BICRON

BICRON CORPORATION 12345 Kinsman Road, Newbury, Ohio 44065-9677

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April 26, 1991

Mr. J. O. Lubenau
Senior Project Manager
U.S. Nuclear Regulatory Commission
M/S 3-D-23
Washington, DC 20555

Dear Mr. Lubenau:

Thank you for responding to the item recently published in *Scrap Processing and Recycling* which described Bicron's radioactive material detection systems for monitoring incoming scrap. I have enclosed information on our various systems for your reference including a technical paper by independent consultant, Tony LaMastra, entitled "Radioactive Material in Scrap Steel - Its Occurence, Consequence, and Detection". In addition, you will also find enclosed data sheets on two handheld survey meters which complement our systems.

Bicron makes several systems in order to match the sensitivity, location, and budget requirements of your application more closely. These include the following systems:

The ASM-12000S is the most sensitive system manufactured by Bicron. Its detectors incorporate 12,000 cubic inches of plastic scintillator. A 16-bit microprocessor subtracts out natural background and enables you to detect radioactive sources shielded in lead containers which produce a signal equal to 1/20th that of natural background at the radiation detector.

The ASM-6000-D system incorporates 6,000 cubic inches of plastic scintillator divided between two detectors and a 16 bit microprocessor which subtracts out natural background. The system monitors vehicles passing the detectors at speeds less than five miles per hour. This system is capable of detecting shielded radioactive sources with an external exposure rate of 1mR/h on contact when buried in a scrap vehicle.

The ASM-200 system consists of 200 cubic inches of plastic scintillator (2 detectors) coupled to a digital, alarming rate meter electronics package. It is capable of finding small, unshielded radioactive sources buried in vehicles. This system will detect ten microcuries of ^{137}Cs at seven feet from the detectors.

A/6

Please call if you have any questions or need a quotation. I will help you get the best system for your application.

Sincerely,

BICRON CORPORATION

Dale Lewis
Technical Sales

DL/sdm
Enc.
cc: Jim Monde, Sales Engineer, Bicron
Michael Oras, Marketing Services, Bicron

Radioactive Material Detection Systems for Steel Scrap

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Radioactive Material Detection Systems for Steel Scrap

Features

- Rail car, truck and charge bucket monitoring
- Shielded and unshielded source detectability
- High sensitivity and reliability
- Low false alarm rate
- Automatic operation under microprocessor control
- Rugged detectors designed for steel mill and scrap yard environments

Introduction

There have been several incidents in recent years of accidental melt-down of radioactive soures in steelmaking furnaces. Many sources which find their way into scrap are still encased in their heavy lead and steel safety shields. Even though they may contain very large amounts of radioactive material, these sources may not be detectable by ordinary methods because of the heavy shielding.

Bicron Corporation, a world leader in the design and manufacture of radiation monitoring detectors and instruments, has developed a series of monitoring systems for the steel industry which overcome the limitations of conventional radiation detectors.

Each system is configured for the conditions found at the specific site - at weighing scales, on railroad sidings, or at scrap loading areas.

In actual installations, Bicron microprocessor-controlled systems have been shown to detect a variety of both shielded and unshielded radioactive sources.

System Description

Bicron Radioactive Material Detection Systems consist of:

- Multiple large-area plastic scintillation detectors suitably placed to view the scrap from as many angles as possible. Plastic scintillators are chosen for their ruggedness and high sensitivity.
- A microprocessor-based control unit which continuously monitors the output of each detector This control unit may be located remotely from the detectors in an office or other convenient area.

The combination of custom large-area plastic scintillators, low-noise counting electronics,carefully shielded enclosures and proprietary computer algorithms, provides a high level of sensitivity with a minimum of trouble-some false alarms.

Control Module:

Each system includes a microprocessor-based readout and control instrument featuring simple push-button operation, alphanumeric display panel and printer.

The count from each detector is monitored individually and independently by the appropriate microprocessor module. The Bicron system makes use of a high-speed 16-bit microprocessor which is capable of processing and manipulating data from a number of channels simultaneously.

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Radioactive Material Detection Systems for Steel Scrap

Each detector is monitored for operation, background count, background trends, and background subtraction. During periods when scrap is not being monitored, independent count rates for each of the detectors are averaged and stored. These stored average count rates provide for background compensation using computer techniques based upon the laws of counting statistics. When scrap is being monitored, as indicatd by a signal taken from the scale electronics, the charge bucket control electronics, or other proximity sensor, the microprocessor compares the measured count to the stored background. This count is then tested for radiation significance and for signal quality.

A major benefit of the Bicron system is its methods used to prevent undue false alarms. The microprocessor control module is capable of continually testing the data it receives from the detectors and, by use of proprietary computer algorithms, reducing the number of false alarms which might otherwise be generated due to external interference or other factors.

The control module provides for independent tests of each detector, and will indicate a channel failure if the count rate for any one of the detector channels falls to zero.

A green light and appropriate indications on the alphanumeric display are used to show that monitoring is satisfactory, and that no radiation has been sensed.

When radiation is sensed, a red light is illuminated on the control module front panel, an alarm indication is displayed on the alphanumeric display and an audible alarm is turned on.

The design of the system is such that the operator can determine the status of the system quickly and without confusion.

The control module has the capability of displaying the radiation level in counts per count interval for each detector.

Detector Assemblies:

Each detector includes one or more Bicron large-area plastic scintillators, photomultiplier tubes, magnetic shields, and voltage divider assemblies. The photomultipliers are selected for their low noise output, and are optically coupled to the scintillator element in such a way as to provide optimum signal. Line drivers are used to drive cables between the detector modules and the control module.

The scintillator and photomultiplier tube assemblies are shock mounted in environmental cabinets which provide protection against both magnetic and electrical interference.

Typical Bicron detector assemblies measure 72 inches long by 18 inches to 36 inches wide, and about 1 foot deep. However, larger or smaller detectors may be specified for individual applications.

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Radioactive Material Detection Systems for Steel Scrap

Detectability:

The amount of radiation which may be detected is a function of a number of factors including background radiation, detector size and placement, the amount of shielding between the source and detectors, the length of the measuring time, and the false alarm rate.

Bicron syste. pecifications are based on detecting ielded sources. A shielded source is much harder to detect than the same source which is unshielded.

Bicron system specifications are based on very low false alarm rates (as low as 1 in 3 months or longer). Conventional systems may false alarm frequently in an attempt to increase detectability.

Shielded radioactive sources such as cesium-137 or cobalt-60 which contain more than a few millicuries typically measure between 0.1 and 10 milliroentgens per hour (mR/h) at 1 foot from the source. The combination of distance and scrap shielding reduces the rate to a small fraction of this amount, which is often unmeasurable by ordinary means.

- A Bicron four-detector monitoring system installed at a charge bucket scrap loading area is able to detect the smallest source described above, through the 1.5 inch thick bucket walls, approximately 12 feet away, in a 15-second measurment period during the scrap loading process.

- A two-detector dynamic system set up to view rail cars or trucks as they drive by at 5 miles per hour, is capable of detecting most typical sources described above, when mixed in with random demolition scrap in the rail car or truck.

- An eight-detector static system set up to view trucks or rail cars at a weighing scale is capable of detecting most typical sources described above, when mixed in with random demolition scrap in the rail car, in a measurement period of about one minute. This system is more sensitive than the dynamic system and improves statistical accuracy.

While actual performance varies with location, the ability of Bicron monitoring systems to detect radioactive materials in scrap steel is unsurpassed.

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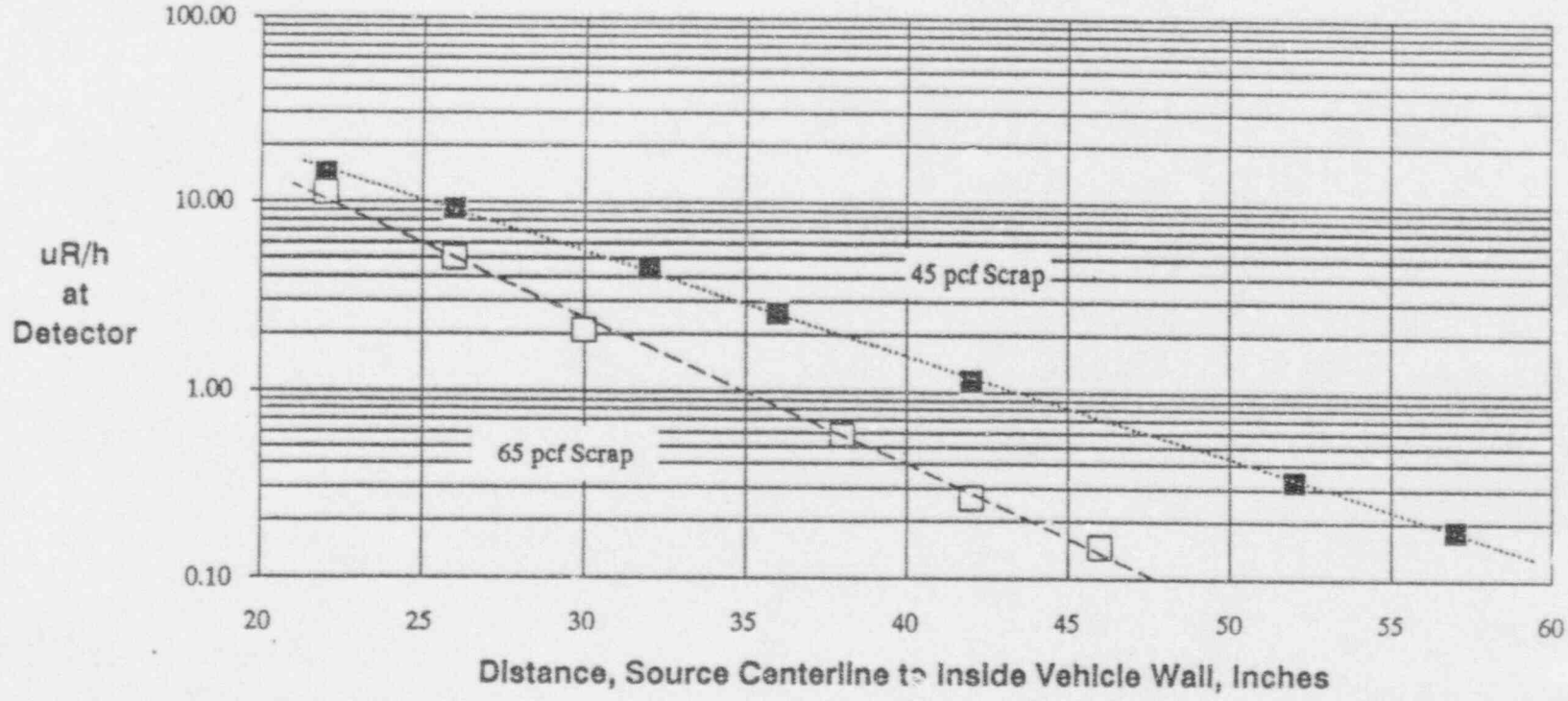
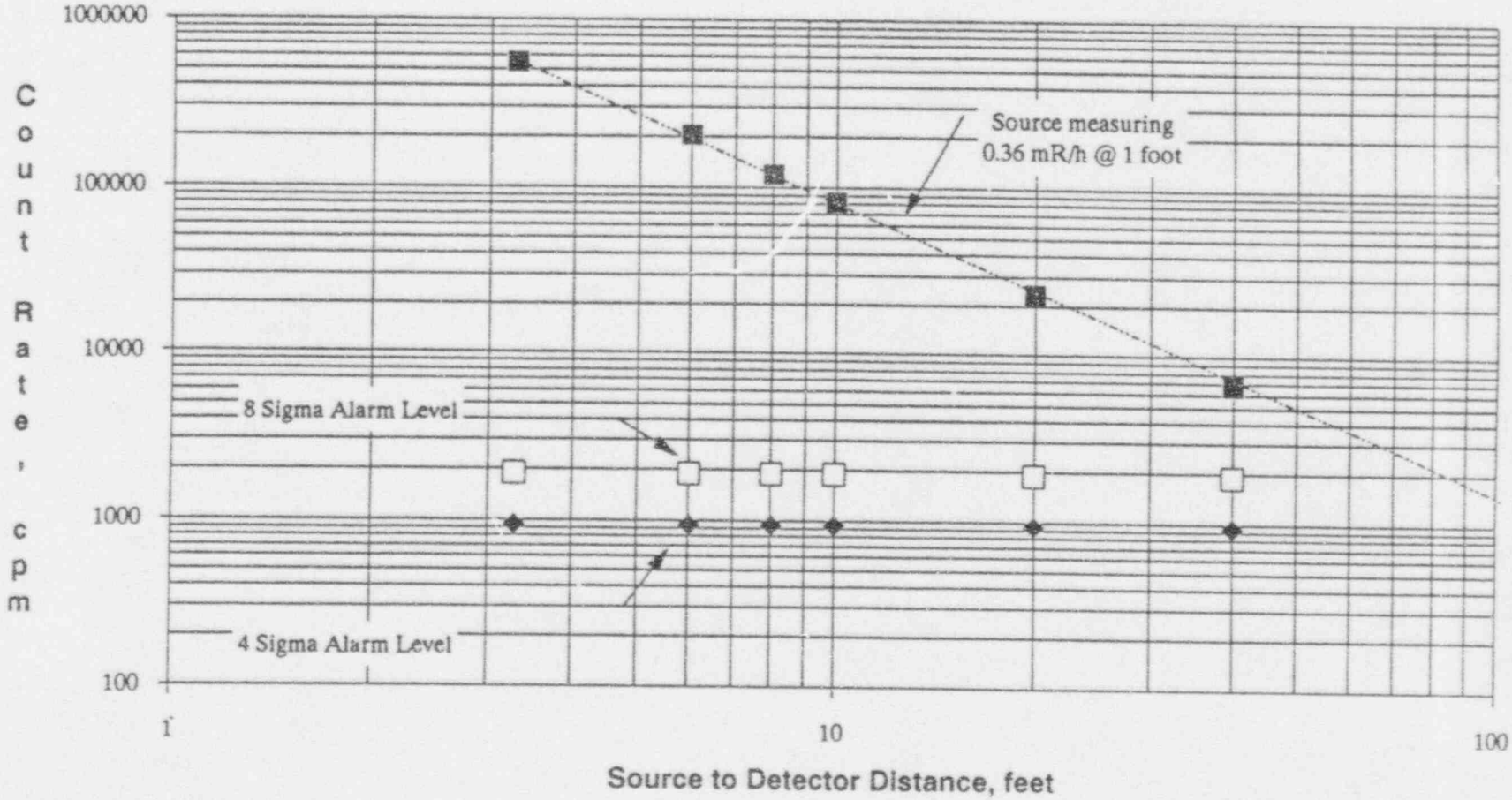
Detection of Cs-137 Test Source Buried in Steel Scrap in a Rail Car or Truck



Detectability of Cs-137 Source by Bicron Monitoring System in 1 Minute Count Time



Models: ASM-6000-D, ASM-200, ASM-6
Radioactive Material Detection Systems for Scrapyards

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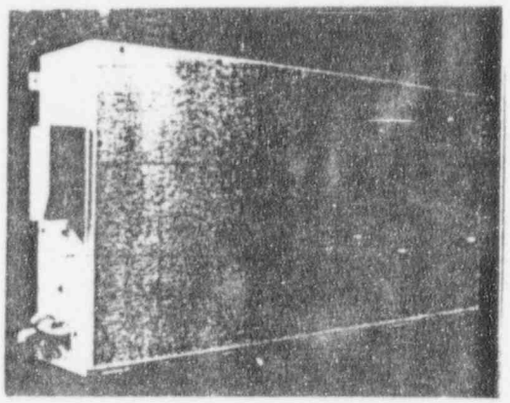
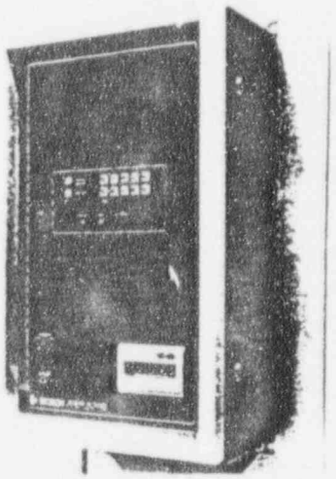


Model ASM-6000-D Detector Assemby (2 per system) and Control Unit



The model **ASM-6000-D** radioactive material detection system monitors scrap-filled railcars or trucks as they move past the system's detectors (dynamic mode). The system detects both shielded and unshielded radioactive sources mixed with the scrap, while maintaining a very low false alarm rate.

The ASM-6000-D consists of two, large-area detector assemblies located near truck or rail scales (or other convenient locations), and a microprocessor-based, control/readout unit. The detector assemblies can be positioned up to 1000 feet from the control unit.

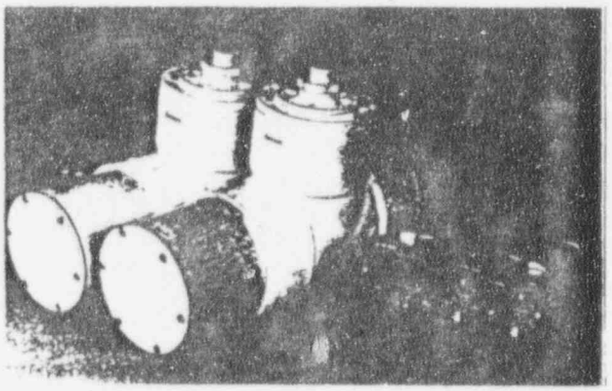
Each detector assembly contains two organic scintillation detectors and associated signal-processing electronics. The components are shock mounted within lead-lined, weatherproof housings.

The control unit performs all signal-processing and calculations required for detecting radioactive materials in the incoming scrap. The unit monitors each detector independently and stores the resulting counts in memory. If radiation is detected, the system alarms and prints out the alarm conditions, date and time of alarm, and location of the source in the vehicle.

The **ASM-200** and **ASM-6** are radioactive material detection systems designed to monitor scrap-carrying vehicles as they stop to be weighed or checked in. These systems detect unshielded, medium and high energy gamma radioactive sources (neutron radiation as well for the ASM-200) which may be mixed with the scrap.

The **ASM-200** system consists of 2 each, shielded, 3" diameter, 12" long, plastic scintillation detectors mounted in separate, PVC pipe housings and connected via cables (2, 50' cables supplied) to an electronics readout package.

Model ASM-200 System



The **ASM-6** system is similar to the **ASM-200** in that the scintillation detectors are mounted in separate, PVC pipe housings and connected via cables (2, 50' cables supplied) to an electronics readout package. 2 each, shielded, 2" diameter, sodium iodide scintillation detectors are used instead of the plastic detectors.

Models: ASM-6000-D, ASM-200, ASM-6
General Specifications

Specification	ASM-6000-D	ASM-200	ASM-6
Scintillator Type	BC-408 Plastic	BC-408 Plastic	NaI(Tl)
Radiation Detected	^{60}Co, ^{137}Cs, ^{192}Ir, ^{226}Ra/Th Neutrons, ^{241}Am	^{60}Co, ^{137}Cs, ^{192}Ir, ^{226}Ra/Th Neutrons, ^{241}Am	^{60}Co, ^{137}Cs, ^{192}Ir, ^{226}Ra/Th
Number of Detectors	4 in 2 assemblies	2 in 2 assemblies	2 in 2 assemblies
Total Detection Surface Area	2880 in^2	72 in^2	6.25 in^2
Detection Mode/ Speed/Time	Drive-through at 5 mph (max)	Stop for 15 sec	Stop for 15 sec
Sensitivity	Will detect shielded sources emitting 1 mR/h buried in #1 or #2 sheared steel scrap	Will detect 10 µCi ^{137}Cs at 7' from the detector	Will detect 75 µCi ^{137}Cs at 7' from the detector

The **ASM-6000-D** is a widely used, highly reliable and sensitive system capable of detecting lead-shielded, radioactive sources buried under scrap metals in a truck or railcar. Typical lead-shielded sources (such as radiography sources) contain 100 millicuries to 50 curies of ^{137}Cs or ^{60}Co and produce exposure rates on the outsides of their shields of 2 to 10 milliroentgens/hour.

The **ASM-6000-D** can detect a shielded source emitting only 1 milliroentgen/hour in #1 or #2 sheared steel scrap while the vehicle carrying the scrap moves by the system's detectors at 5 mph.

The **ASM-200** is designed to detect unshielded sources in medium and small vehicles containing randomly distributed scrap. In some cases, it can also detect shielded sources (if the source is close to one of the system's detectors). Because of its plastic scintillators, the **ASM-200** also will detect ^{241}Am sources (found in static precipitators) and other neutron-generating sources.

The most appropriate place for mounting the system's detectors is at the scale where they can monitor the vehicle as it is being weighed. It takes just 15 seconds to make an accurate measurement.

The **ASM-6** is designed to detect unshielded sources in small vehicles containing small quantities of scrap. Like the **ASM-200**, this system's detectors should be mounted where the vehicles come to a stop (such as at the scale).

The **ASM-6** will detect gamma-emitting isotopes (energies greater than 32 keV) in just 15 seconds. Because of size of the detectors and the scintillator used, the **ASM-6** has ~ 1/12th the sensitivity of the **ASM-200**.

Manufacturer reserves right to alter specifications.

Notes on Sensitivity

The amount of radiation detected (the sensitivity of the system) depends upon background radiation, detector size (detection area) and placement, density of the scrap covering, measurement time, and false alarm rate. Scrap cover density has a profound effect on the probability of a system detecting a source. This is due to the attenuation of the radiation beams by the scrap material. The greater the density, the more attenuation; and, therefore, the lower the probability of detecting a source.

Bicron's detection capability specifications take these factors into account. For example, the probability of an ASM-6000-D system detecting a typical, shielded ^{137}Cs source covered by #2 sheared scrap in a railcar or truck moving at 5 mph or less is virtually 100% at a low false alarm rate (1 in 3 months).

02/91

Model: ASM-21000-S
Radioactive Material Detection System

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General

The model **ASM-21000-S** radioactive material detection system monitors scrap-filled railcars or trucks while they are stationary between the system's detectors (static mode) and as they move into and out of this position (dynamic mode). The system detects both shielded and unshielded radioactive sources mixed with the scrap while maintaining a very low false alarm rate.

The **ASM-21000-S** consists of fourteen detector assemblies located near truck or rail scales (or other convenient locations), and a microprocessor-based, control unit. The detector assemblies are connected to the control unit via two cable runs.

Each detector assembly contains one organic scintillation detector and associated signal-processing electronics. The components are shock mounted within lead-lined, weatherproof housings.

The control unit performs all signal-processing and calculations required for detecting radioactive materials in the incoming scrap. The unit monitors each detector independently and stores the resulting counts in memory. It then analyzes the data over two time intervals: the Background Update Interval and the Counting Interval.

Effectiveness

Detection probability is defined as that percentage of the total volume of a railcar or truck in which the specified test source is detected at the 90% detection confidence level or greater. The scrap cover density has a profound effect on detection probability because the scrap attenuates the radiation beams.

The **ASM-21000-S** achieves the following detection probabilities for a shielded, 100 mCi ^{137}Cs test source (centered in a 2' x 2' x 2' steel box reading 1 mR/h at the side surfaces) in various scrap covers and at a very low false alarm rate:

- #2 sheared scrap (30-35 lb/ft^3) - virtually 100%
- #1 sheared scrap (50-60 lb/ft^3) - virtually 100%
- Demolition scrap (60-70 lb/ft^3) - 85-100%
- High density scrap (80-90 lb/ft^3) - 75-85%

The system detects larger sources with proportionally higher detection probabilities.

continued

Model: ASM-21000-S
Specifications

Control Unit

OPERATING MODE: Static/dynamic; system is designed to monitor trucks or railcars while they are stationary and moving into and out of position

BACKGROUND UPDATE INTERVAL: Period of time over which the background is averaged; adjustable to 1000 seconds

COUNTING INTERVAL: Time period (1 second or longer) during which the counts from each detector are analyzed using computer techniques based upon the laws of counting statistics; the ratio between the counting interval and the background update interval is typicaliy 1:10

MOUNTING: Unit is designed for table-top mounting; other configurations optional

READOUTS: 3 indicator lights - READY, WAIT, and ALARM; alphanumeric display panel for system paramcters

AUDIBLE ALARM: Sounds when alarm conditions are encountered

OPERATOR CONTROLS: Single pushbutton for silencing alarm and resetting the system after cause of alarm is determined; illuminates when an alarm occurs

OTHER CONTROLS: Power ON/OFF switch; 12 key, numeric keypad for input of system parameters and for system checkout and maintenance; keypad locks to prevent unauthorized access and is not used during normal operation

POWER REQUIREMENTS: 117 V, 60 Hz AC

POWER CABLE: 6' cable fitted with a standard NEMA 15-5, 3 terminal plug

Detector Assemblies

DETECTOR TYPE: BC-408 premium organic scintillator with low noise photomultiplier tube and magnetic shield

NUMBER OF DETECTORS: 14 each in individual housings

DETECTOR VOLUME: 1500 in^3, each detector; 21,000 in^3 total for the system

HOUSING: Weatherproof, 14 gauge (NEMA 4) with gasketed, hinged front door for access to internal components

SIZE: 70" long X 18" high X 12" deep, each housing

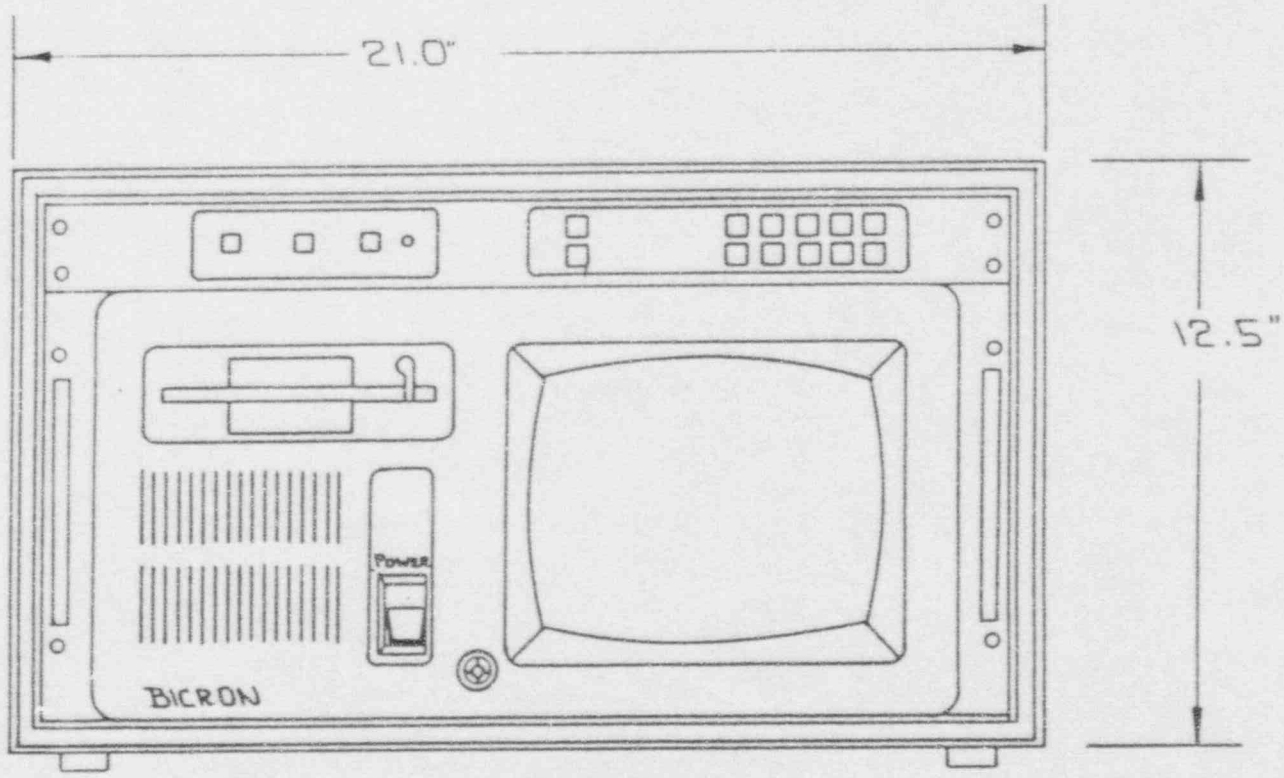
MOUNTING: Mounting hole pattern provided for installation on customer-provided I-beams

SHIELDING: The plastic scintillator is lead shielded on all sides except the door which serves as the radiation entrance window; the shielding provides background reduction and improved directional response

ELECTRONICS: Each detector has a remotely controlled, high voltage bias supply and voltage divider assembly (for the photomultiplier tube), pulse discriminator, and line driver

CONNECTING CABLE: Belden type 9777 for connecting detector assemblies to control unit; nominal OD is 0.82"; only 2 runs required; supplied by customer

CABLE CONDUIT: Weatherproof recommended; carries cable from detector assemblies to control unit; supplied by customer



NOTE: OVERALL DEPTH IS 22.0"

REV.	DATE	DESCRIPTION	BY
A	4-17-90	ADDED NOTE	RJD

TOLERANCES UNLESS OTHERWISE SPECIFIED

FRAC. ±
.X ±
.XX ±
.XXX ±
ANGLES ± °

MICRO FIN. √

DE-BURR & BREAK ALL EDGES

DO NOT SCALE PRINT

SCALE: NONE
DRAWN: RJD
DATE: 5-28-87
CHECKED:
DATE: 5-28-87

BICRON CORPORATION
NEWBURY, OHIO U.S.A.

MICROPROCESSOR MULTI-DETECTOR CONTROL SYSTEM

PROD. CODE	Dwg Code	BASIC PART NUMBER	Dimension	FINISH	REV.
	A	9700045			A

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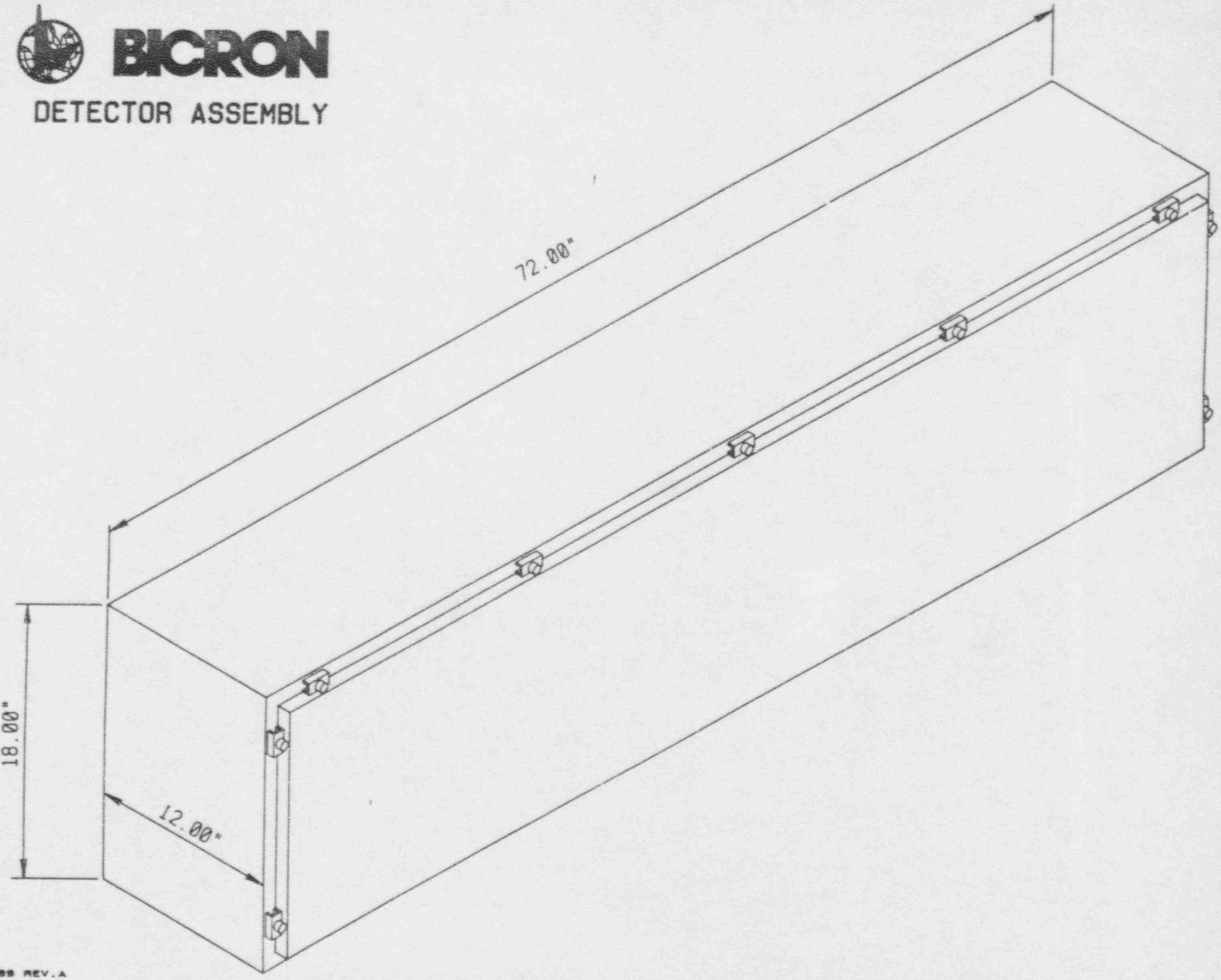
DETECTOR ASSEMBLY



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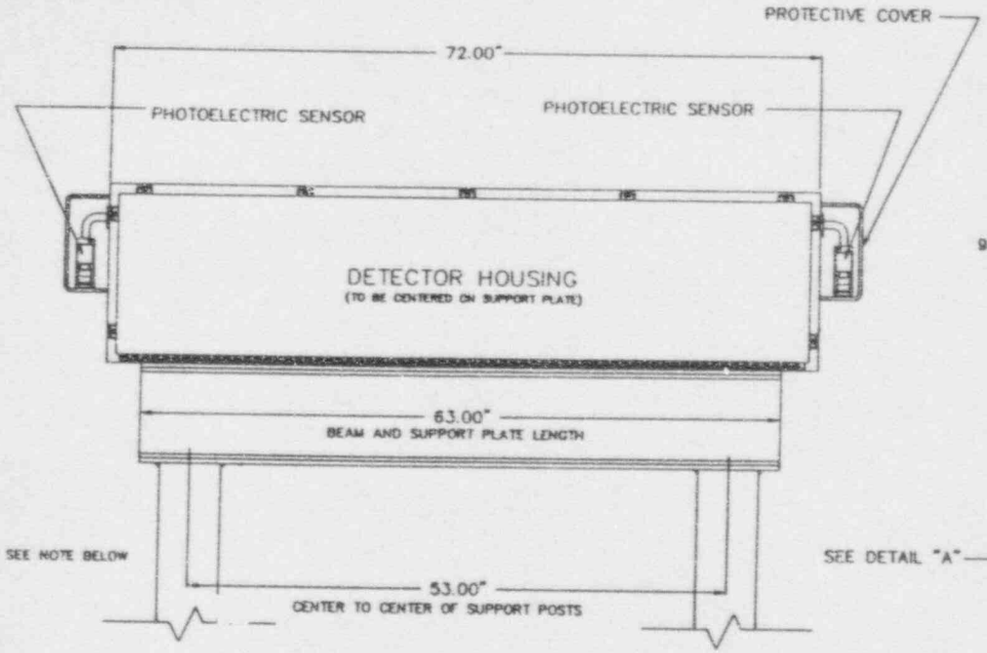
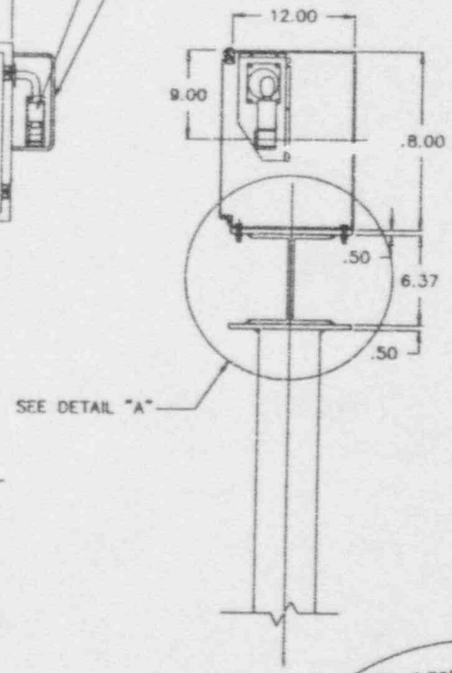
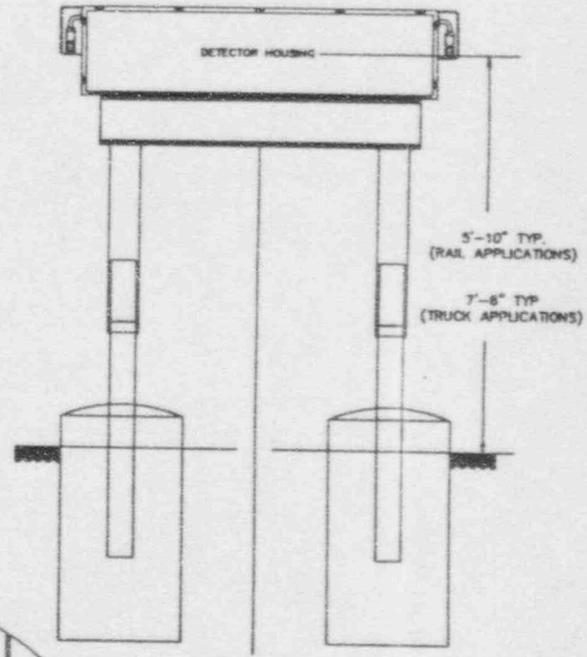
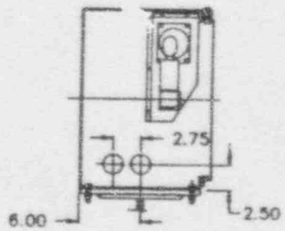




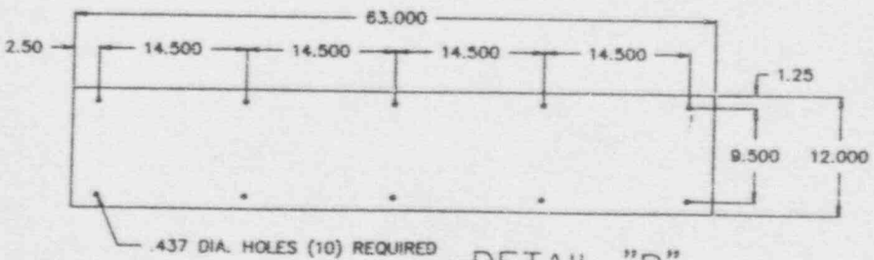


NOTE: USE 1 1/2" SEALTITE CONNECTORS.
90 DEGREE PULLING ELBOW

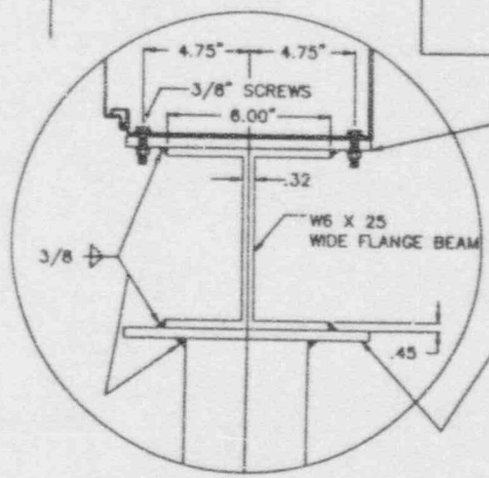
DETECTOR #1 AND #5 WILL HAVE (ONE) 1 1/2" CONNECTOR.
DETECTORS #2, #3, #4, #6, #7, & #8 WILL HAVE (TWO) 1 1/2" CONNECTORS.



LEFT SIDE VIEW



DETAIL "B"



DETAIL "A"

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REV.	DATE	DESCRIPTION	BY				

	NONE				
	SJD				
	4-4-90				
	5-2-96				

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SIZE	DRAWING NO.	REV.
D	9700113	A

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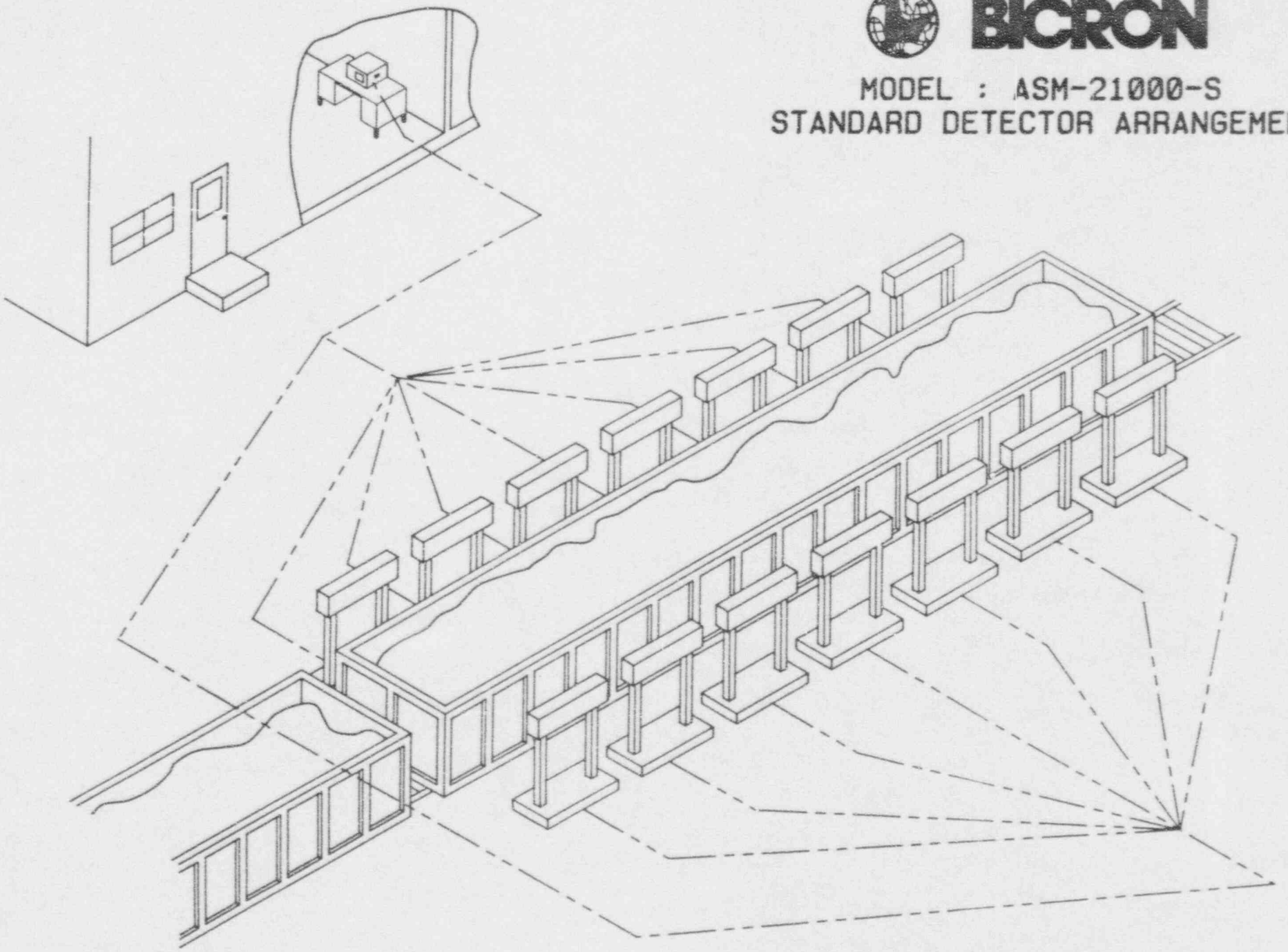
MODEL : ASM-21000-S

STANDARD DETECTOR ARRANGEMENT



Model: ASM-12000-S
Radioactive Material Detection System

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General

The model **ASM-12000-S** radioactive material detection system monitors scrap-filled railcars or trucks while they are stationary between the system's detectors (static mode) and as they move into and out of this position (dynamic mode). The system detects both shielded and unshielded radioactive sources mixed with the scrap while maintaining a very low false alarm rate.

The **ASM-12000-S** consists of eight detector assemblies located near truck or rail scales (or other convenient locations), and a microprocessor-based, control unit. The detector assemblies are connected to the control unit via two cable runs.

Each detector assembly contains one organic scintillation detector and associated signal-processing electronics. The components are shock mounted within lead-lined, weatherproof housings.

The control unit performs all signal-processing and calculations required for detecting radioactive materials in the incoming scrap. The unit monitors each detector independently and stores the resulting counts in memory. It then analyzes the data over two time intervals: the Background Update Interval and the Counting Interval.

Effectiveness

Detection probability is defined as that percentage of the total volume of a railcar or truck in which the specified test source is detected at the 90% detection confidence level or greater. The scrap cover density has a profound effect on detection probability because the scrap attenuates the radiation beams.

The **ASM-12000-S** achieves the following detection probabilities for a shielded, 100 mCi ^{137}Cs test source (centered in a 2' x 2' x 2' steel box reading 1 mR/h at the side surfaces) in various scrap covers and at a very low false alarm rate:

- #2 sheared scrap (30-35 lb/ft^3) - virtually 100%
- #1 sheared scrap (50-60 lb/ft^3) - virtually 100%
- Demolition scrap (60-70 lb/ft^3) - 85-100%
- High density scrap (80-90 lb/ft^3) - 75-85%

The system detects larger sources with proportionally higher detection probabilities.

continued

Model: ASM-12000-S
Specifications

Control Unit

OPERATING MODE: Static/dynamic; system is designed to monitor trucks or railcars while they are stationary and moving into and out of position

BACKGROUND UPDATE INTERVAL: Period of time over which the background is averaged; adjustable to 1000 seconds

COUNTING INTERVAL: Time period (1 second or longer) during which the counts from each detector are analyzed using computer techniques based upon the laws of counting statistics; the ratio between the counting interval and the background update interval is typically 1:10

MOUNTING: Unit is designed for table-top mounting; other configurations optional

READOUTS: 3 indicator lights - READY, WAIT, and ALARM; alphanumeric display panel for system parameters

AUDIBLE ALARM: Sounds when alarm conditions are encountered

OPERATOR CONTROLS: Single pushbutton for silencing alarm and resetting the system after cause of alarm is determined; illuminates when an alarm occurs

OTHER CONTROLS: Power ON/OFF switch; 12 key, numeric keypad for input of system parameters and for system checkout and maintenance; keypad locks to prevent unauthorized access and is not used during normal operation

POWER REQUIREMENTS: 117 V, 60 Hz AC

POWER CABLE: 6' cable fitted with a standard NEMA 15-5, 3 terminal plug

Detector Assemblies

DETECTOR TYPE: BC-408 premium organic scintillator with low noise photomultiplier tube and magnetic shield

NUMBER OF DETECTORS: 8 each in individual housings

DETECTOR VOLUME: 1500 in^3, each detector; 12,000 in^3 total for the system

HOUSING: Weatherproof, 14 gauge (NEMA 4) with gasketed, hinged front door for access to internal components

SIZE: 70" long X 18" high X 12" deep, each housing

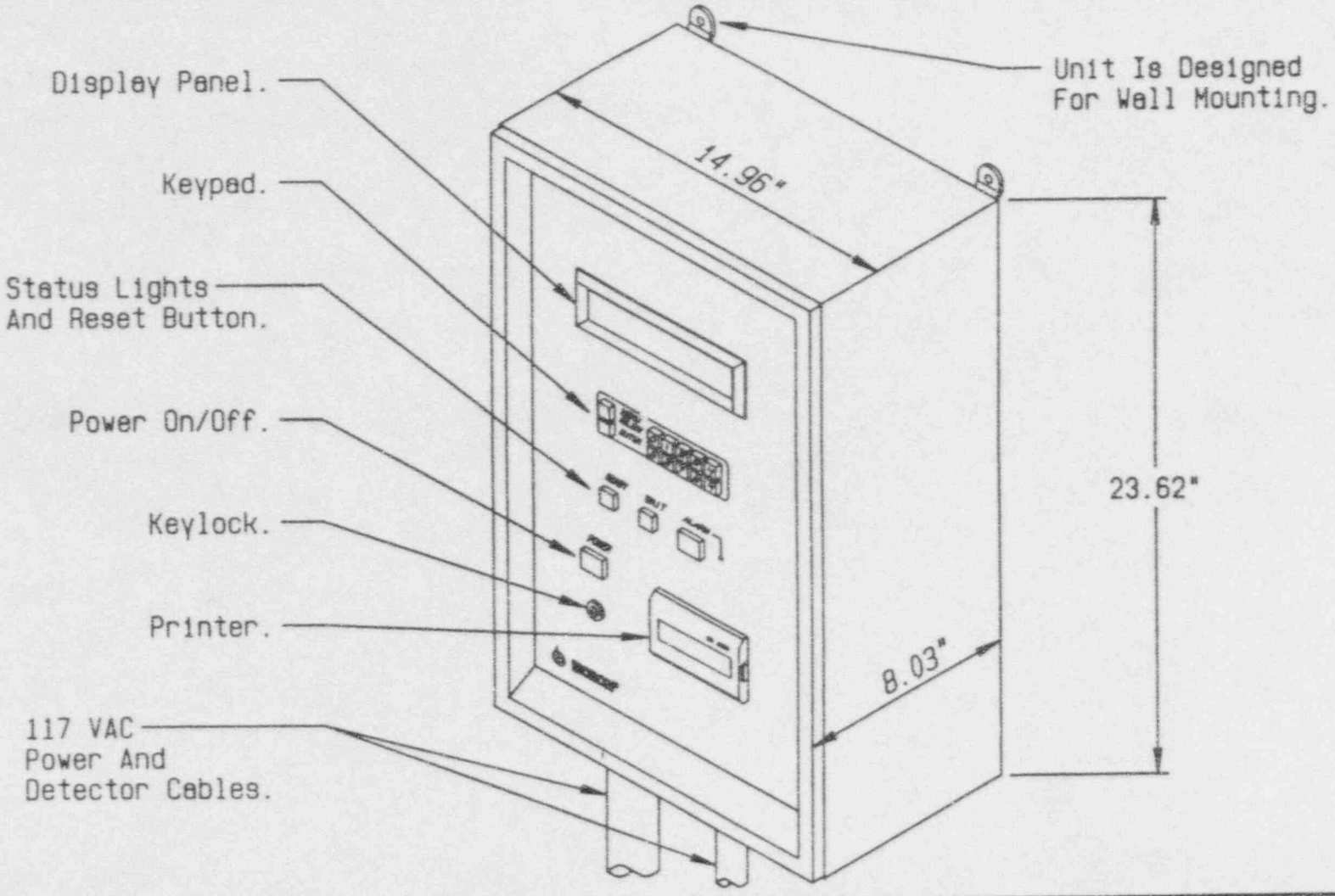
MOUNTING: Mounting hole pattern provided for installation on customer-provided I-beams

SHIELDING: The plastic scintillator is shielded on all sides except the door which serves as the radiation entrance window; the shielding provides background reduction and improved directional response

ELECTRONICS: Each detector has a remotely controlled, high voltage bias supply and voltage divider assembly (for the photomultiplier tube), pulse discriminator, and line driver

CONNECTING CABLE: Belden type 9777 for connecting detector assemblies to control unit; nominal OD is 0.82"; only 2 runs required; supplied by customer

CABLE CONDUIT: Weatherproof recommended; carries cable from detector assemblies to control unit; supplied by customer



TOLERANCES UNLESS OTHERWISE SPECIFIED	SCALE: None
FRAC.:	DRAWN: J.Vasko
.x:	
.xx:	DATE: 4-17-90
.xxx:	CHECKED:
ANGLES:	
MICRO FIN. √	DATE:
DEBURR & BREAK ALL EDGES	DO NOT SCALE PRINT

BICRON CORPORATION
NEWBURY, OHIO U.S.A.

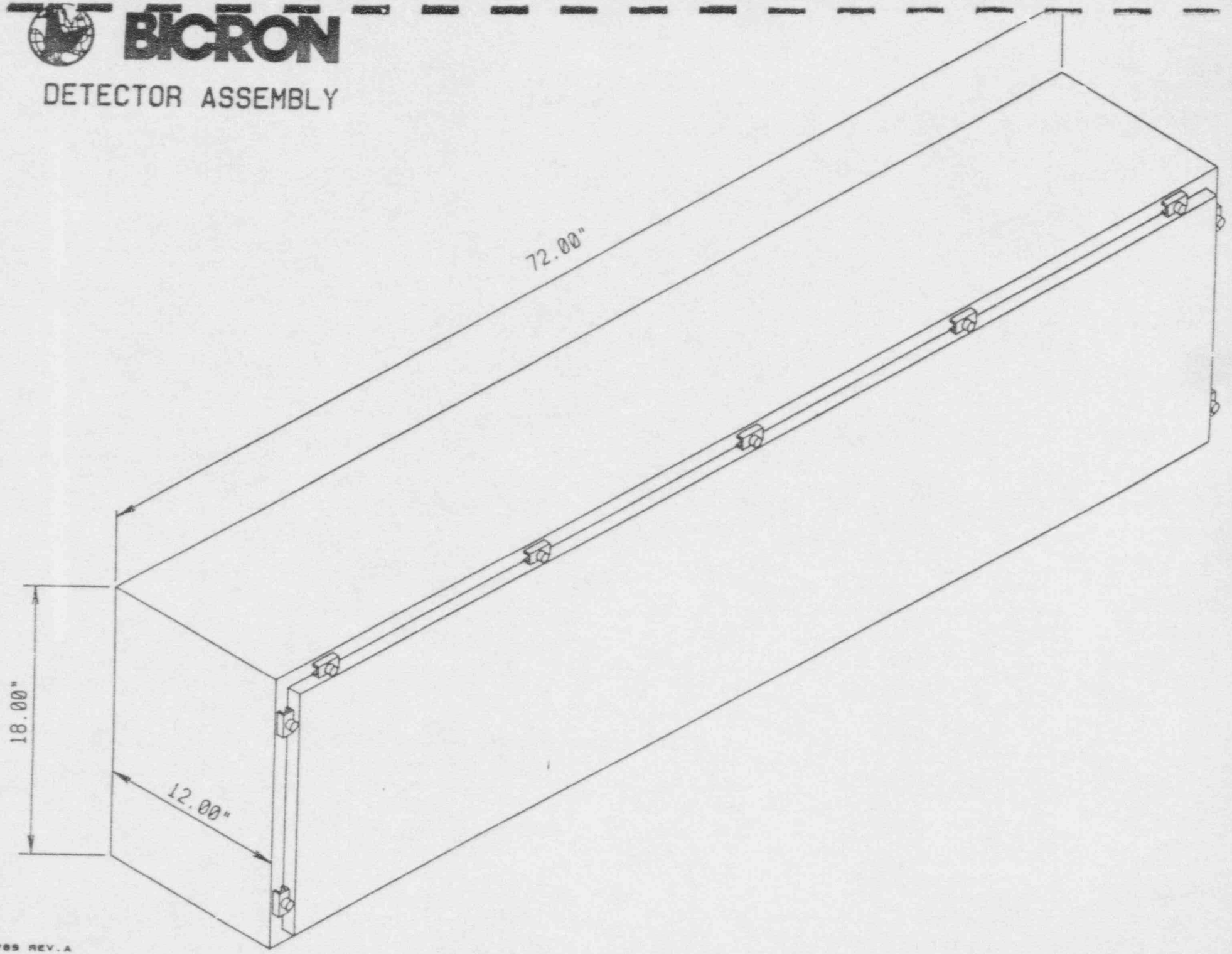
Microprocessor Control Unit
For
Radioactive Material Detection System

PROD. CODE	BASIC PART NUMBER	DIMENSION	FINISH	REV.
	A 9700114			A

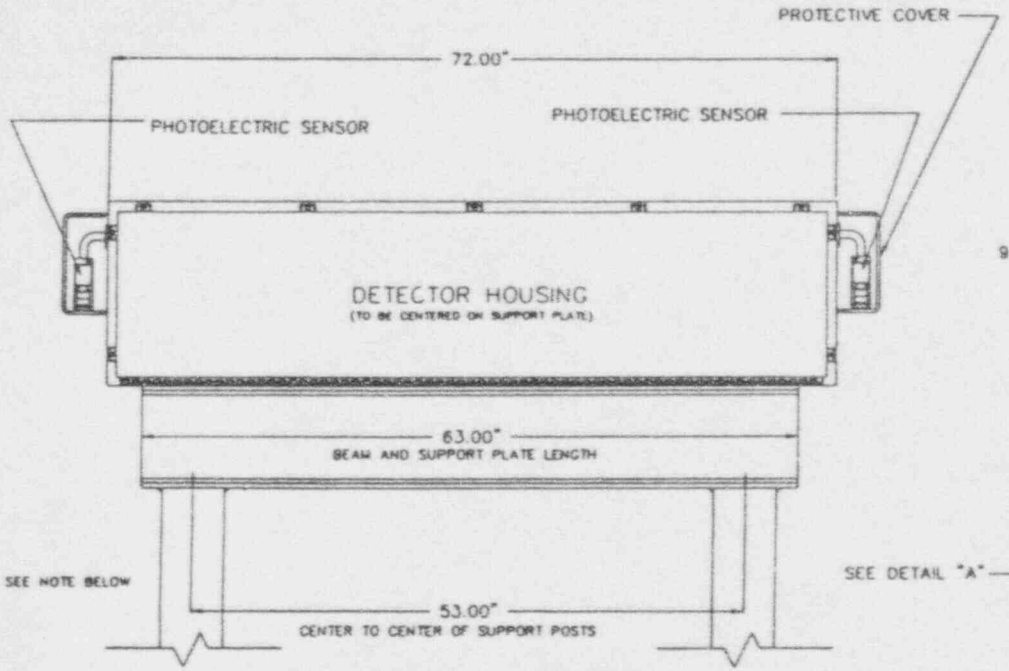
REV.	DATE	DESCRIPTION	BY
A	11-12-90	Title was "For ASM 6000D"	RJD

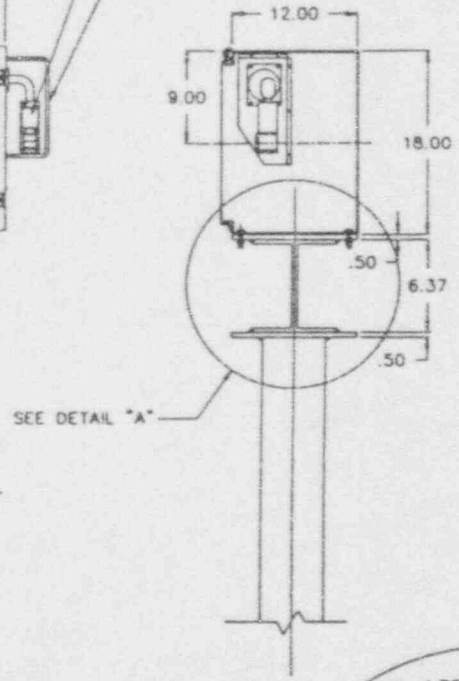
BICRON

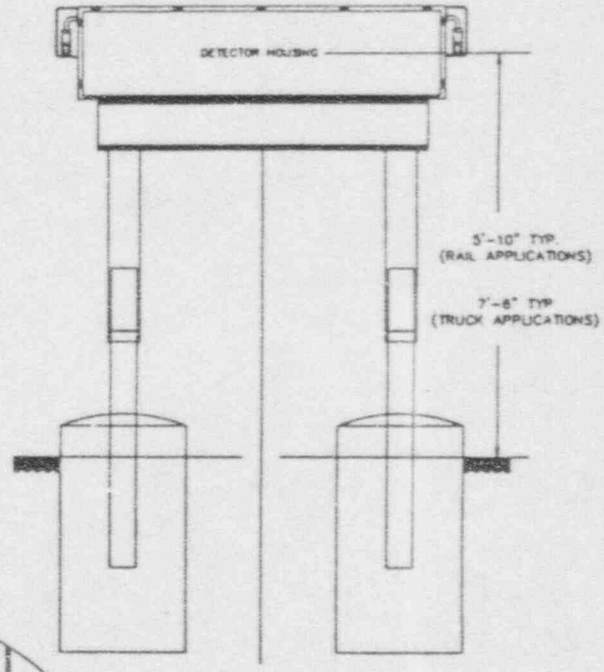
DETECTOR ASSEMBLY



5K092785 REV. A

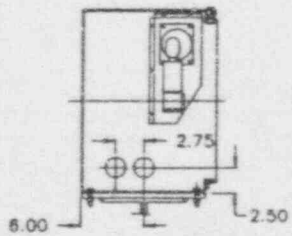




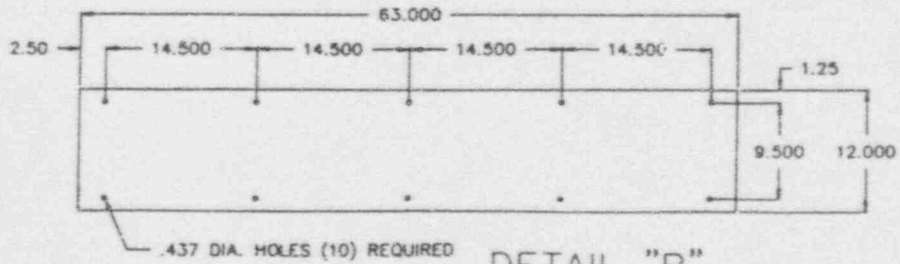


NOTE: USE 1 1/2" SEALTITE CONNECTORS.
90 DEGREE PULLING ELBOW

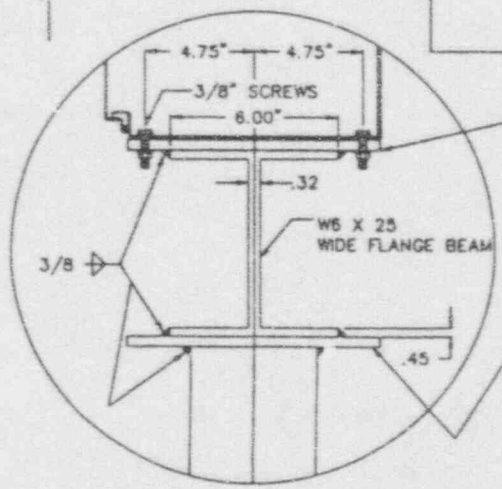
DETECTOR #1 AND #5 WILL HAVE (ONE) 1 1/2" CONNECTOR.
DETECTORS #2, #3, #4, #6, #7, & #8 WILL HAVE (TWO) 1 1/2" CONNECTORS.



LEFT SIDE VIEW



DETAIL "B"



DETAIL "A"

REV.	DATE	DESCRIPTION	BY
A	5-10-90	CHILDCARE LENGTH WAS 78.00"	TJB

NONE
R.D.
6-4-90
5-17-90

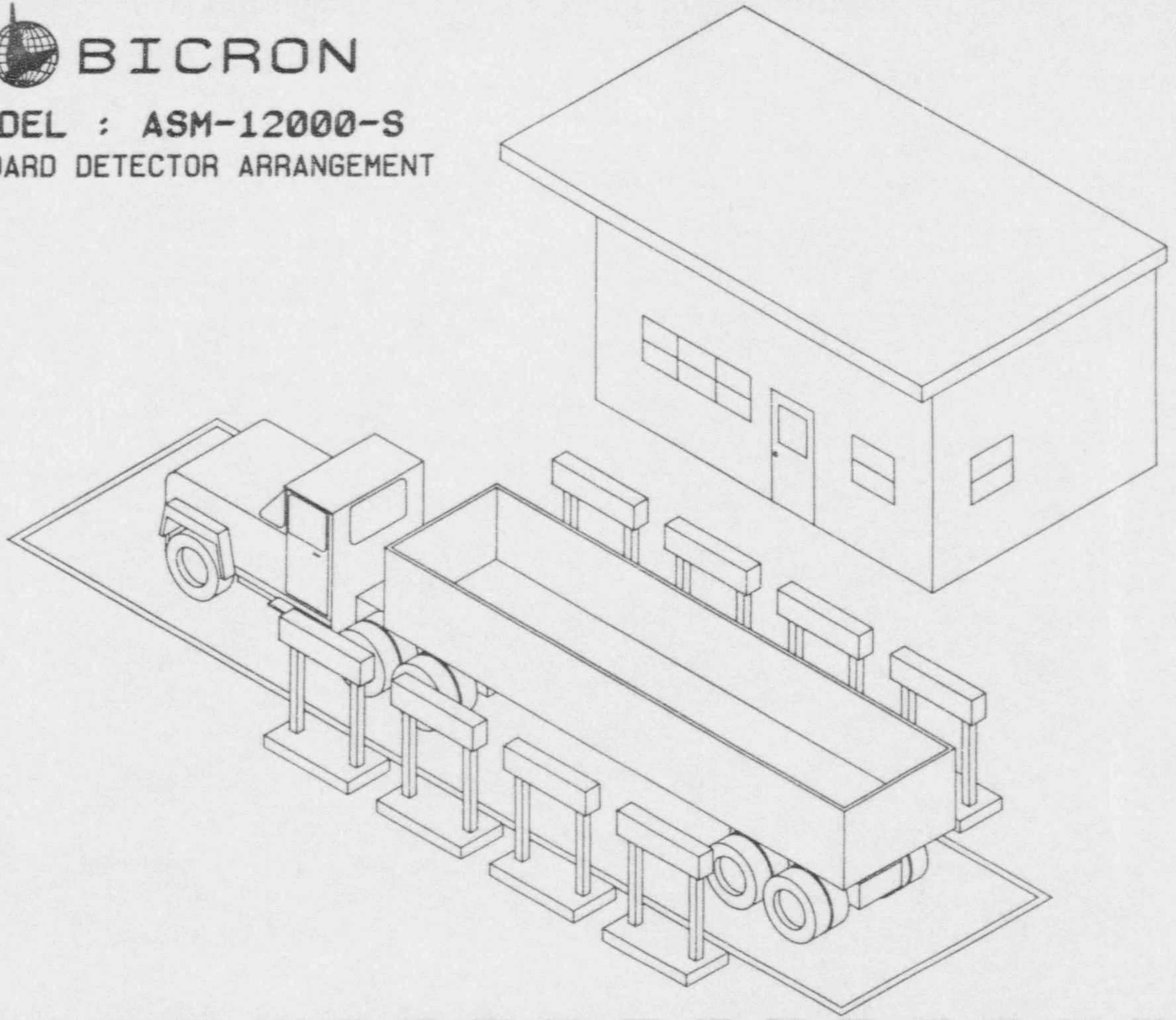
BICRON CORPORATION
NEWBURY, OHIO U.S.A.

D 9709113 A

BICRON

MODEL : ASM-12000-S

STANDARD DETECTOR ARRANGEMENT

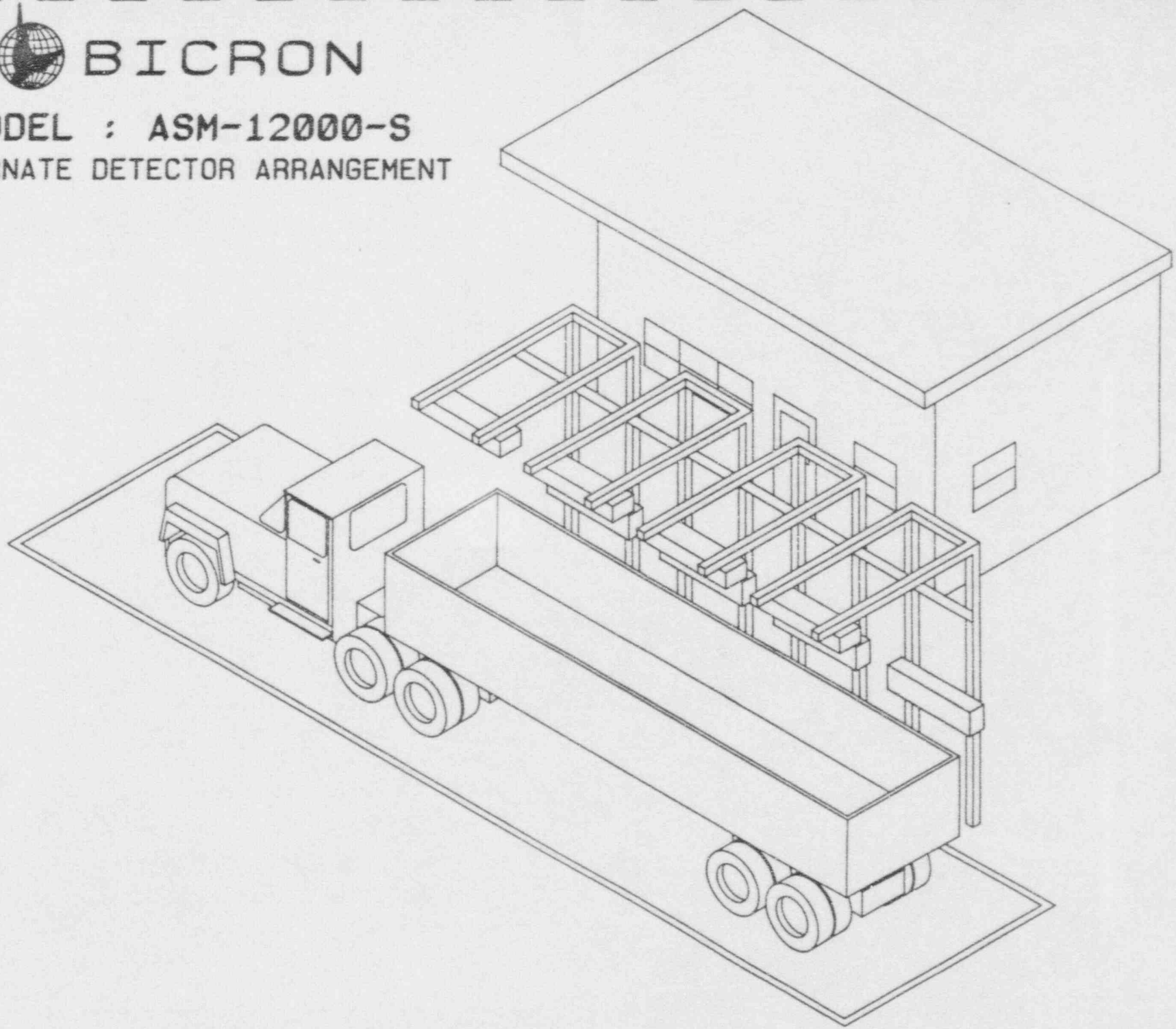


SK261589

BICRON

MODEL : ASM-12000-S

ALTERNATE DETECTOR ARRANGEMENT



3K881488

Model: ASM-6000-D
Radioactive Material Detection System

BICRON®

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Nippon Bicron
Room No. 805, 1-8, 1-Chome
Shinyokohama, Kohoku-Ku
Yokohama 222 Japan
Telephone: 045(474)5786
Telex: 045(474)5787

General

The model **ASM-6000-D** is a widely used, highly reliable, and sensitive radioactive material detection system which monitors scrap-filled railcars or trucks as they move past the system's detectors. The system detects both shielded and unshielded radioactive sources buried under scrap, while maintaining a very low false alarm rate.

The system can detect a lead-shielded source emitting only 1 mR/h in #1 or #2 sheared steel scrap while the vehicle carrying the scrap moves past the system's detectors at 5 mph. Typical lead-shielded sources (such as radiography sources) contain 100 mCi to 50 Ci of ^{137}Cs or ^{60}Co and produce exposure rates on the outsides of their shields equal to 2 to 10 mR/h.

The **ASM-6000-D** consists of two detector assemblies located near truck or rail scales (or other convenient locations), and a microprocessor-based, control unit. The detector assemblies can be positioned as far as 2000 feet from the control unit.

Each detector assembly contains two organic scintillation detectors and associated signal-processing electronics. The components are shock mounted within lead-lined, weatherproof housings.

The control unit performs all signal-processing and calculations required for detecting radioactive materials in the incoming scrap. The unit monitors each detector independently and stores the resulting counts in memory. It then analyses the data over two time intervals: the Background Update Interval and the Counting Interval. If radiation is detected, the system alarms and prints out the alarm conditions, date and time of alarm, and location of the source in the vehicle.

Effectiveness

The **ASM-6000-D** achieves the following detection probability with the system's sensitivity adjusted to yield a low false or nuisance alarm rate (1 in 3 months) and the railcar or truck moving at 5 mph or less.

For a shielded 100 mCi (or an unshielded 300 μCi) ^{137}Cs source which is mounted in a 2' x 2' x 2' steel box and which produces a 1 mR/h exposure rate on the outside of the box, the system will detect the source 99% of the time when:

The box is buried in #1 or #2 sheared scrap or randomly distributed demolition scrap within a vehicle and the distance between the source centerline and the inside vehicle wall is 48" or less.

The box is buried in shredded scrap (frag) and the distance between the source centerline and the inside vehicle wall is 35" or less.

continued

Model: ASM-6000-D Specifications

Control Unit

OPERATING MODE: Dynamic; system is designed to monitor moving trucks or railcars

BACKGROUND UPDATE INTERVAL: Period of time over which the background is averaged; typically, the time it takes a vehicle to pass the detector array

COUNTING INTERVAL: Time period during which the detector counts are analyzed using computer techniques based upon the laws of counting statistics; typically 0.2 seconds

MOUNTING: Unit is designed for wall mounting; other configurations optional

READOUTS: 3 indicator lights - READY, WAIT, and ALARM; alpha-numeric panel for system parameters; printer which prints out date, time, count rate, background count rate, and location of the source in the vehicle for each alarm incident

AUDIBLE ALARM: Sounds when alarm conditions are encountered

OPERATOR CONTROLS: Single pushbutton for silencing alarm and resetting the system after cause of alarm is determined; illuminates when an alarm occurs

OTHER CONTROLS: Power ON/OFF switch; 12 key numeric keypad for input of system parameters and for system checkout and maintenance - locks to prevent unauthorized access and is not used during normal operation

POWER REQUIREMENTS: 117 V, 60 Hz AC

POWER CABLE: 6' cable fitted with a standard NEMA 15-5, 3 terminal plug

SIZE: 14.96" wide x 23.62" high x 8.03" deep

Detector Assemblies

DETECTOR TYPE: BC-408 premium plastic scintillator with low noise photomultiplier tube and magnetic shield; BC-434 if temperatures inside the detector housing are to exceed 150°F

RADIATION DETECTED: ^{60}Co, ^{137}Cs, ^{192}Ir, $^{226}Ra/Th$, neutrons, ^{241}Am and other medium and high energy gamma-emitting isotopes

NUMBER OF DETECTORS: 4 each, 2 per assembly

DETECTOR VOLUME: 1500 in^3, each detector; 6000 in^3 total for the system

TOTAL DETECTION SURFACE AREA: 2880 in^2

HOUSING: Weatherproof, 14 gauge (NEMA 4) with gasketed, hinged front door for access to internal components

SIZE: 72" long X 36" high X 12" deep, each housing

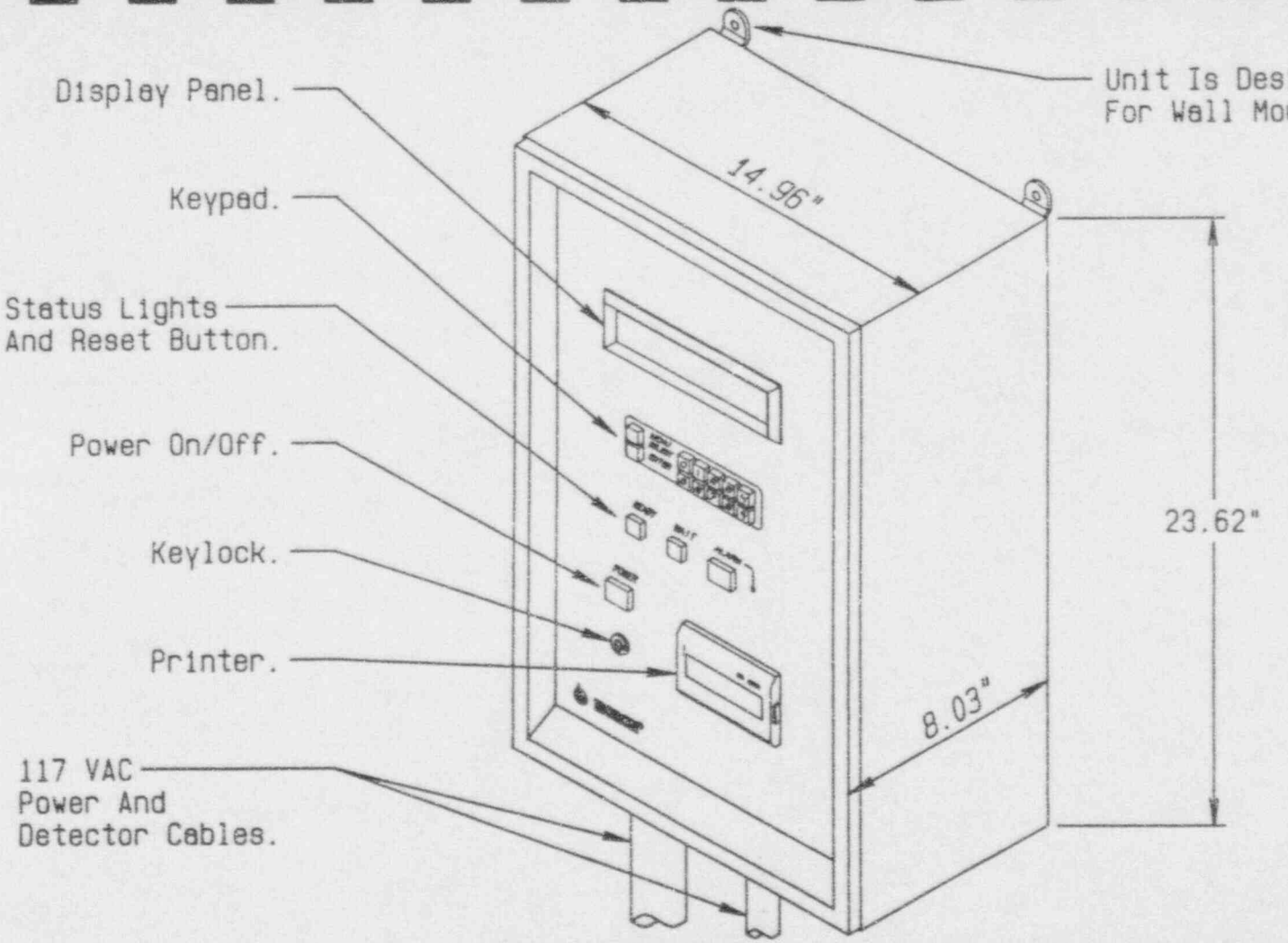
MOUNTING: Mounting hole pattern provided for installation on customer-provided I-beams

SHIELDING: The plastic scintillator is lead shielded on all sides except the door which serves as the radiation entrance window; the shielding provides background reduction and improved directional response

ELECTRONICS: Each detector has a remotely controlled, high voltage bias supply and voltage divider assembly (for the photomultiplier tube); pulse discriminator; and line driver

CONNECTING CABLE: Belden type 9777 multiconductor for connecting detector assemblies to control unit; nominal OD is 0.82"; supplied by customer

CABLE CONDUIT: Weatherproof recommended; carries cable from detector assemblies to control unit; supplied by customer



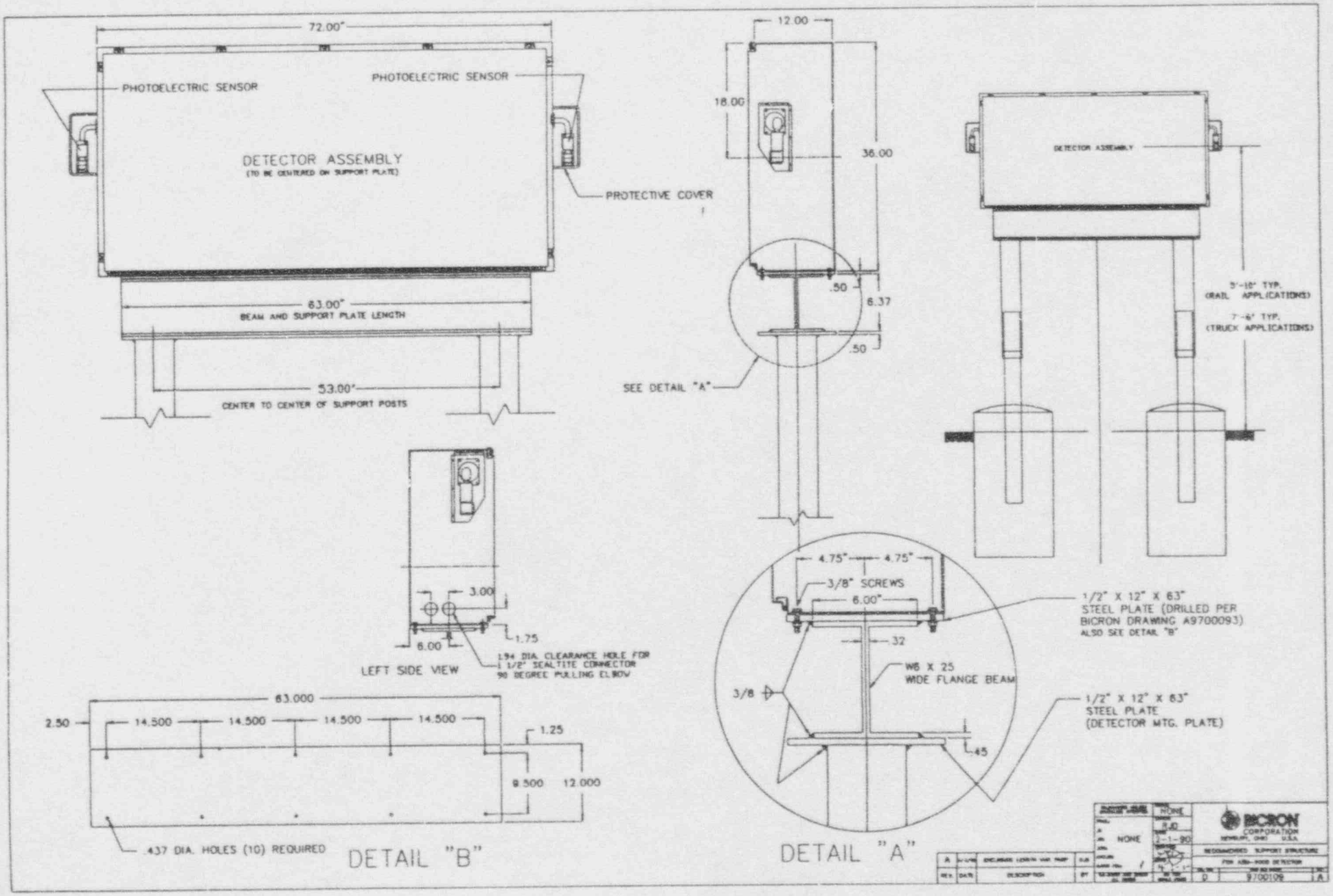
TOLERANCES UNLESS OTHERWISE SPECIFIED	SCALE: None
FRAC.:	DRAWN: J.Vasko
.X:	
.XX:	DATE: 4-17-90
.XXX:	CHECKED:
ANGLES:	
MICRO FIN. J	DATE:
DEBURR & BREAK ALL EDGES	DO NOT SCALE PRINT

BICRON CORPORATION
NEWBURY, OHIO U.S.A.

Microprocessor Control Unit
For
Radioactive Material Detection System

PROD. CODE	BASIS PART NUMBER	DIMENSION	FINISH	REV.
	A 9700114			A

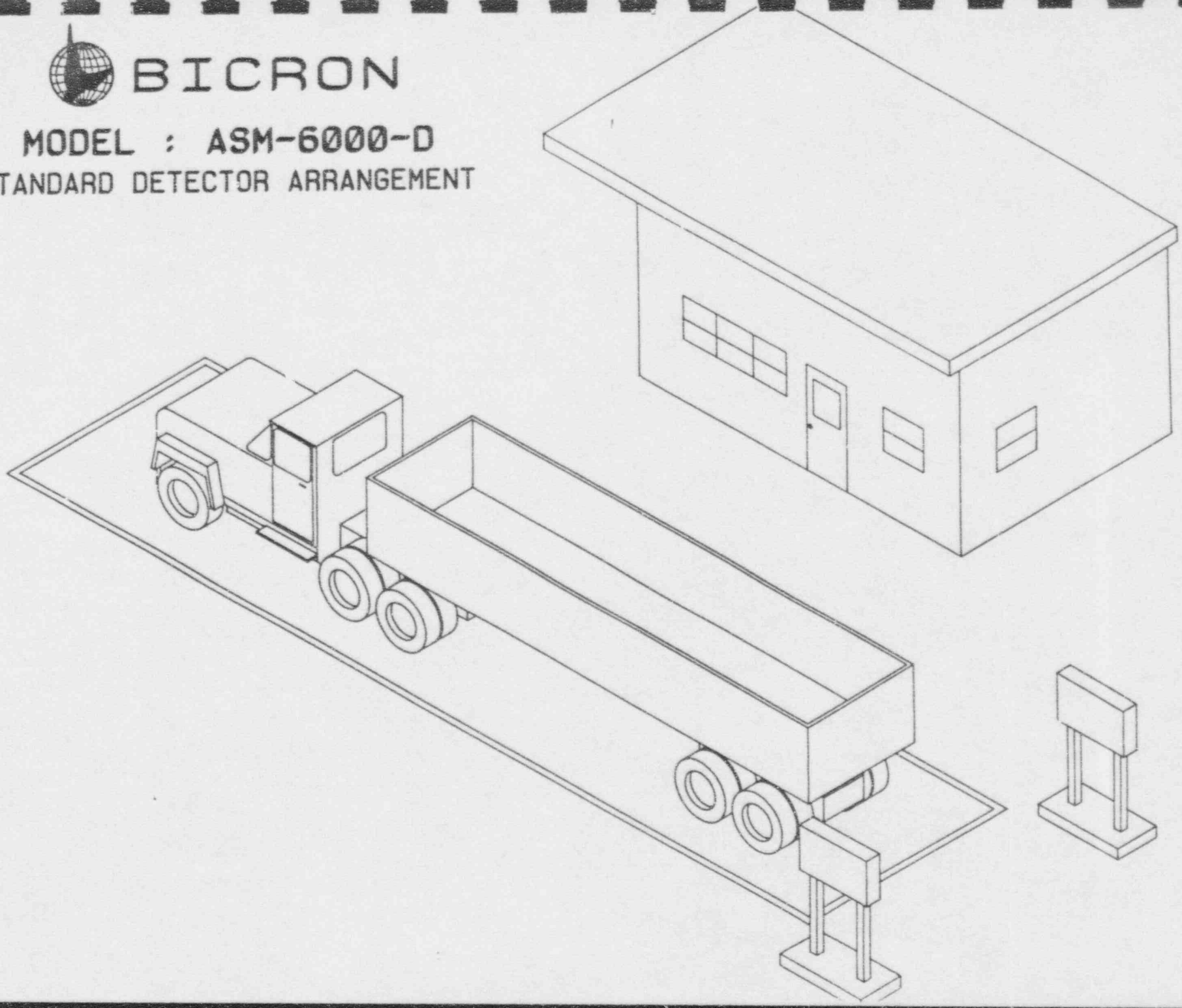
REV.	DATE	DESCRIPTION	BY
A	11-12-90	Title was "For ASM 6000D"	RJD


72.00"
PHOTOELECTRIC SENSOR
PHOTOELECTRIC SENSOR
DETECTOR ASSEMBLY
(TO BE CENTERED ON SUPPORT PLATE)
PROTECTIVE COVER
83.00"
BEAM AND SUPPORT PLATE LENGTH
53.00"
CENTER TO CENTER OF SUPPORT POSTS
12.00
18.00
36.00
.50
6.37
.50
SEE DETAIL "A"
DETECTOR ASSEMBLY
5'-10" TYP.
(RAIL APPLICATIONS)
7'-6" TYP.
(TRUCK APPLICATIONS)
3.00
1.75
6.00
1.94 DIA. CLEARANCE HOLE FOR
1 1/2" SEALTITE CONNECTOR
90 DEGREE PULLING ELBOW
LEFT SIDE VIEW
4.75"
4.75"
3/8" SCREWS
6.00"
1/2" X 12" X 63"
STEEL PLATE (DRILLED PER
BICRON DRAWING A9700093)
ALSO SEE DETAIL "B"
.32
W8 X 25
WIDE FLANGE BEAM
3/8
1/2" X 12" X 63"
STEEL PLATE
(DETECTOR MTG. PLATE)
.45
63.000
2.50
14.500
14.500
14.500
14.500
1.25
8.500
12.000
.437 DIA. HOLES (10) REQUIRED
DETAIL "B"
DETAIL "A"
NONE
8-10
2-1-90
BICRON
CORPORATION
NEWBURY, OHIO U.S.A.
RECOMMENDED SUPPORT STRUCTURE
FOR ABS-ROAD DETECTOR
D
9700198
A

BICRON

MODEL : ASM-6000-D

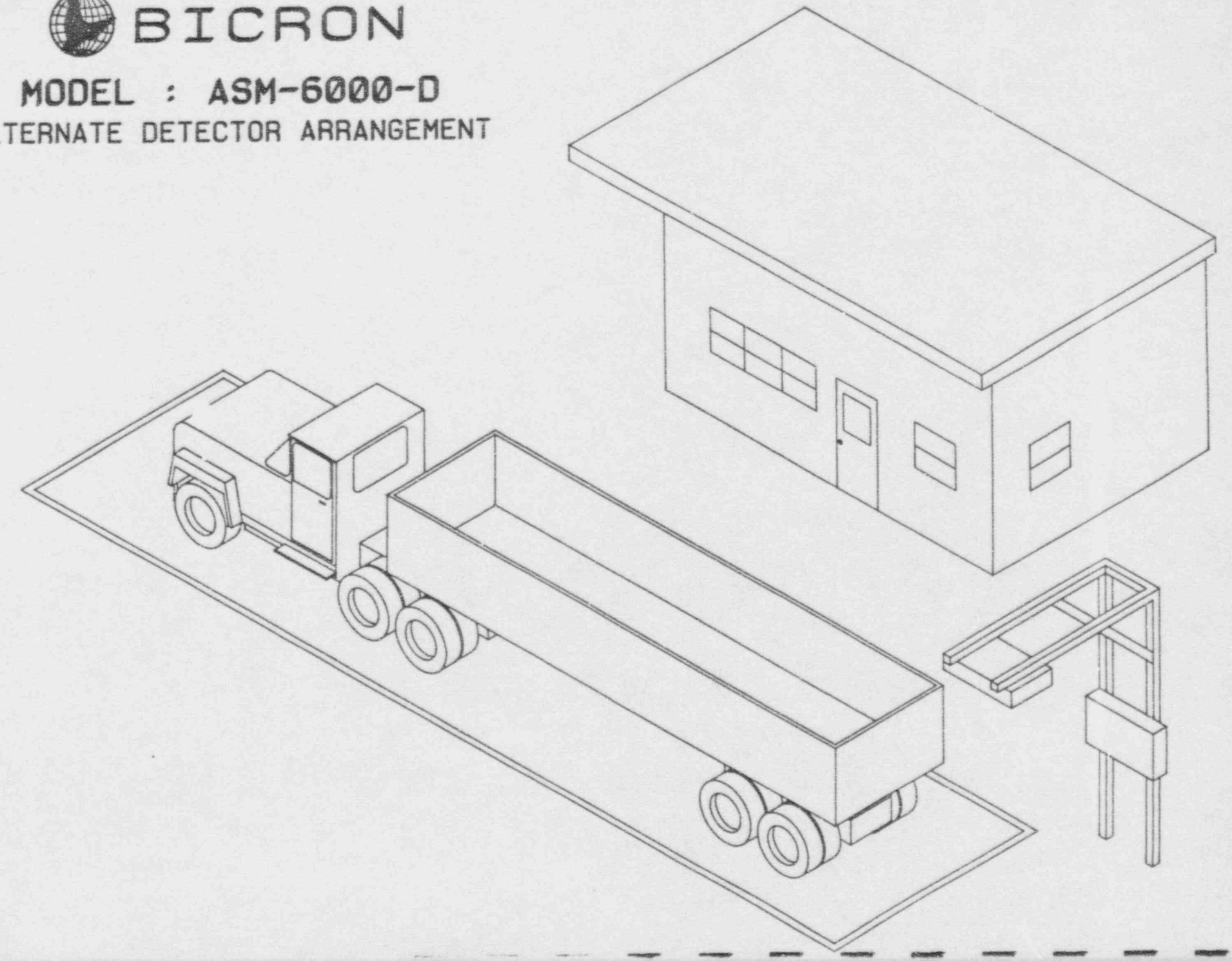
STANDARD DETECTOR ARRANGEMENT



BICRON

MODEL : ASM-6000-D

ALTERNATE DETECTOR ARRANGEMENT



Model: ASM-3000-S
Radioactive Material Detection System

BICRON®

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2410 AG Bodegraven, The Netherlands
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Telefax: 1726-14316
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Nippon Bicron
Room No. 805, 1-8, 1-Chome
Shinyokohama, Kohoku-Ku
Yokohama 222 Japan
Telephone: 045(474)5786
Telex: 045(474)5787

General

The model **ASM-3000-S** is a highly reliable and sensitive radioactive material detection system used primarily for monitoring a charge bucket during the scrap loading process. The system detects both shielded and unshielded radioactive sources mixed with the scrap, while maintaining a very low false alarm rate.

The **ASM-3000-S** consists of a microprocessor-based control unit and one detector assembly which is located near the charge bucket. The detector assembly can be positioned as far as 2000 feet from the control unit.

The detector assembly contains two plastic scintillation detectors and associated signal-processing electronics. The components are shock mounted within a lead-lined, weatherproof housing.

The control unit performs all signal-processing and calculations required for detecting radioactive materials in the scrap. The unit monitors the detectors and stores the resulting counts in memory. It then analyzes the data over two time intervals: the Background Update Interval and the Counting Interval. If radiation is detected, the unit alarms and prints out the alarm conditions and date and time of alarm.

Effectiveness

Monitoring at the charge bucket during the scrap loading process is one of the most reliable and effective ways to detect shielded radioactive sources mixed with scrap. The system gets to look for sources in the scrap both while the materials are dropping from the magnet and while they're in the charge bucket. In both situations, the scrap covering the source is greatly reduced.

The scrap cover density has a profound effect on detection probability because the scrap attenuates the radiation beams. Monitoring at this location thus increases the probability of detecting shielded sources greatly.

The **ASM-3000-S** achieves the following detection probability:

For a shielded 100 mCi (or an unshielded 300 μCi) ^{137}Cs source which is mounted in a 2' x 2' x 2' steel box and which produces an exposure rate of 1 mR/h on the outside of the box, the system will detect the source 99% of the time when the source is located inside the charge bucket and detected only through the charge bucket wall with the distance between the detector faces and the far wall of the charge bucket at 23'6" or less.

This probability is achieved with the system sensitivity adjusted to yield a low false or nuisance alarm rate (1 in 3 months). In use, the system will see these sources virtually 100% of the time since it also is operating when the scrap drops into the bucket and there is no intervening charge bucket wall to attenuate the radiation.

continued

Model: ASM-3000-S Specifications

Control Unit

OPERATING MODE: The system detects radioactive sources as scrap is loaded into a charge bucket

BACKGROUND UPDATE INTERVAL: Period of time over which the background is averaged; is greater than the time it takes to move the charge bucket from its loading area and replace it with a new charge bucket

COUNTING INTERVAL: Time period during which the detector counts are analyzed using computer techniques based upon the laws of counting statistics; typically 1 second or longer

MOUNTING: Unit is designed for wall mounting

READOUTS: 3 indicator lights - READY, WAIT, and ALARM; alphanumeric display panel for system parameters; printer which prints out date, time, count rate, and background count rate for each alarm incident

AUDIBLE ALARM: Sounds when alarm conditions are encountered

OPERATOR CONTROLS: Single pushbutton for silencing alarm and resetting the system after cause of alarm is determined; illuminates when an alarm occurs

OTHER CONTROLS: Power ON/OFF switch; 12 key numeric keypad for input of system parameters and for system checkout and maintenance; keypad locks to prevent unauthorized access and is not used during normal operation

POWER REQUIREMENTS: 117 V, 60 Hz AC

POWER CABLE: 6' cable fitted with a standard NEMA 15-5, 3 terminal plug

SIZE: 14.96" wide x 23.62" high x 8.[illegible] deep

Detector Assemblies

DETECTOR TYPE: BC-408 premium plastic scintillator with low noise photomultiplier tube and magnetic shield; BC-434 if temperatures inside the detector housing are to e[illegible]eed 150°F

RADIATION DETECTED: ^{60}Co, ^{137}Cs, ^{192}Ir, $^{226}Ra/Th$, neutrons, ^{241}Am and other medium and high energy gamma-emitting isotopes

NUMBER OF DETECTORS: 2 each in one assembly

DETECTOR VOLUME: 1500 in^3, each detector; 3000 in^3 total for the system

TOTAL DETECTION SURFACE AREA: 1440 in^2

HOUSING: Weatherproof, 14 gauge (NEMA 4) with gasketed, hinged front door for access to internal components

SIZE: 72" long X 36" high X 12" deep

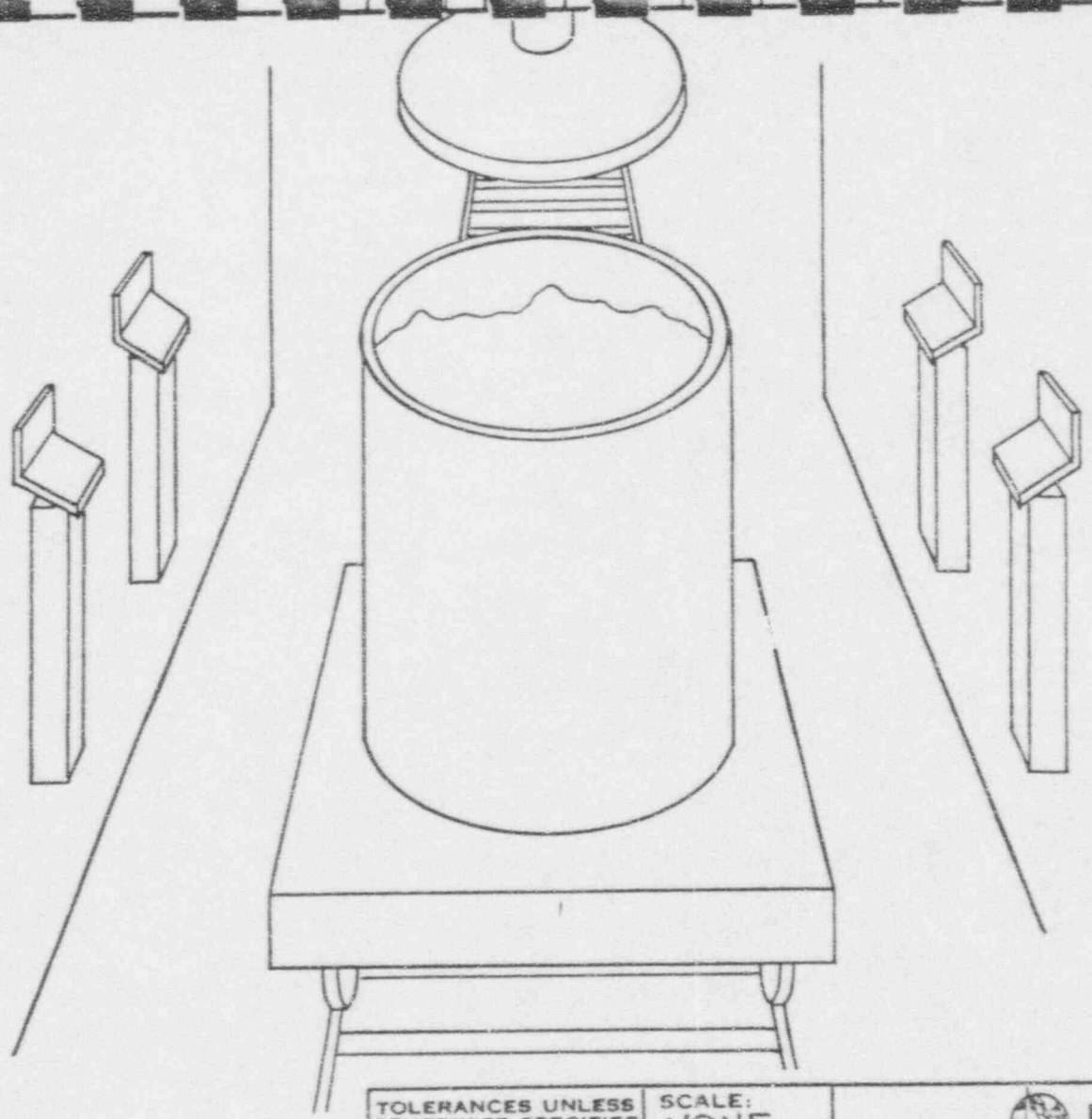
MOUNTING: Mounting hole pattern provided for installation on customer-provided I-beams

SHIELDING: The plastic scintillators are lead-shielded on all sides except the door which serves as the radiation entrance window (it faces the charge bucket); the shielding provides background reduction and improved directional response

ELECTRONICS: Each detector has a remotely controlled, high voltage bias supply and voltage divider assembly for the photomultiplier tube; pulse discriminator; line driver

CONNECTING CABLE: Belden type 9777 multiconductor for connecting detector assembly to control unit; nominal OD is 0.82"; supplied by customer

CABLE CONDUIT: Weatherproof recommended; carries cable from detector assembly to control unit; supplied by customer



REV.	DATE	DESCRIPTION	BY

TOLERANCES UNLESS OTHERWISE SPECIFIED

FRAC. ±
.X ±
.XX ±
.XXX ±
ANGLES ± °

MICRO FIN √
DE-BURR & BREAK ALL EDGES

DO NOT SCALE PRINT

SCALE: NONE
DRAWN: J.VASKO
DATE: 11-15-88
CHECKED:
DATE:

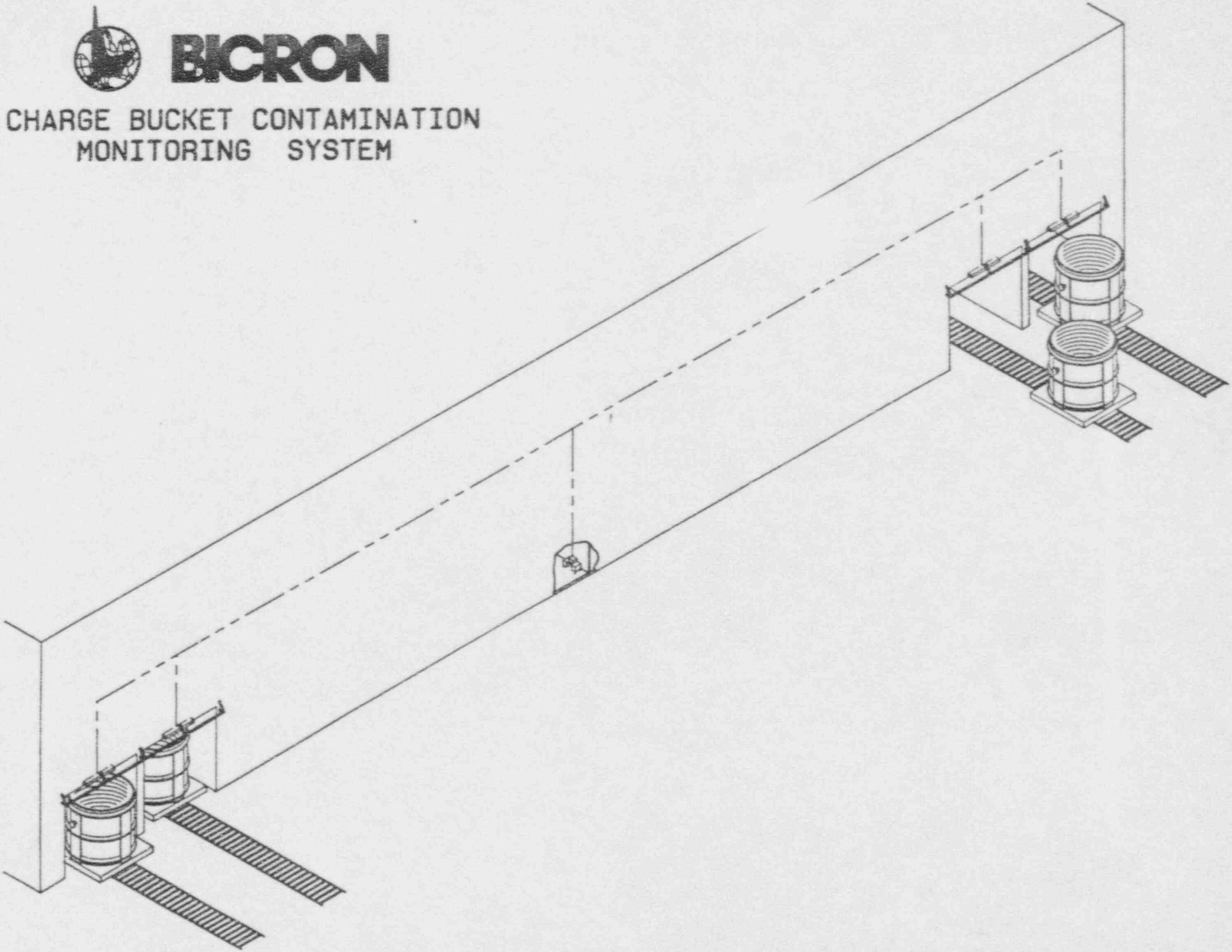
BICRON CORPORATION
NEWBURY, OHIO U.S.A.

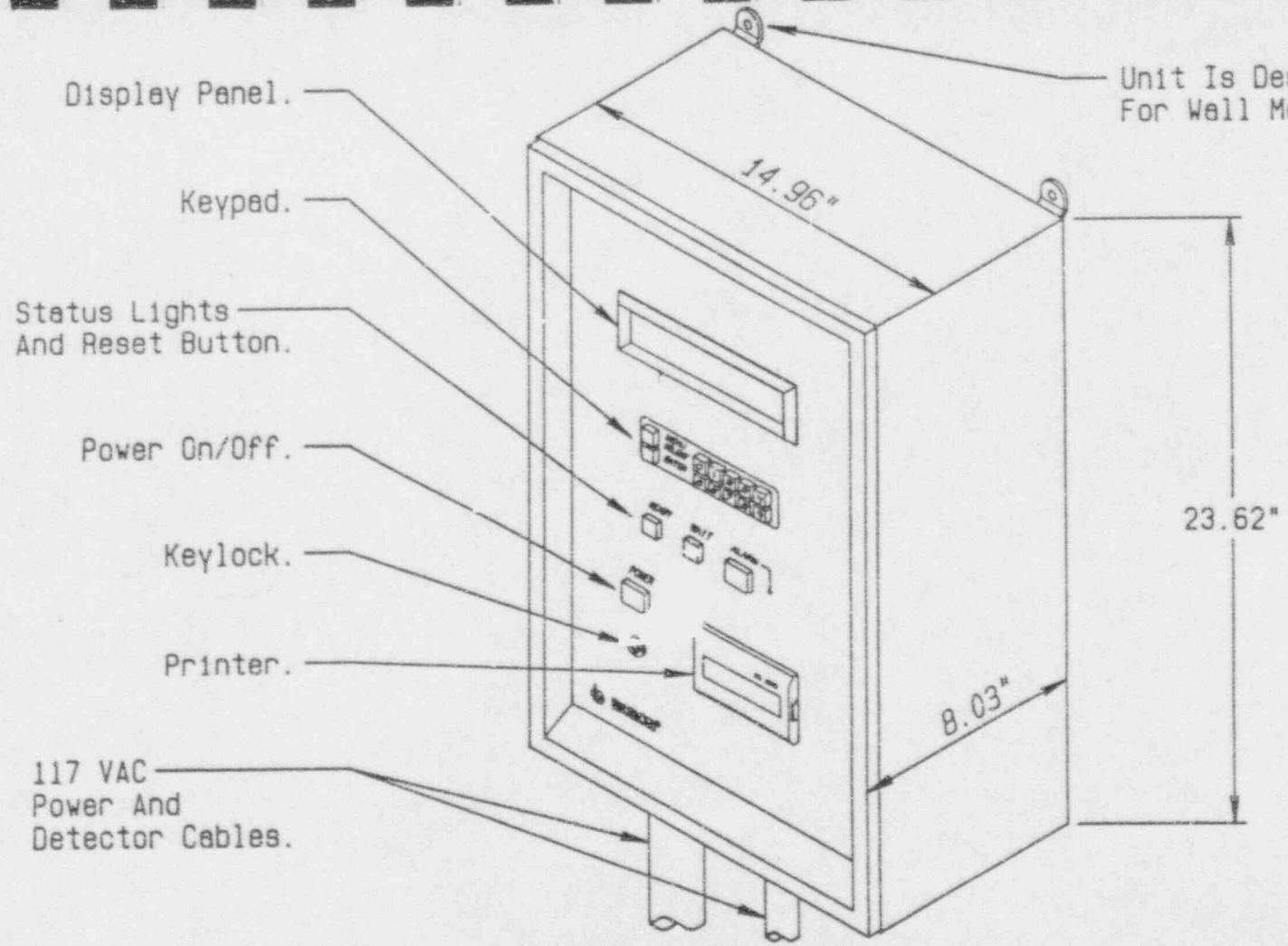
CHARGE BUCKET SCRAP STEEL MONITORING SYSTEM.

PROD. CODE	Dwg. Code	BASIC PART NUMBER	Dimension	FINISH	REV.
	A 9	7 0 0 0 6 2			

BICRON

CHARGE BUCKET CONTAMINATION MONITORING SYSTEM





TOLERANCES UNLESS OTHERWISE SPECIFIED	SCALE: None
FRAC.:	DRAWN: J.Vasko
.X:	
.XX:	DATE: 4-17-90
.XXX:	CHECKED:
ANGLES:	
MICRO FIN. √	DATE:
DEBURR & BREAK ALL EDGES	DO NOT SCALE PRINT

BICRON CORPORATION
NEWBURY, OHIO U.S.A.

Microprocessor Control Unit
For
Radioactive Material Detection System

PROD. CODE	BASIC PART NUMBER	DIMENSION	FINISH	REV.
	A 9700114			A

REV.	DATE	DESCRIPTION	BY
A	11-12-90	Title was "For ASM 6000D"	RJD

Model: ASM-200
Radioactive Material Detection System

BICRON®

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Telex: 980474 BICRON NWBY

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Room No. 805, 1-8, 1-Chome
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Yokohama 222 Japan
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Telex: 045(474)5787

GENERAL DESCRIPTION

The ASM-200 is a radioactive material detection system designed to monitor scrap-filled vehicles as they stop to be weighed or checked in. The system detects (at a very low false alarm rate) unshielded radioactive sources (medium and high energy gamma, and neutron radiation) in medium and small vehicles containing randomly distributed scrap. In some cases, it also can detect shielded sources (if the source is close to one of the system's detectors). Because of its plastic scintillators, the ASM-200 also will detect ^{241}Am sources (found in static precipitators) and other neutron generating sources.

The system consists of 2 each, shielded, 100 in^3, organic scintillation detectors mounted in separate, PVC housings connected via cables (2, 50' cables supplied) to an electronics readout package. The most appropriate place for mounting the system's detectors is at the scale where they can monitor the vehicle as it is being weighed. It takes just 15 seconds to make an accurate measurement.

SPECIFICATIONS

Detector Complement: 2 BC-408 plastic scintillation detectors with lead shielding, each shock-mounted in a weatherproof, PVC housing.

Radiation Detected: ^{60}Co, ^{137}Cs, ^{192}Ir, ^{226}Ra/Th, neutrons, ^{241}Am.

Total Detection Surface Area: 72 in^2

Detection Mode/Time: Stop for 15 seconds.

Sensitivity: Will detect 10 µCi of ^{137}Cs at 7' from the detector.

Range: 0-200,000 cpm in two linear ranges; factory set for 20,000 cpm full scale.

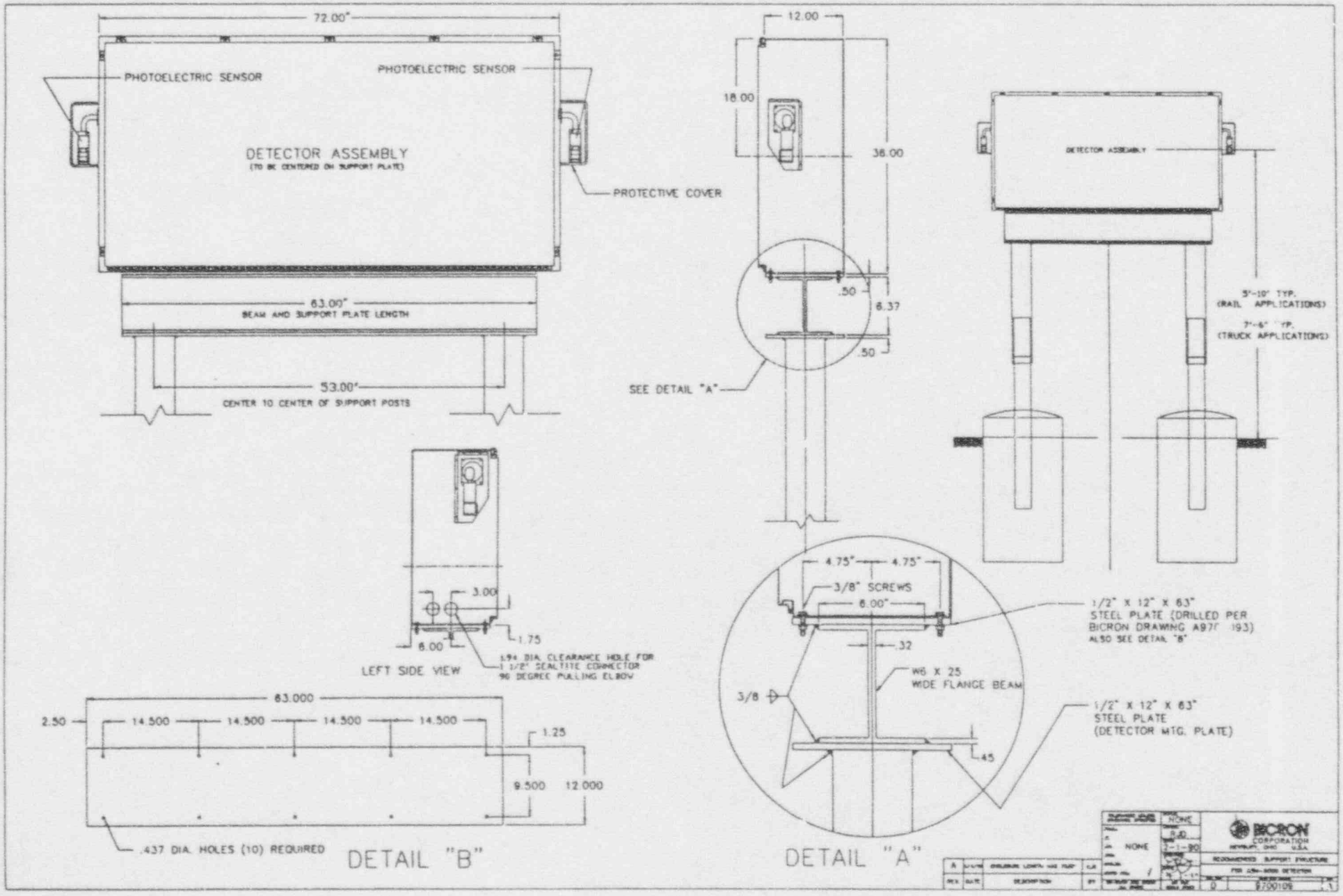
Accuracy: Within 5% of reading above 20% of full scale.

HV: Factory set, internally regulated.

Detector Connectors: (2) MHV.

Response Time: Signal - continuously adjustable from 2 to 20 seconds; LCD display - less than 1 second in Alarm Set, Bat, and HV modes; and 6 seconds in Rate mode.

continued


72.00"
PHOTOELECTRIC SENSOR
PHOTOELECTRIC SENSOR
DETECTOR ASSEMBLY
(TO BE CENTERED ON SUPPORT PLATE)
PROTECTIVE COVER
63.00"
BEAM AND SUPPORT PLATE LENGTH
53.00"
CENTER TO CENTER OF SUPPORT POSTS
12.00
18.00
38.00
.50
6.37
.50
SEE DETAIL "A"
DETECTOR ASSEMBLY
5'-10" TYP.
(RAIL APPLICATIONS)
7'-6" TYP.
(TRUCK APPLICATIONS)
3.00
1.75
6.00
LEFT SIDE VIEW
.594 DIA. CLEARANCE HOLE FOR
1 1/2" SEALTITE CONNECTOR
90 DEGREE PULLING ELBOW
4.75"
4.75"
3/8" SCREWS
6.00"
1/2" X 12" X 63"
STEEL PLATE (DRILLED PER
BICRON DRAWING A97(193)
ALSO SEE DETAIL "B"
.32
W6 X 25
WIDE FLANGE BEAM
3/8
1/2" X 12" X 63"
STEEL PLATE
(DETECTOR MTG. PLATE)
.45
63.000
2.50
14.500
14.500
14.500
14.500
1.25
9.500
12.000
.437 DIA. HOLES (10) REQUIRED
DETAIL "B"
DETAIL "A"
NONE
NONE
B40
7-1-90
BICRON
CORPORATION
NEWBURY, OHIO U.S.A.
RECOMMENDED SUPPORT STRUCTURE
0
8700109

Model: ASM-200
Radioactive Material Detection System (cont.)

Power Requirements: 105-125 VAC, 50-60 Hz.

Battery: Rechargeable gelled cell which provides 12 hours (minimum) of backup operation between charges.

Recharge: Regulated; 16 hours when batteries have reached 10.0 VDC on the LCD display; charging automatic whenever unit is connected to AC line.

Battery Dependence: Less than 10% change is reading from fully charged to 10.0 VDC.

LCD Display: 3-1/2 digit display (1999) with 0.7" (1.8 cm) high digits.

Detector Status: (2) green LED's which are illuminated whenever detector activity is sensed - one LED is assigned to each detector; LED turns off if corresponding detector does not produce any activity for a 15 second period; non-latching.

Shock: 100G per lightweight machine of MIL-STD 202C, method 202B.

Vibration: 5G in each of three mutually orthogonal axes at one or more frequencies from 10-33 Hz.

Controls: Response control, volume control, 4 position mode switch, 3 position audio switch, display reset switch, power ON/OFF switch, ratemeter sensitivity switch (internally mounted).

Audio: Switch selectable to provide and audible "click" for each detector pulse and an audible alarm above the alarm set point, an audible alarm only, or disable audio output.

Audio Volume: Adjustable when audio switch is in the "pulse" position. Disabled (full volume) whenever an alarm condition occurs, or when audio switch is in the "alarm" position.

Alarm: Audible, non-latching rate alarm with front panel adjustment from 10% to 130% of full scale with readout on the LCD display; red LED alarm indicator on front panel.

Display Reset: Pushbuttom switch which quickly zeros the LCD display in the "Rate" mode.

Recorder Output: Rear panel BNC connector provides 100 mV signal for a full scale (20 kcpm or 200 kcpm) LCD display reading; output will drive 100 kohm loads.

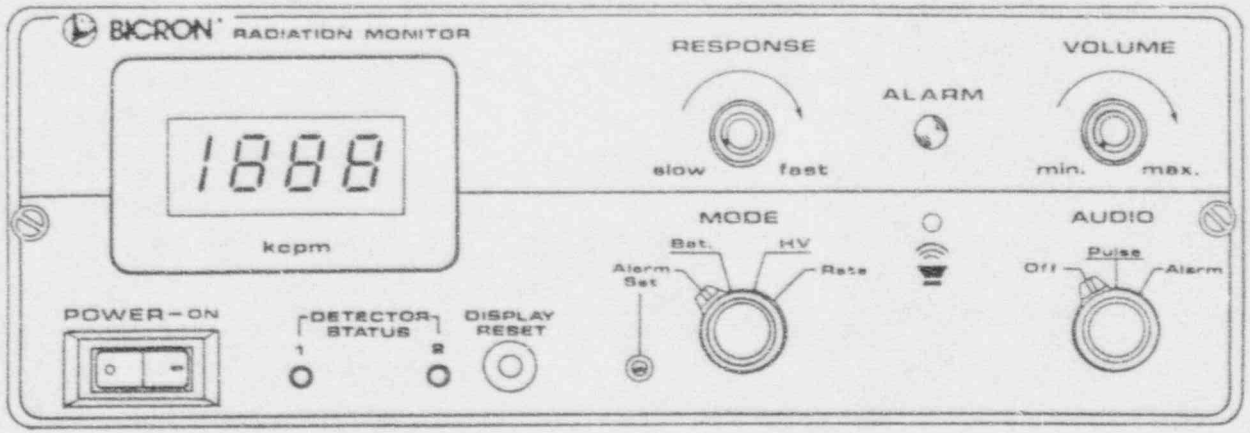
Temperature: Readout unit operational from -20°C to +50°C (+4°F to +122°F); detectors operational from -35°C to +50°C (-31°F to +122°F)

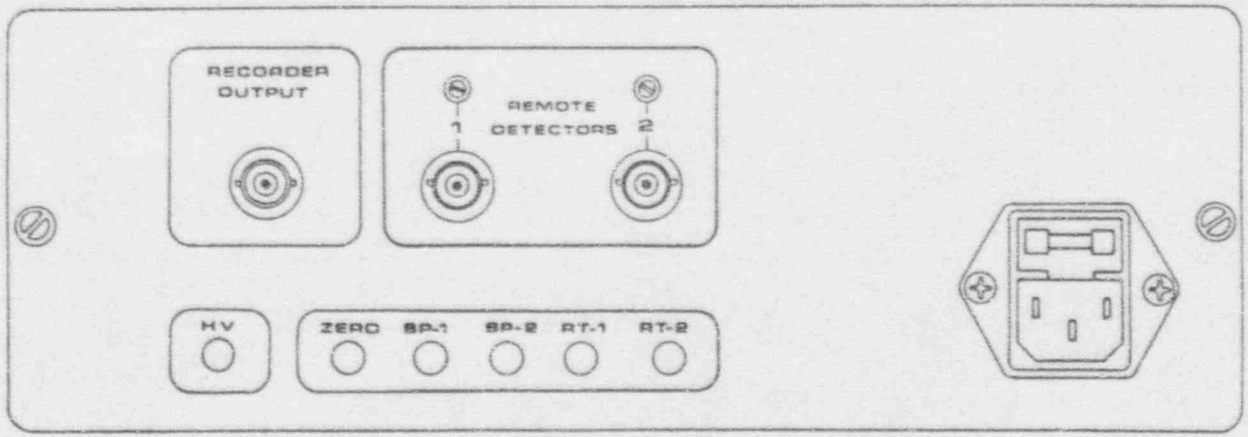
Size: 10.0" wide X 5.4" high x 7.8" inch deep (25.4 X 13.7 X 19.8 cm) including case-top handle, excluding detectors and cables.

Weight: 5.5 pounds (2.5 kg) excluding all detectors and cables.

Construction: All-aluminum case with textured polyurethane paint finish and silkscreened nomenclature.

Power Cord Connector: 3-wire type with 1/4 amp fuse; UL approved.





REV.	DATE	DESCRIPTION	BY

TOLERANCES UNLESS OTHERWISE SPECIFIED
FRAC. ±
.X ±
.XX ±
.XXX ±
ANGLES ±
MICRO FIN. √
DE-BURR & BREAK ALL EDGES

SCALE: Full
DRAWN: J. Vasko
DATE: 8-19-89
CHECKED:
DATE: 8-14-89
DO NOT SCALE PRINT

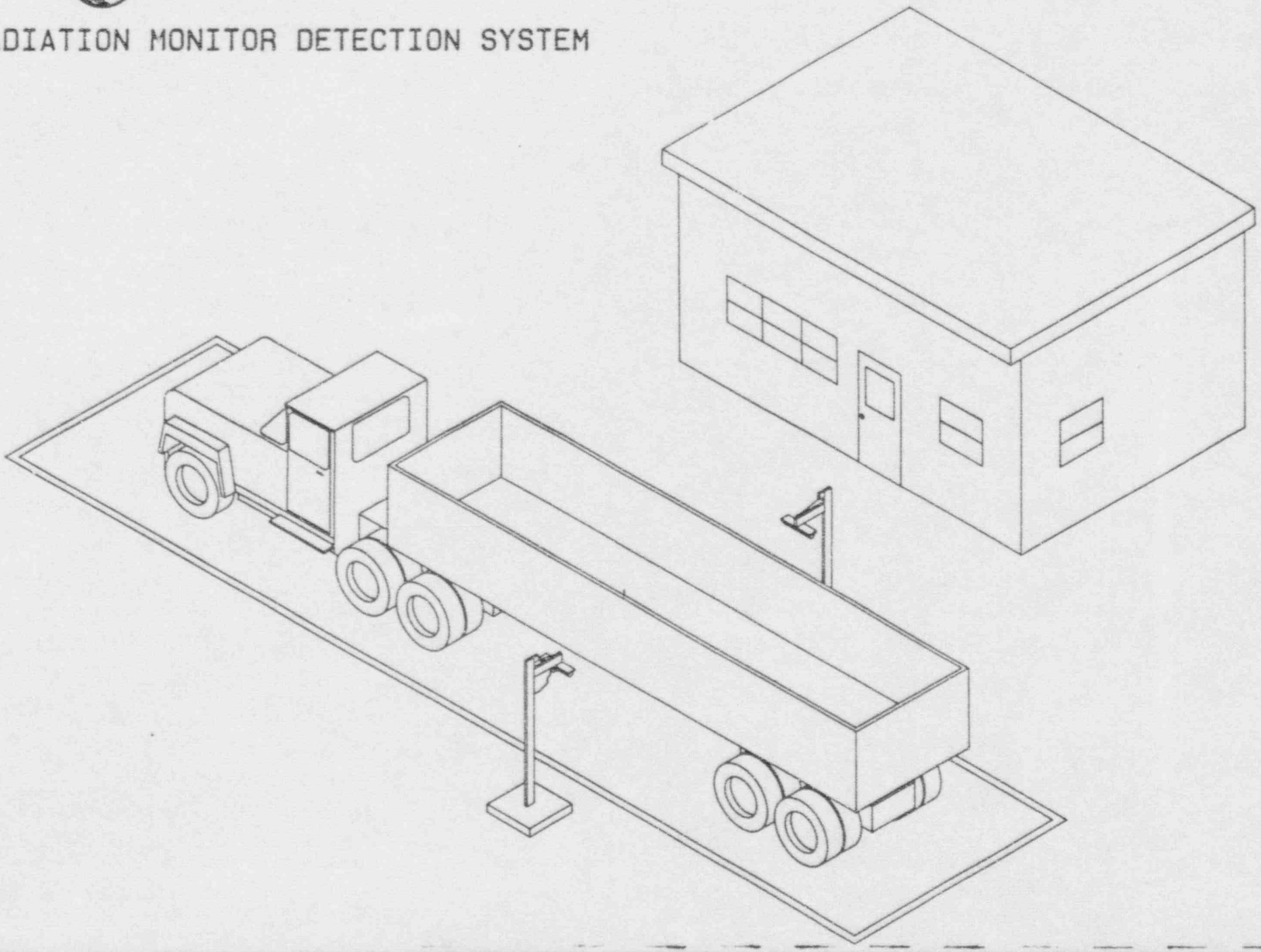
BICRON CORPORATION
NEWBURY, OHIO U.S.A.

ENGINEERING SALES DRAWING
BICRON RADIATION MONITOR

FROM CODE	Group Code	BASIC PART NUMBER						Revision	FINISH	REV.
		B	9	7	0	0	1	0	1	

BICRON

RADIATION MONITOR DETECTION SYSTEM



Model: ASM-6
Radioactive Material Detection System

BICRON®

Bicron Corporation
12345 Kinsman Road
Newbury, Ohio 44065-9677
Telephone: (216) 564-2251
Telefax: (216) 564-8047
Telex: 980474 BICRON NWBY

European Office
Marktstraat 27A, P.O. Box 271
2410 AG Bodegraven, The Netherlands
Telephone: 1726-14243
Telefax: 1726-14316
Telex: 39772 BICIN NL

Nippon Bicron
Room No. 805, 1-8, 1-Chome
Shinyokohama, Kohoku-Ku
Yokohama 222 Japan
Telephone: 045(474)5786
Telex: 045(474)5787

GENERAL DESCRIPTION

The ASM-6 is a radioactive material detection system designed to monitor scrap-filled vehicles as they stop to be weighed or checked in. The system detects (at a very low false alarm rate) unshielded radioactive sources (gamma-emitting isotopes with energies greater than 32 keV) in small vehicles containing small quantities of scrap.

The system consists of 2 each, shielded, 2" diameter, sodium iodide scintillation detectors mounted in separate, PVC pipe housings connected via cables (2, 50' cables supplied) to an electronics readout package. The most appropriate place for mounting the system's detectors is at the scale where they can monitor the vehicle as it is being weighed. It takes just 15 seconds to make an accurate measurement.

SPECIFICATIONS

Detector Complement: 2 NaI(Tl) scintillation detectors with lead shielding, each mounted in a PVC pipe housing.

Radiation Detected: ^{60}Co, ^{137}Cs, ^{192}Ir, $^{226}Ra/Th$

Total Detection Surface Area: 6.25 in^2

Detection Mode/Time: Stop for 15 seconds

Sensitivity: Will detect 75 µCi of ^{137}Cs at 7' from the detector

Range: 0-200,000 cpm in two linear ranges; factory set for 20,000 cpm full scale.

Accuracy: Within 5% of reading above 20% of full scale.

HV: Factory set, internally regulated.

Detector Connectors: (2) MHV.

Response Time: Signal - continuously adjustable from 2 to 20 seconds; LCD display - less than 1 second in Alarm Set, Bat, and HV modes; and 6 seconds in Rate mode.

Power Requirements: 105-125 VAC, 50-60 Hz.

continued

Model: ASM-6
Radioactive Material Detection System (cont.)

Battery: Rechargeable gelled cell which provides 12 hours (minimum) of backup operation between charges.

Recharge: Regulated; 16 hours when batteries have reached 10.0 VDC on the LCD display; charging automatic whenever unit is connected to AC line.

Battery Dependence: Less than 10% change is reading from fully charged to 10.0 VDC.

LCD Display: 3-1/2 digit display (1999) with 0.7" (1.8 cm) high digits.

Detector Status: (2) green LED's which are illuminated whenever detector activity is sensed - one LED is assigned to each detector; LED turns off if corresponding detector does not produce any activity for a 15 second period; non-latching.

Shock: 100G per lightweight machine of MIL-STD 202C, method 202B.

Vibration: 5G in each of three mutually orthogonal axes at one or more frequencies from 10-33 Hz.

Controls: Response control, volume control, 4 position mode switch, 3 position audio switch, display reset switch, power ON/OFF switch, ratemeter sensitivity switch (internally mounted).

Audio: Switch selectable to provide and audible "click" for each detector pulse and an audible alarm above the alarm set point, an audible alarm only, or disable audio output.

Audio Volume: Adjustable when audio switch is in the "pulse" position. Disabled (full volume) whenever an alarm condition occurs, or when audio switch is in the "alarm" position.

Alarm: Audible, non-latching rate alarm with front panel adjustment from 10% to 130% of full scale with readout on the LCD display; red LED alarm indicator on front panel.

Display Reset: Pushbuttom switch which quickly zeros the LCD display in the "Rate" mode.

Recorder Output: Rear panel BNC connector provides 100 mV signal for a full scale (20 kcpm or 200 kcpm) LCD display reading; output will drive 100 kohm loads.

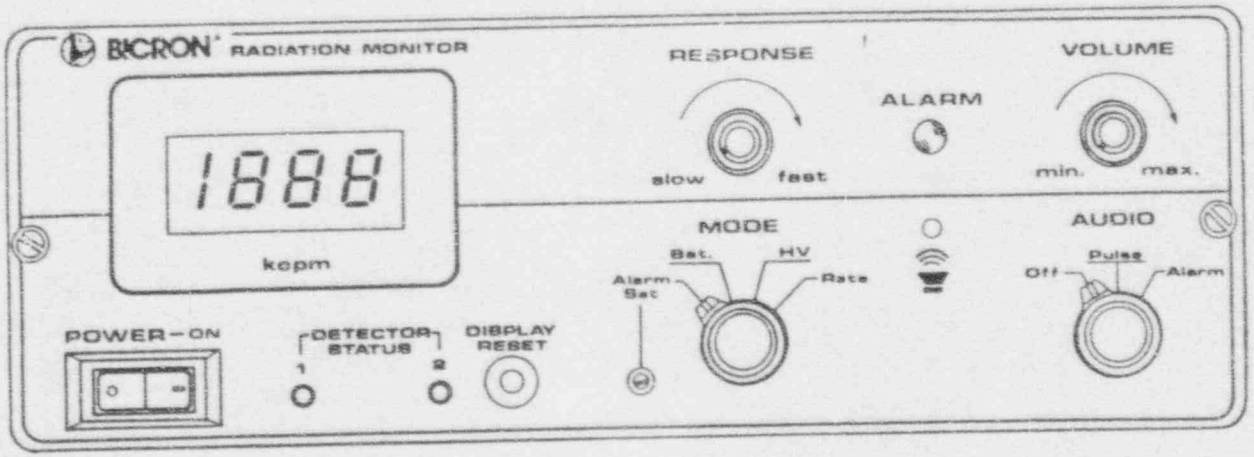
Temperature: Readout unit operational from -20°C to +50°C (+4°F to +122°F); detectors operational from -35°C to +50°C (-31°F to +122°F)

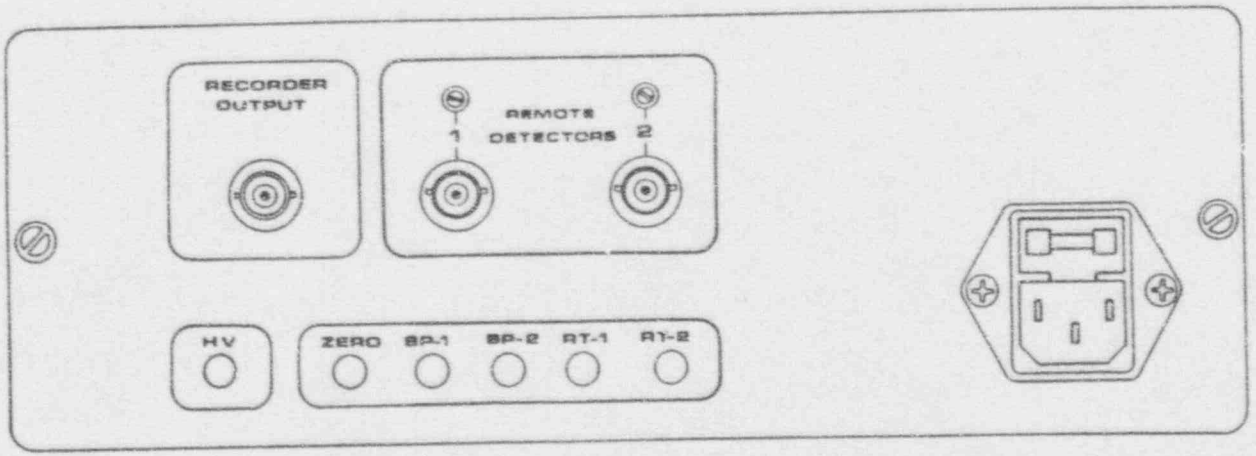
Size: 10.0" wide X 5.4" high x 7.8" inch deep (25.4 X 13.7 X 19.8 cm) including case-top handle, excluding detectors and cables.

Weight: 5.5 pounds (2.5 kg) excluding all detectors and cables.

Construction: All-aluminum case with textured polyurethane paint finish and silkscreened nomenclature.

Power Cord Connector: 3-wire type with 1/4 amp fuse; UL approved.





REV.	DATE	DESCRIPTION	BY

TOLERANCES UNLESS OTHERWISE SPECIFIED
FRAC. ±
.X ±
.XX ±
.XXX ±
ANGLES ±
MICRO FIN. √
DE-BURR & BREAK ALL EDGES

SCALE: Full
DRAWN: J. Vasko
DATE: 8-14-89
CHECKED:
DATE: 8-14-89
DO NOT SCALE PRINT

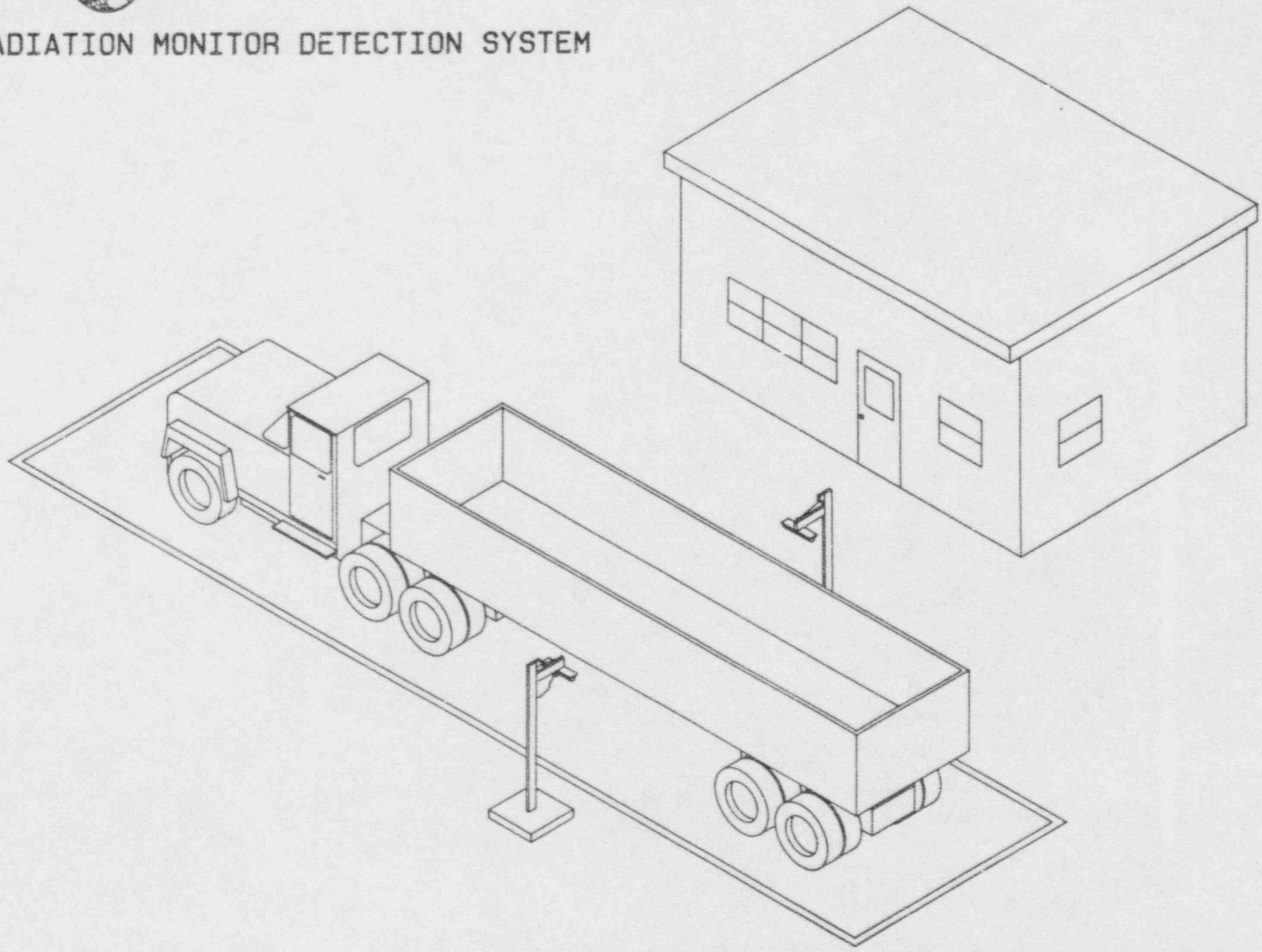
BICRON CORPORATION
NEWBURY, OHIO U.S.A.

ENGINEERING SALES DRAWING
BICRON RADIATION MONITOR

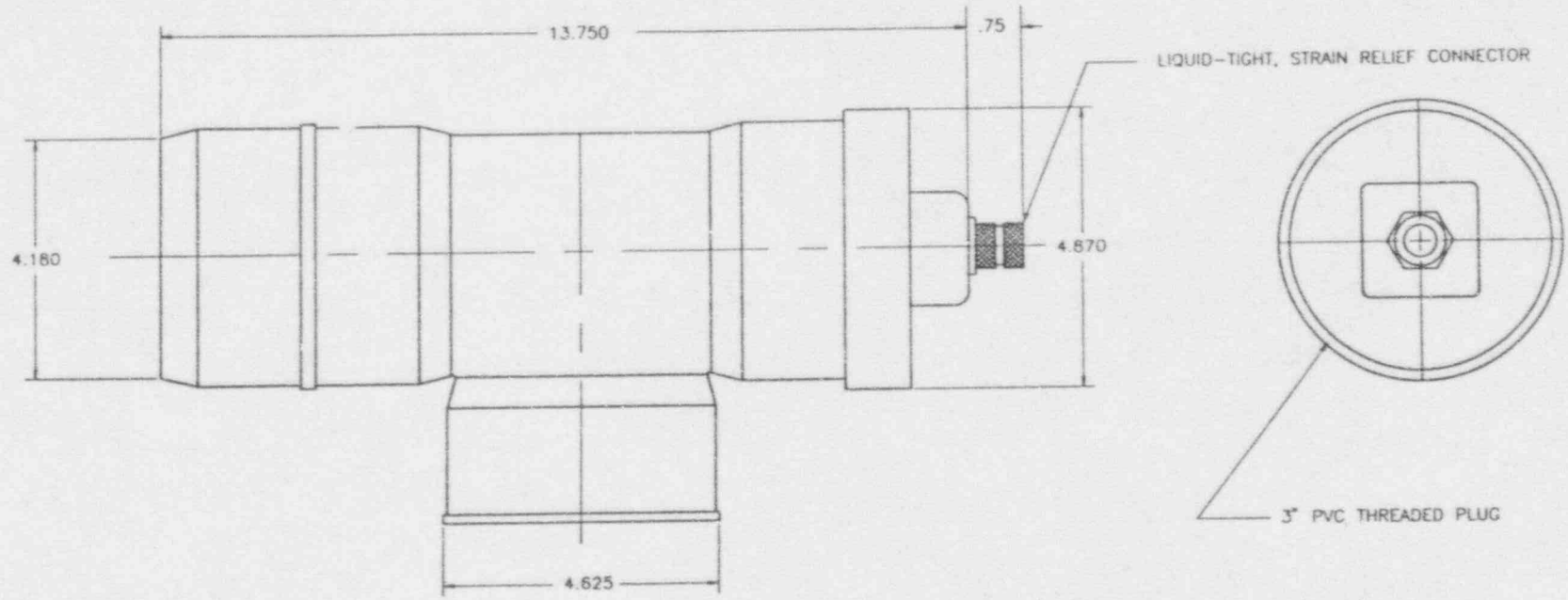
PROD CODE	BASIC PART NUMBER							DASH	FINISH	REV.
	B	9	7	0	0	1	0	1		

BICRON

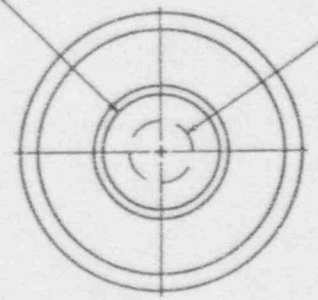
RADIATION MONITOR DETECTION SYSTEM



SK681589



ADAPTER FOR 1 1/2" PVC PIPE



NOTE:
A SUBSTITUTE HOLE WILL BE PROVIDED FOR THE DETECTOR CABLE TO BE ROUTED THRU THE MOUNTING POST WHEN AN APPLICATION CALLS FOR UNDERGROUND TOTALLY CONCEALED WIRING.

REV.	DATE	DESCRIPTION	BY

TOLERANCES UNLESS OTHERWISE SPECIFIED	SCALE: FULL
FRAC.:	DRAWN: DMYTRYK
.X:	DATE: 12-10-90
.XX:	CHECKED:
.XXX:	
ANGLES:	DATE:
MICRO FIN.: √	
DE-BURR AND BREAK ALL EDGES	DO NOT SCALE PRINT

BICRON CORPORATION
NEWBURY, OHIO U.S.A.

DETECTOR ASSEMBLY
FOR ASM-6

DWG. SIZE	BASIC PART NUMBER	REV.
B	1098000	

BICRON CORPORATION
RADIOACTIVE MATERIAL DETECTION SYSTEMS AND INSTRUMENTS FOR STEEL SCRAP
PRICE LIST

Effective 1 February 1991; prices are FOB Newbury, Ohio, subject to change without notice. Terms: Net 30 days.

The prices quoted herein do not include state, gross receipts, or local sales tax. Tax will be added as a separate item if the transaction is determined to be taxable.

Model	Description	Unit Price U.S. Dollars
ASM-6000-D	2 each, 3000 in^3, organic scintillation detector assemblies; readout assembly which incorporates a 16-bit microprocessor, alphanumeric display panel and printer.	$ 35,000.00
ASM-3000-S	1 each, 3000 in^3, organic scintillation detector assemblies; readout assembly which incorporates a 16-bit microprocessor, alphanumeric display panel and printer.	$ 24,000.00
ASM-12000-S	8 each, 1500 in^3, organic scintillation detector assemblies; readout assembly which incorporates a 16-bit microprocessor, alphanumeric display panel and printer.	$ 89,000.00
ASM-21000-S	14 each, 1500 in^3, organic scintillation detector assemblies; readout assembly which incorporates a 16-bit microprocessor and color CRT.	$143,000.00
ASM-200	2 each, 106 in^3, organic scintillation detector assemblies; 50 ft of connecting cable for each detector, and digital, electronic, automatic, alarming readout assembly.	$ 7,500.00
ASM-6	2 each, 2" diameter NaI(Tl) scintillation detector assemblies; 50 ft. of connecting cable for each detector, and digital, electronic, automatic, alarming readout assembly.	$ 4,000.00
MICRO ANALYST	A handheld micro R measuring survey meter containing a NaI(Tl) scintillation detector.	$ 1,025.00
MICRO REM	A handheld micro R measuring survey meter containing tissue equivalent plastic scintillation detectors	$ 1,295.00
Checkout and Training	3 consecutive days of installed-system checkout and training for the ASM-6000-D, ASM-3000-S, ASM-12000-S, ASM-21000-S (not required with the ASM-200 or ASM-6).	$ 5,000.00

BICRON®

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12345 Kinsman Road
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Telex: 980474 BICRON NWBY
Telefax: (216) 564-8047

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2410 AG Bodegraven The Netherlands
Telephone: 1726-14243
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BICRON CORPORATION
RECOMMENDED SPARE PARTS
ASM-12000-S RADIOACTIVE MATERIAL DETECTION SYSTEM
PRICE LIST

Effective October 30, 1990
Prices subject to change without notice

Recommended Quantity	Part Number	Description	Unit Price	Extended Price
1 each	1075700	Complete detector module	$ 9,000	$ 9,000
1 each	9100291	Detector enclosure assembly	3,210	3,210
2 each	9100292	Scintillation detector assembly	3,580	7,160
1 each	1091100	Master control unit, Including I/O interface assembly	12,000	12,000
2 each	9100198	Photomultiplier probe assembly	690	1,380
2 each	9420050	Remove driver/HV module	830	1,660
1 each	9420019	Counter - I/O module	630	630
1 each	9420055	Microprocessor module	1,800	1,800
1 each	9420024	Keyboard module assembly	440	440
1 each	9865003	Alphanumeric display	300	300
1 each	9830016	Thermal printer assembly	600	600
20 each	9990032	Printer paper	5	100
1 each	9830014	Non-volatile RAM	895	895
1 each	9420056	Local line driver	650	650

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BICRON CORPORATION
RECOMMENDED SPARE PARTS
ASM-6000-D RADIOACTIVE MATERIAL DETECTION SYSTEM
PRICE LIST

Effective May 1, 1990
Prices subject to change without notice

Recommended Quantity	Part Number	Description	Unit Price	Extended Price
1 each	1091700	Complete detector module	$12,000	$12,000
1 each	9100364	Detector enclosure assembly	3,460	3,460
2 each	9100292	Scintillation detector assembly	3,580	7,160
1 each	1091100	Master control unit, Including I/O interface assembly	12,000	12,000
2 each	9100198	Photomultiplier probe assembly	690	1,380
2 each	9420050	Remove driver/HV module	830	1,660
1 each	9420019	Counter - I/O module	630	630
1 each	9420055	Microprocessor module	1,800	1,800
1 each	9420024	Keyboard module assembly	440	440
1 each	9865003	Alphanumeric display	300	300
1 each	9830016	Thermal printer assembly	600	600
20 each	9990032	Printer paper	5	100
1 each	9830014	Non-volatile RAM	895	895
1 each	9420056	Local line driver	650	650

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Telefax: (216) 564-8047

Bicron Corporation
European Office, P.O. Box 271
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Telephone: 1726-14243
Telex: 39772 BICIN NL
Telefax: 1726-14316

BICRON CORPORATION
RECOMMENDED SPARE PARTS
ASM-21000-S RADIOACTIVE MATERIAL DETECTION SYSTEMS
PRICE LIST

Effective March 25, 1990
Prices subject to change without notice

Recommended Quantity	Part Number	Description	Unit Price	Extended Price
1 each	1075700	Complete Detector Module	$ 9,000	$ 9,000
1 each	9100291	Detector Enclosure Assembly	3,210	3,210
1 each	9100292	Scintillation Detector Assembly	3,580	3,580
1 each	1075100	Master Control Unit	18,500	18,500
2 each	9100323	Probe Assembly (ALM)	690	1,380
2 each	9420050	Remote Driver/HV Module	830	1,660
1 each	9420019	Counter - I/O Module	550	550
1 each	9420049	Local Line Driver Module, Includes 8 input and 8 output channels	970	970
1 each	9420053	Microprocessor Module	1,800	1,800
1 each	9420024	Keyboard Module Assembly	440	440

BICRON®

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Telefax: (216) 564-8047

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2410 AG Bodegraven The Netherlands
Telephone: 1726-14243
Telex: 39772 BICIN NL
Telefax: 1726-14316

BICRON CORPORATION
RECOMMENDED SPARE PARTS
ASM-3000-S RADIOACTIVE MATERIAL DETECTION SYSTEM
PRICE LIST

Effective January 15, 1991
Prices subject to change without notice

Recommended Quantity	Part Number	Description	Unit Price	Extended Price
1 each	1091700	Complete detector module	$12,000	$12,000
1 each	9100364	Detector enclosure assembly	3,460	3,460
1 each	9100292	Scintillation detector assembly	3,580	3,580
1 each	1091100	Master control unit, Including I/O interface assembly	12,000	12,000
1 each	9100198	Photomultiplier probe assembly	690	690
1 each	9420050	Remove driver/HV module	830	830
1 each	9420019	Counter - I/O module	630	630
1 each	9420055	Microprocessor module	1,800	1,800
1 each	9420024	Keyboard module assembly	440	440
1 each	9865003	Alphanumeric display	300	300
1 each	9830016	Thermal printer assembly	600	600
20 each	9990032	Printer paper	5	100
1 each	9830014	Non-volatile RAM	895	895
1 each	9420056	Local line driver	650	650

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Bicron Corporation
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2410 AG Bodegraven The Netherlands
Telephone: 1726-14243
Telex: 39772 BICIN NL
Telefax: 1726-14316

ELECTRONIC PRODUCTS
STANDARD SYSTEM WARRANTY

Systems manufactured by Bicron are warranted against defects in materials and workmanship for a period of one year from the date of shipment, unless otherwise agreed upon by Bicron and the customer in writing.

Bicron's obligation with regard to such products shall be limited to repair or replacement, FOB Bicron factory or authorized repair station, at Bicron's option.

The calibration (when applicable) for each system is warranted to be within its specified accuracy at the time of shipment. If this initial calibration is determined to be in error, the system will be recalibrated at no charge.

The aforesaid warranty does not cover systems, options or probes which are subject to excessive physical abuse or are used for purposes other than those intended. In no event shall Bicron be liable for consequential or special damages, transportation, installation, adjustment, work done by customer, or other expenses which may arise in connection with such defective product or parts.

EXCLUSION OF LIMITED WARRANTY

THERE ARE NO WARRANTIES, EXPRESS OR IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTY OF MERCHANTIBILITY OR FITNESS, WHICH EXTEND BEYOND THE DESCRIPTION OF THE FACE HEREOF. THIS EXPRESS WARRANTY EXCLUDES COVERAGE OF AND DOES NOT PROVIDE RELIEF FOR INCIDENTAL OR CONSEQUENTIAL DAMAGES OF ANY KIND OR NATURE, INCLUDING, BUT NOT LIMITED TO LOSS OF USE, LOSS OF SALES OR INCONVENIENCE. THE EXCLUSIVE REMEMDY OF THE PURCHASER IS LIMITED TO REPAIR, RECALIBRATION, OR REPLACEMENT OF THE SYSTEM AT BICRON'S OPTION.

This warranty specifically excludes the following items which are covered by their original manufacturers' warranties: photomultiplier tubes, GM and proportional tubes, crystal and other solid-state detectors, and batteries.

ELECTRONIC PRODUCTS
STANDARD WARRANTY

Instruments and options manufactured by Bicron are warranted against defects in materials and workmanship for a period of two years from the date of shipment, unless otherwise agreed upon by Bicron and the customer in writing.

Bicron's obligation with regard to such products shall be limited to repair or replacement, FOB Bicron factory or authorized repair station, at Bicron's option.

The calibration (when applicable) for each instrument is warranted to be within its specified accuracy at the time of shipment. If this initial calibration is determined to be in error, the instrument will be recalibrated at no charge, provided it is returned as described above.

The aforesaid warranty does not cover instruments, options or probes which are subject to excessive physical abuse or are used for purposes other than those intended. In no event shall Bicron be liable for consequential or special damages, transportation, installation, adjustment, work done by customer or other expenses which may arise in connection with such defective product or parts.

EXCLUSION OF LIMITED WARRANTY

THERE ARE NO WARRANTIES, EXPRESS OR IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTY OF MERCHANTIBILITY OR FITNESS, WHICH EXTEND BEYOND THE DESCRIPTION OF THE FACE HEREOF. THIS EXPRESS WARRANTY EXLUDES COVERAGE OF AND DOES NOT PROVIDE RELIEF FOR INCIDENTAL OR CONSEQUENTIAL DAMAGES OF ANY KIND OR NATURE, INCLUDING, BUT NOT LIMITED TO LOSS OF USE, LOSS OF SALES OR INCONVENIENCE. THE EXCLUSIVE REMEDY OF THE PURCHASER IS LIMITED TO REPAIR, RECALIBRATION, OR REPLACEMENT OF THE INSTRUMENT AT BICRON'S OPTION.

This warranty specifically excludes the following items which are covered by their original manufacturer's warranties: photomultiplier tubes, GM and proportional tubes, crystal and other solid-state detectors, and batteries.

BICRON DETECTION SYSTEMS

	COMPANY	LOCATION	MONITORING
1	Lukens Steel Company	Coatesville, PA	Charge bucket*
2	Lukens Steel Company	Coatesville, PA	Charge bucket*
3	Luria Brothers	Coatesville, PA	Rail cars/trucks
4	Luria Brothers	Coatesville, PA	Trucks
5	Dofasco Steel	Hamilton, Ontario	Atlas car*
6	Dofasco Steel	Hamilton, Ontario	Atlas car*
7	Dofasco Steel	Hamilton, Ontario	Atlas car*
8	Dofasco Steel	Hamilton, Ontario	Crane
9	Dofasco Steel	Hamilton, Ontairo	Crane
10	Luria Brothers	East Chicago, IN	Trucks
11	Luria Brothers	East Chicago, IN	Rail cars
12	Bethlehem Steel	Burns Harbor, IN	Trucks, Rail cars
13	Bethlehem Steel	Sparrows Point, MD	Rail cars
14	Atlas Steel	Welland, Ontario	Trucks
15	Bethlehem Steel	Johnstown, PA	Charge bucket*
16	Bethlehem Steel	Johnstown, PA	Charge bucket*
17	Bethlehem Steel	Johnstown, PA	Charge bucket*
18	Bethlehem Steel	Johnstown, PA	Charge bucket*
19	Owen Electric Steel	Cayce, SC	Trucks, Rail cars
20	C F & I Steel	Pueblo, CO	Rail cars
21	Cytemp Specialty Steel	Bridgeville, PA	Trucks

	COMPANY	LOCATION	MONITORING
22	Oregon Steel Mills	Portland, OR	Rail cars
23	Oregon Steel Mills	Portland, OR	Trucks
24	Oregon Steel Mills	Portland, OR	Charge bucket
25	Oregon Steel Mills	Portland, OR	Charge bucket
26	Oregon Steel Mills	Portland, OR	Charge bucket
27	Golden Industries	Gulfport, MS	Trucks
28	Parkwood Iron & Metal	Cleveland, OH	Trucks
29	Shapiro Bros. of Illinois	Mt. Vernon, IL	Trucks

*Networked systems

Model: MICRO ANALYST
Micro R Survey Meter With SCA

BICRON®

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12345 Kinsman Road
Newbury, Ohio 44065
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Telex: 980474
Telefax: (216) 564-8047

Bicron Corporation
European Office, P.O. Box 271
2410 AG Bodegraven The Netherlands
Telephone: 1726-14243
Telex: 39772
Telefax: 1726-14316

Features

- GAMMA AND X-RAY DETECTION
- SINGLE CHANNEL ANALYZER
- μR/h MEASUREMENTS
- HV READOUT
- INTERNAL NaI(Tl) SCINTILLATOR
- BUILT-IN AUDIO
- LIGHTED METER OPTION

GENERAL: The **MICRO ANALYST model** is a portable survey meter designed to measure gamma and x-radiation from environmental (background) levels up to normal survey levels. The instrument features a direct reading, calibrated μR/h mode, and a single channel analyzer mode.

The single channel analyzer permits energy discrimination and significant background reduction. This feature gives the MICRO ANALYST detection capability beyond that of conventional micro R meters.

Rugged construction and quality components make it durable, and the instrument is easy to service. Internal components are laid out on modular circuit boards. Span, HV and calibration pots (one for each range) are clearly marked.

The HV readout assures that the detector operates at its proper high voltage and allows peak centering within the single channel analyzer mode. A single 9-volt battery powers the instrument.

A lighted meter option is available for the MICRO ANALYST. Built-in lights illuminate the meter face when a pushbutton switch in the handle is pressed.

Model MICRO ANALYST
Specifications

RADIATION DETECTED: Gamma and x-ray
DETECTOR: Internal, 1" x 1" NaI(Tl) scintillator
RANGE: Four linear ranges of

0-5 μR/h
0-50 μR/h
0-500 μR/h
0-5000 μR/h

ACCURACY: Within 10% of reading for ^{137}Cs between 20% and 100% of full scale on any range
HIGH VOLTAGE: Electronically stabilized, factory set during calibration, with readout on the meter
WARMUP TIME: None
RESPONSE TIME: Switch selectable, optimized for each range, 0-90% of final reading as follows:

	Time	
Range	Fast	Slow
X1	12 sec	20 sec
X10	1 sec	8 sec
X100	<1 sec	2 sec
X1000	<1 sec	1 sec

MODES: Selected by front panel control as follows:

μR/h - Readings based on factory calibration for ^{137}Cs in microroentgens per hour; overrides single channel analyzer settings

SCA - Readings based on signals within the analyzer window only (see below)

SINGLE CHANNEL ANALYZER

LOWER LEVEL DISCRIMINATOR: Adjustable over a 1V range above a factory-set minimum with internal potentiometer

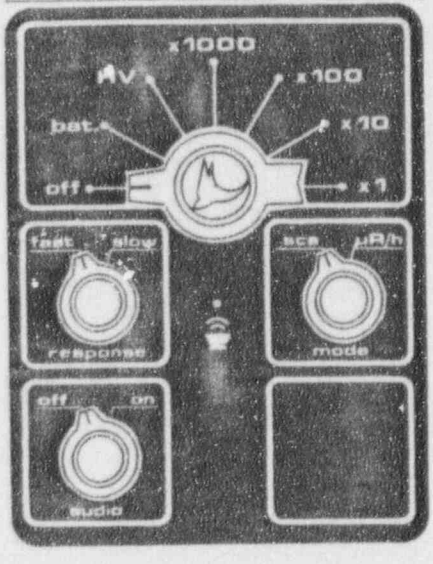
WINDOW: (Upper Level Discriminator) adjustable from 0 to 1V above the Lower Level Discriminator setting with internal potentiometer

PULSE-PAIR RESOLUTION: Typically 10 microseconds or less

TEMPERATURE: Operational from -20° to + 50°C
HUMIDITY: <5% change in reading fro n 10-95% RH
BATTERY COMPLEMENT: Single 9-volt, MN1604 or equal. The second battery clip may be used for storage of spare or parallel wired
BATTERY LIFE: >50 hours or >100 hours with parallel option, audio off (audio use may reduce battery life)
CONTROLS: Seven position rotary switch as illustrated; two position rotary switches for 'response', 'audio' and 'mode'
DISPLAY: Ruggedized, recessed, high-torque 1 mA meter with 3.35in (8.51cm) scale marked:

0-5 μR/h and 0-2.0 kilovolts, with 'Bat. ok' check band

Meter protected by impact-resistant Lexan® polycarbonate window



GEOTROPISM: Within ± 2% of full scale
SHOCK: 100g per lightweight machine of MIL-STD 202C, method 202B
VIBRATION: 5g in each of three mutually orthogonal axes at one or more frequencies from 10-33Hz
CONSTRUCTION: Splash proof, shock proof, two piece, all metal case

Scratch resistant laminated control panel and Bicron Kleen Krome® trim on case top

Durable black polyurethane paint on handle and case bottom

AUDIO: A built-in speaker (with panel mounted on/off switch) provides an audible "click" for each detector pulse. With the speaker off, an audible alarm sounds (if desired) when the meter is > full scale on any range. No separate battery is required.
SIZE: 4.25 x 8 x 7.5 in (10.8 x 20.3 x 19.1cm) including handle
WEIGHT: 3.1 pounds (1.4 kg)

LIGHTED METER OPTION: Built-in lights illuminate the meter face when a pushbutton in the handle is pressed; the lights shut off when the pushbutton is released. A 9-volt battery mounted in the "spare" battery clip powers the lights.

Manufacturer reserves right to alter specifications.

APPLICATION NOTE: The single channel analyzer allows the MICRO ANALYST to be much more sensitive than conventional (gross counting) micro R meters. For example, when ^{241}Am (60 keV) is centered in the analyzer window, background from ^{60}Co is reduced by a factor of 30.

9891019 9/85

Models: MICRO REM/MICRO SIEVERT
Tissue Equivalent Survey Meters

BICRON®

Bicron Corporation
12345 Kinsman Road
Newbury, Ohio 44065-9677
Telephone: (216) 564-2251
Telefax: (216) 564-8047
Telex: 980474 BICRON NWBY

European Office
Markstraat 27A, P.O. Box 271
2410 AG Bodegraven, The Netherlands
Telephone: 1726-14243
Telefax: 1726-14316
Telex: 39772 BICIN NL

Nippon Bicron
Room No. 805, 1-8, 1-Chome
Shinyokohama, Kohoku-Ku
Yokohama 222 Japan
Telephone: 045(474)5786
Telex: 045(474)5787

With Optional
Expanded Low Energy Response

Features

- **GAMMA AND X-RAY DETECTION**
- **FLAT ENERGY RESPONSE**
- **TISSUE EQUIVALENT SCINTILLATOR**
- **HV CHECK**
- **WIDE VIEW METER**
- **FIVE RANGES**
- **EXTENDED DETECTOR OPTION**
- **EXPANDED LOW ENERGY RESPONSE OPTION**

Patent Pending

GENERAL: The **MICRO REM** and **MICRO SIEVERT models** are portable survey meters which give tissue equivalent photon response down to 40 keV (17 keV for low energy option) from environmental levels of 0-20 µrem/h (0-0.2 µSv/h) full scale up to normal survey levels of 200 mrem/h (2 mSv/h) full scale.

Rugged construction and quality components make them durable, and the instruments are easy to service. Internal components are laid out on modular circuit boards. Span, HV and calibration pots (one for each range) are clearly marked.

The exclusive HV check assures that the detector operates at its proper high voltage. Two 9-volt batteries power each instrument.

The instruments' nearly flat, rem energy response (energy independence) sets them apart from conventional "micro R" meters using NaI(Tl) scintillation detectors and other instruments using plastic scintillation detectors.

An extended detector option is available for the MICRO REM and MICRO SIEVERT. The internal detector is mounted so that its sensitive area extends out from the front of instrument case bottom, making it easier to survey certain hard-to-reach locations.

With the expanded low energy response option, these instruments meet or exceed the regulatory requirements for instruments used to survey color TVs and baggage X-ray machines.

Models: MICRO REM/MICRO SIEVERT Specifications

RADIATION DETECTED: Gamma and x-ray
DETECTOR: Internal, tissue equivalent organic scintillator
WINDOW DENSITY: 1.3 mg/cm² (total) mylar (low energy option)
RANGE: Five linear ranges of

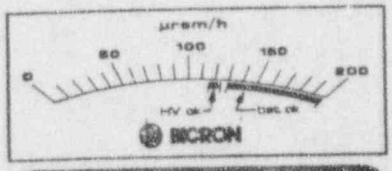
µrem/h	µSv/h
0-20	0-0.2
0-200	0-2
0-2000	0-20
0-20,000	0-200
0-200,000	0-2000

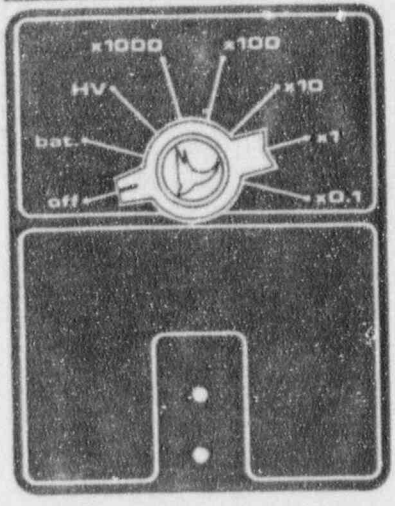
ACCURACY: Within 10% of reading for ^{137}Cs between 20% and 100% of full scale on any range
ENERGY RESPONSE: See energy response curves
HIGH VOLTAGE: Electronically stabilized, factory set during calibration, with check band on the meter
WARMUP TIME: None
RESPONSE TIME: Optimized for each range, 0-90% of final reading as follows:

Range	Time
X0.1	<15 sec
X1	<15 sec
X10	<5 sec
X100	<2 sec
X1000	<2 sec

TEMPERATURE: Operational from -20°C to + 50°C
HUMIDITY: <5% change in reading from 10-95% RH

BATTERY COMPLEMENT: Two 9 volt, MN1604 or equal
BATTERY LIFE: >100 hours
CONTROL: Eight position rotary switch as illustrated
DISPLAY: Ruggedized, recessed, high-torque 1 mA meter with 3.35 in (8.51cm) scale marked 0-200 µrem/h (0-2 µSv/h), with 'Bat. ok', 'HV ok' check bands; meter protected by impact-resistant Lexan ® polycarbonate window



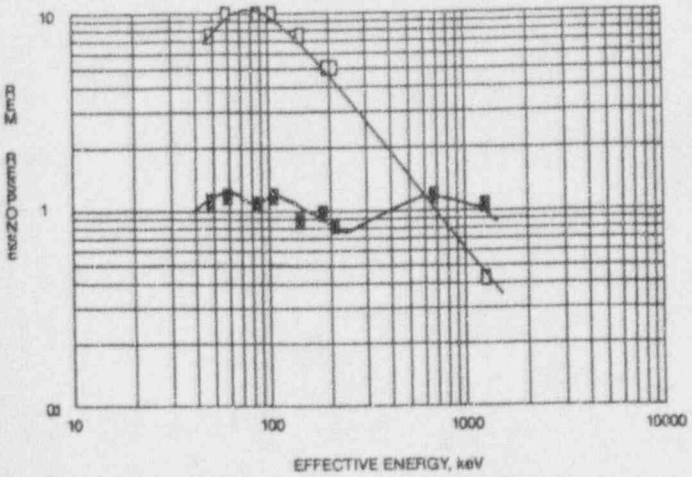


GEOTROPISM: Within ± 2% of full scale
SHOCK: 100g per lightweight machine of MIL-STD 202C, method 202B
VIBRATION: 5g in each of three mutually orthogonal axes at one or more frequencies from 10-33Hz
CONSTRUCTION: Splash proof, shock proof, two piece, all metal case; scratch resistant laminated control panel and Bicron Kleen Krome ® trim on case top; durable black polyurethane paint on handle and case bottom
SIZE: 4.25 x 8 x 7.5 in (10.8 x 20.3 x 19.1cm) including handle
WEIGHT: 3.1 pounds (1.4 kg)

EXPANDED LOW ENERGY RESPONSE OPTION: The internal detector and case bottom are fitted with low density, radiation entrance windows to expand the energy response (through the window only) down to 17 keV.
EXTENDED DETECTOR OPTION: The internal detector is mounted so that its sensitive area extends 1.75" (4.4 cm) beyond the front of the instrument case bottom. The detector is protected by an aluminum extension (with window for low energy option) fitted to the case bottom.

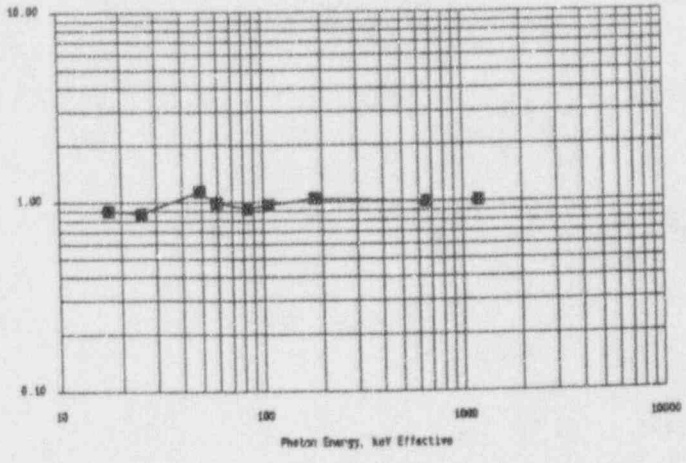
RESPONSE

BICRON MICRO—REM Survey Meter vs. Conventional Micro—R Meters



▓ BICRON MICRO—REM ▯ Micro—R Meter

RESPONSE THROUGH DETECTOR WINDOW
(Low Energy Option only)



Manufacturer reserves right to alter specifications.

9891056 06/90

RADIOACTIVE MATERIAL IN STEEL SCRAP: ITS OCCURRENCE, CONSEQUENCES AND DETECTION

BY

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Rev. 03/89

ABOUT THE AUTHOR

Anthony LaMastra is a Certified Health Physicist currently engaged as a full-time consultant in ionizing and non-ionizing radiation protection to major steel companies. He is also involved as a referee/observer in emergency drill exercises and effluent assessment at nuclear reactors. He has prepared court testimony from his review of the environmental monitoring data gathered during the TMI accident.

Mr. LaMastra represents the American Iron and Steel Institute on four ANSI accredited committees and five sub-committees dealing with radiation hazards, protection, and equipment. He serves as Chairman of one committee and Co-Chairman of a sub-committee.

His direct involvement in the steel industry began in 1972 when he joined Bethlehem Steel. During his twelve year tenure, Mr. LaMastra was responsible for the development and oversight of the corporate radiation control program as Senior Health Physicist. His experience also includes three years with the Pennsylvania Department of Environmental Resources as Eastern Area Health Physicist.

Mr. LaMastra earned his Bachelor of Science degree from St. Joseph's College in 1964 and his Master's degree from the University of Minnesota in 1970. He has four publications to his credit, including *Practical Considerations of Detecting Radioactive Material in Steel Scrap*, presented at the Health Physics Society Annual Meeting, June,1986.

RADIOACTIVE MATERIAL IN STEEL SCRAP
ITS OCCURRENCE, CONSEQUENCES AND DETECTION

INTRODUCTION

Inadvertent radioactive contamination of steel during manufacture was brought to national attention following an incident which occurred at an Auburn, NY steel plant in February, 1983. Since 1983, there have been a total of thirty reported incidents in which radioactive material or radioactive material containers have been found in steel scrap, melted in a steel making facility, or contained in slag or other byproducts of the steel making or aluminum manufacturing process. A summary of the incidents is presented in Table 1[1],[2],[3]. Table 2 is a partial listing of decontamination costs developed for the US Nuclear Regulatory Commission for its consideration of a requirement for decontamination insurance for licensees [4]. It provides data to show the approximate cost of decontamination.

Decontamination costs at those plants unfortunate to have melted radioactive material have ranged from a few hundred thousand dollars to greater than 2.2 million dollars. When lost revenue from production stoppage and decreased sales, plus a loss in customer confidence is added to decontamination costs, it can easily be appreciated that a radioactive contamination incident can have disastrous effects on steelmaking and scrap processing facilities.

Following the Auburn, NY incident and the highly publicized Mexican incident in January, 1984, many companies began investigating the feasibility, cost and practicality of monitoring incoming scrap for radioactive material. Since that time, the efficiency of these systems has dramatically increased. This paper will discuss likely radioactive sources to be found in scrap, the consequences of melting a radicactive source, current approaches to monitoring, and proposed detection systems with estimates of detectability under typical conditions.

HOW RADIOACTIVE MATERIAL ENTERS THE SCRAP STREAM

Radioactive material can become incorporated in steel scrap in several ways. The scrap may be contaminated with loose radioactive material. The scrap may be material that was made radioactive by a high energy particle accelerator or nuclear reactor; radioactive materials may have alloyed with the iron or steel during its manufacture; or there may be shielded or unshielded sealed radioactive sources among the pieces of scrap.

TABLE 1

REPORTED INCIDENTS OF RADIOACTIVE MATERIAL IN STEEL OR STEEL SCRAP

DATE	TYPE OF FACILITY	STATE OR COUNTRY	RADIONUCLIDE	QUANTITY	LIKELY SOURCE	COMMENTS
Feb 1983	Steel plant	NY	cobalt 60	25-300 Ci	Industrial radiography or medical therapy source in scrap	420 nCi/g in steel billets
Jan 1984	Steel plant, foundry, scrap yard	Mexico	cobalt 60	400 Ci	Medical therapy source in scrap	0.02 - 375 mR/hr at surface of table legs and rebar
Aug 1984	Steel plant	Taiwan	cobalt 60	10-20 mCi	Gauge in scrap	0.08 mR/hr at surface of plumbing fixture
Oct 1984	Steel plant	PA	none		Medical diagnostic radionuclide shield still having radiation symbol	Symbol recognized by worker
Oct 1984	Steel plant	SC	cesium 137	1 Ci	Gauge melted when covered by molten steel	17 nCi/l in cooling water
Mar 1985	Scrap yard	MT	cesium 137	0.5 Ci	Gauge lost by licensee, found at scrap yard	
Apr 1985	Steel plant	Brazil	cobalt 60	unknown	Reportedly refractory wear indicating sources from furnace lining	26 pCi/g in steel well casing pipe

DATE	TYPE OF FACILITY	STATE OR COUNTRY	RADIONUCLIDE	QUANTITY	LIKELY SOURCE	COMMENTS
May 1985	Steel plant	CA	cesium 137	1.5 Ci	Gauge in scrap	10-40 pCi/g in baghouse dust
Jul 1985	Steel plant	WA	NORM	unknown	Scale in oil well casing	
Jul 1985	Steel plant	AL	cesium 137	10-50 mCi	Gauges in scrap	492 nCi/g in soil contamination
Jul 1985	Steel plant	PA	none		Unknown radionuclide shield still having radiation symbol	Symbol recognized by worker
Aug 1985	Scrap yard	PA	unknown	unknown	Stainless steel tubes	0.7 mR/hr at contact
Nov 1985	Steel plant	FL	NORM	unknown	Scrap steel from phosphate plant	10 mR/hr at contact
Feb 1986	Steel plant	TX	NORM	unknown	Water softener housing in scrap	3 mR/hr at contact
May 1986	Scrap yard	TX	NORM	unknown	Scale in oil well casing	0.045 mR/hr at contact
Aug 1986	Scrap yard	TX	unknown	unknown	1" diameter water pipe in scrap	
Aug 1986	Scrap yard	TX	unknown	unknown	Pipe in scrap	
Oct 1986	Steel plant	FL	strontium 90	unknown	Source found in empty rail car	800 mR/hr at contact

DATE	TYPE OF FACILITY	STATE OR COUNTRY	RADIONUCLIDE	QUANTITY	LIKELY SOURCE	COMMENTS
Nov 1986	Highway cattle guard	TX	NORM	unknown	Oil well casing fabricated into highway cattle guard	1.5 mR/hr at contact
Nov 1986	Scrap yard	WI	none		Industrial radiography shield still having radiation warning symbol	Symbol recognized by worker
Dec 1986	Scrap yard	PA	NORM	unknown	Mixing paddles from kaolin plant	2 mR/hr at contact
Jan 1987	Scrap yard	PA	NORM	unknown	Stainless steel pipes from Fla. phosphate processing plant	2 mR/hr at contact
Feb 1987	Steel plant	PA	radium 226 thorium	unknown	Stainless steel pipes containing scale	1 mR/hr at contact 40 nCi/g (Ra) 27 nCi/g (Th)
Apr 1987	Scrap yard	PA	radium 226 thorium	unknown	Stainless steel pipes from Fla. phosphate processing plant	0.5 mR/hr at contact
Apr 1987	Scrap yard	PA	NORM	unknown	Scale in pipe from Fla. phosphate processing plant	---
Apr 1987	Steel plant	IL	radium 226	unknown	Static eliminators	275 mr/hr at contact 1 mR/hr at 3 feet
May 1987	Steel plant	PA	NORM	unknown	Stainless steel pipes	1 mR/hr at contact

DATE	TYPE OF FACILITY	STATE OR COUNTRY	RADIONUCLIDE	QUANTITY	LIKELY SOURCE	COMMENTS
Jun 1987	Steel plant	TN	cesium 137	20-25 mCi	Unknown probable gauge	5-725 pCi/g in baghouse dust, 1.5 mR/hr at contact with truck sides
Sep 1987	Steel plant	IN	radium 226	unknown	Dross from aluminum plant, detect- by plant processing dross	2-3 nCi/g in dross
Oct 1988	Scrap yard	TX	cesium 137	50 mCi	Gauge discarded by licensee	___

NORM - Naturally occurring radioactive material

Note: PA and TX appear to predominate in the number of reported incidents because personnel from those states are trying to track such incidents.

Table adapted from data taken from references (1), (2), (3), and from data collected by the author.

TABLE 2

COST OF CLEANUP AND DISPOSAL - RADIOACTIVE CONTAMINATION INCIDENTS

DATE	TYPE OF FACILITY	STATE OR COUNTRY	RADIONUCLIDE	QUANTITY	INCIDENT	COST
1979	Irradiator	NJ	cobalt 60	> 1000 Ci	Rupture of source capsules	Several million
1982	Coal mine	PA	americium 241	0.25 Ci	Ruptured of well logging source	> $1,000,000
1983	Public areas	OH	cesium 137	20 Ci	Rupture of well logging source	> $600,000
1983	Steel mill	NY	cobalt 60	25 - 300 Ci	Melted source in furnace	> $2,200,000
1984	Steel mill	SC	cesium 137	1 Ci	Melted source in furnace	> $450,000
1985	Steel mill	AL	cesium 137	10 - 50 mCi	Ruptured gauge in scrap	$50,000 to $500,000
1985	Steel mill	CA	cesium 137	1.5 Ci	Melted source in furnace	> $1,000,000

The way radioactive material enters the scrap stream has a major impact on the detectability, the potential hazard to employees or customers, and the likelihood of causing widespread contamination.

Initially, the steel making industry felt that the melting of a radioactive source in a steel making furnace was only a problem for electric furnaces because of their heavy dependence on scrap steel. However, as more scrap is being used in all types of steel making furnaces, the potential for melting a radioactive source is being realized throughout the steel industry. In many cases, a large integrated steel plant will use more scrap than an average size mini-mill that depends totally on scrap.

TYPES OF SCRAP

The grades of scrap used in a steel plant will be determined by the end product of the plant, the market price of the different scrap grades, the type and size of furnaces, the closeness of scrap generators to the plant, and the type and amount of recycled steel produced in the plant.

A primary consideration in detecting radioactive material in the scrap is the density of the scrap as loaded in a vehicle. Solid steel has a density of about 490 pounds per cubic foot (pcf). Most steel scrap will have a density of from 25 to 200 pcf. However, if one looks at the grades of scrap most likely to contain a radioactive source, we find a much more restricted density range of from 30 to 100 pcf. Table 3 lists various scrap grades and their density range.

Probably the most likely scrap grade to contain a radioactive material source is cut up plate and structural. It is sometimes referred to as demolition scrap or railroad scrap. This class tends to include heavier structural and plate sections that might have been part of an industrial facility to which a radioactive gauge was attached. If the gauge was not properly disposed of, it could still be attached to the steel when the facility is demolished. Without its identity being known, the source housing could be included with the cut up steel and sold as scrap. If the radioactive material is contained in a shielded housing, some protection is offered to employees. If the radioactive material is an unshielded source, personnel exposure could likely result.

Another class that could contain a radioactive source would be shredded scrap, sometimes called "frag". This class consists of lighter structural steel, thin plate, car bodies, etc. that are shredded. A possible scenario is an industrial facility with storage tanks having level gauges attached to the tank walls. If the tanks are cut and sold as scrap, and the scrap shredded, the radioactive material could be included in the scrap. In this case, there would not be an intact shield, and it is possible that the actual radioactive material would be dispersed as contamination throughout the shredded scrap.

Number 1 sheared scrap consists of many of the same items that would be shredded, and could also be a source of radioactive material. Number 2 sheared scrap usually consists of very light conduit and fencing and is not as likely a candidate. This is also true for busheling which consists of loose residual from stamping and punch press operations, or trimmings which result from the manufacture of tin cans.

Number 1 bundles usually consist of light scrap that is bundled and compressed. It is more likely to contain a radioactive source than loose busheling or trimmings, but less likely than demolition scrap. Number 2 bundles usually consist of compressed cars and other miscellaneous materials and are a candidate for radioactive material simply because this grade is a general catch-all.

TABLE 3 - TYPICAL SCRAP DENSITIES

SCRAP NAME	POUNDS PER CUBIC FOOT
#2 Sheared Scrap	30 - 35
Busheling	30 - 75
#2 Bundles	40 - 70
#1 Sheared Scrap	50 - 60
Turnings	50 - 80
Plate and Structural (Demolition scrap)	60 - 70
Slitter Scrap	60 - 80
Shredded Scrap (Frag)	65 - 75
#1 Bundles	80 - 90
Cast Borings	90 - 140
Cut Plate, Foundry Scrap, Ship Scrap	150 - 170
Packed Bars	180 - 250
Overall Range	25 - 300
Likely Range	30 - 100
Solid Steel	490

Turnings are the scrap generated by machining steel parts. The scrap is usually in long thin pieces. Cast borings are from a similar process on cast pieces. Cast borings tend to be produced as small chips which pack better and therefore yield a denser scrap. Generally, these two grades are not likely to contain radioactive material unless the actual steel being machined is radioactive.

Cut plate, foundry steel or ship scrap is typically uniformly cut pieces of plate that pack well. Another type of dense scrap would be round bars or rods. These grades are not likely to contain radioactive material because of their higher quality and more uniform appearance.

The density of the scrap has a profound effect on the shielding ability of the scrap. One foot of solid steel has the ability to attenuate or stop the radiation being emitted by almost any source that could conceivably end up in scrap. However, the air pockets generally found in scrap will allow a "streaming" of the radiation, thereby increasing the likelihood of detection of a contained radioactive material source.

Two points should be stressed about the interaction of radiation and steel. First, the penetrating ability of the radiation (especially gamma radiation) is directly related to the energy. Second, as the radiation interacts with the steel, it is randomly scattered in all directions and there is a substantial decrease in energy of the scattered gamma rays. After a few interactions, the energy of the scattered radiation is much lower than the original. This makes the scattered radiation much more likely to be attenuated or stopped by the steel scrap, and therefore, much less likely to be detected.

The degradation of energy can easily be seen in Figures 1 through 7, which show the energy spectrums of a cesium 137 source with various thickness of steel or lead in the beam [5]. Figure 1 shows the spectrum of an unattenuated cesium 137 beam. The dark peak is centered around an energy of 662 kiloelectron volts (keV). Figure 2 shows the same beam after passing through 1/4 inch of steel. Notice that the primary cesium peak has been reduced to about 75 percent of that in Figure 1. There is not much difference between Figures 2 and 3, with Figure 3 representing the spectrum after passing through 3/8 inch steel. The peak integral in Figure 3 is reduced to about 68 percent of the unattenuated spectrum in Figure 1. These figures show that after passing through 1/4 to 3/8 inch of steel, a cesium 137 beam would still possess about 70 percent of its original penetrating power.

However, note the reduction in the peaks shown in Figures 4 and 5 which show the energy degradation after passing through one and two inches, respectively, of lead. The degradation is especially significant for two inches of lead where only 8 percent of the original 662 keV energy radiation remains. Figure 5 represents a cesium 137 spectrum after penetrating a typical lead shielded source housing. This means that after penetrating the lead shield, the resultant spectrum has very little energy left to penetrate steel scrap.

Figures 6 and 7 show the energy degradation of a cesium 137 spectrum after penetrating thick sections of steel. Figure 6 would be approximately equivalent to the attenuation caused by about 3 feet of 30 to 50 pcf scrap. The spectrum retains about 11 percent of the original 662 keV peak energy. Figure 7, in which the primary 662 keV peak has been completely degraded, is approximately equivalent to about 5 to 6 feet of 30 to 50 pcf scrap. These two figures show that there is an effective upper limit of about 4 feet of scrap that will permit sufficient transmission of gamma radiation from a radioactive source to allow the practical detection of a contained source. It is a fortunate coincidence that a typical rail car measures slightly less than 10 feet in width and dump trucks are generally around 8 feet in width.

The reason the resultant radiation is less able to penetrate the scrap is that the likelihood of the interactions between the gamma rays and the steel taking place via the Compton effect diminishes as the energy is reduced. At lower energies, the predominate interaction is the photoelectric effect. It is the Compton interaction that produces scattered gamma rays, while the photoelectric interaction produces electrons. The scattered Compton rays are what we typically see penetrating through the air pockets in the scrap, while the photoelectrons are absorbed in the steel and provide no real assistance in detection.

Should the radioactive material be dispersed throughout the scrap, the lack of shielding and the likelihood that some of the radioactive material will be close to the surface, should result in this scenario presenting a higher detection capability.

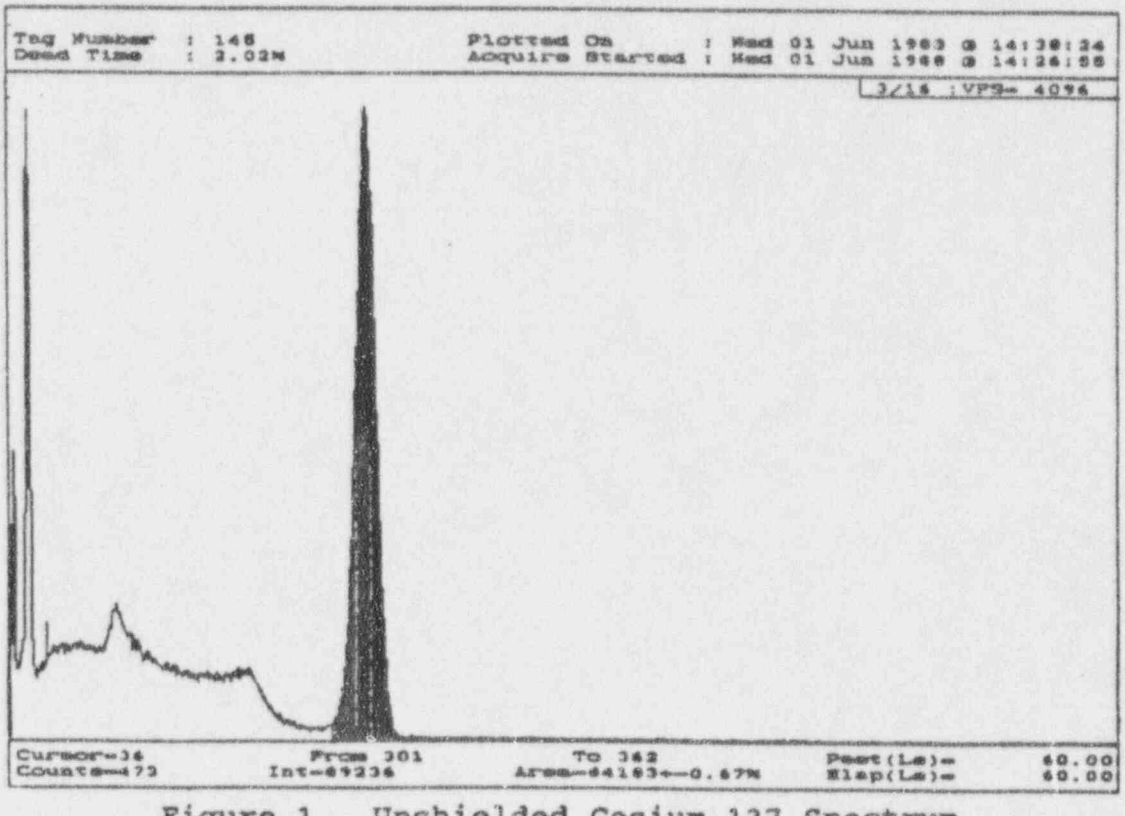


Figure 1. Unshielded Cesium 137 Spectrum

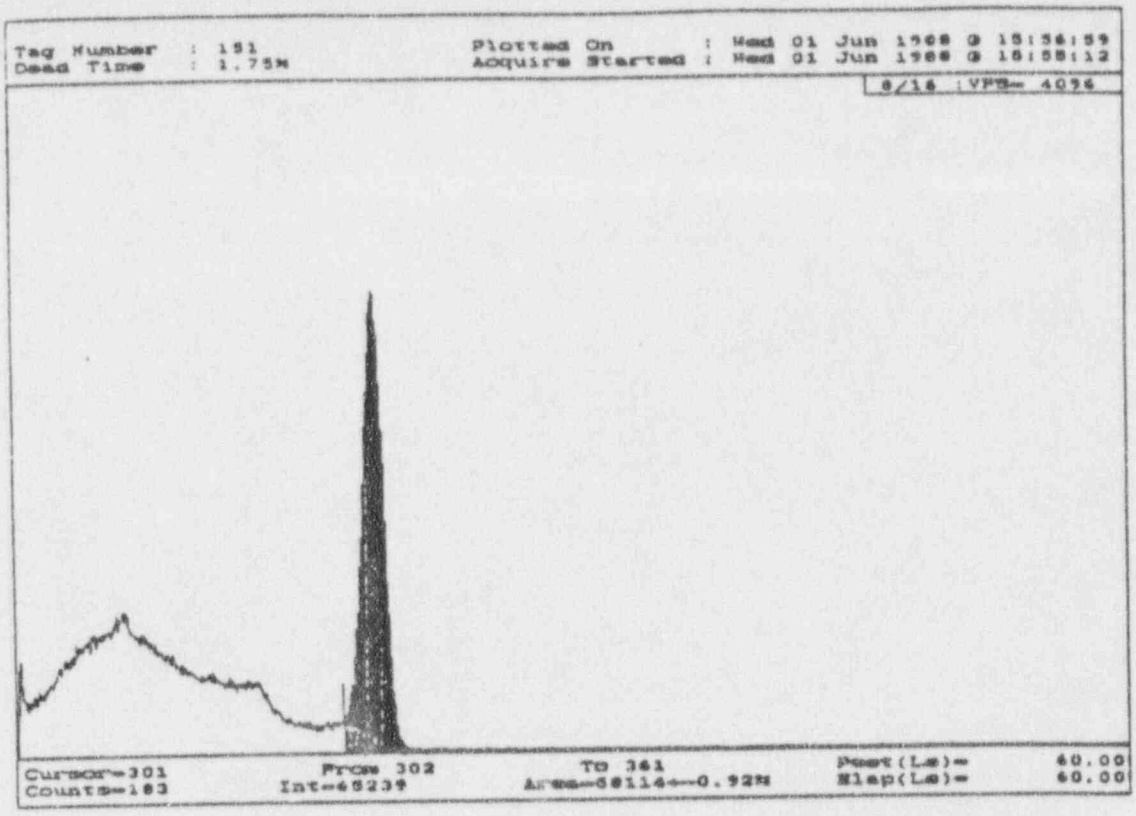


Figure 2. Cesium 137 Through 1/4" of Steel

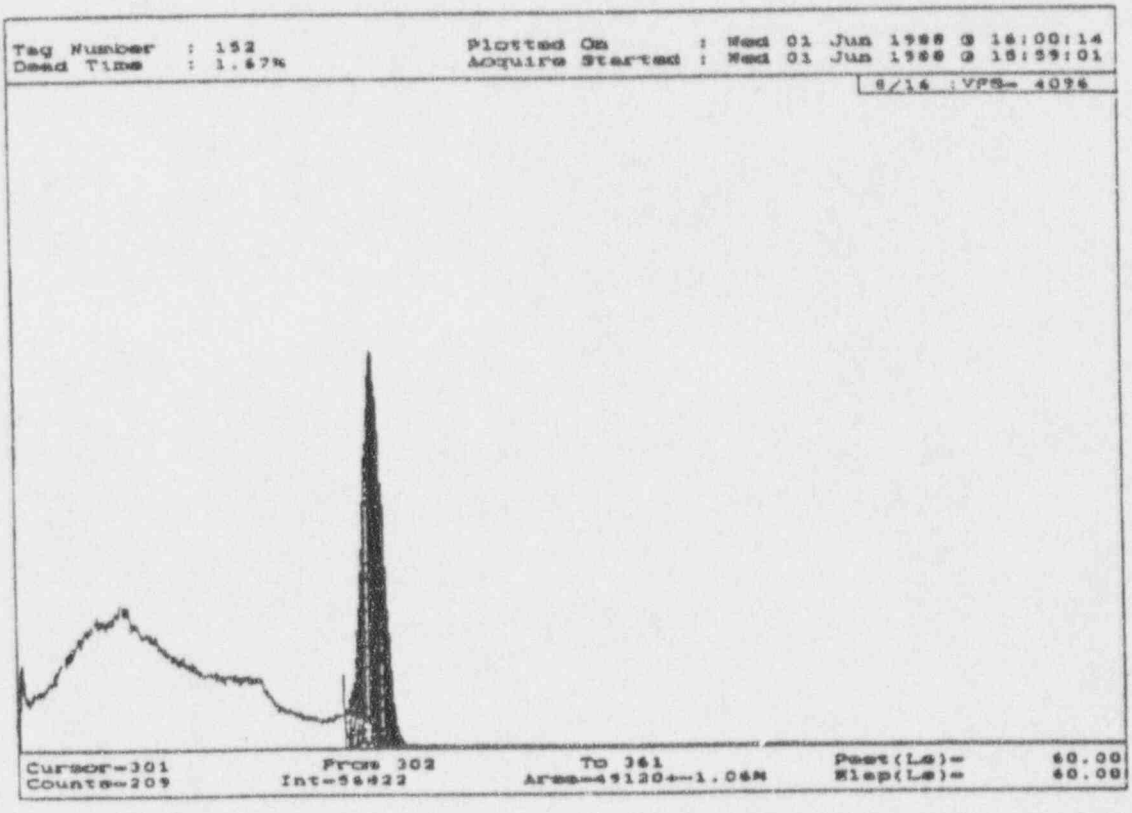


Figure 3. Cesium 137 Through 3/8" of Steel

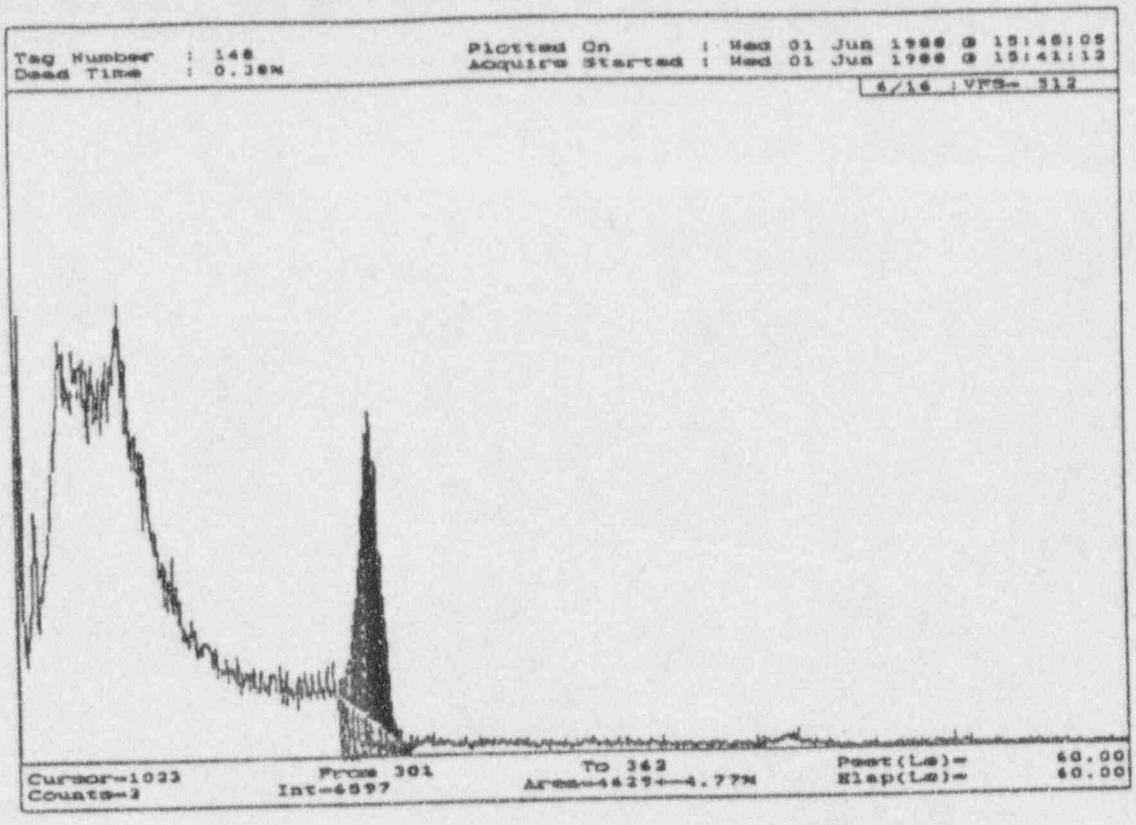


Figure 4. Cesium 137 Through 1" of Lead

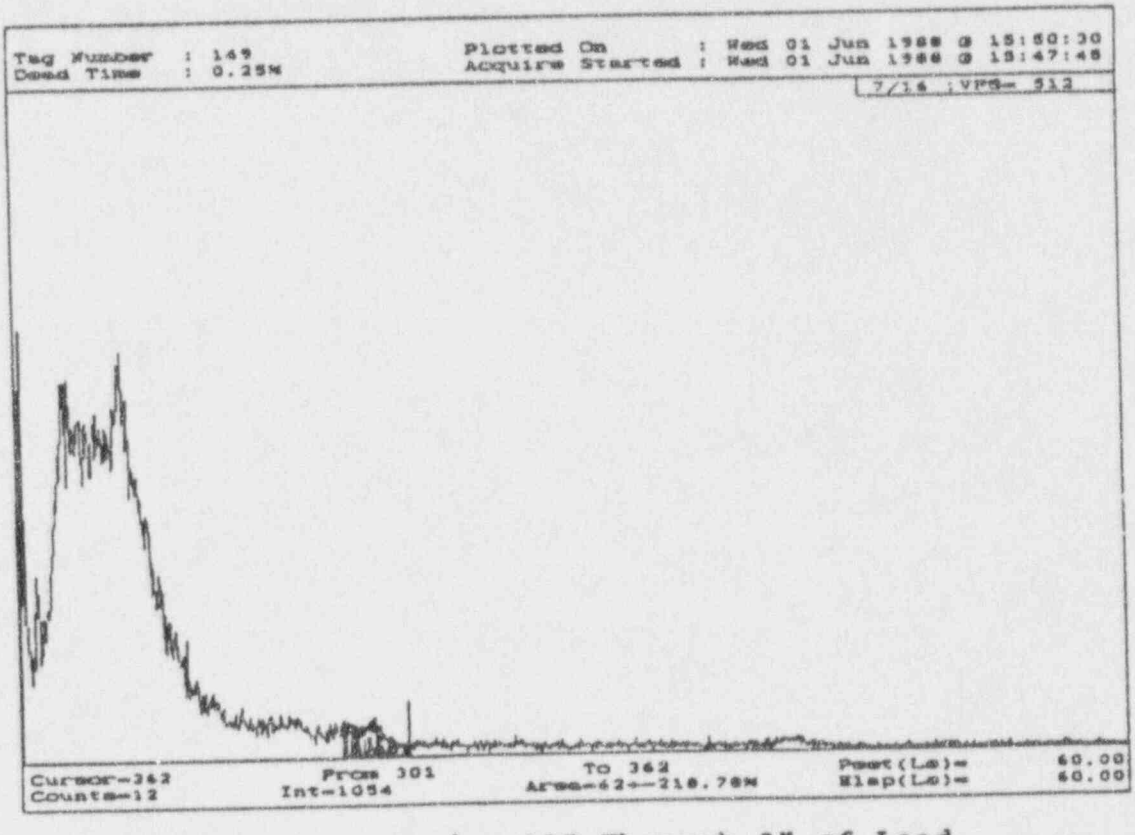


Figure 5. Cesium 137 Through 2" of Lead

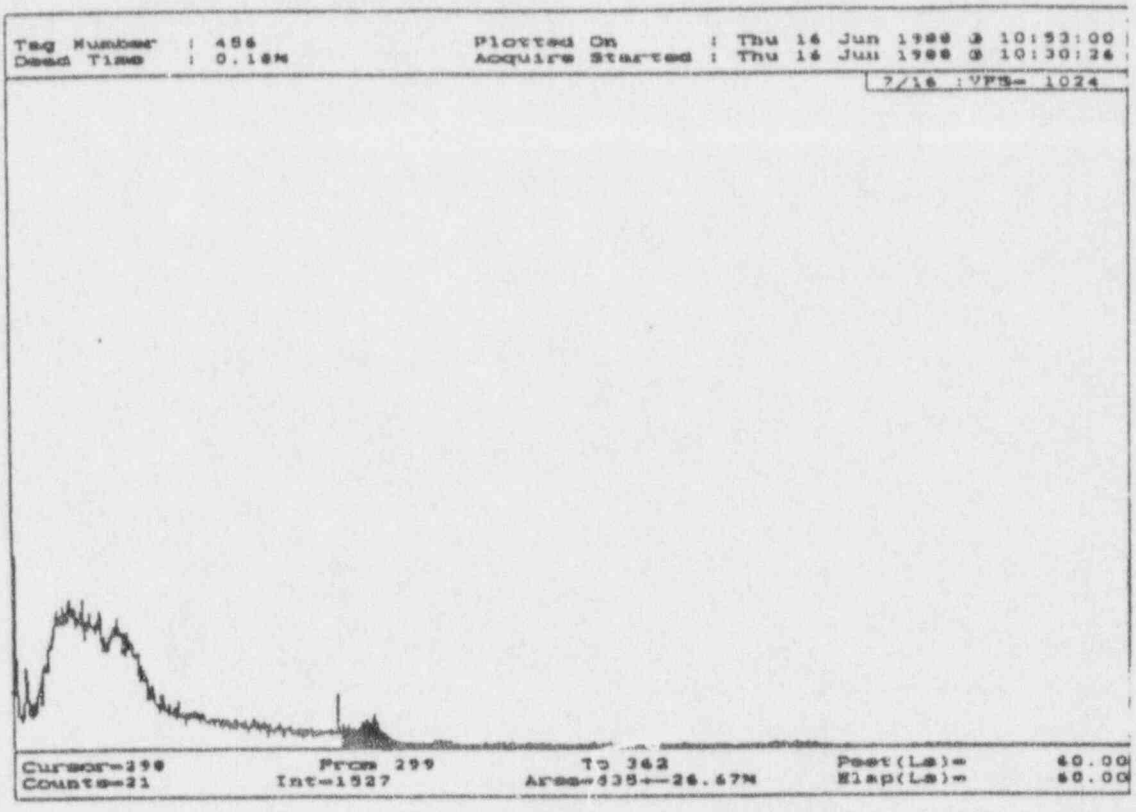


Figure 6. Cesium 137 Through Approximately 3' of Steel Scrap

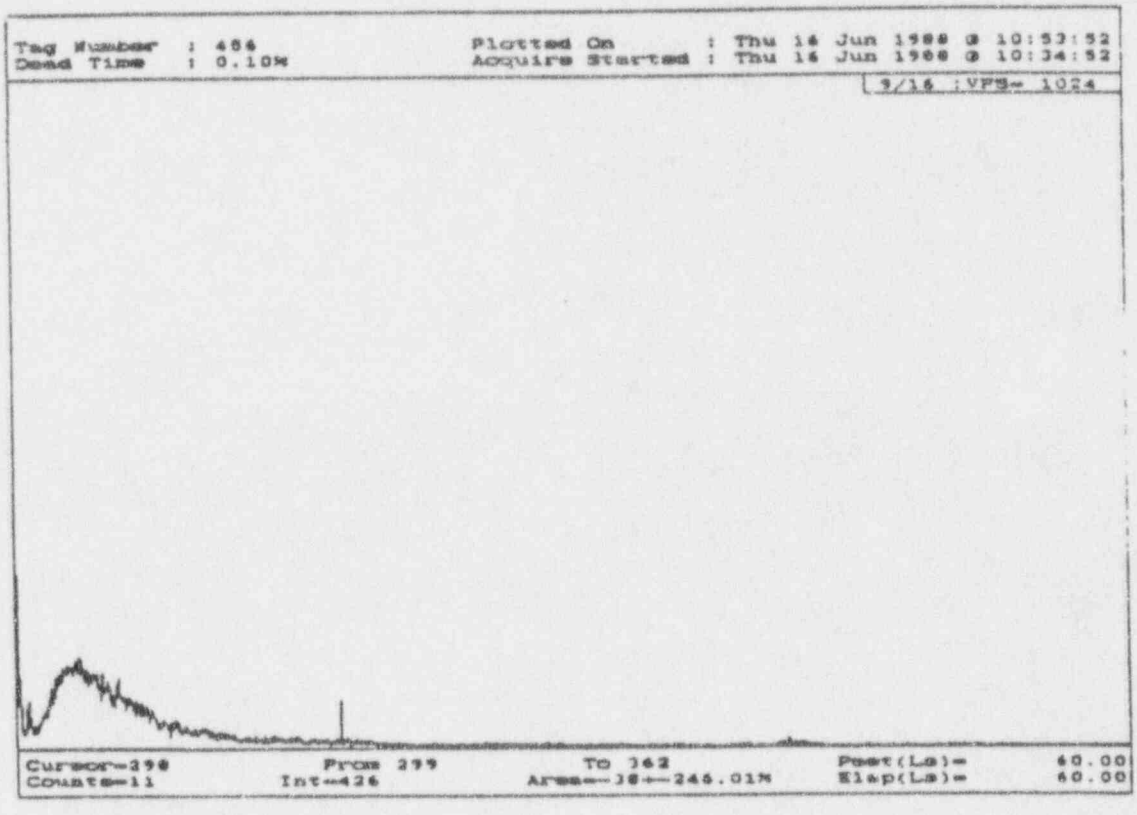


Figure 7. Cesium 137 Through Approximately 5' of Steel Scrap

The concept of degraded gamma rays is also important when one considers the type of source to use to test a detection system. Obviously, in testing a detection system one would want to present a relatively severe test. This means that the radiation flux should approximate what might be encountered from a heavily shielded source and a radionuclide having a moderate gamma energy. A shielded cesium 137 source is a prime candidate with its initial gamma energy of 662 keV. However, if one only is concerned with the exposure rate exiting the source housing, it is easy to be deceived. For example, because of a conservative concern for safety, one might place a small cesium 137 source, in the microcurie range, inside a steel pipe having a wall thickness of about 1/4 inch. As can be seen from Figure 2, this results in the emerging beam still possessing an average energy close to 600 keV. A larger cesium 137 source in the range of a few hundred millicuries, enclosed in a 2 inch lead shield will have an emerging radiation energy around 200 keV. If both test sources have an equivalent exposure rate in milliroentgens per hour through the housing walls, the lead shielded source will be more easily attenuated by the scrap than the steel encased source because of its lower average gamma energy. Thus, an actual gauge source housing with more radioactive material has a much lower chance of being detected than a smaller source in a 1/4 inch steel shell, even though both have the same external exposure rate in milliroentgens per hour (mR/hr). The author prefers a 200 millicurie cesium 137 source in a steel encased, lead shielded housing designed for 1000 millicuries of cesium 137. This in turn, is enclosed in a 3/8 inch thick steel box for protection of the source housing. Such a source will be about as low an activity that can be consistently detected by a high quality detection system.

TYPES OF RADIOACTIVE MATERIAL SOURCES

There are hundreds of different radioactive materials used in medicine, research, and industry. However, very few offer the combined properties of a long half-life, a large enough quantity of the radioactive material and a sufficient number of sources in use to make their entry into the scrap stream probable.

Probably the greatest number of radioactive material sources are those used as radiopharmaceuticals for medical diagnostic and therapeutic purposes. One scenario would be if a container of loose radioactive material intended for use in a medical facility was accidentally discarded and found its way into steel scrap. However, radiopharmaceuticals are generally short-lived and contain a small amount of radioactivity which would reduce the potential consequences.

Another scenario would involve loose radioactive material used in industrial research. The smaller number of total sources makes this a less likely possibility. However, should such an event occur, there could be greater consequences, namely, radioactive contamination of the scrap handling facilities and a possibility of contamination throughout the steelmaking shop, with potential external and internal contamination of personnel. The radionuclide involved and its amount would determine the severity of the incident. For example, a short-lived weak gamma or beta emitter would typically present a minimal

personnel or plant contamination hazard. An energetic gamma or beta emitter, such as cesium 137 or strontium 90, having either a long physical or biological half-life would present more of a hazard from both external and internal exposure. The greatest hazard would be presented by long-lived alpha emitting nuclides that have an affinity for depositing in bones, such as radium 226. None of the contamination incidents occurring to date are known to have been caused by loose industrial or medical radioactive material entering the scrap stream. However, two of the reported incidents involved empty labeled shields that most likely contained loose radioactive material at one time.

It is generally felt that loose contamination is relatively easy to detect compared to shielded sources. However, the response by the plant would have to be more deliberate and better planned, and the consequences could be more severe.

Another way that radioactive material may become incorporated in steel scrap is through the purchase of scrap which has become radioactive through its use in particle accelerators or nuclear reactors, or consists of steel made radioactive by alloying with radioactive cobalt placed in the refractory brick of blast furnaces. In this case the radioactive material is an integral part of the steel and not available for widespread contamination. Acquiring accelerator activated scrap is not a likely event because of the small number of particle accelerators which have the capability of activating materials and the awareness of the accelerator facility's personnel of the hazards presented by the activated metal. Generally, only the larger universities or government laboratories will have such accelerators. Although, with the increased use of high energy accelerators for product sterilization and cancer therapy, it is conceivable that should a commercial sterilization company or a private radiologist go out of business, the accelerator could become scrap if the regulating state did not enforce proper disposal methods. With respect to material used in nuclear reactors, there are programs in place to prevent the release of activated parts to the public. Generally, these programs are well enforced. Blast furnaces in which refractory wear indicating sources are used are becoming commonplace both in the United States and other countries. Within the United States, the size of the cobalt 60 sources used in refractory wear studies is generally in the 5 to 10 millicurie range, with a total of 100 to 600 millicuries used in a single furnace. Since the sources are placed throughout the refractory, it is unlikely that more than 20 or 30 millicuries would be melted into a single iron heat of 250 to 800 tons. This would represent a worst case concentration of from 0.025 to 0.12 millicuries per ton which is less than the exempt concentration for cobalt 60 in steel (0.455 millicuries per ton). However, the likelihood of 20 to 30 millicuries being melted is very low. It would have to involve a large portion of the furnace's refractory which most likely would freeze the furnace and prevent removing any molten iron. However, the incident involving Brazilian pipe was reportedly due to refractory wear sources. A recent (April 1988), but unsubstantiated report of thin rolled sheet from Germany setting off a state-of-the-art scrap monitoring system may have also been due to refractory wear sources. It could be that the technique

of refractory wear monitoring in other countries utilizes much larger size sources than in the United States.

Should activated metal from an accelerator or a reactor, or steel containing radioactive cobalt find its way into a steel plant, there would be minimal contamination of the scrap handling facilities and the steelmaking shop, and personnel exposure would generally not be significant. This is because the total amount of activated material is small and it is already alloyed to the steel or is a radioactive isotope of iron.

One should understand the significance of the difference between activated or radioactive materials alloyed in the steel on the one hand and loose contamination. There is a great difference in impact on a steelmaking shop between the two. Activation is making a material radioactive by changing its atomic structure. Only those atoms that are part of the original material can become radioactive. Thus, only those elements found in steel, or in scrap added to steel are possible candidates for activation. Since it is the atoms already in the material that become radioactive, and since these same atoms retain their chemical and general physical properties; there is less likelihood of causing widespread facility contamination. The radioactive atoms remain alloyed or otherwise bound up in the steel.

Contamination, on the other hand, is when the scrap or the steel becomes "dirty" with some radioactive material. This can be compared to someone dumping a drum of lead oxide dust onto a carload of steel scrap. The impact of contamination is that it is not chemically fixed to the scrap, and is available for dispersal by wind, other physical means of dispersion, and for chemical reactions such as oxidation (fuming). Thus, contamination offers a much greater potential for health effects to the employees, contamination of the steelmaking shop, and potential cost of cleanup than does activated steel scrap.

Another example of contained radioactive material is scrap oil well casing or crude oil transmission pipe that has scale, consisting of naturally occurring radioactive material, deposited on the walls. The potential from this source for personnel or plant contamination is low. First, the actual quantity of the radioactive material is low. It is usually chemically or physically bound to the pipe and not available for dispersion. And, it will usually readily incorporate into the slag. Several of the reported incidents involved naturally occurring radium 226 as fixed scale on oil well piping.

Pipe containing radioactive scale or activated scrap is comparatively easy to detect as evidenced by the many incidents reported to date involving such scrap.

Existing monitoring systems have also detected radioactive material present in new refractory brick, fluor spar and other additives entering a plant and points out the widespread presence of radioactive material normally present in ingredients used to produce steel and the fact that some of it will become incorporated in the steel, increasing the radioactive content of the steel.

A fourth way that radioactive material could become incorporated in steel scrap is by the inclusion of sealed radioactive sources within the steel scrap. Sealed sources consist of radioactive material, either encapsulated inside a solid container, for example, a stainless steel capsule that is welded closed; or plated to a surface in such a way that the radioactive material does not come loose, under normal conditions of use. Gauge sources, industrial radiography sources and medical therapy sources are examples of sealed source capsules. Typically, a sealed source capsule does not lose its integrity as long as it remains within its shielded housing. Static eliminators are a common example of plated sources. Obviously, subjecting a plated source to the abuse received when it is discarded in scrap is not a normal condition of use, and one would expect that some of the radioactive material could become dislodged and contaminate the scrap.

Plated sources are used extensively for such items as smoke detectors, static eliminators, luminescence sources, and gauges incorporating alpha emitting radionuclides. Many contain a small quantity of radioactive material which, if melted in a steelmaking furnace, would present a minimal contamination or health hazard. However, some, such as commercial static eliminators used in the plastic and paper industries do contain reasonably large quantities of radioactive material. In many cases this material is of a short half-life and does not present a long term hazard. However, some manufacturers have used radium and americium radionuclides having half-lives of 1600 and 450 years, respectively. A large static eliminator containing tens to hundreds of millicuries, which is melted in a small electric furnace of 25 to 50 tons, could easily cause air concentrations, facility contamination, and activities within steel and slag exceeding safe levels. In one near miss incident, a piece of a static eliminator containing radium was discovered on a scrap truck. The piece found appeared to be an 18 inch length of what could have been a 4 to 6 foot static eliminator. The remainder of the static eliminator was never found.

It is estimated that there could be 10,000 to 30,000 large static eliminators used in industry. The danger would be from companies ceasing operation but not properly disposing of their radioactive material. If the equipment to which it is attached is sold for scrap, the radioactive material could end up being melted or shredded by a scrap processor. This latter scenario may be the more hazardous since most radionuclides used for plated sources tend to be those presenting a greater radiotoxicity if ingested or inhaled. A severe incident would be where an obsolete static eliminator containing significant quantities of radium 226 is shredded, causing contamination to the scrap yard and transferred by the employees to their homes causing significant internal exposure to members of the households.

A second category of sealed sources are those found in gauges and devices containing gaseous radioactive material. These devices present a minimal hazard since the radioactive material in the form of a gas will usually be released prior to reaching the steel plant due to breakage of the source capsule. Most gaseous radioactive sources used for this purpose are chemically inert and would readily disperse. Once released, the gas dissipates into the atmosphere. Most gaseous

sources are low energy, beta emitting radionuclides which would be difficult to detect in steel scrap.

A third category of sealed sources are beta emitting devices utilizing a solid radioactive material source. A prime example are devices containing strontium 90. Depending on the amount of radioactive material present, it could be possible to detect these sources from the x-rays generated when the beta rays intercept the steel. However, either the radioactive source would have to be outside its shielding, or the "shutter" would have to be open, allowing the beam to exit the container. Such devices can present a significant risk of plant contamination as well as an employee health risk. One reported incident involved a strontium 90 source found in an empty rail car in a Florida steel mill.

A fourth category of sealed sources are gauging devices containing sealed gamma emitting materials. This is the category of sealed sources most likely to be found in steel scrap as evidenced by past occurrences. It is estimated that there are from 200,000 to 500,000 gauges containing gamma emitting radioactive materials in the country. The most common is cesium 137. Other radioactive materials commonly used in gamma emitting gauges are cobalt 60, and americium 241. There are probably in excess of 300,000 gauging devices in the country containing either cesium 137, cobalt 60, or americium 241. These devices have the greatest probability of causing contamination of a steelmaking facility because of the quantity of radioactive material and their sheer number. However, with the exception of americium 241, they are also reasonably easy to detect in scrap. To date, ten of the known incidents have involved this category of device. Since these devices have a reasonable volume (6 to 8 inches in diameter and 10 to 12 inches long), they are relatively easy to visually see in scrap at a processing facility and can be segregated for further examination.

A fifth category of sealed source devices are large activity sources (>100 curies) contained in medical therapy or industrial radiography devices. This category was the cause of the Auburn, NY, and Mexican incidents. There are probably less than 20,000 such devices, nationwide. However, the potential consequences of melting such a device is great because of the high amount of radioactivity contained. These are usually very large volume devices and should be easy to identify during scrap handling.

CONSEQUENCES OF RADIOACTIVE CONTAMINATION

AREA CONTAMINATION

Should loose radioactive material enter a scrap yard or steel plant, the consequences and cost of decontamination will depend on the radionuclide, the quantity released and the degree of dispersion throughout the facility. The relative radiotoxicity of several radionuclides is discussed in the next section dealing with melting sources.

Table 2 provides a partial listing of costs involved in decontaminating facilities, including loose contamination incidents and incidents in which sources were melted in steel making furnaces. The table provides an appreciation for the high costs associated with radioactive decontamination.

The greater the direct personnel contact with the scrap, the greater the potential for personnel contamination. While radioactive contamination can usually be adequately removed by normal washing, it requires that the person know that he is contaminated. Unlike the highly publicized September, 1988 Brazilian contamination incident, in which children and adults applied loose radioactive cesium 137 powder to their bodies because of its iridescence, we normally cannot tell that something is radioactive by just looking at it. Radioactive material is normally not something that glows! Thus, the greatest consequence of a major contamination incident would be spreading the contamination from the scrap yard or steel plant to the homes of the workers. This happened in the Mexican incident when the loose cobalt 60 pellets were found to be distributed in residential areas.

MELTING A RADIOACTIVE SOURCE

The specific radioactive nuclide will determine the potential consequences once the radioactive material is melted, since a radioactive nuclide will react chemically with the steel or the impurities and flux the same as its stable (non-radioactive) element.

Cobalt 60 and cesium 137 are two radionuclides that are generally available in large enough quantities and common enough to be capable of causing widespread contamination in a steel making facility and personnel contamination. Since they have been involved in several past incidents, they will be discussed first. Much of what is said in the discussion of cobalt 60 is applicable to other radionuclides.

Radioactive cobalt 60 is usually found as metallic cobalt metal contained in welded stainless steel capsules. This means that the radioactive material is not readily available for contamination of the scrap unless the capsule is broken open. Since most capsules will be located in shielded housings, the likelihood of having the cobalt 60 metal in direct contact with the scrap is minimal, unless the shielded housing has been destroyed.

Cobalt is ferro-magnetic and is attracted to a magnet. If the cobalt 60 metal is outside its capsule, it will be carried along with the steel by the charging magnet. Most stainless steels are not as ferro-magnetic and are not as likely to be charged with the scrap. Should the cobalt 60 be contained in a shielded housing, it is likely the housing will be carbon steel clad. Thus, there will be an opportunity for lifting the entire device with a magnet. However, the mass of the device due to the shielding material within the steel cladding, typically lead, will make it difficult, but not impossible, to pick the device up with a magnet.

This is a point that should be stressed with scrap handlers: if the object falls off the magnet and resembles a container, further attempts at picking it up should not be made until it is checked.

If melted, cobalt 60 will react similarly to non-radioactive or stable cobalt. Most of it will alloy with the steel, a small portion will oxidize and become part of the fume and a very small portion will become incorporated in the slag. If cobalt 60 is melted, we would expect to have contaminated steel where the contamination is mostly fixed. This means that once the steel cools, the contamination is not easily removed or wiped off. Such contamination in the steel will present very little potential for further contamination to rolling or finishing mills or the cooling water used in those mills. Any cobalt 60 occurring as scale that becomes incorporated in the cooling water will usually not dissolve. It could present an external exposure problem for workers cleaning the mill scale pits. A 0.25 Ci cobalt 60 source melted in a 50 ton furnace will result in easily detected radiation fields emanating from the steel using conventional survey equipment.

Depending on the amount of cobalt 60 melted, the steel could present a hazard to employees or to customers from the radiation emitted from the radioactive material contained within the steel. Past incidents have produced steel having external radiation exposure rates at the surface of the steel from less than 1 milliroentgens per hour to greater than 1000 milliroentgens per hour. The author has calculated that 25 curies of cobalt 60 melted into 60 tons of steel, which is then rolled into 4.5 inch by 4.5 inch billets, would have a gamma intensity at 1 meter from the steel, in excess of 375 mR/hr. This external exposure rate could easily produce personnel doses well above acceptable guidelines.

If the steel is made into products that have a high degree of contact with the public, such as legs for fast food restaurant tables, the total population dose could be in a range comparable to that received from natural background.

Cobalt 60 present in the slag may be available for leaching because of the acidic nature of slag. This could present a possible, but usually small, potential for environmental contamination. A more likely impact would be from the oxidized fume which can escape to the melt shop environment and also cause contamination in the air pollution control system. This could result in extensive contamination of maintenance personnel unsuspectingly entering a baghouse.
In the case of a baghouse, such contamination has required the total cleaning and rebagging of the facility. A more severe consequence would be to scrubber systems where the cost of cleaning and handling liquid radioactive waste is much greater than the cost to dispose of solid baghouse dust. Scrubber systems also increase the chance of release of the radioactive material to surface water.

Cobalt 60 offers a low to moderate personnel hazard as was readily demonstrated in the Auburn incident where no internal contamination was found in melt shop workers even though significant contamination occurred from the fume. If ingested or inhaled, approximately 50 percent will be directly excreted. About 5 percent will localize in the liver with a 60 day biological half-life. The remainder will be distributed uniformly throughout the other organs in the body and have an approximate 800 day biological half-life.

Cobalt 60 is commonly used in industrial radiographic, medical therapy, and industrial gauging devices. It has a very high energy gamma ray which makes cobalt 60 relatively easy to detect, even when covered by scrap. A likely scenario for a cobalt 60 source finding its way into steel scrap is if a building containing the device is demolished and the shield is included with the scrap steel. This was probably the scenario for the Auburn incident, in which the entire device, including the shielding, was charged into the furnace as part of the scrap. The Mexican incident occurred, however, when someone removed the actual source capsule from within the shielded housing and sold the unshielded capsule to a scrap yard.

Should a cobalt source be melted and contaminate a melt shop, the external radiation measured using hand-held survey meters would be relatively minimal as shown in Table 4. As can be seen from the table, even a minimal resuspension of the dust from a surface could cause airborne concentrations well in excess of occupational limits. The important point to realize from Table 4 is that a major contamination incident may result in external exposure rates that are not much greater than natural background, using conventional survey equipment that might be available at a steel mill. Thus, the incident may not be readily discovered.

TABLE 4

NUCLIDE	MAXIMUM PERMISSIBLE OCCUPATIONAL AIRBORNE LIMITS (uCi/ml) SOLUBLE	INSOLUBLE	uCi/100 FT^2 TO GIVE 1 mR/hr AT 3 FEET	EXPOSURE RATE IN mR/hr AT 3 FEET FROM SURFACE IF CONTAMINATION IN uCi/100 FT^2 IS 100	1000	10,000
Co 60	1×10^{-8}	3×10^{-10}	603	.2	1.7	16.6
Cs 137	1×10^{-10}	1×10^{-8}	3157	.03	.3	3.2
Ir 192	4×10^{-9}	8×10^{-9}	2214	.06	.65	6.5
Ra 226	3×10^{-12}	2×10^{-12}	939	.0	1.1	10.6
Am 241	2×10^{-13}	4×10^{-12}	20214	ND	.05	.5

ND - Not detectable above natural background radiation

Table 5 presents some of the important radiological properties of cobalt 60 and the other radionuclides discussed.

Cesium 137 is another radioactive material that has been melted in steel plant furnaces. It is typically found as a chloride, oxide or nitrate. As either a loose or compressed powder contained in stainless steel capsules, it presents a serious contamination hazard if the capsule is broken open. Cesium 137 is commonly found as a ceramitized pellet or many ceramitized microspheres enclosed in a stainless steel capsule. While the ceramitized form does not present as great a contamination problem, it would facilitate the dispersal of the radioactive material throughout the scrap. Like cobalt 60, cesium 137 is typically present in stainless steel capsules encased in a shielded housings and not readily available for contamination of the scrap unless the capsule is broken open. Cesium 137 is not ferromagnetic. However, the shielded housing may present an opportunity for lifting with a magnet similar to a cobalt 60 source shield.

If melted, very little of the cesium 137 will alloy with the steel since cesium is an alkaline earth element and chemically similar to calcium. The low decomposition temperature of the oxide and nitrate, and the high boiling point of the chloride means that if melted, most of the cesium that is not incorporated in the slag will escape in the furnace exhaust. Thus, cesium 137 presents a greater in-plant and environmental contamination hazard than does cobalt 60. However, there will be very little contamination of the product and materials fabricated from the steel which should present a low hazard to the general public.

With respect to the slag, We would expect a much larger percentage of cesium 137 than cobalt 60 to be present in the slag. This could present a potential for environmental contamination. Cesium chloride, because of its high boiling point will usually escape in the fume causing contamination of the melt shop and the air pollution control system with the same consequences as cobalt 60.

Cesium 137 also presents a moderate personnel hazard. If it is inhaled or ingested, it is rapidly and completely absorbed from the intestinal tract or the lungs and has a biological half-life in the body of about 100 days. It tends to localize in all tissues throughout the body, with the muscle being a major site.

Cesium 137 is probably the most common radioactive material used in process control gauges. Common examples would be as a gauge used to measure the level of material in a steel tank or the density of material flowing through a pipeline or on a conveyor belt. Like cobalt 60, most cesium 137 sources will be housed in lead shields encased in steel shells. Typical source sizes will range from 100 millicuries to over 10 curies. There are some irradiator sources with activities exceeding several thousand curies. These are rare, however. Cesium 137 has a moderate gamma energy and is capable of being detected in its shielded housing, even when covered with steel scrap, although not as easily as cobalt 60. It is generally expected that the entire source housing (shield) would be discarded as part of the equipment to which it is attached.

Two of the incidents involving cesium 137 sources were discovered when the dust from the baghouse was being trucked away for disposal. In one case, a detection system installed at a weigh scale detected the contaminated baghouse dust in the truck. Obviously, the source entered the plant undetected in the scrap, probably past the same detection system.

Other radioactive materials which could easily find their way into steel scrap include isotopes of americium, radium, and strontium. Since they are alkaline earth elements, they would tend to become incorporated in the slag, with some fuming. However, unlike cobalt and cesium, they tend to settle in the bone and remain incorporated in the body for several decades. Thus, these isotopes present a greater personnel hazard because of their constant irradiation, over many years, of nearby tissue; as well as a potential in-plant and environmental contamination hazard.

Of the three, radium 226 is probably the most likely to be incorporated in scrap, and also the most likely to be detected because of its relatively energetic gamma ray output. It's very long physical half-life means that radium 226 retains its hazardous nature for many centuries. Radium is not as controlled a radioactive material as many others because it is not regulated by the US NRC. Its regulation is left to the individual states. Some states have the same degree of regulation of radium as there is for other radioactive materials. However, some states have minimal regulatory programs.

Radium was commonly used for many years in gauging devices, medical therapy devices and for static eliminator sources. It could be found as a sealed source in a shielded housing or as a plated source with minimal outer protection. At least three incidents have involved radium 226 in manufactured devices, most likely static eliminators. In two incidents, the radioactive material was discovered before it was melted. In a third incident involving an aluminum plant, the radioactive material was discovered by another company processing the

dross or slag from the aluminum mill. The numerous incidents in which oil well casing triggered an alarm were also due to radium and the radioactive decay products of radium deposited as scale in the pipe.

TABLE 5

RADIOLOGICAL PROPERTIES OF SELECTED RADIONUCLIDES

RADIO-NUCLIDE	TYPE OF RADIATION	ENERGY (MeV)	HALF LIFE	TYPICAL FORM	ACTIVITY CURIES
Cobalt 60	Gamma Beta	1.25 .3	5.25 years	Sealed sources Metallic cobalt	0.1 - 10k
Strontium 90	Beta	.5	28 years	Sealed, plated sources Strontium salts	0.01 - 1
Cesium 137	Gamma Beta	.66 .5	30 years	Sealed sources Cesium salts	0.1 - 10
Polonium 210	Alpha	5.3	138 days	Plated sources	0.001-0.1
Radium 226	Alpha Gamma	4.8 .8	1600 years	Sealed, plated sources, Radium salts	0.001 - 1
Americium 241	Alpha Gamma	5.5 .06	458 years	Sealed, plated sources, Oxide	0.001 - 1

Of the other two radionuclides, strontium 90 offers a reasonable chance of detection even though it is a beta emitter. Beta radiation is easily stopped. However, when it is stopped by dense materials, such as steel, it produces x-rays which have a greater degree of penetration than the original beta radiation. Thus, strontium 90, with a high energy beta emission, could be detected by the secondary x-rays produced by the scrap cover. This appears to have been the case in the one Florida incident. Strontium 90 is usually found as a sealed source, and may commonly be used as a "free-air" source, i.e., not in a shielded container. This latter configuration would make a strontium 90 source relatively easy to detect.

Americium 241 is a weak gamma emitter and presents the greatest difficulty of detecting in steel scrap if one is only considering the emitted 60 keV gamma photon. Its long half-life and its tendency to settle in bone also make it one of the more hazardous radionuclides that could enter the scrap stream. Americium 241 is commonly used to measure the thickness of thin gauge metals, as a source in smoke alarms and as a source in static eliminators. Its use determines whether it will be enclosed in a welded capsule or exist as a plated source. Americium 241 and other alpha emitting radionuclides are often combined with low atomic number materials such as beryllium or

lithium to produce neutrons. Since neutrons are not well shielded by steel, it is possible to detect americium-beryllium, and other isotopic neutron generator sources by the emitted neutron radiation. Very little unclassified data has been published to date on the detectability of straight americium 241 sealed sources or alpha generated neutron sources in steel scrap. Some limited data using an americium 241 low energy gamma source and an americium-beryllium neutron source are presented in Tables 8 and 9.

A fourth radioactive material is polonium 210, a naturally occurring radioactive material that is commonly used for static eliminators. While it is inherently relatively difficult to detect, its predominate use in static eliminators means that it will not be contained in any type of shielded housing. Thus, if it is close to the surface of the scrap, it may be detected with a better system. Polonium's short half-life somewhat reduces the practical consequences should a polonium source be melted. Polonium has a tendency to vaporize and be driven off as part of the fume since its common oxide form decomposes at relatively low temperatures (930^{o}F). If taken into the body, it tends to distribute throughout all tissues in the body and has a biological half-life of approximately 50 days.

Finally, natural thorium (thorium 232) is commonly incorporated in metals to give the materials better heat resistance and with tungsten wire to increase the wire's electron emission or control the tungsten grain size. Both the metallic and oxide forms have very high melting and boiling points and would tend to remain available for reaction with either the steel or the slag. If taken into the body, thorium tends to deposit on the surfaces of bone with a biological half-life of a couple of decades. Thus, natural thorium presents a risk similar to radium 226 and americium 241 if melted and dispersed throughout a steelmaking facility.

DETECTION SYSTEMS

Following the Auburn, NY incident, the general perception within the steel industry was that detection of radioactive material in steel scrap was impractical because most radioactive sources would be contained in lead shields buried deep in the scrap. It was believed that while it might be possible to detect a large shielded medical teletherapy or industrial radiography source in a load of scrap, one could not hope to detect the average gauge source. It was commonly felt by industry that the lead shield and the scrap would effectively shield the emitted radiation from the detectors for most gauge source housings and that only the largest source sizes offered any hope of being detected. What must be realized is that for most gauging devices containing radioactive material, a de facto standard exists which limits the radiation emitted through the housing walls to 5 milliroentgens per hour or less at a distance of 1 foot from the outer surface of the source shield. Gauge manufacturers will usually design a few shield (housing) sizes to contain their entire range of source sizes. Thus, smaller sources will be placed in a small shield while larger sources are placed in larger shields. The net result is that the emitted radiation will usually be in the same intensity range, at

a distance of a few feet, irrespective of the source size. As a result of this, the activity of a radioactive source contained in a commercial gauge housing is relatively unimportant when discussing detectability. A shielded 200 millicurie source can have the same radiation intensity at three feet as a shielded 2000 millicurie source. If a system can detect a typical gauge source in scrap, it should be able to detect most gauge sources, as well as the larger teletherapy and radiography sources.

Thus, the first task was to determine if typical radioactive sources, contained in their lead shielded housings could be detected.

FIELD TESTS

The author began evaluating the feasibility of detecting shielded radioactive sources buried in steel scrap, following the Auburn incident in 1983. The detection capabilities of various systems are presented in Table 7 along with estimated false alarm rates and costs for an installed system, including barriers to protect detectors.

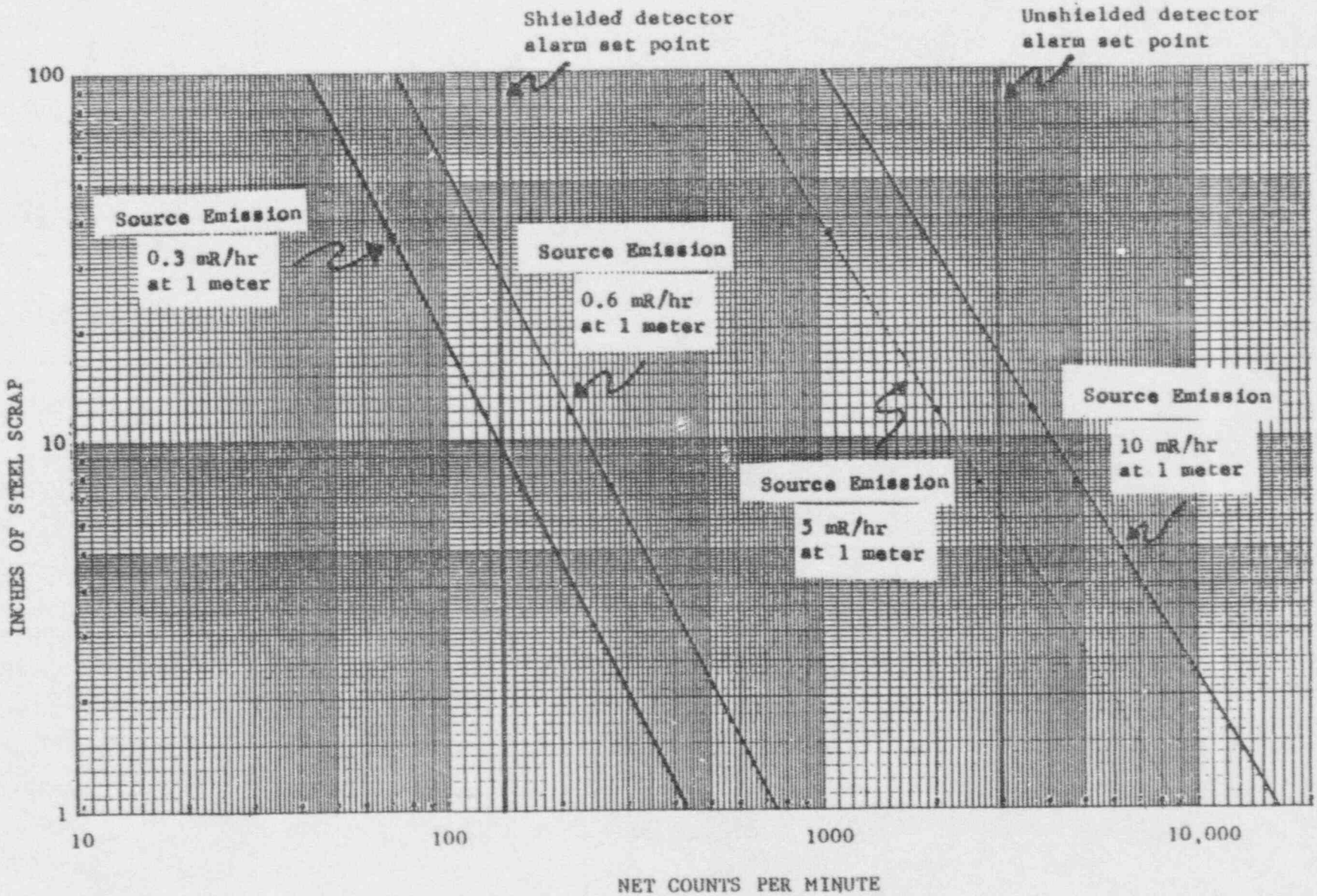
In the first evaluation, a simple field test was conducted in which sources contained in typical gauge housings were placed in scrap containers and covered with scrap steel. An unshielded 2x2 inch sodium iodide (NaI) detector attached to a simple scaler was used as the monitoring system. This is very similar to systems being sold for $1000 to $3000. Because the detector was unshielded, the system had a high natural background count of 1500 counts per minute (cpm), and therefore, an elevated minimum detectable level.

A ratemeter based system uses a manually set alarm point which is usually set at 2 times the background count rate to reduce the possibility of false alarms. The high set point results in an elevated minimum detectable level and means that a minimal scrap cover would prevent detecting most shielded sources, including source housing such as the one actually involved in the Auburn, NY incident. Such a system would be able to detect sources approaching the US Department of Transportation's maximum limits for shipments containing radioactive material (10 milliroentgens per hour, gamma, at approximately 3 feet from the surface of the container), covered with no more than one foot of scrap.

Thus, an unshielded 2x2 inch NaI detector with a simple alarming ratemeter is a poor detector system, even for a stationary portal monitor.

When the detector was shielded to reduce the background rate to about 70 cpm, a typical gauge appeared to be detectable in no more than one foot of steel scrap. Sources such as the ones involved in the Auburn incident would be detectable in up to about four feet of steel scrap having a density of 30 to 50 pounds per cubic foot. Figure 8 shows a comparison of detection capabilities for simple, shielded and

Figure 8 - Shielded/Unshielded 2" X 2" Sodium Iodide Detector with Ratemeter Based Circuit



unshielded ratemeter based systems using a 2" X 2" sodium iodide detector.

These initial tests suggested that it was possible to detect some hard gamma emitters even in a shielded condition using a simple detection system which could be purchased and fully installed for around $5,000 to $10,000 as long as the source is stationary for at least one minute, the source to detector distance does not exceed approximately 10 feet, and the scrap cover does not exceed one to two feet.

These conditions may be achieved, on the average, when all scrap is delivered via smaller dump trucks that are weighed upon arrival. However, where scrap is delivered in trailer dump trucks or by rail, the larger capacity increases the probability that the scrap cover would effectively shield the source. Additionally, rail cars may be weighed as the cars are moving over the scale at 3 to 5 mph. This would decrease the detection time to about 5 seconds. These two factors effectively eliminate the practical detection of even source housings having higher gamma flux rates using a ratemeter based shielded detection system for rail car and large truck monitoring.

It was also noted that many low cost alarming ratemeters will only accept one signal input. Many ratemeters having dual signal inputs respond to only one channel at a time, or respond to only the stronger signal. As such, they are not true two channel ratemeters.

While such a system was not tested, a ratemeter based or even a microprocessor based system using large volume Geiger Mueller tubes would not be much more sensitive than a 2 x 2 inch shielded sodium iodide detector system and less sensitive than an equal volume (of the GM tube) of plastic scintillator, simply based on the relative efficiencies of the detectors. A plastic scintillator is about 1000 times more likely to attenuate a 200 to 600 keV gamma photon than a gas filled GM detector, and sodium iodide is an even better photon detector than plastic.

Since the nuclear reactor industry was rapidly installing portal monitoring systems, during the mid-1980's, incorporating microprocessor based electronics, it was decided to test such a system. A Bicron Laundry Monitor having 4 x 4 x 1 inch plastic detectors was used in both a shielded and unshielded mode. This size of plastic scintillator was found to have a detection efficiency similar to a 3 x 3 inch sodium iodide detector. A 100 millicurie cesium 137 source was used with the shutter open. The purpose was to test the effect of both shielding the detectors and to determine the attenuation of simulated scrap thicknesses. In this test the source to detector distance was set at 168 inches and various thickness of steel plate were placed in the beam. The results of this test are shown in Table 6. As can be seen, shielding the detector permitted the detection through 7 inches of steel. The Bicron Laundry Monitor has several fixed counting intervals that may be selected by the user. The data presented in Table 6 was obtained using a 90 second count interval.

TABLE 6

CONDITION	PLATE STEEL PLATE INCHES	ESTIMATED SCRAP THICKNESS INCHES	CPM
Detector unshielded			
Natural background			7,000
Steel in beam	0	0	14,000 *
	2.25	17	8,900 *
	7.0	53	4,000
Detector shielded			
Natural background			2,500
Steel in beam	7.0	53	4,000 *

* - System alarmed at end of count cycle

Another field test involved placing a 200 millicurie cesium 137 source in a housing rated for 1000 millicuries (Texas Nuclear model 5191) in a scrap bucket. The source when placed in a protective steel box has an external gamma exposure rate of 0.03 to 0.2 milliroentgens per hour at one foot from the protective box. The energy of the emitted photons are in the 100 to 200 keV range.

The shielded source was easily detected in less than 1 minute using a single plastic scintillator/photomultiplier tube assembly connected to a multi-channel analyzer. The 2x12x24 inch plastic scintillator was placed about 18 feet from the source. The wall of the scrap bucket was 1.5 inches thick, and the source was buried in about 3 feet of scrap having a density of 30 to 50 pounds per cubic foot.[6]

Tests were also made using the same source buried in about 4 feet of scrap having a density of about 30 pounds per cubic foot, in a moving rail car. It was possible to detect the source in this configuration as long as the rail car was moving at 1 to 2 miles per hour. The detection system used for this test was a 3 x 3 inch shielded sodium iodide crystal connected to a multi-channel analyzer. Detectability was statistically demonstrated from a computer analysis of the recorded data. Higher density scrap (greater than 50 pounds per cubic foot), or speeds faster than 2 miles per hour, significantly reduced detectability in a moving vehicle for a typical shielded gauge source. However, it was felt that with larger detectors, it may be possible to consistently detect a typical shielded gauge source in a moving vehicle.[6]

Comparisons were also made between stationary and moving vehicles for individual and summed detector inputs using a Bicron Corporation Automated Scrap Monitoring System and the 200 millicurie test source described above. The data is presented in Table 7.

TABLE 7

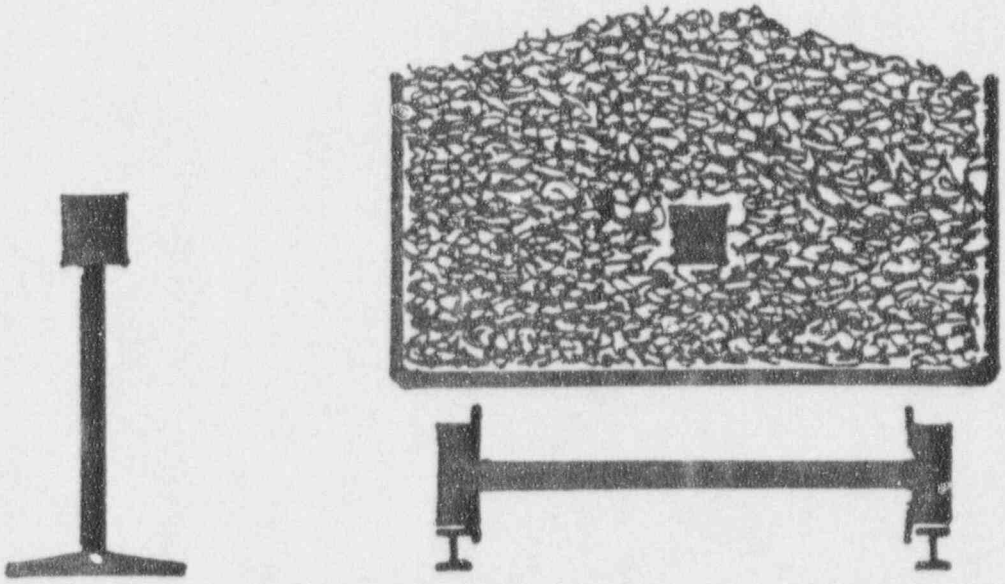
COMPARISON OF DETECTOR INPUT
STATIONARY AND MOVING SOURCE DETECTION - CESIUM 137

VEHICLE SPEED	SIGNAL INPUT	SCRAP THICKNESS (INCHES)	SYSTEM ALARM	PERCENT ABOVE BACKGROUND
Stationary	Individual	0	Yes	594
Stationary	Individual	30	Yes	64
Stationary	Summed	30	Yes	30
Stationary	Individual	36	Yes	6
Stationary	Summed	36	Yes	3*
Stationary	Individual	40	No	---
Stationary	Summed	40	No	---
1.4 MPH	Individual	30	Yes	13
1.4 MPH	Summed	30	Yes	6
1.4 MPH	Individual	36	No	---
1.4 MPH	Summed	36	No	---
3.8 MPH	Individual	30	No	---
3.8 MPH	Summed	30	No	---

* May not be detectable in a real system

The detection system consisted of approximately 1200 cubic inches of plastic scintillator media connected to a microprocessor based monitor built by Bicron Corporation to the specifications found later in this paper. The shielded source, housed in a 3/8 inch protective steel box was placed in a 60 foot rail car. Various thicknesses of 65 to 75 pounds per cubic foot shredded scrap (frag) was placed between the source and detector as shown in Figure 9. A 64 cubic inch sodium iodide scintillation detector attached to a multi-channel analyzer (MCA) was located adjacent to the plastic scintillator in order to obtain data relative to the energy of the detected gamma photons, since plastic does not possess good gamma energy resolution capabilities. The MCA display can show the specific energies as peaks, and allow one to determine the contribution from a specific energy, identify which radionuclide is present, or observe the change in peak pattern with changes in test conditions. One minute counts were taken, primarily to accommodate the needs of the less sensitive sodium iodide system.

FIGURE 9



Several important conclusions were derived from this series of tests:

1. The gamma test source used, represents a reasonable "worst case" test source. Sources having a significantly greater emission rate or higher energy will not adequately challenge a highly sensitive system while sources having a significantly lower emission rate will be difficult to detect by high sensitive systems under many test conditions.

2. The photon energy exiting the rail car from a heavily shielded cesium 137 source is in the range of 200 keV with no discernable photon peak.

3. Sixteen inches of shredded scrap (65 pounds per cubic foot), seems to reduce the radiation from a heavily shielded cesium 137 source by about 90 percent (tenth value thickness).

4. Table 8 shows the percent chance of detecting radiation sources most likely to be found in steel scrap based on the data used to generate Tables 7 and 9. The table includes data for each detector signal analyzed individually and for detector signals summed prior to statistical data analysis, in stationary and moving vehicles. The percentages are calculated from the scrap thicknesses found to permit sufficient radiation flux to cause an alarm and are factored for the total volume of both a 60 foot rail car and a 20 foot dump trailer.

TABLE 8

DETECTION PERCENTAGES

VEHICLE/SOURCE	INDIVIDUAL DETECTOR ANALYSES			SUMMED DETECTOR ANALYSES	
	STATIONARY	1 MPH	4 MPH	STATIONARY	1 MPH
Rail car/americium 241	42	35*	21*	26	23*
Rail car/cesium 137	63	53	32*	56	49
Rail car/unmoderated neutron	90	76*	46*	90	76*
20' truck/americium 241	60*	52*	43*	37*	34*
20' truck/cesium 137	83*	72*	60*	74*	55*
20' truck/unmoderated neutron	100*	87*	72*	100*	87*

* Estimated

Because of a lack of available data on the detectability of large activity, low energy photon sources, tests were also made using a 3 curie americium 241 source housed in approximately 2 inches of lead. A review of the manufacturing process for americium 241 sources led the author to question whether neutron generation, sufficient to measure, was occurring. Communication with a representative of Amersham, a large manufacturer of neutron sources, disclosed that Amersham quotes a nominal emission rate of 10^4 neutrons per second per curie due to the (alpha/neutron) reaction with the aluminum and silicon in the ceramic or fritted glass matrix of the source. This same phenomenon is also present in other large activity alpha emitting sources such as plutonium. Additionally, the self-fissioning nature of curium 244 and californium 242 should render these radionuclides even more detectable than americium 241.

Limited data showing the neutron detection capability of plastic scintillators using an unmoderated (unshielded) 2 curie americium-beryllium neutron source and a 3 curie americium 241 source in a 2.5 inch lead shield are presented in Table 9. All entries in Table 9 for the americium-beryllium neutron source resulted in a system alarm.

TABLE 9

NEUTRON DETECTION USING PLASTIC SCINTILLATORS

SIGNAL INPUT	SCRAP THICKNESS (INCHES)	SYSTEM ALARM	PERCENT ABOVE BACKGROUND
Americium 241			
Individual	0	Yes	15
Individual	22	Yes	5
Summed	22	No	---
Americium-Beryllium			
Individual	0	Yes	1543*
Individual	19	Yes	1112*
Summed	19	Yes	420*
Individual	45	Yes	470*
Summed	45	Yes	222*

* - System alarm

The tests which generated the data for Table 9 used both the Bicron Automated Scrap Monitoring System and a 64 cubic inch sodium iodide crystal connected to a multi-channel analyzer (MCA). The MCA is

sensitive only to gamma photons and can show the spectral response over a wide energy range. It can provide both a total count and show the relative contribution from specific energy peaks. The plastic scintillator is sensitive to both gamma photons and fast neutrons, but has no spectral resolution. As such, plastic can only provide a total count.

The MCA showed no increase above background when the americium 241 source was placed in the scrap. This is understandable since the 60 keV gamma photon is 1600 times more likely to be attenuated or stopped by the scrap than an unshielded 662 keV cesium 137 gamma photon, or 800 times more likely to be attenuated by the scrap than a heavily shielded cesium 137 gamma photon (200 keV). It is felt that the low neutron output of approximately 3 X 10^4 neutrons per second (4 PI geometry) is not sufficient to generate detectable gamma from the (neutron/gamma) reaction with the steel. The lack of detection by the MCA, even with a detector as large as 64 cubic inches of sodium iodide, shows that plastic is the preferred detector medium, independent of price and other considerations.

One important factor which was seen early in the testing is that a loaded vehicle will provide sufficient shielding of the detectors to lower the background count rate by about 10 to 15 percent, or approximately by the amount above background that would cause an alarm. This is a factor that must be taken into consideration when designing any system. Simply moving a vehicle in and out of the detector area could cause an alarm or suppress an alarm, due only to the changes caused in background.

SYSTEM DESIGN

These tests show that adequate detection of typical gauge housings in normal scrap can be achieved if the efficiency of the detection system is increased by using large volume plastic scintillators with a microprocessor based system. Sodium iodide detectors are ruled out because they are cost prohibitive in large volume, too difficult to protect in a hostile steel plant environment, and cannot detect neutrons without some type of neutron sensitive cover. Large volume liquid scintillator detectors are also ruled out because of their fragility in the hostile environment of a steel plant and the potential fire hazard of the scintillator solvent.

The microprocessor system referred to in this paper has under gone significant development based on input from Graham Wolford of Gull Engineering, Joseph Johnston of Bicron Corporation and the author. At present, Bicron is the only manufacturer known to the author that incorporates the entire specification. The system uses an algorithm to trend the background rate over the last 15, one second count periods. Each measurement is then compared to this updated average background, as well as the rate of change in the photon flux between measurements. This permits the system to apply a statistical test to these two parameters, and more closely differentiate an actual low reading from background. This has two advantages. It can detect lower photon fluxes, while reducing the occurrence of false alarms.

Plus, the large volume detectors will increase the overall sensitivity of the system. Additionally, the algorithm will examine the signal as to its randomness and accept only the random input typical of radiation emissions. This latter point will also tend to reduce the occurrence of false alarms.

With such a system, the minimum alarm level can be lowered from 100% above background, or twice the background rate to less than 10% above background. Data obtained during the last test described showed alarm annunciations in the range of 5 percent above background. This enables the monitor to detect the test source covered with approximately three feet of 65 to 75 pounds per cubic foot scrap, while having a false alarm rate of less than 1 in three months.

A Bicron system built to the specification and installed in early 1988 at a Pennsylvania steel plant to monitor the charging of scrap buckets was able to detect the 200 millicurie cesium 137 test source while covered with about 4 feet of 30 to 40 pounds per cubic foot scrap in less than 15 seconds, while having a calculated false alarm rate of less than 1 in 10^9 years (9 sigma above background).

Multiple detectors should be individually analyzed by the microprocessor. This affords two advantages as shown in Table 8. First, it is easy to determine if a single detector is malfunctioning. And second, with the exception of a single, unlikely case, multiple signal inputs provide a more sensitive system than a single added input. With the exception of the americium-beryllium neutron source which was sufficiently strong to be detected, even when in the center of the rail car; the other two test sources showed a significant reduction in detectability when the signals were summed prior to data analysis. If it is assumed that a single detector has a background count rate of 150 counts per second (cps) and an alarm set point of 10 percent above background, then the detector will alarm at about 165 cps. If four detectors are used in a system, then any of the detectors can alarm the system if more than 165 cps is detected. If a small source produces 170 cps at only one detector, the system with multiple channel inputs would alarm, since at least one detector picked up the increased radiation.

By combining all inputs into a single channel, four detectors produce a background count rate of 4 times 150, or 600 cps. The resultant alarm point then becomes 660 cps. The same source producing 170 cps in one detector and no increase in the others would cause a total count rate of 620 cps, or less than the alarm point of the system.

The one case in which combined inputs are as good as multiple channel inputs is where the source produces an alarm state in each detector. If 170 cps were produced in each of the combined detectors, then the total would be 680 cps, or 20 cps above the alarm point.

The goal of any system is to detect radioactive sources that could cause personnel hazards and plant contamination. Most attention has been focused on energetic gamma emitters like cobalt 60 or cesium 137. These are relatively easy radionuclides to detect as this paper shows, even in a shielded housing. While all radioactive material can

present a personnel hazard, there is a gradient of hazard among the various radionuclides. Cobalt 60 or cesium 137 are not two of the more hazardous. Consideration must be given to detecting such radionuclides as americium 241 or plutonium 238 which are highly radiotoxic and are used in commercially available products. They are very difficult to detect because of their low gamma radiation energy and output, but present an extreme personnel hazard if melted in a furnace. As a result, a steel plant will want the most sensitive system available to provide the best chance of detecting the more dangerous sources.

PERSONNEL RESPONSE TO AN ALARM

Another item that is very important is assuring a very low false alarm rate. A low false alarm rate will be combined with maximized sensitivity in a good detection system.

When a system alarms, the facility does not know if: (1) it is a false alarm; (2) it is a "nuisance" source that involves no threat to employees, the physical plant, or customers; (3) it is a very small unshielded source near the surface of the scrap; (4) it is a shielded source buried in the scrap; or, (5) it is a decayed, but still a sufficiently large activity source in its original shield. All can cause the same intensity reading in a detection system. Also it will not be readily known if the radioactive material is intact or dispersed. The response to the alarm must initially assume that the alarm is real and that the source presents a potential personnel hazard in terms of external exposure and radioactive contamination, until it has been determined to be otherwise.

The argument is often heard that if the system detects something, the plant simply refuses to accept it. That may be an acceptable approach where the inbound vehicle is a truck, the monitoring point is very close to the plant's property line and the truck driver agrees to drive the truck away. However, what does the plant do when the truck driver becomes fearful for his own safety and refuses to drive the truck back to its origin? How will the plant determine whether there is a threat to its employees from the parked truck? Or, what will the plant's policy be where the monitoring point is at a scale, reasonably inside the plant's property? Does management blindly assume that no contamination has occurred and that employees are not carrying radioactive contamination home with them? Does management even want the driver to drive a truck potentially leaking radioactivity back through the plant? Will management be legally liable if the truck contaminates public roadways? Does management want such adverse publicity? How will management handle a rail car that a national railroad has just delivered? Can they still get the railroad to remove the car? Does the plant now become the legal shipper subject to US Department of Transportation regulations? How does the plant legally ship a vehicle containing an unknown quantity of an unknown radioactive material? These are all important questions that management must consider and answer.

Once a system alarms, management is forced to respond with a plan that first rules out that a personnel and plant contamination hazard exists. Such a response could take several hours because personnel have to be protected from potential external exposure and contamination. To do otherwise opens the company to potential liability from employees that could make a million dollar decontamination bill pale in comparison, especially if an employee becomes accidentally contaminated and, in turn, contaminates his home and family.

There is usually no full-time radiation protection staff on duty around the clock that can immediately respond to an alarm. The closest a plant may come to a trained health physicist is an industrial hygienist or safety specialist who has had a course in radiation protection, sometime in the past. In many cases, steel plants will not have a trained individual who can respond to a suspected radiation source contained in scrap. This is even less likely for a scrap processor. This function will become an additional duty assigned to an existing employee who may be only minimally familiar with radiation monitoring. Thus, an alarm indicating a detected source could result in a significant delay in operations. If it's a false alarm and happens several times, management will disconnect the system. Therefore, system reliability and a low false alarm rate are as important from a practical viewpoint as the systems' detectability.

If the plant has a microprocessor based system installed, this system is many times more sensitive than any hand-held detection system. In a recent test a rail car containing a buried source activated an alarm. But, it was not possible to detect the buried source on the outside of the rail car using a conventional hand-held "micro-R" meter. It is possible that higher sensitivity hand-held instruments can be developed for this purpose, however, equipment manufacturers should be sensitive to the need for lightweight, non-bulky instruments. Typically the user is walking in a hazardous area where caution against tripping and walking into overhanging scrap must exercised. An ideal instrument would be one that leaves both hands free, has an audible response that is transmitted through an earphone, has the sensitivity of at least a 3 x 3 inch sodium iodide crystal, is directional, and weighs less than 7 pounds.

Another point that should be realized is that while the typical steel plant or scrap yard worker may be highly skilled in his particular craft, he is a prime example of the general public, and probably has a mistaken perception of radiation hazards and risk, usually greatly over-estimated. Radiation is generally perceived to mean "cancer, sterility, death, and something that will make you glow in the dark, especially after TMI & Chernobyl." At best, an alarm may result in unnecessary delays in production, and at worst, in major work stoppages due to fear for their own safety. This latter consideration is one reason why a comprehensive training program must be instituted for the scrap handlers.

DETECTION SYSTEM LOCATION AND EFFECTIVENESS

There are several areas within a steel plant where monitoring for radioactive materials can take place. The primary pre-requisite is that the site should allow for the monitoring of all or nearly all scrap entering the facility. Other major considerations are to prevent contaminating personnel or facilities from an incoming source or during the preparation process, and to prevent external radiation exposure of employees from an unshielded source. In a scrap yard the potential for destroying an intact source is even greater because of shredding operations and general preparation activities. Finally, the monitoring process should optimize causing the least amount of interference to the steelmaking process while maximizing detectability; and if at all possible, permit identifying the producer of the scrap.

The most common location for a monitoring system is the weigh scale over which trucks and rail cars pass when bringing scrap into the facility. If multiple scales are used, each scale would require a detection system. If a system is located at a stationary scale (truck or rail), there should be no difficulty detecting small gauge sources covered with 3 to 5 feet of scrap having a density of 30 to 60 pounds per cubic foot. If a rolling scale is used, especially in the case of rail cars, it is doubtful that small shielded sources will be consistently detected unless they are close to the surface. The advantages of scale monitors are that there is the least amount of disruption to production, the identity of the supplier may be more easily determined, and contamination can usually be discovered before the material is off-loaded. The disadvantage is that some detection efficiency is lost compared to other methods and it is possible that a shielded source will enter and be either shredded by the scrap processor or melted in a furnace.

General contamination caused by loose radioactive material, provided it is not carried out of the facility, is generally less expensive to decontaminate than the contamination resulting from melting the same source in a furnace. Typically, costs have ranged in the thousands to tens of thousands of dollars as compared to the hundreds of thousands to millions of dollars for melted source decontaminations (see Table 2).

If all scrap is processed, it could be possible to have an employee hand monitor scrap piles, provided the scrap volume is low. This could provide adequate detection efficiencies if there is minimal scrap cover since an unshielded hand-held portable detector would be used. Generally, this is not an economically practical method because of its labor intensive nature. Also the disadvantage of depending on the consistent monitoring technique of one or more employees makes this an impractical method in all but the smallest facilities. The advantages of this type of system are that there should be minimal interference to production, equipment cost is low, and detectability is high in relation to the cost.

If scrap is loaded via a conveyor, a system could be installed on the conveyor, provided some means of rejecting suspect scrap is incorporated. This could provide excellent detection efficiencies because of minimal scrap cover. The greatest disadvantage would be the assurance that the rejection system was totally effective. There should not be an adverse effect on production with this type system provided all radioactive scrap was entirely removed from the scrap stream. Should contaminated scrap enter the facility, it is possible that the detection system could become contaminated and cause a steady alarm state with a severe impact on production.

A fourth approach would be to install the monitoring system where the charging of scrap buckets or other containers used to load the scrap into the furnace takes place. The advantage of this location is that there is usually the least amount of scrap cover to shield a radioactive source and such a location will usually provide the greatest detection efficiency for shielded sources. The disadvantages are that this location is immediately prior to the steelmaking furnaces and could have the greatest impact on production, the identity of the scrap producer is lost, and contamination would not be discovered until the scrap had moved through major areas of the facility. However, by installing a less expensive system at the scales, loose contamination could be easily detected before entering the plant and the best of both conditions would be achieved.

A fifth method would be to mount detectors on a truck and have a mobile system. This could be a practical approach if scrap comes into the plant via multiple routes and vehicle types. The advantages would be that a single monitoring vehicle could service several points provided they are not all used at the same time. This method would have the same advantages and disadvantages as a fixed scale monitoring system with respect to equipment sensitivity. However, such a system would be subject to the integrity and reproducibility of the operator similar to the hand-held monitoring method described earlier.

No matter which method is chosen, maximum detection potential would require the optimization of the following conditions:

1. A minimum of scrap cover,
2. The greatest amount of time practicable for the radioactive source to remain in the vicinity of the detectors,
3. The least distance between the radioactive source and the detector,
4. The lowest practicable natural background radiation rate.

In a well designed system, each of these factors will be optimized for the dollar amount allocated and the limitations imposed by production needs.

TABLE 10

Type System	Detection Range	False Alarm Rate	Installed Cost
Unshielded 2"x2" Sodium Iodide with alarming ratemeter	10 - 30 % (stationary)	Around 1 per week	$5000 to $10,000
Shielded 2"x2" Sodium Iodide with alarming ratemeter	20 - 40 % (stationary)	Around 1 per month	$5000 to $10,000
Shielded 10"x40" Plastic scintillator (2) with alarming ratemeter	30 - 50 % (stationary)	Around 1 per month	$25,000 to $50,000
Shielded 10"x40" Plastic Scintillators (2) with true 2 channel digital ratemeter	40 - 60 % (stationary)	Around 1 per 3 months	$75,000 to $100,000
Shielded 10"x40" Plastic scintillator (2) with microprocessor based monitor - single channel input	50 - 70 % (stationary) 40 - 70 % (1.5 MPH)	Around 1 per 6 months	$75,000 to $100,000
Shielded 10"x40" Plastic scintillator (6 - 8) with microprocessor based monitor - single channel input	60 - 80 % (stationary) 50 - 80 % (1.5 MPH)	Around 1 per 6 months	$75,000 to $150,000
Shielded 10"x40" Plastic scintillator (6 - 8) with microprocessor based monitor - multiple channel inputs	70 - 100 % (stationary) 60 - 90 % (1.5 MPH)	Around 1 per year	$75,000 to $200,000

Note: All detection percentages in Table 10 are calculated with 4 feet of 40 pound per cubic foot steel scrap cover and a source to detector distance of 10 feet.

There is an effective detection ceiling of approximately 80% for scale based systems. This is due to approximately 20% of all shielded sources having either a low gamma energy or a very small source size that would limit detection when the scrap cover is more than a foot of steel. Table 10 presents various detection systems and compares detectabilities, false alarm rates and estimated total cost (with installation).

GENERAL SYSTEM SPECIFICATION

The general specification of a state-of-the-art system is as follows.

The count from the detectors should be analyzed for both the actual count rate above background as well as compared to the background count over several previous count intervals. Statistically, the count rate should be tested for radiation significance and also signal quality.

Each detector should have its own input channel for data collection and analysis.

Should the count rate for any channel fall to zero, then a system failure for that channel should be annunciated.

If the monitoring is satisfactory and no radiation is sensed in the incoming scrap, a green light should be continuously illuminated. If radiation is detected and is determined to be significant by the microprocessor data analysis program, then both a red visible signal and an audible signal should be annunciated. Additionally, the CPU should have the ability to freeze the background count when the system goes into an alarm state and continue counting using the "frozen" background.

Automatic digital count rate display should occur for each channel when the system is in an alarm state, and be obtainable upon request during times of no alarm.

The control module should be protected from the environment in which it is placed, including excessive corrosion.

The monitor system status should be continuously displayed (alarm/no alarm). Annunciation should be provided for alarm and system failure conditions. A display should be provided to indicate which detector is annunciating. The radiation level in counts per count interval should also be displayed.

All photomultiplier tubes should be selected for their low noise output and are to be optically and securely coupled to the detector element. Since the control module may be located many hundreds of feet from the detector, adequate provisions should be taken to assure signal quality at the control module at distances up to 1000 feet.

The scintillator and photomultiplier tube assemblies should be shock mounted in an environmental cabinet that also provides both magnetic and electrical interference protection as well as protection from other elements. The detector elements should be able to withstand vibrations common to a steel mill. This does not include direct impact from steel mill equipment.

The detector enclosure should be temperature stabilized, adequately shielded to reduce counts due to natural radiation background, and sealed against the external environment. Optimally, the detector housings should be shielded to reduce natural radiation background to less than 300 cps per 1000 cubic inches of detector media. Signal variation should not exceed 40 cps over an internal detector housing temperature range of -50°F to +150°F.

The false alarm rate should be less than 1 in 6 months, and preferable less than 1 in 12 months.

The monitor should have the ability to drive remote audio and visual alarm signals.

The system should have the ability to perform automatic and manual system tests and change internal system parameters.

The system should possess an RS232 output and the capability to communicate in ASCII.

CONCLUSION

It is felt that the decision to install a radioactive material monitoring system for steel scrap should be viewed as an insurance policy. The likelihood of having a radioactive material source in scrap that could cause widespread contamination to the plant is low, but not rare. When the impact on public and employee relations and potential sales losses are added to the financial cost of cleanup and disposal, the cost of a state-of-the-art monitoring system pales in comparison.

The original concern of the industry, that few sources could be detected in their shielded housing covered with scrap has been addressed since 1985 by the development of good microprocessor based systems using large volume plastic scintillator detectors. It is possible to detect most shielded radioactive material gauge sources as well as the larger industrial radiography and medical teletherapy sources that may find their way into steel scrap. The location and application of the system and the degree of detectability will be influenced by the price of the system and the needs of production.

There are three price ranges of monitoring systems at this time. The lower cost system, typically around $5000 to $10,000, when installation costs are included, consists of small, shielded sodium iodide detectors connected to an alarming ratemeter. These systems will detect from 20 to 40 percent of the radioactive sources likely to find their way into steel scrap, and have a false alarm rate of less than one per week.

The second range consists of large volume plastic detectors connected to an alarming ratemeter. The increased cost is felt to be justified by the increase in detectability afforded by the plastic scintillator detector media and the slight decrease in the false alarm rate.

The third price range of system currently available is one incorporating large volume detectors and microprocessor driven electronics. The typical cost is between $50,000 and $200,000, including installation. Such a system should have a detection capability of 70 to 100 percent and a false alarm rate of less than 1 in 6 months. While the price tag is significantly higher, the increased detection capability should make the microprocessor based system the system of choice in most cases.

However, equipment installation is not the end of the problem. Rather, it may only be the beginning. Procedures will have to be developed by management to adequately respond to an alarm to determine the reason for the alarm and the severity of the potential hazard. Failure to do so will open the facility to potential liability from employees and the public that may become contaminated, and civil authorities. Such a program must include detailed procedures to protect responding personnel from excessive radiation exposure and contamination. Arrangements with radiation protection specialists (health physicists) will have to be made to prepare these procedures and to direct the handling of contaminated material and sources presenting high external radiation exposure potential, once they are identified by plant personnel. Also, responding personnel must be instructed in the relative risks from radiation exposure and the methods of protection so that they will feel secure in performing these newly assigned duties. Since the number of responses per year should be low, refresher training may be necessary to maintain the level of competency.

Finally, any effort to detect radioactive material in steel scrap cannot depend on equipment alone. The equipment must be augmented with a program for scrap handlers to train them to look for suspicious objects. This should already be a part of their training, since there are numerous objects such as compressed air bottles, hydraulic cylinders, etc., that present a hazard to both personnel safety and equipment. The addition of the recognition of radioactive material containers should become an added feature of such training. The US NRC has produced a poster showing some radioactive material containers. The poster is available by writing to the Superintendent of Documents, Washington, DC 20407, and requesting the US Nuclear Regulatory Commission's publication, NUREG/BR-0108.

There is no reason why any facility in the iron and steel industry has to suffer the financial burden that can accompany the melting of a radioactive source. The equipment and technology to prevent such an occurrence is available now and at a reasonable cost.

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REFERENCES

1. Lubenau, J. O. and Nussbaumer, D. A., "Radioactive Contamination of Manufactured Products," Health Physics 51, 409-425 (October 1986).

2. Yusko, J., PA Department of Environmental Resources, personal communication, (November 1986).

3. LaMastra, A., "Practical Considerations in Detecting Radioactive Material in Steel Scrap." Presented at the 31st Annual Health Physics Society meeting, Pittsburgh, PA. (July 1, 1986).

4. NUREG/CR-4958 PNL-6233, USNRC, "Impact of Proposed Financial Assurance Requirements on Nuclear Materials Licenses," (September 1987).

5. Hurlbut, C. R., Bicron Corporation, (June 1988).

6. Gull Engineering Project 69A Report to Bethlehem Steel Corporation, November 6, 1985.

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RADIOACTIVE CONTAMINATION OF MANUFACTURED PRODUCTS†

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Abstract—Cases of inadvertent radioactive contamination of manufactured articles have occurred sporadically in the past and bore little relationship to each other. Since 1983, however, seven instances have occurred of accidental radioactive contamination of steel either manufactured in or imported into the United States. Five of the contamination events went unrecognized by the mill operators and were discovered by others through radiation monitoring conducted for other unrelated purposes. Impacts have included costs to mill operators in the United States for decontaminating their steel plants which have ranged from $50,000 to more than $2,200,000. The states, the U.S. Nuclear Regulatory Commission and the private sector have taken steps to further assess the scope of the problem and to improve responses when such incidents occur.

INTRODUCTION

IN EARLY 1984, residents of the United States and Mexico learned that regulatory agencies in those countries were trying to locate and isolate steel products contaminated with ^{60}Co, a radioactive by-product of nuclear reactors (Ma84). A ^{60}Co source had become mixed with scrap steel distributed by a scrapyard in Cuidad Juarez, Mexico to foundries in Mexico, and they and their products became contaminated. Some of the products, concrete reinforcing bars called rebar and cast-iron table legs, were distributed in the United States. The initial discovery that inadvertent radioactive contamination had occurred was made purely by chance. At Los Alamos, NM, in January 1984, a truck carrying some of the rebar took a wrong turn into the Los Alamos Scientific Laboratory and set off a radiation monitor at the entrance. That alarm set off a sequence of events that eventually led to the identification of about 3.7 Gg (7300 tons) of contaminated metal in the United States and Mexico. In the United States, virtually all of it was recovered and returned to the manufacturers in Mexico. Public exposures to the contaminated steel in the United States were minimal, but some Mexican citizens who were exposed to the source pellets, received serious radiation doses which in a few cases produced readily apparent evidence of injury including skin burns, hematological changes and sterility (NRC85; IAEA85).

In 1961, the National Academy of Sciences–National Research Council published a report on radioactive contamination of materials used in scientific research (De61). That report, while focusing on the impact of radioactive contamination upon laboratory measurements, considered all sources of contamination—natural and artificial. This paper does not intend to address naturally occurring radioactivity, fallout or other environmental contamination from nuclear weapons testing or the impact of the deliberate releases of radioactive materials into the environment under controlled (and usually regulated) conditions. Rather, we will focus on the problems reported when controls of use and disposal of radioactive materials break down and the materials inadvertently contaminate manufactured products and the environment. Instances of inadvertent radioactive contamination of materials

† This article was prepared by employees of the U.S. Nuclear Regulatory Commission (NRC). It presents information that does not currently represent an agreed-upon staff position. The NRC has neither approved nor disapproved its technical content.

in the public domain have occurred sporadically in the past and bore little relationship to each other. The Mexican steel case, however, because of the great amount of radioactivity involved and the widespread distribution of the contaminated products, focused attention not only on how to properly respond to such events but also on how to preclude reoccurrence. Was this an isolated case or is inadvertent radioactive contamination of manufactured products becoming a potential generic problem?

HISTORY

Manufactured products can by design contain or incorporate radioactive materials, and the public has become accustomed to use of some radioactive materials in consumer products. For example, ionization smoke detectors incorporate small, typically kilobecquerel (microcurie) or less, amounts of ^{241}Am. Studies have demonstrated both their effectiveness in saving lives and property, as well as the negligible radiological impact upon the public and the environment (NRC79). Self-luminous clock and wrist-watch dials and hands are other examples of consumer products which make use of radioactive materials. In the United States, strict manufacturing standards prescribed by the U.S. Nuclear Regulatory Commission (NRC) must be met by the manufacturers using radioactive materials which are covered by the Atomic Energy Act for distribution of these products to the public (US85a).

Other products incorporating radioactive materials as radiation sources include industrial gauges to measure such things as thickness or levels in vessels, radiography sources, radiopharmaceuticals and sealed sources. The latter two items are either emplaced in the body or used as a remote source (such as in a teletherapy unit) to irradiate diseased tissue.

The foregoing is by no means an exhaustive list of products incorporating radioactive substances, but is intended to demonstrate the variety and the value of using radioactive materials. Such use of radioactive materials is not a recent development. For example, since 1910, luminous compounds containing Ra became available in the United States and in Europe. These compounds were applied to watches, clocks, aircraft instrument dials and later to other consumer products (Ho78).

In addition, the value of medical applications of Ra was recognized very quickly after the element's discovery, and it continues to be used extensively to this day (Br69; Nu77; Bo84).

REGULATION OF RADIOACTIVE MATERIALS

In the United States most, but not all, radioactive materials are regulated by the NRC under the Atomic Energy Act, as amended. The regulated materials include:

- Source materials—U and Th which are the building blocks of nuclear energy.
- Special nuclear materials—generally, these are the radioisotopes capable of undergoing nuclear fission.
- By-product materials—radioisotopes produced as a product of the nuclear fission process or the radioactive residues (tailings) left from the milling of source material ore.

Materials excluded from NRC regulation are natural radioisotopes (except source materials and mill tailings) such as Ra and radioisotopes produced in accelerators. Radium has been used extensively in industrial applications and in consumer products, and it is still used widely in medicine. Accelerator-produced isotopes usually have short half-lives but have widespread application in nuclear medicine. These materials are subject to state control, but state programs responsible for such materials vary widely in their effectiveness.

The NRC's radiation protection standards are specified by regulation (US85b). The deliberate introduction into products of NRC-regulated radioactive materials may take place only upon specific authorization and, for consumer products, only after the need for its introduction has been demonstrated and it can be shown that doses to the public will be acceptably small (US85a).

Radioactive materials may appear in manufactured products for several reasons. They may be added deliberately to use the radioactive properties of the material, such as in luminous compounds and smoke detectors. Radioactive materials also may be added to products as a contaminant either deliberately or unintentionally. For example, radioisotopes may be used in process controls such as tagging interfaces in pipelines or as inserts in steel-making furnaces to

measure refractory brick wear. In these cases, very low levels of radioactivity are carried over into products and, in normal use, the resultant doses to the public are insignificant. In addition, concentrations of naturally occurring radioisotopes, such as U and Th, may increase in the slags and other by-products after processing of rare earth ores. Lastly, radioactive contamination of products can occur after their use in conjunction with nuclear processes or other applications of radioactive material. For example, in 1974 the U.S. Department of Energy requested NRC approval to recycle metal scrap from U-enrichment plants slightly contaminated with U and ^{99}Tc, and in 1980, the NRC published for public comment a proposed rule to allow this (NRC80). In 1986, the NRC, after recieving more than 3700 public comments (mostly opposed), withdrew the proposed rule and denied the request without prejudice (NRC86).

If the radioactive materials are subject to NRC regulation, then their possession and use is controlled through licensing. Licenses are issued by the NRC or by 28 "Agreement States" which have qualified to enter into agreements with the NRC and which carry out their own regulatory programs (Fig. 1). In those states, certain regulatory powers are reserved for the NRC, such as licensing of nuclear reactors and licensing of the distribution of consumer products containing radioactive materials subject to the Atomic Energy Act. On the other hand, those 28 states (and a few others) license naturally occurring and accelerator-produced radioactive materials (NARM) which are not covered by the Atomic Energy Act.

Licenses are of two types, general and specific. General licenses are issued by regulation and do not require application (although a registration requirement applies to some). Conditions for using the licensed material are also spelled out in the regulations. General licenses cover many of the radioisotope gauges currently in use and a number of minor medical uses. The normal circumstances of these uses when considered along with the quantities and other characteristics of the sources pose minimal hazards to the users and to the public during use. Hence, detailed information about the qualifications of the users and the facilities where they will be used is not needed to assure that the material can be used safely. Currently, there are 20,000 to 30,000 general licensee users in the United States.

Specific licenses require that an application be filed, which includes detailed information on the user's training and experience, facilities and radiation protection program. Applications are subject to review and approval by qualified technical persons such as health physicists. When issued, the licenses specify what materials may be used and their form, limit their quantities, indicate their uses and govern the conditions of their use. There are presently approximately 21,000 specific licenses issued by the NRC and the Agreement States.

Similar regulatory programs exist in the 28 Agreement States for NARM. Of the other 22 states, only five (Delaware, Illinois, New Jersey, Pennsylvania and Virginia) carry out licensing programs for NARM (Bo84). No federal licensing program exists for NARM, and thus NARM is not subject to uniform regulatory control in the United States. This gap has been of concern to the states, and a 1984 report of the National Governors' Association recommended amending the Atomic Energy Act to include NARM (Br83). More recently, the Conference of Radiation Control Program Directors, Inc., also made this recommendation (CRCPD85). NRC studies of NARM indicate that there are 5630 users of NARM and that consumer products containing Ra continue to be manufactured and distributed (Bo84; Nu77).

INADVERTENT INTRODUCTIONS OF RADIOACTIVE MATERIALS INTO PRODUCTS

Gold contamination. One of the earliest reports of potentially hazardous inadvertent radioactive contamination of products concerned radioactive Au jewelry. A comprehensive report prepared for the governor and state legislature of New York in 1982 by the State Department of Health discussed both the history and the present problems concerning use of radioactive Au (NY82).

Radon seeds have been a source of radioactive contamination of Au. Radon, a short-lived, radioactive gaseous daughter of Ra, decays into a chain of radioactive daughters. Hollow Au tubes were filled with Rn, sealed (simply by clipping the ends) and implanted into diseased tissue, such

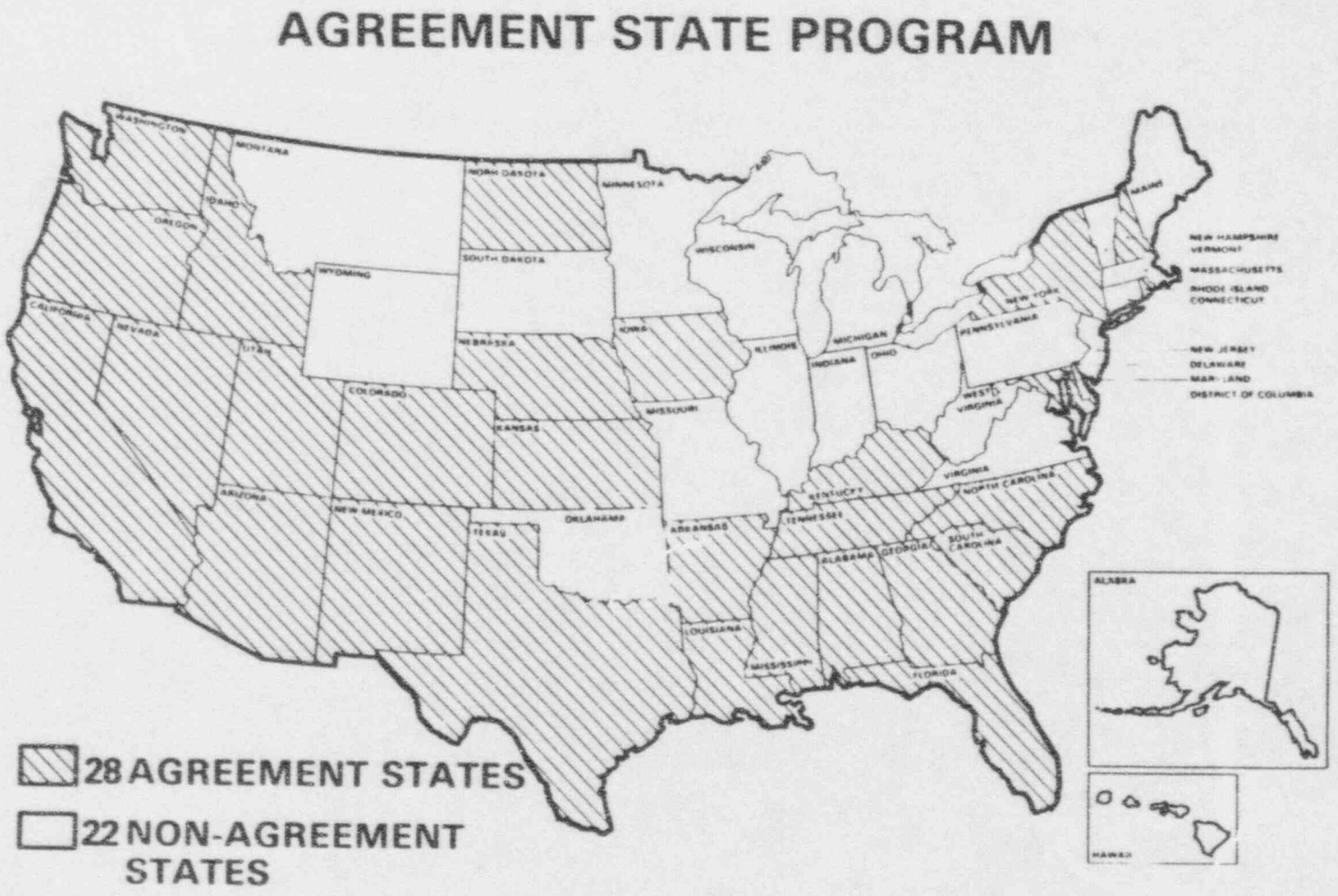


FIG. 1. Agreement State program.

as cancer tumors, as a therapeutic treatment. The immediate short-lived radioactive daughters of the Rn produced penetrating radiation that was absorbed in the cancerous tissue. Normally such implants were left in place since the longer-lived radioactive daughters of Rn did not produce radiation that could penetrate the walls of the seeds. Typical practice often resulted in more seeds ordered than used, and the excess seeds were stored or returned to the supplier. After time, the unused seeds were themselves not a significant external radiation hazard since the radiation of the long-lived daughters was absorbed by the Au walls.

If, however, the Au seeds were recycled into the marketplace and melted, the radioactive material would become dispersed and intimately mixed with the Au. Direct contact of skin with such contaminated Au, such as with rings, could produce radiation doses to the skin sufficient over long periods of exposure to cause dermatological changes including cancer.

According to the New York report, a paper on radioactive Au rings presented at the 1980 meeting of the American Academy of Dermatology was printed in the 5 January 1981 issue of *Medical World News*, and a Buffalo, NY, television station then offered to survey Au jewelry (NY82). Their survey discovered three radioactive pieces within the first two days. As a result of this finding, the New York State Health Department began a comprehensive campaign in 1981 to find radioactive, contaminated jewelry. More than 160,000 pieces were surveyed, and, of these, about 170 pieces were found to be radioactive—mostly from western New York and nearby Pennsylvania. Nine individuals were identified who developed squamous cell cancer. These individuals wore their jewelry an average of about 17 y while others, who wore the jewelry for lesser periods of time, exhibited other symptoms related to exposure to the radioactive jewelry (Ba84). The report estimated that the number of contaminated pieces still in circulation (in the Buffalo, NY area) to be perhaps in the thousands.

Radon seeds are no longer manufactured in the United States and, if this remains the case, the potential for contamination problems from this source should decrease in the future. (However, in 1982, about 2.5 kg of Au, in the form of spent Rn seeds, stored at the plant of a Ra processing company in New York City, was reported to be missing and has not yet been accounted for.)

Gold, however, is extensively used today in conjunction with another radioisotope, ^{241}Am, which is used in ionization smoke detectors. Their distribution is regulated by the NRC. The kilobecquerel (microcurie) amounts of ^{241}Am are plated on Au foil and serve as the ionization source. The use of such smoke detectors in residences and in other buildings, and subsequent disposal of them as individual units through normal trash disposal channels, has been shown to pose no hazard to the public (NRC79). In 1983, however, the NRC discovered three Au "nuggets" obtained by a Virginia Au refiner from a Niagara Falls, NY, jewelry store which contained between 19 to 33 kBq (0.5 to 0.9 μCi) of ^{241}Am, the origin of which was never ascertained. Measured dose rates ranged from 1 to 5 μGy h^{-1} (0.1 to 0.5 mrad hr^{-1}). Because commercial low-level radioactive waste disposal sites do not accept ^{241}Am for disposal (except in very low concentrations), alternative arrangements were made with a manufacturer of ^{241}Am sources for smoke detectors which accepted the "nuggets" for storage.

Contamination of gemstones. In 1981, the NRC learned that radiation had been detected in blue topaz gemstones imported from Brazil. Radiation levels were reported to range from 51 nC kg^{-1} h^{-1} (0.2 mR hr^{-1}) per stone to 3.1 μC kg^{-1} h^{-1} (12 mR hr^{-1}) from a bag of 100 stones. Although the colors of some gemstones can be enhanced via irradiation by electrons, γ rays or neutrons, only neutron radiation will induce radioactivity. The topaz gemstones in question had been irradiated in a Brazilian nuclear reactor and the neutron irradiation induced a residual radioactivity, principally from ^{46}Sc and ^{182}Ta. Since the radioactivity resulted from exposure to a nuclear process, the gems were considered to be by-product material and thus subject to NRC regulation. Following exchanges between the NRC and the Government of Brazil, Brazil took action to discontinue the further irradiation and distribution to the United States of such gemstones.

Steel product contamination. Before 1983, there had been no reports of inadvertently contaminated steel products. Since 1983, however, seven incidents have occurred in the United

Table 1. Summary of radioactive contamination of steel products, 1983 to 1985

Year	Location of Steel Mill	Radioisotope and Quantity	Probable Source of Contamination
1983	New York	^{60}Co, 930 GBq (25 Ci)	Teletherapy or Industrial Radiography
1984	Mexico	^{60}Co, 15 TBq (400 Ci)	Teletherapy
1984	Taiwan	^{60}Co, 370 to 740 MBq (10 to 20 mCi)	Gauge
1984	South Carolina	^{137}Cs, 37 GBq (1 Ci)	Gauge
1985	Brazil	^{60}Co, ? MBq (? mCi)	Furnace Wall
1985	California	^{137}Cs, 56 GBq (1.5 Ci)	Gauge
1985	Alabama	^{137}Cs, 370 to 1900 MBq (10 to 50 mCi)	Gauge

States. These incidents are summarized in Tables 1–4 and details provided in Table 5.

The first incident, at a steel plant in Auburn, NY, was discovered in February 1983 when an in-plant isotope level gauge responded abnormally after a charge was ladled into the casting machine (Br86). Prompt actions by plant personnel identified the steel product as contaminated, and the contaminated steel product was isolated at the plant. The contamination source was the addition of 930 GBq (25 Ci) or more of ^{60}Co. The steel company obtained its scrap from about 100 sources in the northeastern United States and Canada. Given the isotope and its quantity, the ^{60}Co most likely could have been a radiography source or a decayed source from an old teletherapy unit—both of which are specifically licensed by the NRC or the Agreement States in the United States. However, no notifications of losses of such a source had been received in the United States. Despite notices sent to such licensees, coordination with Canadian authorities and subsequent investigations, efforts to further identify the origin of the radioactivity were unsuccessful. The decontamination cost for the plant was estimated to be in excess of $2.2 million.

Table 2. Summary of sources of contamination of steel products

Foreign - 3

1 - Teletherapy
1 - Gauge
1 - Furnace Wall

Domestic - 4

1 - Teletherapy or Industrial Radiography
3 - Gauges

The second incident began in the fall of 1983 when a teletherapy unit was removed from storage in Ciudad Juarez, Mexico, and was disassembled (NRC85). In the process, the 15-TBq (400-Ci) sealed ^{60}Co source was penetrated and some of 6000 1 × 1 mm diameter Co pellets were dispersed. The pellets contaminated a scrapyard and a scrapyard employee's truck. More than 60 pellets were later found in the streets of Juarez. Each pellet contained 2.6 GBq (70 mCi) of ^{60}Co and produced radiation levels of 1.8 μC kg^{-1} s^{-1} (25 R hr^{-1}) at 5 cm. Some pellets became mixed with scrap metal used by Mexican foundries in the production of table bases and rebar which were exported to the United States. In addition, significant radiation exposures were incurred by some Mexican residents.

The teletherapy unit was originally manufac-

Table 3. Method of discovery of steel contamination

Location of Steel Plant	Discovery and Follow-up
New York	Abnormal response of plant isotope level gauge. Follow up surveys by plant personnel pinpointed ^{60}Co contamination in steel product.
Mexico	Truck carrying ^{60}Co contaminated rebar made wrong turn into Los Alamos National Lab and tripped radiation monitor. Later, an Illinois State Highway patrolman, carrying radiation detection equipment in his patrol car detected radiation from a truck carrying ^{60}Co contaminated iron table bases.
Taiwan	Contaminated steel fittings were purchased by an isotope user from a hardware store for use in hot lab. When found to be wrong size they were to be returned but were subject to standard radiation survey for all items leaving lab, thus finding the ^{60}Co contamination.
South Carolina	In-plant isotope level gauge was observed to be struck by stream of molten steel. Subsequent surveys confirmed that source housing and ^{137}Cs source were partially melted.
Brazil	Contaminated 25.4 cm (10 in) diameter pipe was implaced in water well bore and a gamma log taken. The gamma log disclosed continuous, elevated radiation from the ^{60}Co contamination.
California	State Highway Patrol radiation monitor installed at weigh station detected contamination from ^{137}Cs in truckload of flue dust from the plant.
Alabama	Aerial radiation survey made at request of Alabama as part of effort to locate four lost ^{137}Cs gauges disclosed contamination at the steel plant.

Table 4. Radioactive steel products: summary of consequences of the contamination

Location of Steel Plant	Consequences
New York	In excess of $2,200,000 to decontaminate steel plant.
Mexico	Serious overexposures in Mexico. Decontamination of steel plants in Mexico. The states incurred $233,000 in costs to locate product.
Taiwan	Relatively minimal.
South Carolina	$400,000 to $500,000 to decontaminate steel plant.
Brazil	Relatively minimal.
California	$1,000,000 to decontaminate steel plant.
Alabama	$50,000 to $500,000 to decontaminate steel plant.

tured in the United States and sold to a hospital in Lubbock, TX. In 1971, the hospital transferred the unit to an equipment broker who sold it to a clinic in Ciudad Juarez. The clinic never used the teletherapy unit and stored it in a warehouse.

Possession and use of the unit in the United States were subject to specific licenses issued by the NRC and the State of Texas. Export to Mexico was also in compliance with U.S. regulations.

Decontamination of the steel foundry and scrapyard in Mexico has been accomplished but no cost figures are available. The identification and recovery of the contaminated table bases and rebar in the United States was not possible without the extensive assistance of the state radiation control programs as requested by the NRC (NRC85). Overall, about 7.9 professional staff-years were expended by the states, and $233,000 of out-of-pocket costs were incurred in the recovery effort. For state radiation control programs, this represented significant diversions of critical, limited resources from other, scheduled radiation-control program activities. Two states requested reimbursement from the NRC, but federal statutes do not permit monetary payments for these cooperative state efforts.

In addition to this case, two other incidents in the United States have involved contamination of imported steel, one in 1984 involving steel from Taiwan and the other in 1985 involving steel from Brazil. Fortunately the levels of contamination in these cases were extremely low, and extraordinary efforts to recover the products were not deemed to be necessary to protect public health and safety. The discoveries of the contamination, as in the Mexican steel case, were serendipitous. The Taiwanese steel contamination was discovered when a California laboratory licensed to use radioactive materials purchased a steel plumbing fitting from a local hardware store for use in a hot lab. The fitting was not the proper size and was to be returned. All equipment leaving the hot lab is subject to a survey for contamination and this survey disclosed the problem. The Brazilian contamination was discovered after the steel pipe was emplaced in a water well bore and a γ log taken by the well driller showed unusual radiation levels inside the bore.

As in the Mexican case (and in three U.S. cases), the Taiwanese contamination resulted from a radioactive source inadvertently mixed with scrap feed.

The Brazilian contamination was explained to the NRC staff as the result of the melting of ^{60}Co sources placed in the steel furnace walls to measure the wear of the refractory brick. Such applications are permitted in the United States under specific licenses, but the resulting introduction of ^{60}Co into the steel product normally results in exceedingly low concentrations that would not be observable except by sensitive laboratory instruments. Unusual circumstances during the melting of the ^{60}Co sources in the Brazilian steel furnace may have arisen, in view of the higher-than-expected concentrations of ^{60}Co in the metal.

Many steel plants use radioactive sources as product process control devices, and an October 1984 incident in South Carolina involved such an in-plant source. In this case, an in-plant level gauge was struck and melted by a stream of molten steel. As in the Auburn, NY, incident, the potential radiological problem was quickly recognized by plant personnel and radiological problems were confined to the plant. The decontamination cost was between $400,000 and $500,000.

In 1985, two U.S. steel plants—one in California and the other in Alabama—became contaminated with ^{137}Cs that had become mixed with scrap. In the first case, the discovery was the result of a special state radiation monitoring system and, in the other, the discovery was made as a result of special surveys that were initiated by the state after it was learned that four isotope gauges were improperly disposed of by a licensee and were missing.

The California plant contamination was discovered when a truck carrying flue dust from the plant for disposal at a toxic waste site stopped at a state weigh station. Radiation monitors installed by the California State Highway Patrol at the weigh station detected radiation from the contaminated material. Subsequent investigations and analyses by California, an Agreement State, disclosed that about 56 GBq (1.5 Ci) of ^{137}Cs, probably from a gauge, had become mixed with scrap steel. The physical and chemical characteristics of the Cs led the state to conclude that most of the ^{137}Cs had volatilized and was captured either with the flue dust or in the slag. Surveys at the plant site and surrounding area seemed to confirm this. Field radiation surveys of suspect product did not disclose detectable activity. Plant contamination had occurred and the contaminated slag and flue dust must be disposed of at a licensed low-level radioactive waste disposal site. The total decontamination cost was estimated to be $1 million. This does not include the cost incurred by the state for responding to this incident and overseeing the cleanup.

In April 1985, Alabama, an Agreement State, learned that one of its licensees could not account for four level and density gauges containing 0.37 to 1.9 GBq (10 to 50 mCi) of ^{137}Cs each. The licensee had retired some product process equipment and inadvertently included the gauges when the equipment was disposed of to scrap metal dealers. Alabama mounted an effort to notify and survey metal scrap dealers in Alabama and nearby states. One gauge was subsequently found in a scrapyard 64 km (40 miles) away. In July 1985, a routine aerial radiation survey was scheduled by the U.S. Department of Energy (DOE) for NRC of the Brown's Ferry nuclear power reactor in Alabama. At the State of Alabama's request, the DOE contractor also agreed to fly over selected scrapyards, steel mills and other sites in Alabama as part of the effort to locate the other missing gauges. The flyover disclosed ^{137}Cs contamination at a pipe plant in Bessemer, AL. Ground surveys showed the contamination to be largely confined to a dump area in the plant. As in the California incident, it appears the chemical and physical behavior of the Cs resulted in its retention primarily at the plant site. Cost of decontamination is estimated to be between $50,000 and $500,000 depending on disposition of the material. This does not include the costs to the state for responding to this incident and overseeing the cleanup.

'Near misses'. Near misses that have occurred have been reported to the NRC. For example, in November 1984, a Pennsylvania manufacturing company contacted the NRC when it discovered that a piece of scrap metal was radioactive. The company routinely conducted radiation surveys of incoming scrap. NRC Regional Office inspectors were dispatched and discovered the radiation source to be a ^{226}Ra static eliminator with a β dose rate of 50 mGy h^{-1} (5 rad hr^{-1}) and a γ dose rate of 2 mGy h^{-1} (200 mrad hr^{-1}) at the

Table 5. Radioactive contamination of steel products

Date of Discovery	Location of Steel Plant	Contaminant	Reported Contamination Levels	Probable Source	Consequences
February, 1983	New York	^{60}Co 930 GBq (25 Ci)	16 kBq g^{-1} (420 nCi g^{-1}) in steel.	Not definitely established, possibly radiography or old teletherapy source from the United States or Canada mixed with scrap.	Contamination of 51 Mg (100 tons) of steel products and of steel plant. No off-site releases. No significant doses to workers. All contaminated steel products contained in plant. Cost of decontaminating the plant was estimated to be in excess of $2,200,000.
January, 1984	Mexico	^{60}Co 15 TBq (400 Ci)	Tables legs emitted 5 nC kg^{-1} h^{-1} to 100 μC kg^{-1} h^{-1} (0.02 to 375 mR/h maximum at surface). Rebar typically was 2.6 to 10 μC kg^{-1} h^{-1} (10 to 40 mR hr^{-1}) at surface.	Teletherapy source mixed with scrap.	914 Mg (1800 tons) of table bases and 2.8 Gg (5500 tons) of rebar contaminated and distributed. Contamination of at least one steel plant and one scrapyard in Mexico. Ten persons in Mexico displayed clinical symptoms related to exposure to the teletherapy source. In the United States virtually all of the contaminated products were recovered and returned to Mexico. Cost of recovery efforts incurred by states was $233,000 in out-of-pocket expenses.

Table 5. (Contd.)

Date of Discovery	Location of Steel Plant	Contaminant	Reported Contamination Levels	Probable Source	Consequences
August, 1984	Taiwan	^{60}Co 370 to 740 MGq (10 to 20 mCi)	7.8 Bq g^{-1} (210 pCi g^{-1}) in fittings. Maximum surface radiation level was 21 nC kg^{-1} h^{-1} (0.08 mR hr^{-1}).	Gauge	The ^{60}Co was mixed with 39 Mg (76.8 tons) of scrap. The product, steel plumbing fixtures, was distributed in the United States. In view of the low levels of radioactivity, no recall was deemed necessary.
October, 1984	South Carolina	^{137}Cs 37 GBq (1 Ci)	Removable contamination up to 2.53 Bq cm^{-2} (15,180 dpm 100 cm^{-2}). Cooling spray water contained up to 629 Bq dm^{-3} (17 nCi l^{-1}).	In-plant level gauge used to control level of molten steel in molds was struck by a stream of molten steel.	Source holder and source partially melted. Three workers were slightly contaminated. Plant decontaminated at estimated cost of $400,000 to $500,000.
April, 1985	Brazil	^{60}Co Quantity uncertain	1 Bq g^{-1} (26 pCi g^{-1}) in steel pipe. 20.6 nC kg^{-1} h^{-1} (80 μR hr^{-1}) maximum contact radiation level.	^{60}Co sources were imbedded in furnace walls to measure wear and melted out.	Pipe for well casing was contaminated. Twenty-two contaminated pieces were found in three states. Some contaminated piping had been distributed and installed. In view of the low levels of radioactivity, no recall was deemed necessary.

Table 5. (Contd.)

Date of Discovery	Location of Steel Plant	Contaminant	Reported Contamination Levels	Probable Source	Consequences
May, 1985	California	^{137}Cs 56 GBq (1.5 Ci)	0.4 to 1.5 Bq g^{-1} (10 to 40 pCi g^{-1}) in captured air filter residues.	Isotope gauge mixed with scrap.	Plant contaminated. About 51 Mg (100 tons) of flue dust also contaminated. No off-site releases or significant doses to workers. Because of physical and chemical characteristics, most of ^{137}Cs was retained in slag or in flue dust. Cost of decontamination estimated to be $1,000,000.
July, 1985	Alabama	^{137}Cs 370 to 1900 MBq (10-50 mCi)	Soil contamination, 18 Bq g^{-1} (492 pCi g^{-1}) maximum. Up to 28 nC kg^{-1} g^{-1} (110 μR hr^{-1}) gamma radiation levels from soil.	One or more isotope gauges mixed with scrap. Gauge could have been one of four that were removed by an Alabama licensee following closure of parts of a product line and released to scrap dealers. One gauge was subsequently recovered at an Alabama scrapyard.	Portions of steel plant environs, primarily soil, contaminated, no evidence of off-site releases or significant exposures of workers. Because of physical and chemical characteristics, most of ^{137}Cs was retained on-site. Cost of decontamination estimated to be $50,000 to $500,000 depending on how material is disposed of.

surface. Although the scrap supplier was identified, the origin of the static eliminator was never established.

Another example of a near miss occurred in March 1985 when a Montana licensee could not account for a density gauge containing 1.9 GBq (50 mCi) of ^{137}Cs. Mistakenly included in scrap generated by maintenance work during a three-month shutdown, the gauge was transferred with scrap metal to dealers in Utah and Montana. Following extensive searches, which included assistance from the states of Montana and Utah, the gauge was located in Montana.

A near miss having international implications occurred in December 1985, when a small Ra source was included in a scrap steel-metal shipment from a Michigan plant. The 14.8-MBq (400-μCi) source was part of a gauge. The scrap was delivered to a Windsor, Ontario, Canada, scrapyard. A scrapyard worker noticed and reported the radiation warning label on the gauge. Scrapyard operations were shut down until the hazards were fully assessed. The gauge was packaged and returned to the Michigan plant for proper disposal the next day. No contamination occurred. Michigan and Canadian regulatory agencies responded to this incident.

Factors leading to loss of licensed materials. Under federal and Agreement State regulations, licensees are responsible for establishing programs to ensure that radioactive materials under their control are accounted for. Such programs would typically include identification of knowledgeable persons responsible for the sources, maintenance and safety testing of the equipment using the sources, leak-testing the sources, periodic inventory of the sources and maintenance of radiation warnings and other safety labels. Nonetheless, sources that should be accounted for have sometimes escaped licensees' controls. Contributing factors include theft, loss of knowledgeable personnel, or deterioration and illegibility of warning labels intended to alert people as to the radioactive contents. Plant shutdowns and scrapping of process equipment (as in the Alabama and Montana cases) are a potential source of this kind of problem. In 1982, Oregon, an Agreement State, seeing the impact of the economy on the wood products industry imposed special requirements on gauge licensees to assure identification and proper securing of isotope gauges in the event of plant closures.† Oregon officials have also pointed out the special problems associated with closures of plants which possessed ^{241}Am sources.‡ As noted earlier, ^{241}Am is not normally accepted for disposal at the licensed commercial low-level radioactive waste disposal sites. Thus, for a plant that is closed and is being dismantled, disposal provisions become critical. In Oregon, arrangements had to be made with a licensee to take possession of ^{241}Am sources from a plant that was being dismantled.

Preliminary results of an ongoing NRC survey of gauges distributed to general licensees suggest that accountability may be a problem for this category of users. Some Agreement States have conducted inspections of their general licensees routinely and their results have caused them to suggest upgrading the regulatory inspection programs for general licensees. The NRC staff is examining measures that can be taken to improve assurance that general licensees are exercising adequate control over their sources. In cases where NRC licensees have lost sources, escalated enforcement action, including imposition of civil penalties, has been taken by the NRC.

EFFECTS OF INADVERTENT RADIOACTIVE CONTAMINATION

The impacts of inadvertent radioactive contamination of manufactured products are multifaceted. Radiological effects have included significant doses and injury to persons who unknowingly handled or were near the source of

† Letter (5 April 1982) D. G. Wagstaff, Radiation Control Section, Oregon Department of Human Resources to L. A. Bolling, Office of State Programs, NRC. (Available in NRC Public Document Room at 1717 H Street NW, Washington, DC, for inspection and copying for a fee.)

‡ Letter (15 June 1982) M. L. Blazek, Radiation Control Section, Oregon Department of Human Resources to G. W. Kerr, Office of State Programs, NRC. (Available in NRC Public Document Room at 1717 H Street, NW, Washington, DC, for inspection and copying for a fee.)

contamination. Workers in plants manufacturing the product that becomes contaminated may also be exposed. Environmental dispersion of radioactive material into plant environs is possible, particularly after a source is breached. In the Mexican incident, environmental contamination occurred, in the form of ^{60}Co pellets spread on roads and streets.

These cases represented a challenge to regulatory authorities to properly assess the probable risk of public exposure to the radiation and to determine the degree of response, including—when appropriate—recovery of contaminated products. NRC staff developed case-specific guidance for many of the cases cited after consideration of existing standards for radiation protection, including the NRC's "Standards for protection against radiation" (10 *CFR* 20), and the recommendations of the International Commission for Radiation Protection (US85b; ICRP77).

Non-radiological impacts include the costs to manufacturers and distributors whose products have become contaminated. For the four steel mills in the United States, estimated decontamination costs have ranged from $50,000 to more than $2,200,000 dollars each (Tables 4 and 5). In comparison, the devices containing the contamination sources when purchased new would cost between $8,000 and more than $100,000 if they are gauges, or about $180,000 if they are teletherapy units.

The impact upon government agencies responsible for regulating these materials has been significant because staff effort was diverted to respond to these incidents. Attention to scheduled radiation safety oversight activities suffered as a result.

Eventually, consumers may also pay for such incidents through increased costs charged by manufacturers to recover clean-up costs, increased costs of supporting government efforts to respond to incidents, and, if a contaminated plant cannot afford cleanup, paying for the cleanup costs and losing part of a region's employment and tax base if the plant is closed and cannot reopen.

Another possible, if immeasurable, cost may be the erosion of public confidence in manufactured goods and in the ability of the government to effectively regulate the uses of radioactive material.

ISSUES AND ACTIONS

It is not clear from what is presently known whether the reports to date of inadvertently contaminated manufactured products represent a fairly complete picture of the problem or a small, unknown fraction of it. What is readily apparent is a common pathway: the recycling of metal, especially steel. Of the seven contaminated steel mill cases, however, five of the contamination events at the mill went unrecognized by mill operators and were discovered by others (Table 3). Their subsequent discovery occurred through routine, independent monitoring programs, conducted for unrelated purposes.

The following monitoring and educational programs are in place:

(1) The California and Illinois Highway Patrol radiation monitoring programs are part of a larger, joint endeavor established originally between the states, the NRC and the U.S. Department of Transportation (DOT) (NRC75). This program is now supported by the DOT primarily to enhance compliance inspection programs for shippers of radioactive material.

(2) In 1985, in a separate action, Florida installed radiation monitors at 22 state highway weigh stations.

(3) In 1985, the New York Department of Labor amended its regulations for ionizing radiation protection to require Au refiners in the state to register with the department (NY85).

(4) In 1985, the Institute of Scrap Iron and Steel, Inc., following consultation with the NRC, issued a booklet providing guidance to its members for identifying radioactive scrap (ISIS85), which will help stimulate self-monitoring of scrap by scrap dealers. As noted earlier, a contamination event involving a Ra source was avoided by monitoring of scrap by a Pennsylvania scrap metal dealer.

(5) In 1982, the Los Angeles County Sanitation District installed a radiation detection system at its largest disposal site (SNM85).

(6) In Canada, the Canadian Atomic Energy Control Board published and distributed to scrap

Atomic Energy Control Board | Commission de contrôle de l'énergie atomique

NOTICE

In 1984 two serious incidents occurred in the steel industry abroad, involving the accidental processing of radioactive material.

In both cases, metal devices containing highly radioactive sources found their way into scrap handling facilities, were later processed along with normal scrap at steel foundries, and converted to various steel products. This resulted in widespread contamination of the production facility and equipment involved, and the exposure of workers to possibly dangerous levels of radiation. The contaminated steel products that were produced could also have presented a hazard to members of the public who came in contact with them.

The Atomic Energy Control Board, the federal agency which regulates the users of radioactive materials in Canada, believes that the possibility of such incidents in this country is extremely small. Because of the strict system of control and accountability imposed on Canadian users of devices containing a radioactive substance, the chances of inadvertent disposal of such a device in scrap are very remote. Nevertheless, the possibility still exists, particularly when scrap imported from other countries is processed.

At present the steel industry does not have a practical and efficient system for monitoring incoming scrap material, to ensure it does not contain radioactive sources. Until some practical methods of control are available, industry workers should be alert to the possible presence of devices which may contain radioactive sources. They should familiarize themselves with the type of markings that appear on the various devices, such as the three-bladed radiation warning symbol, pictured at right, and the terms used to describe the radioactive materials most commonly used in these devices. Typical devices which could turn up in scrap material and which could contain a radioactive substance are also illustrated.

Should any piece of scrap be suspected of containing a radioactive substance, it must not be processed. The piece should be set aside, and handling and time spent in close proximity to it should be kept to a minimum. The Atomic Energy Control Board should be contacted immediately for more information.

Enquiries should be addressed to:

Mr. R.A. Gauthier
Radioisotopes and Transportation Division
Atomic Energy Control Board
P.O. Box 1046
Ottawa, Ontario
K1P 5S9

Telephone: (613) 995-0561

Canada

HAZARDOUS SCRAP – BEWARE!

These devices may contain radioactive material. If you see these markings on a piece of scrap, or if you otherwise suspect the presence of radioactive material, it must not be processed. The piece should be set aside, and handling and time spent in close proximity should be kept to a minimum. Immediately contact the Atomic Energy Control Board for more information.

Radiation Warning Symbol

The symbol appears on containers or devices which hold radioactive substances. Its color is reddish purple (magenta) or black, on a yellow background. Its size may vary.

Nature and Quantity of Radioactive Material

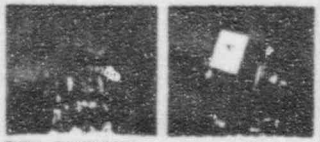
These terms are normally used in association with the Radiation Warning Symbol to indicate the nature of the radioactive material and its quantity. Certain other markings describing the type of container may also appear.

Typical devices that may contain radioactive material

Radiography Cameras

Portable

Movable



Gauges

Transportation Containers

Cancer Therapy Machines

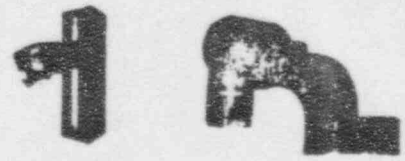


FIG. 2. Canadian Atomic Energy Control Board educational poster, "Hazardous scrap—beware!" (English version).

metal yards in Canada a bilingual educational poster that was developed following the Mexican steel incident.† The poster provides illustrations of typical radioactive source containers and warning labels (Fig. 2).

Continuation and expansion of these educational and independent radiation monitoring programs can enhance our ability to prevent future cases of inadvertent contamination of manufactured products.

Responses to such incidents will normally involve both NRC and state resources as well as coordination with other regulatory agencies (e.g. U.S. Customs). Recognizing these special needs the NRC, following the Mexican contaminated steel incident, developed a response plan specifically for cases involving the finding of nuclear materials in unauthorized places.‡ The plan helps to ensure that appropriate and timely steps are taken to protect health, minimize danger to property, and alleviate public concern about the event.

In 1984, NRC contracted a study to investigate the feasibility of detecting the import of unauthorized radioactive materials into the United States (Be85). The study "... defined potential threats in terms of isotopes and radioactive materials in past and current industrial and commercial usage, and explored the various pathways by which such radioactive materials might accidentally enter new product manufacturing processes. The types and availability of radiation monitoring equipment necessary to detect such contamination in imported products in transit during Customs inspections were examined, and a technical system description for such a monitoring system were developed along with capital, operating, and maintenance costs. . . . An economic analysis was performed to provide a common basis for their comparison by decision makers." The study was intended to provide decision makers with an understanding of the dimensions of the problem, thus providing an improved basis for decision-making on future actions to control this problem.

Data on incidents involving radioactive contamination of manufactured products are now being handled as a separate incident category by the NRC in its collection and analyses of licensee operational data. The continued monitoring for such events and analyses of event data should establish a better understanding of the potential scope of the problem and help forecast future trends.

Collection, analysis and dissemination of such data and analyses should also help determine whether a reexamination is needed of the present regulatory framework governing the use and distribution of radioactive materials.

Note in proof—The NRC will publish a hazardous scrap warning poster similar to the Canadian poster. Our thanks to the Canadian Atomic Energy Control Board for their excellent idea and model to follow. The NRC publication number is NUREG/BR-0108.

On 5 May 1986 and 14 July 1986, the NRC issued IE Information Notices Nos. 86-31 and 86-31, Supplement 1, "Unauthorized transfer and loss of control of industrial nuclear gauges." These were sent to the Agreement States, to the NRC's 2,200 specifically licensed gauge users, and to all 11,000 NRC and Agreement State general licensed gauge users in the United States. The notice reminds gauge licensees of regulatory requirements to properly account for, transfer and dispose of licensed sources.

The NRC staff has recently received inquiries concerning distribution to unlicensed persons of gemstones and silicon chips following irradiation in research reactors. In response, NRC Generic Letter 86-11 dated 25 June 1986, "Distribution of products irradiated in research reactors," was sent to all licensed U.S. research reactors. The letter reminds them of NRC licensing requirements for distribution of radioactive products to persons not licensed to received them.

Copies of the NRC poster may be purchased from the Superintendent of Documents, Washington, DC 20402. Copies of the IE Information Notices and the generic letter are available for inspection and copying for a fee at the NRC Public Document Room, Washington, DC 20555.

† Memorandum (24 January 1986) from K. D. Burke, Office of International Programs, NRC to G. W. Kerr, Director, Office of State Programs, subject: *Radium source in scrap metal shipment.* (Available in NRC Public Document Room at 1717 H Street, NW, Washington, DC, for inspection and copying for a fee.)

‡ Memorandum (28 June 1985) from J. G. Davis, Director, Office of Nuclear Material Safety and Safeguards, NRC, to NRC Regional Administrators and Program Office Directors, subject: *NRC response plan for incidents involving nuclear material in authorized places.* (Available in NRC Public Document Room at 1717 H Street, NW, Washington, DC, for inspection and copying for a fee.)

REFERENCES

Ba84 Baptiste M. S., Rothenberg R., Nasca P. C., Janerich D. T., Stutzman C. D., Rimawi K., O'Brien

W. and Matuszek J., 1984, "Health effects associated with exposure to radioactively contaminated gold rings," *Journal of the American Academy of Dermatology* **10**, 1019–1023.

Be85 Bee R., Gordan J., Kwan Q., Vierzba E. and Wallo A., 1985, *The Feasibility of Detecting the Import of Unauthorized Radioactive Materials into the United States*, USNRC Report NUREG/CR-4357, September 1985 (Springfield, VA: National Technical Information Services).

Bo84 Bolling L. A., Lubenau J. O. and Nussbaumer D. A., 1984, *Regulation of Naturally Occurring and Accelerator-Produced Radioactive Materials. An Update*. USNRC Report NUREG-0976, October 1984 (Springfield, VA: NTIS).

Br69 Brecher R. and Brecher E., 1969, *The Rays* (Baltimore, MD: The Williams and Wilkins Company).

Br83 Brown H., 1983, *The Agreement State Program: A State Perspective* (Washington, DC: National Governors' Association).

Br86 Bradley F. J., Cabasino L., Kelly R., Awai A. and Kasyk G., 1986, *The Auburn Steel Company Radioactive Contamination Incident*, USNRC Report NUREG-1188, April 1986 (Springfield, VA: NTIS).

CRCPD85 Conference of Radiation Control Program Directors, Inc., 1985, "Position paper on NRC regulatory control of NARM," *Newsletter, Conference of Radiation Control Program Directors, Inc.* **19**, 2 (1 July 1985).

De61 DeVoe J. R., 1961, *Radioactive Contamination of Materials Used in Scientific Research*, Publication 895 (Washington, DC: National Academy of Sciences—National Research Council).

Ho78 Holm W., 1978, "Radium in consumer products: an historical perspective," in: *Radioactivity in Consumer Products*, USNRC Report NUREG/CP-0001, August 1978 (Springfield, VA: NTIS).

IAEA85 International Atomic Energy Agency, 1985, *Nuclear Safety Review*, 1984 (Vienna: IAEA).

ICRP77 International Commission on Radiological Protection, 1977, "Radiation Protection, Recommendation of the International Commission on Radiological Protection," *ICRP Publication 26*, *Annals of the ICRP* (Oxford: Pergamon Press).

ISIS85 Institute of Scrap Iron and Steel, Inc., 1985, *Caution! It Could be Radioactive Scrap* (Washington, DC: ISIS).

Ma84 Marshall E., 1984, "Juarez: an unprecedented radiation accident," *Science* **223**, 1152 (16 March 1984).

NRC75 U.S. Nuclear Regulatory Commission, 1975, *Annual Report* 1975 (Washington, DC: U.S. Government Printing Office).

NRC79 U.S. Nuclear Regulatory Commission, 1979, *Environmental Assessment of Ionization Chamber Smoke Detectors Containing Am-241*, USNRC Report NUREG/CR-1156, November 1979 (Springfield, VA: NTIS).

NRC80 U.S. Nuclear Regulatory Commission, 1980, "Exemption of technetium-99 and low enriched uranium as residual contamination in smelted alloys" (proposed rule), *Federal Register*, Vol. 45, pp. 70874ff., 27 October 1980 (Washington, DC: U.S. Government Printing Office).

NRC85 U.S. Nuclear Regulatory Commission, 1985, *Contaminated Mexican Steel Incident*, USNRC Report NUREG-1103, January 1985 (Springfield, VA: NTIS).

NRC86 U.S. Nuclear Regulatory Commission, 1986, "Exemption of technetium-99 and low enriched uranium as residual contamination in smelted alloys; withdrawal of proposed rule," *Federal Register*, Vol. 51, p. 8842, 14 March 1986 (Washington, DC: U.S. Government Printing Office).

Nu77 Nussbaumer D. A., Lubenau J. O., Cool W. S., Cunningham L. J., Mapes J. R., Schwartz S. A. and Smith D. A., *Regulation of Naturally Occurring and Accelerator-produced Radioactive Materials*, USNRC Report NUREG-0301, July 1977 (Springfield, VA: NTIS).

NY82 New York State Department of Health, 1982, *Report to the Governor and Legislature. Radioactive Gold Jewelry*, September 1982 (Albany, NY: State Department of Health).

NY85 New York State Department of Labor, 1985, *Industrial Code, Rule* 38 (12 *NYCRR* 38), *Ionizing Radiation*, Section 38.4(c) (Albany, NY: State Department of Labor).

SNM85 SNM Newsline, 1985, "LA nuclear medicine community improves radiation monitoring at landfills," *The Journal of Nuclear Medicine* **26**, 336.

US85a U.S. Government, 1985, "Specific domestic licenses to manufacture or transfer certain items containing by-product material," *U.S. Code of Federal Regulations Title* 10, *Part* 32 (Washington, DC: Office of the Federal Register, U.S. Government Printing Office).

US85b U.S. Government, 1985, "Standards for protection against radiation," *U.S. Code of Federal Regulations, Title* 10, *Part* 20 (Washington, DC: Office of the Federal Register, U.S. Government Printing Office).