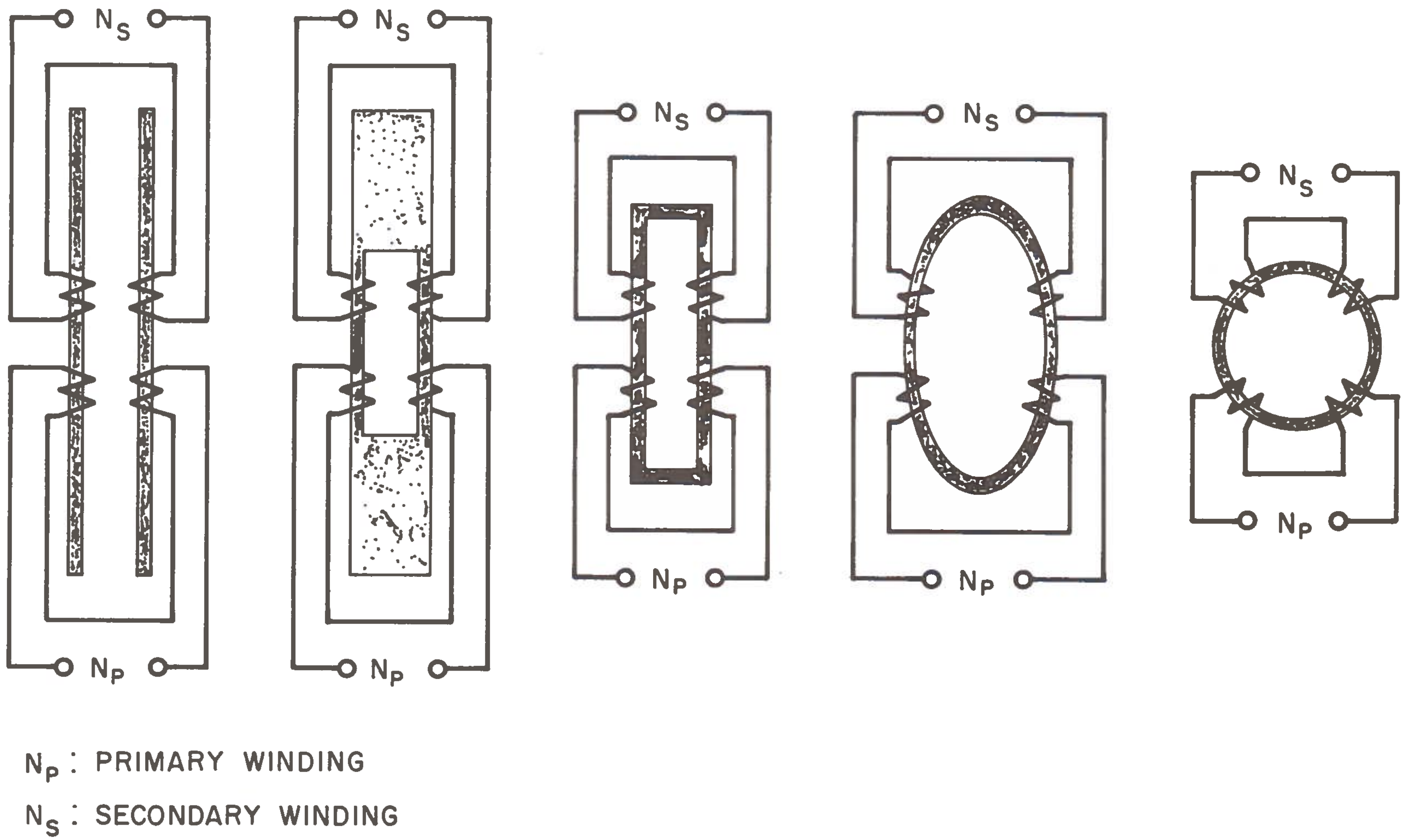

Figure 3. Core Configurations

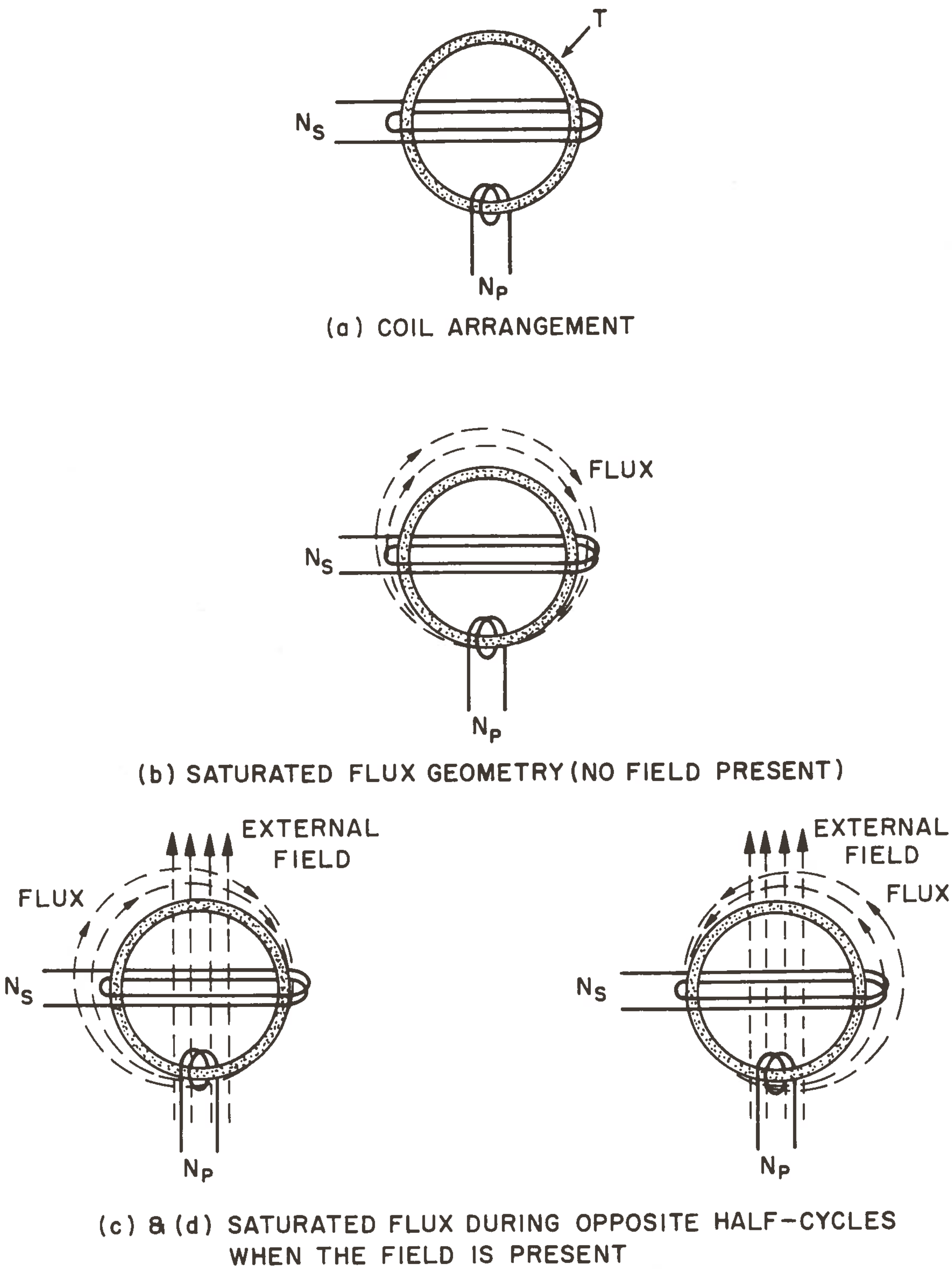

Figure 4. Second Harmonic Fluxgate Magnetometer Configuration

this case since the net flux linkage is zero. When, however, an external field is present, the toroid will saturate asymmetrically as shown in Figures 4c and d, which indicate the peak flux during successive half cycles of the applied alternating current. Since the flux linking the coil pulsates at twice the frequency of the current in N_p, the frequency of the voltage induced in N_s is twice the frequency of the current in N_p.

DETECTORS OF ALL METALS

These devices measure disturbances in an alternating magnetic field caused by the presence of any metallic object. In the typical configuration shown in Figure 5, two coils (primary and secondary) are located several feet apart. The primary coil, energized by an oscillator, produces a magnetic field which links the secondary coil. By means of a bridge circuit, primary and secondary coils are balanced (zero signal). If a magnetic object is introduced between the coils, the flux linking them is increased; if a nonmagnetic metallic object is introduced, the flux is decreased. Magnetic and nonmagnetic metal objects can be distinguished by the polarity of the unbalance displayed on the indicator. The unperturbed magnetic field is characterized by its amplitude, distribution and frequency, all of which vary for the various commercial models. The modification of this field by a metal object is measured; if the measured change exceeds a preset threshold, an alarm circuit actuates a warning light or a buzzer.

In its simplest form the detector consists of a single coil of wire. This coil forms one element in an alternating current bridge circuit. A metal object in or near the plane of the coil changes the impedance of the coil and therefore unbalances the bridge. Many variations of this basic concept are employed in commercial models. For maximum effectiveness, the all-metal detector requires a high uniformity of magnetic field, otherwise, its performance will vary greatly, depending on the location of a metal object relative to the primary coil. Also, the frequency should not be too high. Several of the less expensive models produce highly nonuniform fields (only a single primary coil) and operate at frequencies of 20kHz or higher, where they register foil wrappers of cigarettes, tobacco and candy. This tendency is clearly undesirable since it produces a high "false-alarm" rate. The more costly units employ multiple coils and lower frequencies. The mode of operation of the most advanced models can be understood by a more detailed analysis of the interaction between the alternating magnetic field and a metal object located in the

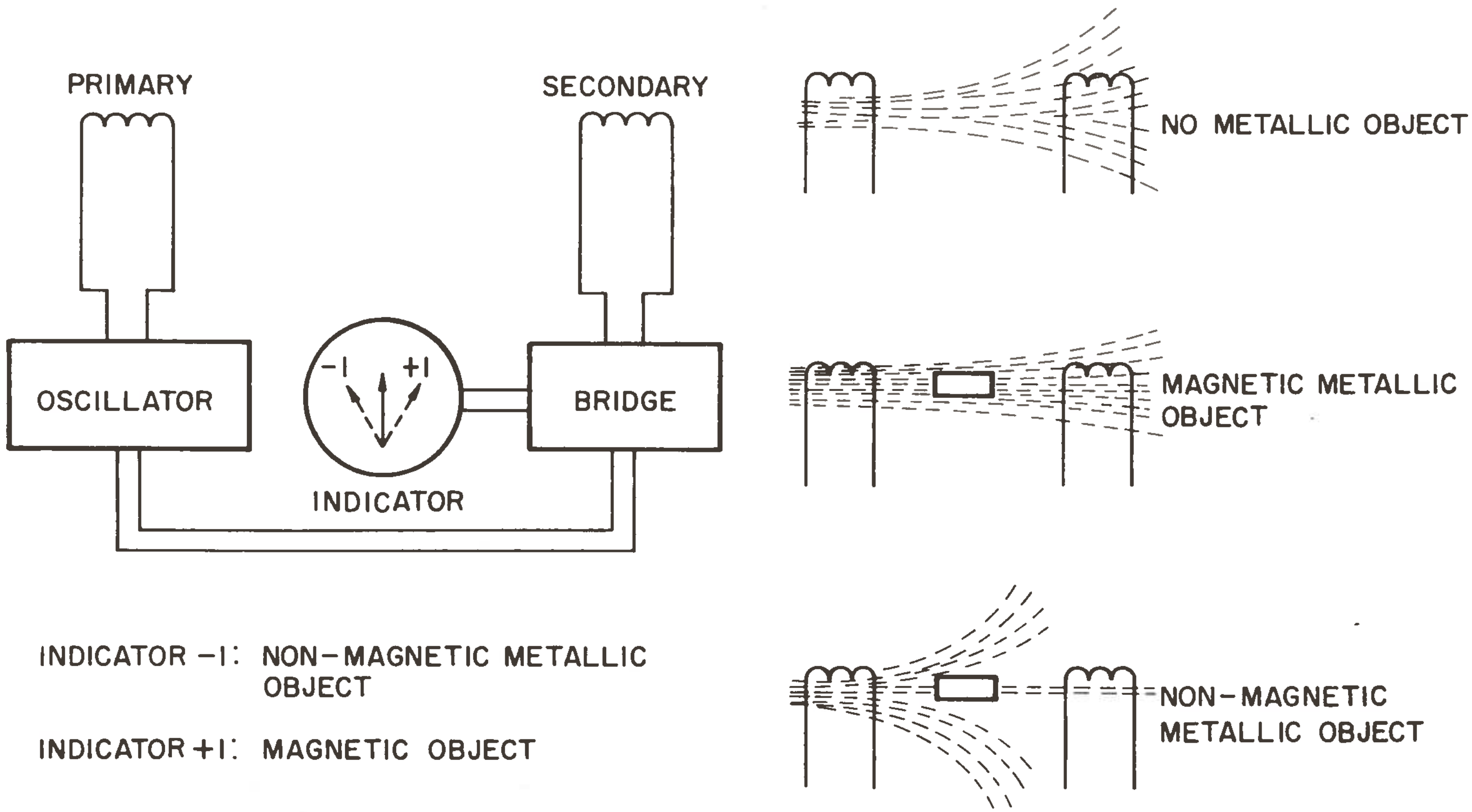

Figure 5. Principles of All-Metal Detector

field. The eddy currents induced in the object produce ohmic losses and a secondary magnetic field. The respective magnitudes of these two effects depend on the geometry of the metal object, on its thickness and on the applied frequency. The resulting change in the primary current consists of two components which differ in phase by 90 degrees, their amplitudes for a given metal object depending on the applied frequency. If more than one frequency is utilized, multiple values of the amplitudes of the two components can be measured, which result in a "signature" of specific metal objects. This signature can be identified by "logic" circuitry.

TEST AND EVALUATION PROCEDURES

In order to arrive at a meaningful basis of comparison for the many types and models of metal detectors, it was necessary to devise a controlled set of reproducible laboratory test conditions. It became evident very early in the investigation that metallic arch supports in shoes were a major source of false alarms. It was also observed that the response of some models was dependent on the velocity of travel of a metal object. This latter characteristic occurred in models with an automatic balancing feature of the various bridge circuits. Since critical time constants are involved, it was suspected that with such models a weapon on a slowly moving individual might escape detection. Other models were found to react to magnetic or electrical disturbances and required critical clearances; controlled environmental conditions, therefore, had to be maintained before reproducible data could be obtained in such cases.

A typical early test setup is shown in Figure 6, where uniform passage of weapons can be obtained at different velocities and locations. It was soon found that consistent data could also be obtained by locating specific objects on an individual who would then be exposed to a particular model at normal walking pace. Having established the appropriate test conditions, a representative set of test weapons was then selected after a number of trials (Table 1). A typical set of locations used for these tests is shown in Table 2. For each test weapon, repeated trials established the percentage response of a particular model. The numerical box score for ten typical locations then represented the probability of detection averaged over various positions of a test weapon at a given location. It was necessary, of course, also to ascertain the probability of "false positives," due to shoes and small every-day objects such as keys, buckles and tie clasps, also to bulk extraneous metal objects and to electrical disturbances. Once this

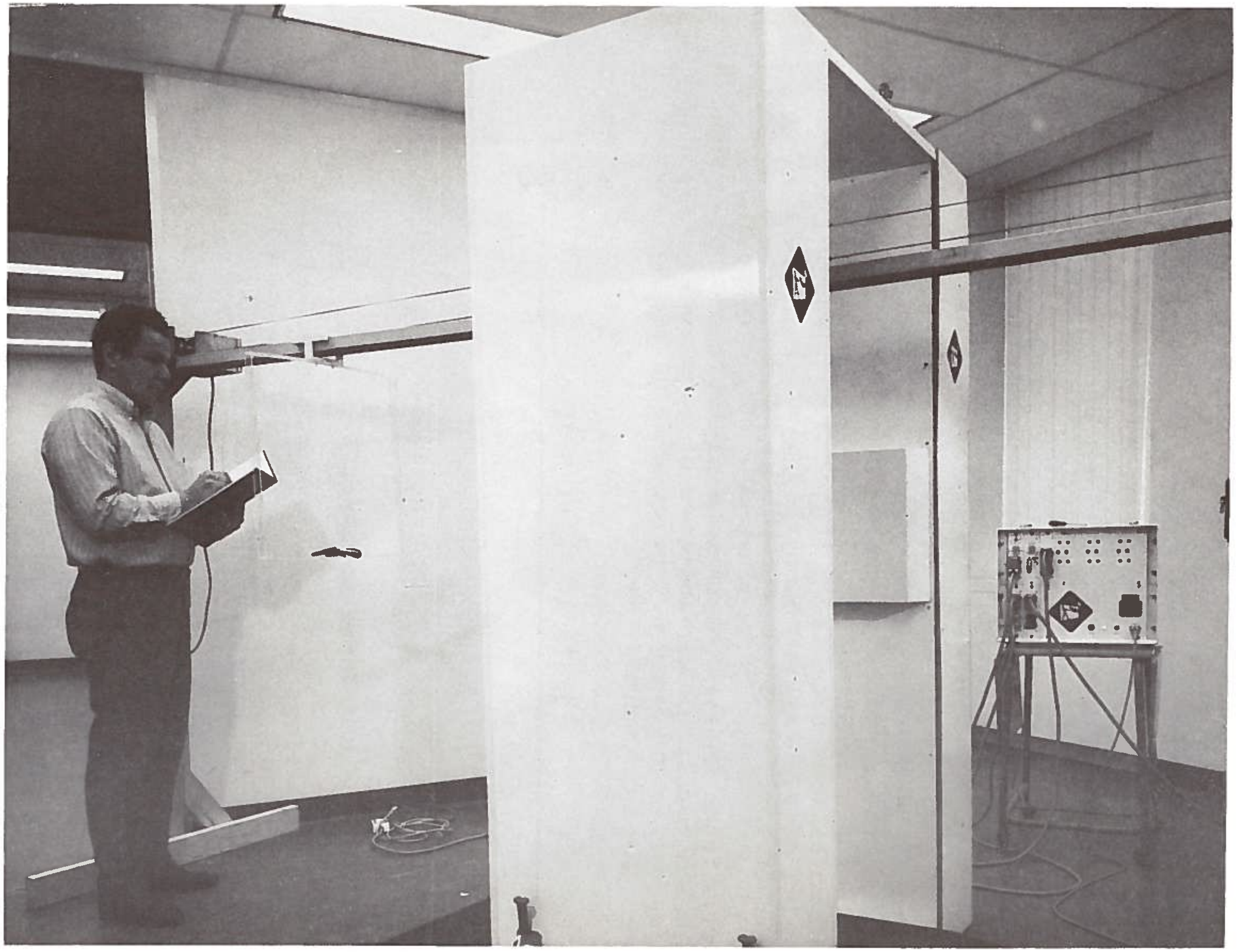

Figure 6. Typical Early Test Setup for Metal Detectors

probability was established, the performance of a model could be expressed on the basis of the following primary numerical factors.

1. Response Factor: This factor is the average probability of detecting the ten test weapons at all test locations. Perfect score is 100%.

2. False Alarm Factor: This multiplying factor is a measure of the number of false alarms when no weapons were carried by the subject. The numerical value of this factor is given by 1.00 minus the percentage of false alarms. Thus, a rating of 0.8 indicates a 20% false alarm rate, a factor of 0.6 a 40% false alarm rate, etc.

3. Disturbance Factor: This multiplying factor is a measure of detector response to extraneous metal objects and electrical disturbances. It was obtained in the same manner as the False Alarm Factor. For example, a rating of 0.9 implies good shielding, a rating of 0.6 is inferior.

4. Convenience Factor: This multiplying factor is a measure of detector stability and ease of handling. A rating of 0.8 implies average, 0.7 below average and 0.9 above average performance.

Table 1. Test Weapons

.22 automatic
.25 long revolver
.30 revolver
.38 aluminum frame revolver
.38 stainless revolver (slightly magnetized)
3 1/2-inch single-blade knife
5-inch Bowie knife
Stiletto (long needle)
beryllium-copper simulated weapon (hammer-claw)
hand grenade

Table 2. Matrix of Weapons Locations

	RIGHT	CENTER	LEFT
HEAD	———		———
SHOULDER		———	
CHEST			
BELT			
POCKET		———	
HIP		———	
LEG			

A set of secondary numerical factors has also been established which takes into account whether a flight can be designated as being of "high risk" or "low risk." The numerical performance scores and performance ranking of the various detectors investigated are topics dealt with in a previous publication.(1) The information presented herein contains specifically the pertinent technical and engineering data of the following eighteen commercial models.

DETECTOR - MAGNETIC METALS

Manufacturer:	Schonstedt Instrument Co. 1775 Wiehle Avenue Reston, VA 22070
Type and Model No.:	Model GB-3 Magnetic Detector
Mode of Application:	Battery operated electronic unit carried in pocket, sensor probe with arm straps, and earphone.
Physical Description:	Worn under a jacket or overcoat, the electronic unit and sensor are completely concealed and earphone is hardly noticeable.
Cost:	$400.00
Delivery:	Off-the-shelf
Operating Principle:	Presence of object containing magnetic material (iron steel, but not nonmagnetic stainless steel) produces electrical signal.
Technical Evaluation:	(based on limited field tests) Space required: Scanning close to subject. Response to extraneous metal objects and electrical disturbances: Low at distances greater than one foot. Likelihood of false alarms: Medium Operator's skill required: High Need for adjustment: Occasional Sensitivity: Will detect magnetic objects, occasionally including small knives. Performance rating: Acceptable (Good) Cost effectiveness: Acceptable (Good)

Application Status: Surveillance of crowds at rallies, demonstrations, or on public conveyances to detect people carrying weapons.

Recommendation: Use for boarding passengers not recommended except in unusual situations.

DETECTOR - MAGNETIC METALS

Manufacturer:	Infinetics, Inc. 1601 Jessup Street Wilmington, DE 19802
Type and Model No.:	"Friskem" Night Stick Mark 3 (Figure 7)
Mode of Application:	Battery operated, portable, self-contained, hand-held search unit to scan subject at about 3 inches from subject.
Physical Description:	Resembles policeman's night stick in appearance; rugged enough to be used as club. Detector uses solid-state electronics.
Cost:	$135 (1), $117 (10-49), $113 (50 or more)
Delivery:	Off-the-shelf
Operating Principle:	Presence of object containing magnetic material (iron steel, but not nonmagnetic stainless steel) produces electrical signal.
Technical Evaluation:	(based on laboratory tests at TSC) Space required: Scanning at distance of about 3 inches from subject. Response to extraneous metal objects and electrical disturbances: Low at distances of one foot. Likelihood of false alarms: Low Operator's skill required: Medium Need for adjustment: Rare Sensitivity: Will detect magnetic objects, including small knives. Performance rating: Acceptable (good) Cost effectiveness: Acceptable (good)
Application Status:	Not known.

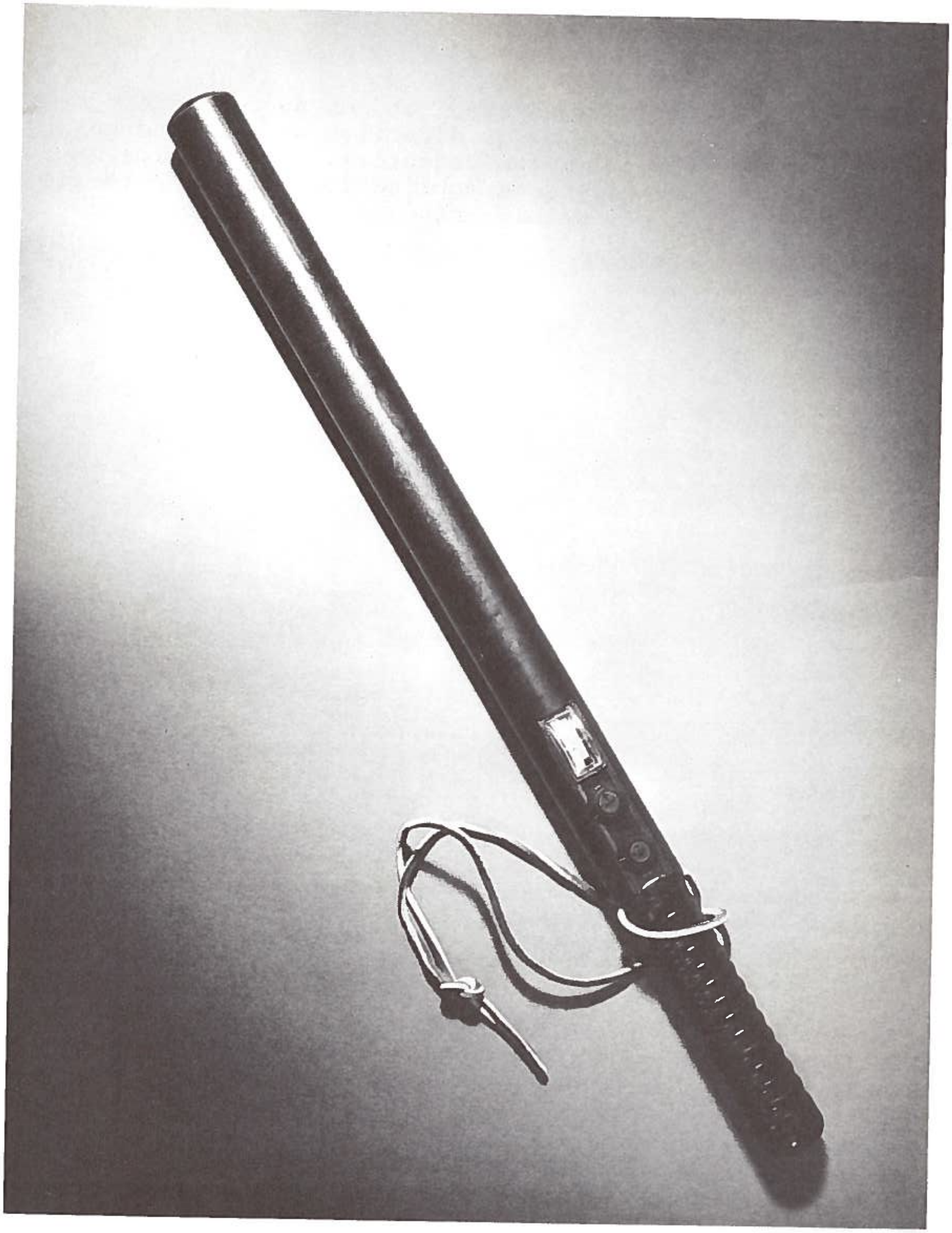

Figure 7. "Friskem" Night Stick Mark 3

Recommendation: Inexpensive, but not as consistent, stable, or effective as the hand-held all-metal detectors. This device may have some application for the detection of metal concealed in luggage.

DETECTOR - ALL METALS

Manufacturer: Federal Laboratories, Inc.
Saltsburg, PA 15681

Type and Model No.: Transfrisker #6010 (Fig. 8)

Mode of Application: Battery-operated, hand-held search unit to scan subject at about 3 inches from subject.

Physical Description: Under 10 lbs., slightly bulky, search paddle about 4" x 10".

Cost: $595.00

Delivery: Off-the-shelf

Technical Evaluation: (based on limited field tests)

Space required: Scanning at distance of about 3 inches from subject.

Response to extraneous metal objects and electrical disturbances: Low at distances of one foot.

Likelihood of false alarms: Operator must be familiar with response to coins, keys or metal foil, to distinguish these from small metal weapons; or subject must divest himself of all extraneous metal.

Operator's skill required: Medium to high

Need for adjustment: Rare

Sensitivity: Will detect all metal objects, including small knives, readily.

Performance rating: Excellent

Cost effectiveness: Good to excellent

Magnetic Field: .03-.05 gauss

Frequency: 10kHz

Figure 8. Transfrisker #6010

Operating Principles: This device utilizes a primary coil and secondary coil, coupled with a null balance until a metal object is brought into the vicinity. The design is more complex than that of the Rens or Riwosa units, consisting essentially of a signal-producing circuit dependent on the changes in inductance as measured by the capacitance-inductance bridge circuit that was initially at null balance.

Application Status: Presently used by Department of Defense.

Characteristics: Limited tests indicate excellent discrimination, provided the "on" switch can be made to function properly and provided the instrument is used correctly; for example, by maintaining a uniform distance from the subject while scanning.

Recommendations: This unit is heavy, bulky and somewhat awkward to use. The discrimination between small innocuous objects and potential weapons is excellent, when the detector is functioning properly. No maintenance is required, except for a battery change. This unit is highly recommended by the U.S. Army Land Warfare Laboratory, Aberdeen, MD.

DETECTOR - ALL METALS

Manufacturer: Rens Manufacturing Co.
P.O. Box 337
Creswell, Oregon 97426

Type and Model No.: Squealer Model 15 (Fig. 9)

Mode of Application: Battery-operated, hand-held search unit to scan subject at about 3 inches from subject.

Physical Description: Weight less than 2 lbs., 7" x 2" x 3", with 9" x 2" search loop - attractively housed.

Cost: $350.00

Delivery: Off-the-shelf

Technical Evaluation: (based on extensive laboratory tests at TSC)

Space required: Scanning at distance of about 3 inches from subject.

Response to extraneous metal objects and electrical disturbances: Low at distances greater than one foot.

Likelihood of false alarms: Operator must be familiar with response to coins, keys, or metal foil, to distinguish these from small metal weapons; or subject must divest himself of all extraneous metal.

Operator's skill required: Medium to high.

Need for adjustment: Rare

Sensitivity: Will detect all metal objects, including small knives, readily.

Performance rating: Excellent

Cost effectiveness: Excellent

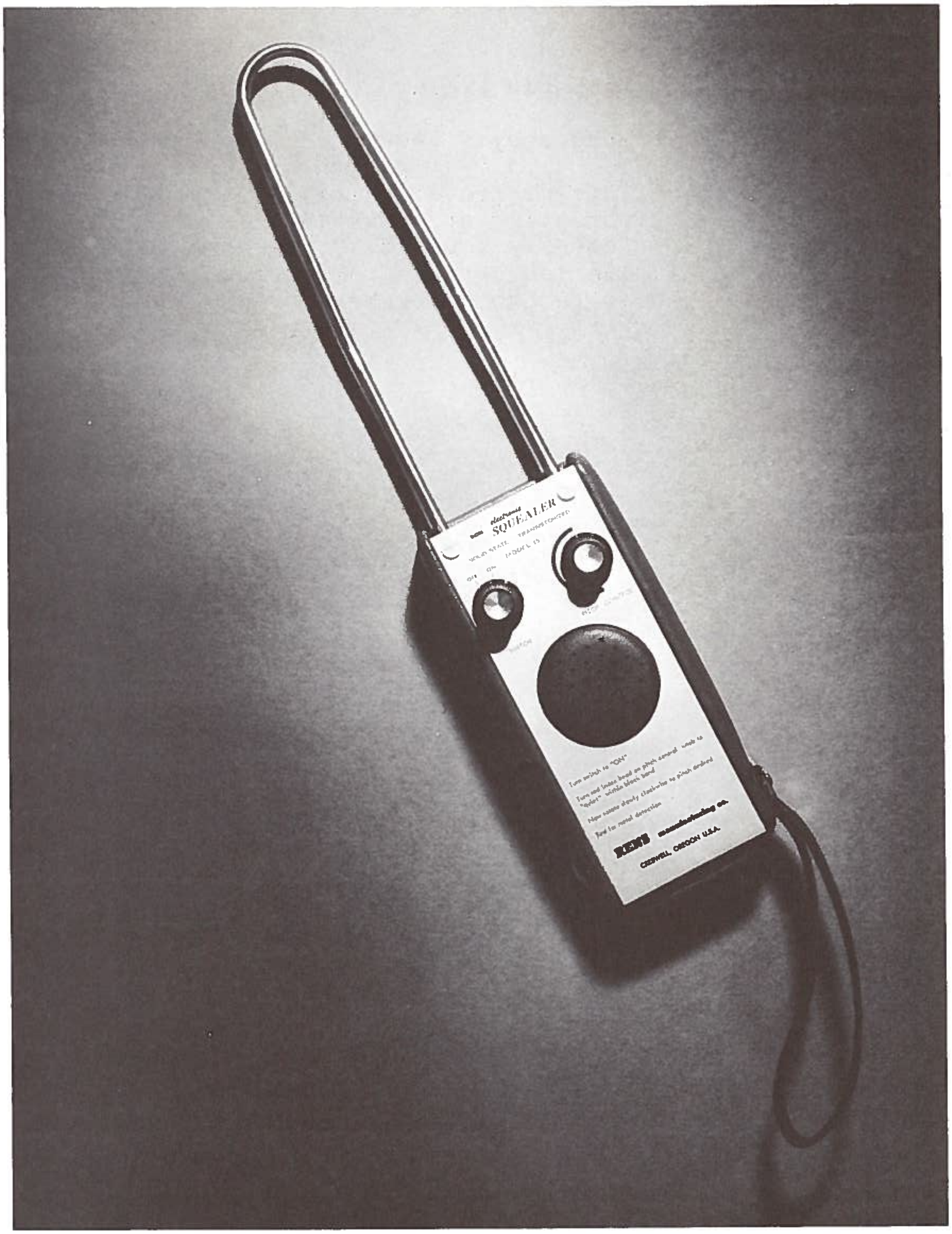

Figure 9. Rens Squealer Model 15

Magnetic Field: 0.1-0.3 gauss

Frequency: 500kHz

Operating Principles: This device incorporates two oscillators operating at about 450kHz. One of these is coupled to a search loop. The (adjustable) difference frequency is fed to a speaker.

SUMMARY OF TEST RESULTS

UNIT: Rens Squealer

	RIGHT	CENTER	LEFT
HEAD		100	
SHOULDER	100		100
CHEST	100	100	100
BELT	100	100	100
POCKET	100		100
HIP	100		100
LEG	100	100	100

FALSE ALARM RATE: 0%

NOTES: Pockets empty, Belt will give alarm.

Application Status: Currently in experimental use with Rens PS-5 unit at Gate 26B, Pan American, L.A. and in U.S. mints and prisons.

Characteristics: This as well as other hand-held units is highly stable, reliable, effective and inexpensive. Since the operating frequency is high, these units will respond to coins and foil wrappers, and all metal objects should therefore be removed by the passenger before search. An experienced operator could search a person quite rapidly and in an unobjectionable manner.

The shape of the search loop which has the form of a hairpin is helpful in determining the shape of an object and revolvers can be identified by the sequence of sound as the loop is scanned over the grip, drum and barrel respectively.

Recommendations: The use of this unit is in conjunction with one of the walk-through units, such as the Rens Personnel Scanner or Metor detector, is highly recommended. The application of the Rens "Squealer" to search those passengers who register on the walk-through is an excellent alternative to personal search.

DETECTOR - ALL METALS

Manufacturer:	Riwosa S.A. Witikonerstrasse 80 8032 Zurich, Switzerland
Type and Model No.:	Metal Detector MD-12 (Fig. 10)
Mode of Application:	Battery-operated, hand-held search unit to scan subject at about 3 inches from subject.
Physical Description:	Under 5 lbs., circular loop about 6" in diameter for search.
Cost:	$170.00
Delivery:	Off-the-shelf
Technical Evaluation:	(based on limited field tests)

Space required: Scanning at distance of about 3 inches from subject.

Response to extraneous metal objects and electrical disturbances: Low at distances greater than one foot.

Likelihood of false alarms: Operator must be familiar with response to coins, keys, or metal foil to distinguish these from small metal weapons; or subject must divest himself of all extraneous metal.

Operator's skill required: Medium to high

Need for adjustment: Rare

Sensitivity: Will detect all metal objects, including small knives, readily.

Performance rating: Good to excellent

Cost effectiveness: Excellent

Magnetic Field: .05-0.1 gauss

Frequency: 150kHz

Figure 10. Riwosa Metal Detector MD-12

Operating Principles: Similar to Rens Squealer.

Application Status: Presently used by all BOAC crews prior to boarding of passengers.

Characteristics: Similar to Rens Squealer.

Recommendation: A quick evaluation at Logan Airport indicated excellent detector capability. Discrimination is slightly hampered by the circular shape of the search coil. Altogether, it appears to be an inexpensive, rather reliable unit. Further analysis will be forthcoming after the unit on order presently has been thoroughly examined.

DETECTOR - ALL METALS

Manufacturer	Excelsior Electronics Co. Solco Engineering 7448 Deering Avenue Canoga Park, CA 91303
Type and Model No.:	Excelsior hand-held detector (Fig. 11)
Mode of Application:	Battery-operated, hand-held search unit to scan subject at about 3 inches from subject.
Physical Description:	Around 2 lbs., search loop 2" x 9".
Cost:	$150.00, usually included with walk-through gate (SG-2C).
Delivery:	Off-the-shelf
Technical Evaluation:	(based on extensive laboratory tests at TSC)

Space required: Scanning at distance of about 3 inches from subject.

Response to extraneous metal objects and electrical disturbances: Low at distances greater than one foot.

Likelihood of false alarms: Operator must be familiar with response to coins, keys, or metal foil, to distinguish these from small metal weapons; or subject must divest himself of all extraneous metal.

Operator's skill required: Medium to high.

Need for adjustment: Rare

Sensitivity: Will detect all metal objects, including small knives, readily.

Performance rating: Acceptable (Good)

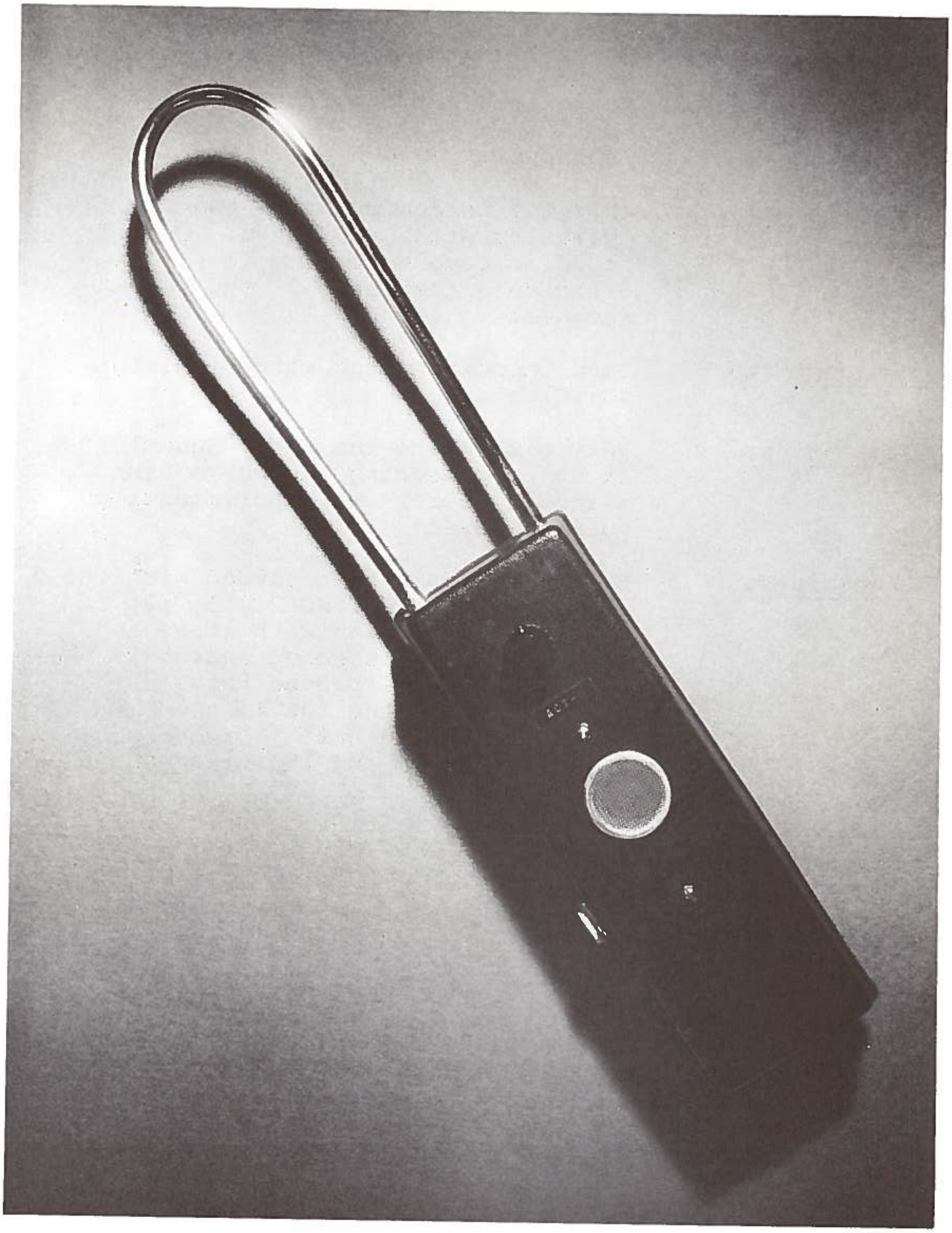

Figure 11. Excelsior Hand-Held Detector

Cost effectiveness: Acceptable (Good)

Magnetic Field: 0.1-0.3 gauss

Frequency: 700kHz

Operating Principles: This device incorporates two oscillators operating at about 700kHz. One of these is coupled to the loop. The difference frequency is fed to a speaker.

Application Status: Used in conjunction with Excelsior SG-2C detector.

Characteristics: Very similar to the Rens "Squealer" except engineering and workmanship slightly poorer and discrimination quality lower.

Recommendations: Since this unit is included with the walk-through model SG-2C, it may be used in conjunction with it as an alternative to personal search if the subject that has passed through the SG-2C triggers the red light. If only a hand-held unit is to be purchased we recommend the Rens "Squealer", the Riwosa unit, or even the Federal Transfrisker for their somewhat better qualities and only marginally higher initial investment.

DETECTOR - ALL METALS

Manufacturer:	Dr. Hans Boekels & Co. P.O. Box 847 51 Aachen, Federal Republic of Germany
Type and Model No.:	Boekels Metal Detector for Control of Persons
Mode of Application:	Walk-through gate
Physical Description:	96 1/2" high, 43 1/4" wide, 38 3/8" deep overall; 83" high, 29 1/2" wide, 35 1/2" deep aperture; weight about 1,320 lbs.; with 16 indicators for 16 different locations on subject.
Cost:	About $7,000.00
Delivery:	Experimental, airport tests in Germany anticipated.
Technical Evaluation:	(based on Government reports on experimental model by Federal Republic of Germany) Space required: Less than 10 feet in all directions from unit. Response to extraneous metal objects and electrical disturbances: Extremely low. Likelihood of false alarms: Extremely low. Operator's skill required: Medium Need for adjustment: Occasional Sensitivity: Will detect all metal weapons, and often discriminate between them and innocuous metal objects. Performance rating: Excellent Cost effectiveness: Good

Operating Principles: This device has not been available for evaluation during this investigation. From a description of its performance by the German authorities it is an all-metal detection device employing 16 individual sensing elements each of which operate at a different frequency. These frequencies are high enough to make the device respond to cigarette packages.

Application Status: This device is experimental. Deliveries have apparently been made to the Soviet Union of several units for tests in Soviet airports.

Characteristics: From a description of tests conducted by the German authorities it appears that this device has excellent sensitivity and indicates the location of all metal objects on a person reliably.

Recommendations: No firm recommendations can be made until the instrument has been tested and compared with other devices at our facilities here.

DETECTOR - ALL METALS

Manufacturer:	Diver Detection Devices, Ltd. Griff Clara, near Nuneaton Worcs., England, U.K.
Type and Model No.:	"Diver" Detection Device
Mode of Application:	Walk-through gate
Physical Description:	Doorway consisting of rectangular posts connected by wooden lintel, with upper and lower zones.
Cost:	$3,000.00
Delivery:	Off-the-shelf to 90 days.
Technical Evaluation:	(based on limited field tests) Space required: 10 or more feet in all directions from unit. Response to extraneous metal objects and electrical disturbances: Fair Likelihood of false alarms: Fair Operator's skill required: Medium Need for adjustment: Occasional, especially due to problems of drift. Sensitivity: Will detect all metal objects larger than small keycase; discrimination between regions of upper and lower body. Performance rating: Fair Cost effectiveness: Fair
Operating Principles:	This unit was tested only briefly during demonstrations at Kennedy Airport and at Logan Airport and complete details of its operating principles could not be obtained. Apparently, however, two separate systems are involved for the lower and upper sections utilizing separate coils and associated elec-

tronics. The operating frequencies of the two sections apparently are different also, and seem to be in the high audio range.

Application Status: Used by BOAC in airports. Units are at Logan Airport in Boston, JFK in New York, Bermuda.

Characteristics: Because of the short exposure of these units to critical examination within the framework of this investigation it is not possible to give a full account of the behavior of this device. It appears, however, that there exists a severe drift problem of the balance conditions requiring frequent adjustments. The units appeared sensitive to metal foil wrappers while, at the same time, there seemed to be a lack of detectivity in some areas and positions.

Recommendations: On the basis of the observations indicated above and also based on reports received from German sources, this device has disadvantages which make its application in the present configuration problematical.

DETECTOR - ALL METALS

Manufacturer:	Rank Precision Industries, Ltd. Rank Pullin Controls Phoenix Works, Great West Road Brentford, Middlesex, United Kingdom
American Rep.:	Rank Precision Industries, Inc. 260 North Route 303 West Nyack, NY 10994
Type and Model No.:	Metal Weapon Detector, MWD/Air I (Fig. 12)
Mode of Application:	Walk-through gate.
Physical Description:	Walk-through doorway: 9.7 ft. x 6 ft. x 3.2 ft., with indicators for different locations on subject.
Cost:	$6,150 (1), $5,875 (10-49), $5,200 (50 or more)
Delivery:	Orders of more than 10, U.S. manufacture, 60 days for one or two units imported.
Technical Evaluation:	(based on extensive laboratory testing at TSC) Space required: 10 feet in all directions from unit. Response to extraneous metal objects and electrical disturbances: Low Likelihood of false alarms: Low, because of location discrimination, metal support in men's shoes can be quickly determined, as well as location of innocuous metal. Operator's skill required: Medium Need for adjustment: Occasional, depends on volume of passengers. Sensitivity: Will detect all metal objects larger than small keycase.

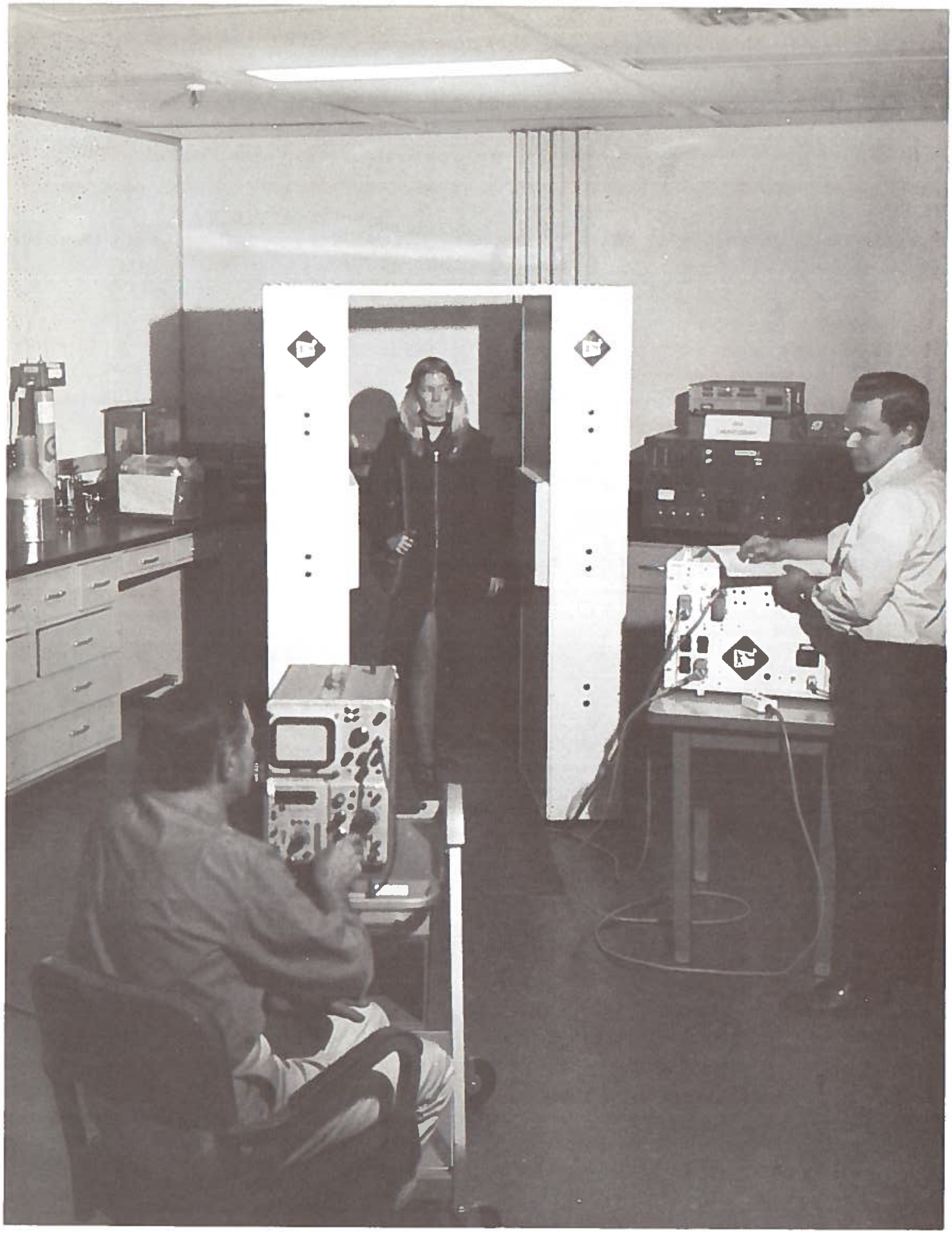

Figure 12. Rank Metal Weapon Detector MWD/AIR I

Performance rating: Good

Cost effectiveness: Good

Magnetic Field: 0.2-0.3 gauss

Frequency: 10kHz

<u>Operating Principles</u>: Three rows of coils in each side of the doorway are arranged so as to give a very uniform field at about 10kHz throughout the doorway. This uniformity is accomplished by the location of primary and secondary coils on both sides of the enclosure. Initial balancing requires the adjustment of 12 trimming elements. The subsequent balancing is accomplished automatically with a manually adjustable time constant. Three levels of sensitivity may be selected.

<u>Application Status</u>: Used at Heathrow Airport. There are two units in the U.S.A.; at TSC and Fort Belvoir.

<u>Characteristics</u>: This device has a very high sensitivity and no discrimination capabilities. It is therefore necessary to have passengers remove all metal objects including shoes, belts and metal brooches from their person. Under these conditions the performance is excellent. In the presence of many small metal objects, belts and boots there is a certain amount of internal interference and the lights flash in a random sequence which confuses the position indication. Also the timing circuits cause a degree of confusion in the presence of large objects and recycling occurs when any one of the positions is overloaded.

SUMMARY OF TEST RESULTS

UNIT: Rank

	RIGHT	CENTER	LEFT
HEAD	———	50	———
SHOULDER	50	———	50
CHEST	50	30	50
BELT	50	30	50
POCKET	30	———	30
HIP	30	———	30
LEG	100	100	100

FALSE ALARM RATE: 70%

NOTES: This device has a position display. Under the conditions of this test the shoes usually result in a false alarm at the lower position when no weapon is carried.

Recommendations: The false alarm rate is high. Where absolute security is required and where passengers may be asked to remove shoes, belts and other such items the Rank unit is reliable and will facilitate the location of a concealed weapon. It should be re-emphasized however, that this device is not convenient for any boarding procedure which involves the passage of persons with shoes and belts regardless of how the unit is adjusted.

DETECTOR - ALL METALS

Manufacturer:	Westinghouse Electric Corporation Specialty Electronics Division Box 8606 Pittsburgh, PA 15221
Type and Model No.:	WD-4 Weapon Detector (Fig. 13)
Mode of Application:	Walk-through gate
Physical Description:	Walk-through housing, 78" x 53" x 30", attractive, light-colored plastic, attractively contoured - also carpeted walking area.
Cost:	About $8,000.
Delivery:	About 90 days or more.
Technical Evaluation:	(based on extensive laboratory tests at TSC)

Space required: 10 feet in all directions from unit.

Response to extraneous metal objects and electrical disturbances: Low

Likelihood of false alarms: Extremely low, even from metal support in men's shoes.

Operator's skill required: Medium to major.

Need for adjustment: Occasional, although most of the time the pressing of one button proves sufficient.

Sensitivity: Will detect all metal weapons and usually discriminate between them and innocuous metal objects.

Performance rating: Excellent

Cost effectiveness: Good

Magnetic Field: 0.5-4.0 gauss (Figs. 14-16)
Frequency: 93Hz, 750Hz

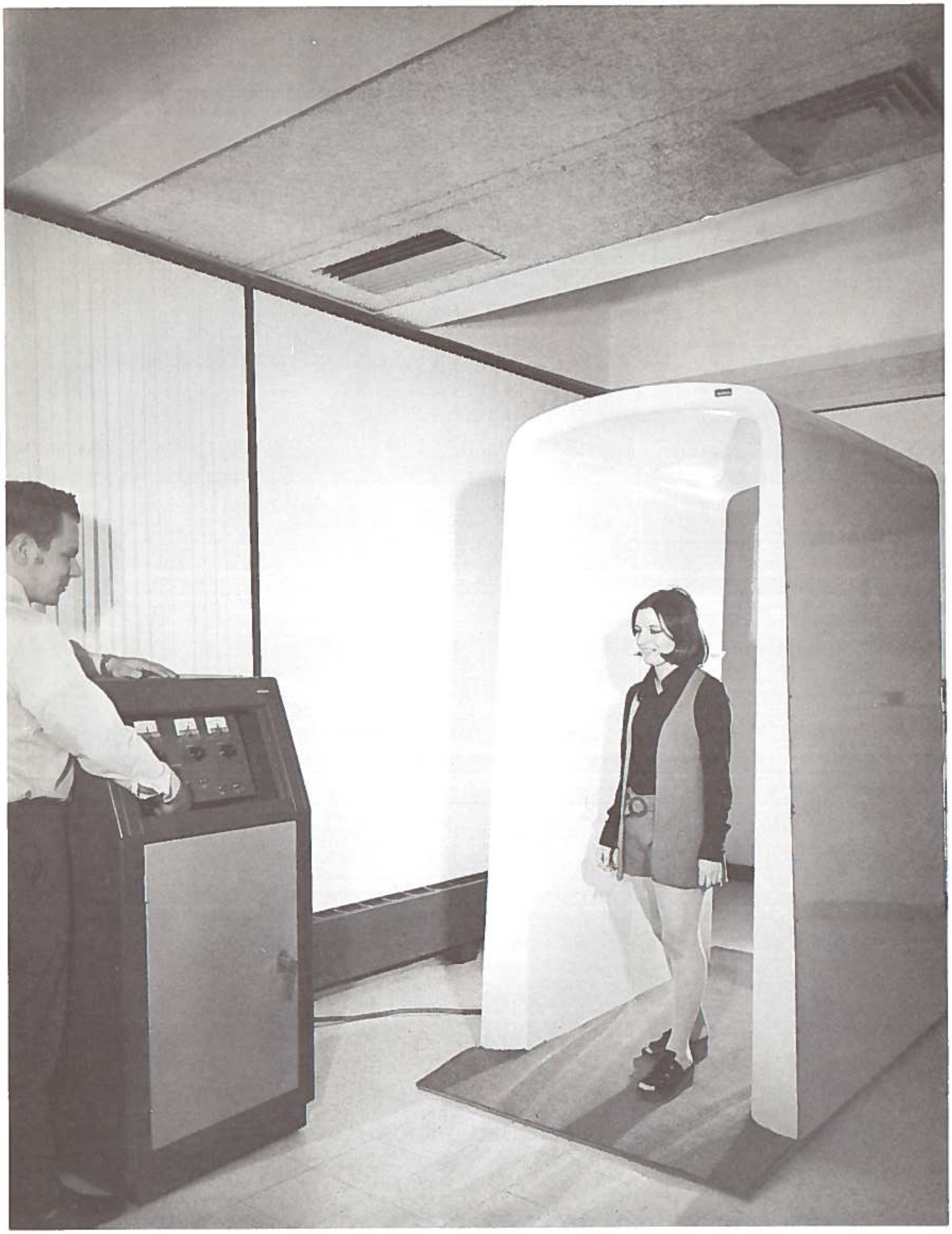

Figure 13. Westinghouse WD-4 Weapon Detector

Operating Principles: The Westinghouse device is the most sophisticated of the all-metal detection units and provides metered outputs for inphase and quadrature components of the unbalance signals at two frequencies. A more detailed discussion of this device is therefore very instructive and sheds light on the general problem of metal detection and weapons discrimination.

In brief, the unit consists of a control cabinet containing the crystal oscillator operating in the 120kHz frequency region, dividers providing 93Hz and 750Hz, the necessary functional amplifiers for transmit and signal processing steps, phase shift reference signals and alarm logic. A cable connects the control cabinet to the curved, arched doorway which contains the coils. The coils are arranged so as to provide a field the direction of which varies along 3 spatial axes as a function of the position of traverse. The field is furthermore so arranged that false alarms due to metal arch supports are suppressed. The signals read on the meters A B C and D represent:

A. High frequency magnetization component

B. High frequency loss (quadrature) component

C. Low frequency magnetization component

D. Low frequency loss (quadrature) component

The alarm responds when:

$$(D-\alpha B) > x \text{ and } C > y$$

where α, x and y are adjustable.

The excess metal alarm reacts when:

$$B > z$$

where, again, z is adjustable.

A fifth meter reading D-B directly is also provided. This meter is also used for various adjustment and housekeeping functions. This arrangement is best understood from Table 3. Table 3 gives the meter reading and warning indicators corresponding to various objects.

It may be seen that the ferrite and the aluminum rod each produce large magnetizations (in opposite directions) but insufficient loss to cause any warnings. The standard revolver produces insufficient high frequency losses to cause an excess metal warning but sufficient low frequency loss and positive magnetization to cause the alarm to operate. Finally, the stainless steel revolver, because of its high resistivity, causes insufficient low frequency loss to open up the yes-gate on the loss difference but it does have enough high frequency loss to operate the excess metal warning. It is important to note that low frequency magnetization and loss difference are both required to operate the alarm.

<u>Application Status</u>: One unit at TSC, one unit at FAA-Washington, DC, to be used in field test at Dulles International Airport.

<u>Characteristics</u>: A. Two Frequency Operation

As may be seen from Table 3, the two frequency system allows some discrimination but, if used as envisaged by the manufacturer, will permit special weapons such as the stainless gun or an aluminum frame weapon whose barrel and drum have been replaced with berillyium copper parts to pass through undetected. Even so, if passengers are allowed to board with metal objects on their persons, the false alarm rate is high.

To facilitate a comparison of discrimination for many objects, a list of meter readings and alarm status was compiled. The readings were taken with the respective objects in two positions where each of these objects caused maximum indication providing that these positions were compatible with the normal range of locations of such objects on a person.

The results listed in Table 4 demonstrate the difficulties inherent in any attempt to discriminate between a variety of objects. Thus, the two guns give readings differing markedly in column D. On the other hand, the can of 20 Schimmelpenninck mono cigars gave a reading nearly identical to the Bowie knife. The Schimmelpenninck monos are a popular brand of cigars which a traveler at Amsterdam International is likely to purchase.

The Nikorex movie camera gives readings which, depending on orientation, may simulate either the stainless steel gun or the regular gun. When passengers remove metal objects, the false alarm rate is reduced considerably and under the conditions envisaged here for high-risk security operation the false alarm rate would be quite small. To improve the detection capability for unusual weapons or for smaller weapons, such as a .22 caliber automatic the alarm logic may be changed. In particular, with reference to Table 3 it may be seen that if the contribution of the high-frequency loss

B to the loss difference (D-αB) is reduced by reducing the factor α then the detectivity for the stainless gun improves also. The correct setting for a given situation must be determined on the basis of judgement as to what constitutes a weapon on a particular flight.

B. Single Frequency Operation

If α is turned to zero then the weapons alarm system becomes independent of the high frequency unbalance signals and in that condition the device is most sensitive but, of course, also no longer has specific discriminatory capabilities. In this mode of operation it differs very little from some of the less expensive units such as the Outokumpu Metor except for sensitivity to position and location of the weapon. (See Table 5).

C. Position and Location Sensitivity

An attempt was made in the design of this device to minimize false alarms due to men's shoes by arranging the field to be vertical near the bottom of the doorway. The presumption was that a weapon carried on the lower leg would be carried in a vertical position. Actually it is possible to conceal a weapon in almost any position and a trained saboteur should have no difficulties to devise means of concealment in footwear or in a coat carried over the arm. Table 5 lists the alarm status for various weapons as a function of position and location.

D. Operating Personnel Requirements

This device is quite sophisticated and the setting of the alarm logic requires considerable finesse and experience.

In addition, because of the low sensitivity to cleverly concealed weapons, a sharp lookout must be kept for passengers who carry coats, paper shopping bags or bulky shoes. Furthermore, this device, as in fact all walk-through devices, cannot be relied upon to disclose very small disassembled firearms or knives with fixed blades and nonmetallic handles, stilettoes, awls and similar objects.

TABLE 3. METER READINGS AND ALARM STATUS FOR VARIOUS OBJECTS

OBJECT	A	B* >20=YES, <20=NO		C* >30=YES, <30=NO		D	(D-αB)* >15=YES, <15=NO α=1/2		WEAPON ALARM** (D-αB) & C YES α=1/2	EXCESS METAL,** B YES
Ferrite	+50	0	no	+50	yes	0	0	no	–	–
Aℓ-rod	-50	0	no	-50	no	0	0	no	–	–
Regular gun	+50	+18	no	+50	yes	10	+50	yes	✓	–
Stainless gun	+100	+26	yes	+100	yes	10	7	no	–	✓

Notes : *The inequalities represent the settings of the respective logic step for the corresponding meters

**Conditions for the alarm to be actuated are shown below alarm designations

TABLE 4. METER READINGS FOR VARIOUS OBJECTS

OBJECT	A	B	C	D	WA	EM
Briefcase	+100	+50	+100	+40	√	√
(Cowhide)	+100	+30	+50	+20	√	√
Attache Case	+50	0	+60	+10	√	
(Card Board)	+100	-5	+100	+10	√	√
Nikorex 8mm	-100	+100	-10	+100		
(Movie Zoom)	+80	+80	+50	+70	√	√
Zipper Leather	0	0	-10	0		
Folder	0	0	-10	0		
Small Can of	+100	+20	+100	+10	√	
MacBaren's Tobacco	+100	+50	+30	+5		√
Allen & Hopkins	+100	+50	+100	+50	√	√
30L Revolver	+100	+15	+90	+25	√	
Smith & Wesson	+100	+50	+100	5		√
38S Stainless Revolver	+90	+10	+80	10	√	
Bowie Knife	+60	0	75	10	√	
	-10	0	-10	0		
Pocket Knife	-20	+5	-30	0		
4" 3 Blades	+100	-5	+100	5		
Flash Light	30	+5	+15	0		
(Pen Light)	40	+5	+10	0		
Flash Light	+100	+60	+100	+10		√
	90	+40	+90	+20		√
Cigar Can	100	0	100	7	√	
4" x 4" x 3/4"	50	0	50	0		
Cigarette Lighter	-20	0	-30	0		
5/8" x 2.5"	+20	0	+10	0		
35mm Camera	75	60	100	40	√	√
(Beseler Topcon)	20	30	40	20	√	√
Dictaphone (Pocket size)	-100	+100	+100	+100	√	√
(IBM)	-100	+70	+90	+50	√	√

TABLE 5. DETECTION AS A FUNCTION OF ORIENTATION AND LOCATION[1]

POSITION	3-1/2 INCH KNIFE[2]		.30 LONG REVOLVER		LARDING NEEDLE		BERYL COPPER HAMMER	
ORIENT	H[4]	V[5]	H	V	H	V	H	V
HEAD	E[3] A[3]	E A	E A	E A	NONE	NONE	NONE	NONE
SHOULDER	A	A	E A	E A	NONE	NONE	NONE	NONE
CHEST CENTER	A	A	E A	A	NONE	NONE	NONE	NONE
BELT LEFT	A	A	A	A	A	NONE	NONE	NONE
BELT CENTER	A	A	A	A	A	NONE	NONE	NONE
BELT RIGHT	A	A	A	A	A	NONE	NONE	NONE
FOOT	NONE	NONE	NONE	A	NONE	NONE	NONE	NONE

Notes :
1) Single Frequency Operation, Maximum Sensitivity
2) This is a flat folding knife with a single, lockable 3-1/2 inch blade
3) E = Excess Metal Warning, A = Weapon Alarm
4) H = Horizontal Orientation
5) V = Vertical Orientation

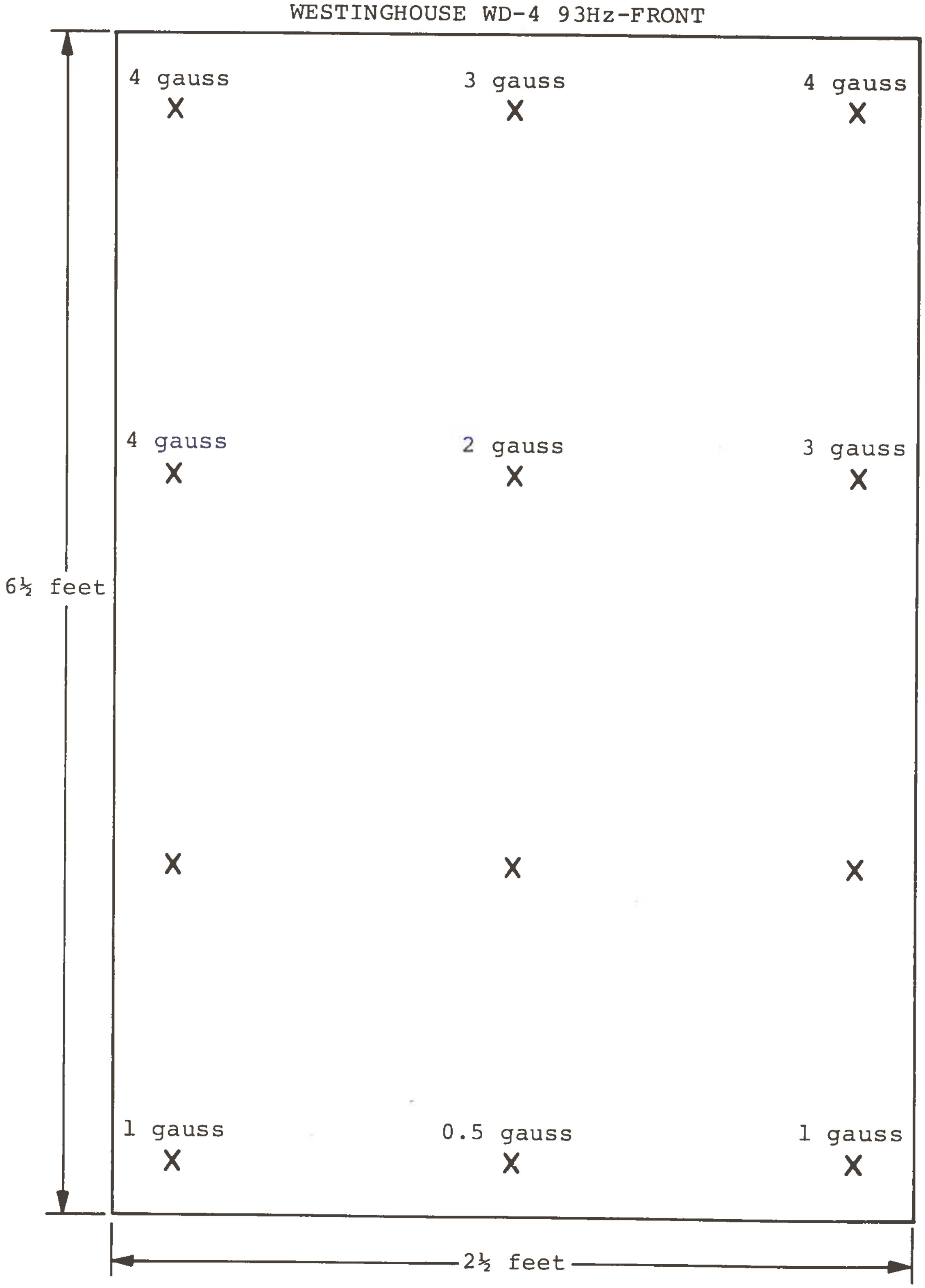

Figure 14. Magnetic Field in Gauss

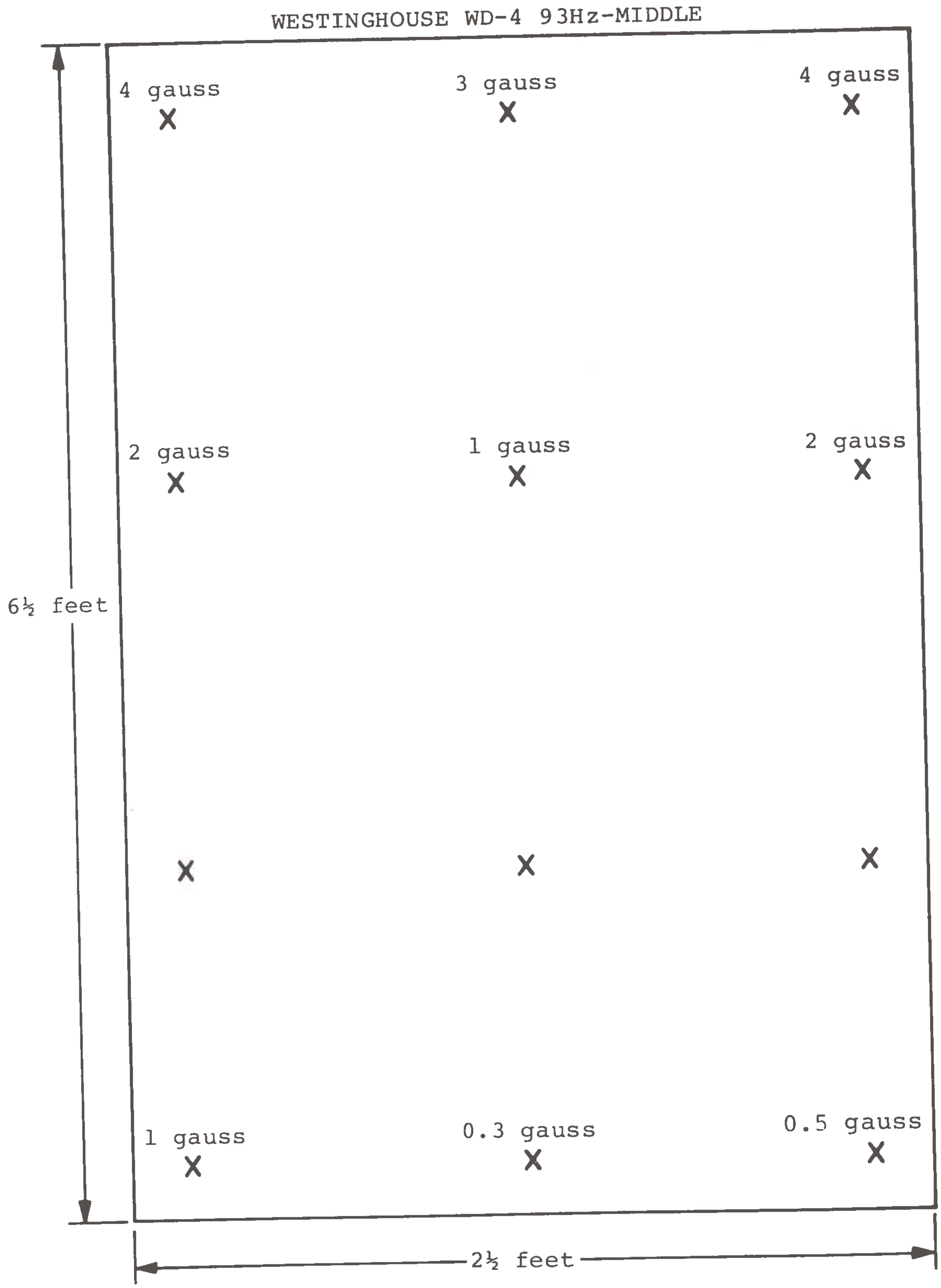

Figure 15. Magnetic Field in Gauss

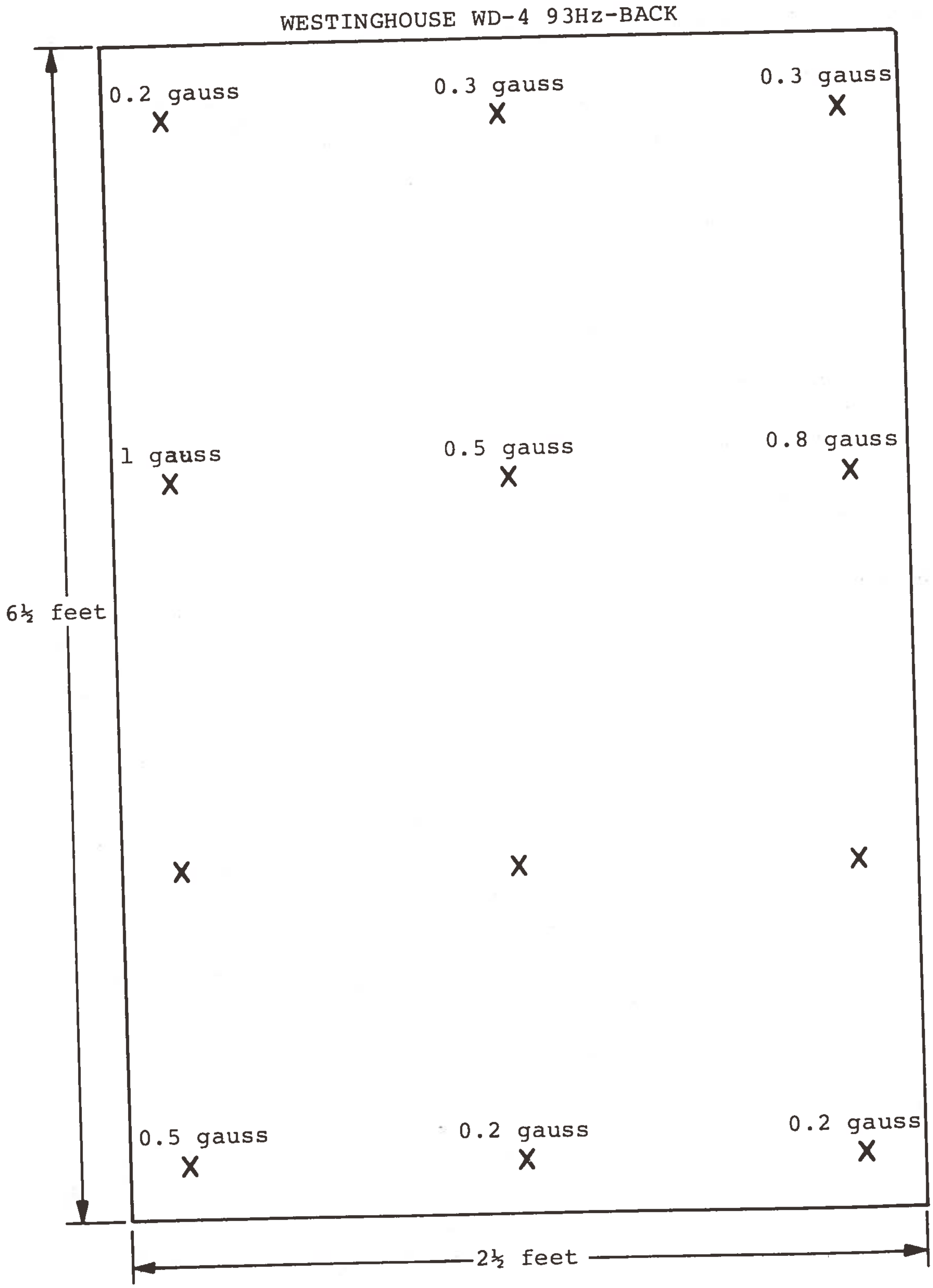

Figure 16. Magnetic Field in Gauss

SUMMARY OF TEST RESULTS

UNIT: Westinghouse

	RIGHT	CENTER	LEFT
HEAD	——	100	——
SHOULDER	100	——	100
CHEST	100	100	100
BELT	100	70	100
POCKET	90	——	90
HIP	80	——	90
LEG	50	50	50

Recommendations:

This unit is suitable for use in all but the most stringent security situations and will reliably disclose the presence of a gun of .25 caliber or larger except when carried by a skilled saboteur familiar with the operating principles of the device.

The unit is highly flexible and adaptable to all security requirements and will give a low false alarm rate. No false alarms are caused by men's shoes. Residual false alarms may be caused by belt buckles, back braces and other prosthetic devices. In low-risk security applications cheaper units may be more cost-effective.

Skilled operating personnel and security agents are required for best performance results. It is recommended that the walkway be raised higher to achieve a better detection capability for weapons carried on the lower leg. This is particularly important for the detection of aluminum frame weapons.

DETECTOR - ALL METALS

Manufacturer:	Outokumpu Oy Research Laboratory Tapiola, Finland
American Rep.:	Harrison R. Cooper Associates AMF Box 146 Salt Lake City, Utah 84101
Type and Model No.:	Metor Airport Security Metal Detector (Fig. 17)
Mode of Application:	Walk-through gate.
Physical Description:	Glass fiber frame with coil system; control unit includes primary and secondary coil electronics, amplifier signal analyzing electronics, settings for detection sensitivity, monitor and relay output for alarm units and control, a reset unit and light alarm display unit. Dimensions: 8 ft. high, 8 ft. long, 5 ft. wide.
Cost:	$4,500 (1-49), $4,000 (50 or more). Orders 10 units and up U.S. manufacture.
Delivery:	About 60 days.
Technical Evaluation:	(based on extensive laboratory testing at TSC) Space required: 20 feet in all directions from unit. Response to extraneous metal objects and electrical disturbances: Low Likelihood of false alarms: Extremely low, except for occasional response to metal supports in men's shoes. Operator's skill required: Medium Need for adjustment: Occasional, especially to readjust balance setting. Sensitivity: Will detect all metal objects, usually even small knives and guns.

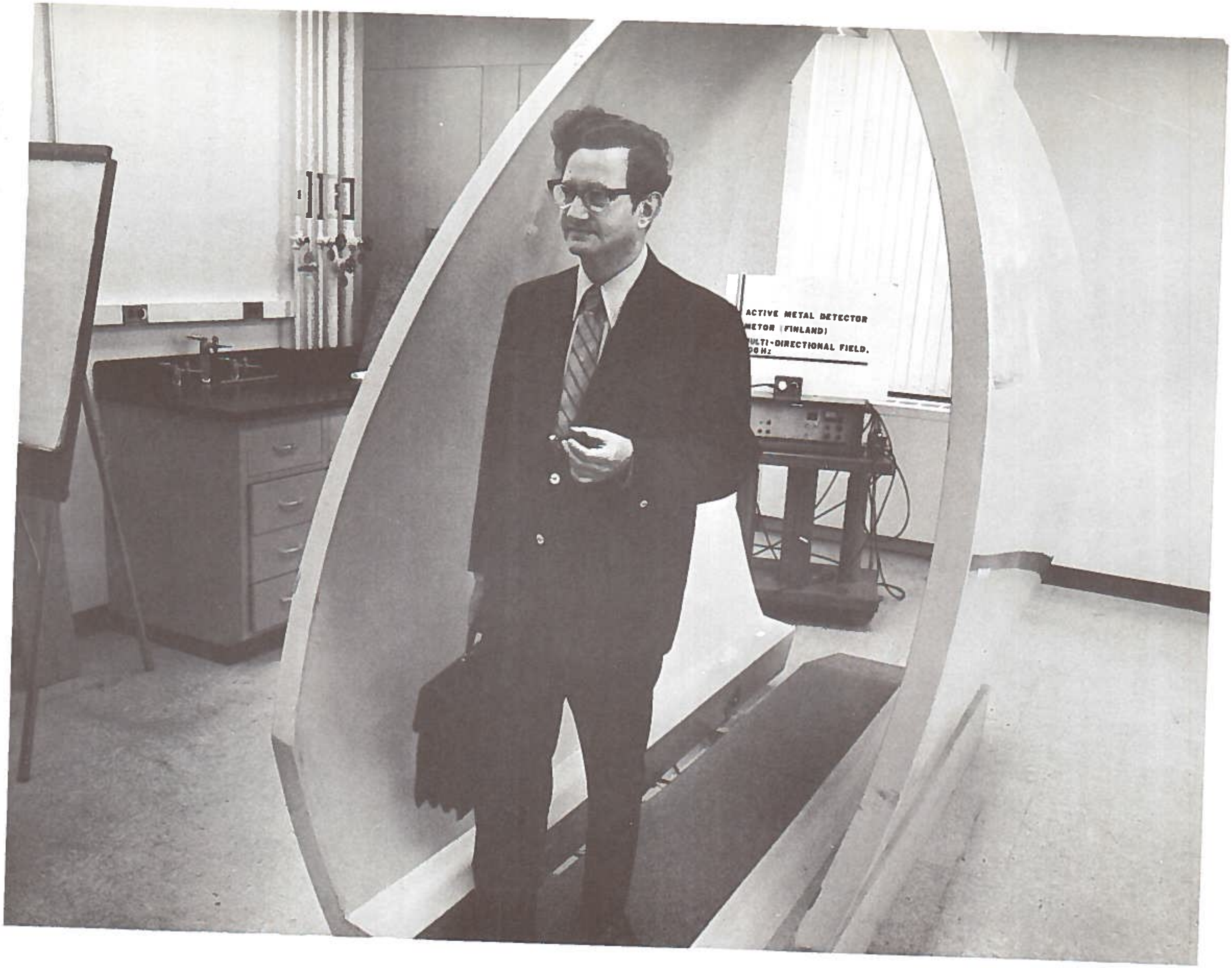

Figure 17. Metor Airport Security Metal Detector

Performance rating: Excellent

Cost effectiveness: Good to excellent.

Magnetic Field: 0.8-2.0 gauss
(Figs. 18-20)
Frequency: 380Hz

Operating Principles: This device operates at a frequency of 380 Hz and employs a primary-secondary coil system in the doorway. The primary coils are located on one side of the arch-shaped doorway and the secondary coil on the other. The field pattern is quite complicated and nonuniform. Several field reversals and changes in direction occur throughout the walkway in order to facilitate pickup of weapons in any orientation. Since only one frequency is used, only two data points are available, magnetization and loss. A front panel adjustment for manual balance is provided and the phase of the reference signal must be adjusted so that introduction of a ferrite rod placed in the doorway causes no unbalance.

Application Status: Detector at Helsinki Airport; two in Germany; two in the Soviet Union.

Characteristics: This device has excellent detectivity but there is a greater tendency than in the Westinghouse unit for false alarms to occur due to men's shoes and also due to bulk metal moving near the unit. On the other hand, special weapons such as the stainless steel or aluminum frame gun or weapons made of beryllium copper are easily detected in any position and orientation. The 3 1/2" knife can be detected at maximum sensitivity but only at the cost of an increased false alarm ratio. Since the balance is manual, occasional readjustment is required. The balancing is a delicate operation and requires skill and aptitude.

Just as in the Westinghouse unit, small changes in the balance cause significant changes in the performance; however, the inherent electronic and mechanical stability of this device are good.

Recommendations: The "Metor" is suitable for all levels of security but will require moderately skilled operating personnel. While the false-alarm rate is likely to be slightly higher than in the Westinghouse unit this device will give a higher protection against the smuggling of concealed firearms because of the greater uniformity of detectivity. Altogether, this seems to be the most cost-effective device in the active walk-through category.

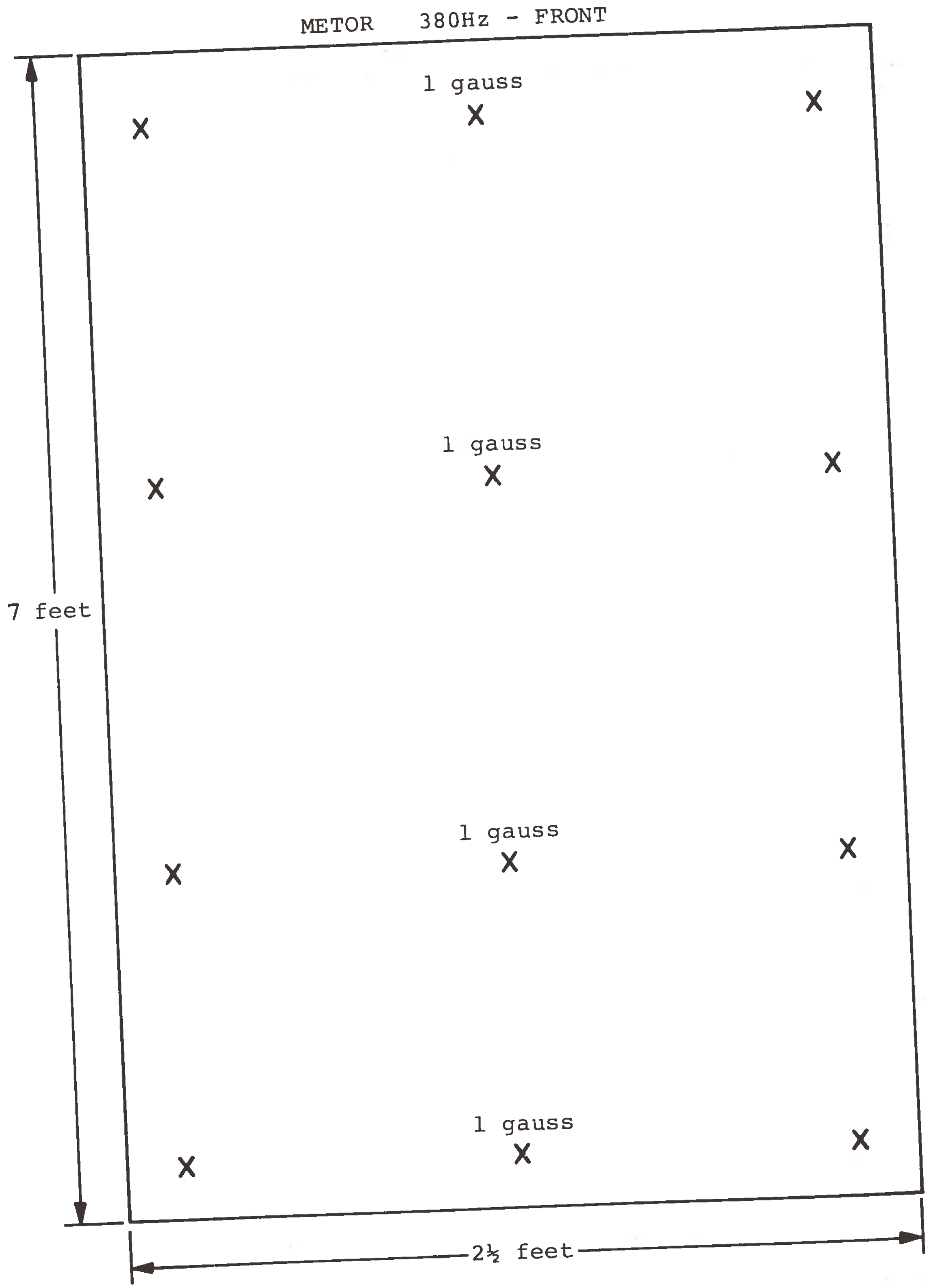

Figure 18. Magnetic Field in Gauss

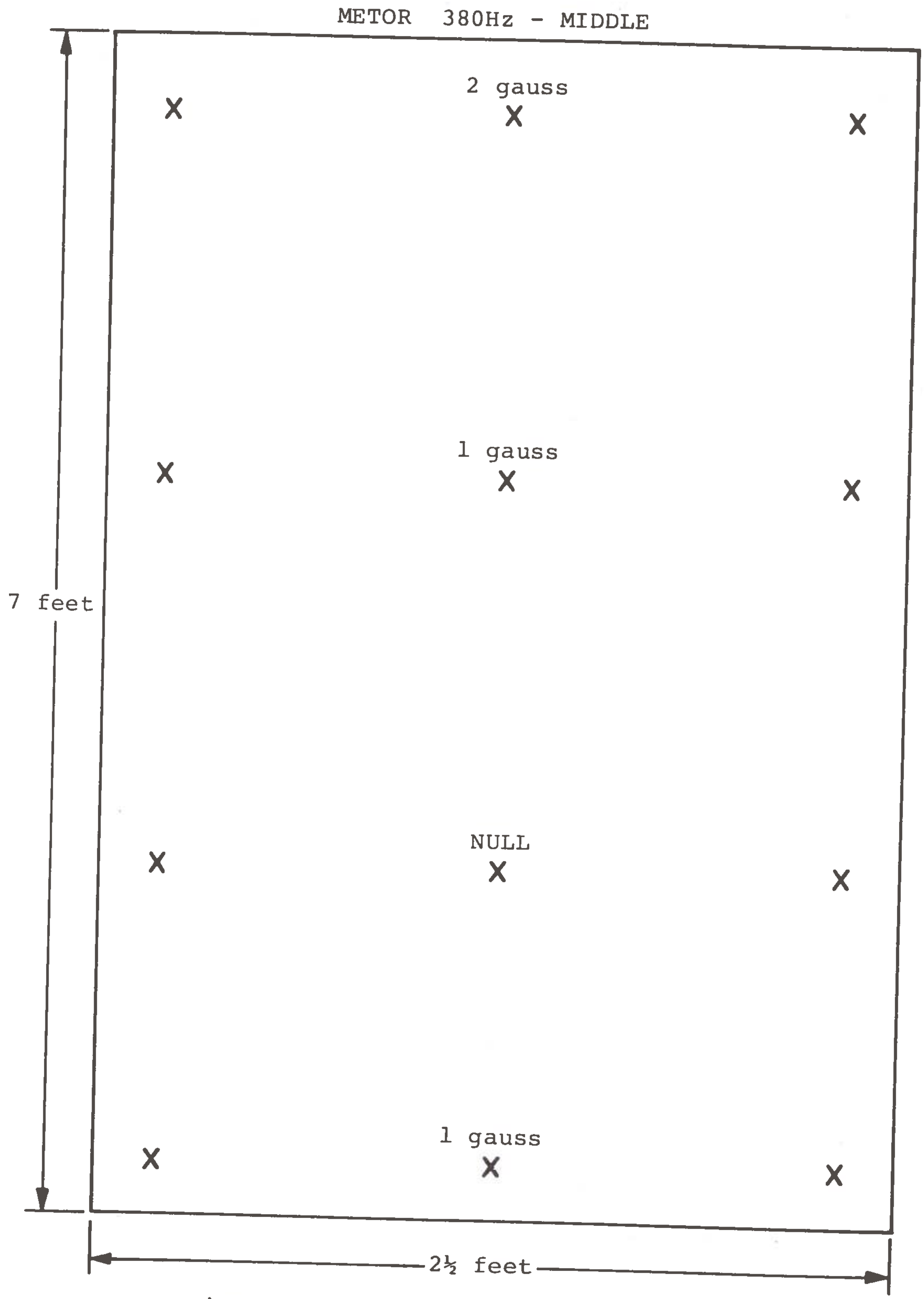

Figure 19. Magnetic Field in Gauss

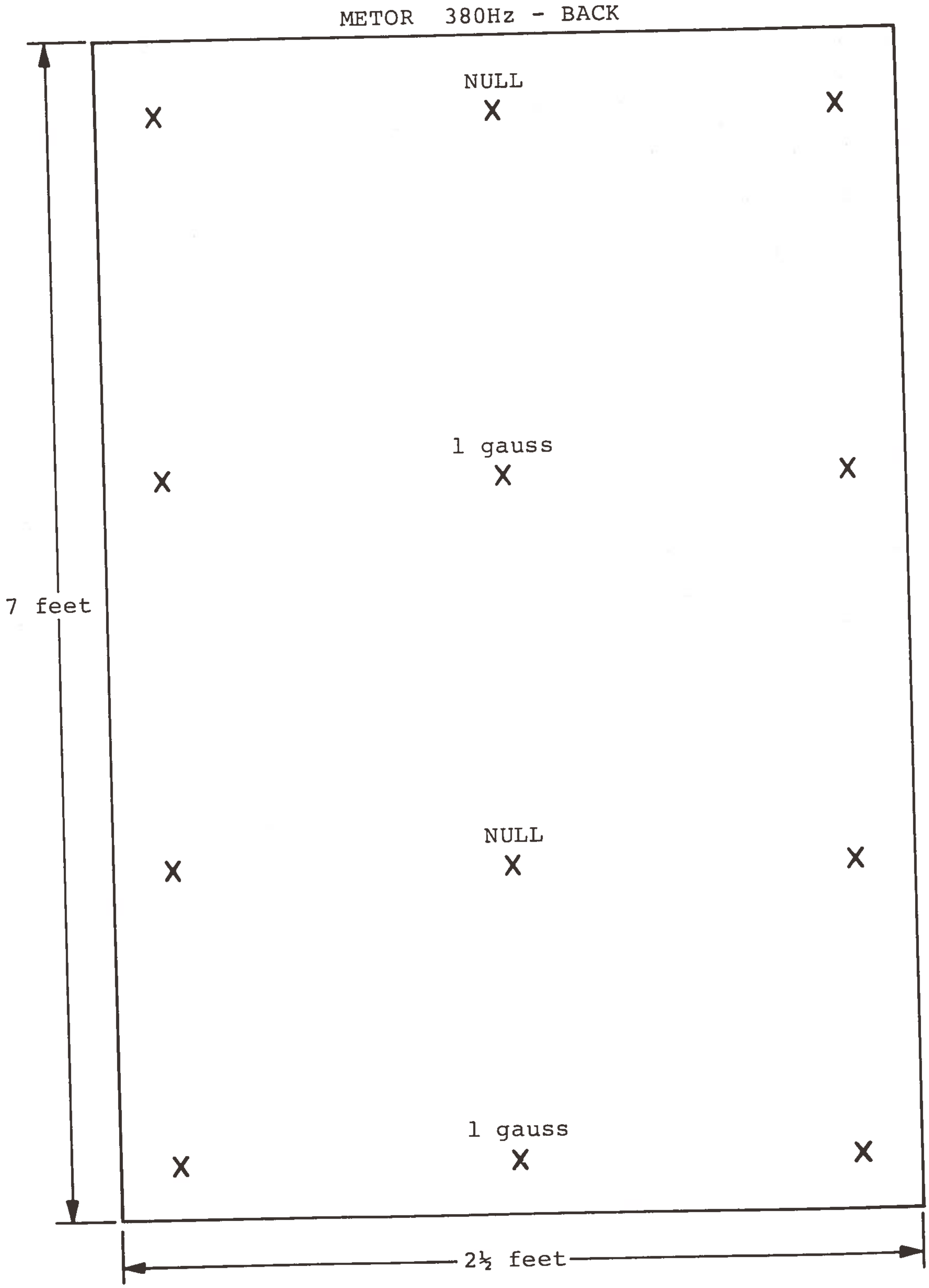

Figure 20. Magnetic Field in Gauss

SUMMARY OF TEST RESULTS

UNIT: Metor

	RIGHT	CENTER	LEFT
HEAD	———	100	———
SHOULDER	100	———	100
CHEST	100	100	100
BELT	100	100	100
POCKET	100	———	100
HIP	100	———	100
LEG	100	100	100

FALSE ALARM RATE: 10%

NOTES: Sensitivity adjusted to 2.5. This unit requires a 20 ft. radius of free space around it.

DETECTOR - ALL METALS

Manufacturer: Rens Manufacturing Co.
P.O. Box 337
Creswell, Oregon 97426

Type of Model No.: Rens Personnel Scanner - PS-5

Mode of Application: Walk-through gate.

Physical Description: 84.5" x 38.2" x 22.5", attractively finished in padded vinyl.

Cost: $3,000.00

Delivery: Off-the-shelf in small quantities.

Technical Evaluation: (based on limited field tests)

Space required: 10 feet in all directions from unit.

Response to extraneous metal objects and electrical disturbances: Low

Likelihood of false alarms: Fair

Operator's skill required: Minor

Need for adjustment: Infrequent

Sensitivity: Will detect all metal objects larger than small knife.

Performance rating: Good

Cost effectiveness: Good

Operating Principles: No description of this device is available and tests were confined to short demonstrations at the factory and at Los Angeles Airport where the unit was used by Pan American Airways. It appears that the coil system is lateral to the passageway and that both sides are used as primary-secondary combinations. The frequency of operation is in the order of 30-40 kHz.

Application Status: Used at Gate 26B in Los Angeles International Airport. Also widely used at mints, weapons factories and in general security applications.

Characteristics: This all-metal detection device is operating at a very high frequency and is therefore subject to false alarms due to cigarette packages and similar articles. Another problem concerns the motion detector and automatic balance design circuit. This circuit involves a very short time constant so that a slowly moving person may be able to smuggle a weapon through the device undetected while the same weapon can be detected on a fast moving passenger. The field distribution on this device, as far as this could be determined during the demonstrations, is good.

Recommendations: Because of the false alarm problem resulting from the use of a high frequency this device is not as useful for high risk situations as it might otherwise be. On the other hand, it is too expensive to use exclusively on low-risk situations.

DETECTOR - ALL METALS

Manufacturer: Excelsior Electronics Co.
Solco Engineering
7448 Deering Avenue
Canoga Park, CA 91303

Type and Model No.: Excelsior SG-2C Metal Detector (Fig. 21)

Mode of Application: Battery-operated, walk-through gate.

Physical Description: 88 1/2" high x 38" wide; weight 50 lbs., plywood construction with walnut exterior. Meter deflection, audio tone (can be monitored with headphones or loud-speaker), amber and red lights, incorporated into multiple thresholds. Sensitivity and threshold controls.

Cost: $1,800.00

Delivery: Off-the-shelf.

Technical Evaluation: (based on extensive laboratory testing at TSC)

Space required: 10 feet in all directions from unit.

Response to extraneous metal objects and electrical disturbances: Low

Likelihood of false alarms: High, due to metal support in men's shoes and sundry small metal objects.

Operator's skill required: Minor

Need for adjustment: Infrequent

Sensitivity: Will detect all metal objects larger than keycase, including many commonly carried innocuous items -

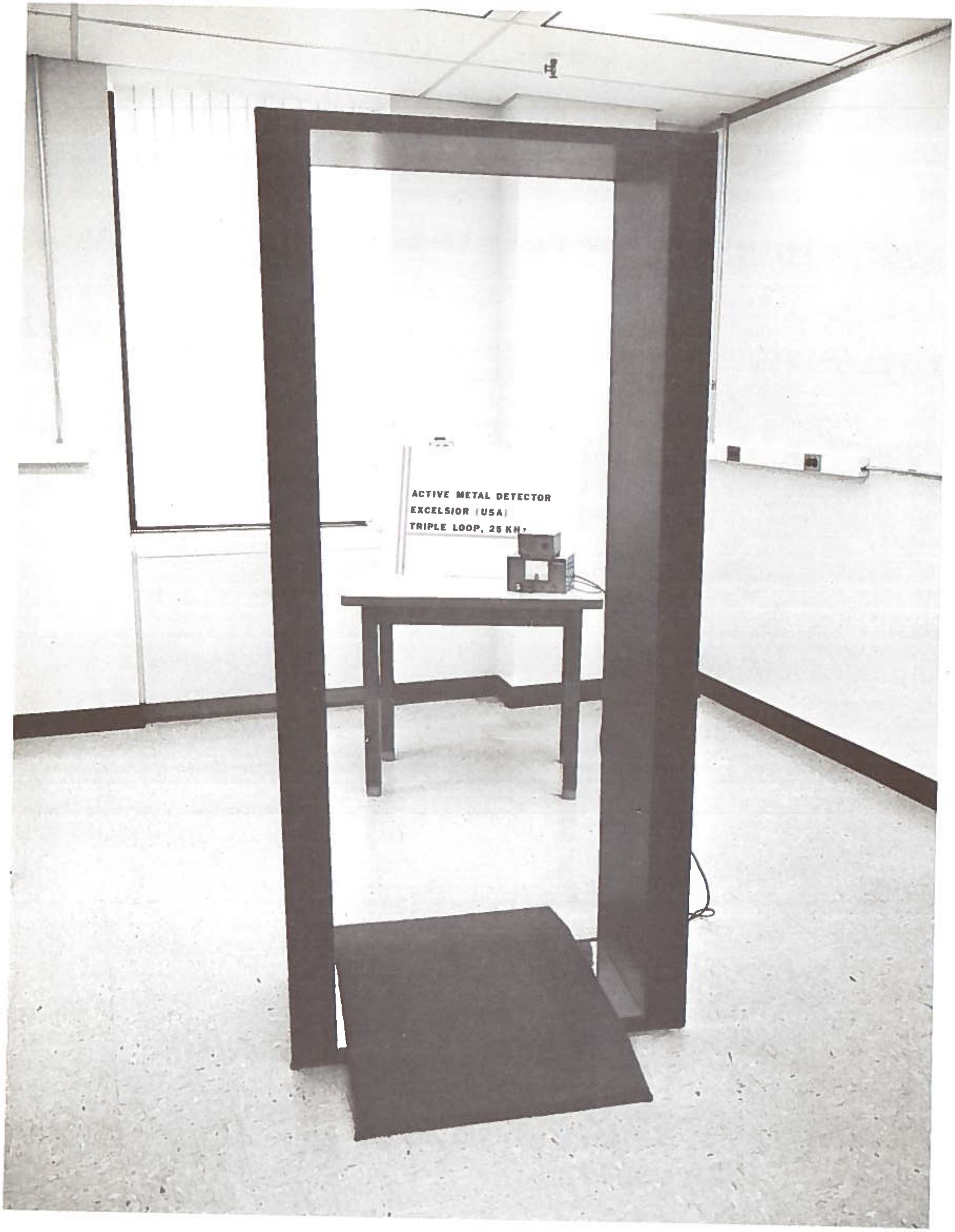

Figure 21. Excelsior SG-2C Metal Detector

although will occasionally permit small weapons to pass through.

Performance rating: Good

Cost effectiveness: Good

Magnetic Field: 0.03-0.3 gauss (Figs. 22-24)

Frequency: 25kHz

Operating Principles: The coil system consists of three coils around the plane of the doorway. These are located at the entrance, center and exit, respectively. The center coil is used as the primary at 25kHz. The outer coils are used as secondaries and are connected in opposition. The presence of a weapon unbalances the coupling and the resulting signal is amplified. The detector consists of rectification into a condensor-resistor network with long time constant.

Application Status: Purchase by Pan American World Airways of at least 25 units.

Characteristics: This is one of the three devices tested at Dulles Airport. The airport experience duplicates and confirms conclusions reached in laboratory tests. Basically, this device suffers from two defects. First, because of the high operating frequency, it will respond to cigarette packages, metal foil tobacco pouches and other metal objects which passengers would not normally remove; this leads to a very high false alarm rate. Second, this coil arrangement leads to a very nonuniform detectivity. While a pack of cigarettes carried in a coat pocket close to the wall of the doorway will sound an alarm, the 30 caliber long-barrel revolver will not register as a weapon (red light) and, in some positions, not even as a suspicious object (amber light).

This unit is battery operated and requires an occasional readjustment as the battery power fades. This adjustment is not difficult but requires some technical ability on the part of the operator. The long time constant on this instrument frequently requires long waiting periods between passengers.

Recommendations: This unit may be used in low risk situations.

EXCELSIOR SG-2C 25 kHz - FRONT

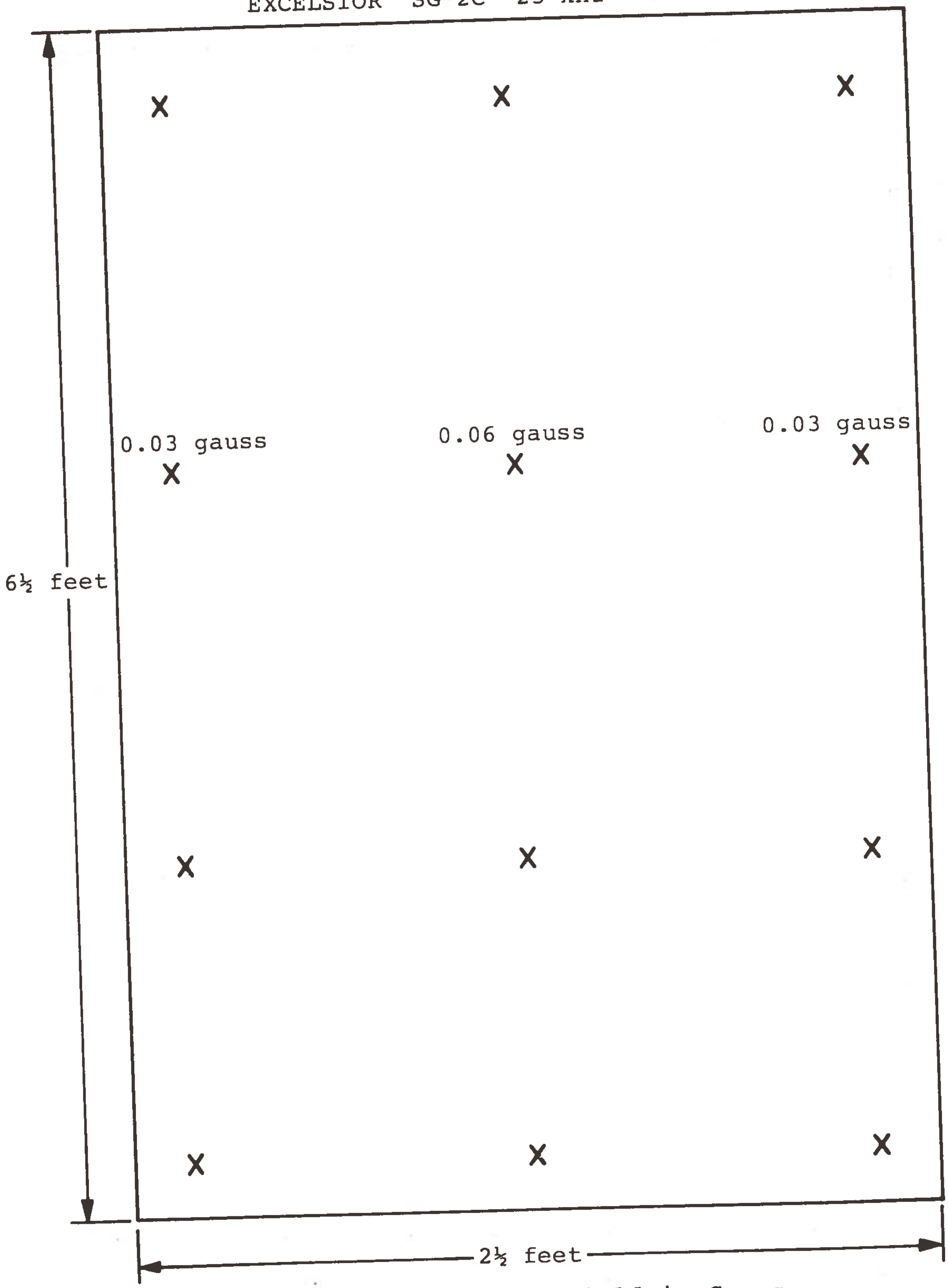

Figure 22. Magnetic Field in Gauss

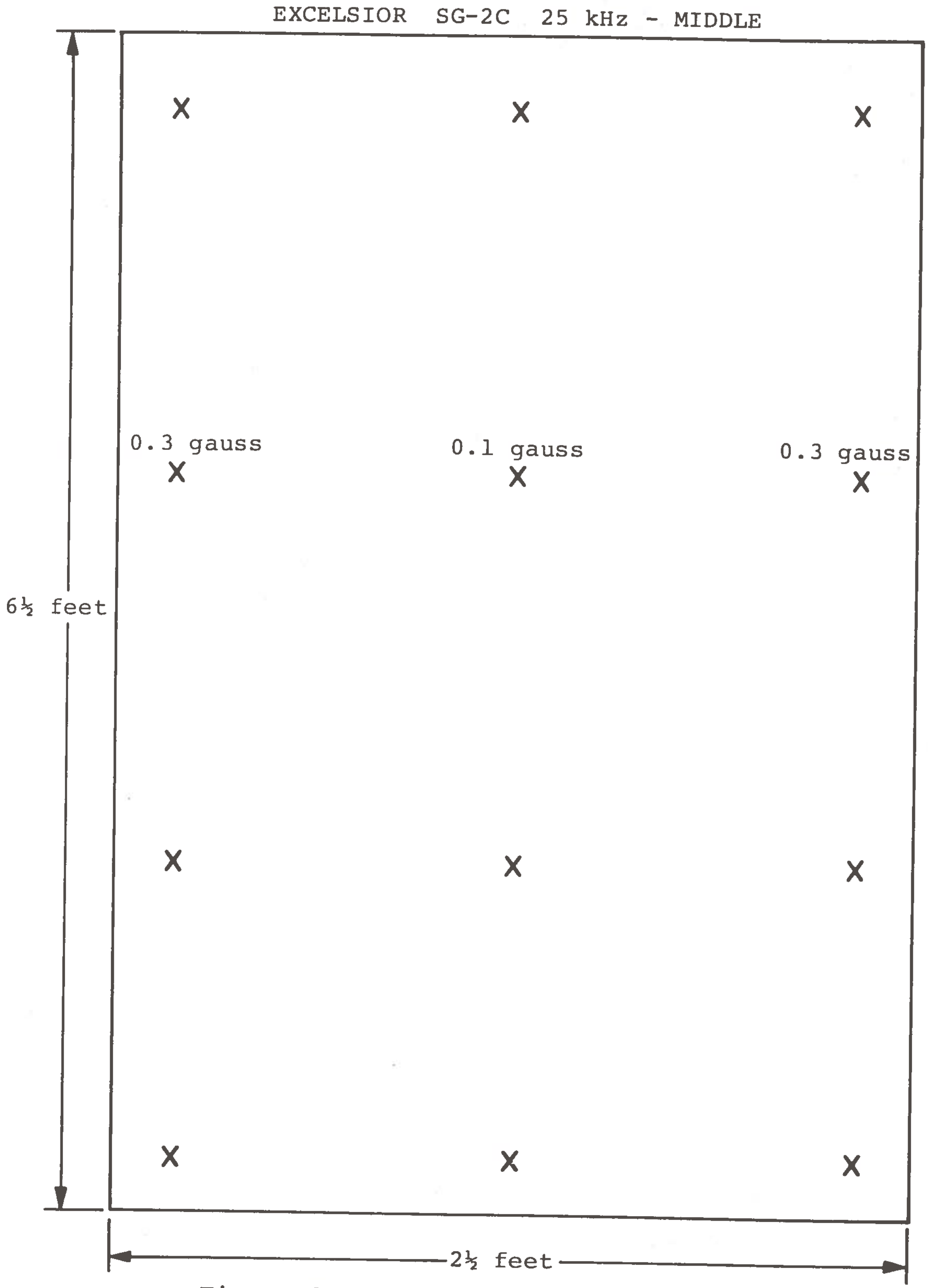

Figure 23. Magnetic Field in Gauss

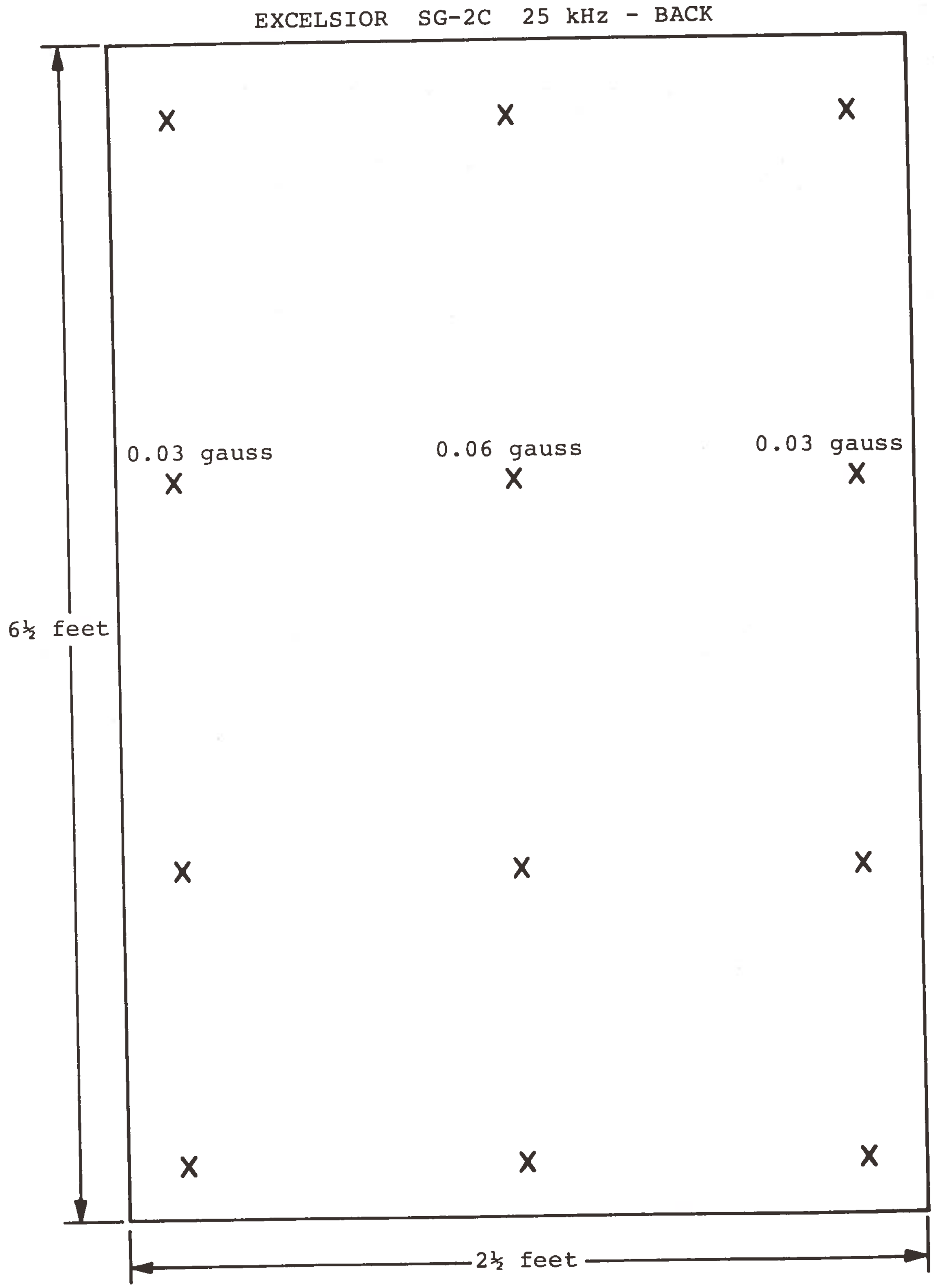

Figure 24. Magnetic Field in Gauss

SUMMARY OF TEST RESULTS

UNIT: Excelsior

	RIGHT	CENTER	LEFT
HEAD		90	–
SHOULDER	90	–	90
CHEST	90	80	90
BELT	90	70	90
POCKET	90	—	90
HIP	90	—	90
LEG	90	90	90

FALSE ALARM RATE: 50%

NOTES: The sensitivity was at minimum. The false alarm rate was nevertheless very high.

DETECTOR - ALL METALS

Manufacturer:	Densok Measuring Instrument Works, Ltd. Nikko Shoji Co., Ltd. Tokyo International Airport Haneda Ota-ku, Tokyo, Japan
Type and Model No.:	"Magnetic Eye" (Type-MGG) (Fig. 25)
Mode of Application:	Walk-through rectangular loop coil gate.
Physical Description:	Lightweight enclosed coil about 1 inch in diameter, 8 ft. high, 3 ft. wide. Three warning lights, for small, medium and large weapons, are provided in a separate metal cabinet.
Cost:	$1,200.00
Delivery:	Off-the-shelf
Technical Evlauation:	(based on extensive laboratory testing at TSC)

Space required: 20 feet in all directions from unit.

Response to extraneous metal objects and electrical disturbances: High

Likelihood of false alarms: High, due to metal support in men's shoes and sundry small metal objects; low to medium, due to metal foil wrapping.

Operator's skill required: Minor

Need for adjustment: Infrequent to occasional, depending on initial installation.

Sensitivity: Will detect all metal objects larger than small knife.

Performance rating: Fair

Cost effectiveness: Fair to good

Magnetic Field: 0.1-0.8 gauss (Fig. 26)

Frequency: 3400Hz

Operating Principles: This device has a single coil in a bridge circuit operating at 3400 Hz. An unbalance in the bridge caused by impedance changes in the coil is used to stimulate an oscillator at an amplitude corresponding to the unbalance signal. Three separate amplifiers are used to actuate the relays which light the three alarm lamps. Each amplifier has a different basic gain to permit discrimination of large, medium and small objects. Manual adjustment of the gain setting is provided. The initial balance of the bridge is accomplished manually and requires some degree of technical aptitude. A motion detector permits slight balance changes to occur without need for manual balance adjustments.

Application Status: Used at Tokyo Airport.

Characteristics: Because of the single coil arrangement this unit has a very nonuniform sensitivity. An effort has been made to shield the part of the coil under the walkway from responding to men's shoes. Nevertheless men's shoes are a frequent source of false alarms. This unit requires special installation since the coil is not self supporting.

Recommendations: In view of the variable sensitivity this device is not suitable for high-risk applications. There are no particular virtues which would make the unit desirable for low risk use.

Figure 25. Densok "Magnetic Eye" Type MGG

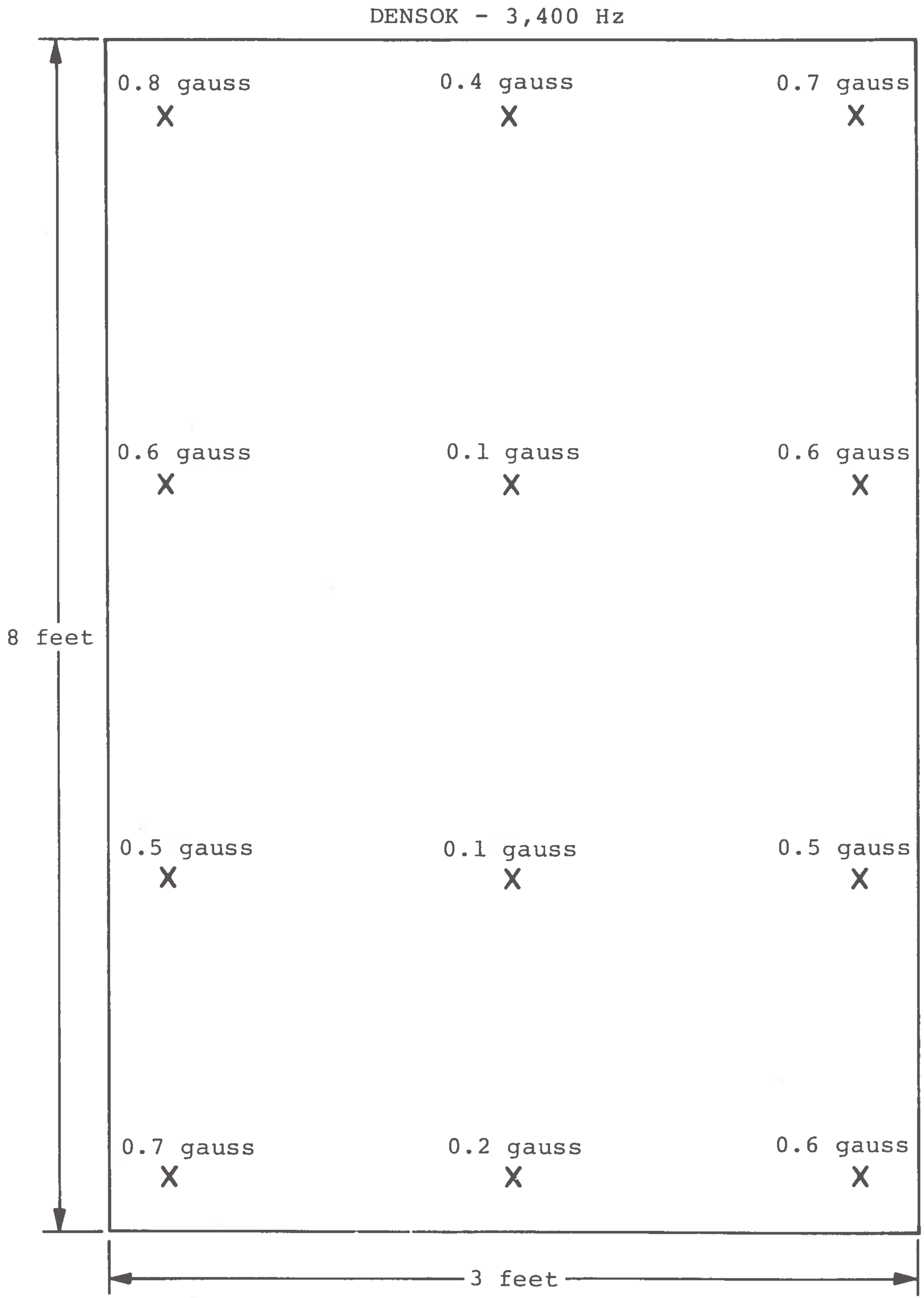

Figure 26. Magnetic Field in Gauss

SUMMARY OF TEST RESULTS

UNIT: Densok

	RIGHT	CENTER	LEFT
HEAD	———	10	———
SHOULDER	30	———	30
CHEST	30	10	30
BELT	50	10	50
POCKET	30	———	30
HIP	30	———	30
LEG	50	50	50

FALSE ALARM RATE: 30%

NOTES: This device has three sensitivity controls; when these are adjusted to a high level of sensitivity the false alarm rate is 100% on men's shoes. If adjusted so that men's shoes cause no alarms then the detectivity is 0.

DETECTOR - MAGNETIC METALS

Manufacturer:	Infinetics, Inc. 1601 Jessup Street Wilmington, DE 19802
Type and Model No.:	"Friskem" Type III walk-through station
Mode of Application:	Semifixed tower type, walk between mounted doorway panels.
Physical Description:	Separation of changeable decor panels about 3 ft., about 6 ft. high, with different indicators for different locations on subject.
Cost:	$1,900 (1), $1,653 (10-49), $1,596 (50 or more)
Delivery:	Off-the-shelf
Technical Evaluation:	(based on limited field tests) Space required: About 10 feet in every direction from unit. Response to extraneous metal objects and electrical disturbances: Medium; unit can indicate the direction from which the disturbance originates. Likelihood of false alarms: Medium, although location discrimination minimizes this problem. Operator's skill required: Low to medium Need for adjustment: Occasional Sensitivity: Will detect most objects constructed of magnetic metal larger than a small knife. Performance rating: Good to excellent Cost effectiveness: Good to excellent

Operating Principles: This unit differs from other magnetic-detection units in the arrangement of sensors which are located in balanced pairs within each panel. Furthermore, the display indicates the location of the weapon.

Application Status: At the present time only one or two experimental units exist. However, Eastern Airlines has ordered 219 units which are now being manufactured. One unit will be acquired at TSC.

Characteristics: The device could only be tested during a 3 hour period at Kennedy Airport in New York during National Transportation Week. Because this device is for magnetic metals, it exhibits the same sensitivity to residual magnetism on small objects as other similar devices and has the same lack of sensitivity toward objects made in part or in total of nonmagnetic metals. The device does, however, constitute a definite improvement over the simpler magnetometers. In the simpler units there is no indication of the origin of an alarm signal while in the Type III unit the position of the object is indicated. This makes it possible to discount alarms due to men's shoes in many instances. Further, it appeared from the brief testing conducted that the arrangement of sensors in the panels greatly improved the uniformity of detection capability with regard to orientation except in the horizontal plane. Further details must await in-house tests which will be conducted in the Fall of 1971.

SUMMARY OF TEST RESULTS

UNIT: Infinetics

	RIGHT	CENTER	LEFT
HEAD	———	30	———
SHOULDER	70	———	30
CHEST	70	30	30
BELT	50	75	70
POCKET	70	———	50
HIP	50	———	70
LEG	50	30	30

FALSE ALARM RATE: 30%

NOTES: Sensitivity and threshold adjustments set for a tolerable false alarm rate due to shoes.

Recommendations: This unit is not fully suitable for high risk applications in international flights. On the other hand, it may very well be suitable in intermediate risk situations. The use of this unit could have prevented the types of air piracy which have occurred on domestic flights in the USA which were carried out with large or medium caliber fire arms. Unlike some other magnetic metal detection units it is more than a psychological deterrent and probably can be used in any but the highest risk situation.

DETECTOR - MAGNETIC METALS

Manufacturer:	SPS, Inc. P.O. Box 1278 Greenville, TX 75401
Type and Model No.:	Gamma 2WD Concealed Weapon Detector (Fig. 27)
Mode of Application:	Walk between two or more 3-inch cubes attached to posts in a semipermanent fashion.
Physical Description:	Detector consists of 3-inch cubes to be attached to the side of existing walkways or posts or poles, separated by about 3 feet.
Cost:	$950.00 (1), $900 (10 or more)
Delivery:	Off-the-shelf
Technical Evaluation:	(based on extensive laboratory tests at TSC) Space required: About 20 feet in every direction from sensor units. Response to extraneous metal objects and electrical disturbances: Medium, especially if large objects constructed of magnetic material are in motion in the vicinity. Likelihood of false alarms: Medium, although location discrimination reduces this problem. Operator's skill required: Low to medium. Need for adjustment: Occasional, especially dependent on attachment of sensor units to posts or doorway. Sensitivity: Will detect many objects constructed of magnetic metal larger than a small knife provided the sensor units are properly located and maintained.

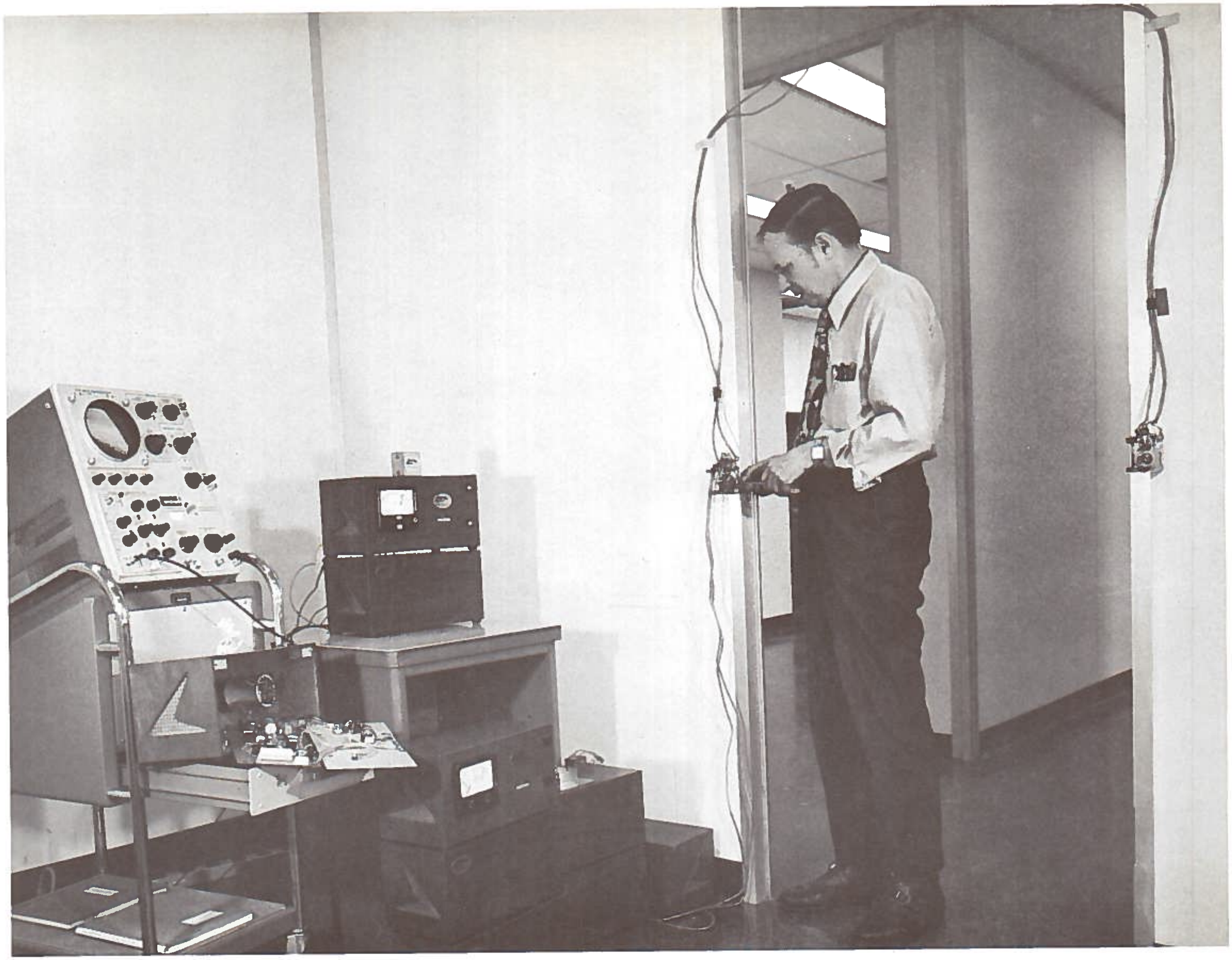

Figure 27. SPS Gamma 2WD Concealed Weapon Detector

Performance rating: Good

Cost effectiveness: Good

Operating Principles: This device is a second harmonic fluxgate magnetometer. Two sensors are provided with the unit but any number could be used. The sensors are individually adjusted in orientation so that, in the absence of magnetic material in the passageway, there is no signal. The primary coils are arranged in series and the secondary coils in parallel so that any one sensor can actuate the alarm. The position of the sensors in the passageway is left to the user.

Application Status: Presently purchased for ten or more gate positions at airports in the U.S.A.

Characteristics: This is one of the lowest priced walk-through weapons detectors and does not provide means for installation of the sensors so that installation costs must be allowed for in comparing costs with other units. On the other hand the user has the choice of positioning the sensor wherever it may be convenient.

This is a fluxgate magnetometer and therefore responds strongly to objects which possess residual magnetism. This is often the case with metal shanks in men's shoes.
Sensor sensitivity drops off rapidly with distance and for this reason more sensors than the two provided with the instrument are desirable.

As tested in the laboratory, using two sensors, on either side of a doorway, the instrument will not reliably respond to a single-blade 3.5 inch knife or to an aluminum frame .38 caliber short gun. A regular .30 caliber long-revolver was at first easily detected; after demagnetization, this same weapon readily went undetected. When a sensor was placed close to the floor, about 8 inches up on the doorway, the false alarm rate due to men's shoes was very high. As in all units, sensitivity controls are provided to permit a compromise between false alarm rate and detectivity, but in view of the nonuniformity of the detectivity with distance from the sensors it is easy to defeat this device when the sensitivity is adjusted to yield a low false alarm rate.

SUMMARY OF TEST RESULTS

UNIT: SPS "Gamma II"

	RIGHT	CENTER	LEFT
HEAD	———	0	———
SHOULDER	0	———	50
CHEST	50	20	100
BELT	100	20	50
POCKET	50	———	20
HIP	20	———	0
LEG	0	0	0

FALSE ALARM RATE: See below

NOTES: The percentages in the table refer to sensitivity settings of $\pm$10 divisions. Under these circumstances the device will pick up elevators and from time to time there are fortuitous alarms. The false alarm rate due to shoes and small magnetized objects can be minimized by correct positioning of sensors. In the test above one of the sensors was set at the right "Belt" level and the other at the left "Chest" level.

<u>Recommendations</u>: The difficulties of installation and adjustment of the sensors nullify the advantages of low unit cost.

DETECTOR - MAGNETIC METALS

Manufacturer:	Infinetics, Inc. 1601 Jessup Street Wilmington, DE 19802
Type and Model No.:	"Friskem" Walk-through station Type I (Fig. 28)
Mode of Application:	Semifixed tower type, walk between poles.
Physical Description:	Separation of poles 30" to 36", 6 ft. high, 1 1/4" diameter.
Cost:	$1,300 (1), $1,131 (10-49), $1,092 (50 or more)
Delivery:	Off-the-shelf
Technical Evaluation:	(based on extensive laboratory tests at TSC)

Space required: About 20 feet in every direction from unit.

Response to extraneous metal objects and electrical disturbances: Medium, especially if large objects constructed of magnetic material are in motion in the vicinity.

Likelihood of false alarms: Medium, especially due to metal support in men's shoes.

Operator's skill required: Low

Need for adjustment: Infrequent

Sensitivity: Orientation sensitive. Will detect most objects constructed of magnetic metal larger than a small knife.

Performance rating: Fair to good

Cost effectiveness: Good

Figure 28. "Friskem" Walk-Through Station Type 1

Operating Principles: This device is a fluxgate magnetometer. The electronics incorporates separate controls for sensitivity and threshold. The sensitivity control determines amplifier gain and the threshold control determines the point at which the alarm, in this case a blue light, flashes. Provisions are made for both automatic and manual balancing and the manual balancing control is used to adjust the initial balance in the automatic mode, so as to enable the unit to operate in the presence of large fixed metallic objects. The sensors located in the towers are arranged in balanced pairs, so as to minimize effects due to large objects moving at a distance, such as trucks, metal doors and elevators. Provisions are also made for remote indication.

Application Status: Presently installed and used at more than 400 gate positions throughout the U.S. and elsewhere.

Characteristics: Although this unit appears to be one of the better designed and constructed models of the simple magnetic detection devices, it suffers from the same inherent problem, in that it is impossible to eliminate false alarms due to slightly magnetized innocuous metal, while at the same time maintaining good detectivity for a demagnetized gun or knife. Like other magnetic detection units, detectivity is orientation and position sensitive. Despite the balanced pair detector design the unit will register a 5" bar magnet at 30 ft., but pass a .38 caliber aluminum frame revolver without alarm. Trucks, elevators, and baggage carts have an effect at considerable distances.

Recommendations: This device represents a cost effectiveness compromise solution to the minimum security problem. If this unit can be placed in a quiet environment it can be used for the positive detection of conventional guns of .38 caliber.

DETECTOR - MAGNETIC METALS

Manufacturer:	Schonstedt Instrument Co. 1775 Wiehle Avenue Reston, VA 22070
Type and Model No.:	Magnetic Surveillance SD2 (Fig. 29)
Mode of Application:	Walk between poles
Physical Description:	Lightweight, including small pedestals for poles - separation of 30" to 36", 5 ft. high, 1 1/8" diameter.
Cost:	$1,000.00
Delivery:	Off-the-shelf
Technical Evaluation:	(based on extensive laboratory tests at TSC)

Space required: About 20 feet in every direction from unit.

Response to extraneous metal objects and electrical disturbances: Medium, especially if large objects constructed of magnetic material are in motion in the vicinity.

Likelihood of false alarms: Medium, especially due to metal support in men's shoes.

Operator's skill required: Low

Need for adjustment: Infrequent

Sensitivity: Orientation sensitive. Will detect most objects constructed of magnetic metal larger than a small knife.

Performance rating: Fair

Cost effectiveness: Good

Figure 29. Schonstedt Magnetic Surveillance SD2

Operating Principles: This device is a fluxgate magnetometer.

Application Status: Presently installed and used at about 70 gate positions in the U.S. (including several at Dulles Airport.)

Characteristics: This model behaves very much like the SPS model and detectivity is largely dependent on the residual magnetization, orientation and position of the weapon. A demagnetized gun or knife as well as the aluminum frame weapon can easily be carried through undetected when the sensitivity is set for a low false alarm rate.

Passengers with luggage standing near the unit are likely to set off the alarm. This is particularly true for purses and briefcases with magnetic metal frames. False alarms also occur as a result of electrical transients in the environment. The laboratory tests indicate that this unit is susceptible to a high false-alarm rate when installed in a building that is electromagnetically "noisy" (i.e. elevator systems, radio communications, etc.).

Recommendations: If this unit is to serve any operational function such as facilitating an occasional spotcheck on a person for concealed weapons the following precautions must be taken:

A. The space (about a 20 ft. radius) around the unit must be cleared of passengers.

B. The suspect must deposit hand-luggage and metal objects outside the unit.

C. Sensitivity must be at maximum setting.

Under these conditions most ordinary firearms and large knives (4" by 1" blade) will be detected if carried in a natural position and location on a person. If the suspect carries a small demagnetized gun, detection can not be assured; furthermore, alarms due to the suspect's shoes may occur if these contain large metal shanks.

SUMMARY OF TEST RESULTS

UNIT: Schonstedt

	RIGHT	CENTER	LEFT
HEAD	———	0	———
SHOULDER	20	———	20
CHEST	50	20	50
BELT	20	20	20
POCKET	20	———	20
HIP	20	———	20
LEG	20	20	20

FALSE ALARM RATE: 20%

NOTES: This device strongly responds to shoes and for this reason the sensitivity has to be kept low; even so, a 20% false alarm rate is usual. Threshold is set to 10th position. Aluminum frame weapons give lower detectivity values.

INSTALLATION REQUIREMENTS

All units tested are sensitive to metal carried past the outside of the housing of the sensors or coils. The degree of interference depends on the size of the object. Large objects such as metal suitcases, steel furniture, baggage carts, trucks and trolleys have an effect at considerable distances. It is therefore important to examine the question of installation very carefully.

The most convenient place for locating a unit is a boarding ramp. For maximum security, however, the passengers' hand luggage would have to be examined at tables in front of the detector and then conveyed past the detector to the other side on a conveyor belt. Since hand luggage may include metal suitcases, the conveying operation must be coordinated with the examination of passengers in a discontinuous operation. Boarding a full complement of passengers for a 747, for example, in this manner poses a logistics problem of considerable magnitude.

Where concourses are part of the airport, single units could perhaps be installed in each concourse to serve all gates located in the concourse. This, however, involves a logistics problem since the flow of passenger traffic would be impaired when the unit is in use. Airports with large open areas such as Dulles and several of the terminal buildings at Kennedy could be modified with a minimum of cost to accommodate spatially well isolated detection devices. At other airports hand held, all-metal detection friskers may present the most practical alternative for the screening of passengers.

A suitable layout is shown in Figure 30. It is assumed that several inspectors for hand luggage are available. In this arrangement, groups of passengers are allowed to proceed to the examiners desk. Their hand luggage is searched and passed to the pickup table while the passengers proceed via the walk-through gate to the inspection area. After clearance they collect their luggage and the next group enters.

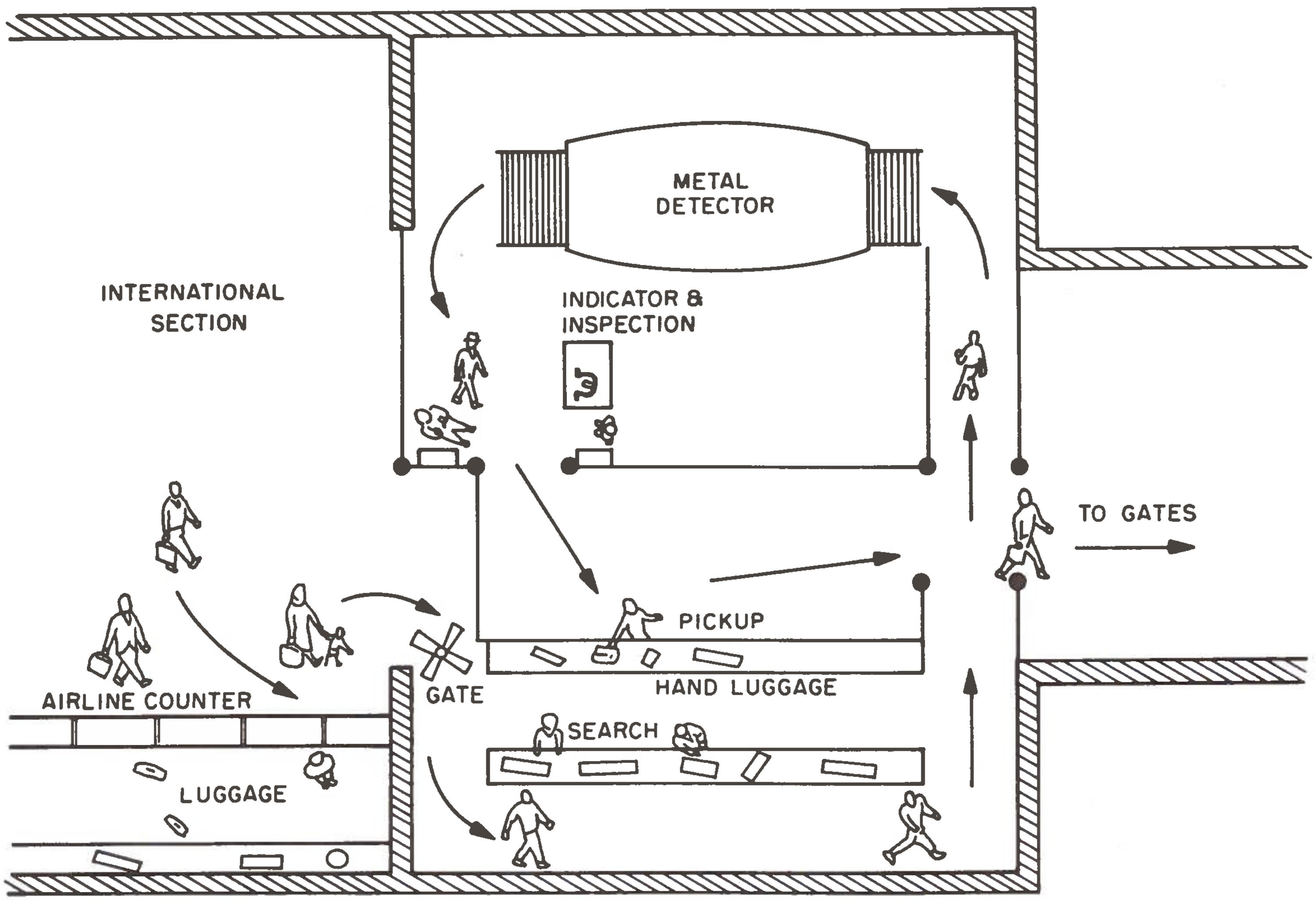

Figure 30. Suggested Layout for Metal Detection Stations

SUMMARY

From the results of this investigation it may be seen that weapons detection requires a separate treatment of passengers and hand luggage. The most cost-effective means of assuring security is to screen passengers (after deposition of all metal objects) by means of a hand held search device such as the Rens "Squealer". On those domestic flights where minimum security procedures are acceptable, any of the magnetic metal detection units and the less expensive all-metal units, i.e. Densok or Excelsior, may be used for psychological, deterrence or to establish cause for search by hand-held friskers. For more serious work, certainly wherever carry-on-luggage is searched, a device at least as sophisticated as the Infinetics Type III detector followed by a hand-held locator is recommended. The Westinghouse and Outokumpu devices are also applicable. It should also be remembered that these devices require skilled personnel and spatial isolation of about 20 feet in any direction.

Concerning maximum security on international flights it again appears that search by hand-held devices is the only means of reliably disclosing the presence of any and all weapons including that of 3.5" knives, larding needles, awls, stillettos or other close combat weapons. Where such objects are not considered to be weapons the use of the Outokumpu Oy device is recommended. Also acceptable in this category is the Boekels device and the Rank unit followed by a hand frisker. The Westinghouse unit is recommended for use in any of the maximum security modes only when the walkway is raised by 5"-6" and single frequency operation is used. The Rens unit may be used only if passengers can be asked to take off belts and shoes.

EVALUATION OF SURVEILLANCE TECHNIQUES FOR WEAPONS AND EXPLOSIVES (LUGGAGE)

Technologically, the detection of weapons and explosives in luggage without search is more difficult than the detection of concealed metallic objects carried by passengers. Commercial detectors for this purpose are therefore considerably more expensive than metal detectors. As in the case of metal detectors, there exists the need for reliable test and performance data of candidate commercial detection systems.

X-RAY INSPECTION SYSTEMS.

Various civil aviation security situations exist where x-ray inspection techniques might be of potential value:

(1) search of luggage after a bomb threat,

(2) routine search of carry-on luggage,

(3) routine search of checked luggage, and

(4) passenger surveillance.

Although very-low-dosage x-ray equipment might be developed to examine passengers at radiation levels lower than those experienced during a flight at high altitudes, the application of x-rays for passenger surveillance has not been considered at this time, because of uncertainties in exposure standards and the availability of safe metal-detection equipment. Therefore, only the first three applications are discussed further.

X-ray devices for the examination of packages at post-offices or custom stations have been developed and field tested by the pertinent user groups during the last two years and the question arises whether any of this equipment is suitable for use in civil aviation security.

High-Dosage X-Ray Inspection

The use of x-ray fluoroscopy began in 1896 [1] and has become a routine technique in medical radiography [1-5]. Essentially, a beam of x-rays is passed through the object to be examined, and a fluorescent screen records the varying intensities of the x-ray beam attenuated in differing degrees by the materials composing the object. The x-ray dosage required for simple fluoroscopy will fog photographic film (considered "high-dosage"). Heavy shielding, usually 1/8" or more of lead, is required to protect the operator and others from the x-ray beam and stray radiation.

A survey of commercially available equipment has been initiated with preliminary results as follows: A simple x-ray fluoroscopic system has been used at New Orleans Airport to inspect luggage after a bomb threat. The system utilizes a Kramex 80 kv x-ray source with a fluoroscopic screen viewed by the operator through a mirror. It was constructed by Louisiana X-Ray Sales of New Orleans. Inquiry by letter and telephone was not successful in eliciting a quotation for a duplicate of this system, since the company is no longer interested in constructing inspection systems. However, a Kramex source has been ordered from New England X-Ray and Electronics, with delivery expected at TSC in July, 1971. A Westinghouse radiographic amplifier screen has also been ordered, with delivery expected in August, 1971, for an evaluation of this type of screen in comparison with conventional fluoroscopic screens.

Quotations have been received from Lico, Inc., for the Philips Electronics Airport Baggage System at $10,700, based on a larger size version of model Radifluor 360, now available off-the-shelf. Some preliminary experiments were conducted with the Radifluor 360 equipment, indicating that a 3-mil copper wire could be observed as far as 4 inches from the fluorescent screen. However, the image could be masked by covering the wire with a 1-inch-thick book, as a result of scattered radiation.

A quotation on another "high-dosage" x-ray inspection system was received from Cenco/Medical/Health Supply Corporation of Chicago. The equipment contains a two-station mobile baggage inspection unit with two 24" belt conveyors for continuous fluoroscopic operation at 100 kvp and 4 ma. The equipment is contained in a mobile van that is self-powered, heated and air-conditioned. The quotation was for $21,000 with 60-day delivery.

LOW-DOSAGE X-RAY INSPECTION

One may define "low-dosage" x-ray inspection as operating below the level of radiation that will fog photographic film. It should be noted that various types of film - color, high speed, low speed, movie film, etc. - differ substantially in their sensitivities to x-rays. The most sensitive film, that made specially for x-ray work, might be assumed to be an insignificant item in travelers' luggage.

An essential feature of all low-dosage devices is electronic storage to form and display an image produced by a single short exposure of an object to the x-ray beam. There are available two types of low-dosage systems: (1) equipment which "floods" the entire field of view with x-rays simultaneously and (2) equipment which "scans" the field of view with a narrow pencil of x-rays.

The former is similar to the high-dosage equipment, in that an image is formed by the image storage system while all parts of the object are exposed to the x-ray beam. Owing to image storage, the required dosage is reduced since less time is needed for the exposure. The dosage is also reduced by using a light amplifier to increase the sensitivity of the screen. Equipment of this type identified by a preliminary survey includes the following: (a) The Bendix-Ray Inspection System, where a dosage as low as 0.05 milliroentgen (mr) is claimed to be sufficient for inspection. Quotations range from $35,700 per single unit to $24,000 for quantities of 10. The detector unit consists of an 18" x 24" fluoroscopic screen, a light amplifier, and a closed circuit TV camera. The Post Office has purchased this equipment. (b) The Baird-Atomic "Film-Safe" Parcel and Mail Inspection System, with two units delivered to U.S. Customs. The estimated cost of an Airport Baggage Inspection System is $55,000, for small quantities. With a viewing screen 24" x 32", it is estimated that 1 to 3 mr are required per exposure. (c) A system constructed by American Science & Engineering for the Post Office.

A unique scanning type system, Model AM-x212, Micro-Dose X-Ray Parcel Inspection System, is under construction by American Science and Engineering, also for delivery to the Post Office. This equipment uses a collimated "flying spot" x-ray beam which scans in the vertical direction while the luggage is carried in the horizontal direction by a conveyor belt. Preliminary tests of the resolution of the stored image have been carried out on the demonstration model at the Cambridge plant. It should be noted that the scanning x-ray beam does not produce as much scattered radiation as the conventional flooding beam, in which secondary radiation from a large x-ray absorber may obscure the image of a small object, such as a fine wire. The dosage is less than .01 mr per image. The equipment is quoted at $38,425.

VAPOR DETECTORS

These devices can indicate the presence of trace quantities of effluents characteristic of explosives. In an initial survey three promising candidate detectors were identified. These are the "Chemical Vapor Analyzer", a mass spectrometer system manufactured by Varian; the "Vapor Trace Analyzer", a gas chromatograph system manufactured by Hydronautics-Israel; and a bioluminescence detector manufactured by RPC Corporation. All three have been ordered; the Varian unit was delivered in March, the RPC unit in June and the Hydronautics equipment is scheduled for delivery in July. Consequently, detailed performance tests have been made only of the Varian unit which has exhibited extremely high sensitivity for dynamite. Concurrently, a Perkin-Elmer 900 gas chromatograph has been adapted for determining the composition of specific effluents. The various devices and their operation are discussed in the following section.

MASS SPECTROMETRY

Mass spectrometry involves the separation of gaseous ions according to their mass-change ratio. Neutral molecules are first converted into gaseous ions in an ion source. Although the field of mass spectrometry dates back to the analysis of positive rays by J.J. Thomson in 1907 and the first mass spectrograph of Aston in 1919, the mass spectrometer as a truly analytical instrument owes much to the development of electronic techniques during the last decade(8-11). This fact is borne out by the large number of references (1696) cited in a review(12) of the two-year period 1968-69.

The principal building blocks of a mass spectrometer are shown in Figure 31. They comprise a sample introduction system, an ion source, a mass analyzer, and an ion detector. Not shown are the necessary vacuum pump and accessories. There are many ways in which any one of these components can be made to function; the performance of a particular mass spectrometer, therefore, depends both on the type of building blocks and how they are combined. The features common to all are that once the substance to be analyzed is partially ionized in the ion source the ions are sorted according to their mass-change ratios by the action of magnetic and/or electric fields in the mass analyzer section, and the rate at which such ions pass through the analyzer is measured by the ion detector.

Ion Production

By detaching one or more of the electrons from a neutral atom or molecule, a positive molecular or atomic ion is produced. The positive charge remaining on the particle is equal to the negative charge removed. Since the charge of a single electron equals 1.6×10^{-19} coulomb, the positive charge

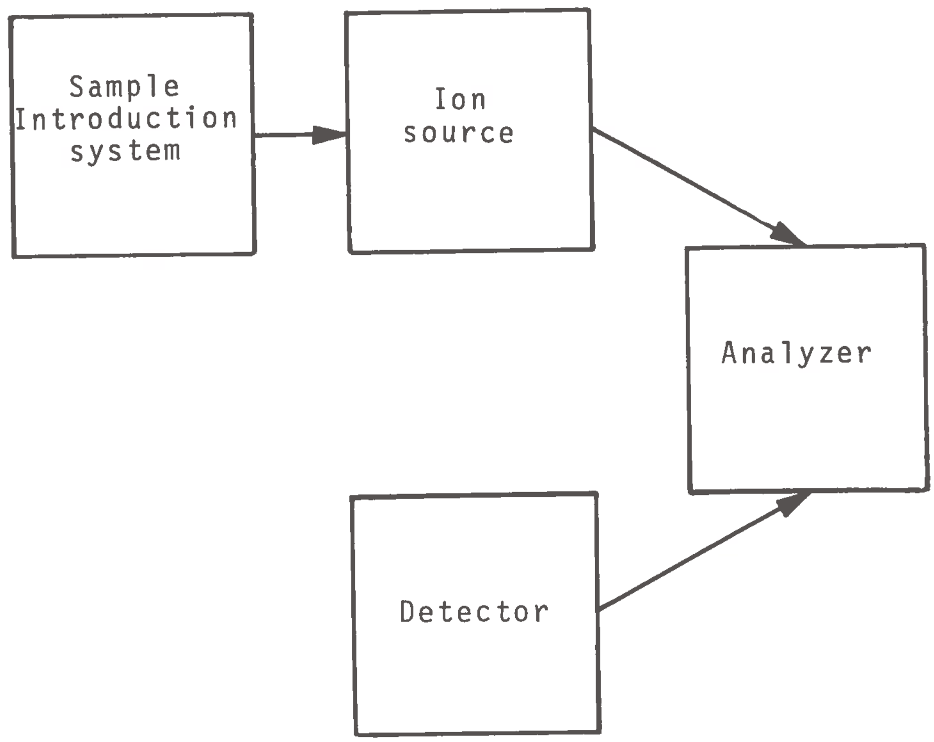

Figure 31. Schematic representation of principal features of a mass spectrometer. (From Ref. 8)

is always a whole number multiple of this quantity. Under certain conditions, negative ions can be formed by adding an electron to a neutral particle, but this process will not be considered in this review.

By far the most widely used method for the ionization of gases is by electron impact. Electrons produced at a heated filament are accelerated so that their energy exceeds the ionization potential of the gas molecules. Other methods for the ionization of gases are photoionization and field ionization. Photoionization is effected by quanta of light whose energy exceeds the ionization potential of the gas molecules. Field ionization (Fig. 32) occurs purely by the action of an electric field and requires potential gradients of the order of a few volts per angstrom. At manageable voltages such fields can be generated by using fine metal tips, fine wires, or sharp metal edges. In the vicinity of a metal surface at a high positive potential, an electron from the outer shell of a gas molecule is attracted into the metal, thus producing a positively charged ion.

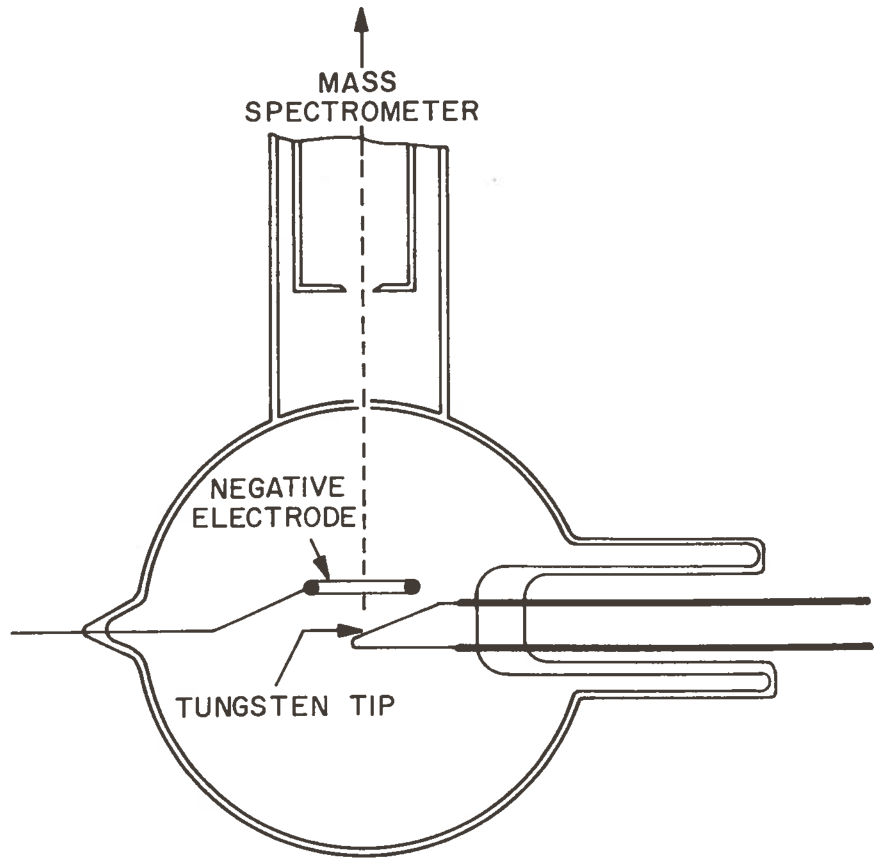

Figure 32. Field Ionization Source

Varian Chemical Vapor Analyzer

The Varian Chemical Vapor Analyzer (CVA) mass spectrometer (Figure 33) is now installed and operating at TSC. The outstanding features of this equipment are portability and continuous sampling of the air through a membrane preconcentrator. A schematic diagram of the device is shown in Figure 34. The sample is pumped through the first chamber at atmospheric pressure. The membranes are permeable to some molecules (H_2O, NO_2, CO_2), but less permeable to others (O_2, H_2, CO). It turns out, for example, that the effluent from dynamite can readily penetrate successive membrane stages with enhanced concentration as the pressure of an air sample containing this effluent is reduced from an initial 760 torr to about 10^{-6} torr required for operation of the mass spectrometer.

During operation two of the chambers of the membrane concentrator are pumped through partially opened microvalves which keep the chambers at the proper pressures. Molecules of oxygen and nitrogen, in particular, are thus removed by the pumps while other molecules preferentially diffuse through the membranes. The separator is purged after sampling by opening the fast ("dump") valves to the pumps. Mechanical pumps are used while operating the equipment in the laboratory. The Varian CVA mass spectrometer can be moved out of the laboratory and can be operated with zeolite pumps (without mechanical pumps) for about 6 to 8 hours.

The gas sample is ionized by electron impact. The analyzing section of the instrument is of the quadrupole type, which employs a combination of dc and radio frequency electric fields applied to two pairs of symmetrically spaced rods, as shown in Figure 35.

Ions are injected in a direction normal to the quadrupole field. The mathematical analysis of the ion trajectories is too complex to be treated herein; in effect, for any particular frequency and combination of dc and rf voltages, ionic species of only one particular value of q/m can move along the axis to the collector. All others are removed from the ion beam and eventually collide with the rods.

Early experiments with the Varian equipment demonstrated its capability for detecting dynamite through the seam of a closed suitcase. In another test, a sample of 0.07 gram of dynamite was placed in a two-quart bottle and covered with a glass petri dish. Dynamite vapor was easily detected by sampling the air near the edge of the cover. The mass spectrum of the effluent as displayed by the device consisted of prominent peaks at 29, 30, 46 and 76 atomic mass units. A

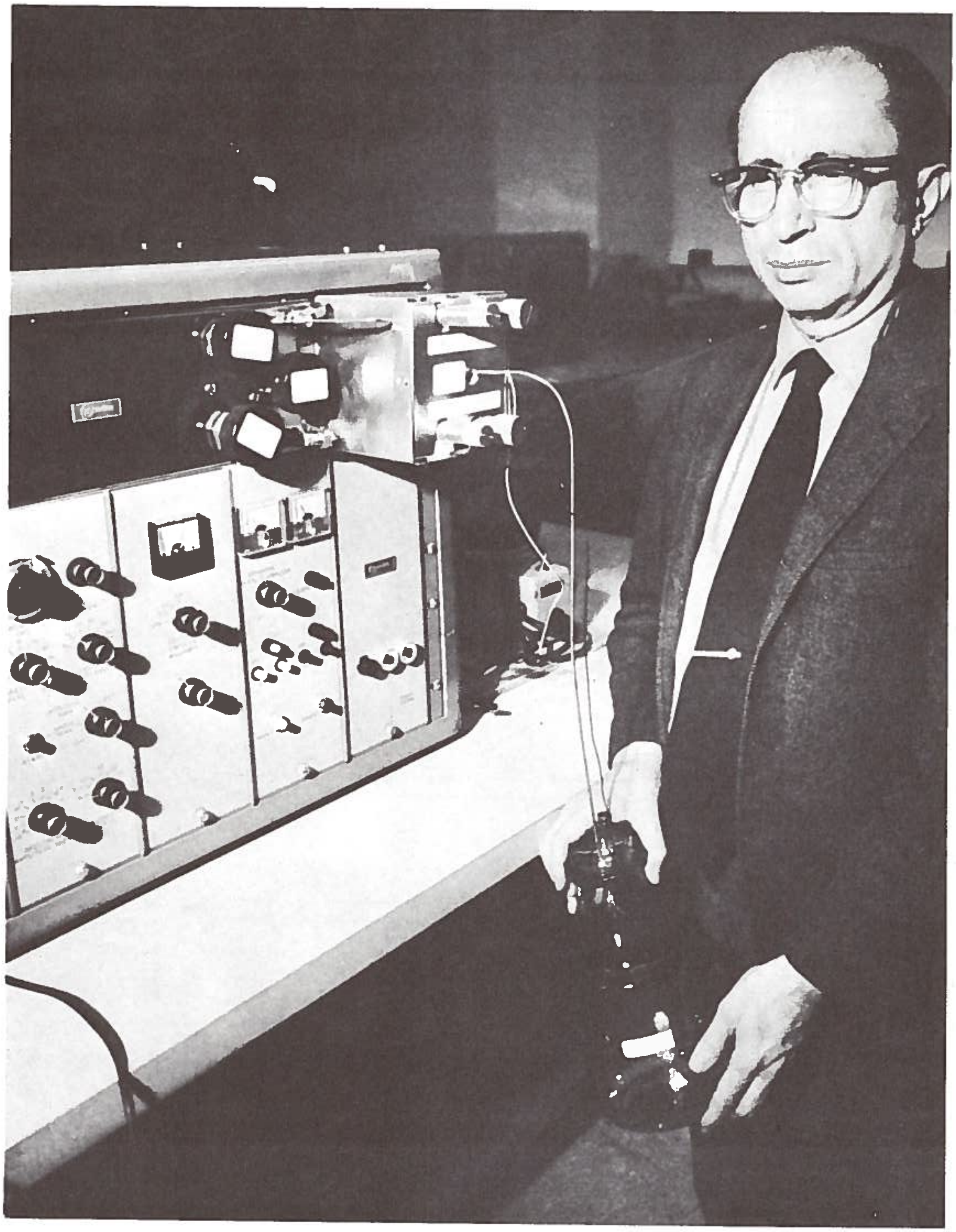

Figure 33. Varian CVA Mass Spectrometer

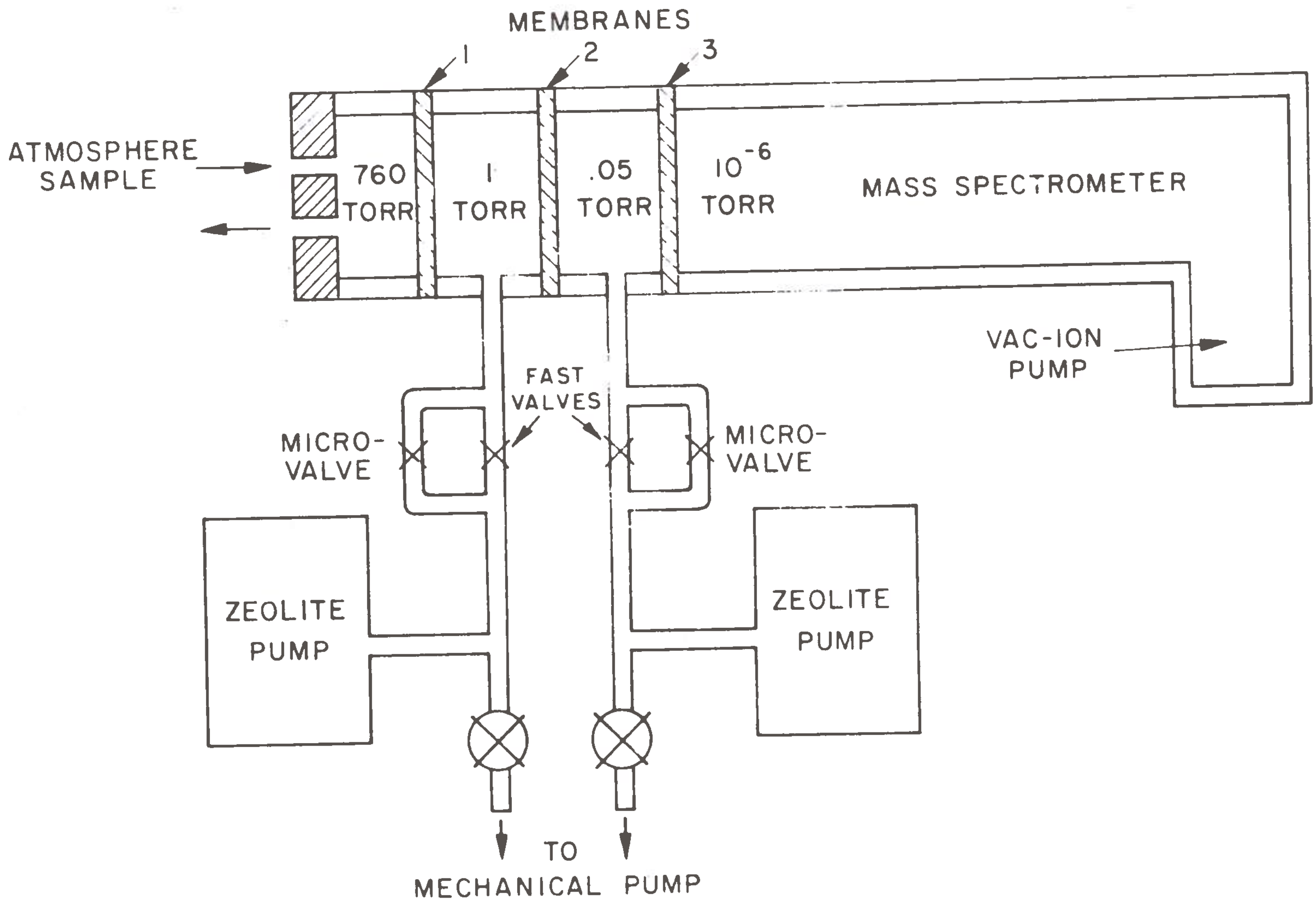

Figure 34. Schematic Diagram of Varian CVA Mass Spectrometer with Membrane Proconcentrator

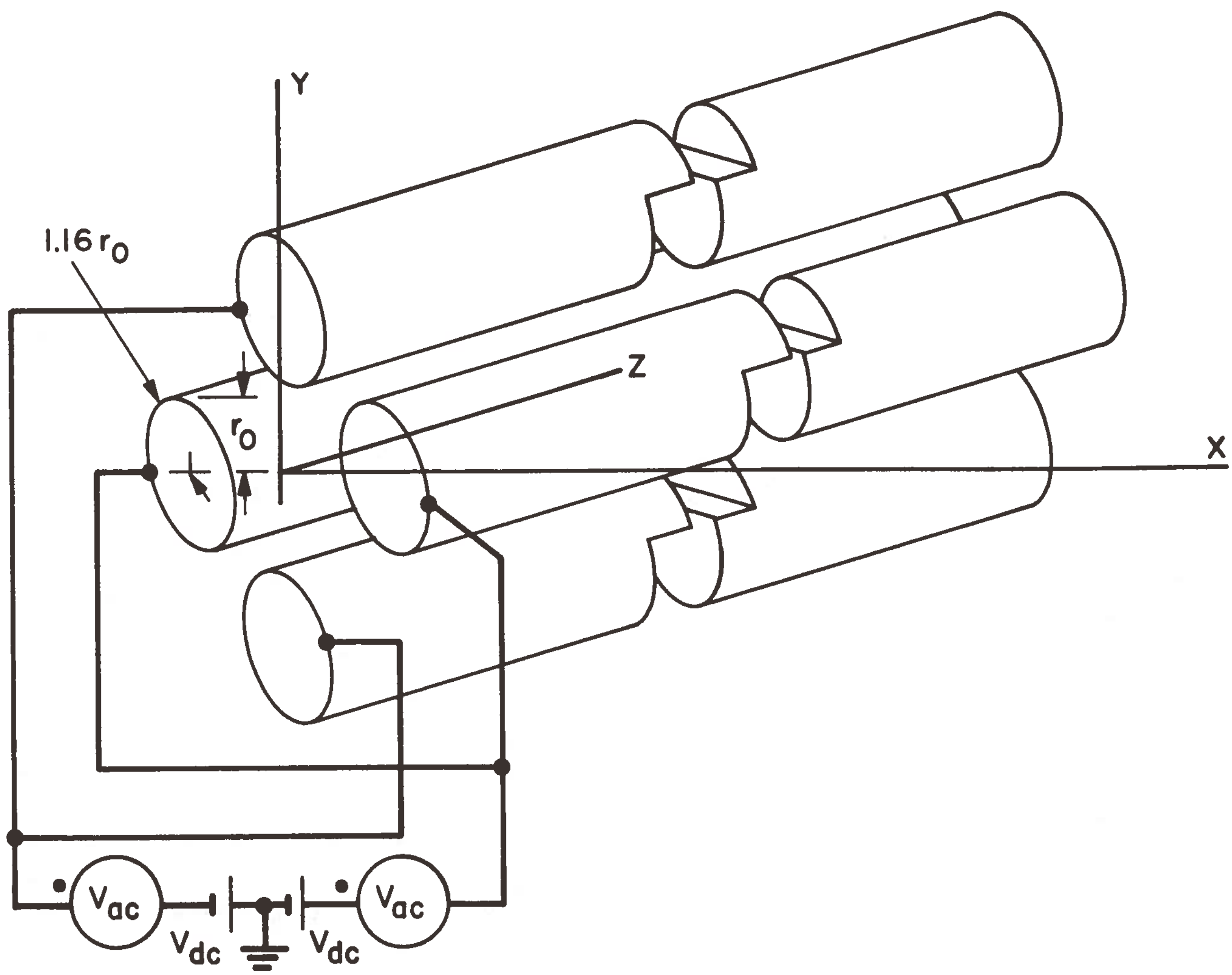

Figure 35. Quadrupole Analyzer Schematic

portion of the display from 29 to 33 atomic mass units is shown in Figure 36. The largest peak observed in all tests occurred at 30 atomic mass units and is probably due to nitric oxide (NO+). It remains to be established whether nitric oxide is present in the effluent or whether it is produced by the fragmentation of ethylene glycol dinitrate (EGDH) in the ion source of the mass spectrometer.

A major drawback of ionization of the gas sample by electron impact is the fragmentation of gas molecules. As a result, the signature of even simple molecules is complicated by the presence of ions other than those of the parent molecule. In order to minimize the formation of fragment ions, a development program has been initiated for field ionization sources under contract with the University of Missouri. Previous work by the NASA Electronics Research Center[13] indicated that such sources could be constructed in a manner sufficiently rugged for routine analysis. It is proposed to use these sources first in a laboratory instrument (Hitachi Perkin-Elmer RMυ-6) which can be operated at accelerating potentials up to several kilovolts where optimum results can be expected with field ionization.

GAS CHROMATOGRAPHY

Gas chromatography is another important area in modern analytical chemistry and there are many excellent recent texts covering this field[14-17]. A review of the literature[18] in the period 1966-1969 cites 742 references. Gas chromatography has been applied with success to the determination of traces of organic materials, such as residues of pesticides, and it can be considered one of the most promising techniques available for detection of explosive vapors.

The block schematic diagram of an analytical gas chromatograph is shown in Figure 37. In this technique a sample is injected into a carrier gas stream in the form of gas or vapor. A liquid sample must be heated during injection so that its vapor is carried in the gas stream. Separation of the components of the sample is performed in the gas chromatographic column, typically containing a non-volatile liquid coating on solid granular material. Depending on the vapor pressure of the sample components and their solubility in the column material, each component has a characteristic retention time in the column. The period of time required by the various components to reach the detector facilitates a qualitative analysis. Integration of the response of the detector during the emergence of a particular component permits a quantitative measure of the composition. Details of the gas chromatographic techniques

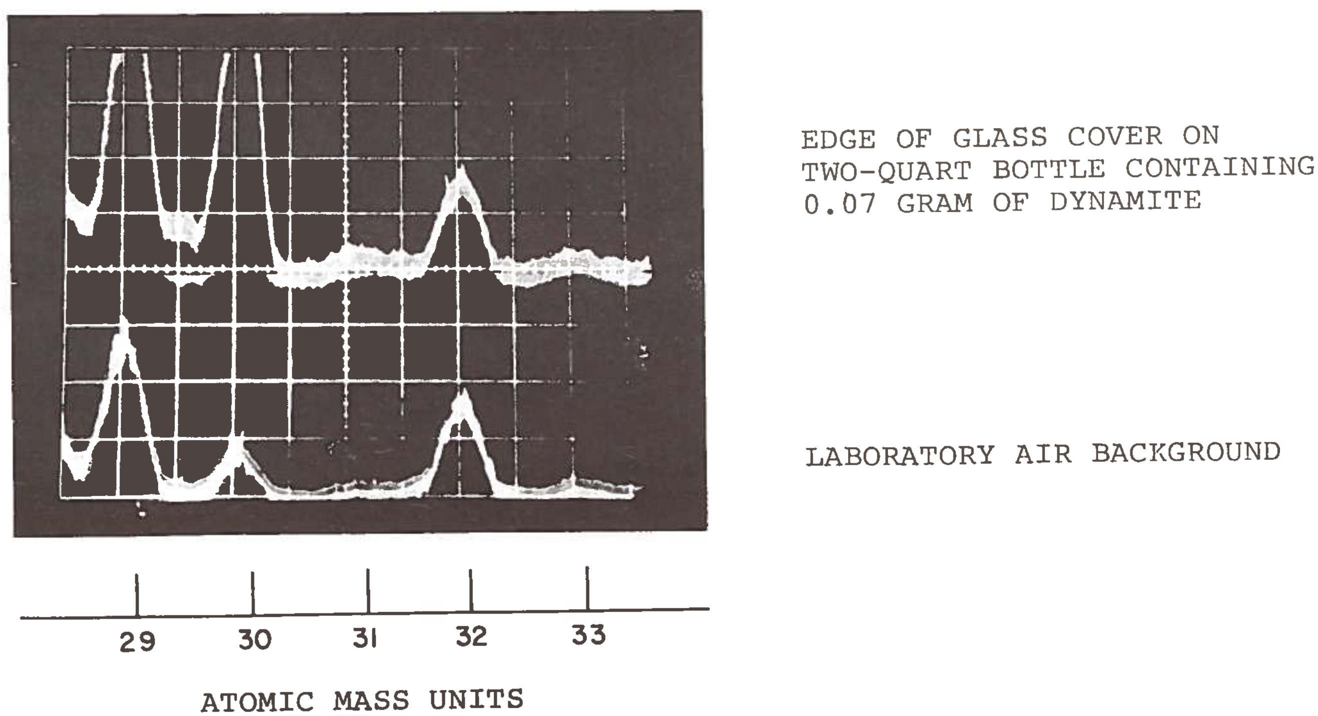

Figure 36. Response of Varian CVA Mass Spectrometer to Dynamite Vapor at 29 and 30 Atomic Mass Units

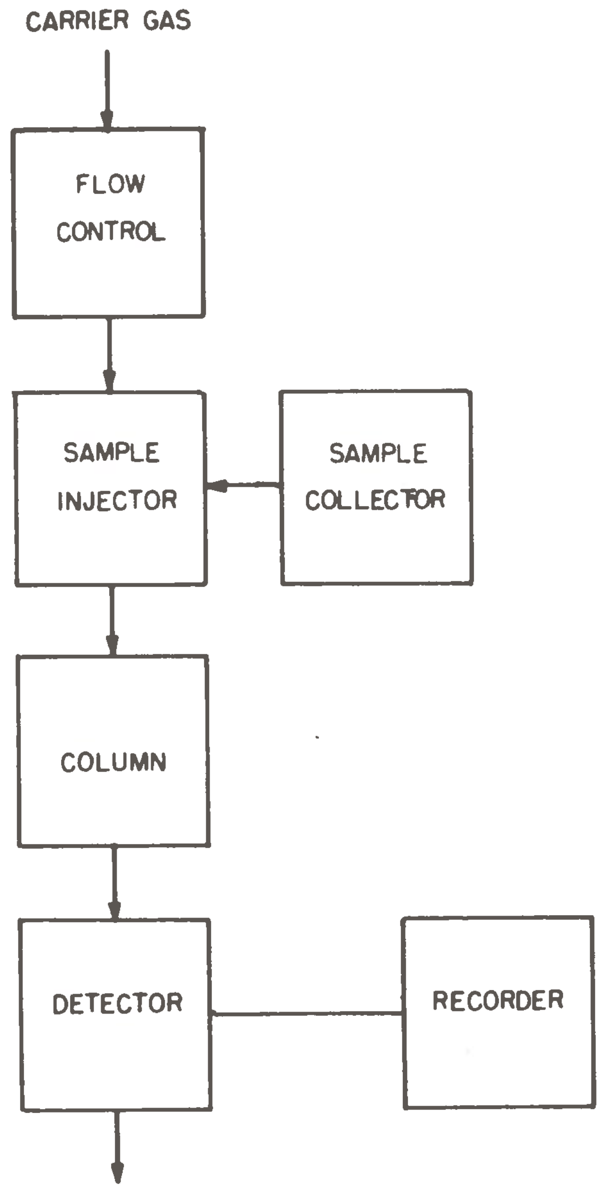

Figure 37. Block Schematic Diagram of Analytical Gas Chromatograph

are covered here briefly as they relate to the detection of explosive effluents:

1. Carrier gas - Any convenient gas that is easily distinguishable from the components of the mixture can be used as the carrier gas. In the development work at IIT Research Institute(19-22), carried out partially under sponsorship of the FAA (Contract Nos. FA 65WA-1200 and FA 67WA-1665) argon was recommended as the carrier gas; helium is used in the HI Vapor Trace Analyzer, Model 103A, demonstrated during March 1971 at Hydronautics Inc., Laurel, Maryland.

2. Flow control - Since the retention times of the components are dependent on the rate of carrier gas flow, a flow control procedure is necessary. This can be accomplished with a choke valve monitored by a flow meter, or, as is done in the HI Vapor Trace Analyzer, by setting a constant input pressure with the column acting as a constant choke.

3. Sample concentrator - For many analytical samples, collection is a simple process, such as drawing the sample into a glass syringe. However, for detection of explosive effluents in air a more elaborate procedure is required. To avoid disturbing the controlled carrier gas flow, it is not advisable to inject more than about 2 cc of air. Since explosive effluents are present only in very low concentrations it is necessary to concentrate the sample from a relatively large volume of air, and discard most of the air.

   In the development at IITRI much effort was spent in developing this technique. The major constituent of dynamite, ethylene glycol dinitrate (EGDN), is an electron-accepting, polar compound that is readily adsorbed at a metal surface by a transfer of electrons from the metal. Since this process is inhibited by oxide layers gold surfaces were used in two adsorbers of the IITRI equipment. After the EGDN is adsorbed on the first adsorber containing gold foil or gold-plated copper foil, this is heated to 80° C; the EGDN is then transferred by a flow of carrier gas (argon) into a second adsorber, consisting of a gold tube cooled to 0° C.

   In the HI Vapor Trace Analyzer, the vapor is adsorbed on a cold platinum coil, made from wire, about 3 mm diameter and 30 cm long, entirely enclosed in the body of a Teflon Valve, as shown in Figure 37. The sample is collected by blowing air at the rate of 10 liters per minute for a period of 5 to 30 seconds. At the same time, the carrier gas, helium, flows through a bypass in the valve into the gas chromatograph column and an electron capture detector.

4. Sample Injection - In the IITRI equipment injection is accomplished by heating the gold tube and passing argon through it to carry the desorbed effluent into the column.

   In the HI Vapor Trace Analyzer injection is performed by turning the valve, shown in Figure 38. First, the air is flushed out by helium into the inlet tube; second, helium passes over the platinum coil through the column. A series of about 40 short current pulses through coil causes desorption and injection of the effluent into the column. Most of the coil heating cycle is used to purify the platinum for the next adsorption cycle.

5. Column - The gas chromatographic column is the primary means of separating the components of the injected mixture. Some separation occurs before injection: the effluent is extracted from air in the sample concentrator and some separation is accomplished by selective desorption from the metal surface. The usual column is a long tube containing a high-boiling point liquid (stationary liquid) held on an inert solid support of porous material. As the carrier gas with injected effluent passes through the column, the vapors are dissolved in the stationary liquid and re-vaporized into the carrier gas; thus each component passes through the column at its own characteristic rate. The retention time of the component is dependent on its vapor pressure, solubility in the stationary liquid, temperature of the column and rate of carrier gas flow.

   In the IITRI equipment the column contained a packing of shredded Teflon coated with Apiezon-L at a recommended temperature of 90°C and flow rate of 50 cc/min. In this type of column the retention time of EGDN is about one half that of nitrobenzene.

   In the HI Vapor Trace Analyzer the column contains a polar stationary liquid, diethylene glycol succinate,

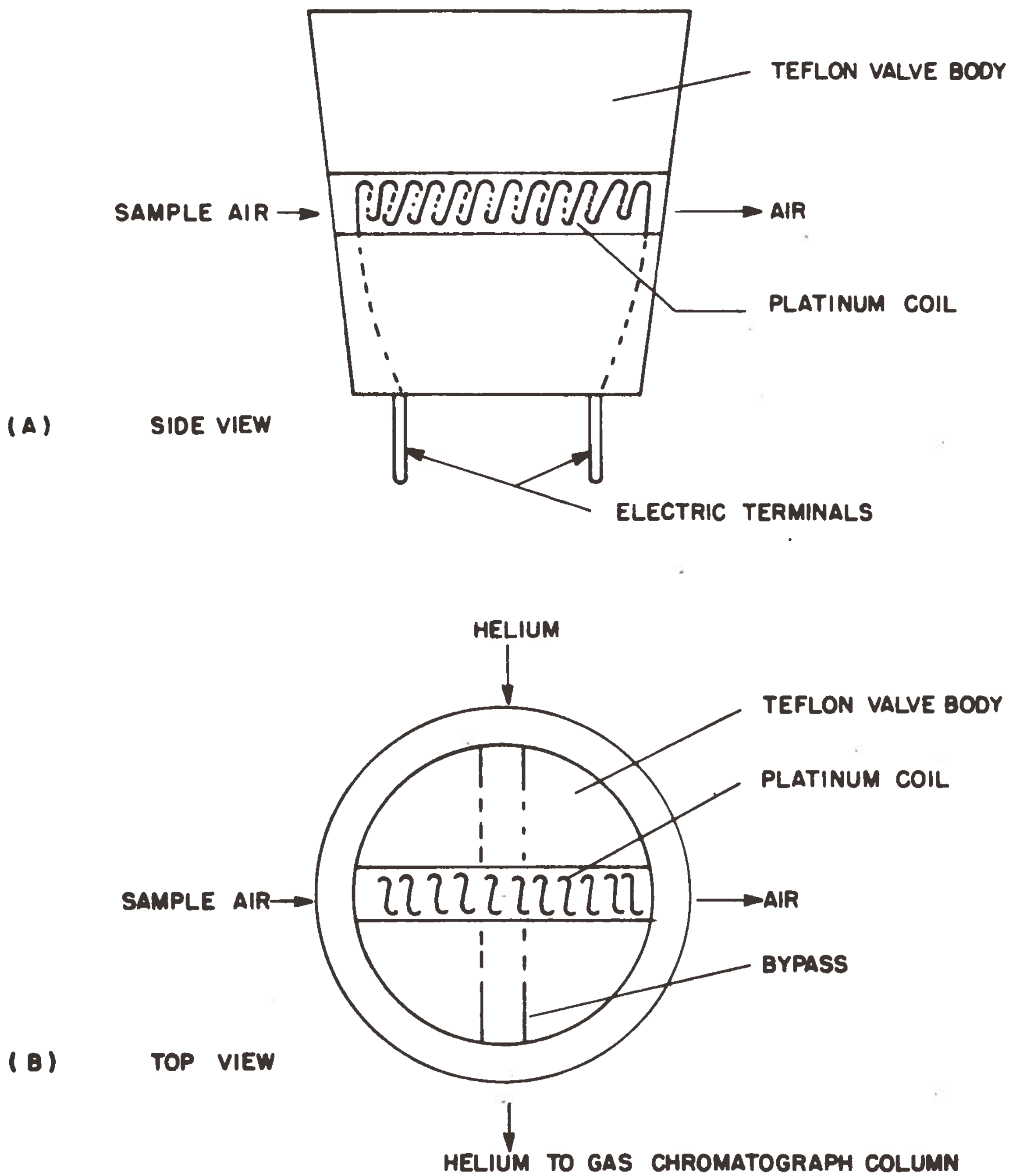

Figure 38. Valve with Coil to Collect Vapors in H-I Vapor Trace Analyzer

and the retention time of EGDN is about twice that of nitrobenzene. The Teflon column, 1.5 mm internal diameter, is 30 cm long. The retention time for dynamite effluent is about 10 to 30 seconds depending on the temperature (about 75°C) and inlet pressure settings. The retention time for TNT is about 45 seconds at 175°C. It takes about one hour to reset the HI Vapor Trace Analyzer from the operating conditions for dynamite to that for TNT.

6. Detector - Common detectors used are: (1) the thermal conductivity detector which detects the difference in thermal conductivity of the carrier gas with and without the vapor component (2) the flame ionization detector which detects ions produced in a hydrogen flame and (3) the electron capture detector which detects molecules by their ability to capture electrons emitted by a radioactive material. Both the IITRI and HI instruments use electron capture detectors because of their high sensitivity to polar molecules, such as explosive effluents, and their lack of response to nonpolar molecules, such as those found in airplane fuel. It has been claimed that the HI instrument is sensitive to 5 parts of TNT in 10^{12} parts of air and to 5 parts of nitroglycerin in 10^{11} parts of air. The HI Vapor Trace Analyzer was ordered for evaluation at TSC, with expected delivery in July 1971.

At TSC, a Perkin-Elmer 900 gas chromatograph shown in Figure 39 has been installed for studying the effluents present of common explosives. This equipment has a much longer column than the HI Vapor Trace Analyzer, which increases the time of analysis but improves the discrimination between various components. At 75°C it was found that the EGDN from dynamite emerged in 8.8 minutes from the time of injection, while at 100°C the time was 3.2 minutes. The column material was Apiezon L, similar to that used in the IITRI device. A flame ionization detector was used which is very sensitive to all organic components, but not sensitive to air or water. Direct injection of 2 cc of air containing the effluent to be analyzed was accomplished by means of a glass syringe with a hypodermic needle to penetrate a silicone septum. Comparison of the retention times of the dynamite effluent and nitrobenzene, confirmed the IITRI report that the major component of dynamite vapor is EGDN.

Figure 39. Perkin-Elmer Gas Chromatograph

BIOLUMINESCENCE DETECTOR

The RPC Corporation, El Segundo, California, has developed instruments for detection of effluents in air by utilizing the variation of light emitted from luminescent bacteria. The organisms, which are obtained from marine sources, are mutated and cultivated on proprietary nutrient media for sensitivity to selected effluents.

A demonstration of the equipment was held during a plant visit at El Segundo, March 8 and 9, 1971. In this demonstration sticks of conventionally wrapped dynamite were placed in a suitcase and in a plastic jar provided with a small hole. The luminescent bacteria growing on agar nutrient in a small capsule were placed in a metallic cylindrical housing which also contained the photocell used to monitor the light generated by the bacteria. A small pump drew the air sample over the bacteria from a tubular probe. When the probe tip was inserted 1/2 inch into the suitcase a signal characteristic of dynamite was obtained in about 3-5 seconds.

As shown in Figure 40, chart records of various substances such as breath, dynamite, and polish remover show different patterns. In this demonstration two simultaneous chart records were made of the rate of change of light intensity emitted by the bacteria as a function of time: Figure 40(a) with a reset function which automatically returns the rate signal to zero if it reaches a full scale reading and Figure 40(b) with the reset off.

The RPC Vapor Detection System, Model 10402-002, with biosensors for dynamite detection was ordered for evaluation at TSC and delivered on June 29, 1971.

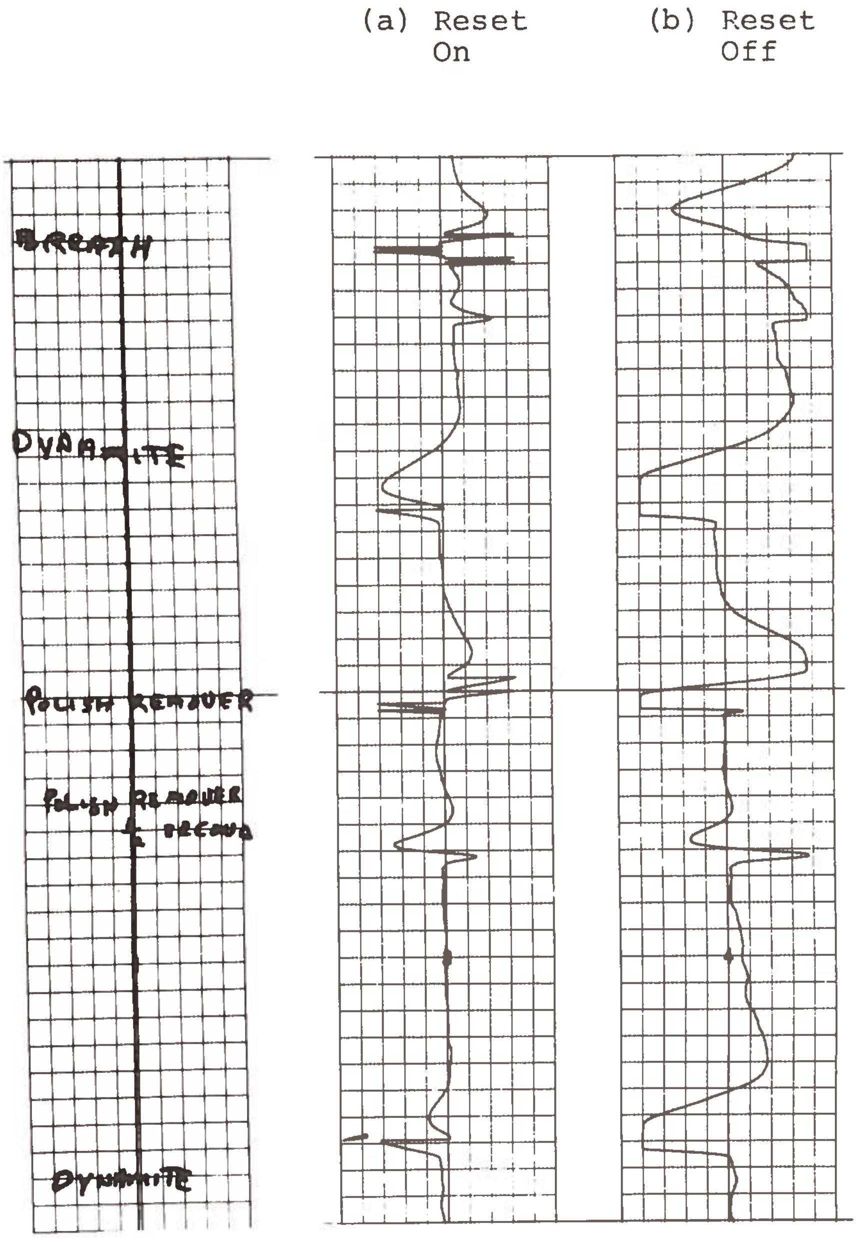

Figure 40. Chart Records of RPC Bioluminescence Chemical Vapor Detector with Reset On and Reset Off

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