NUREG-1669

A Risk Analysis of Fixed Nuclear Gauges

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555-0001

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Manuscript Completed: March 2000
Date Published: April 2000

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U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

ABSTRACT

Fixed nuclear gauges containing the radionuclides ^{137}Cs, ^{60}Co, or ^{241}Am are used in many industries to improve the quality and lower the costs of products for industrial, commercial, and private uses. But gauges that are improperly controlled during use and transfer can expose people to radiation and, upon entering the stream of recycled steel, can cause steel mills to spend millions of dollars to decontaminate equipment and dispose of contaminated materials. The risk to licensees and the recycling industries that nuclear gauges pose is incompletely understood. An analysis of fixed nuclear gauges was performed to study the risk to life and property, from facilities where the gauges are used to steel mills where the gauges might be melted. A risk analysis should be of interest to all stakeholders— agencies that promulgate regulations, licensees who must comply with the regulations, and the recycling industries who use scrap steel as a resource for making products. Although risk could not be estimated because data are lacking, observations and insights were made that can be used by all stakeholders to reduce their risk, even if the extent of the reduction is unknown.

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PREFACE

This report documents a 3½ year study on the risk of fixed nuclear gauges that began in the autumn of 1995. The risk analysis was conducted with the assistance of experts in relevant disciplines. Each expert listed as a contributor in the Acknowledgments was essential to the risk analysis. Site visits provided valuable perspectives on industrial operations where the nuclear gauges are located. Many of the site visits (listed on pages xxi and xxii) were made possible by two State regulators and an inspector at the Nuclear Regulatory Commission (NRC). Mentoring from the contributors and discussions with employees at industrial facilities allowed the principal investigator to make use of decades of experience.

The principal investigator benefited from a series of meetings between the NRC and the Agreement States.† Representatives from industry participated in the meetings to give their views on what should be done to improve regulatory controls. During these meetings, the principal investigator learned of the perspectives of different industries as people, one after another, stated their concerns. The meetings were opportunities for the principal investigator to learn the perspectives in a way that could not have been obtained with separate site visits.

This report requires a basic understanding of nuclear gauges, steel making, statistics, systems analysis, and risk analysis. However, it is not a tutorial in any of these subjects. The study draws on these subject areas and explains them enough to demonstrate how they were utilized.

This analysis of one type of device, fixed nuclear gauges, consumed considerable resources. The concepts and analyses developed for this group of radioactive devices are readily applicable to at least some other types of devices. Thus, an analysis of other devices can benefit from this analysis.

The risk analysis has been documented so that the reader can understand how the study was conducted without a myriad of details. Some detail has been omitted to direct attention toward concepts yielding observations and insights. Plain English was used instead of jargon to convey a common understanding of the subject among Federal regulators, State regulators, the public, and a wide variety of industries.

† U.S. Nuclear Regulatory Commission, "Final Report of the NRC-Agreement State Working Group to Evaluate Control and Accountability of Licensed Devices," NUREG–1551, October 1996.

EXECUTIVE SUMMARY

Fixed nuclear gauges containing the radionuclides ^{137}Cs, ^{60}Co, or ^{241}Am are used in many industries to improve the quality and lower the costs of products for industrial, commercial, and private uses. Gauges that are improperly controlled during use and transfer can expose people to radiation and, upon entering the stream of recycled steel, can cause steel mills to spend millions of dollars to decontaminate equipment and dispose of contaminated materials. The risk to licensees and the recycling industries that nuclear gauges pose is incompletely understood.

This report discusses an analysis of fixed nuclear gauges that was performed to study the risk to the public, to workers, and to property. All plausible scenarios of gauges traveling from facilities where the gauges are used to unintended locations where adverse consequences might result were considered. The focus of the analysis is on the recycling stream, where the gauges can be breached in scrap yards or melted in steel mills. Using established methods, elements of risk are examined, the relationships of the elements are elucidated, and the data needed to evaluate the elements for estimating risk are specified. For reasons discussed in this report (principally a lack of needed data), a quantitative assessment of risk could not be made.

Industrial facilities that use nuclear gauges are required by their licenses to maintain accountability. But under some conditions and circumstances at these facilities, control mechanisms may be compromised, allowing gauges to be inappropriately used or transferred. For example, gauges have been inadvertently locked on instead of off when a process unit is serviced, placing workers at risk to radiation exposures. Gauges have been improperly transferred when a process unit is moved to another facility or when equipment is scrapped and discarded in landfills or collected for recycling. When a gauge enters the recycling stream and is processed along with sorted, cut, and baled scrap metal, the processing may dislodge and disperse the radioactive material in the gauge. Employees may be exposed to radiation. Equipment may be contaminated by radioactive material. Sophisticated monitors at scrap yards and steel mills can detect minute amounts of radiation emanating from loads of scrap metal. But an intact gauge may not emit enough radiation to be detected, allowing a gauge to be melted with scrap metal in the furnace of a steel mill. Depending on the type of radioactive material, the steel product, the furnace dust, or the slag may be contaminated. Finally, there have been instances where contaminated steel products have entered the marketplace.

Although many thousands of gauges are used in domestic industries, most of them are usually not a risk to life and property because they are in use, controlling industrial processes. Licensees implement control mechanisms to reduce risk. A gauge that is at risk (controls have been lost) does not necessarily mean that it causes exposures or enters the recycling stream; it means that the gauge has a potential to do so. An effective control is one that operates immediately and continuously when gauges are at risk to prevent them from being inadvertently removed from their intended places. Three effective forms of immediate and continuous control (ICC) sometimes used at industrial facilities are as follows:

- Although not typically viewed as a control, a gauge in use, controlling production, cannot be removed and discarded without drawing attention.
- When a gauge must be removed from a process unit, storage in an area that is dedicated only for gauges reduces the chances of the gauge being discarded with scrapped materials and equipment.
- An unused gauge that has been returned to a vendor is not at risk of being discarded into the recycling stream.

These three controls–in use, interim dedicated storage, and return to a vendor–are considered *hard controls*, because they place a gauge in a definite location where it is unlikely to be removed unnoticed. Whatever reliance that is not placed on hard controls is typically placed on so-called *soft controls*, such as labels, semi-annual inventories, education and communications, and civil penalties. Soft controls are less effective than hard controls in providing ICC because they do not always gain enough attention at the right times and they can be degraded by conditions and circumstances at facilities. A difficulty for licensees in maintaining accountability is that they lack the collective experience of all industries of what does and does not provide ICC. Because regulations are necessarily broad and non-prescriptive, licensees have considerable leeway to devise their own control programs. Many licensees might benefit from learning about effective ICC practices.

Perfect control that eliminates the risk to life and property is impractical to require by regulatory agencies (i.e., NRC or Agreement States) and implement at industrial facilities. Many factors placing the gauges at risk are outside the jurisdiction of regulatory agencies. For example, regulatory agencies cannot direct licensees how to perform maintenance shutdowns, a circumstance where gauges might be discarded with scrap materials. Other factors cannot be completely controlled by licensees. For example, former employees cannot be told to implement the responsibility for gauges at a facility that has suddenly closed, a circumstance where gauges might be discarded when the facility is dismantled. This reality leaves a regulatory agency with the task of devising and communicating ICC practices that can be efficiently implemented. This reality also leaves licensees and the recycling industries with the responsibility for making business decisions to accept certain risks. For licensed facilities, employees may sometimes risk exposure to radiation because completely preventing exposure is impractical. For the recycling industries, scrap metal facilities may sometimes incur the cost to provide a level of protection that is not completely adequate to prevent a nuclear gauge from being inadvertently recycled.

The primary means of ensuring that the gauges are kept in their intended locations are controls. However, because controls sometimes fail to prevent nuclear gauges from entering the recycling stream, many scrap yards and steel mills have installed radiation monitors. Although the radiation monitors are important protection for scrap yards and steel mills, too much reliance seems to be placed on the technology alone instead of understanding the ramifications of using the technology:

- The chances of detecting radioactive material with a radiation monitor are dependent on several factors, not always under the control of scrap yards or steel mills.

- Even when a radiation monitor is present, it is sometimes disabled because numerous false alarms are annoying and established procedures are not always followed.

- Some scrap yards and steel mills will prevent a truck load of scrap metal from coming onto their grounds after a radiation alarm is activated and turn the load away without assurances that it will be safely investigated. A rejected load can be taken elsewhere, such as a scrap yard without radiation monitors or another steel mill, on the chance that the radiation monitors there will not alarm. At least some steel mills are unaware of a Department of Transportation exemption that allows a load that is suspected of containing radioactive material to be rejected and then readily sent to a facility where it can be safely investigated.

- Instead of encouraging recycling facilities to investigate the cause of a radiation alarm, which may just be a benign form of radioactive material, contractual arrangements between steel mills and the scrap yards supplying them sometimes encourage facilities to reject a load of scrap metal suspected of containing radioactive material.

Furthermore, even when the radiation monitors are used as intended, the shielding characteristics of large scrap metal loads have not been evaluated to accurately assess the chances of detecting a nuclear gauge in the load.

A risk analysis should be of interest to all stakeholders—agencies that promulgate regulations, licensees who must comply with the regulations, and the recycling industries who use scrap steel as a resource for making products.

ACKNOWLEDGMENTS

Name	Affiliation	Contribution
Lee Abramson	Office of Nuclear Regulatory Research, NRC	Provided conceptual and technical input for statistics and risk analysis. Met with the principal investigator weekly to give technical guidance. Assisted in developing concepts and writing selected sections. Reviewed selected sections.
Steven Baggett	Office of Nuclear Materials Safety and Safeguards, NRC	Provided an understanding of regulations and communicated regulatory needs that the risk analysis is to address. Reviewed the final draft of the report.
Ann Beranek	Office of Nuclear Regulatory Research, NRC	Edited notes, letters, memoranda, and selected sections on a short-notice basis. Gave valuable opinions on the presentation of concepts.
Michael Calley	Lockheed Idaho Technologies Co., Idaho Falls, ID	Gave support in using a computer program to calculate risk.
Mark Cunningham	Office of Nuclear Regulatory Research, NRC	Reviewed and approved the final manuscript to be published.
Martha Dibblee	Oregon Health Division, Portland, OR	Hosted site visits and gave technical support. Provided extensive mentoring about licensees in an Agreement State. Reviewed Section 6.
Richard Ladun	Region I, NRC	Hosted site visits during inspections.
John Lubinski	Office of Nuclear Materials Safety and Safeguards, NRC	Provided an understanding of regulations and communicated regulatory needs that the risk analysis is to address. Reviewed the final draft of the report.
Dan Lurie	Office of the Chief Financial Officer, NRC	Explained statistical concepts. Met with the principal investigator as needed for technical guidance. Assisted in developing risk analysis concepts and writing selected sections. Reviewed selected sections and the first draft manuscript.
Harry Martz	Los Alamos National Laboratory, Los Alamos, NM	Provided consultation early in the study and referral to a professional survey designer.
Mary Mejac	Office of Information Resources Management, NRC	Edited selected sections of the manuscript early in the study.
Mary Meyer	Los Alamos National Laboratory, Los Alamos, NM	Provided guidance on survey procedures and design. Reviewed licensee and steel industry surveys before and during pilot testing.
David Nigg	Lockheed Martin Idaho Technologies Company	Reviewed concept of the detection probability in Section 7.5.2.
Samuel Pettijohn	Office of the Analysis of Operational Data, NRC	Assisted with an NRC database about incidents of sealed source devices.
Rayleona Sanders	Office of Information Resources Management, NRC	Edited selected sections.
Maria Schwartz	Office of the General Counsel, NRC	Provided guidance on laws and statutes.
Harold VanderMolen	Office of Nuclear Regulatory Research, NRC	Served as a technical and strategic advisor. Assisted in developing the concepts in Section 8.4. Provided moral support.
James Yusko	Pennsylvania Department of Environmental Protection, Pittsburgh, PA	Hosted site visits and gave technical support. Provided extensive mentoring about the subject of the risk analysis. Reviewed Sections 6, 8.3, and 8.4.

SITE VISITS

3M Co., Cottage Grove Center, Cottage Grove, MN

Allegheny Ludlum Corp., Allegheny Ludlum Steel, Brackenridge, PA

Allegheny Power Co., Mitchell Power Station, Courtney, PA

Allied Signal Advanced Materials, Inc., Specialty Films, Pottsville, PA

American Iron and Steel Institute, Washington, DC

Armco, Inc., Specialty Flat-Rolled Steel, Butler, PA

Auburn Steel Co., Inc., Auburn, NY

Bar Technologies, Inc., Johnstown, PA

Barletta Materials and Construction Co., Inc., Hazelton, PA

Bemis Co., Inc., Film Division, West Hazelton, PA

BJ Services Co., Fairmount City, PA

Boise Cascade Corp., White Paper Division, St. Helens, OR

Brandenburg Industrial Service Co., Chicago, IL

Calbag Metals Co., Portland, OR

Caparo Steel Co., Farrell, PA

Cascade Steel Rolling Mills, McMinville, OR

Columbia American Plating Co., Portland, OR

East Stroudsburg University, East Stroudsburg, PA

Erie Forge and Steel, Inc., Erie, PA

Evergreen Helicopters, Inc., McMinnville, OR

Faxe Paper Pigments, Johnsonburg PCC Plant, Johnsonburg, PA

First Miss Steel, Inc., Hollsopple, PA

Gottlieb, Inc., Neville Island, PA

GS Roofing Products Co., Inc., Portland, OR

Horsehead Resource Development Co., Inc., Palmerton, PA

Institute of Scrap Recycling Industries, Inc., Washington, DC

International Paper, Erie Mill, Erie, PA

J&L Specialty Steel, Inc., Midland, PA

Keywell Corp., West Mifflin, PA

Koppel Steel Corp., Beaver Falls, PA

Lehigh Asphalt Paving and Construction Co., Tamaqua, PA

Liberty Iron and Metal Co., Inc., Erie, PA

Lukens Steel Co., Coatesville, PA

Luria Brothers, Koppel, PA

Maple Creek Mining, Inc., Preparation Plant, New Eagle, PA

McKeesport Municipal Authority, McKeesport, PA

Mercer Lime and Stone Co., Slippery Rock, PA

National Association of Demolition Contractors, Doylestown, PA

Ohmart Corp., Cincinnati, OH

Oregon Department of Human Resources, Radiation Protection Services, Portland, OR

Oregon Steel Mills, Portland Steelworks, Portland, OR

Pennsylvania Department of Environmental Protection, Field Operations — Radiation Protection, Pittsburgh, PA

Pennzoil Products Co., Rouseville, PA

Pittsburgh Brewing Co., Pittsburgh, PA

Schuller International, Inc., Building and Insulation Division, Richmond, IN

Sequa Precoat Metals, McKeesport, PA

Simpson Timber Co., Oregon Overlay Division, Portland, OR

Smurfit Newsprint Corp., Newberg, OR

Spang Specialty Metals, Advanced High Technology Alloys, Butler, PA

Steel Dynamics, Inc., Butler, IN

Steel Manufacturers Association, Washington, DC

SITE VISITS

SteelMet, Inc., McKeesport, PA

The Carbon/Graphite Group, Inc., St. Marys, PA

Tube City, Inc., Pittsburgh, PA

U.S. Generating Co., Scrubgrass Generating Plant, Kennendell, PA

USX Corp., U.S. Steel Mon Valley Works, Dravosburg, PA

USX Corp., U.S. Steel Gary Works, Gary, IN

Widmer Brothers Brewing Co., Portland, OR

Willamette Industries, Inc., Albany Paper Mill, Albany, OR

ABBREVIATIONS

BC	benign contamination
BOF	basic oxygen furnace
DEP	Pennsylvania Department of Environmental Protection
DMR	data-mix ratio
DOT	U.S. Department of Transportation
E&C	education and communication
EAF	electric arc furnace
EPA	U.S. Environmental Protection Agency
GL	general license (licensee)
HLA	high-level accountability
ICC	immediate and continuous control
IDS	interim dedicated storage
IRM	iron-rich material
ISRI	Institute of Scrap Recycling Industries
IU	in use
LANL	Los Alamos National Laboratory
LLW	low-level waste
MW	mixed waste
NMSS	Office of Nuclear Materials Safety and Safeguards
NORM	naturally occurring radioactive material
NRC	Nuclear Regulatory Commission
OMB	Office of Management and Budget
OSHA	Occupational Safety and Health Administration
OU	out of use
P&S	plate and structural scrap metal
QCR	query at a change in responsibility
RSO	radiation safety officer
SL	specific license (licensee)

LIST OF VARIABLES

Variable	Description	Units	Defined on Page
Area n	n^{th} detection area in a load of scrap metal	—	81
C_j	consequence of the j^{th} sequence of risk elements	Note (a)	24
C_{fine}	amount of a civil penalty	monetary	44
C_{melt}	financial damage of melting radioactive material	monetary	44
C_p	capacity factor of a process unit	—	51
f_{supply}	fraction of the domestic scrap metal supply consumed by a mill	—	22
E(@)	expected value of a random variable, @	—	27
$\mathcal{F}_j$	fraction of risk from the j^{th} group of risk element sequences	—	26
h	height of a vehicle transporting scrap metal	ft	83
I_{load}	incidence of nuclear gauges in a load of scrap metal	1/time	21
I_{mill}	incidence of nuclear gauges reaching a mill	1/time	22
ℓ	length of a vehicle transporting scrap metal	ft	83
L	tare weight of one load of scrap metal	tons	21
M	amount of scrap metal consumed by a mill in the period T	tons	22
N_A	number of gauges at risk in a given year	—	54
N_F	number of gauges found in the recycling stream (both before and after melting at a steel mill) in a given year	—	54
N_{IU}^{OP}	number of gauges at a facility in use on operating process units	—	51
N_{OU}^{OP}	number of gauges at a facility out of use, but on operating process units	—	51
$N_{j,k}$	number of gauges in the j^{th} possibility of the k^{th} element	—	51
N_T^F	total number of gauges in any location of a facility given the state of the facility (e.g., constant ownership, changing ownership)	—	51
$\mathcal{P}_j$	prevalence of gauges along the j^{th} sequence of risk elements	1/time	24
$\mathcal{P}_x$	prevalence of nuclear gauge throughout the U.S. X = GL, SL, or T, for the prevalence of generally, specifically, or both generally and specifically licensed gauges, respectively	1/time	47
$\mathcal{P}_{supply}$	prevalence of nuclear gauges in the domestic supply of scrap metal	1/time	21
$\mathcal{P}(t)$	prevalence of gauges throughout all industries at time t	1/time	19
Pr_j	probability of a nuclear gauge being in the j^{th} area of a scrap metal load	—	81
Pr{F|A}	probability of finding a nuclear gauge that has been discarded into the recycling stream	—	54
Pr{accept}	probability of accepting a load of scrap metal containing a nuclear gauge	—	87
$Pr\{accept\}_X$	probability of accepting a load after only primary monitoring, p, or after both primary and secondary monitoring, ps	—	93
Pr{detect}	prbability of detecting a nuclear gauge in a load of scrap metal	—	44
Pr{miss}	probability of missing a nuclear gauge in a load of scrap metal	—	44
Pr{reject}	probability of rejecting a load of scrap metal containing a nuclear gauge	—	87
R	total aggregate risk	C/t	24
$R_{j,k}$	k^{th} aggregate risk for the j^{th} group of risk element sequences	C/t	26
R_T	aggregate risk for all groups of risk element sequences	C/t	26
S	weight of the scrap metal supply	tons	21
t	time	Note (b)	Note (b)
T	time period	Note (b)	22
V	volume of a vehicle transporting scrap metal	ft^3	83
w	width of a vehicle transporting scrap metal	ft	83
$x_j(t)$	number of gauges in the j^{th} location at time t	—	19

(continued next page)

LIST OF VARIABLES

Variable	Description	Units	Defined on page	Pronunciation
Γ_n	change is risk from the n^th alternative expressed as a **ratio**	—	25	gamma
Δ_n	change is risk from the n^th alternative expressed as a **difference**	—	25	delta
ρ	density of a load of scrap metal	$tons/ft^3$	84	rho
$\varphi_{j,k}$	fraction of gauges at the j^th possibility of the k^th element	—	51	phi
φ_{Mntn}	fraction of gauges on process lines shut down for maintenance	—	51	phi
φ_{IU}^{OP}	fraction of gauges in use on operating process units	—	51	phi
φ_{OU}^{OP}	fraction of gauges out of use on operating process units	—	51	phi
$\varphi(t)$	proportion of gauges in the j^th location at time t	—	19	phi
μ	expected values (i.e., mean) of a random variable	Note (c)	27	mu
Ψ	probability of detecting a nuclear gauge in a load of scrap metal	—	81	psi
Ψ_{blend}	net detection probability for a blend of scrap metal commodities	—	84	psi
Ψ_j	detection probability in the j^th scrap metal commodity	—	84	phi
$\Psi(A_x \mid A_{x-1})$	probability of an alarm on the nth pass through a monitor station given an alarm on the (n-1)^th pass	—	88	phi
$\Psi(A_x \mid N_{x-1})$	probability of an alarm on the nth pass through a monitor station given **no** alarm on the (n-1)^th pass	—	88	phi
σ^2	variance of a random variable	Note (c)	27	sigma
τ	sequence of elements in a risk triplet	—	24	tau
ω_j^c	weighting factor: relative weight of the j^th scrap metal commodity	—	84	omega

NOTES

(a) Consequences are expressed in units of radioactivity and dollars.
(b) Usually expressed as a year throughout this report.
(c) Units of the random variable.

1 INTRODUCTION

1.1 Definitions

Analyze conveys the notion of separating the subject into its parts to identify or study its structure, to examine and interpret. An analysis is the basis for an assessment.

Assess means to decide on the amount or fix the value. With information, an analysis can be used to assess risk.

Control mechanisms are the means by which regulators and licensees keep licensed nuclear material in intended locations. Typical mechanisms include warning labels and physical security. The phrase is mentioned here and discussed in detail in Section 5.

Stakeholders are individuals, organizations, or industries that can be affected by changes in control mechanisms.

1.2 Concepts

Radioactive material in the recycling stream is a complex subject. A comprehensive analysis allows the subject to be systematically examined. At first, the subject appears formless. But through a risk analysis, the pieces can be sorted, disentangled, and unfolded into a clear picture.

A risk analysis complements and builds on other work that has been done:

1. Identify and document the subject. Discoveries of radioactive material in the recycling stream have been summarized and documented in the literature (Ref. 1). Reference 1 is regarded by many stakeholders as an excellent summary of reported discoveries.

2. Develop solutions. Discussions among Federal regulators, State regulators, and members of industry resulted in recommendations to Nuclear Regulatory Commission (NRC) staff.

3. Analyze the subject and evaluate solutions. The interaction of the control mechanisms, the regulated community (i.e., licensees), and other industries (i.e., in the recycling stream) forms a complex system that can be analyzed. An analysis has value over postulating the net effect of the control mechanisms themselves; facets of the subject can be delineated, related, reviewed, and discussed.

A risk analysis can also be used to estimate what changes in current circumstances may produce desired outcomes. Current circumstances are reported in Reference 1 and experienced by both regulators and industry staff. Desired outcomes include making appropriate changes in control mechanisms and business practices.

A risk analysis must consider what is known, could be known, and cannot be known:

- Known are the implications of the analyses, assumptions, and currently available data. For example, qualitative observations and insights can be deduced from the analyses shown in Sections 5.5, 6.4, 7.7, and 8.4. Implications of the currently available data are discussed in Section 10.

- Could be known is how risk changes when control mechanisms are changed or more information became available. The changes in the control mechanisms may be postulated with expert judgment. The additional information may consist of more detail in the analyses, more data, or expert judgment. For example, the probability of detecting radioactive material in the recycling stream is poorly characterized (see Section 7.5). The analyses can be used to determine how risk estimates change as the detection probability is changed by postulating plausible values. If the risk estimates are significantly affected by the plausible values, then the benefits of obtaining more information for more precise risk estimates, more accurate estimates, or a more solid basis for the risk estimates can be related to the expense of obtaining better information (see also Section 4.2).

- Cannot be known is information for risk factors that is impractical or infeasible to obtain. The factors are relevant to risk; hence, they must be delineated. But information for assessing the factors is limited to plausible judgments. An example is the effectiveness of control mechanisms (see Section 5.5).

A risk analysis explicitly states the factors that have been taken into account to analyze and assess risk. Stakeholders (e.g., regulators, scrap dealers, demolition contractors, steel mills, gauge vendors, radiation monitor vendors) can understand risks and how changes in control mechanisms and business practices will change the risks. A systematic analysis then provides a means to discuss and evaluate disagreements.

A comprehensive risk analysis gives a sound foundation by providing assurance that reasoning leading to conclusions is cogent. Reference 2 states that cogent reasoning uses all relevant information, valid premises, and correct logic. A risk analysis makes these elements explicit:

- Relevant information. When faced with a large number of possibilities, people usually limit their view of a problem and focus instead on narrow areas. The subject of radioactive material in the recycling stream is not readily amenable to understanding with intuition. The perception of uncertainty fundamentally changes the view of a problem. When unknowns are acknowledged, clear-cut decisions for any stakeholder are shown to be overly simplistic (Ref. 3, page 298, and Section 3.5). Hence, neither expert judgment nor a simplified analysis are completely satisfactory substitutes for an analysis where relevant facets of a subject have been delineated. Doing so can lead to changes in a system that have only a secondary effect on risk. Any evaluation that fails to look systematically at a large fraction of the possibilities has a high probability of missing important aspects of the problem (Ref. 3, page 308).

Figure 1 shows a simple system with three elements. Each element has only two possible outcomes. The number of possible outcomes for the entire system is $2^3 = 8$. When the number of elements increases to five, the number of outcomes increases exponentially to $2^5 = 32$. The subject of the risk analysis, viewed as a system, has more than 30 elements, each element having usually two to six outcomes; the number of outcomes to be evaluated are far beyond what can be done intuitively. But as discussed in Sections 2.4 and 2.5, some sequences were not taken into account; thus some relevant information is excluded. In practice, "all" means that which is cost-effective to obtain and is necessary for making meaningful risk estimates.

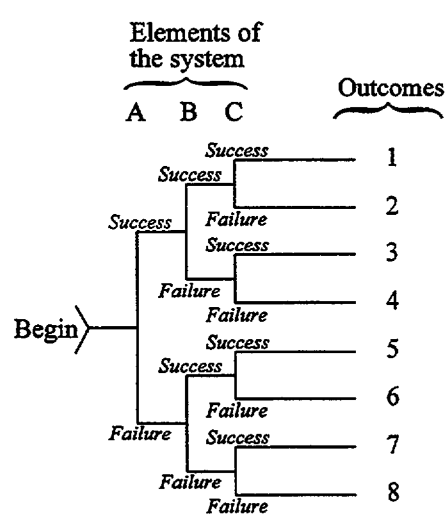


Figure 1 Number of outcomes from three binary elements.

- Valid assumptions. The basis for much planning and decisions is the assumption that circumstances and responses to changes made under those circumstances are known. This simplifies a complex problem by reducing the number of possibilities and ignoring uncertainty. However, this assumption, although convenient, is usually false (Ref. 3, page 272). Circumstances are not fully known. With the analyses of the licensees (Section 5.5), scrap yards (Section 6.4), steel mills (Section 7.7), and the public domain (Section 8.4) many possible paths of radioactive material through the recycling stream are enumerated, expanding the scope of the subject beyond what has been reported.

  Proving every aspect of an analysis is unnecessary. Assumptions can be made. But assumptions should not be made on the points of an analysis that are at issue. Within the analyses, reasons are given to support the claim that assumptions are valid.

- Correct logic. Sometimes reliance can be placed on unsophisticated analyses to identify critical issues from a clear perspective; this can be more effective than the use of complex analyses whose assumptions are partially or totally hidden (Ref. 4, page 1). However, a highly structured analysis, pulling together information about relevant areas of the complex subject, is necessary to consistently evaluate options, systematically assess unknowns, and balance benefits and consequences.

One could argue that Reference 1 is sufficient reason to change regulations. Furthermore, when combined with specific information about consequences, the empirical data summarized in Reference 1 can be used to make a rough estimate of risk as defined by the NRC (Ref. 5). But the constituents of risk are the sequences of risk elements of a radioactive source from licensees through the recycling stream, the prevalence of nuclear gauges along the sequences, and the consequences of the gauges from the sequence of risk elements. From Reference 1, a few general categories of sequences can be defined in terms of endpoints, such as finding radioactive material before or after it has been melted at a steel mill. Consequences can be associated with these categories of sequences. Then, using the definition of risk in Reference 5, an estimate of risk can be computed. However, such an estimate is insufficient for predicting the effect of changes to control mechanisms because of the following:

- A risk analysis must take into account aspects of the subject that are relevant to risk.

- The situation is complex, reflecting the influence of control mechanisms, the radiation monitors, the practices of using the monitors, the practices of responding to alarms, and the practices of record keeping. Likewise, the data about the situation are complex and must be carefully studied.

- The uncertainty in an empirical risk estimate cannot be readily determined from the data summarized in Reference 1. Uncertainty is present; whether or not it is expressed, it is an integral part of an estimate. Uncertainty has a bearing on how the predicted effects of changes are perceived (see Section 3.5).

- An estimate of risk from empirical data may apply only to the situations from which the data are collected. The empirical data summarized in Reference 1 apply only to the status quo (more precisely, only the more recent part of the data apply because circumstances changed as the data were collected). Therefore, data are scarce.

Calculating risk requires information about the sequences of events leading to consequences, the prevalence of gauges along the sequences, and the consequences (e.g., exposure to radiation) of the gauges at the end of the sequences. The empirical data summarized in Reference 1 supply only some of this information. The reference is essential for beginning a risk analysis, which in turn can be used to evaluate control mechanisms.

2 SUBJECT

2.1 Overview

The goal of this study is to analyze and assess the risk from using nuclear gauges containing ^{137}Cs, ^{60}Co, and ^{241}Am.

Reference 1 is an excellent starting point for an analysis. The reference clearly documents that nuclear devices have been found in the recycling stream of scrap steel. The reported discoveries of ^{60}Co, ^{137}Cs, and ^{241}Am, often used in fixed nuclear gauges to control industrial process units, are a hazard to life and property. Adverse consequences from the gauges have occurred at licensees, scrap yards, and steel mills.

The licensees, scrap yards, and steel mills can be viewed as a system to analyze. Although many aspects of these area are beyond the jurisdiction of regulatory agencies, the aspects can influence both the control of gauges in the licensees and recovery of gauges from the recycling stream. The data on discovered radioactive material reveals aspects of this system that need to be taken into account.

2.2 Definitions

Benign contamination (BC) refers to innocuous forms of radioactive materials, such as NORM (defined below) and thorium in alloys.

A *comprehensive risk analysis* both accounts for all relevant aspects of the subject and gives a thorough understanding of the findings.

A *goal* is a broadly stated purpose (Ref. 6).

Label refers to the radiation trefoil.

Naturally occurring radioactive material (NORM) refers to pipe scale, other deposits, dirt, and refractory materials. This is the way that NORM is characterized in Reference 1.

An *objective* is a specific accomplishment necessary to achieve a goal (Ref. 6).

Radium refers to discrete sources of ^{226}Ra used in nuclear devices. This is the way that radium is characterized in Reference 1.

A *risk element* is an event or state placing a sealed source at risk.

A *sequence of risk elements* is a combination of risk elements leading to a consequence.

2.3 Goal and Objectives

The goal of this study is to analyze and assess the risk from fixed nuclear gauges. The objectives of the study are taken from risk analysis in general and then from Reference 7. The objectives from risk analysis in general are as follows:

- Develop a concise and rigorous perspective of radioactive material in the recycling stream.
- Develop concepts necessary for understanding the control of gauges.
- Develop a framework for estimating risk.
- State observations and insights derived from thoroughly studying the subject.
- Show what is known, what can be known, and what cannot be known.
- Estimate risk.

The objectives from Reference 7 are as follows:

1. Determine the resources the Nuclear Regulatory Commission (NRC) or Agreement States should expend in searching for a lost device or source that is believed to be in the public domain.
2. Provide a basis for the Office of Nuclear Materials Safety and Safeguards (NMSS) staff to assess changes to current NRC positions regarding nonlicensees who find a lost nuclear device.

3. Develop a basis for the NMSS staff to propose resource allocations for preventing or mitigating incidents where radioactive material is lost, and determine the impacts of proposed changes in control mechanisms.

4. Develop issues that the risk analysis is to address and delineate the necessary technical detail to address the issues.

5. Assess the potential for consequences to identify important sequences of risk elements.

6. Estimate potential doses to occupational workers and members of the public.

Table 1 shows supplemental objectives, their references, and the means by which they are met. The study began as a result of a request from NMSS to the Office of Nuclear Regulatory Research (Ref. 7). Discussions between the staffs of the two offices resulted in specific technical requirements (Ref. 8). The *Code of Federal Regulations* (Ref. 9) encompass regulations that the NRC establishes. Some concerns were from public meetings (Ref. 10) and site visits.

Objectives 1 through 4 require an assessment of risk. The framework for an assessment was developed, but an assessment could not be done , principally because necessary data could not be obtained (see Section 9). Objective 5 was accomplished; many issues that were poorly

Table 1 Guideposts for developing the risk analysis. LEGEND: ✓ indicates facets that are within the scope of the analysis. ✕ indicates that an item is outside the scope.

Item	*Code of Federal Regulations* (Ref. 9)	Request from regulators (Ref. 7)	Other request from regulators (Ref. 8)	Statements from public meetings (Ref. 10) and site visits	Means To Accomplish
Risk, probabilities	✓	✓			Use the definition of aggregate risk (Section 3.4)
Analysis		✓			Examine the subject (Section 1)
Assess changes in control mechanisms	✓	✓			Structure of the risk analysis (Section 3.3)
Technical detail to address relevant issues		✓			Delineate risk elements (Section s5.5, 6.4, 7.7, and 8.4)
Exposures to radiation	✓	✓	✓	✓	Precluded (Section 8.4)
Property damage	✓		✓	✓	Analyze financial impacts (Section 8.4)
State of devices:					
Lost					Concepts of immediate and continuous control, at risk, and probability of improper disposal (Sections 5.3, 5.4, and 5.5)
Improperly transferred and disposed		✓			
Entering the recycling stream					
Melted in furnaces					Impacts on scrap metal processors (Sections 6.4 and 7.5)
Resources spent to find			✓		Assess changes in risk (Section 3.3)
Manufacture and transport			✕		Outside the scope of the study
Activity of radioactive material to regulate			✓		Measures of impacts to health (Section 8.4)
Use empirical data		✓			Information is specified in Sections 5.6, 6.5, 7.8, and 8.5

known are discussed throughout this report. Objective 6 could not be definitively done; hence, an alternative was developed and is discussed in Section 8.4. Consequences to life and property are discussed in Sections 5.5, 6.4, 7.7, and 8.4. The supplemental objectives were met as indicated in Table 1.

2.4 Subject of the Risk Analysis

The subject of this risk analysis is the accountability of fixed nuclear gauges containing either ^{137}Cs, ^{60}Co, or ^{241}Am. The gauges are used in many industries to measure the density of materials in pipes, the amount of materials in tanks, the amount of materials on conveyor belts, or the thickness of metal films. When accountability at the licensees is lost, the gauges are usually found in the ferrous metal recycling stream. Other places where they may go include landfills and other facilities when equipment is salvaged. This analysis is focused on the accountability at the licensees and on the movement through the recycling stream for the following reasons:

- Enough of the subject is analyzed to make robust estimates of risk. Many results of the risk analysis will apply to other final states of the gauges that have not been analyzed. Some other final states of nuclear gauges do not merit an analysis. Gathering information, not only to develop an analysis but also to obtain data for risk calculations, is expensive. A well-designed study will make effective use of resources so that the *entire* subject does not have to be analyzed.

- Nuclear gauges are often found in ferrous scrap metal, possibly because they have a steel exterior and are on steel equipment. Scrap metal is valuable; most of it is recycled and little is discarded.

- The risk of melting radioactive material is proportional to the consumption of scrap metal. Steel mills consume most of the scrap metal supply. Therefore, the steel industry is subject to most of the risk.

- According to the information documented in Reference 1, most of the discoveries of radioactive material that are dangerous to life and property are ^{137}Cs, ^{60}Co, or ^{241}Am sources in recycled steel. Reference 1 suggests that the types of gauges found in the recycling stream are those that are attached to pipes or tanks, move across conveyor belts, or move across metal films. Another source of information on the occurrence of nuclear gauges in the recycling stream may show

Summary of the Reasons for Studying Nuclear Gauges in Recycled Steel

- Most of the subject is analyzed. Many results of the risk analysis will apply to other final states of the gauges that have not been analyzed. Other final states of nuclear gauges do not merit an analysis.

- The risk of melting radioactive material is proportional to the consumption of scrap metal. Steel mills consume most of the scrap metal supply. Therefore, the steel industry is subject to most of the risk.

- According to Reference 1, most of the discoveries of radioactive material that are dangerous to life and property, ^{137}Cs, ^{60}Co, and ^{241}Am, have been found in recycled steel.

- The gauges are expected to be mostly in ferrous scrap metal because the equipment they are on is made of steel.

- Scrap metal is valuable and likely to be in recycled.

- Two trade associations representing the steel industry and a third association representing scrap dealers have been most vocal about a need for more stringent controls on licensees.

otherwise. But only the data for Reference 1 were used in this study. Each database will have its own characteristics because each database about nuclear gauges is a sample of convenience, not a random sample (see Section 4.3.2). Limited resources in this study precluded comparing and contrasting databases, then building a common database. Also, the data of Reference 1 are in a form that is readily manipulated. Reference 1 is recognized as a credible reference.

- Two trade associations for the steel industry have been pointing out the need for more stringent regulations. A third trade association, which represents many different recycling industries, also recognizes the problem as primarily occurring in ferrous scrap.

The number of times different radionuclides have been found in the recycling stream are shown in Figure 2. The figure shows the reported discoveries of radioactive material in the ferrous recycling stream, expressed as both a percentage of all reported discoveries and as absolute numbers. The radionuclide groups listed in the figure are annotated to aid in understanding the selection for the subject of the risk analysis. Some radioactive material does not present an immediate safety concern or is not regulated by the NRC. Radioactive materials such as NORM (as characterized in Section 2.2) and thorium in alloy metals pose little or no radiological danger to health or property. Hence, they are of little concern in the context of this risk analysis. Although ^{137}Cs, ^{60}Co, and ^{241}Am are not the most prevalent radioactive materials in the recycling stream, their prevalence cannot be dismissed as flukes and their potential to cause damage (unnecessary exposures to the public, contaminated property) warrant concern. ^{137}Cs, ^{60}Co, and ^{241}Am are found in nuclear gauges. Most of the nuclear gauges in service contain ^{137}Cs. Based on judgment from regulators, the prevalence of gauges containing ^{137}Cs is much greater than the prevalence of gauges containing ^{60}Co. This is reflected in the number of devices discovered in the recycling stream. The prevalence of ^{241}Am gauges is a little less than the prevalence of ^{137}Cs gauges.

When in use under proper controls, a nuclear gauge presents little hazard. But in the recycling stream, nuclear gauges potentially threaten life and property. If the shutter of a gauge were closed, then exposures would be minimal. However, without control mechanisms, assurances that the gauge is not causing harm are gone; the shutter may be open or the sealed source may become dislodged from its holder. The recycling stream is not designed for radioactive material. Unnecessary exposures have occurred in the United States; in foreign countries, deaths have occurred from other types of devices containing sealed sources.

2.5 Subject as a System To Analyze

The subject of this risk analysis, fixed nuclear gauges in the recycling stream, is illustrated in Figures 3 through 6. Figure 3 shows the movement of the nuclear gauges by the line arrows. Vendors of nuclear gauges are specific licensees (SLs) who manufacture and distribute nuclear gauges to other SLs or to industrial facilities. The gauges are shipped in proper packages and installed by qualified people; hence, these routes of the gauges are of minimal risk and are not analyzed further.

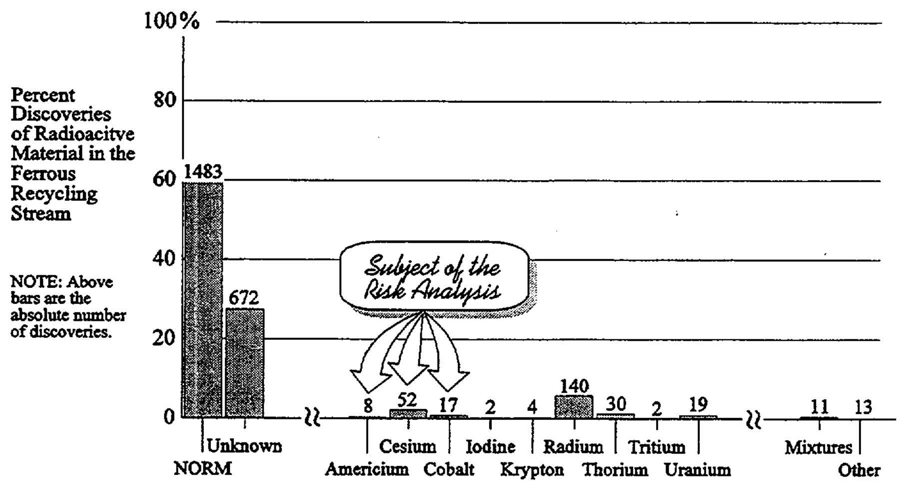


Figure 2 Discoveries of radioactive material in the recycling stream. Source: James Yusko, Pennsylvania Department of Environmental Protection, Pittsburgh, PA. The data file is dated November 20, 1998. The last entry in the file is numbered 3044. Earlier versions of the data are summarized in Reference 1.

Notes on Figure 2

NORM, in this study, is pipe scale, other deposits, dirt, and refractory materials. It can be a health concern when radiation levels are high. NORM can cause alarms at portal monitors of scrap yards and steel mills. In general, it is not a danger to life or property.

Unknown, questionable incidents, where the type of radioactive material cannot be identified, are of little use in making decisions that are costly to many industries.

Americium, cesium, and cobalt are gamma emitters; hence, they can impact health. When these isotopes are melted in a furnace at a steel mill, large financial damages result. Also, ^{241}Am is an alpha emitter, which can be a danger to life if such a sealed source is breached and the radioactive material is inhaled or ingested.

Iodine is likely from medical waste. It is not a concern in the recycling stream because employees are usually not close to scrap metal long enough for harmful exposures. Steel products and byproducts will not be contaminated because iodine is volatile.

Krypton is a beta emitter, raising some concerns for exposure. Steel products and byproducts will not be contaminated because krypton is a gas.

Radium, in this study, refers to a discrete source, not to a constituent of deposits. It is a strong beta and gamma emitter. When melted in a furnace at a steel mill, it is thought to contaminate mostly slag. Radium is not regulated by the NRC.

Thorium is a health concern if ingested or inhaled. Small amounts of thorium are sometimes added to metals to improve metallurgical characteristics. Thorium is not a concern.

Tritium is mostly found in self-illuminating exit signs. It is usually not a health hazard unless ingested because it is an alpha emitter.

Uranium has a low activity. Depleted uranium is used for counter weights and shielding. Other radioactive materials with more significant hazards are found in the recycling stream more often.

Mixtures found in the recycling stream are cesium and cobalt, cesium and americium, and uranium and thorium. These mixtures were reported without explanation. Also, they are not easily placed in other classes. This group is considered to have a low prevalence because it consists of four types of mixtures. Thus, this *group* is of no concern.

Other radioactive material found in the recycling stream includes accelerator products, radium daughter products, strontium, germanium, uranium contamination. Some materials may be of concern under certain circumstances. This group has a low prevalence because it has many types of radioactive material. Thus, this *group* of no concern.

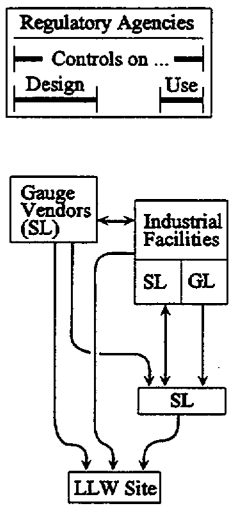


Figure 3 Nuclear gauges in industries overseen by regulatory agencies. LEGEND: GL = general licensee. LLW = low-level waste. SL = specific licensee.

NOTE: Usually ^{137}Cs and ^{60}Co sources can be disposed in an LLW site; usually a ^{241}Am source cannot be disposed there.

Regulatory controls are imposed by the NRC and Agreement States; this regulatory regime is shown at the top of Figure 3. Regulatory controls are imposed on the manufacture, transfer, possession, use, and disposal of nuclear gauges and are intended to prevent nuclear gauges from leaving the regulatory regime. The controls on the nuclear gauges during use are specified in the terms of the license under which the gauge is issued, and may include the following:

- The nuclear gauges are subject to periodic inspections and inspections related to events.
- The licensee must periodically take an inventory of the nuclear gauges.
- Labels must be maintained to identify clearly that the gauge contains radioactive material.
- Usually some training about safe operation is provided by the vendor or required by the regulatory agency.
- Records must be maintained properly.
- Physical security is necessary.

A regulatory agency has, or can impose, control on only some of the factors that influence nuclear gauges. In Figure 3, this is illustrated by the controls on use covering only part of the width of the box representing industrial facilities. A loss of control is not just a matter of regulations; it is also a matter of the many aspects in a facility, most of which are not under, or only partially under, the jurisdiction of the NRC or the Agreement States. (see Sections 2.5, 5.3, and 5.4). In Figure 3, the plant controls are inside the box representing industrial facilities.

Depending on the conditions of a license, a specific licensee can usually install, remove, and service nuclear gauges. A general licensee (GL) is usually allowed to use and store a nuclear gauge, not to move or service it. An industrial facility may be an SL, a GL, or both.

When the radioactive material in the sealed source has decayed and becomes insufficient for use in a nuclear gauge, the sealed source is typically removed by either the gauge vendor or another specific licensee. The sealed source may be recycled into another gauge. The disposal method for a sealed source that is no longer of use depends on the radionuclide and the activity. A sealed source that cannot be sent to a low-level waste (LLW) site is held in dedicated storage at a licensee under a possession-only license or sent to a broker who will hold the source indefinitely. Otherwise, a sealed source is sent to a LLW site. Usually, ^{137}Cs and ^{60}Co sources meet the criterion for disposal in a LLW site (see Ref. 9); usually a ^{241}Am source does not meet the criterion. Vendors will seldom take back a source manufactured by another vendor; if they do, it is taken back as a service to their customers or for reuse.

Figure 4 illustrates the recycling stream. Because scrap metal is valuable, most of it enters the recycling stream; little is intentionally discarded directly into landfills. The value of scrap metal and current technology are making landfill mining economically feasible, but this industry is still in its infancy; because of this, landfill mining is not

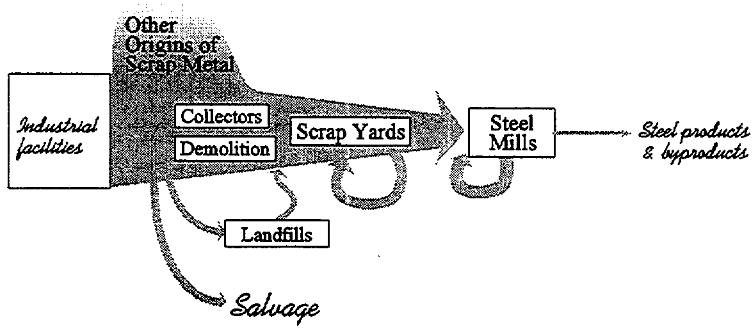


Figure 4 The recycling stream of scrap steel.

analyzed further. Scrap metal enters the recycling stream from many origins in the following groups:

- Demolition contractors who renovated or dismantled industrial facilities.
- Collectors, known as scavengers, peddlers, or gypsies, who gathered scrap metal from a variety of unspecified places.

At the smaller scrap yards, metal is collected, cut, and sorted. At the larger scrap yards, beyond collection and sorting, additional processing is done, such as shearing, shredding, cutting, and baling. The scrap metal is then sent to steel mills. Both integrated mills and minimills consume scrap metal. The scrap metal used by steel mills has been graded and assayed into lots of known size and composition (known to parts per million). At a scrap yard or steel mill, a load can be rejected because it does not meet specifications (e.g., pieces of the wrong size, wrong composition, or with undesirable chemical constituents). The circular paths on the large arrow represent rejected loads of scrap metal.

Scrap metal that enters the mill is melted to make industrial and consumer products. The gray lines in Figure 5 indicate the flow of products and byproducts to the marketplace. The steel is made into products for direct use, such as reinforcing rods and plates, or sent to other industries that reheat the steel and roll it into other products. One byproduct from minimills, furnace dust, is usually sent to processors where metals are removed to be recycled and used in other industries; zinc is sent to a zinc plant. Lead and copper are sent to smelters. Cadmium is sent to a hazardous waste landfill because the markets for this metal are currently depressed. A liquid containing halides (e.g., chloride, bromide) is pumped into deep injection wells. The destination chosen by a mill for the dust is the economical pathway. The remaining material is rich in iron and is called iron-rich material. It is used in a variety of products, such as aggregate material in asphalt and construction or as an iron ingredient in cement, and reused in manufacturing steel. This furnace dust is sometimes glassified and then used in a variety of products, such as roofing material and sandblasting grit. It can also be sent to a hazardous waste site where it is stabilized and then buried. Furnace dust from an integrated mill can be buried because it is not classified by the Environmental Protection Agency (EPA) as a hazardous waste.

Figure 6 is a composite of Figures 3, 4, and 5. On the left is the movement within the regulatory regime among licensees, gauge vendors, and

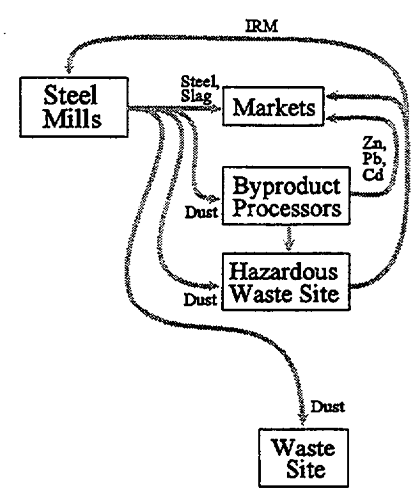


Figure 5 Product and byproduct pathways from recycled scrap steel. LEGEND: IRM = iron-rich material.

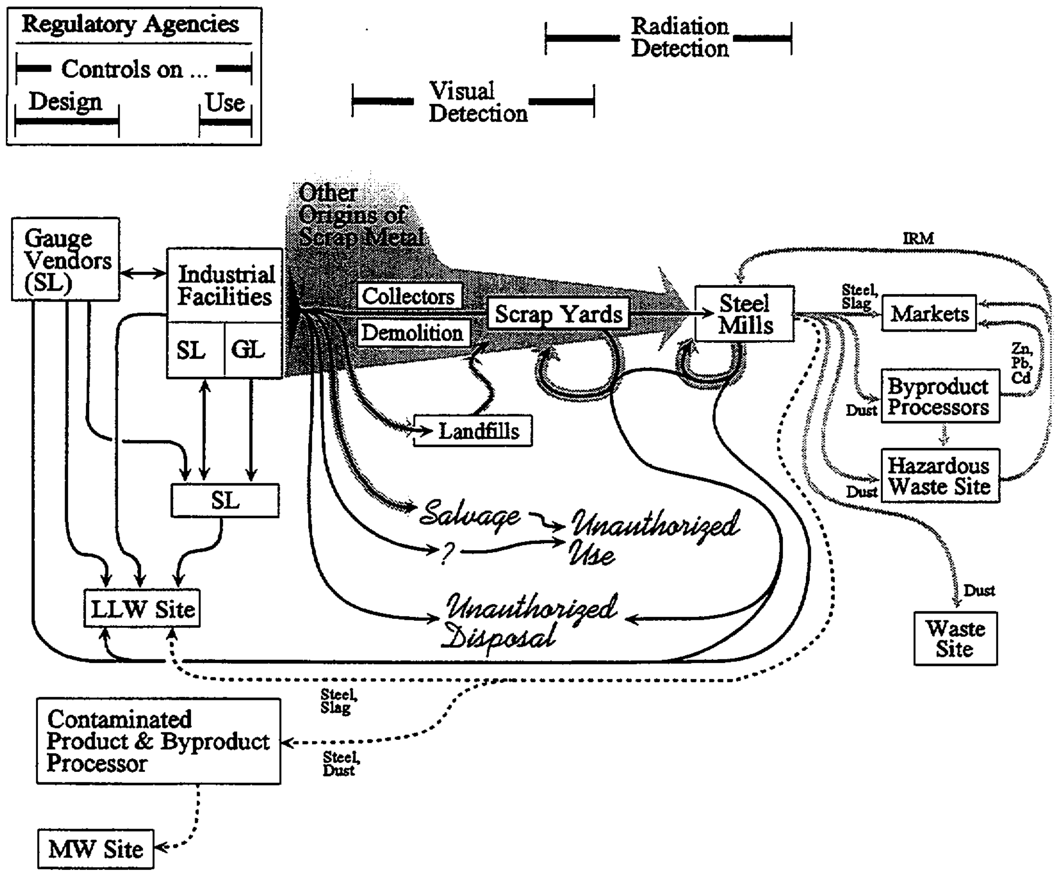


Figure 6 Nuclear gauges moving from licensees, through the recycling stream, and contaminating steel products and byproducts. LEGEND: BC = benign contamination. GL = general licensee. LLW = low-level waste. MW = mixed waste. SL = specific licensee. ? = unknown. NOTE: Usually ^{137}Cs and ^{60}Co sources can be disposed in an LLW site; usually a ^{241}Am source cannot be disposed there.

industrial users. In the middle is the recycling stream, consisting of scrap metal collectors, demolition and salvage contractors, scrap yards, and steel mills. On the right are the destinations of products and byproducts, both during normal operations and after a nuclear gauge has been melted in a steel mill. Steel mills are shown as being distinct from industrial facilities having nuclear gauges; this is a limitation of the figure. Some steel mills use nuclear gauges to measure the level of molten steel in the continuous caster and the thickness of slabs in the finishing mill.

Nuclear gauges leaving the regulatory regime may enter the recycling stream and landfills or get into unknown places, or their use may be unauthorized. Intuitively, the flow of nuclear gauges along the recycling stream is much larger than the pathway into landfills because most nuclear gauges are attached to metallic components and scrap metal is valuable. Some flow is, no doubt, outside the ferrous metal recycling stream; unauthorized use may involve salvage when a process unit is taken apart, moved, and reassembled. Unauthorized disposal can also occur when the staff at an industrial facility improperly transfer a nuclear gauge. Unspecified pathways are indicated in Figure 6 by the question mark.

For the most part, little radiation monitoring is done at the beginning of the recycling stream. The volumetric flow of scrap metal is seldom sufficient to justify the expense of large portal monitors found further along the recycling stream. Radiation detectors are possible along the stream, before the large portal monitors at the mill or large scrap yards feeding the mills, but the use of such equipment, even survey meters, is uncommon. Small-scale collectors usually do not have the resources required to purchase and operate the devices. The primary means of detection is visual inspection, which may be impeded in the following ways:

- The bulk of the scrap metal may hide a nuclear gauge.
- The orientation of the nuclear gauge may hide a label.
- Corrosive environments may degrade a label.
- Paint and dirt may cover a label.
- Ambient conditions, such as snow, rain, and fog, may reduce visibility.
- Workers may not know what to look for.

These factors have three implications. First, the chances of visually finding a nuclear gauge along the recycling stream are remote. Second, if gauges are frequently found visually, then many nuclear gauges are present in the recycling stream. Third, a more durable label, such as embossing, is of limited benefit when a gauge is in the recycling stream.

Further along the recycling stream, the volume of scrap metal justifies the use of sophisticated radiation detectors at the entrances and exits of scrap yards and steel mills. Before being sent to a steel mill, the scrap metal is sorted, shredded, or bundled, compacting the scrap metal. The detection of nuclear gauges using radiation monitors may be impeded in the following ways:

- Shielding of the nuclear gauge reduces the radiation that can reach the radiation monitor.
- A large volume and high density of scrap metal may shield a nuclear gauge.
- The background radiation necessitates a lower limit on the alarm point. A point near the background level would cause the monitor to alarm frequently.
- The alarm point may be set high to reduce false alarms from background radiation, BC, and people who have undergone treatment with nuclear medicine.

When a sealed source is melted along with scrap metal, the products and byproducts that are contaminated depend on the radioactive material that is melted. ^{137}Cs vaporizes from the molten steel and adheres to the furnace dust. Little if any of the cesium remains in the steel. ^{60}Co forms an alloy with steel. Because furnace dust and slag contain iron, they will also contain ^{60}Co (Ref. 11).

Little is known about the fate of ^{241}Am, but it is believed that it will reside mostly in slag. These pathways are denoted by the dotted black line arrows to indicate that the sealed source has changed from its encapsulated form to a dispersed form in the steel, slag, and furnace dust. Contaminated steel can go to a low-level waste site. Contaminated slag can go to either a processor or a low-level waste site. Contaminated furnace dust is no longer simply a hazardous waste but, instead, a mixed waste (heavy metals and radioactivity); it is sent to a processor where it is solidified, then buried in a mixed-waste site.

Figure 7 illustrates some aspects of the subject that are taken into account in the risk analysis. The figure is necessarily qualitative, not quantitative, to illustrate concepts. A quantitative illustration would leave important areas too small to observe and data necessary to report quantitative aspects are unavailable. Nevertheless, Reference 1 serves as a basis for Figure 7.

The top illustration in Figure 7 is an overview. The rectangle represents all loads of scrap metal that are being monitored for radioactive material as they enter a steel mill. The area outside the larger circle represents the loads that do not cause

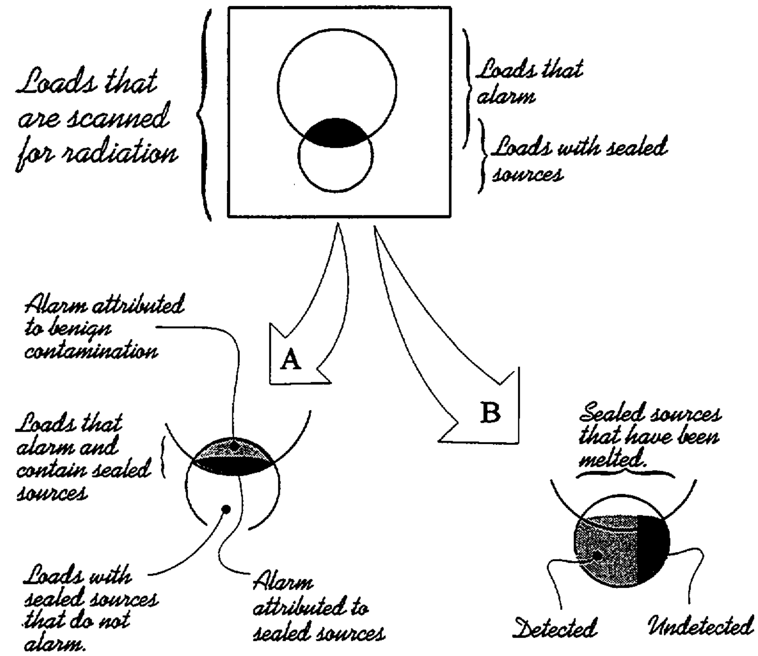


Figure 7 Aspects of the subject deduced from reported discoveries of radioactive material in the recycling stream.

a radiation alarm. The larger circle represents loads that alarm because they contain only BC and loads that alarm because they contain a sealed source. Only a portion of the smaller circle overlaps with the larger circle; these are loads containing sealed sources that alarm.

Illustration (A) in Figure 7 is a breakdown of the overlapping area loads that alarm and contain sealed sources. In some of these loads, the alarm is attributed to the sealed sources. In other loads, the alarm is attributed to BC, not to the sealed sources that are also in the loads. The load is superficially investigated; if NORM is seen or radiation appears to be coming from the rib of the transporting vehicle, the alarm may be attributed to the BC.

Illustration (B) in Figure 7 represents sealed sources that are missed because either the alarm was attributed to BC or heavy shielding around a sealed source prevented detection. In either case, the sealed source will be melted in a furnace at a steel mill. The lighter shaded area represents the incidents where a sealed source is melted and then detected. The darker shaded area represents the sealed sources that are not known to have been melted.

Although parameters cannot be readily estimated from the data summarized in Reference 1 to obtain the relative sizes of the areas in Figure 7, insights about the area of undetected meltings in Figure 7 can be obtained from statistical inferences. During the period from 1983 through 1994, fourteen incidents of melting ^{137}Cs and one incident of melting ^{60}Co at minimills processing carbon steel scrap metal were reported. During the same period, no such incidents were reported at integrated mills. This observation suggests that the minimills are more vulnerable to melting radioactive material than the integrated mills. The reasons given to explain why integrated mills have not reported melting radioactive material to date are chance and high-quality (e.g., added assurance of no radioactive material) supplies of scrap metal (Ref. 10). The data summarized in Reference 1 can be used to estimate the chance. The discussion focuses on incidents of ^{137}Cs meltings. Because of the paucity of data, the discussion of ^{60}Co meltings is more tentative. The discussion is important for a risk analysis in the following ways:

- The statistical inference strengthens the argument for the existence of the area in Figure 7 representing undetected meltings of radioactive material.

- In the analysis of the steel industry, the integrated mills must be taken into account when gathering information with a survey for the analysis of the steel industry (see Section 7.7).

Monitoring for ^{137}Cs

Minimills currently consume about 70% of the scrap metal supply, leaving integrated mills consuming about 30%.[1] Intuitively, the vulnerability of a mill is expected to be proportional to the amount of scrap metal consumed. Making this assumption of proportionality and using the 1996 consumption ratio of 70/30, about six meltings would have been expected at integrated mills during the 1983 through 1996 period, yet no meltings have been reported. The chance of observing zero meltings when about six meltings were expected would have been about 1 in 400, which is highly unlikely.[2] The 1 in 400 chance seems to refute one possible reason why integrated mills have not melted ^{137}Cs — good luck. The estimate of 1 in 400 is a lower bound of the chance. The fourteen incidents of ^{137}Cs being melted are those that have been *reported*. Between 1983 and 1996, before radiation monitoring became a common practice (see Figure 18), radioactive material may have been unknowingly melted. More than 14 incidents at the minimills would mean that more than six incidents are expected at the integrated mills.

Another possible reason for the apparent lack of meltings at integrated mills is higher quality control of scrap metal at the integrated mills than at the minimills. This, too, does not seem to be a plausible explanation of the observed prevalence of melting radioactive material at the minimills. High-quality controls also exist at minimills, especially at the mills that melted radioactive material; yet some of these mills melted radioactive material a second time. While integrated mills tend to purchase only high-quality scrap metal, this should not be confused with a high quality of practices to ensure that scrap metal contains no radioactive material. Though differences can be found from one mill to another, the quality of the monitoring practices at minimills and integrated mills seems to be the same. Weaknesses in the practices at both types of mills are evident (e.g., see Section 7.6).

Though only speculation is possible at this time, a reason for the lack of detection at the integrated mills may be the treatment of the furnace dust. When melted, ^{137}Cs vaporizes and adheres to the furnace dust. The U.S. EPA classifies dust from a minimill as a hazardous waste because of the high content of heavy metal. This furnace dust cannot be simply buried, but must be sent to a processor.[3] When hazardous waste is known to be radioactive, it must be treated as a mixed waste and processed by a more expensive method. The expense of mixed waste disposal has created incentives for hazardous waste processors to monitor furnace dust for radiation before taking possession of it; if radiation is detected in the furnace dust, the processor will return it to the shipper. To avoid the expense of returned loads of radioactive furnace dust and other expenses, minimills monitor the dust for radiation before shipping it to a processor. Therefore, radioactive furnace dust is likely to be detected. In contrast, the furnace dust from an integrated mill is not considered a hazardous waste by the EPA. The furnace dust from an integrated mill can be buried in a landfill. Although radiation monitors may also be at landfills, this does not appear to be the case for the landfills receiving the furnace dust from the integrated mills. There is no reason to monitor this furnace dust. Therefore, radioactive furnace dust from integrated mills may not be detected.

1 / Source: Telephone conversation on March 6, 1997, with C. Bechak, Steel Manufacturers Association, Washington, DC.

2 / The chance is calculated with the Poisson distribution.

3 / Furnace dust can be processed by a mill, such as in glassification, to make materials that can be used for sandblasting or fillers. Onsite processing appears to be uncommon.

Monitoring for ^{60}Co

Some steel mills have radiation gauges (nuclear, x-ray) to monitor their production lines. These same gauges might also detect ^{60}Co, which forms an alloy with steel; others do not. Some mills monitor their product going out of the mill; others do not. While test pieces may be monitored for radiation (see Section 7.4), both the capabilities of the equipment and the practices of using the equipment that allows its capabilities to be realized vary considerably from mill to mill. This raises a concern that products containing ^{60}Co may exit some steel mills without being detected.

2.6 Progression of the Analyses

The topics represented by Figure 6 are shown in Figure 8 Shade-coded boxes indicate the treatment of the topics in the risk analysis. A black box indicates a rigorous accounting of a topic. A shaded box indicates that a topic is accounted in some way, such as in a simplified form or at least acknowledged. A white box indicates that the topic is not analyzed. The large shaded arrows at the top of the figure indicate the progression of both the nuclear gauges when control is lost and the order of the discussions. The thin lines at the bottom of the figure indicates that portions of the licensees, scrap metal consolidation, and steel mills are part of the public domain.

2.7 Observations and Insights

1. The data about radioactive material discovered in the recycling stream is difficult to analyze.

2. Much of the reported discoveries of radioactive material in the recycling stream posed no danger to life and property. NORM, iodine, krypton, thorium, and tritium pose no danger to the property of the steel industry; these radioactive materials constitute 62% of the discoveries.

3. All of the reported meltings of radioactive material have been at minimills, and none have been reported at integrated mills. Differences in the purchasing and processing of scrap metal do not seem plausible because differences are neither evident in site visits nor specified in explanations that have been

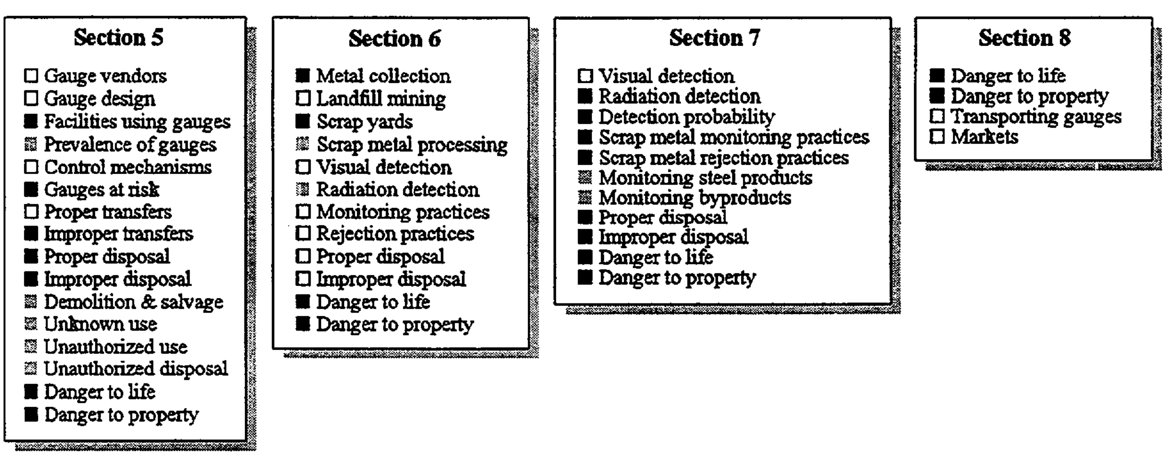


Figure 8 Topics discussed in this report. LEGEND: Black bullets indicate that a topic is rigorously taken into account in the risk analysis. Gray bullets indicate that a topic is qualitatively taken into account. White bullets indicate that a topic is beyond the scope of the risk analysis.

offered. If chance is the reason, the integrated mills are indeed lucky; the chance is 1 in 400. There may be a reason; it is just not evident. But the reason should be stated so that other mills can benefit.

4. Visually detecting nuclear gauges in the recycling stream is a remote possibility. If nuclear gauges are visually found in the recycling stream, then the prevalence of gauges in the stream is high.

5. If the prevalence of hazardous radioactive materials could almost be eliminated, the steel industry would still be subject to the costs of false alarms from BC.

3 PRINCIPLES OF THE RISK ANALYSIS

3.1 Overview

The principles of the analyses in Sections 5, 6, 7, and 8 need to be understood to understand insights and interpret risk estimates. Though the system is nebulous at first glance, firm principles clearly demarcate what the analyses represent. This study is not a straightforward application of systems analysis to a device or a facility. The *system* that is analyzed consists of domestic stakeholders (licensees, scrap yards, and steel mills). The industry wide view is appropriate because the problem itself is regional, not localized to a particular industry or geographic location.

For discussing the principles of this risk analysis, the licensees are represented simply as the prevalence of gauges in all locations throughout all industries; the movement of the gauges between these locations is irrelevant. The scrap yards and the steel industry are represented as a stream of scrap steel going from a source to a sink; the scrap steel is a carrier medium in which the gauges are "floating" past radiation monitors.

A simple example of a risk calculation shows the structure of the analyses that is applied to the study of nuclear gauges. Sections 5.5, 6.4, 7.7, and 8.4 give the details of particular stakeholders. These calculations allows *changes* in controls on the gauges to be evaluated by assessing *changes* in risk.

Typical products of a risk analysis are insights, aggregate risk estimates, and risk triplets. Insights, that are of use to all stakeholders, can be obtained from a structured analysis without calculating risk. Aggregate risk accounts for the chances and consequences of all plausible pathways. The risk triplet distinguishes between high likelihood-low consequence pathways and vice versa. Uncertainty is an integral part of risk and must be expressed. Clear displays of risk estimates facilitate an understanding of observations and insights.

3.2 Concepts

The risk analysis reflects a compromise of many competing factors. The limiting factor is the availability of information for inputs to the analyses. Within this limitation, the detail in the analyses of licensees, scrap yards, and steel mills is more or less the same.

3.2.1 Licensees

The prevalence of nuclear gauges at any time throughout the United States is the number of gauges present at the time. Let $x(t)_i$ be the number of gauges in the jth location throughout industry at a time t. The prevalence is expressed by Equatioh.

$$\mathcal{P}(t) = \sum_{j=1}^{m} x_j(t) \qquad [1]$$

$\mathcal{P}(t)$ = prevalence of gauges throughout all industries
$x_j(t)$ = number of gauges in the jth location
t = time
m = number of locations

In the analysis of the licensees, the possible locations of the gauges are as follows:

- in use, on an operating process unit
- out of use, on an operating process unit
- on a process unit that is in maintenance
- in storage
- on a defunct process unit
- on a process unit being dismantled

The proportion of gauges in the jth location at time t is given by Equation 2.

$$\varphi_j(t) = \frac{x(t)_j}{\mathcal{P}} \qquad [2]$$

$\varphi_j(t)$ = proportion of gauges in the jth location at time t

Substituting Equation 2 into Equation 1, and dividing by $\mathcal{P}(t)$ yields Equation 3.

$$1 = \{\varphi(t)_1 + \varphi(t)_2 + \cdots \varphi(t)_m\} \qquad [3]$$

Equation 3 is a conservation equation—the gauges have to be somewhere.

With a given set of economic and regulatory conditions, an equilibrium is established and $\varphi(t)_j$ for any location throughout industry is assumed constant over time. The equilibrium is a result of the market forces for the gauges and the products made with the gauges. The equilibrium is also a result of the regulatory system in that the system imposes costs for using the gauges; high costs create incentives for industry to find substitutes, either by replacing the gauges themselves with another type of measuring device or by changing the process so that the gauges are no longer needed. The equilibrium has a risk depending on the distribution of all gauges among all locations. When regulations are changed, stress may be placed on the equilibrium, causing it to shift—gauges are redistributed among the locations. An example is not allowing unused gauges to be stored at a facility. The reestablished equilibrium has another value of risk.

> Assumption: The distribution of gauges among the locations is approximately constant. Basis: The U.S. economy and the regulatory systems (environmental, occupational, and nuclear) are changing little.

The gauges in the locations are in an equilibrium. Though gauges are being taken in and out of the locations, there is no appreciable change in the distribution. This is important for three reasons:

- The transitions during which the gauges move among the locations are unnecessary to take into account for a risk analysis. A transition is not where the risk arises. For example, a gauge may not move itself, but instead, the process unit changes state, from operating to being shut down for maintenance. Or, if the gauge is moved, such as to storage, it is being taken to a definite place, not being discarded. In either case, the gauge is not at risk of being discarded as a result of the transition from one location to another. The risk results from the location that the gauge is in at any given moment.
- The distribution of gauges among the locations can be determined from a survey of licensees (see Appendix B). The results of the survey are relevant so long as economic and regulatory circumstances change little.
- Time can be dropped from the designation of prevalence and location. Thus, $\mathcal{P}(t)$ and $x_j(t)$ can be written simply as $\mathcal{P}$ and x_j.

3.2.2 Scrap Yards

Scrap metal is collected and processed before it is sent to the steel mills. The numerous and varied routes of scrap metal entering the scrap yards are of little consequence for a risk analysis (see Section 6.3). The concern, particularly in this discussion, is for the supply of scrap metal going to the mills along with whatever gauges it may contain. Two assumptions are made about the scrap metal supply containing nuclear gauges:

> Assumption: The temporal variability in the consumption of scrap metal by the mills can be ignored. Basis: Economic conditions in the United States are relatively stable.

> Assumption: Nuclear gauges are uniformly dispersed in the recycling stream. Basis: Nuclear gauges are used in many different industries throughout the country. The recycling stream is dynamic. Scrap metal is moved from sources, through scrap dealers that process it, to mills that consume it. Sealed source devices have been found in the recycling stream hundreds of miles from where they were licensed to be used.

Although two mills, Auburn Steel in New York and Newport Steel in Ohio, have melted radioactive material on two occasions while most mills have not had such a melting, this observation is statistically consistent with the total number of meltings in the United States (18 meltings; see Ref. 1) from 1983 through 1997. If a mill had an incidence of four or five meltings, then the assumption would be doubtful.

Most of this supply goes to steel mills; hence, the risk along the pathways to the steel mills is assessed. Other destinations of scrap metal, occurring in smaller proportions, are not assessed (see Sections 2.4 and 2.5).

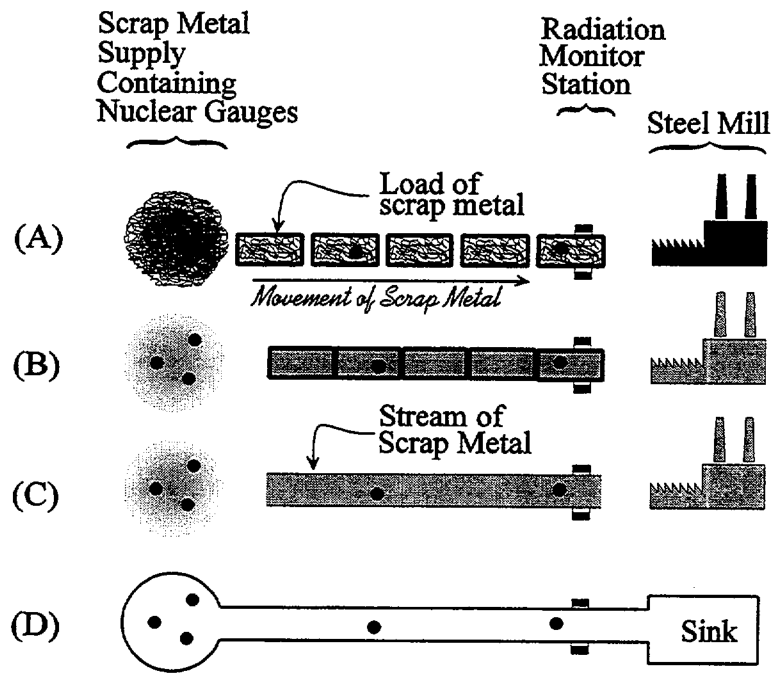


Figure 9 Movement of gauges through the recycling stream.

Figure 9 shows the movement of nuclear gauges in the supply of scrap metal. In Panel (A), vehicles are carrying scrap metal from a supply into a mill. The vehicles can be either trucks or railcars. Because the supply of scrap metal contains nuclear gauges, some of the loads also contain the gauges. Along the way from the scrap metal supply to a mill, the vehicles pass through a monitor station where they are scanned for radiation. The spaces between the vehicles are irrelevant. Panel (B) illustrates the vehicles without the spaces between them. Ignoring the ends of the vehicles, as in Panel (C), allows the individual loads to be viewed as a stream of scrap metal from the supply to a mill.

Once a load is suspected of containing a radioactive source, the radioactive source becomes the concern, not the scrap metal. Panel (D) is a stylized version of Panel (C), treating the scrap metal as a carrier for nuclear gauges moving from a supply to a sink. Along the way, the gauges may be removed when they are detected with a radiation monitor.

3.2.3 Steel Mills

Scrap metal arrives at the mills from the supply in loads. The supply is replenished with more scrap metal (and possibly more gauges). Although scrap metal arrives at the mills in loads, the stream of these loads, not the individual loads, is relevant to a risk analysis.

Further analysis will explain and justify the stream perspective in Figure 9. For clarity, discoveries of gauges at the scrap yards have been ignored for this discussion. The incidence of nuclear gauges in a *load* of scrap metal going to a mill is given by Equation 4.

$$I_{load} = \rho_{supply} \frac{L}{S} \qquad [4]$$

I_{load} = incidence of nuclear gauges in a load of scrap metal

ρ_{supply} = prevalence of gauges in the supply of scrap metal going to a steel mill at any time

L = tare weight of one load of scrap metal

S = total weight of the scrap metal supply

The incidence I_{load} is the mean number of gauges in a load of weight L. Because I_{load} is a very small number, it can be thought of as the probability of a load containing a nuclear gauge. The probability of a load containing more than one gauge is so small that it can be ignored.

At the mills, scrap metal arrives in loads L_1, L_2, ... L_n in a time period of length T. The incidence of gauges arriving at a mill in the period T is given by Equation 5.

$$I_{mill} = \sum_{j=1}^{n} \rho_{supply} \frac{L_j}{S} \qquad [5]$$

I_{mill} = incidence of gauges reaching a mill in a period T
L_j = tare weight of the j^{th} load of scrap metal
n = number of loads

The quantities ρ_{supply} and S can be factored out of the summation, leaving the summation of the total number of loads. This is the consumption of scrap metal in the period T.

$$I_{mill} = \rho_{supply} \frac{\sum_{j=1}^{n} L_j}{S} \qquad [6]$$

$$M = \sum_{j=1}^{n} L \qquad [7]$$

Then M is the total amount of scrap metal consumed by a mill in the period T.

The fraction of scrap metal consumed at a mill in the period T is given by Equation 8.

$$f_{supply} = \frac{M}{S} \qquad [8]$$

Then f_{supply} is the fraction of the domestic supply of scrap metal consumed by a mill in the period T.

$$I_{mill} = \rho_{supply}\, f_{supply} \qquad [9]$$

Equation 9 shows that the incidence of gauges reaching a mill depends on the amount of scrap metal consumed relative to the size of the supply and the prevalence of gauges in the supply of scrap metal for the mills. A load is only a means of transporting the scrap metal from the yards to a mill. Thus, the stream of scrap metal to the mills, not the individual loads, is relevant to the risk analysis. This is in agreement with Figure 9.

Considering a load of scrap metal itself for analysis, instead of the stream illustrated in Figure 9, has intuitive appeal because the load is the unit of scrap metal that is transported and because the size of the load can affect the probability of detection (a nuclear gauge is more likely to be detected in smaller loads than in larger loads). However, difficulties would be encountered when collecting information for such an analysis:

- At a given mill, and from mill to mill, the weight of a load varies.
- The data required to determine load variability would be too burdensome to request from the mills, such as through a survey of the steel industry (see Appendix C).
- A load is incompletely characterized by just its weight. Its volume is also important. Even considering vehicles of the same volume, the weight of scrap metal can vary, depending on the grade of scrap metal. Characterizing the loads with a single number, such as an average weight, may not represent the loads if the variability is high.

3.3 Structure of a Risk Calculation

A simple example (Figure 10) illustrates a risk calculation if data were available (see Section 9). The calculation in Figure 10 begins on the far left with the prevalence, ρ, of nuclear gauges throughout all the industries. Three elements describe what can happen to the gauges. The elements divide the prevalence among the plausible sequences of risk elements. A gauge subject to a given sequence has a consequence, in this example, a cost, C_i.

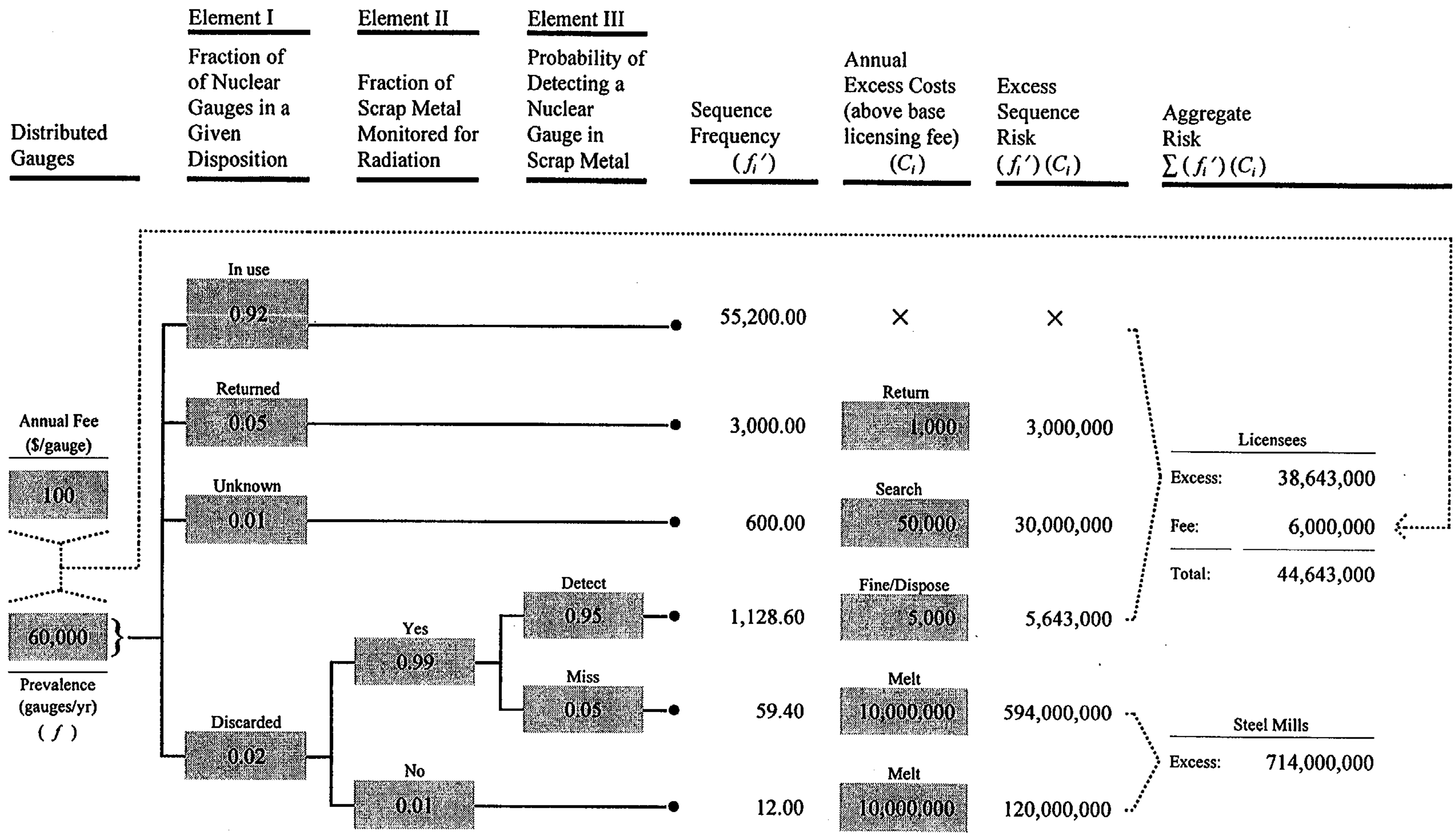


Figure 10 Example of a risk calculation. LEGEND: A number in a shaded box is an input to the analysis. Other numbers are calculated from the analysis. Solid lines (—) indicate a sequence of risk elements. } = beginning of all sequences. ● = end of a sequence.

This is the cost in excess of regular licensing fees. The product of the prevalence and consequence of each sequence is the excess risk of each sequence. The sum of the products is aggregate risk.

In Figure 10, Element I represents the various states of the gauges — in use, returned to the vendor, unknown, and discarded. Element II represents the fraction of scrap metal that is scanned for radiation. The scanning can be done incorrectly for a variety of reasons (see Item 1 in Section 7.4). This element is irrelevant for gauges in use and returned; it is undeveloped along these branches of Element I. Element III is the probability of detecting a nuclear gauge in a load of scrap metal.

The calculations in Figure 10 yield two risk estimates, one for the licensees and the other for the steel mills. Although the risk to the mills is greater than the risk to the licensees in the example, this by itself is an insufficient basis for evaluating changes in control mechanisms. These two estimates only say what Reference 1 already clearly documents — a problem exists. The two risk estimates are just two constituents of one situation; no choice is present. A decision arises when there is a choice between two situations. This is shown in Table 2. The risk given the current situation is considered the base case, R_B. A proposed change in control mechanisms is then represented by changing the inputs to Elements I, II, or III and recalculating risk. The result is Alternative 1. The comparison quantities in Table 2 are computed. A decision can then be made about the worth of changes. Other changes are assessed in a similar manner.

The example shown in Figure 10 was prepared with costs because costs readily lend themselves to illustrating a risk calculation for evaluating changes in risk. The analysis can also be performed in terms of danger to life, expressing consequences as the activity of radioactive material (see Section 8.4.1). Changes in the activity of intact gauges with the shutter closed, intact gauges with the shutter open, dislodged sources, and breached sources are compared to changes in the cost to licensee and regulatory agencies. Then, as before, changes in controls on gauges are evaluated by looking at changes in risk.

3.4 Products of the Risk Analysis

The typical products of a risk analysis are insights, aggregate risk estimates, triplet risk estimates, and fractional contribution measures:

Insights. Qualitative understandings of the subject are just as important as the quantitative risk estimates. A systematic analysis serves as a structure for inductive reasoning.

Aggregate Risk Estimates. The term *risk* has many definitions. Equation 10 is modified from the definition of risk in Reference 5.

$$R = \sum_{j=1}^{n} \mathcal{P}_j C_j \qquad [10]$$

- R = aggregate risk
- $\mathcal{P}_j$ = prevalence of nuclear gauges on the j^{th} risk element sequence from a licensee to the final disposition
- C_j = consequence of the j^{th} sequence of risk elements
- j = sequence of risk elements
- n = number of sequences from the use of gauges to the consequences

Triplet Risk Estimates. The risk triplet is the set $\{\tau_j, \mathcal{P}_j, C_j\}$ in which τ_j represents the j^{th} sequence, $\mathcal{P}_j$ is the associated prevalence of gauges in an environment, and C_j is the resulting consequence (Ref. 12). This definition distinguishes sequences with low prevalence and high consequence from sequences with high prevalence and low consequence. Aggregate risk (i.e., Equation 10) is appealing because it is a single number, but information is lost in going from the risk triplet to aggregate risk. The triplets can be displayed as shown in Figure 11. The contour lines indicate constant risk isorisk curves. The shaded areas represent triplets that have been grouped.

Table 2 Evaluating changes in risk.

	Licensee	Steel Mill	Purpose of the Calculations
Base Case			
	R_B^L	R_B^S	Evaluate the current situation.
Alternative 1			
	R_1^L	R_1^S	Evaluate a proposed set of changes in control mechanisms.
$\Delta_1 = R_1 - R_1$	Δ_1^L	Δ_1^S	Decision based on considering difference and ratio of risk relative to the base case.
$\Gamma_1 = \frac{R_1}{R_B}$	Γ_1^L	Γ_1^S	
Alternative 2			
	R_2^L	R_1^S	Evaluate another proposed change in control mechanisms.
$\Delta_2 = R_2 - R_B$	Δ_2^L	Δ_2^S	Decision based on difference and ratio relative to the base case.
$\Gamma_2 = \frac{R_2}{R_B}$	Γ_2^L	Γ_2^S	
		⋮	
Alternative n			
	R_n^L	R_n^L	Evaluate the n^{th} set of changes in control mechanisms.
	⋮	⋮	⋮

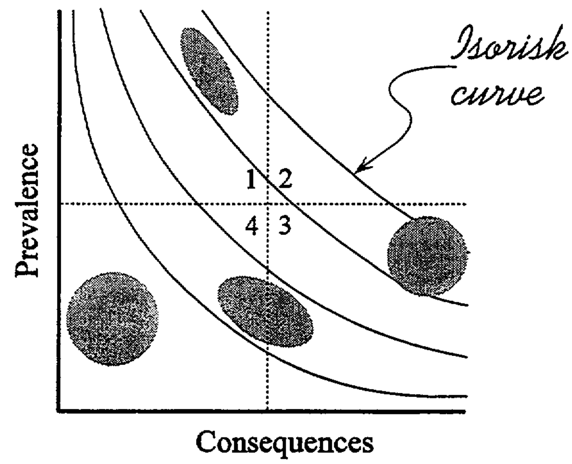


Figure 11 Resolving the prevalence and consequence of risk estimates. LEGEND: Shaded areas are groups of triplets having similar prevalence and consequence.
1 = quadrant of high prevalence and low consequence risk.
2 = quadrant of high prevalence and high consequence risk.
3 = quadrant of low prevalence and high consequence risk.
4 = quadrant of low prevalence and low consequence risk.

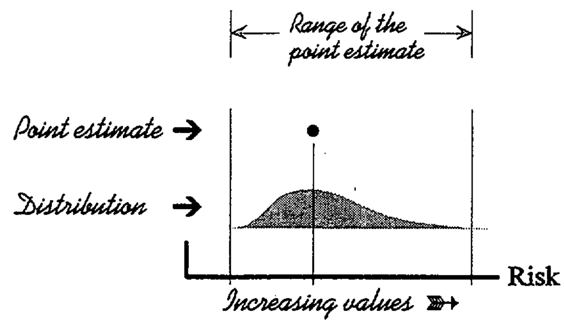


Figure 12 Differences in perspectives given by a point estimate and the distribution of a random variable.

Fractional Contribution Measure. Sequences can be grouped according to the final state of the nuclear gauge. The risk from each group is computed according to Equation 11.

$$\mathcal{F}_j = \frac{\sum_{j=1}^{n} \frac{R_{j,k}}{R_T}}{n} \quad [11]$$

$\mathcal{F}_j$ = fraction of risk from the j^{th} group of risk element sequences
$R_{j,k}$ = k^{th} risk estimate of the j^{th} group of sequences
R_T = total aggregate risk for all groups of risk element sequences
n = number of sequences in the j^{th} group

3.5 Uncertainty in Risk Estimates

Figure 10 shows a simplified view of the calculations using only one value for each of the inputs. A point estimate of risk is computed from a single set of inputs. But the practices and phenomena represented in a risk analysis are only partially understood—there is often much uncertainty about the inputs.. For many of the inputs, many plausible values may exist; hence, many plausible results exist. With uncertainty being an integral part of a risk estimate, a point estimate is only one of many possible risk estimates. A point estimate without an indication of the uncertainty can be taken to imply that the uncertainties are negligible, which is doubtful.

A point estimate can be misleading for may reasons. Figure 12 shows a hypothetical distribution drawn on an arbitrary scale. The distribution represents a large amount of uncertainty. Given a point estimate and not knowing the distribution in advance, where would the point value fall in relationship to the distribution?

There is a tendency to try to associate the location of the point estimate with the unknown distribution by characterizing the input as a "best" estimate. This implies that the point estimate output of a mathematical function is also a best estimate. A problem with the term *best estimate* is that it is vague and seldom defined. One possibility is that *best* means *unbiased.* An *unbiased estimate* of a parameter is one whose mean value is equal to the parameter being estimated. Mathematically, the mean of a random variable is called the *expected value*. The output of a mathematical function would be a best estimate only for a linear function. Suppose that a random variable X has a mean μ. Consider the function Y = aX. The mean of Y is $a\mu$ and is written as:

$$E(Y) = a\mu \qquad [12]$$

E(Y) = expected value of Y
a = constant
μ = E(X), the expected value of the random variable, X

Thus, if X is a best (unbiased) estimate of μ, then Y is a best estimate of $a\mu$. But the mathematical functions in a risk analysis can be nonlinear. If a mathematical function is nonlinear, such as $Z = X^2$, then a best estimate of μ^2 should be an unbiased estimate of μ^2. However, the expected value of Z is not μ^2. Rather, it is:

$$E(Z) = \mu^2 + \sigma^2 \qquad [13]$$

σ^2 = variance of X

If σ^2 is large (large uncertainty about X), then E(Z) would be a highly biased estimate of μ^2 and would not be a best estimate of μ^2. Thus, the rules for propagating point values through the equation differ from the rules for propagating both distributions and the quantities describing distributions (i.e., mean, median, mode).

Expressing the uncertainties can change the way in which risk estimates are perceived. Figure 13 shows hypothetical point estimates and distributions of three quantities, A, B, and C. Suppose that the relative importance of A, B, and C is to be determined. Using the point estimates, $C < B < A$ and $C < A$. However, using distributions is more complicated. Because of the large amount of overlap, one concludes that $C \approx B$ and $B \approx A$. But one cannot conclude that $C \approx A$ because there is little overlap in these distributions. In fact, one could make a case that $C < A$. Thus, transitivity does not hold when uncertainty is taken into account. These problems do not exist with point estimates, but point

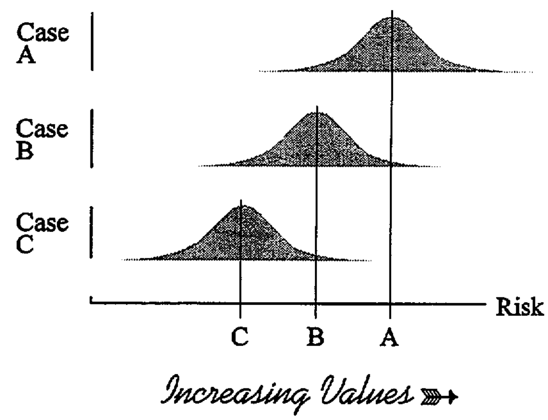


Figure 13 A comparison of point estimates can lead to conclusions that differ from a comparison of distributions.

estimates clearly give a distorted view of the relative importance of the quantities. Ranking issues and comparing issues is more complicated when uncertainties are expressed.

Figure 13 portrays a situation in which risk estimates A, B, and C are independent. Dependency must be assessed for it, too, influences the way in which the uncertainty in risk estimates are perceived. Suppose, for example, that A, B, and C were dependent: $A = B + k'$, $B = C + k''$, and k' and k'' are positive constants. Then each estimate of A, B, and C in their distributions is always such that $A > B > C$; in this regard, the overlap of the distributions is irrelevant. The spread of the distributions mean that A, B, and C cannot be precisely estimated. In practice, risk estimates will likely be somewhere between independent and dependent. A careful analysis of dependencies is warranted.

3.6 Illustration of Risk Results

A distribution of risk results is illustrated in Figure 14. The distribution on the bottom is what is calculated. The box-plot on the top is common because it is easy to draw and to interpret.

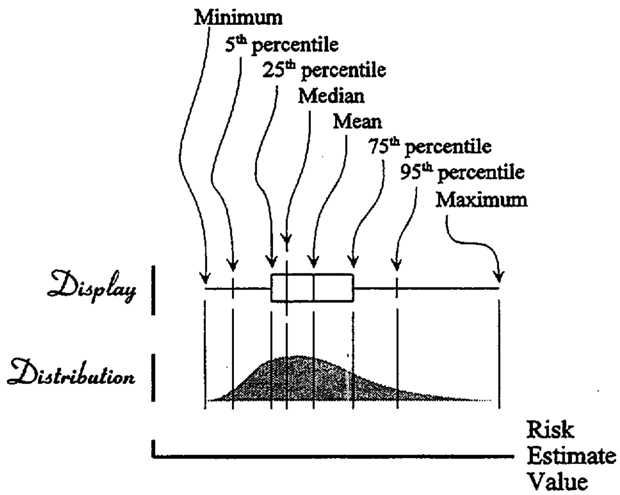


Figure 14 Box-plot (top) and distribution (bottom) of risk estimates.

Caution is necessary when displaying risk estimates. In Figure 15 (A), the number of risk estimates in each interval is the ordinate. Because the abscissa is expressed as an exponential scale, only the heights, but not the areas, of the blocks are proportional to the number of outcomes in the intervals. Therefore, Panel (A) is properly considered a bar chart, not a histogram. The graph can be converted to a histogram by converting the abscissa from an exponential scale to a linear scale, plotting the logarithm of risk. Using the logarithm of risk, Panel (A) is properly termed a histogram because the areas, not the heights, are proportional to the number of risk estimates in the intervals. The shape of the blocks remains the same, but the abscissa is now unitless. The difficulty with such a transformation is that the unitless abscissa has no physical meaning; the interpretation of the histogram is unclear.

The exponential scale of Panel (A) gives a distorted view of the risk estimates from an analysis. The intervals on the left of the graph are much smaller than the intervals on the right. This distortion can be removed by dividing the number of counts for each block by the interval width. In Figure 15, Panel (B) shows what happens when this is done. Because the block counts are now proportional to the areas, the graph is properly called a histogram. The shape of the graph has been shifted to the left. But a distortion still remains; because of the exponential scale, the visual width of the blocks does not correspond to the numerical width.

The graph can be redrawn to make the visual width coincide with the numerical width by converting the abscissa from an exponential scale to a linear scale, as shown in Panel (C) of Figure

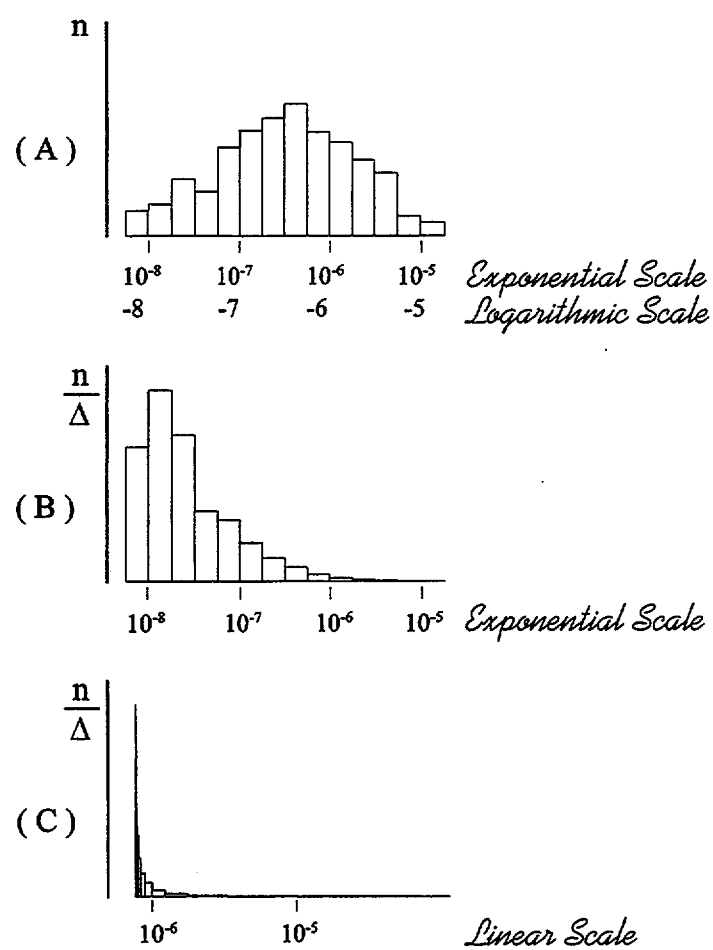


Figure 15 Visual displays can influence perceptions of risk estimates.

15. The shape of the graph is pushed far to the left, giving a much different impression of the distribution than Panel (A).

Panels (A) through (C) illustrate how easily impressions can be changed simply by changing the scale of the abscissa. While bar charts, such as in Panel (A), do not in and of themselves misrepresent the results of a risk analysis, their visual appearance can be misleading. Because the appearance of bar charts (e.g., Panels (A) and (B) of Figure 15) can change drastically, depending on the scale of the abscissa, the visual interpretation of the charts can also change. Inferences made from the visual appearance of a bar chart having a log scale can be misleading; they are of limited use. While Panel (C) accurately represents the density function, it too is of limited use because the details of the distribution are lost. Other pictorial representations on log scales can suffer from limitations similar to the bar charts. Inferences should be based directly on numerical results, not on somewhat uninformative pictorial representations.

4 INFORMATION

4.1 Overview

Information can be divided into three categories. First-degree information are data. Second-degree information is informed judgment. Third-degree information is plausible judgment. This characterization facilitates discussion about the information supporting the elements of risk in an analysis.

Reference 1 is an excellent summary of the radioactive material discovered in the recycling stream. With other information, the data of Reference 1 can be reworked to gain insights for a risk analysis. But the data are a sample of convenience. Because it was not obtained with statistical methods, it cannot used to estimate probabilities.

Experiments are needed to characterize the probability of detecting a nuclear gauge in the recycling stream. To date the capability of some radiation monitor equipment have been characterized. Of more use would be fundamental information about the shielding characteristics of scrap metal loads that could be used to predict the detection probability using other equipment and loads of scrap metal commodities.

4.2 Concepts

The analysis is to be supported by empirical data as much as possible (Ref. 7). A strategy is needed to characterize the parameter estimates according to the type of information on which they are based. Such a strategy consists of three categories of information and the resultant parameter estimates:

- First-degree estimates are completely based on data. If the data are sparse or highly variable, a first-degree parameter may be highly uncertain.

- Second-degree estimates are based on informed judgments. Informed judgments are made by experts who are familiar with relevant data. Such people may be found in industry. The key to informed judgment is familiarity with data. Second-degree estimates can have varying amounts of uncertainty.

- Third-degree estimates are based on plausible judgments. A plausible judgment is based only on superficial knowledge and is generally highly uncertain.

Degrees of information are used in Sections 5.6, 6.5, 7.8, and 8.5 to discuss the information that can be obtained for assessing risk.

Here, for discussion, parameters are sometimes referred to by the degree of their associated estimates (e.g., a third-degree parameter is one that is estimated with third-degree information).

The quality of risk estimates is a function of both the quality of the information used to estimate the parameters of an analysis and the significance of the parameters in determining risk. Low-quality information for estimating some parameters may be of little concern if the parameters do not significantly contribute to the risk. The contribution of parameters estimated with low-quality information may be overshadowed by the contribution of parameters estimated with higher quality information. On the other hand, significant parameters may be unknown.

The quality of a risk estimate can be determined with importance measures (Ref. 5). The measures can be applied here to calculate the percent contribution of each risk element to an estimate of aggregate risk. These percentages can be grouped by the degree of information used for their respective elements. A ratio can then be formed to express the quality of information used to estimate risk. This ratio, called the data-mix ratio (DMR), conveys the relative amounts of information types in the risk estimate. Suppose a risk assessment was made and 43% of the risk was attributable to elements with first-degree information, 31% to second-degree information, and 26% to third-degree information. The DMR would be 43:31:26, with the understanding that the first number is for first-degree information, the second number is for second-degree information, and the third number is for third-degree information. This particular DMR conveys the notion that most of the risk is based on data and informed judgment; about a quarter of the estimate is based on plausible judgment.

In addition to examining the elements of risk and making risk estimates, the risk analysis serves as a structured way to address the issue of what resources should be expended to obtain data. A simplified analysis is illustrated in Figure 16. The figure shows three stages of nuclear gauges — at risk, discarded in the recycling stream, and detected with radiation monitors at scrap yards and steel mills. The shaded area in the box of the licensees represents the control mechanisms. The controls are imperfect, placing the gauges at risk of being improperly disposed of and transferred; hence, the regulatory area is shaded, not opaque. The extent to which the gauges are at risk is measured by the probability of the gauge being at risk, Pr{at risk}; this is the extent to which the mechanisms operate. The discard probability, Pr{discard}, measures the extent to which a gauge, which is at risk, will be inadvertently discarded into the recycling stream. Toward the end of the recycling stream are radiation monitors, whose effectiveness is measured by the detection probability, Pr{detect}.

If Pr{at risk} could be made zero, then the availability of data for estimating Pr{discard} and Pr{detect} would become irrelevant. But some gauges are at risk; Pr{at risk} > 0. Hence, the availability of data to estimate the discard probability and the detection probability is of concern. However, if Pr{at risk} is sufficiently small, then the quality of information to estimate Pr{discard} and Pr{detect} may not need to be very high. An analogous argument holds if the gauges could always be detected by the radiation monitors (i.e., Pr{detect} = 1). But because gauges can be missed, Pr{detect} < 1, and the availability of data to estimate the probability of

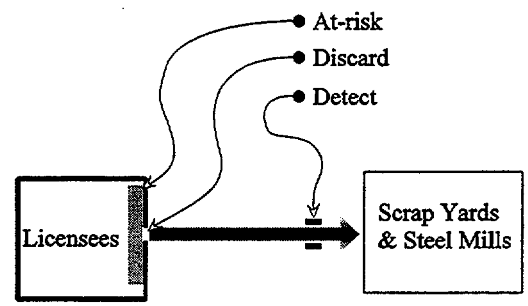


Figure 16 Three stages of nuclear gauges in the recycling stream for illustrating concepts of information.

gauges being at risk and being discarded is of concern as well.

A survey cannot be done in stages as parameters are known to be important; for convenience, a well-designed survey must be done all at once. Nonetheless, the above concepts are valid. Valid estimates of parameters allow a starting point for determining what is and what is not important. More attention, possibly supplemented with data or expertise from other sources, can then be focused on important parameters.

4.3 Sources of Information

4.3.1 Surveys

First-degree and second-degree information for most of the elements of risk are readily available through surveys (see Appendices B and C). Thus, third-degree information is, for the most part, unnecessary. Surveys are also needed to collect information on the conditions that exist in industry in a way that is compatible with the analyses in Sections 5.6, 6.5, 7.8, and 8.5. Every licensee is unique; there are many practices for caring for and maintaining control of nuclear gauges. Every steel mill is unique; there is no standard configuration of radiation monitor equipment at steel mills, nor can there be because what is possible at one mill may be impractical at another mill. Surveys are the only practical way to obtain the technically sound information necessary for assessing risk.

Surveys were developed by consulting experts as appropriate. No single review group could have developed the surveys because of the diversity of expertise needed—survey design, risk analysis, industrial operations, regulations, and statistics. The development of the survey was guided by a professional survey designer at the Los Alamos National Laboratory to conform with established and tested practices (Ref. 13). But ultimately the development of the survey was between the principal investigator and people in industry.

The method for developing the surveys was intensive pilot testing (Ref. 13). This method is employed when there is a shortage of resources, or when the population to be surveyed is small. A survey can be tested on a small number of people because the testing gathers information that would otherwise require a larger sample. During pilot testing, the short-term memory of respondents is meticulously tapped to determine flawed aspects of the survey. While a respondent thinks out loud, notes are taken about verbal and nonverbal communications (e.g., pauses, hesitations, tone, exclamations, emphasis, hand movements, facial expressions). The test results were carefully studied to understand the flaws in the survey, then to decide upon changes to correct the flaws. Many times, changes were discussed with the survey designer as were intentions to revise the survey form and make appropriate adjustments to plans for completing the pilot tests.

Some deviations occurred from the established procedures during the test sessions and include the following:

- Respondents reviewed the survey, instead of attempting to complete the survey, because some information would have to be obtained from other people not present at the test sessions. The reviews were sufficient for exploring the reasonableness of the questions, the interpretation of the questions, the transitions to parts of the survey, and the opinions of the survey.

- The principal investigator asked questions and gave prompts while a respondent was reading the survey, instead of waiting until the respondent had completed the survey. The disruption in the flow of thought was traded for readily tapping into short-term memory.

- Some tests were done at facilities previously visited, instead of all tests at unfamiliar places. The rapport developed during those visits may bias the test and make the testing somewhat nonrepresentative. Only a few tests were done as such, either to ease the principal investigator's transition into testing the survey at unfamiliar facilities or to readily gain access to facilities.

The deviations were judged to have a minor impact on test results.

The testing addressed difficulties that typically arise when conducting a survey. The cover letter was the means of motivating respondents. There was some concern about proprietary or sensitive information but, in general, this concern did not dissuade respondents from looking at the questions; as respondents read the survey, this concern dissipated. The length of the surveys was always a concern. Though the number of pages of the steel industry survey was a little daunting at first, respondents soon found that the pages were not completely filled with questions and the questions could be readily answered.

Some questions were about sensitive issues. These survey questions were worded, and the analysis constructed, to desensitize the questions:

- The questions were asked in the future tense, "How likely is it that the following would be done?"

- Nonsensitive possibilities were listed and sensitive possibilities were grouped into a nondescriptive category called "Other."

Section 5.6, 6.5, 7.8, and 8.5 show the need for each question of the surveys in Appendices B and C. The questions themselves focused on issues of risk. For example, the survey of the steel industry asked about the use of scrap metal. But some commodities of scrap metal are unlikely to contain nuclear gauges; scrap metal turnings are a byproduct of lathes. Also, information about scrap metal turnings may be sensitive because turnings may contain cutting oil, which is an environmental hazard. Therefore, questions asking about the use of scrap metal were about the commodities that are likely to contain nuclear gauges. Focusing on the risky types of scrap metal has another advantage; the amount of information that is collected through a survey can be reduced.

The testing was done until the changes appeared to be getting into the realm of personal preferences rather than finding flaws in the survey. At this point, respondents said that the surveys were very reasonable. The pilot testing resulted in surveys that asked for a minimal effort from respondents to obtain essential information in a proven manner.

Some people might consider a survey to be biased because it was reviewed by industry. Bias because of self-interest would be a concern if industry wanted a particular outcome. But the surveys are collecting information about nuclear gauges, radiation monitors, and practices. There is no obvious reason to bias the response to questions. Inaccurate answers may create a view of the circumstances in industry that may lead to changes in controls on the gauges (see Section 5.4) that are either more or less stringent than necessary.

4.3.2 Empirical Data

Reference 1 is an excellent summary of the radioactive material discovered in the recycling stream. The reference is essential for beginning a risk analysis, documenting that control over nuclear devices is less than desirable, thereby justifying a risk analysis. The data show that the loss of control is not an unusual event and is recurring. Though the information in Reference 1 is first degree, it is unsuitable for a risk assessment for many reasons.

Reference 1 is an observational study, not a controlled experiment. An observational study is useful; many times, this is all that can be done. No plant manager of a steel mill is going to allow sealed sources to be placed in loads of scrap metal to determine how many will be found by radiation detectors and how many will be found after being melted in a furnace. But difficulties in using the data stem from the way in which the data were necessarily collected and the time over which they were collected.

Collecting Data

The data summarized in Reference 1 are from many sources:

- Nuclear Regulatory Commission (NRC) reports;
- notices from mills of detections in loads of scrap metal;
- notices from scrap yards of detections in loads of scrap metal;
- trade associations that collect reports of detections from their members;
- notices from people in other States who know of this database; and
- U.S. Department of Transportation Exemption 10656 reports for returning loads of scrap metal suspected of containing radioactive material.

The information in the Reference 1 database focuses on discoveries of radioactive material beyond control mechanisms and includes materials such as naturally occurring radioactive material (NORM) and radium (see Section 2.2) that are not regulated by the NRC. Some of the data are ambiguous, raising a concern for misclassification. Many issues need to be thoroughly understood to draw valid conclusions. Yet many aspects of the data are unknowable considering the following:

- The criteria for reporting are largely unknown. The data summarized in Reference 1 come from a variety of sources, some of which have no reporting criteria.

- The population reporting is unknown. Who was aware of the radioactive material in the recycling stream and when they were aware are unknown. Who was aware of data being collected and specifically what was reportable (discoveries of any radioactive material, NORM, rejected loads) are unknown.

- The extent of reporting is unknown. Collecting data is not a responsibility of steel workers.

- Many alarms of the radiation monitors are unreported. Some mills simply turn away loads that cause an alarm (see Section 7.4). The extent to which these alarms are recorded remains unknown.

The data summarized in Reference 1 were collected as they could be gathered. This means that the data are a sample of convenience, not a random sample (see box, "Sample of Convenience"). Probabilities cannot be estimated from a sample of convenience (Ref. 14, page 369).

With a sample of convenience, uncertainty bounds on a point estimate usually do not make sense and are likely to be incorrect: formulas for the uncertainty bounds have to take into account the details of the method used to draw the sample. An uncertainty bound is an integral part of an estimate that expresses how well an estimate is to be trusted (see also Section 3.6).

Sample of Convenience

The data summarized in Reference 1 are recorded instances of radioactive material discovered in the recycling stream. Because of various difficulties in collecting data, the authors of Reference 1 acknowledged that all discoveries were not reported. Therefore, the data are a sample, but not in the usual statistical sense of the word.

A model of the situation from which the data were obtained is necessary to make valid inferences from the data. The model could then be used to design a statistical sampling procedure to estimate desired parameters. Such a model is lacking. The data were collected without an established protocol. In this regard, the data summarized in Reference 1 are not a statistical sample.

For these reasons, the data reported in Reference 1 can be called a sample of convenience (Ref. 14, page 369). The data have some characteristics of a sample but did not result from an established protocol. The data are simply what was recorded, not a random sample.

<u>Changing Circumstances</u>

Circumstances have been changing since 1983 when radioactive material was discovered in the recycling stream:

- The number of radiation monitors at the scrap yards and steel mills is increasing.

- The capability of the radiation monitors to detect radioactive material is increasing.

- The population of nuclear gauges at risk may slowly be increasing as increasing demands for high-quality products are placed on industry.

The problem may be worsening, as might be concluded from looking at empirical data. Or the awareness of the problem may be increasing, as might be concluded considering other factors. Although the observed frequency of finding radioactive sources has been increasing since the first device was discovered in 1983, a closer look at matters is warranted.

Figure 17 illustrates what appears to have happened over time. Light gray bars indicate the prevalence of NORM as reported in Reference 1. Similarly, dark gray bars indicate the prevalence of ^{137}Cs, ^{60}Co, and ^{241}Am. Both sets of bars refer to the left ordinate. The bars indicate incidents where no ambiguity in the type of radioactive material was reported. The solid line indicates receipts for scrap metal and refers to the right ordinate; this information was first compiled by the U.S. Bureau of Mines, then later by the U.S. Geological Survey (Ref. 15).

The distribution of nuclear gauges began in the late 1950s. Yet the first reported melting of radioactive material in a steel mill was not until 1983 when ^{60}Co, which forms an alloy with steel,

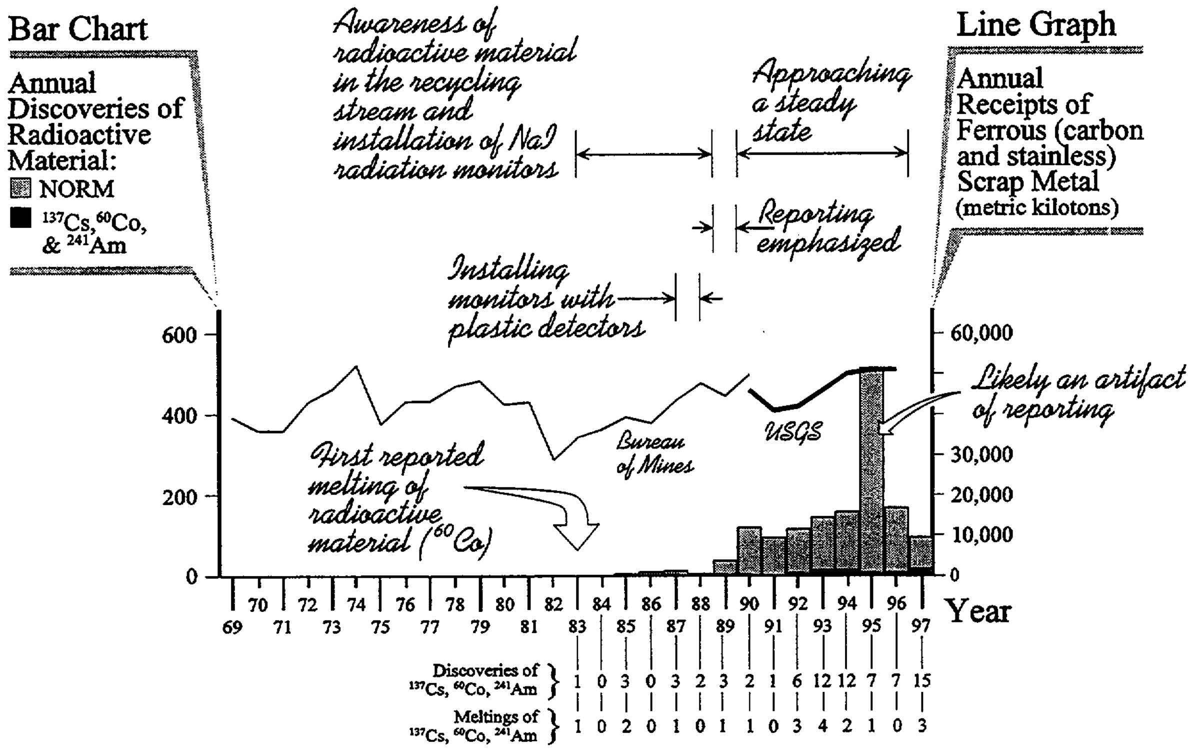


Figure 17 Analytical history of radioactive material in the recycling stream. Source: Data on the discoveries of radioactive material in the recycling stream are courtesy of James Yusko, Pennsylvania Department of Environmental Protection, Pittsburgh, PA. The data file is dated November 20, 1998. The last entry in the file is numbered 3044. Earlier versions of the data are summarized in Reference 1. The information about the consumption of scrap metal is from the U.S. Bureau of Mines and the U.S. Geological Survey (Ref. 15); data for the figure came from the Internet at *http://minerals.er.usgs.gov*. Scrap metal consumption data for the years 1969 to 1990 are in a summary table; consumption data for the years 1991 through 1996 are in the corresponding annual reports of "Iron and Steel Scrap."

caused a nuclear gauge on a continuous caster to give erroneous readings (Ref. 11). The reason for the three-decade lag between the first use and the discovered melting may be the time that gauges were on the process units before the units, and their gauges, were later scrapped. Whatever the reason, radioactive material was bound to be found with the use of nuclear gauges in the steel industry. The 1983 incident made people aware of radioactive material in the recycling stream. For the next few years, radiation monitors, likely with sodium iodide detectors, were installed. The lack of discoveries between 1983 and 1989 does not seem to be based on a lack of radioactive material in the recycling stream because NORM (see Section 2.2), which has nothing to do with regulations, is also apparently lacking. Reference 1 shows that a variety of radioactive material was found—mostly NORM, but also some ^{137}Cs, ^{251}Ra, and uranium. Most of the discoveries were made with radiation monitors, but also to a much lesser extent with survey meters, and on a few occasions, visually. The early versions of today's sophisticated radiation monitors were installed at scrap yards and steel mills in 1987 and 1988; the radiation monitors use large panels of plastic detectors to generate signals from radiation that are processed with software. From then through 1989, the increasing rate of discoveries may be due to increased awareness that radioactive material can be found in the recycling stream and to the use of sophisticated monitoring equipment.

Most of the meltings listed at the bottom of Figure 17 were of ^{137}Cs. These meltings were discovered when steel mills scanned furnace dust before it left the facilities for a hazardous waste processor. Two meltings were of ^{60}Co, one in 1983 and one in 1997. The low prevalence of ^{60}Co has two explanations. One, ^{60}Co is used less often than ^{137}Cs in gauges because of the shorter half-life. Two, the detection after melting may reflect a less rigorous monitoring of steel after it is melted (see Section 7.4). One of the meltings of ^{137}Cs in 1997 also involved ^{241}Am.

Other salient aspects of Figure 17 are as follows:

- The prevalence of ^{137}Cs, ^{60}Co, and ^{241}Am is too low to make definitive statements about trends. All that can be said is that ^{137}Cs, ^{60}Co, and ^{241}Am have been making their way into the recycling stream.

- From 1990 and thereafter, the discoveries appear to be approaching a steady state. By 1990, sophisticated radiation monitors had been developed and installed. The tapering off of the discoveries of NORM also may reflect an established reporting system, albeit with unknown and uncontrolled reporting criteria. It may also reflect the installation of radiation monitors at most metal processors.

- The peak of NORM in 1995 may reflect the lack of reporting criteria and controls. Much of this peak, 81%, consists of the discoveries from two steel mills in Texas where, because of a large petroleum industry, much NORM is expected.

Author's Note

The discussion of Figure 17 is a historical perspective. For a risk assessment, only a more recent period is of interest — a year or so that respondents would typically answer from when providing information through surveys (see Appendices B and C). During a short period, economic and regulatory conditions change little; the prevalence of gauges used in industry is approximately constant. Thus, the assumption in Section 3.2.1 of gauges found in industry being in a steady state is not contradicted by Reference 1.

Reference 1 not only shows that a problem exist but also confirms an intuitive understanding of the situation; the *discoveries* of radioactive sources in the recycling stream have been increasing since the first discovery. An increase in the rate of nuclear gauges entering the recycling stream would suggest that control mechanisms have been deteriorating. But a more plausible explanation is that the use of sophisticated monitoring equipment has been increasing. If the frequency of discoveries had instead decreased, then further investigation would be needed to reconcile the observations and intuition.

<u>Examples of Difficulties in Using a Sample of Convenience</u>

Seemingly obvious "probabilities" computed from empirical data can be misleading. Consider discoveries of radioactive material either by radiation monitors before entering the furnace at a steel mill or by monitors of product and byproduct material after entering the furnace (after melting a sealed source). Suppose there were X discoveries with the radiation monitors and Y discoveries when a sealed source was melted in a furnace and discovered in contaminated product or byproduct material. Looking at the reported experience of the entire industry, an obvious calculation is the probability of detection. Radioactive material has been discovered X times and missed Y times before entering the furnace. In this simple example, all melted radioactive material is detected. Then the probability of detection is given by Equation 14.

$$\Pr\{\text{detect} \mid \text{sealed source}\} = \frac{X}{X+Y} \qquad [14]$$

Equation 14 calculates the probability of detection conditional on a sealed source being present in a load of scrap metal. Of X + Y sealed sources present in the scrap metal being consumed by the industry, some of them, Y, are melted. But some loads causing radiation alarms are rejected without determining the reason for the alarm. Because some of the rejected loads may contain sealed sources, Equation 14 yields an underestimate of the detection probability, where sealed sources present in rejected loads are considered to have been detected. This underestimated detection probability may mislead steel mill managers to purchase less radiation monitors than otherwise would be purchased.

An estimate using Equation 14 applies to the steel industry as a whole. Of concern to each mill manager is not so much what is happening in the entire industry but what can happen to their mill. Here, too, empirical data are difficult to use. Only a few mills have melted radioactive material once. Far fewer have melted it twice. No mill is reported to have knowingly melted it more than twice. An erroneous conclusion is that the probability of melting radioactive material at most mills is zero or of melting it three times at any mill is zero. For many reasons, the detection probability at a specific mill may be quite different, higher or lower, because of the type of monitoring equipment, the placement of monitoring detectors, the practices for using them, the size of the loads of scrap metal, and the commodities of scrap metal purchased.

4.3.3 Experimental Information

Three quantities that determine the probability of detecting a nuclear gauge in a load of scrap metal are the performance characteristics of a detection system, the type and activity of radiation emitting from a gauge, and the shielding characteristics of the scrap metal. Currently, the performance characteristics of the detection systems can be well established. Characterizing the radiation source to be expected in a load of scrap metal is much more difficult. But the radiation sources can still be analytically characterized, for example, from what has been found in the recycling stream (Ref. 1) and compared to what is known to be distributed from gauge vendors. The shielding characteristics of the scrap metal are, for the most part, unknown.

The information available to the NRC staff on the shielding characteristics of scrap metal is from tests on the detection capabilities of monitor systems sponsored by the steel industry.[4] This information, known as the "gauntlet" tests, consisted of placing tubes along axes in a transporting container on a vehicle, then filling scrap metal around the tubes. After a known amount of radioactive material was inserted into one of the tubes, the vehicle was passed though a series of monitor stations. The monitor systems that detected and those that missed the source were noted. The test was repeated, varying the placement of the radioactive source in the tubes. These tests determined the capability of monitoring equipment to detect sources in loads of scrap metal.

The gauntlet tests are a starting point, but are insufficient for thoroughly characterizing the shielding of scrap metal loads in a way that is suitable for a risk analysis (see Section 7.5). The results are difficult to extrapolate to other commodities of scrap metal (such as bundles or plate and structural scrap) and other monitor systems. Experiments need to be designed to collect data about shielding from scrap metal commodities that can then be used to predict the detection probability. An earlier investigation was not fully developed.[5]

Modern radiation transport calculations can be done to simulate a gauge in loads of various commodities.[6] From the simulations, experiments on loads, typical of those in the recycling industry, can be designed to validate the simulations and to characterize the variability of random arrangements of scrap metal in the loads. The shielding from loads of scrap metal could be characterized, accounting for the variations in the packing of scrap metal in loads (see Section 7.5); the detection probability for each commodity could then be derived and extrapolated to loads of other sizes and detectors with other performance characteristics.

4 / Steel Manufacturers Association, Washington, DC.

5 / A. Lamastra, "Radioactive Material in Steel Scrap: Its Occurrence, Consequence and Detection," Health Physics Associates, Inc., Lenhartville, PA, 1986.

6 / Radiation passes through space according to the inverse square law. Transport calculations that predict radiation passing through matter account for attenuated, absorbed, and scattered radiation.

5 LICENSEES

5.1 Overview

Industrial facilities have complex and changing organizations. Most of the time, gauges in these facilities are not vulnerable to being inadvertently discarded—they are in use controlling industrial processes. This circumstance may persist for years until an activity, such as renovating or dismantling a unit, briefly places a gauge at risk of being inadvertently discarded. During this time, there is a chance that it will be discarded. Analyses of the licensees give an understanding of when and how the gauges are vulnerable to being discarded under industrial conditions and the consequences thereafter. Two concepts are key to understanding how gauges are made vulnerable as such:

- *Immediate and continuous control* (ICC) shows the extent to which mechanisms constantly keep attention, in one form or another, on a gauge such that if the gauge were to be removed, its absence would be soon noticed.

- *At risk* shows the circumstances where gauges are vulnerable to being discarded. A gauge that is at risk is not necessarily discarded; it is just vulnerable to being so.

Successful application of the concepts requires an understanding of the industrial environments of the gauges. Production, maintenance, renovating, and dismantling activities can have a large effect on the control mechanisms.

5.2 Importance in Risk

Licensees must be taken into account in estimating risk because this is where the circumstances that place gauges at risk of being discarded into the recycling stream are found. Here, a regulatory agency can influence some of the factors that affect the control of the gauges more so than the factors of recovering gauges from the recycling stream. Some of the conditions that place a gauge at risk of being inadvertently discarded violate regulations, such as lacking labels or not taking an inventory as required. Other conditions that place a gauge at risk are in compliance with regulations, such as storing a gauge in a cluttered area or on a defunct process unit. Most violations are of little danger to life or property—people will not be exposed to radiation, and equipment will not be contaminated. But improper disposal, a violation of potentially high consequence, happens quickly, often without notice, and is difficult to reverse because a gauge in the recycling stream is obscured by large volumes of scrap metal.

The topics taken into accounted in the analysis of the licensees are indicated in Figure 18.

Section 5

□ Gauge vendors
□ Gauge design
■ Facilities using gauges
■ Prevalence of gauges
□ Control mechanisms
■ Gauges at risk
□ Proper transfers
■ Improper transfers
■ Proper disposal
■ Improper disposal
■ Demolition & salvage
■ Unknown use
■ Unauthorized use
■ Unauthorized disposal
■ Danger to life
■ Danger to property

Figure 18 Topics taken into account in the analysis of licensees. LEGEND: A black bullet indicates that a topic is comprehensively taken into account. A white bullet indicates that a topic is beyond the scope of the risk analysis. A gray bullet indicates that a topic is briefly taken into account.

5.3 Concepts

The concept of ICC is essential for understanding how control mechanisms function to keep gauges out of the recycling stream. Such control is immediate when the removal of a gauge other than to a desired location is noticed promptly. Such control is continuous when it occurs without interruption. Two questions must be asked to evaluate ICC:

- What conditions exist when a gauge is at risk?
- What controls are applicable when a gauge is at risk?

To evaluate ICC, control mechanisms must be viewed in the context in which they operate—the industrial setting. Organizations at industrial facilities are complex, changing, and varied. The organization must respond to many demands—customers, competitors, stockholders, corporate oversight, resource suppliers, resources, labor, management, contractors, occupational regulators, environmental regulators, capital maintenance, and capital improvements.
Controls on a gauge can be compromised to different extents by the conditions that exist at a facility:

- Acute hazards, such as toxic chemicals, heavy loads, high pressures, or high temperatures may be present.
- Employees are concerned about the acute demands of business and safety.
- Under unusual circumstances, such as a strike, administrative jobs may be placed on hold; care for the nuclear gauges may be among the administrative jobs.

Many of the controls on nuclear gauges require active involvement of employees. Warning signs, roped-off areas, and verbal directions are of no consequence if people do not take heed. The attitudes of employees will have an influence on the effectiveness of those controls in a facility. Poor attitudes create ambivalence, both for safety and for a facility. But prescribing every detail of every activity becomes unmanageable. In such an ambience, the gauges become more at risk to being inadvertently discarded because the controls that gain the attention of employees are compromised.

Management attention is highly fluid. When an incident involving a nuclear gauge occurs, much attention is given to the gauges, to the exposures that employees may have received, to the possibility of regulatory actions (e.g., fines, license revocation), and the possibility of liabilities. But if another kind of accident occurs, such as with a chemical, then attention is given to that hazard—at the expense of attention given to the gauges.

Many corporations are image conscious; when this occurs, the perspective of employees is that a facility cannot do without the support of customers, stockholders, and the local population. The emphasis on safety begins at the chief executive officer level, passes through the line organization, and is reflected by labor. Communications are kept coherent, such as with monthly safety meetings. Although nuclear gauges may be discussed only once a year, the emphasis on education and communications is present. Meetings held to make changes to the plant for responding to market forces involve people responsible for the gauges. But difficulties arise when the employees who purchase equipment are unaware that nuclear gauges are part of the equipment.

Attention on these matters is attention that is drawn away from the gauges. ICC reflects these and other circumstances.

A regulator is seldom present at a facility to ensure the control mechanisms are functioning properly, placing much of the responsibility for implementing the controls on the licensee. An implicit assumption in the regulations is that a licensee assumes the responsibilities for controlling the gauges. But the incidences reported in Reference 1 suggest that the assumption is not always met. A licensee may be unable to or may not know how to carry out such responsibilities in a way to ensure adequate ICC. Gauges operate under circumstances where the major concerns are for production and employment.

In this context of complex organizations with acute demands and acute hazards are the gauges themselves. However, gauges do not command much attention because they seldom require maintenance and are rarely lost.

5.4 Control Mechanisms

Control mechanisms may prevent gauges from being inadvertently discarded. Typically 16 mechanisms can be found throughout industry, providing ICC on the gauges to different extents. These mechanisms can be placed in two categories, hard controls and soft controls, according to how they provide ICC. An understanding of how each of the control mechanisms operates is necessary to understand why gauges are at risk during the various phases of industrial operations.

5.4.1 Hard Controls

Hard controls operate directly on a gauge to provide ICC by deliberately placing a gauge at a definite location at the moment when control is needed. Their effectiveness is necessarily high. Three hard controls typically found throughout industry are using a gauge in production, placing a gauge in its own storage area, and returning a gauge to its vendor.

<u>In Use</u>

A gauge is controlling production when it is in use. For some process units, the gauge is critical. For other units, the gauge can be removed, such as for servicing, but the process unit must be controlled manually. In either case, the gauge cannot be removed without being noticed.

<u>Interim Dedicated Storage</u>

An area that is used only for temporarily storing a gauge, usually during a shutdown for maintenance or renovation, is interim dedicated storage (IDS). The gauge is returned to the process unit when the shutdown is over. Otherwise, it is returned to its vendor. The storage area is only for the gauge. It is uncluttered, avoiding the possibility of inadvertently discarding a gauge with other materials. It is interim, avoiding the possibility of forgetting about the gauge. It is secure and well marked, so that a gauge cannot be readily discarded.

<u>Return to Vendor</u>

Gauges that are returned to vendors are removed by qualified people. Such people can ensure that a gauge is removed and transported without posing a hazard. A gauge that has been returned to its vendor is no longer at risk in the facility where it was used.

5.4.2 Soft Controls

Soft controls operate indirectly to provide ICC by getting the attention of employees, often at times other than just when needed. These controls are more difficult to assess than hard controls.

<u>Inventory</u>

As the term is used in this risk analysis, *inventory* is done at a facility, initiated by employees, to account for the gauges. It differs from the list of devices secured during a lockout in that it is an accounting of all gauges, not just those on a process unit that is taken out of service for maintenance. It differs from registration (see page 45) in that it is initiated at a facility, not by a regulatory agency. Typically, inventory is done on a semiannual basis. For providing ICC, it must be done after activities placing gauges at risk (e.g., maintenance, housekeeping); attention is focused on the gauges at the moment when they are at risk of being unintentionally removed, and it stays focused until all of the gauges are taken into account and secured. Otherwise, a gauge may have been discarded long before an inventory is taken.

Labels

The primary function of labels is to be a positive indication that a component contains nuclear material. A label is the radiation trefoil sign on or near a gauge warning of the radioactive hazard. A label may not be on a gauge itself because the gauge is inside a process unit, hidden among rollers and supporting beams, or in a harsh ambience. People do not always take notice of labels, such as when they are distracted or tired. Other demands compete for attention; during maintenance and dismantling, people are busy getting their work done. Environments may be dark; although a label may be visible, it may not be illuminated. Employees may overlook a label or mistakenly perceive that the label refers to the contents in a tank or pipe, not the gauge housing.[7] Production materials may obliterate a label in days or weeks.

An inspector can usually identify a nuclear gauge without the labels by its shape, especially when the inspector is familiar with the processes of the facility or the facility itself. The same is true for process engineers and people who respond to emergencies (e.g., fire, hazardous material incidents).

Physical Security

Physical security is a fence, chain, or lock on or around a gauge, or restricted access to a site containing a gauge. A lock or cable on nuclear gauges can be cut with a torch. Sometimes a lock on a storage area can be opened with a screwdriver or penknife just as fast as with a key. The wire fencing of a storage bin can be easily cut. A nuclear gauge is not necessarily secured by a fence, chain, or lock.

Lockout

Lockout is a procedure, required by the Occupational Safety and Health Administration, to secure a process unit for servicing so that the unit cannot be inadvertently started, in full or in part, while people are repairing or maintaining the process unit. Lockout requires that a list of components be locked. While checking the list of components both before and after the process unit is serviced, an inventory of gauges is, in effect, taken. But a lockout is not entirely reliable for providing an accurate inventory for two reasons:

- A lockout may occur during a time when a process unit is being disassembled—a gauge may be slated to be removed and, therefore, may be removed as well from the lockout list when the process unit is restarted, losing, in this regard, the accountability for keeping it out of the recycling stream.

- A lockout list may be incorrect.

The lockout guarantees that a process unit was shut down and gives proof that the process unit was locked; it does not prevent removal of nuclear gauges with a bolt cutter or a cutting torch. Incidents have occurred where employees or contractors have inadvertently removed and discarded nuclear gauges when radiation signs were ignored, roped-off areas were entered, or components with gauges have been removed.

Responsibility

Responsibility is the authority given to a person or a group of people in a facility to account for a gauge. For specifically licensed gauges, the responsibility is clearly defined by the conditions of a license; the radiation safety officer (RSO) is given the responsibility for a gauge. For generally licensed gauges, a responsible person may be present although from a regulatory perspective, the company, not a person, is responsible.

Although regulators can assign responsibility on a case-by-case basis, there is no one place throughout industry where both stability and authority can be identified; in some facilities,

7 / See NRC Preliminary Notification of Event or Unusual Occurrence, PNO–IV–98–033.

upper management is in flux more than lower management and production people, while at other facilities the opposite is true. Furthermore, the responsibilities for production may be shifting and overlapping.

While regulations convey the responsibility to the licensees, they do not provide guidance (information and experience) to personnel who have to implement and manage that responsibility. To provide ICC, a person assigned responsibility for the gauges must be close enough to production to remain close to the gauges as they are used and high enough in the organization to have authority.

Education and Communication

Education is a program to inform employees of the presence and care of the gauges. Communication is the established routes for information necessary to control nuclear gauges. The responsible person informs maintenance staff of the gauges. The maintenance staff inform the responsible person of the need to secure a gauge for servicing the process unit. Education and communication must be supported by facility management to be effective. Education and communication can be compromised for many reasons:

- At an industrial facility, people of almost any educational level may be found.

- Renovations are done continuously to keep a facility current. The responsible person may not be always around to ensure ICC.

- Much outsourcing is done to keep costs down. A contractor may be given training on general plant safety. Whether or not this training is communicated to the contractor workers is another matter.

- An employee can be assigned to other activities, leaving (safety) tasks undone.

High-Level Accountability (HLA)

HLA is holding upper management at a facility accountable in some ways for addressing regulatory infractions. Management, not the person directly responsible for the gauges, explains to regulators why an infraction occurred and what will be changed to improve matters. The effectiveness of HLA might be increased by holding the licensee accountable at the location of the regulator instead of the regulator coming to the licensee; this increases the impact of accountability on the management of a facility.

Inspection

State and Federal regulators go to a facility to evaluate compliance with regulations; they may also be done when an incident involving radioactive material occurs. Inspections are not coordinated with times when gauges are placed at risk. Because gauges are subject to ICC for most of their service life, inspections can significantly reduce risk only when they coincide with at-risk periods.

Civil Penalties

A civil penalty is a monetary penalty that may be imposed for violations of Nuclear Regulatory Commission (NRC) rules or orders, or of any requirement for which a license may be revoked. An assessment of a civil penalty takes into account first the severity of the violation and second the ability to pay. Violations pertaining to greater potential consequences to the public and licensee employees receive higher civil penalties than those involving lower potential consequences. The intention of a civil penalty is *not* to put a licensee out of business; ceasing operations is done by suspending or revoking a license. The intent of the civil penalty schedule is to deter future violations by the licensee where a violation occurred, to deter future violations at licensees conducting similar activities, to encourage prompt identification, to encourage prompt and comprehensive corrections, and to

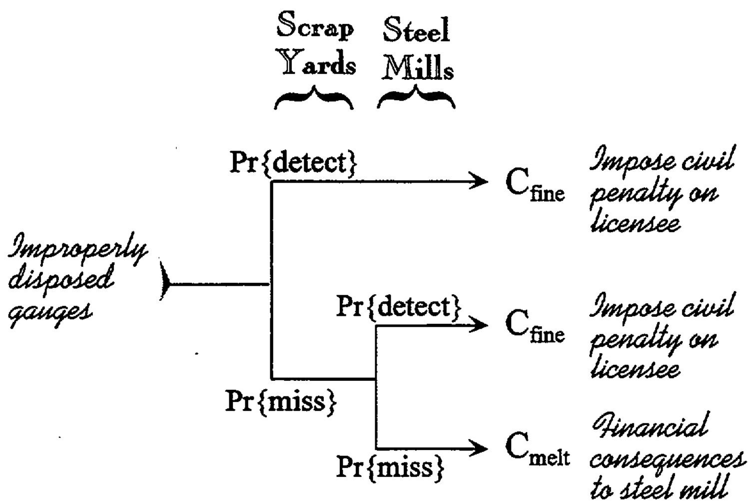


Figure 19 Estimating a civil penalty by equating the risk of a civil penalty at licensees to the risk of melting a nuclear gauge at steel mills.

focus licensees' attention on violations of significant concern. The outcome of an assessment is either no civil penalty, a base civil penalty, or a base civil penalty escalated by 100%.

The effectiveness of a civil penalty for providing ICC is decreased by the circumstances of gauges entering the stream:

- The civil penalty applies to an event that is unlikely to occur. Nuclear gauges are a minute and reliable portion of operations. Memories at facilities fade as the work force changes while business demands attention.
- The gauges are lost because of the actions of a few people, yet a corporation is the entity that is fined.
- A gauge from storage or a dismantled process unit may have entered the recycling stream long before employees realized it was missing. Because scrap metal conceals a gauge from both visual and radiation detection, corrective actions (e.g., recovering the lost gauge) are almost a moot point.

The proper amount of a civil penalty to provide ICC is difficult to determine. A lower limit is obvious for improper disposal—it should be greater than the cost for proper disposal. But how much greater? The proper amount will depend on the value of resources at a facility. The value of resources is determined with an economic evaluation, which in practice, is complex and difficult to do correctly (Ref. 3, page 239). A way to determine the amount of a civil penalty is by determining the point at which the risk of a penalty to a licensee is equal to the risk of a consequence, for example, of melting a gauge at a steel mill. A simplified circumstance is illustrated in Figure 19. On the left of the figure, a gauge has been improperly disposed. Monitoring is done twice along the recycling stream. For simplicity, the detection probability is the same in both the scrap yards and the steel mills. If the gauge is detected at either the scrap yard or the mill, a civil penalty, C_{fine}, is imposed. If the gauge is missed at the scrap yard, it may be detected at the steel mill. If it is missed again at the steel mill, then the mill incurs financial damages, C_{melt}. The probability of detecting the gauge is Pr{detect} and the probability of missing the gauge is Pr{miss}. In Figure 19, each consequence is multiplied by the probabilities along the sequence of risk elements leading to the consequence; the terms for the licensees are equated to the terms for the steel mills; solving for C_{fine} yields Equation 15.

$$C_{fine} = \frac{[Pr\{miss\}]^2 C_{melt}}{Pr\{detect\}[1 + Pr\{miss\}]} \qquad [15]$$

$$= [Pr\{miss\}]^2 C_{melt}$$

Analytically, this method seems reasonable. In practice, difficulties become evident:

- The probability of detecting a gauge is unknown (see Section 7.4). But whatever it is, $[Pr\{miss\}]^2$ is small, offsetting the large value of C_{melt} , thus making the civil penalty small. For example, with a detection probability of 99% and costs to steel mills of about $10 million, the civil penalty is calculated to be $1,000.

- Financial costs of melting a gauge are highly variable. The few incidents limit a good characterization of the consequences to estimate C_{melt}.

- These equations imply that the more monitoring is done and the more effective the monitoring, the lower the civil penalty. A low civil penalty may not be a deterrent to a licensee.

- The purpose of a civil penalty is to deter, in this case, improper disposal, not to compensate for damages. The civil penalty is collected by the treasury of the governing authority, not a licensee. Figure 19 illustrates insurance, where payments are made by licensees into a fund that is used to compensate facilities that incur damages. Unless the purpose of a civil penalty is altered from a deterrent to compensation and a means of transfer payments can be established, this method for determining the amount of a civil penalty is of little use to stakeholders.

A risk assessment can be a structured way to determine the potential for consequences. But a determination of the amount of a civil penalty to provide ICC with a risk assessment is difficult.

Revocation

A license to use a nuclear gauge can be revoked, taking away the authority of a facility to possess a gauge. Revocation occurs only after a violation has occurred. Otherwise, it is just a possibility that may or may not be accurately assessed by plant employees. The effectiveness is greatest when a violation is being addressed and fades over time as other issues at a facility gain attention. When a facility is being phased out, revocation only hastens the closure. When a facility is closed, revocation is irrelevant.

Registration

Registration is done by an enduring organization—a regulatory agency. At a regulatory agency, registration is an accounting of the nuclear material in the public domain and a means for the regulatory agency to keep licensees informed of regulatory concerns. Registration refreshes memories at facilities where there is significant change in the work force. At a licensee, registration operates through the awareness of employees. But the reason for gauges being discarded into the recycling stream is much more complicated than a lack of awareness of the gauges. Time of registration has nothing to do with the activities at a facility that place gauges at risk. Annual registration is infrequent compared to the time when a gauge can be placed at risk and discarded.

Registration might influence other control mechanisms—such as responsibility, education, communication, and revocation—that involve awareness and maintaining a corporate memory of the gauges. Registration only reminds employees of gauges in their facility, where the organization may be complex, diffusing responsibility and impairing communication.

Followup to registration is necessary if registration is used to provide ICC under some conditions of industrial facilities. A lack of response from a licensee may indicate that a facility has been closed or abandoned. A facility in either state is subject to pillage, placing the gauges at risk of entering the recycling stream.

The percentage of the gauge population under some kind of registration (e.g., accurate accounting of all gauges at a facility) is unknown. At least some States register gauges. Many companies, particularly large ones, conduct semiannual inventory of their gauges, which has the same effect as registration, although more localized and in potentially less enduring organizations than government.

Publicity

The NRC and some States hold companies socially accountable for their activities. For example, the names of companies out of compliance with regulations may be published in a newspaper. Such publicity can influence the control of nuclear gauges. Many companies are image conscious; they seek highly skilled people and maintain good relationships with customers and stockholders through well-managed operations. Adverse publicity tends to counter this. But publicity about nuclear gauges is for a rare event in the indeterminate future, which tends to diminish the influence of publicity on ICC.

Query at a Change in Responsibility (QCR)

The current regulations state that informing a regulatory agency of a change in the ownership of a facility is the responsibility of the licensee. There is no situation analogous to the purchase of a house, where the people managing the purchase check legal records to ensure that the seller is the legal owner. Applying the concept to nuclear gauges, a query about the gauges would be required before a transfer could be legally completed, notifying regulatory agencies and asking about records of nuclear material. The same concept can be applied to demolition and salvage; here, although a contractor does not assume ownership, responsibility for the demolition and salvage is assumed. The issue is who is responsible for the activities at a facility where ICC is applicable; hence, the emphasis is on the change in responsibility. QCR differs from a registration system in that the regulatory agency is contacted only when responsibility changes. It differs from an inventory in that an entity managing the transfer is inquiring with the regulatory agency.

5.5 Elements of Risk

Figure 20 is an illustration that is central to understanding the control of gauges. Here, the concept of ICC is applied to 16 control mechanisms in 33 industrial environments throughout industries where nuclear gauges can be found.

Figure 20 shows the applicability of the control mechanisms to provide ICC in the environments found throughout industry. In some environments, many mechanisms operate to provide ICC. In other environments, none of the mechanisms operate as such. After the applicability of the control mechanisms is established by Figure 20, both the extent to which the gauges are at risk to being inadvertently discarded and the fate of the gauges can be analyzed.

The left half of Figure 20 delineates all plausible environments of the gauges with three elements — the factors that influence risk. Orphan sources are treated as a branch of Element 1, but listed under Element 3 (location). Because they are not part of a facility, they are not properly placed under Element 1. Yet they are part of the general population of sealed sources. Orphan sources can be considered a type of location. Given this, the treatment was to consider them a portion of the population of gauges by branching from Element 1 but classifying them under Element 3.

The right half of Figure 20 shows the applicability of control mechanisms (regulations and practices) to the gauges in each of 33 environments; a white box indicates that the control mechanism cannot provide ICC over gauges; a shaded box indicates that the control mechanism can provide ICC. The reasons for specifying that a control mechanism provides ICC in a given environment are provided in Appendix A. Some of the control mechanisms are regulations while others are practices found in industries. Sixteen control mechanisms are grouped into hard and soft controls, according to the means by which the control mechanism functions. A hard control keeps a gauge in a definite place either where it is needed or in a location where it cannot cause harm or damage. Soft controls are warnings (which include barriers and chains) or procedures that may allow a gauge to be removed unnoticed.

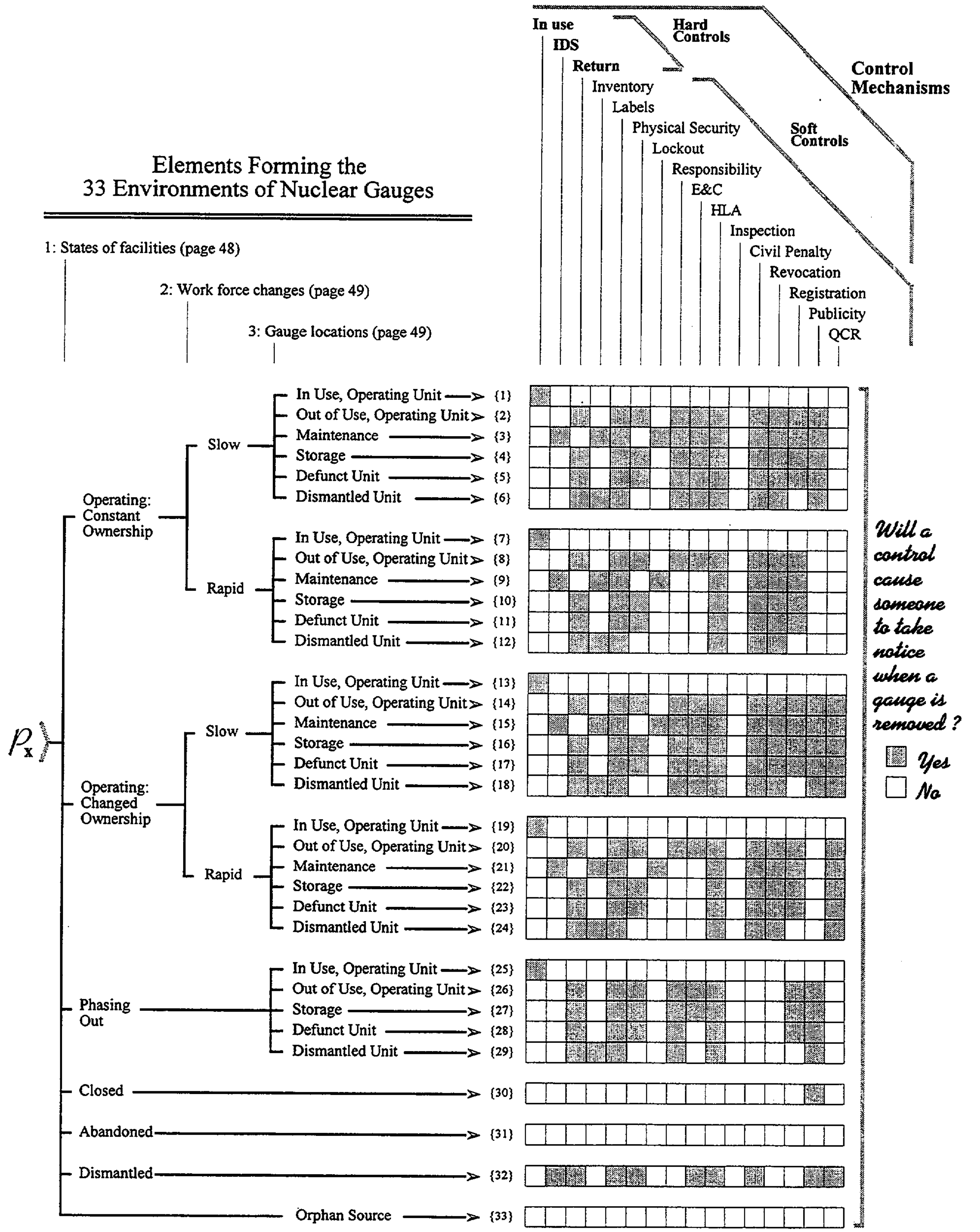


Figure 20 Analysis of the risk elements in the industrial environments of nuclear gauges at licensees. LEGEND: A white box (□) indicates that a control cannot provide ICC in a given environment. A shaded box (▒) indicates that a control can provide ICC in a given environment. P = prevalence nuclear gauges; x = G for generally licensed gauges; x = S for specifically licensed gauges; x = T for both types of gauges. E&C = education and communication. HLA = high-level accountability. QCR = query at a change in responsibility. The reasons for specifying given control as applicable or inapplicable in a given environment are in Appendix A. An arrow (>) indicates that the sequence continues in Figure 21.

The population or prevalence of nuclear gauges throughout all industries in the United States is denoted by P. Two populations of gauges, generally licensed and specifically licensed, need to be kept separate for risk calculations because the control mechanisms applicable to the two groups differ. For example, at a facility with generally licensed devices, responsibility may not be assigned as it is required at a specific licensee, although some general licensees may have an employee fulfilling the activities of an RSO as a matter of business. A facility that has both generally and specifically licensed devices would be treated as the latter.

Elements 1 through 3 in Figure 20 delineate 33 environments in which the gauges are found throughout industries. The distribution is an *equilibrium* because the number of gauges in various environments is approximately constant under stable economic and regulatory conditions. The equilibrium is also *dynamic* in that individual gauges are moving from one environment to another without the distribution of gauges changing appreciably.

Element 1: States of Facilities (Figure 20)

Operating Under Constant or Changing Ownership

In facilities that are operating under constant or changing ownership, production continues without interruption. Employees in facilities that are operating are concerned about production, safety, and their future. To varying degrees across industry, there is also an interest in maintaining the facility.

Phasing Out, Closed, or Abandoned Facilities

Phasing out means that a facility is closed gradually, such as over years. No major renovations are planned. Gradually production may be shifted to other facilities. Employees have time to accommodate their circumstance and find other work. A *closed facility* no longer is operating, but it still is owned. An *abandoned facility* is closed and without an obvious owner; there is no possibility of it being reopened.

Traditionally, industrial facilities closed when markets slowly eroded. But now, closing in several months is becoming more common. When profitability goes below a certain level, the facility is shut down. From the employees' perspective, a facility can close in days or hours. When this happens, (former) employees will be concerned about their families, savings, and when they will work again, not about otherwise innocuous components such as nuclear gauges. What happens to the gauges depends on what happens to the employees. If the company reassigns its people to another operation, then there may be more assurances that the current operation will be closed in an appropriate manner. If employees are left with nowhere to go, their concern is no longer with the facility, unless they have other interests, such as being employed to dismantle the facility.

A facility may be closed for years before being reopened, either under the same ownership or under different ownership. A security guard may be on the site. An abandoned facility is left with no one accountable for what remains in the facility.

Facilities may be closed or abandoned for years or decades before being dismantled. A closed facility is subject to pillage for anything of value, such as copper, steel, tools, and equipment, and it is also subject to unauthorized demolition for scrap metal. Thieves do not limit themselves to small pieces of scrap; they take large pieces too. If pillaging of a facility is indiscriminate, then gauges that are in the facility are at risk of entering the recycling stream.

Dismantled Facility

A dismantled facility is one that has been scrapped or salvaged. More generally, dismantling or salvage is known as demolition. In general, a facility is not dismantled indiscriminately. Imploding a building is a minor part of the demolition business done by only a few companies; afterwards, a pile of rubble must be sorted. A large part of the business is industrial renovation and salvage. Industrial facilities are readily disassembled and reassembled. A facility is taken apart, to the extent it can be, as it went together. Process units are removed to make room for new process units when a company makes a new product or when newer technology can be used to reduce the cost of making current products. Valves are cut away and separated. Motors are separated from ferrous scrap metal to recover the copper. Reinforced concrete debris can be crushed to remove the concrete, leaving the rebar. The pulverized concrete can be used as fill material.

Dismantling and salvage are done in four phases, each of which has standard operating procedures:

- Hazards, such as from chemicals, power lines, heavy loads, and radioactive material, are identified.
- Utility lines are disconnected (some lines may remain active for dismantling and salvage).
- Hazardous materials are removed.
- The facility is dismantled and salvaged.

Some of the materials from a job may be prepared by separating, shearing, and baling to increase the value. The extent to which preparing is done depends on the contractor's access to equipment and the market price of scrap metal.

Portions of the demolition industry may be difficult to reach in keeping workers informed about nuclear gauges. A large, well-established company usually specializes in a particular type of facility, thus accruing knowledge about the intricacies and hazards of such demolition. Such companies can be readily informed and kept informed. Small operations, some of which may not be formal companies and may lack experience, are more difficult if not impossible to reach either by regulators or trade associations.

Element 2: Work Force Changes (Figure 20)

The work force embodies the *corporate memory* of the gauges. Slow turnover allows the corporate memory to be refreshed. Rapid turnover compromises the corporate memory; here, concern may be for continued employment; if so, safety considerations, such as for nuclear gauges, may become secondary considerations.

Element 3: Gauge Locations (Figure 20)

<u>In Use and Out of Use on Operating Process Units</u>

Gauges that are in use on operating process units are not at risk of entering the recycling stream when the gauges are controlling processes. A gauge in use is controlling a process. An out-of-use gauge may be kept on the process unit for reasons that include the following:

- because no one removed the older gauge when a newer gauge was installed,
- because of a pending decision to move it to another process unit, or
- To serve as a backup to an operating gauge.

<u>Maintenance</u>

In a large industrial facility, much activity is occurring during a maintenance shutdown. Most attention is on the shutdown; little attention is on the nuclear gauges. A shutdown is thoroughly planned; except for minor preventive maintenance, it may be scheduled according to the demand for the product. The repairs and renovations are organized to be done in the shortest time. Still, a process unit may be taken out of service for days or weeks for major upkeep or renovations. Before a unit is shut down, the process manager has determined the upgrades to be done, the new technology to be installed, and the components that need to be repaired. Contractors are told about safety procedures. Even so, unforeseen difficulties occur. Employees may be late to meet each other for performing an activity, heightening concerns about completing the shutdown. Inventory lists may have errors. Delays and unforeseen events pull attention further away from the gauges.

Maintenance activities take place on a shop floor that may be cluttered with hoses, electrical wires for lights, flexible ventilation pipes, worn parts, and replacement parts. A gauge that is removed and set on the floor can become lost among the clutter. Many activities during maintenance draw attention away from the gauges. C:

- Cleaning equipment with water hoses and pneumatic tools.

- Lifting components weighing many tons with overhead cranes.

- Unlocking a portion of a process unit to rotate a component a few inches for gaining access, then locking it again according to procedures.

- Entering confined spaces must be preceded by a check of the oxygen level.

- Working in tight places that may be poorly lit.

The work among the contractors is narrowly defined. One set of contractors does not necessarily know what another contractor is doing. A gauge that is set down by one contractor may be easily removed by another contractor.

When many people are involved in a shutdown, communications become complex and activities become nebulous as compared to operation. Consequently, responsibility and fault for inadvertently removing a gauge become nebulous to attribute to one person.

Storage

Gauges not in use may be stored for a variety of reasons:

- A process unit is down for maintenance. After maintenance, the process unit is returned to service.

- A gauge may need frequent service because it operates in a dirty or corrosive environment. While one gauge is being serviced, another gauge is used to maintain production.

- A gauge is used as a backup when a process unit can be damaged. For example, a steel mill may use a gauge to monitor the metal level in a continuous caster. Should steel spill onto the mold where the metal is poured and cover the source housing, the mold can be replaced with another mold and gauge.

In general, storage areas throughout industry take the following forms:

- fenced area or metal room secured with a padlock;

- brightly painted heavy-gauge box locked shut, with a padlock, in production areas;

- open crate on the floor of a cluttered general-purpose room;

- roped-off area of a shop in a facility; or

- cluttered corner of a room containing facility equipment.

These practices can persist for decades without anything happening to a gauge.

Some facilities do not store gauges; instead they make arrangements with a vendor to have a replacement gauge delivered promptly. If the source housing is damaged during production, most assuredly other portions of the process unit that the gauge was controlling will also be damaged. The process unit may not be placed into service immediately. During this time, another gauge can be sent from a vendor.

Defunct Process Unit

A defunct process unit is one that is no longer in use. Nuclear gauges on such a unit are at risk because they are not controlling a process and they can be removed without disrupting activities in the facility. Employees may have a gauge on a defunct unit, anticipating a time when the process unit is brought back into service. A manager may have no definite plans for restarting the defunct unit, and the unit may be in disarray. Although other components may have been removed for safekeeping, a gauge may remain on the defunct unit.

Orphan Sources

An *orphan source* is a discrete radioactive source for which no responsible entity (licensee cannot be located, licensee is not viable) or no disposal option (vendor, another licensee) can be found. The phrase *orphan source* is applied to a variety of devices, including nuclear gauges.

In Figure 20, the prevalence of gauges in the environments, not the movement of gauges among the environments, is analyzed. Treating the prevalence among environments as an equilibrium means that the prevalence of gauges in each environment is constant. The three elements forming the environments change slowly in most cases during a reasonable period, such as a year. For example, the effects of a change in ownership persist both before and after the change; the effects stemming from a turnover rate of the work force persist. Recognizing that the environments change little allows Elements 1 and 2 to be defined as Equation 16.

$$\varphi_{j,k} = \frac{N_{j,k}}{\sum_{j} N_{j,k}} \qquad [16]$$

$\varphi_{j,k}$ = fraction of gauges at the j^{th} possibility of the k^{th} element
$N_{j,k}$ = number of gauges in the j^{th} possibility of the k^{th} element
j denotes an element
k denotes possibility of an element

Element 3, the location of gauges, presents a difficulty. The gauges on operating process units move into a risky state, maintenance, and back again, within a relatively short period of time (e.g., hours to a few days or weeks). The short period precludes an accurate inventory of the gauges on a process unit under maintenance using a survey to collect information. The inventory of gauges in a maintenance environment has be inferred. Let N_{IU}^{OP} be the number of gauges in use (IU) on operating process units (OP), and N_{OU}^{OP} be the number of gauges out of use (OU) but still on operating process units. C_p is the capacity factor of the process units—the percentage of time the units operate. The total number of gauges in any location of facilities given the state of the facilities (e.g., constant ownership, changing ownership) is N_T^F. The two fractions of gauges on operating process units (i.e., in use, out of use but still on an operating process unit) are given by Equations 17 and 18.

$$\varphi_{IU}^{OL} = \frac{N_{IU}^{OP} C_p}{N_T^F} \qquad [17]$$

$$\varphi_{OU}^{OL} = \frac{N_{OU}^{OP} C_p}{N_T^F} \qquad [18]$$

The fraction for both states of gauges on process units that are shut down for maintenance is given by Equation 19.

$$\varphi_{Mntn} = \frac{\left(N_{IU}^{OP} + N_{OU}^{OP}\right)\left(1 - C_p\right)}{N_T^F} \qquad [19]$$

The fractions for the other possibilities of Element 3 are determined with Equation 17.

Figure 20 established which control mechanisms provide ICC in 33 environments. The extent to which the gauges are at risk of being discarded given the control mechanisms that are operating, and the possible fates of the gauges thereafter, are determined by three more risk elements.

Figure 21 illustrates the remaining three risk elements of the licensees. Single black lines are sequences of risk elements. An arrow (➢) indicates that the sequence continues in Figure 28. A dot (●) indicates the end of a risk element sequence. An open dot (○) indicates that a sequence is unresolved; it continues, but is not developed further. Hazard terms are from the *U.S. Code of Federal Regulations* (Ref. 9). A black box (■) indicates that a concern is present between Elements 1 through 6 of a particular sequence.

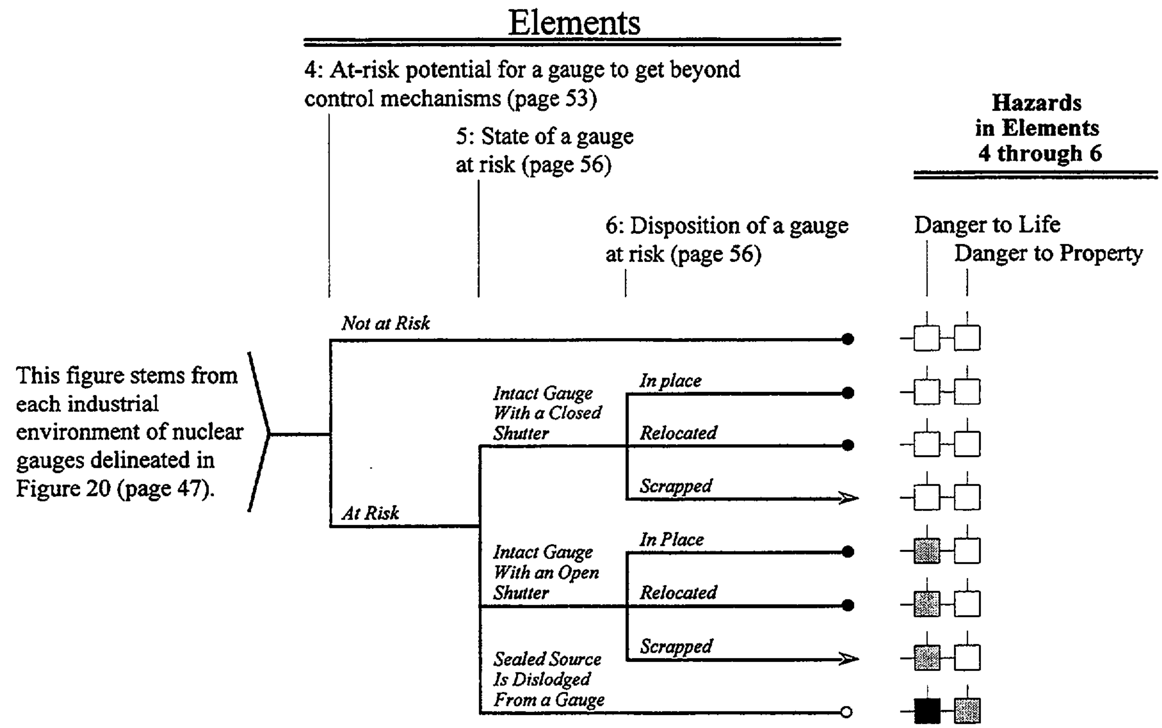


Figure 21 Analysis of the licensees' risk elements (continued). LEGEND: Single black lines are sequences of risk elements. An arrow (>) indicates that a sequence continues in Figure 28. A dot (●) indicates the end of a sequence. An open dot (○) indicates that a sequence is unresolved; it ends here, but not further developed. A black box (■) indicates that a concern is present as of Element 6 of a particular sequence. A shaded box (▩) indicates that a concern might be present as of Element 6 of a particular sequence. A white box (□) indicates that a concern is not present as of Element 6 of a particular sequence. Hazard terms are from the *U.S. Code of Federal Regulations* (Ref. 9).

A shaded box (▩) indicates that a concern might be present. A white box (□) indicates that a concern is not present. The hazards to life and property are as follows:

- A gauge that is not at risk (e.g., in use, properly stored) is not a danger to life or property. Although a gauge is at risk, it is not necessarily a danger.

- If a gauge is in place or relocated, then the sequence terminates. A relocated gauge is moved to another location, not discarded. If the gauge is scrapped, then the sequence continues, but between Elements 4 and 6, it is not a danger to life or property.

- If the shutter is closed, it is not a danger to life. When the shutter of a gauge is open, it may be a danger to life. On a process unit being serviced, an open shutter may cause exposures. When a gauge is relocated or scrapped with the shutter open, exposures may also occur.

- The sequences of in place and relocated gauges terminate. The sequences of scrapped gauges continue. The sequence for a dislodged source at a licensee terminates, but is unresolved; for example, it may, in a way that is too ambiguous at this time to take into account, enter the recycling stream if it is lodged in a piece of scrap metal; it may be in a sump; it may be an a shop floor. Little can be said beyond it is a danger to life and possibly property, such as if it is breached when hammered or cut with an acetylene torch.

Element 4: At-Risk Potential (Figure 21)

An important concept for determining the effectiveness of control mechanisms is the extent to which gauges are at risk of entering the recycling stream because this is the jurisdiction of the NRC and the Agreement States. Figure 22 represents the population of devices containing radioactive sources. The total population of devices is represented by Set {T}. Most nuclear gauges are in use on production lines. These devices are not at risk of being lost because they are in place, controlling production. Only a portion of the gauge population is at risk of being lost. In Figure 22, the population at risk is represented by Set {A}. These gauges are at risk to being lost because they are no longer under hard controls. Instead, they can be removed and set aside during renovation, left on a mothballed process unit, left in a cluttered storage room, or left carelessly in a defunct or abandoned facility. The population at risk is necessarily very small because almost all of the gauges are used to control production. Of the gauges at risk, some have been discarded; this is set {D}. Some gauges will be found, either before or after being melted in a furnace; the gauges that are found in the recycling stream are represented by Set {F}. Set {A} can be divided into many regions, such as gauges that become stranded in the recycling stream, buried in a landfill, or disposed of in an unknown way. The purpose of Figure 22 is to illustrate general states of devices, not to delineate all of the possible states of a nuclear gauge.

From Figure 22, the annual probability of finding a nuclear gauge is given by Equation 20.

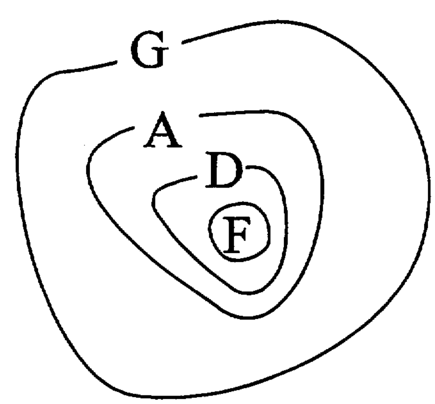


Figure 22 Nuclear gauges throughout all industries. LEGEND: G = set of all gauges. A = set of gauges at risk of being discarded into the recycling stream. D = set of gauges discarded. F = set of gauges found.

$$\Pr\{F|A\} = \frac{N_F}{N_A} \qquad [20]$$

$\Pr\{F|A\}$ = probability of finding a nuclear gauge that has been discarded into the recycling stream

N_A = number of gauges at risk in a given year

N_F = number of gauges found in the recycling stream (both before and after melting at a steel mill) in a given year

The denominator, N_A, is the number of gauges at risk, not the total number of gauges, N_T. Replacing N_A with N_T will result in an underestimate of the probability of finding a gauge in the recycling stream. In Figure 22, the total number of gauges is what can most easily be estimated. The number of gauges at risk and the number lost are both much more difficult to estimate.

Figure 23 illustrates other aspects of Figure 20, showing that the at-risk potential is a complex function determined by the control mechanisms that operate in a given environment to provide ICC. Figure 23 is a qualitative diagram for explaining the matrix, not an illustration for computing the at-risk probability. The figure shows a general form of the logical progression for the controls on a *single* gauge in any one of the 33 environments in Figure 20; the details of Figure 23 vary from one environment to the next because the controls that provide ICC change from one environment to the next:

- A given gauge is either in use or out of use; this is depicted in Figure 23 as GATE 1 (an OR gate). In use alone is sufficient for ICC; no other control mechanisms are needed because the gauge is modulating a process.

- A gauge that is out of use is either returned to its vendor, in IDS, or subject to soft controls; this is depicted by Gate 2 (an OR gate). Return or IDS is sufficient for ICC; no other control mechanisms are needed because the gauge is known to be in a secured place. If a gauge has not been returned or is not in IDS, then soft controls are relied upon.

- Soft controls act on a gauge in combination at each facility; this is depicted by Gate 3 (an AND gate). Each of the 13 soft controls is either present or not present at a facility; this is depicted by Gate 4 (an OR gate). The number of possible combinations of 13 soft controls is 2^{13} = 8192. In practice, many fewer combinations are found throughout industry, because many of the controls are required as a condition for possessing the gauge.

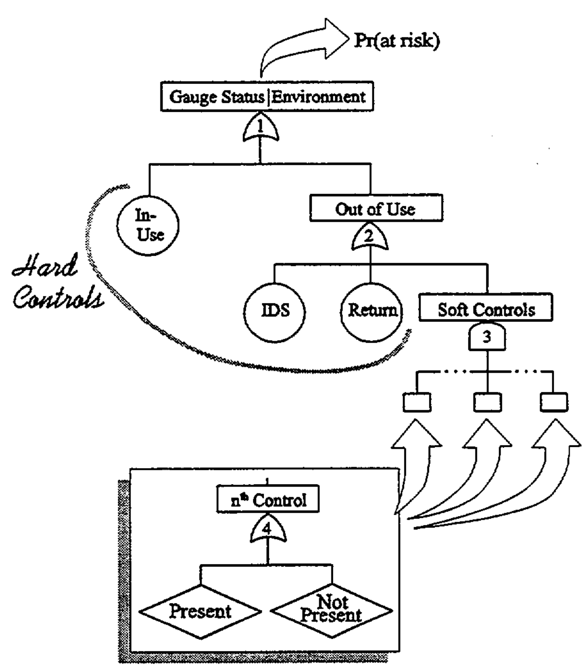


Figure 23 Logic of the environment/control matrix in Figure 20.

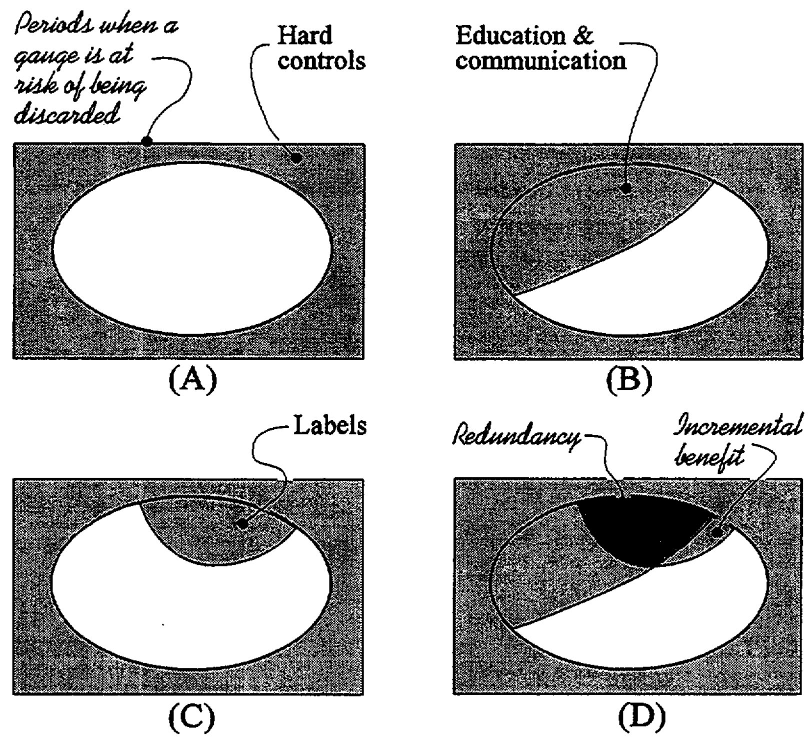


Figure 24 Venn diagram illustrating the coverage and redundancy of control mechanisms.

The three hard controls are mutually exclusive. A gauge is in a definite place—it cannot be in use, in IDS, and returned all at the same time. If a gauge is not subject to a hard control, then it is subject to a soft control. Soft controls may always be present, but ICC is being provided first by a hard control, then by a soft control.

The combination of control mechanisms affecting a particular gauge determine the control effectiveness. The effectiveness of the control mechanisms is not simply the sum of the effectiveness of the individual controls. An assessment for each environment must take into account interactions and redundancy among the control mechanisms. For example, consider the soft controls of education and communication (E&C) and labels. Highly effective E&C may compensate for labels that are obliterated by process material during normal operation. Thus, the effectiveness of a given combination of control mechanisms is a function of the combination and not of the individual controls.

Figure 24 illustrates another aspect of Figure 20—describing applicable controls during the lifetime of a gauge. Figure 24 presents examples of four hypothetical situations. Each part of Figure 24 is an example of a Venn diagram. Figure 24 is qualitative; the areas are drawn to illustrate concepts and are not in proportion. In all four panels, the rectangle represents the lifetime of a gauge. The shaded areas represent periods when controls are present and effective; a gauge is not at risk of being inadvertently discarded. The white areas represent periods when controls are not present or are ineffective; a gauge is at risk.

- Panel (A): Hard controls cover some of the periods during the lifetime of a gauge. Such a gauge is in use on operating process units, in IDS, or returned to a vendor. This means that the gauges are in a definite place; hence, they are not at risk. But during other periods (white area), controls are not present; the gauge may be on a process unit that is being serviced or is defunct, or in a general purpose room without any soft controls.

- Panel (B): A single soft control, E&C, covers some of the periods that are not covered by hard controls. Periods covered might be all those when employees, trained in the proper care and use of the gauge, know the whereabouts of the gauge, regardless of where it is located. Contractors servicing equipment or removing scrap from a facility might not receive this training, and may inadvertently discard the gauge; the white area represents these and other times when the gauge is at risk.

- Panel (C): Hard controls are present as in Panels (A) and (B). Instead of E&C, there are labels on the gauge. Again, the coverage of the area at risk is incomplete; labels can be obliterated with process materials between cleanings or go unnoticed in dimly lit rooms.

- Panel (D): Hard controls are supplemented by both E&C and labels. There is redundancy in that employees who are trained will not need the labels to know the whereabouts of the gauge. For example, a plant engineer would be able to locate the gauge on a process unit, even when the gauges are covered by grease or dirt. But contractors may not have such knowledge of the process unit; hence, the labels provide an incremental benefit over and above the E&C control.

Figure 24 illustrates an important point—control mechanisms can overlap and be redundant. Redundancy increases the overall effectiveness because it compensates for control mechanisms becoming compromised. In the examples of Figure 24, E&C can degrade when the work force changes rapidly and labels can become obliterated or fade.

Gauges that are at risk can enter the recycling stream. This does not necessarily mean that they do enter, but that they are at a potential to do so. The fate of a gauge that is at risk is represented by Elements 5 through 7 in Figure 21.

Element 5: State of a Gauge at Risk (Figure 21)

The extent to which the sealed source of a gauge is exposed influences the health consequences. For gauges that are being used in production, the radiation exposures are minimal. In use, the radiation beam from the source is focused into the detector. Also, people seldom linger near the gauges on process units; they are at control stations or occasionally walking by en route to another area in the plant. Most of the production areas where the gauges are located are deserted. In some environments when a gauge is at risk, people are nearby, such as when a unit is being serviced; if the shutter of a gauge is open, then exposures might occur. In other environments, such as a closed or abandoned facility, people, such as curious youth, can unknowingly move near the gauges. Closed and abandoned facilities, and facilities being dismantled, have been pillaged. The minimal radiation exposure during use is a marketing point of gauge vendors for their customers. But the minimal radiation when the shutter is closed also makes the gauges difficult to detect in the recycling stream. Some people in the steel industry would like to have the gauges made so that enough radiation emanates to allow a gauge to be detected.

Element 6: Disposition of a Gauge At Risk (Figure 21)

A breakdown in ICC, be it total or partial, does not necessarily mean that a gauge will be discarded. A breakdown means that there is a potential for a gauge to be discarded—a gauge is at risk of being discarded. The probability of a gauge being discarded is a complex quantity that is essentially unknowable; no plant manager will allow experiments to be done on a facility to collect statistical data. Some values of the probability, in a given environment, can be intuitively determined to reduce the ambiguity in this quantity. If a gauge is in use, $\Pr\{\text{discard}\} = 0$ because the gauge is controlling a process. If not in use but at a facility, then $0 < \Pr\{\text{discard}\} \leq 1$. There is at least a small chance that it will be removed and discarded. If a facility is indiscriminately liquidated, then $\Pr\{\text{discard}\} = 1$. Other probabilities can be empirically estimated; the probabilities in Element 4 can be chosen by trial and error so that the predicted prevalence of gauges entering the recycling stream is consistent with the observed prevalence, such as given by Reference 1. Probabilities are not being estimated with the data reported in Reference 1; the concerns of using a convenience sample (see Section 4.3.2) are inapplicable here. The probabilities of Element 4 can be chosen to be consistent with data. The nebulous quality of Pr{discard} is not a hindrance to analyzing risk. A use of the analysis is to focus where Pr{discard} is well known and on how low Pr{at risk} can be made with a realistic amount of resources.

5.6 Sources of Information

Tables 3 and 4 are summaries of the sources of information for developing the inputs of the licensee analysis. Along the top are the elements corresponding to the elements in Figures 20 and 21. Along the vertical are classes of information (see Section 4.2). A shaded box indicates that information is available; numbers refer to survey questions in Appendix B; letters refer to notes following the table about the information or lack thereof. A white box indicates that a particular class of information for a particular element is unavailable.

5.7 Observations and Insights

1. The industrial environments and the control mechanisms give rise to a complex system. Any assurance that changing controls will have the desired effect depends on understanding the system. Many aspects of this system are outside the jurisdiction of regulatory agencies, yet these same aspects influence the control of the gauges.

2. Only a small fraction of the total number of nuclear gauges are at risk of entering the recycling stream. Most of the gauges are in use, controlling process units; such gauges cannot be removed without drawing attention. The population of gauges at risk is much smaller than the total gauge population.

3. The concepts of ICC and at-risk are essential for understanding the control of nuclear gauges. ICC allows for a determination of what keeps a gauge in place when a gauge is at risk. The potential for a gauge to be at risk determines the extent to which it is vulnerable to entering the recycling stream.

4. Hard control mechanisms operate by placing a gauge in a definite location. Soft controls operate by gaining attention. Whatever reliance is not placed on the hard control mechanisms is placed on the soft control mechanisms.

5. The control mechanisms have an implicit assumption that a licensee will, can, and knows how to assume the responsibility. Reference 1 suggests that the assumption is not always valid.

6. Responsibility for ICC, not for the gauges, is difficult to assign in industrial organizations. An industrial facility may be complex. The responsibilities of employees are overlapping and changing to meet market demands and the state of a facility. The use of outside contractors during system shutdowns for extensive maintenance and overhauls exacerbates the complexity.

7. The extent to which high-level accountability, civil penalties, and license revocation provide ICC is unclear. The chance of these mechanisms being called upon (the remote possibility of losing a gauge at an unknown time in the future) is overshadowed by acute concerns and hazards at an industrial facility.

Author's Note

Observations and Insights resume on page 60 after Table 4.

Table 3 Sources of information supporting the analysis of risk elements in licensees (Figures 20 and 21). LEGEND: A shaded box indicates available information; a number in a shaded box indicates a question of the survey in Appendix B and a letter indicates a note following the table. A white box indicates unavailable information. Degrees of information are discussed in Section 4.2.

Degrees of Information (Section 4.2)	Sources of Information	1: States of facilities (page 48)	2: Work force changes (page 49)	3: Gauge location (page 49)	4: At-risk potential for a gauge to get beyond control mechanisms (page 53)	5: State of a gauge at risk (page 56)	6: Disposition of a gauge at risk (page 56)
1st	Survey (page 129)	1		1			
	Other				A		
2nd	Survey (page 129)	9		10, 12	A		
3rd	Plausible judgments	B	C		A	D	E

Notes on Table 3

A. See Table 4 for details.

B. The prevalence of states such as phasing out, closed, and abandoned can be inferred from business statistics. Information from the demolition industry can be used to infer the prevalence of facilities that are being demolished. Judgments from regulators about orphaned sources can be used in a similar manner. A rough estimate of the number of gauges in these facilities can be made. Such estimates can be used as a basis for bounding risk estimates.

C. Plausible values can be used to bound risk estimates. To begin, site visits suggest that typically the turnover rate in industrial facilities is low.

D. The state of a gauge at risk or after disposition cannot be rigorously determined. Some event reports may yield insights into the states of the gauge when found. But the event reports are few and often sketchy.

E. The discard probability cannot be determined. Information about discoveries of radioactive material in the recycling stream show, in some unknown way, the results of the preceding elements and their components. With values assigned to Elements 1 through 4, probabilities can be selected to make the predicted number of gauges leaving facilities agree with the observed number. Otherwise, only values to bound risk can be assigned to Element 6.

Table 4 Sources of information supporting the analysis of control mechanisms (Figure 20). LEGEND: A shaded box indicates available information; a number in a shaded box indicates a question of the survey in Appendix B and a letter indicates a note following the table. A white box indicates unavailable information. E&C = education and communication. HLA = high-level accountability. IDS = interim dedicated storage. QCR = query at a change in responsibility. Degrees of information are discussed in Section 4.2.

Control Mechanisms — **Hard Controls** / **Soft Controls**

Degree of Information (Section 4.2)	Source of Information	In Use	IDS	Return	Inventory	Labels	Physical Security	Lockout	Responsibility	E&C	HLA	Inspection	Civil Penalty	Revocation	Registration	Publicity	QCR
1st	Survey (page 129)	1	1	A			6, 7										
	Other							B			C		D	E	F	G	H
2nd	Survey (page 129)				3, 4	2			5, 8, 11	I, 5, 11	J, 11			E			
3rd	Plausible Judgments	K	K	K	K	K	K	K	K	K	K	L	K	K	K	K	K

Notes on Table 4

A. Information can be obtained in a consolidated form from gauge vendors.

B. Lockout is a procedure that is required by the Occupational Safety and Health Administration.

C. Discussions with both State and Federal regulators and reviews of specific licenses can be used to determine who is usually held accountable.

D. Agreement States can be asked about a civil penalty program.

E. Federal and State regulatory agencies always have the option of revoking a license.

F. All Agreement States will eventually have a registration program. States would still have to be asked about the promptness of following up when licensees do not respond to a mailed registration notice.

G. In the NRC's jurisdiction, the names of licensee that are out of compliance may be made public. Agreement States can be asked if this is done in their jurisdictions.

H. QCR is not required by the NRC. Agreement States can be asked if it is required.

I. Education and communication would be more difficult in a large facility a than in a small facility.

J. For specific licensees, the license has a name of someone in the facility. For general licensees, an indication of HLA may available in States that register generally licensed devices.

K. The effectiveness of control mechanisms to provide ICC is a subjective evaluation, done by postulating and discussing plausible values among experienced regulators.

L. Inspections do not provide ICC. See Section 5.4

8. A difficulty for licensees in maintaining ICC is that they lack the collective experience of what works and what does not work for providing ICC. The regulations are necessarily broad and nonprescriptive to cover a diversity of industrial conditions. Yet this leaves licensees to devise their own control program. Communicating ICC practices to licensees might reduce the risk of gauges being inadvertently discarded. Developing such guidance as a survey (e.g., see Section 4.3.1) would make the guidance compatible with the demands for more acute concerns found in industry.

9. The decrease in risk from moderately increasing the frequency of inspections appears to be small. Because gauges are subject to ICC for most of their service life, inspections can significantly reduce risk only when they coincide with at-risk periods.

10. Registration enhances other controls that provide ICC, such as responsibility and accountability. Registration refreshes memory about the gauges, especially important when facilities come and go or when employees change professions or retire. A lack of a response alerts regulators to some forms of at-risk conditions, such as closed and abandoned facilities. Followup is necessary for registration to be effective.

11. A licensee is required to notify a regulatory agency of a change in ownership or when going out of business. A mechanism that is part of the title transfer or procedures for terminating a business, to inform a regulatory agency, might reduce the risk of gauges being improperly transferred.

12. Redundancy in control mechanisms increases overall effectiveness because it compensates for control mechanisms becoming compromised.

6 SCRAP METAL CONSOLIDATION

6.1 Overview

Scrap metal is collected in yards where it is prepared for use in steel mills. The scrap metal comes from many and varied sources, from unskilled individuals to large sophisticated companies. Scrap metal can be shredded into fist-size pieces, compacted into bales, sheared, or cut with an acetylene torch. During the collection and preparation, the shutter of a discarded gauge may be opened or the sealed source may become dislodged or breached. Many, but not all, scrap yards have radiation monitors.

Difficulties are encountered when analyzing scrap metal consolidation:

- The routes of scrap metal can be complex and changing in response to the supply and demand for scrap metal.
- The effects of the processes on a nuclear gauge are unknown. There are no principles or experiments from which to predict what will happen to a nuclear gauge when it is inadvertently processed with scrap metal.
- Reaching the various collectors for information is difficult, if not impossible.

Nevertheless, a meaningful analysis can be done by considering the collectors together, just looking at the processes by assessing the commodities of scrap metal received by the steel mills. There are far fewer steel mills that can be reached than scrap metal collectors that cannot be readily reached.

6.2 Importance in Risk

Scrap metal collectors and scrap yards must be taken into account in estimating risk because the processes of collecting and preparing scrap metal can compromise the integrity of a nuclear gauge or increase the difficulty in recovering a gauge. Health hazards can occur as a result of the following:

- gauge with an open shutter passes along the recycling stream;
- sealed source is dislodged from its housing when the housing is cut, sheared, or shredded; or
- sealed source is breached from cutting or shredding.

The topics taken into account in the analysis of scrap metal consolidation are indicated in Figure 25.

6.3 Concepts

Scrap metal comes from many origins. Though some origins are more risky than others, only some vague statements can be made about those risks:

Section 6

■ Metal collection
□ Landfill mining
■ Scrap yards
■ Scrap metal processing
□ Visual detection
■ Radiation detection
□ Monitoring practices
□ Rejection practices
□ Proper disposal
□ Improper disposal
■ Danger to life
■ Danger to property

Figure 25 Topics taken into account in the analysis of scrap metal consolidation. LEGEND: A black bullet indicates that a topic is comprehensively taken into account. A white bullet indicates that a topic is beyond the scope of the risk analysis. A gray bullet indicates that a topic is briefly taken into account.

- Intuitively, scrap metal from industrial facilities is more risky than scrap metal for other origins; this is where the gauges are used and where ICC breaks down. Industrial facilities may discard small amounts of scrap metal into dumpsters destined for landfills, or they may have contractors remove scrapped equipment. Some of this scrap metal may be, or may have on it, a nuclear gauge.

- "Peddlers" (also known as "scavengers" or "gypsies") may find nuclear gauges that have been improperly disposed of in remote areas or that have been found in abandoned industrial facilities.

- In general, residential scrap metal, such as appliances and automobiles, are low risk. These items do not use nuclear gauges. But the risk of such scrap metal is not zero; nuclear gauges have gone through shredders, which typically process automobiles.

Some scrap yards only gather metal. Others gather, sort, and process the metal to reduce the volume by compacting it.

Scrap dealers have many concerns that demand their time and attention:

- Customers and suppliers of scrap metal change according to market pressures.

- Large market pressures and thin profit margins require constant attention.

- Rail carriers want the set point of radiation detectors at a high value because railcars often have slight contamination from dirt, slag, scale, zirconium sand, or refractory brick. These forms of benign contamination are discussed further in Section 7.6.

- Steel mills want the set point of radiation detectors set low, immediately above background levels, to maximize the chance of finding radioactive sources. They want a safe supply of scrap.

- Dealers do not want loads of scrap metal to be turned away and do not want questions asked about their loads.

Figure 26 illustrates the routes formed by demolition contractors, peddlers, and scrap yards. The routes are varied, complex, and change according to market pressures. Some scrap yards have two radiation monitors, one for trucks and the other for railcars. Scrap metal inappropriately scanned by one monitor may be appropriately scanned by another monitor. Other yards have only one monitor; particular pieces of scrap metal may be inappropriately scanned both on the way in and on the way out of the yard. A given steel mill may receive scrap metal from a few to a hundred suppliers through a broker; these suppliers too may change according to market pressures. Specific suppliers to other dealers and steel mills change according to the supply and demand for scrap metal. Some dealers may have radiation monitors; others may not. Along some

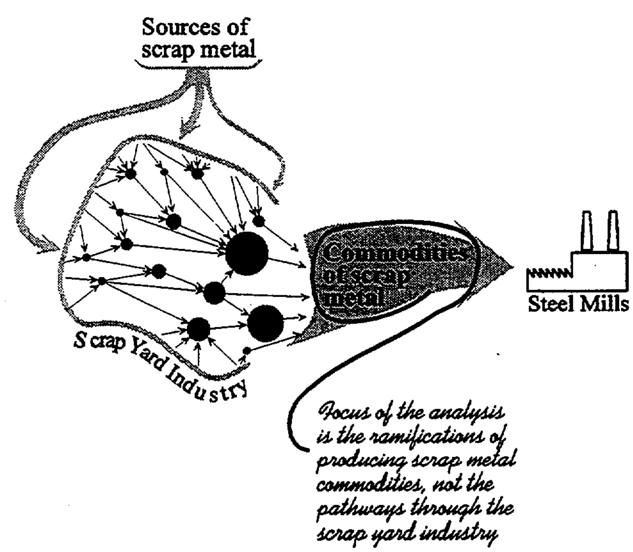


Figure 26 Scrap metal consolidation. LEGEND: ● = scrap yard. Small circles indicate peddlers and small yards. Medium and large circles indicate larger yards, possibly with process equipment such as balers, shredders, and shearers.

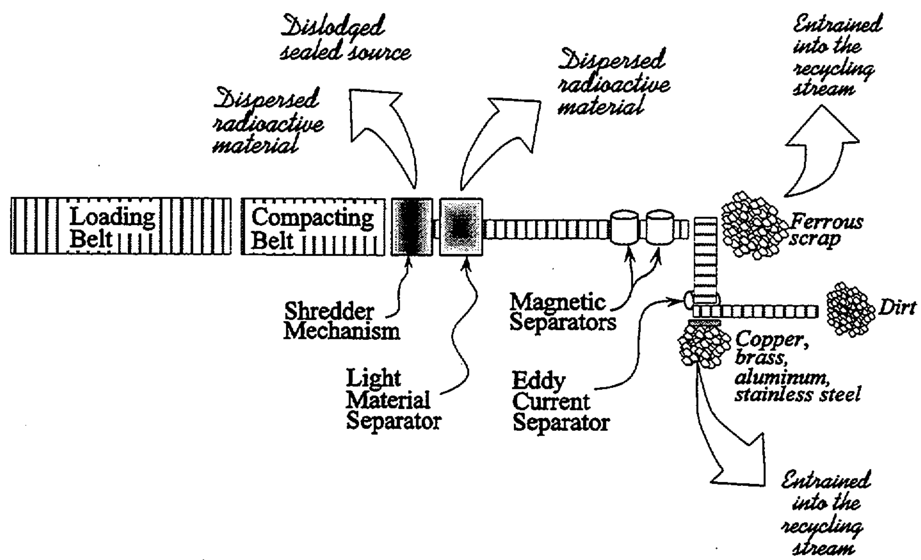


Figure 27 Location of potential radiological hazards when a nuclear gauge is shredded.

of these routes the scrap metal may be scanned multiple times; sometimes the scrap metal will have been unloaded; other times it may go through several monitors without being unloaded. The effect on risk from multiple passes though a radiation monitor is discussed in Section 7.6. Nevertheless, some generalizations can be made:

- Smaller yards may manually compact scrap metal before sending it to larger yards.
- The large-volume process equipment is found at the larger yards that are close to, if not directly, supplying the steel mills because the expense of the equipment can be justified; scrap metal is processed by shredding (pulverizing), baling (binding into rectangular packages), shearing (severing large pieces of metal), and burning (cutting pieces too large to shear with an acetylene torch).
- The sophisticated portal monitors are also near the end of the recycling stream.

The scrap metal industry is, for the most part, unconsolidated (Ref. 16), making efforts to reach most of the scrap dealers very difficult. The scrap yards are numerous. Scrap yards themselves are also in a state of flux, with piles of scrap metal increasing and decreasing during the normal course of business. For this reason, collecting information through site visits and surveys is difficult. An example of such information is the number of radiation monitors along the routes of scrap metal going to the steel mills. The difficulty of obtaining information is compounded by the understandable reluctance of scrap dealers to divulge information because of concerns for adverse impacts on their businesses.

Thus, many details of scrap metal consolidation cannot be resolved for a detailed risk analysis. But useful insights can be obtained from an analysis to determine the ramifications from the processes. The amounts of the various processes are reflected in the amounts of commodities being sent to the steel mills.

Figure 27 shows hazards from processing a nuclear gauge. Normally, many kinds of materials are in the feed stock of a shredder—magnetic and nonmagnetic metals, plastic, dirt. Scrap metal is placed (tossed) on the loading conveyor belt with a crane. The loading belt brings the scrap metal up to the compactor belt that forces it into a shredding mechanism. Here it is reduced to fist-size pieces. Light airborne material is removed from shredded metal by a ventilation system and collected by a cyclone precipitator; much of the air is recirculated. Magnetic drums remove magnetic metals from the scrap stream; a pile of ferrous scrap forms below this belt. The nonmagnetic material (e.g., aluminum, copper, brass, stainless steel[8], dirt) are removed with an eddy current separator. The remaining dirt is disposed in a landfill.

The shredder mechanism may dislodge or breach a sealed source. The shredding mechanism may trap the pieces of a breached source in crushed metal. The light material separator may disperse a breached source. The magnetic and eddy current separators may carry an intact gauge or a dislodged source with scrap metal. A dislodged source may be lodged in a piece of scrap metal.

Though the hazards at a shredder, or other processing (e.g., shearing, cutting with an acetylene torch), can be qualitatively described, a paucity of information precluded determining risk. There have been no studies to determine the probability of dislodging or breaching a sealed source. There have been no studies to determine the probability of a dislodged sealed source dropping into the processing equipment, dropping to the ground, or being carried along with the scrap metal. There have been no studies to determine the dispersion of radioactive material when a sealed source is breached. Only third degree information (see Section 4.2) is possible at this time.

6.4 Elements of Risk

Figure 28 illustrates the risk elements of scrap metal consolidation (e.g., scavengers, scrap yards). Single black lines are sequences of risk elements. For clarity, common portions of the sequences are illustrated in the inset; some of these sequences are discontinued at –A⟩, then continue in the inset at –A⟩; other such sequences discontinue at –B⟩, then continue in another inset at –B⟩. An arrow (➢) indicates that the sequence continues in Figure 41. A dot (●) indicates the end of a sequence. An open dot (○) indicates that a sequence is unresolved; it can continue, but is not developed further. Hazard terms from the *U.S. Code of Federal Regulations* (Ref. 9) apply at this point between Elements 7 through 12. A black box (■) indicates that a concern is present. A shaded box (▒) indicates that a concern might be present. A white box (□) indicates that a concern is not present.

A paucity of information necessarily means that the analysis in Figure 28 is simple. Factors that have not been explicitly taken into account include the capability of radiation monitors, the practices of using the equipment (e.g., see Section 7.6), and the characteristics (e.g., volume, density) of scrap metal loads. Elements 8, 9, and 12 can be assessed only by postulating plausible values to determine the effect on risk; a large effect would justify the expense of collecting information (see Section 4.2). Visual detection has been neglected for the reasons discussed in Section 2.5 and because of a paucity of information to support an assessment.

Most, but not necessary all, scrap yards supplying the mills have radiation monitors. Figure 28 illustrates this with two sets of sequences. Along the sequences branching from (A) are radiation monitors. Those sequences branching from (B) have no such radiation monitors.

<u>Radiation Monitors</u>

- A gauge that goes through the processing intact and with a closed shutter is not a danger to life and property; if the gauge is detected, then the sequence terminates; if the gauge is undetected, then the sequence continues.

- A gauge that goes through the processing intact with the shutter open may be a danger to life, depending on the orientation and its location in the scrap metal. It is not a danger to property. Detection only terminates the sequence.

8 / The 400 series of stainless steel, some of the 300 series of stainless steel, iron, cobalt, and nickel are magnetic.

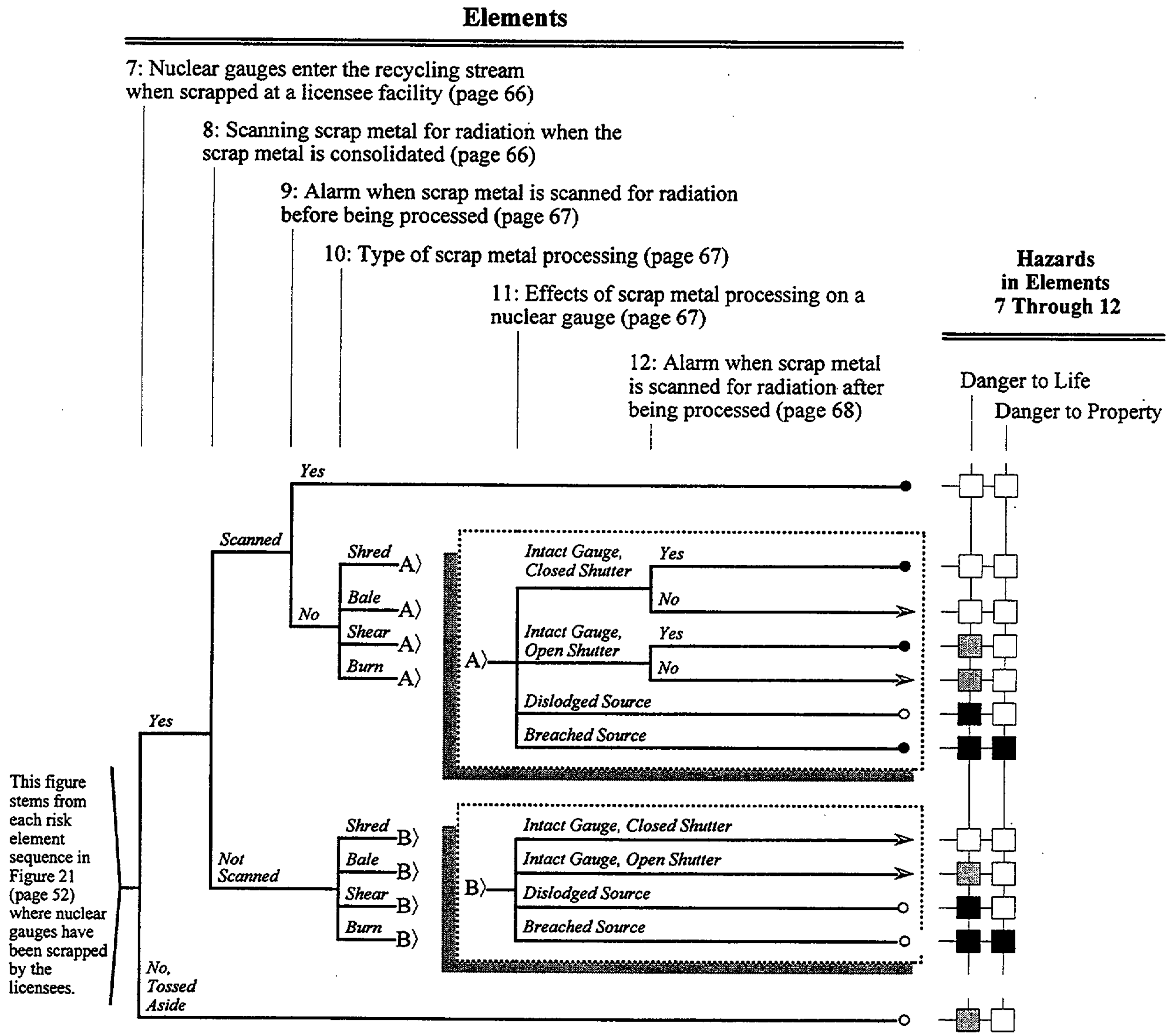


Figure 28 Analysis of risk elements for scrap metal consolidation. LEGEND: Single black lines are sequences of risk elements. For clarity, common elements of the sequences are illustrated in the inset; some of these sequences discontinue at –A⟩, then continue at –A⟩; other such sequences discontinue at –B⟩, then continue at –B⟩. An arrow (➢) indicates that a sequence continues in Figure 41. A dot (●) indicates the end of a sequence. An open dot (○) indicates that a sequence is unresolved; it ends here, but not further developed. A black box (■) indicates that a concern is present as of Element 12 of a particular sequence. A shaded box (▩) indicates that a concern might be present as of Element 12 of a particular sequence. A white box (□) indicates that a concern is not present as of Element 12 of a particular sequence. Hazard terms are from the *U.S. Code of Federal Regulations* (Ref. 9).

- A dislodged source is a danger to life, but not to property. It will be detected if it is lodged in the scrap metal and radiation monitors are present. The sequence is unresolved in the scrap yard; it may be carried along in the recycling stream; it may drop inside processing equipment; it may drop on the ground.

- A breached source is a danger to both life and property; nearby populated areas or heavily traveled roads may be contaminated. Because scrap metal will be contaminated, it will be detected; hence, Element 12 is undeveloped. The sequence terminates in the scrap yard.

No Radiation Monitors

The sequences here present the same dangers as the sequences when radiation monitors are present but do not activate. The difference is that here, there are no chances to terminate sequences because there is no detection.

Other

- A nuclear gauge that is detected when entering a scrap yard is not a danger to life or property. In Figure 28, the three boxes under hazards are white.

- If scrap metal containing nuclear material is tossed aside, there is nothing that can be definitely said about the danger to life and property. The sealed source could be in an intact gauge with the shutter closed or open. Nothing is known about the orientation of the shutter. The source may be dislodged. The actions being taken are also unknown.

Element 7: Gauge Enters the Recycling Stream (Figure 28)

The difficulty in disposing of a nuclear gauge is recognized, at least to some extent, in the recycling industry:

- Disposal costs of $5,000 or more may be incurred.

- Collectors and scrap dealers tend to avoid government assistance, even to address an alarm of a radiation monitor.

- Many people have an alarmist reaction to even minute amounts of radiation or radiation symbols.

- Giving attention to disposing of unwanted material is attention taken away from normal business.

There is a reluctance to assume any responsibility for a discovered gauge. People collecting scrap metal may recognize a gauge and, knowing the difficulty in disposal, may simply leave it or cast it aside, believing it will be readily detected farther along in the recycling stream.

Element 8: Scanning Scrap Metal for Radiation (Figure 28)

The extent to which scrap metal is scanned for radioactive material has implications for risk. Scrap metal may not always be scanned for a variety of reasons:

- Alarms are deactivated because they are annoying.

- The monitor system may have malfunctioned.

- The speed of the vehicle may be excessive, allowing insufficient time for a load to be scanned.

- The radiation monitors at low volume/throughput yards may not be as sensitive as those at the high volume/throughput yards.

Element 8 also applies to scrap yards in which scrap metal is scanned with a hand-held survey meter, not a fixed radiation monitor. The scanning may sometimes be done carelessly.

Sometimes it may not be done because it is inconvenient or weather is inclement. The meter may be out of calibration.

The net effect of radiation monitoring, whether with fixed radiation monitors or hand-held survey meters, is too nebulous to assess. Element 8 can be treated by postulating plausible values and determining the effect on risk estimates.

Element 9: Alarm When Scrap Metal Is Scanned for Radiation Before Processing (Figure 28)

Scrap metal can be monitored twice, once when it enters a yard and again after it has been sorted and processed, when leaving the yard. These opportunities for monitoring are not equivalent. When entering a yard, the dealer has not taken possession of scrap metal; when leaving the yard, the dealer owns the metal and whatever is in it. Processing the scrap metal changes the composition and increases the density, which in turn, reduces the detection probability.

Although scrap metal is more densely packed when leaving a yard than when entering, the processing may have opened the shutter of a gauge or breached the housing of a gauge, exposing the sealed source; even within densely packed scrap metal, an exposed sealed source is likely to be detected. A sealed source that has been dislodged from its housing and lodged in the scrap metal can be easily detected. A breached source will contaminate scrap metal, likely making the breached source easy to detect. A gauge with an open shutter is likely to be detected by sensing either the direct radiation or scattered radiation. Because of the nebulous state of information at this point, Element 9 is simplified relative to a more complex treatment discussed in Section 7.5, justified here by the paucity of information about scrap yards.

Element 10: Type of Scrap Metal Processing (Figure 28)

While a nuclear gauge is robust, it is not designed to withstand the processing of scrap metal. The processes challenge the integrity of a gauge. But the gauges are not equally likely to enter each type of process. Specific sources of metal usually go through specific processes. Long pieces of pipe or beams will be cut with an acetylene torch or sheared. Large industrial rollers will be cut with a torch. Automobiles will be shredded.

The possibilities of Element 10 need to be weighted in three ways:

- weight of the commodities of scrap metal;
- tendency of gauges to be in one commodity rather than another; and
- likelihood of a specific process dislodging and breaching a sealed source.

The first factor can be readily done by determining the commodities consumed by the steel mills. A paucity of information precludes determining the remaining factors; in this regard, all commodities should be treated the same unless a strong argument can be made to show otherwise. For example, turnings come from machine lathes. There is no reason to suspect a gauge in turnings. Furthermore, getting information about the consumption of turnings would be difficult because this commodity is sometimes a sensitive issue at mills; turnings contain cutting oil, which is an environmental hazard. Another source of scrap metal that can be excluded is stampings.

Element 11: Effects of Scrap Metal Processing on A Nuclear Gauge (Figure 28)

A paucity of information leaves much to be understood about the effects of processing on a nuclear gauge. Nevertheless, statements about the effects can be made.

Shredding. Gauges have been known to pass through a shredder intact, although battered. Incidents have occurred when the sealed source was dislodged or breached.

Baling. Compacting a gauge in scrap metal will not open a shutter or dislodge a sealed source. A gauge is, for the most part, solid and not readily crushed. But baling increases the shielding around a gauge, increasing the difficulty of detection. The consequences of baling are low but the difficulty of recovering a gauge is increased.

Shearing. The single blade used to cut scrap metal that is being held by compressing hydraulic equipment is unlikely to damage a gauge. A gauge would have to be wedged under the blade for it to be cut.

Burning. The chance of cutting into a gauge with a cutting torch cannot be ruled out, although intuitively, it is remote. An O-frame or a C-frame gauge with several sources in a housing may be dislodged when the frame is cut. The source may drop onto the ground, out of the recycling stream, where it causes undetected exposures to the few workers doing the cutting. Breaching a source seems unlikely because the source is small and the cutting line is narrow.

Element 12: Alarm When Scrap Metal Is Scanned for Radiation After Processing (Figure 28)

See the discussion in Element 9 on page 67.

6.5 Sources of Information

Table 5 is a summary of the sources of information for developing the inputs of the scrap yard analysis. Along the top are the elements corresponding to the elements in Figure 28. Along the vertical are classes of information (see Section 4.2). A shaded box indicates that information is available; numbers refer to a few relevant questions in the survey of the steel industry (Appendix C); letters are notes following the table about the information or lack thereof. A white box indicates that a particular class of information for a particular element is unavailable. Much of the information available for the analysis of the scrap yards is third degree (Section 4.2). Most information about the scrap yard industry is inaccessible; this point has been proven by the efforts of a trade association to obtain survey information of its members.

6.6 Observations and Insights

1. A quantity that is difficult to estimate is the probability of breaching a sealed source in any of these processes; the experiments necessary for sufficient data would be costly. The fraction of scrap yards with radiation monitors supplying the mills is also difficult to estimate because the information is difficult to gather and would be considered proprietary.

2. The analysis of the scrap metal consolidation necessarily considers this industry as a whole. The routes of scrap metal consolidation are too complex and varied to resolve. Many of the collectors are difficult to reach, for example, to request information through a survey.

3. A health hazard from nuclear gauges is at the scrap yards. Here, schredding, shearing, and burning scrap metal can dislodge and breach a sealed source. Installing radiation monitors at some point in these processes might be an effective way to detect a dislodged or breached sealed source. But the use of radiation monitors may be impractical for these processes. Supports for monitors must be placed where monitoring would be effective. High vibrations, shock waves from explosions (e.g., when a propane tank is accidently processed), and stray pieces of scrap metal could damage a monitor.

4. Scrap yards are often located near populated areas. Some people can be placed at risk of radiation exposure when a breached source is dispersed. The extent of the dispersal is difficult to predict.

Table 5 Sources of information supporting the analysis of risk in scrap metal consolidation (Figure 28). LEGEND: A shaded box indicates available information; a number in a shaded box indicates a question of the survey in Appendix C and a letter indicates a note following the table. A white box indicates unavailable information. Degrees of information are discussed in Section 4.2.

Degrees of Information (Section 4.2)	Sources of Information	Elements: 7: Nuclear gauges enter the recycling stream when scrapped at a licensee facility (page 66)	8: Scanning scrap metal for radiation when the scrap metal is consolidated (page 66)	9: Alarm when scrap metal is scanned for radiation before being processed (page 67)	10: Type of scrap metal processing (page 67)	11: Effects of scrap metal process on a nuclear gauge (page 67)	12: Alarm when scrap metal is scanned for radiation after being processed (page 68)
1st	Survey (page 139)	<........	....	A, B	....	....	........>
2nd	Survey (page 139)				C 4		D
3rd	Plausible judgments	E	F	G		H	

Notes on Table 5

A. A survey of the scrap yards to determine equipment, practices, and experiences could not be done (see Section 6.3).

B. Same reasons in Section 6.3 apply to the demolition contractors.

C. The volume of commodities produced by the scrap dealers can be estimated as the volume of commodities consumed by the steel industry. A survey question in Appendix C asks about the commodities consumed at a mill.

D. The effectiveness of scanning scrap metal commodities is determined from shielding calculations as discussed in Section 7.5. Here, unlike in Element 9, the shielding properties of scrap metal commodities can be better known; they are that of the commodities entering the steel mills.

E. Only anecdotal information is available. Plausible judgments may be used to determine the effect of Element 7 on risk.

F. In a risk analysis, plausible estimates can be made to determine the effect on risk. Although information about the radiation monitors at the scrap yards *directly* supplying the mills could, in principle, be obtained from the survey of the industry, the information is largely inaccessible to many steel mills. In general, mills have an understanding, in some form, with their supplier(s) that scrap metal will be scanned for radioactive material; whether it actually is or is not another matter. Some mills have only a few suppliers and have insisted on radiation monitors that are operated using standard procedures. Other mills obtain scrap metal from as many as a hundred scrap yards through a broker, and the suppliers change according to market conditions. Asking for information about the monitors at the yards may be a burden for steel mills.

G. Only plausible judgment about the shielding properties of scrap metal entering the scrap yards are reasonable.

H. Events are known where a nuclear gauge went through a shredder. Beyond these incidents, the effects of processing can only be speculated. There are insufficient data to determine, for example, the probability that the sealed source will remain in the gauge, be dislodged, or be breached.

7 STEEL MILLS

7.1 Overview

Scrap metal from collectors arrives at steel mills where it is melted to make products for industrial, commercial, and residential products. The chances of radioactive material getting onto a mill's grounds or into the furnace vary from mill to mill because of differences in the configuration of radiation monitors, the equipment, and the practices for using the equipment. Radiation monitors at the steel mills can detect a nuclear gauge in a load of scrap metal, but the detection probability is less than 100% and poorly characterized. Similarly the ramifications of some practices for using radiation monitors are not always well understood. The probability and the practices have important ramifications for both the steel industry and regulatory agencies.

Radioactive material that has been melted will usually be detected, depending on the type of radioactive material that is melted and the equipment that it passes through. Though test pieces taken from the furnace where scrap metal is melted are usually scanned for radiation, the capability and use of the detection equipment varies from one mill to the next. Radiation gauges used in the production of steel product also act as monitors, and may give erroneous readings when steel is contaminated. Usually furnace dust is scanned before it is sent offsite to be processed because the processors usually scan the furnace dust and will not accept it if radiation is detected.

7.2 Importance in Risk

Steel mills must be taken into account in estimating risk because they are the last point at which a nuclear gauge might be recovered before high costs are incurred for decontaminating equipment and disposing of contaminated steel products and byproducts. Also, radiation monitors at steel mills offer protection to the public when contaminated product and byproduct materials (furnace dust and slag) leave a mill. The topics taken into account in the analysis of steel mills are indicated in Figure 29.

7.3 Definitions

A *standard response* after monitoring scrap metal for radiation occurs when a load without a sealed source passes through a monitor station without causing an alarm.

A *false alarm* occurs when scrap metal is scanned for radiation and a monitor alarm activates in the absence of a sealed source. A false alarm is not a malfunction of the monitor, but rather, a response to radiation from benign contamination (BC) or a spurious signal strong enough to cause an alarm. In either case, the monitor is giving erroneous information. See also box entitled "False Alarms" on page 89.

A *heat* is one batch of steel being melted in a furnace.

A *missed detection* occurs when scrap metal is scanned for radiation and a monitor does not

Section 7

- □ Visual detection
- ■ Radiation detection
- ■ Detection probability
- ■ Scrap metal monitoring practices
- ■ Scrap metal rejection practices
- ■ Monitoring steel products
- ■ Monitoring byproducts
- ■ Proper disposal
- ■ Improper disposal
- ■ Danger to life
- ■ Danger to property

Figure 29 Topics taken into account in the analysis of steel mills. LEGEND: A black bullet indicates that a topic is comprehensively taken into account. A white bullet indicates that a topic is beyond the scope of the risk analysis. A gray bullet indicates that a topic is briefly taken into account.A black bullet indicates that a topic is comprehensively taken into account in the risk analysis. A grey bullet indicates that a topic is briefly taken into account. A white bullet indicates that a topic is beyond the scope of the risk analysis.

alarm but a sealed source is present. The sealed source may be highly shielded, preventing a sufficient amount of radiation from reaching the monitor to cause an alarm. Whatever the reason, the monitor is erroneously indicating that a load lacks a sealed source.

A *detection* occurs when a radiation monitor alarms as scrap metal is scanned for radiation, and a sealed source is present.

7.4 Concepts

The use of radiation monitors at steel mills to scan scrap metal for radioactive material differs from mill to mill. Each steel mill has its own arrangement of radiation detectors; there is no standard design of steel mills or installation of radiation monitoring equipment at steel mills. The collective locations of monitors throughout industry are illustrated in Figure 30; few mills have all these means of detecting radioactive material. Monitors of one form or another are found at the following locations:

1. radiation monitors scanning scrap metal entering a mill and going to the furnace;
2. radiation monitors scanning scrap metal entering a charge bucket;
3. radiation monitors scanning a fully loaded charge bucket;
4. survey meter or other detection equipment scanning test pieces taken from the furnace;
5. radiation gauges controlling the flow of steel into the caster;
6. radiation gauges in the finishing mill;
7. radiation monitors scanning steel product and byproduct materials (i.e., slag, furnace dust) leaving the mill; and
8. radiation monitors scanning only furnace dust.

A given mill will purchase affordable monitoring equipment that seems to be the most prudent. If a

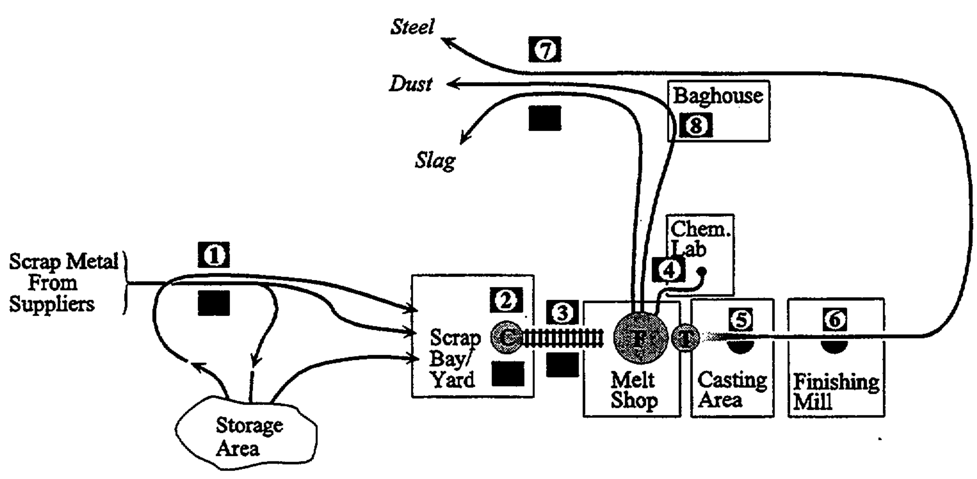


Figure 30 Radiation monitors at mills throughout the steel industry. LEGEND: 1 = radiation monitors for scanning scrap metal entering a mill and for scrap metal taken from the storage area to the scrap bay. 2 = radiation monitor for scanning the charge bucket while it is being filled. 3 = radiation monitor for scanning a fully loaded charge bucket. 4 = survey meter for scanning test pieces. 5 = radiation gauge at a caster. 6 = radiation gauges in the finishing mill. 7 = radiation monitor for scanning products and byproducts (i.e., slag, furnace dust). 8 = radiation monitor for scanning only furnace dust. C = charge bucket. F = furnace. T = transfer ladle.

mill has radiation monitors at all, they will be used to scan incoming scrap metal as it enters the mill. Keeping radioactive material out of the mill, thus avoiding the hazard in its entirety, is of more concern than simply relying on monitors at the charge bucket, where the mill owns the scrap metal and must bear the cost of disposing of unwanted material. Radiation monitors in each location listed above are discussed in the following sections.

Item 1 (Figure 30): Monitoring Incoming Scrap Metal

Trucks and trains deliver scrap metal to steel mills where it is scanned for radiation. Trucks are monitored as they enter a mill. The monitor station may be automated; when a radiation alarm is not activated, a machine dispenses a pass that the driver presents to deliver the scrap metal. The monitor station may be manually operated by plant personnel at a guard station or at a weigh scale; trucks that successfully pass the monitoring are allowed to enter the mill. Railcars (e.g., gondolas) are left on a spur track by a freight carrier. The railcars are brought onto the mill property by their own locomotives. Once on the property, the railcars are scanned before the scrap metal is accepted. Railcars suspected of containing radioactive material are set aside.

A vehicle (truck or railcar) passing through a monitor station must remain in front of the detectors long enough for a sufficient amount of radiation to be received by the detectors. Because of the expense of detectors, they are seldom the length of the vehicle, which would allow the vehicle to be scanned while motionless. Smaller detectors are used to keep their cost reasonable; therefore vehicles must pass through a monitor station slowly to approximate monitoring while stationary. Because the sensitivity of a monitor is inversely proportional to the speed of a vehicle, various methods are used across the industry to ensure that the vehicles will move at no more than the maximum recommended speed (usually 5 mph)—radar, monitor station before or after the weigh scale, or a speed bump in a road before the monitor station. But the recommended speed can still be exceeded. Although an overspeed alarm will activate when a vehicle is passing through a monitor station too quickly for effective scanning, the alarm is not always heeded. The practice at a very busy mill might be to warn truck drivers that cause an overspeed alarm to slow down—the next time.

Usually two detectors scan from the sides of the vehicle; they can be fixed in a position that is close to the vehicles because the vehicle width is essentially constant (i.e., as wide as can fit on a road or railroad track). Sometimes a third detector is also located above the vehicle; this is a little more difficult to do because the height of a load can vary. Seldom is a fourth detector placed on the ground looking up through the vehicle; dirt, oil, and precipitation dissuade this location. Also, the detector must be protected from the weight of the vehicle (e.g., supporting structure for the tires and a grating over the detector).

The practices for responding to a radiation alarm when a vehicle passes through a monitor station can vary from one mill to the next:

- A mill may be encouraged by a scrap dealer to accept a load suspected of containing radioactive material and then to investigate the cause of the alarm. Should radioactive material be found, the scrap dealer will pay for the disposal.
- A mill may not fully accept a load of scrap metal until it has passed radiation monitoring. If a load is suspected of containing radioactive material, then the load will be taken apart. Should radioactive material be found, the scrap metal will be reloaded and sent back to the supplier. The investigation may take place with a third party present (e.g., a State regulator) to witness and certify that radioactive material was not added to the load. See also box, "Reworking a Load of Scrap metal," on page 74.
- A mill may take a load apart, even if such action constitutes accepting the scrap metal. Should radioactive material be found, the truck is refilled and sent away.

- Vehicles that cause an alarm may be rejected with no further action. At some mills, local authorities, such as police or regulators, may be notified. At other mills, they are not.

Other unknown possibilities are suggested by Figure 6.

The manner in which radiation alarms are addressed is influenced by local markets. Competing local mills cannot pressure a scrap dealer who has alternative customers. For this reason, some mills will diversify their suppliers. But some mills form a close alliance with a single supplier; both have an interest in keeping radioactive material out of the furnace.

In Figure 30, after the vehicle enters the mill, the scrap metal is brought to a storage area, where it is sorted and temporarily kept. Across the steel industry, the area has various names, including scrap yard and farm. A mill typically has a 3-week supply of scrap metal in storage, but the amount varies from mill to mill. Some mills form close relations with their suppliers, relying on *just-in-time deliveries*, keeping only enough scrap metal on their grounds to keep the furnace steadily operating during minor fluctuations in supply and demand; other mills prefer a diversity of suppliers (Ref. 16). From the storage area, metal is brought to an area adjacent to the melt shop by truck, railcar, or scale car. At some mills, this metal may pass again through a monitoring station along the way; at most mills, it does not go through a monitoring station again.

The area adjacent to the melt shop is known by different names (e.g., scrap yard if it is not enclosed, scrap bay if it is enclosed, either scrap yard or scrap bay if it is partially enclosed). At some mills the scrap bay is small; for example, when the scrap metal is loaded onto scale cars, the charge bucket on the car is emptied into the furnace. Less often, scrap metal is taken directly from the transporting vehicle and loaded into the charge bucket. This area may receive scrap metal from the storage area or directly from outside the mill. The latter is more prevalent when a mill places much reliance on the supplier for just-in-time deliveries.

Additional discussion about monitoring incoming scrap metal is in Section 7.6.

Reworking a Load of Scrap Metal

Reasons for not wanting to take a load apart to determine the cause of a radiation alarm are easily understood.

- Vehicles are loaded to be dumped from a truck or pulled apart with a magnetic or mechanical grapple without people being nearby. Heavy and sharp pieces of scrap metal may shift or drop when being moved. Heat, cold, rain, and wind may make working conditions more hazardous. Thus, pulling a load apart with people nearby to search for a particular piece is dangerous and costly.
- Under some contractual arrangements for purchasing scrap metal, taking a load apart is tantamount to accepting the load and whatever is in it.
- There is some lack of awareness among scrap yards and steel mills about the Department of Transportation (DOT) exemption (see box entitled "Department of Transportation Exemption 10656") on page 75.

Author's Note

The term *load* is used instead of *shipment*. A shipment can refer to an entire train of many railcars. Usually only one of the railcars is of concern and addressed appropriately. But anecdotal information reveals that entire trains have been rejected because only one railcar caused a radiation alarm.

Items 2 and 3 (Figure 30): Monitoring the Charge Bucket

Some mills are able to monitor the charge bucket (Item C, Figure 30). When the charge bucket is filled, it is moved on tracks near the furnace (Item F, Figure 30), where it is lifted over and unloaded into the furnace. In a minimill, the electric arc

Department of Transportation Exemption 10656

The Department of Transportation (DOT) has requirements for shipping radioactive material (e.g., knowing the type of material, knowing the amount of material, labeling the container). However, obtaining permission to ship radioactive material can take several weeks. Meanwhile, the shipper must pay for use of the transporting vehicle. Furthermore, employees who discover radioactive material may not want to, and may not be trained to, identify, characterize, or package the material for shipment. The exemption allows a load of scrap metal to be turned away from a facility without going through the usual DOT requirements, yet maintaining accountability, even if the load is only *suspected* of containing radioactive material. Attributes of the exemption are as follows:

- The radiation from the load must be below a specified level to ensure there is no immediate threat to public health.
- The exemption is used for loads in trucks and railcars, not barges.
- The exemption is issued by a State Radiation Control Agency to the discoverer of the radioactive material. Copies are given to the carrier, the sending facility, the receiving facility, the receiving State, and the discoverer of the radioactive material.
- A load of scrap metal suspected of containing radioactive material can be returned to a facility other than the originating facility.
- The exemption is implemented on a case-by-case basis.
- Although the exemption was meant for interstate shipments, its use within States has been increasing.

The staffs at some scrap yards and steel mills are unaware of the exemption.

furnace (EAF) is charged usually two to three times with scrap metal; after the first charge is melted, collapsing the voids in the scrap metal, another charge is melted to utilize the entire volume of the furnace. In an integrated mill, the basic oxygen furnace (BOF) is charged first with scrap metal, then with pig iron from a blast furnace.

The configuration of the monitors around the charge bucket is dictated by the geometry of this area and the cost of such monitors in relationship to the budget at the mill. Three practices for monitoring a charge bucket can be found throughout the industry:

- A charge bucket is monitored while it is being loaded. The radiation monitor scans individual loads from the loading crane as the bucket is being incrementally filled.
- A fully loaded charge bucket is monitored while it is stationary in front of a radiation monitor. Before the charge bucket enters the melt shop, the charge bucket is stopped in front of the detectors for scanning. The monitoring time is typically one minute.
- A fully loaded charge bucket is monitored while it is moving into the melt shop.

Scanning the scrap metal while filling the charge bucket avoids much of the shielding from the large bulk of a loaded charge bucket. However, protecting fragile detectors from stray scrap metal while the bucket is being loaded can be difficult. The loading operation must be done quickly to allow the remainder of the mill to operate at capacity. The scrap bay or yard may lack structures that can support and protect detectors from stray pieces of scrap metal. Stray pieces can miss the bucket, or the load in the grips of a crane may collide with a detector. At mills that use scale cars to bring scrap metal to the furnace, the vibration of the cars during loading damages monitor systems; radiation detectors cannot be set on scale cars.

Item 4 (Figure 30): Monitoring Test Pieces

While the scrap metal is melting in a furnace, test pieces (also known as a lollipop sample) are taken from the heat to determine the chemical composition. A radiation monitor scanning the test pieces might detect ^{60}Co, which is known to form an alloy with the steel.

The practices across the industry vary both in the equipment that is used and the placement of the equipment, both of which affect the detection capability. Much of what is done seems to be a matter of preference. Across the industry, the instruments for scanning range from scintillation counters to Geiger counters. Sometimes, the detector of a survey meter is an integral part of the process of analyzing a test piece. The radiation monitor may be adjacent to the quench bucket used to cool test pieces taken from a heat. Or the monitor may be on the spectrophotometer used to determine the composition of the test piece. Other times, the survey meter is separate from the processing of test pieces, such as when the monitor is a survey meter on a table near the chemical analysis equipment.

When the sample arrives at the laboratory, it is placed under the detector for a short time and then removed to determine the chemical composition. Usually at least one sample from the furnace is scanned. In Figure 30, the monitor is drawn across a boundary of the box representing the laboratory to indicate that the location of the monitor can be found outside the laboratory, such as at the quench bucket, or inside the laboratory, with the analytical instrumentation. Two implicit assumptions are being made when monitoring.

The first assumption is that the time the sample is monitored and the distance of the sample from the detector are compatible with the monitor equipment. Some arrangements of the monitor equipment lack controls on the scanning. A survey meter set on a table lacks control on the scanning time. A technician places the test piece under the detector, waits a moment, then responds accordingly. A detector in front of a quench bucket lacks controls on the scanning time and the distance the test piece is from the detector.

The second assumption is that the heat is well mixed. The box entitled "An Incident of Radioactive Scrap Metal," page 79, may cause some doubt about this assumption.

When a heat is complete, it is poured into a transfer ladle (Item T, Figure 30). The molten steel is brought to one of three places, depending on the practices at a mill:

- to the caster to begin forming the product;
- to the lower power furnace to adjust the composition; or
- it is kept in the transfer ladle where minor changes in composition are made by passing gases through the molten steel.

Items 5, 6, and 7 (Figure 30): Monitoring Product

The steel product can be monitored for radiation at three points:

- Radiation gauges are sometimes used to measure the height of metal as it is poured into a continuous caster (Item 5).
- Radiation gauges are sometimes used to measure the thickness of the steel as it is rolled (Item 6). The gauges found in the mills usually have ^{137}Cs, ^{60}Co, or ^{241}Am as a sealed source for the radiation, but x-ray tubes can also be found (see also Section 8.3).
- Steel product is sometimes scanned with radiation monitors as it leaves a mill (Item 7). The equipment ranges from sophisticated portal monitors to survey meters. Sophisticated portal monitors are likely to be the same monitors for scanning incoming scrap metal; in Figure 30, this monitor is indicated separately from the monitors for incoming scrap metal for clarity in the illustration.

Items 7 and 8 (Figure 31): Monitoring Furnace Dust

At many steel mills, furnace dust is scanned for radiation. When ^{137}Cs is melted, it vaporizes from a heat and adheres to the dust. The practices found in the steel industry can be placed into three categories:

- Portal monitors (Item 7). The vehicle transporting the furnace dust is monitored with a sophisticated system that is either dedicated for furnace dust or the same system used to monitor incoming scrap metal. A dedicated monitor may be automated, dispensing a ticket that a driver must present to a guard before being allowed to leave the mill grounds with the dust.

An Incident of Radioactive Scrap Metal

In 1997, a steel mill sent rolls (coils) of steel to a distributor. A manufacturer eventually received the steel coils and made 33,000 shovel blades. The shovel blades were tempered in an oven and blasted with shot or grit, then quenched in an oil bath. The shot or grit had naturally occurring thorium in it. The stampings went through another steel company before going to another steel mill where a radiation monitor alarmed. The load of scrap metal was rejected and sent back to the steel company under a Department of Transportation exemption issued by a State. State inspectors expected to find a piece of radioactive material, but instead found 17,000 pounds of slightly contaminated stampings.

Samples of the metal were sent to a State laboratory and counted overnight. The contamination was found not to be thorium, but instead ^{60}Co at a concentration of 7.7 pCi/g (~0.2 Bq/g). The Nuclear Regulatory Commission (NRC) could not duplicate the radiation levels; nothing was found in the other coils and slabs made from the same batch (i.e., molten steel in a furnace or *heat*). A coupon sample was counted overnight and showed levels of 0.4 pCi/g (~0.01Bq/g). Two coils of unused steel at the manufacturer had radiation levels of 30 μR/hr. Additional coils received later were also found to be contaminated.

The contaminated metal was traced to a batch made on February 1, 1997. The 48 15-mCi sources in the refractory lining of the furnace where the scrap metal was melted were intact. The furnace capacity is 136 to 181 tonnes (150 to 200 tons); given the 7.7-pCi/g activity, the larger capacity figure suggests a 2-mCi source in a 181-tonne (200-ton) batch. It is not known whether or not the test pieces from the molten steel were monitored for radioactivity as the steel was being made. The process line has radiation gauges, but 0.4 pCi/g would not cause erratic readings.

Although the shovel blades were declared to be safe, the manufacturer sent them back to the steel company.

Source: NRC Event Report 32021 and discussions with James Yusko, Pennsylvania Department of Environmental Protection.

- Baghouse monitors (Item 8). The radiation monitor, similar to a survey meter, is fixed to a portion of the baghouse. A convenient place is between the bags, which remove the dust in the air steam coming from the mill, and the dust silo, where the dust is transferred to a vehicle transporting it for disposal.

- Survey meters. A person walks around the transporting vehicle with a handheld meter before the vehicle leaves the mill. The reason for this instrument instead of a portal monitor can be the high cost of a portal monitor and a very limited budget.

The dust processors also monitor the furnace dust and will not accept a load of furnace dust that is found to be radioactive. Contaminated furnace dust is classified as a mixed waste, which most dust facilities are not licensed to accept and process. There is some discontinuity in the practice of monitoring dust among some steel mills and at a hazardous waste processor; a mill may be using the portal monitor, but the furnace dust processor may be using only a survey meter. The waste processor also has potentially high costs for accidentally processing contaminated furnace dust. A reason for the portal monitor at the mill can, at least in part, be explained by a concern for liabilities and public image. Furnace dust on its way to a waste processor belongs to the mill until the processor accepts the load. If a truck carrying contaminated furnace dust were in an accident, spilling mixed waste on a highway, the potential for liability and the negative public perception might be costly to the mill. A mill invests in the state-of-the-art technology necessary to keep the chance of sending mixed waste out of the mill low and to state that whatever is reasonably possible is being done in this regard. This is especially true when a mill has melted radioactive material or has had an investigation where this might have occurred. Another reason is convenience. Some mills use one monitor station to scan everything coming in and going out of the mill.

Item 7 (Figure 30): Monitoring Slag

Although slag can be scanned in the same manner that incoming scrap metal is monitored with a portal monitor, some mills may have a reason for not doing so because refractory materials, also in the slag, may be slightly radioactive and cause many false alarms (see definition in Section 7.3). At other mills, an assumption is made in the policy at a mill that radioactive material will be either in the steel (e.g., ^{60}Co) or the furnace dust (e.g., ^{137}Cs or ^{60}Co). The assumption may be questionable because little is known about the partitioning of materials at high temperatures.

Slag has several uses, some of which depend on its chemical composition. Iron can be recovered and reintroduced into the steel-making process. Slag can be used as filler material and roadbed material. Some slag is highly alkaline and is used to control mine drainage. Slag with a high iron content may be used directly in future heats. Other nonferrous materials in slag may be blended with fluxes used in steel making.

7.5 Probability of Detecting a Radioactive Source in Scrap Metal

7.5.1 Statement of the Problem

Radiation monitors form the primary defense in steel mills (and scrap yards) when a nuclear gauge escapes control mechanisms. Yet the effectiveness of the equipment, as measured by the probability of detecting radioactive material in a load of scrap metal, is incompletely known. The typical value cited, 99%, is an educated guess, based on intuition, what is known about the use of monitor equipment, and nontechnical reasons. Any number greater than 99% may be questioned on the basis of being implausible. A monitor vendor cannot state that its equipment is 100% effective for the following reasons:

- The vendor would be assuming a high degree of liability.
- Some steel mills installed monitors after melting radioactive material, yet despite these monitors, another nuclear gauge was melted (Ref. 1).
- Ways are known that can defeat a radiation monitor (e.g., a nuclear gauge in the center of a bale of scrap metal is unlikely to be detected).

The 99% number is of little use for a risk assessment.

The value of the probability has implications for the public, licensees, the steel industry, and regulatory agencies. If the detection probability is low when monitoring equipment is sophisticated, then stringent controls at the licensee facilities will be needed, placing heavy burdens on both the gauge users and on the regulatory agencies. If the detection probability is high, then the chances of recovering a gauge in the recycling stream are high; less stringent controls would be needed to balance predictable costs against uncertain consequences.

7.5.2 Concepts of the Detection Probability

Vehicles pass through sophisticated radiation monitor stations. A sophisticated monitor station is, for this risk analysis, considered to have large plastic or multiple sodium iodide detectors, fixed in place, the signals of which are processed by a system to initiate an alarm. Usually the sides of a vehicle will be scanned by a monitor station when the vehicle enters a scrap yard or steel mill. A monitor station, with side-mounted detector panels, is illustrated in Figure 31. The concepts of the detection probability developed for this situation can be extended to other configurations, such as a vehicle between three panels (one on each side and one above) and four panels (two on each side). An analysis of these other situations is beyond the scope of this report.

Because the scrap metal is randomly loaded, irregular gaps are present between the pieces of metal. The amount of radiation received by a detector depends on the activity of a sealed source, the location of the sealed source in a load of scrap metal, and the void fraction of the scrap metal. The load of scrap metal appears to a radiation detector as a pile of leaves appears to a

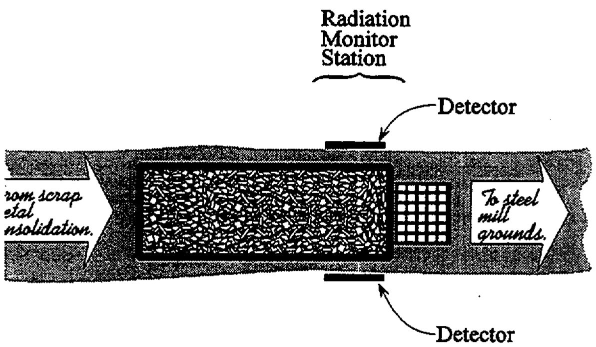


Figure 31 Truck entering a radiation monitor station with a load of scrap metal.

person. A flashlight in the pile, near the surface, will certainly be seen. Deep in the pile, the light will not be seen. Between the surface and deep within the pile, the light might be seen. A compact pile is more opaque than a loosely packed pile. The flashlight itself does not have to be directly seen to be noticeable. Light will pass through and be reflected off the surfaces of the leaves.

In an analysis of the detection probability, the commodity of scrap metal can be taken as a boundary condition. The characteristics of a monitor station can be considered another boundary condition. The following aspects remain to be considered:

- activity of the radioactive material;
- dimensions of the load; and
- position of the nuclear gauge in the load.

The activity of the sealed source is not an issue as this point in the concepts, the radiation level of 5 mR/hr at one foot can be taken as a starting point. Nuclear gauges are designed so that the radiation field is low enough to allow their use in an area that does not have to be posted as a radiation area; this level is 5 mR/hr at a distance of one foot from the gauge. Once the concepts have been established, lower radiation levels can be postulated, each time estimating the detection probability and the effect on risk estimates.

A load of scrap metal can be viewed from either end of the vehicle. The problem of locating a nuclear gauge in the load becomes a two-dimensional instead of a three-dimensional problem. In doing so, special effects at the ends of the load are considered insignificant. Though the detection probability is higher when radioactive material is near the end of the vehicle than when it is in the center of the load, it is unlikely that a nuclear gauge is near enough to the ends to significantly raise the detection probability.

In Panel (A) of Figure 32, contours represent constant amounts of shielding from the scrap metal in a load. A nuclear gauge near the sides of the load will be shielded little by the scrap metal. Deep in the load, a gauge will be highly shielded. The contours would be different for different commodities of scrap metal. The contours cannot readily be determined. Shielding calculations are challenging because of the random geometry of a load. Also, shielding calculations typically yield only the amount of radiation emanating from a shielded source, not the probability of detecting the source. Experiments to determine the probability contours would be challenging as well. Many trials would be needed on loads of typical sizes and commodities of scrap metal. Loads are large; the weight of scrap metal in a truck can be as much as 23 tonnes (25 tons) and the weight of scrap metal in a railcar can be as much as 91 tonnes (100 tons). Because of the difficulty in performing mathematical studies and experiments to determine the detection probability, the contours have to be simplified.

Panel (B) of Figure 32 illustrates how the detection probability varies with the location of a gauge in a load of scrap metal. The left ordinate of the graph is the radiation field, showing the field from immediately outside a load as a function of the location of a gauge in three commodities: a low-density commodity gives little shielding, while a high-density commodity gives a large amount of shielding. The plot for the intermediate commodity is used for illustration. Effects from the top and bottom of the load have been neglected to simplify the illustration. Then, the radiation field increases as the detector on the other side is approached. When a gauge is near either side of the load, the radiation field is high and will be detectable. When a gauge is in the center, the radiation field is low; depending on the commodity of scrap metal, the field may be too weak to detect. If a load of scrap metal contains a nuclear gauge, the gauge can be anywhere in the load with equal probability.

The right ordinate of Panel (B) in Figure 32 is a probability scale corresponding to the chances of being able to detect a given radiation field. Some minimal radiation field is, almost certainly, detectable with the radiation monitors found at the mills. This level is represented as RF_{detect}. For radiation levels at RF_{detect} and higher, the detection probability is approximated by one. Similarly, there is a level below which a radiation field is likely to be undetectable; for this level, RF_{miss} and lower, the detection probability is approximated by zero. For radiation fields between RF_{detect} and RF_{miss}, the chance of detection is between zero and one because, for many reasons, both the radiation and the monitor response may vary.

In Panel (C) of Figure 32, only the inner and outer shielding contours have been drawn, corresponding to RF_{detect} and RF_{miss}. The detection probability is approximately one for a nuclear

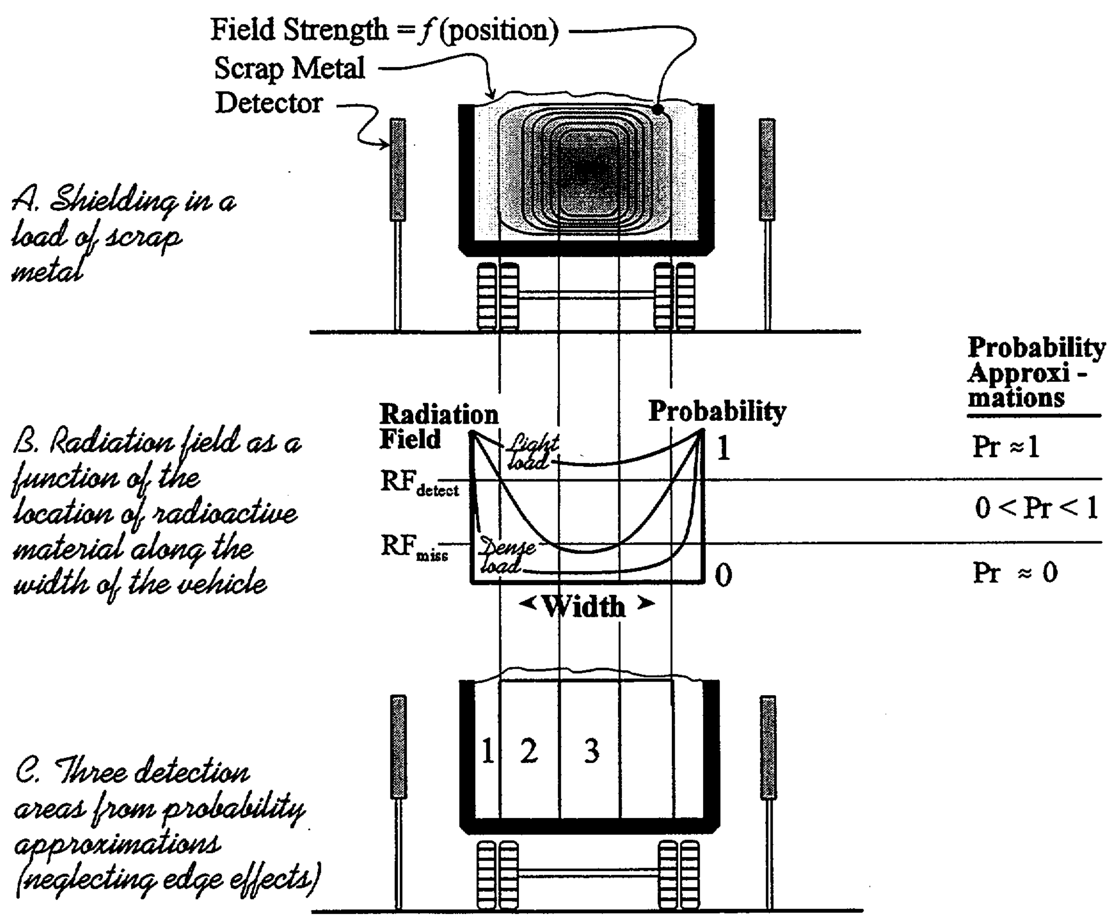


Figure 32 Areas of detection in a load of scrap metal.

gauge in the region outside the outer contour (Area 1). The probability that a gauge will be in Area 1 is the proportion of Area 1 to the total cross-sectional area of the load. This is given by Equation 21.

$$Pr_1 = \frac{\text{Area 1}}{\text{Total Area}} \qquad [21]$$

Pr_1 = probability of a nuclear gauge being in Area 1 of Figure 32.C
Area 1 = peripheral cross-sectional area of a load (see Figure 32.C)
Total Area = total cross-sectional area of a load (see Figure 32.C)

The detection probability is between zero and one in the intermediate region (Area 2). The probability of a nuclear gauge being in Area 2 is given by Equation 22.

$$Pr_2 = \frac{\text{Area 2}}{\text{Total Area}} \qquad [22]$$

Pr_2 = probability of a nuclear gauge lying in Area 2 of Figure 32.C
Area 2 = intermediate cross-sectional area of a load (see Figure 32.C)

The detection probability is approximately zero inside the inner contour (Area 3). The probability of a nuclear gauge being in Area 3 is given by Equation 23.

$$Pr_3 = \frac{\text{Area 3}}{\text{Total Area}} \qquad [23]$$

Pr_3 = probability of a nuclear gauge lying in Area 3 of Figure 32.C
Area 3 = inner cross-sectional area of a load (see Figure 32.C)

Let Ψ_n be the probability of detecting a nuclear gauge in the n^{th} area of Figure 32 during one pass through a monitor station. The overall probability of detection can be expressed as Equation 24.

$$\Psi = Pr_1 \Psi_1 + Pr_2 \Psi_2 + Pr_3 \Psi_3 \qquad [24]$$

Ψ = overall probability of detection during one pass through a monitor station if a gauge is present in the load

Ψ_n is a complicated function that depends on many factors. Nonetheless, statements can be made about Ψ_n in certain areas of a load. In Area 1, where the detection probability is close to one, $\Psi_1 \approx 1$. In Area 3, where the detection probability is close to zero, $\Psi_3 \approx 0$. In Area 2, Ψ_2 is between zero and one. Here, Ψ_2 is an average value over the possible locations of a gauge in Area 2. Equation 24 reduces to Equation 25.

$$\Psi = Pr_1 + Pr_2 \Psi_2 \qquad [25]$$

Equation 25 is key to understanding the detection probability and its ramifications. The equation applies when a load of scrap metal passes once through a radiation monitor; after the single pass, if a radiation alarm occurs, an action is taken; if an alarm does not occur, then the load enters the mill. For multiple passes (see Section 7.6), the equation is readily modified.

Although the detection probability in Area 2 cannot be readily determined, a useful risk assessment is still possible by considering two bounding cases of Ψ_2. Case (A): Compute the risk to scrap yards and steel mills postulating that a nuclear gauge in Area 2 will be detected. Here, Ψ_2 is set to one and the resulting detection probability becomes $\Psi_A = Pr_1 + Pr_2$. Case (B): Compute the risk postulating that a gauge in Area 2 will be missed. Here, Ψ_2 is set to zero and the detection probability becomes $\Psi_B = Pr_1$. The actual, but unknown, detection probability is bounded by Cases A and B, as shown in Equation 26.

$$\Psi_B \le \Psi \le \Psi_A \qquad [26]$$

The actual risk is also bounded by Cases A and B. If risk estimates made with the bounding cases are close together, then a precise determination of Ψ_2 is unnecessary. This would occur when Area 2 in Figure 32 is small for one of two reasons. First, the void fraction of the scrap metal in the load may be large because the scrap metal is loosely

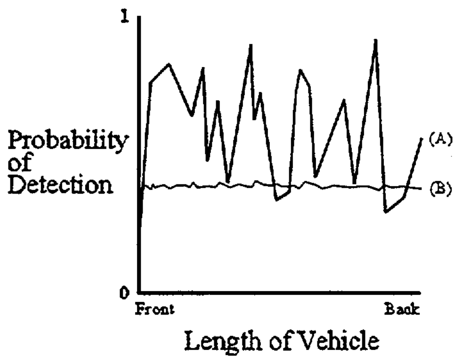


Figure 33 Hypothetical variability in the detection probability for (A) heterogeneous and (B) homogeneous commodities of scrap metal.

packed, giving rise to a large Area 1. Second, the void fraction is small because the scrap metal is tightly packed, giving rise to a large Area 3. If these bounding risk estimates are far apart, then a precise determination of Ψ_2 may be necessary. This would occur when Area 2 is large.

The detection probability may vary along the length of a vehicle. In heterogeneous commodities, such as plate and structural scrap (i.e., P&S) or bundles, the variability will be relatively large. In homogeneous commodities of scrap metal, such as frag, the variability will be relatively small. Such variability is illustrated in Figure 33. Curve (A) represents the variability in a heterogeneous commodity. Curve (B) represents a homogeneous commodity.

A load of scrap metal viewed from the end of the vehicle has three concentric cross-sectional areas. Also, the scrap metal entering a steel mill can be viewed as a continuous stream (see Section 3.2). In Figure 34, the concepts of the detection areas and the continuous stream are brought together. A load will have characteristics (e.g., density, homogeneity) that determine the shielding. This makes the detection probability dependent on the commodity. The detection probability must be expressed in a way that is conditional only on the relative amounts of each commodity used at a mill. The expression must relate Areas 1, 2, and 3 to the terms in which scrap metal is purchased, which is weight. Such an expression can be readily determined. The following assumptions are made:

Assumption: Nuclear gauges in the recycling stream are rare. In the recycling stream, they are far apart. A load of scrap metal is unlikely to contain more than one nuclear gauge. Basis: Reference 1 suggests that sealed sources in the recycling stream are rare. An updated version of the information is shown in Figure 2.

Assumption: A nuclear gauge is randomly located in a load of scrap metal. Basis: Intuitive. The scrap metal is processed and loaded into vehicles at random. There may be some placement of large pieces to distribute weight during transportation, but there is no placement of particular pieces. Therefore, there is no placement of a nuclear gauge that would be on a piece of scrap metal.[9]

Assumption: Commodities are not mixed when they arrive at a mill. Basis: Steel mills order scrap metal from dealers by commodity and this is how the orders are filled.

Figure 34 shows a load of scrap metal viewed from above, in a truck or a railcar, passing between the detector panels of a monitor station. A load is divided into sections that are the width of the monitor panels. The dotted lines from the detectors to the vehicle represent the view of the detector panels. The lighter horizontal lines through the cross-sections demarcate Area 1, Area 2, and Area 3. A nuclear gauge, represented by the black dot, is in an area of one cross-section. The bottom portion of Figure 34 shows one of the cross-sections as viewed from another angle. The nondetectable region is represented as a shaded elliptical volume. The detectable region is the unshaded surrounding volume.

9 / Deliberate placement to conceal a gauge (i.e., sabotage) is beyond the scope of this study.

Considering the stream of scrap metal as very long (e.g., scrap metal continuously coming into the mill), the widths of the cross-section become very small. Also, end effects, such as the detector panels receiving radiation from adjacent cross-sections, become negligible.

The amounts of each commodity are measured in weight, not volume, because this is how scrap metal is purchased. But the monitor does not see the weight of a load; it looks at the volume of the loads passing between the detector panels. The vehicles can be represented by a typical height and width. There is a tendency to use the largest trucks and railcars that can fit on the transportation system. Roads and tracks can accommodate vehicles up to a specific height and width. Although differences in the heights of scrap metal in railcars and trucks are evident, the differences are negligible because of other uncertainties. Although differences between the cross-sectional areas of old and new railcars occur, the differences are of no concern for the same reason; other uncertainties are larger. The same argument holds for large trucks.

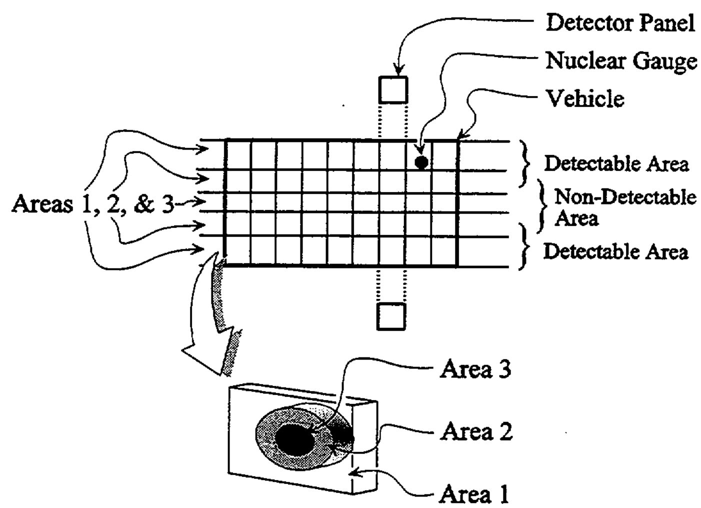


Figure 34 Recycling stream illustrated to determine the detection probability of a commodity of scrap metal entering a steel mill.

> Assumption: Scrap metal arriving at a mill is usually brought in large trucks (tri-axle or larger) and railcars. Basis: Although some mills will take peddler trade, such sources of scrap metal *at the mills* account for a small amount of the scrap metal that is used at the mills. Scrap metal is usually taken to the mills in the largest vehicles fitting on roads and rails to reduce cost.

> Assumption: The cross-sectional area of trucks and railcars is about the same and constant. Basis: To keep transportation costs low, the largest vehicles will be utilized. Limits on the transportation system that are soon reached are the width and height of vehicles, leaving the length that can be readily changed. Even the length has limits; vehicles have to be able to get around curves.

The second assumption allows the width and height of the vehicle to be represented by a constant, k, as in Equation 27.

$$V = \ell wh = \ell k \qquad [27]$$

V = volume of the vehicle transporting scrap metal
ℓ = length of the transporting vehicle
w = width of the transporting vehicle
h = height, as measured from the bottom to the top of the compartment carrying scrap metal

More generally, the length is proportional to the volume.

$$V \propto \ell \qquad [28]$$

The detectors receive radiation through cross-sections of the loads. The cross-sections are along the length of the continuous stream of scrap metal entering a mill. This length is proportional to the volume of scrap metal, which can be related to the quantity that is measured—weight. Thus, Equation 28 allows the volume of the loads used in a period to be used as the factor for combining the probability of each commodity used at a mill. This is Equation 29.

$$V = \frac{L}{\rho} = \omega^c \qquad [29]$$

ρ = density of the load
L = tare weight of the load

The detection probabilities of each commodity can then be weighted for averaging. The average probability depends on the relative amount of commodities. This is Equation 30.

$$\Psi_{blend} = \frac{\sum_{j=1}^{n} \Psi_j \, \omega_j^c}{\sum_{j=1}^{n} \omega_j^c} \qquad [30]$$

Ψ_{blend} = detection probability for a blend of commodities used at a mill
Ψ_j = detection probability for the j^{th} scrap metal commodity used at the mill
ω_j^c = weighting factor: amount of the j^{th} scrap metal commodity
j = index of scrap metal commodities
n = number of scrap metal commodities

Equation 30 is applicable to the unconditional probability during the first pass through a monitor station. Similar expressions can be made for the conditional probabilities of the second and third passes (see Section 7.6). The detection probabilities are computed for each mill of a given configuration, then aggregated to form a distribution.

7.6 Multiple Passes Through a Radiation Monitor Station

7.6.1 Statement of the Problem

Three ways of using radiation monitors to detect sealed sources in scrap metal appear to be in common practice—pass a load through a monitor station one, two, or three times. Usually a mill will not pass a vehicle through a monitor station more than three times because the multiple passes are time consuming. The reasons for choosing the one-pass, two-pass, or three-pass strategy of using a monitor are not always well understood by employees who operate the systems. The manufacturer of the monitor or a consultant to the facility may have recommended passing a load through several times without being able to give specific reasons. An employee at a mill may pass a load through until there is confidence that it does not contain radioactive material, without definite criteria for deciding whether to accept or reject the load. The decision logic for determining when to

Some Factors That Influence the Probability of an Alarm at a Radiation Monitor Station During Multiple Passes

LEGEND: □ = factors that are constant during multiple passes. ■ = factors that can change during multiple passes.

Ambient Conditions
- □ Background radiation levels
- □ Weather conditions

Radiation Monitor
- □ Type of equipment
- □ Alarm set point
- □ Care and upkeep
- ■ Diligence in use

Transporting Vehicle
- □ Size
- □ Construction
- ■ Speed during monitoring
- □ Position of vehicle in a station

Load of Scrap Metal
- □ Type
- □ Density
- ■ Arrangement of scrap metal

Sealed Source
- □ State (intact, separated, breached)
- □ Source strength
- □ Radionuclide
- ■ Location in a load of scrap metal†

Unknowable Factors
- ■ Scrap metal shifting between passes
- ■ Other

† Movement occurs as a result of shifted scrap metal.

accept a load after one or more passes through a monitor station has important implications for the capability of keeping radioactive material out of its facility.

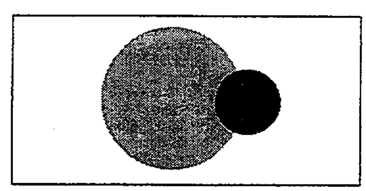
7.6.2 Chance of Alarming

Figure 35 illustrates the possible combinations of radioactive materials in loads of recycled metal. The figure is suggested by Reference 1. BC, represented by the larger circle, is occasionally found in loads. Sealed sources, represented by the smaller circle, are occasionally found in loads or, even less frequently, reported as being melted at mills. The occurrence of both BC and a sealed source in the same load, represented by the overlap of the circles in the figure, appears to be rare. Background radiation, represented by the rectangle, is always present.

When a vehicle passes through a monitor station, an alarm either will or will not activate. An alarm depends on many factors that may interact and compensate for one another in complicated ways, the details of which are beyond the scope of the risk analysis. Though a sophisticated monitoring system is preferable to an unsophisticated system, a sophisticated monitoring system does not necessarily guarantee a high assurance of detecting a sealed source because other factors contribute to the capability of detection (see box entitled "Some Factors That Influence the Probability of an Alarm at a Radiation Monitor Station During Multiple Passes").

If all factors remained exactly the same during each pass through a monitoring station, the outcomes of multiple passes through a monitor station would always be the same. But this is not the case; all factors do not remain exactly the same. Random variations in some of the factors occur and, hence, alarming is not predictable from one pass to another. Taking the factors together, there is an overall probability that the factors assume the values necessary to cause a radiation alarm. The situation of concern is when the sealed source is shielded by its device holder and scrap metal, bringing factors near the threshold of alarming, where random fluctuations may move the factors above or below the threshold.

The distributions of radiation fields a monitor "sees" are illustrated in Figure 36. The figure is not drawn to scale, but is drawn to illustrate concepts qualitatively. Each curve represents the distribution of radiation intensity. The area under each curve is equal to one because it accounts for all possible radiation levels. For any curve, the probability that the radiation intensity would be no higher than a stated amount is the area bounded by the curve up to the stated amount. Curve (I) represents the distribution of only background radiation, which varies from one location to another and from one time to another, but is always present to some degree. Curve (II) represents the distribution when BC is present in a load. BC is occasionally present; when it is, it adds to the background radiation, resulting in higher radiation intensities. Curve (III) represents the distribution when a sealed source, but no BC, is present. Similar to BC, its radiation adds to the background radiation, pushing the distribution to higher radiation intensities. Many sealed sources are stronger than BC, so that the sealed source distribution (Curve (III) is generally larger than the BC distribution (Curve (II). But some sealed sources may be shielded by their holders and their position in the load of scrap metal, resulting in the tail of the lower intensities. Curve (IV) represents the distribution when BC and a sealed source are present together in the same load. The radiation from both BC and the sealed source adds to the background radiation.



Key
BC = Benign contamination
Background radiation
BC
Sealed sources
BC & sealed source

Figure 35 Possible combinations of radioactive material in loads of scrap metal.

A vehicle undergoing radiation monitoring is represented by one of the distributions. The curve that determines the probability of alarming depends on the specific radioactive contents (background, BC, sealed source) of the load. But the radiation monitor cannot discriminate between BC and a sealed source; it detects only the amount of radiation.

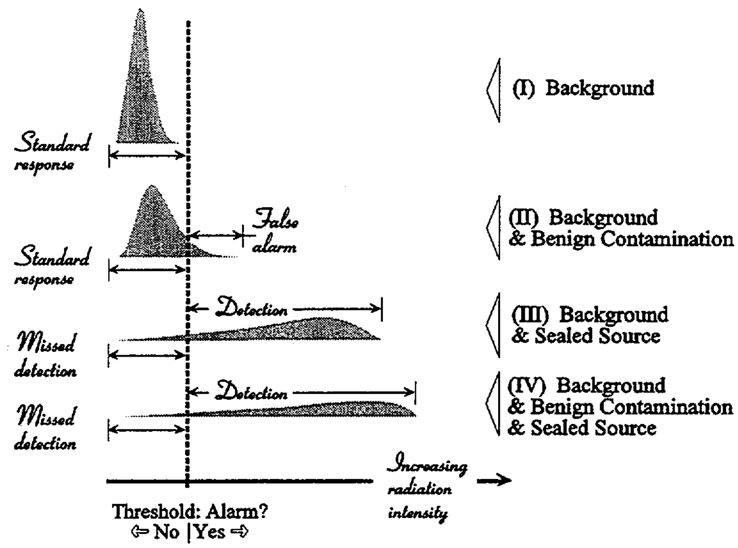


Figure 36 Relation of monitor response, alarm threshold, and hypothetical distributions of radiation levels from background, BC, and sealed sources.

The relationship between monitor responses, the alarm threshold, and the hypothetical distributions of radiation levels is also illustrated in Figure 36. The alarm threshold is the vertical dashed line; in sophisticated monitors, the threshold varies to stay at a predetermined amount above the background level at a given moment. Radiation intensities below the threshold do not cause an alarm; intensities above the threshold cause an alarm. In Curve (I), a load contains only scrap metal, with neither BC nor sealed sources. Because the alarm threshold is above background, the probability of no alarm (and a standard response) is one. In Curve (II), BC is present and its distribution extends above the alarm threshold. This leads to the possibility of a false alarm (see definition in Section 7.3) whose probability is the area of the curve above the alarm threshold; the probability of no alarm is the area of the curve below the alarm threshold; this is the probability of a standard response. In Curve (III), where a load contains a sealed source but no BC, the alarm threshold may be low enough to detect some, but not necessarily all, sealed sources. The probability of an alarm is the area of the curve above the alarm threshold; this is the probability of detection. The probability of no alarm is the area of the curve below the alarm threshold; this is the probability of a missed detection. In Curve (IV), where both BC and a sealed source are present in the same load, the probability of an alarm has been increased by the radiation from both BC and the sealed source. In this case, BC is beneficial because it increases the probability of an alarm.

Figure 36 illustrates difficulties in detecting a sealed source. The shielding from the source holder and the scrap metal may make the intensity of the radiation from the sealed source similar to that of BC and background radiation. The BC radiation complicates the detection. Were BC nonexistent, the matter of detecting sealed sources would be simpler. A monitor threshold could be set below all of the distribution of radiation from sealed sources. But the distribution of BC radiation overlaps the distributions of background and sealed source radiation. This overlap can result in false alarms. False alarms are detrimental because they consume resources, such as determining the cause of an alarm or turning loads away when they should have been accepted.

Table 6 shows all four possible outcomes of a vehicle, with a load of scrap metal, passing once through a monitor station. The actions taken, based on the outcomes, are discussed in the next section. The columns show the two possible responses of the monitor; the monitor will either alarm or not alarm. The rows show the two possible states of the load; the load either does or does not contain a sealed source. When a vehicle passes through a monitor station, the column becomes known. If no alarm occurs, then either there is no sealed source (standard response) or a sealed source is missed (missed detection). This corresponds to Curve (I) or (II) below the alarm threshold when no sealed source is present, or Curve (III) or (IV) below the alarm threshold when a sealed source is present. If an alarm occurs, then either there is no sealed source (false alarm) or there is a sealed source (detection). This corresponds to the area that is above the alarm threshold in Curve (II) when no sealed source is present, or to the area that is above the alarm threshold in Curve (III) or (IV) when a sealed source is present. The response of the monitor gives the column of Table 6; but it is the row, not the column, that is desired.

7.6.3 Monitoring Strategies

A common practice at steel mills (and scrap yards) is to pass a load through a monitor station more than once, given an alarm on the first pass. Because of the probabilistic aspects of monitoring, the monitor's response may change on subsequent passes. After one or more passes through a monitor station, a load is either accepted or rejected. For any monitoring strategy, let Pr{reject} be the probability of rejecting a load and Pr{accept} be the probability of accepting a load. Then $\Pr\{\text{reject}\} + \Pr\{\text{accept}\} = 1$. In the discussion that follows, a nuclear gauge somewhere in a load of scrap metal is postulated.

One-pass strategy. The most basic decision strategy is to pass a load through a monitor station once and act according to the outcome of the monitoring (see Table 6). The left panel of Figure 37 illustrates the logic for a one-pass strategy. In the figure, the upper branch represents a radiation alarm when a vehicle passes through a monitor station; the lower branch represents a pass without an alarm. If an alarm is activated, then the load is rejected; if an alarm is not activated, then the load is accepted. In the one-pass strategy, the probability of rejecting or accepting a load is given by Equations 31 and 32.

$$\Pr\{\text{reject}\} = \Psi \quad [31]$$

$$\Pr\{\text{accept}\} = 1 - \Psi \quad [32]$$

Ψ = detection probability as defined by Equation 25 (page 81).

Two-pass strategy. The middle panel of Figure 37 illustrates a typical two-pass strategy. If no alarm sounds on the first pass, then the load is accepted and delivered to the facility. If the first pass results in an alarm, then the vehicle is sent through the monitor station again and the load is rejected only if the alarm activates on the second pass. The vehicle is not unloaded between passes for reasons discussed in Section 7.4. Thus, a gauge in the load remains fixed in position during each pass through a monitor station. To obtain the expression for Pr{accept}, the products of the acceptance sequences of risk elements are

Table 6 Outcomes when a load of scrap metal passes once through a monitor station.

	Monitor Response	
State	**No Alarm**	**Alarm**
No sealed source present	Standard Response	False Alarm
Sealed source present	Missed Detection	Detection

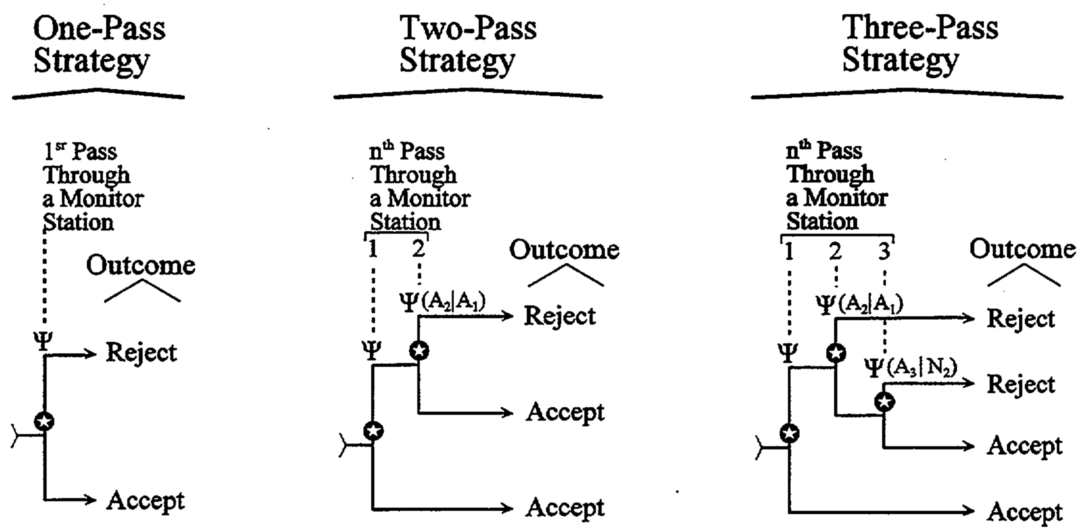


Figure 37 Logic of the one-pass, two-pass, and three-pass strategies for monitoring scrap metal. LEGEND: ✪ indicates a radiation alarm during the nth pass through a monitor station. A_n = alarm. N_n = no radiation alarm. Ψ = probability of an alarm on the first pass. Ψ(n+1 | n) = conditional probability of an alarm during the n+1 pass, given the nth pass.

summed. If the passes were independent, then Ψ on the first pass could be used as the detection probability on the second pass; then the acceptance expressions could be readily determined as the sum of the products of the probabilities along each sequence of risk elements. For example, the rejection probability would be $\Pr\{reject\} = \Psi^2$. But the second pass is conditional on the first pass, precluding this treatment.

The first pass through the monitor station gives information about the location of a gauge. If an alarm occurred, then the gauge was in either Area 1 or Area 2 (see Section 7.5.2 for a discussion of the areas); it could not have been in Area 3. If no alarm occurred, then the gauge was in either Area 2 or Area 3; it could not have been in Area 1. An alarm or lack of an alarm during the first pass precludes one of these areas during the second pass. Therefore, the probability of alarming on the second pass becomes conditional on the outcome of the first pass. Let A_1 denote an alarm on the first pass and A_2 denote an alarm on the second pass. The probability of an alarm on the second pass given an alarm on the first pass becomes $\Psi(A_2|A_1)$.

The first pass also yields information about the detection probability of Area 2, Ψ_2. In Equation 25 (page 81), the probability is an average representing the probability gradient shown in Figure 32. If an alarm occurred, then the gauge is likely to be closer to Area 1 where it can be detected. If no alarm occurred, then the gauge is likely to be closer to Area 3 where it cannot be detected.

Accounting for dependencies, the probability expressions of rejecting or accepting a load are given by Equation 33.

$$\Pr\{reject\} = [\Psi][\Psi(A_2|A_1)] \qquad [33]$$

If a sealed source is present, then the second pass will reduce the chance of rejecting the load. The two-pass strategy gives a load of scrap metal a second chance to enter a facility. But the second pass may or may not lead to the correct action.

False Alarms

In Section 7.3, a *false alarm* was defined as an alarm that occurs in the absence of a sealed source when scrap metal is scanned for radiation. A false alarm is a response of the monitor system to radiation that is not from a nuclear gauge. The alarm is "false" in the sense that the monitor is indicating that there is something of concern in a load of scrap metal, when in fact, there is only a benign form of contamination.

This application of the false alarm concept to radiation monitoring may be easier to understand when viewed alongside an analogous situation. In the test for tuberculosis, the substance used to diagnose tuberculosis, called tuberculin, is injected into the skin on the arm. If the skin remains unchanged, it is likely there is no tuberculosis. If localized inflammation occurs, there is a reason for more extensive and costly testing. But the inflammation does not necessarily mean that the person has tuberculosis because the test is not for the presence of the disease state. Instead, the test detects antibodies for tuberculosis in the blood that are responding to the injection. The antibodies may be present because the person has the disease, but antibodies may be present for other reasons, too; the person may have been exposed to the bacteria without developing the disease, may have been exposed to similar bacteria, or may have been vaccinated. In these latter situations, the person does not have what is of concern — tuberculosis. The test result is false in the sense that it is taken as suggesting disease.

Laboratory radiation detectors can discriminate between benign contamination and sealed sources. Such a system for monitoring scrap metal would be impractical in scrap yards and steel mills because the equipment would be more expensive than the already costly equipment that is used, the time needed for the scanning would be too long to be profitable, and test results may be difficult to interpret. The tradeoff for using a less expensive system is a higher possibility for false alarms.

Three-pass strategy. A typical three-pass strategy is shown in the right panel of Figure 37. As before, scrap metal is not unloaded between passes. Also, only loads that alarm on the first pass are retested. The third pass is used to confirm either the first pass or the second pass if these passes disagree. The uppermost branch of the second pass is not subject to a third pass because the second alarm confirms the first alarm. To obtain the probability expressions, dependencies between the passes must be taken into account as in the two-pass strategy. Doing so, the probability expressions are obtained by multiplying along each sequence of risk elements; to obtain the expression for Pr{reject}, the products of the rejection sequences are summed.

$$\Pr\{\text{reject}\} = [\Psi]\,[\Psi(A_2|A_1)] + [\Psi]\,[1-\Psi(A_2|A_1)]\,[\Psi(A_3|N_2)] \qquad [34]$$

The third pass reduces the chances of incorrectly accepting a load based on the second pass.

7.6.4 Implications of the One-Pass, Two-Pass, and Three-Pass Strategies

The two-pass strategy makes the facility more vulnerable to accepting a sealed source than either the one-pass or three-pass strategy. The two-pass strategy gives a load that has been flagged as containing radioactive material another chance to enter the facility; the alarm on the first pass, which may be true, can be overridden by the lack of alarm on the second pass, which may be false. The alarm on the first pass, not the absence of the alarm on the second pass, may indicate the true state of the load. This situation occurs elsewhere. Some people recheck a calculation and, getting an answer that differs from the first, instinctively take the second answer as correct. The three-pass strategy brings the rejection probability up somewhat compared with the two-pass strategy because the third pass confirms either the first or the second pass. However, because the three-pass strategy has more pathways for acceptance, it has a lower chance of finding a sealed source than the one-pass strategy.

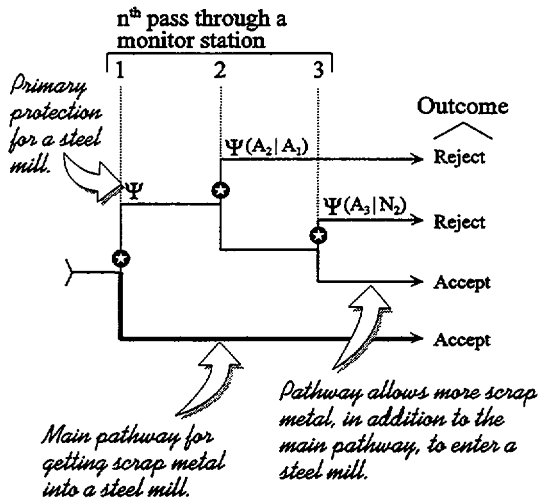


Figure 38 Main pathway and an additional pathway in risk element sequences for scrap metal entering a steel mill.

If the primary concern is detecting sealed sources, then the best of the three strategies considered here is the one-pass strategy. The decision to reject or accept a load would be made on the first pass through a monitor station. The two-pass and three-pass strategies reduce the probability of a false alarm at the risk of missing a sealed source. However, if the primary concern is false alarms, then the best of these strategies is the two-pass strategy. In practice, both detection and false alarms are of concern; the three-pass strategy is a compromise between the one-pass and two-pass strategies.

The effect of the multiple passes, given an alarm on the first pass, is to bring more scrap metal into the facility. Loads that have alarmed on the first pass are given another chance to enter the facility. The price for giving loads another chance to enter a facility is the higher chance of missing a sealed source. Figure 38 illustrates this with the three-pass strategy.

7.6.5 Secondary Monitoring

In the strategies illustrated by Figure 37, a high probability of alarming when a sealed source is present is critical for protecting the facility because there is no redundancy in monitoring after the first pass on the acceptance pathway. Each strategy accepts a load if there is no alarm on the first pass. But some mills conduct monitoring at the charge bucket or in the yard. At either location, *secondary monitoring* refers only to when scrap metal is scanned, unloaded from the transporting vehicle, reloaded, and scanned again.

Monitoring at the charge bucket is discussed in Section 7.4 (Items 2 and 3). Charge bucket monitoring is the more common form of secondary monitoring than monitoring in the yard. Monitoring in the yard takes two forms: one form occurs when scrap metal is unloaded in the yard, then reloaded prior to monitoring; the other form occurs when scrap metal passes through the second monitor without unloading and reloading. The yards may have developed as the mill operations were expanded. Several layouts are illustrated in Figure 39; the versions are a consequence of the layout of the mill, not a result of arriving at a means of improving monitoring effectiveness. After passing through the second monitor, the vehicle is unloaded in the storage area. Panel (A): At some mills, scrap metal is scanned once, then unloaded, sorted, and reloaded into vehicles, going from the storage area to the scrap bay/yard where it is scanned again. Trucks

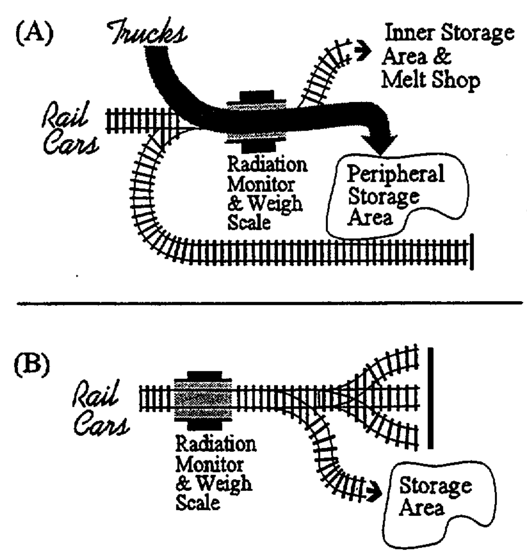


Figure 39 Configurations of steel mills where a vehicle passes through a monitor station several times; (A) with unloading and reloading between passes; (B) without unloading between passes.

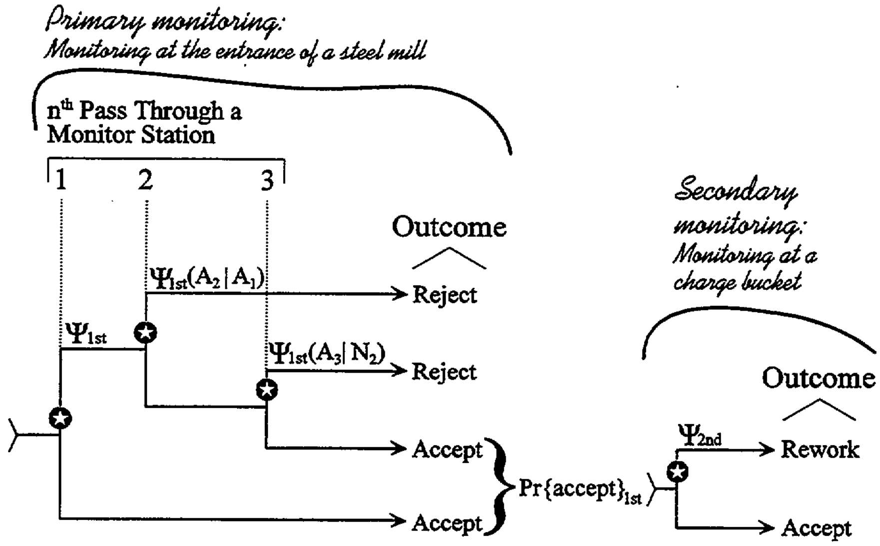


Figure 40 Primary and secondary monitoring.

pass through a radiation monitor and are weighed, then unloaded in a scrap yard near the entrance. As the scrap metal is needed, railcars on a spur track are loaded and switched onto a track leading into the mill, where they again pass through the same monitor station. Panel (B): At other mills, a vehicle passes through another monitor while remaining in the same vehicle. Railcars are brought into the mill and temporarily stored on spur tracks. When operations permit, the railcars are moved off the spur tracks; to clear the rail switch, all of the railcars must be brought through the monitor station, then pushed through the monitor station again onto tracks going into the mill. Railcars may also be brought directly into the mill and unloaded in the storage area.

These two layouts give rise to very different chances of detecting a nuclear gauge. In Panel (A), unloading and reloading a vehicle randomizes the placement of the scrap metal in the vehicle. It also randomizes whatever else was in the load. If a nuclear gauge was in the nondetectable region while going through the first monitor station, it might be in the detectable region while going through the second monitor station. If the gauge was in the detectable region while going through the first station, it would have been detected. If it was in the intermediate region and missed while going through the first station, it may be in the detectable region or again in the intermediate region while going through the second station. In Panel (B), a pass through a second radiation monitor without unloading and reloading leaves the gauge in place in the vehicle. If the gauge was embedded deep within a load, then it might not be detected, no matter how many monitor stations it passes through. If it was near the surface of a load where it is easily detected, then it would have been found when passing through the first monitor station. If it is in the intermediate area, another chance of detection arises. Because nothing more definitive can be said about intermediate area, which is Area 2, statements can be made only about Areas 1 and 3. If any one of these regions is large, then it "squeezes" out the other regions. If a region is small, then the relative size of the other two regions is unknown.

Table 7 states four cases. White boxes show what can be stated. Grey areas indicate what cannot be definitively stated. The following preferences can be stated when information about the processing of scrap metal is taken into account.

Table 7 Possibilities of finding a nuclear gauge when scrap metal is scanned, unloaded, reloaded, and scanned again. LEGEND: Pr{detect} = net detection probability.

	Original Load		After Reloading			
Case	Area 1	Area 3	Area 1	Area 3	Chance of Finding a Nuclear Gauge	Notes
I	Large		Large		Large	Pr{detect} is large because the detection region (Area 1) is large in both the original load and the reload.
II	Large			Large	Large	Pr{detect} is large because the detection region (Area 1) is large in the original load. Scanning the reload becomes irrelevant.
III		Large	Large		Large	Pr{detect} is large because the detection region (Area 1) in the reload is large.
IV		Large		Large	Small	Pr{detect} is small because detection region (Area 1) is small in both the original load and the reload.

Case I > Case II > Case III > Case IV

Case I is most desirable because the region where the detection probability is one (Area 1) is large in both the original load and the reload. Case II is preferable to Case III: from the standpoint of readily disposing of a gauge at no expense, it is best to find it in the original load; here, the scrap metal can still be rejected. Case IV is undesirable; here, the detection regions in both the original load and the reload are small.

In general, the detection probability during primary monitoring is not equal to the detection probability during secondary monitoring because the circumstances of monitoring change. Examples include the following ways:

- The density of a scrap metal load may change during sorting and blending. The probability of alarming may or may not change in either direction.

- The structure of the vehicle passing through the secondary monitoring may be different from that of the vehicle passing through the primary monitoring. The walls of a charge bucket are several inches thick, while the walls of a railcar are typically about 2½ cm (1 inch) thick; both are made of steel. The walls of a truck are thinner, less than about 1 cm (½ inch) thick, and are made of steel, aluminum, or an alloy. The probability of alarming is lower with the thicker walled container because of the higher shielding.

- When a charge bucket is monitored while it is being loaded, the metal is in the small amounts that can be lifted by the crane loading the charge bucket, not in the one large amount of a vehicle load, which is about 91 tonnes (100 tons) in a railcar and about 23 tonnes (25 tons) in a truck. The probability of alarming is increased by monitoring smaller amounts of scrap metal.

Usually monitoring the reload occurs at the charge bucket where the load is smaller. Also, scrap metal is often scanned as it is placed into the charge bucket.

A view of secondary monitoring is shown in Figure 40. The primary monitoring is the three-pass strategy; here, scrap metal can be rejected when the radiation alarms suggest that a load of scrap metal contains radioactive material. The secondary monitoring is a one-pass strategy, which is applicable to monitoring a charge bucket while it is being loaded. Figure 40 shows that secondary monitoring gives another level of protection against a missed detection on the acceptance sequence. Because the scrap metal is unloaded after primary monitoring, then reloaded for secondary monitoring, the primary and secondary monitoring are independent, allowing their probabilities to be multiplied. Thus, the probability of accepting a nuclear gauge is given by Equation 35, where p denotes primary monitoring and s denotes secondary monitoring..

$$\Pr\{accept\}_{ps} = \Pr\{accept\}_{p}\ \Psi_{s} \qquad [35]$$

7.7 Elements of Risk

Element 13: Configuration of Radiation Monitors at Steel Mills (Figure 41)

Each location of radiation monitors illustrated in Figure 30 has benefits and drawbacks, giving rise to a level of protection against melting radioactive material and detecting when radioactive material has been melted. A particular combination of monitors influences risk differently than another combination. For example, one configuration is only a portal monitor for incoming scrap metal. Another configuration is a portal monitor and a charge bucket monitor. To analyze and assess risk, steel mills throughout the industry must be aggregated according to their combination of monitors.

Some of the different configurations of radiation monitors found throughout the steel industry are represented in Figure 41. The eight possible locations of monitors shown in Figure 30 give rise to $2^8 = 256$ possible configurations throughout the steel industry. In practice, there are far fewer configurations because some combinations of monitors make little sense. For example, furnace dust would not be monitored without monitoring incoming scrap metal. Neither would the charge bucket be monitored without monitoring incoming scrap metal. Almost all mills have portal monitors. Far fewer mills have both portal and charge bucket monitors.

The branches of Figure 41 must be emphasized in some way to show that combinations are not equally prevalent. The branches of Element 13 could be weighted by the number of mills with the given configuration of monitoring equipment. But such a weighting would ignore the differences in the sizes of mills. A more appropriate weighting that accounts for the different sizes of the mills is the total amount of scrap metal passing through all mills of a given configuration. But the commodities of scrap metal are not equally likely to contain a nuclear gauge. Commodities, such as machine turnings, that are unlikely to contain a nuclear gauge are irrelevant to risk. Only the commodities of scrap metal that are relevant to risk need to be taken into account by Element 13.

The lowest branch of Element 13 can be used to ascertain what might not be taken into account by the risk analysis. The production of steel is reported by the U.S. Geological Survey; the amount of steel that is reported through a survey can be determined—the difference is what has not been analyzed.

An assumption is are made about the supply of scrap metal to represent the consumption of scrap metal in the analysis of monitor configurations.

> Assumption: The probability of a mill being at risk for radioactive material in the recycling stream is proportional to the amount of scrap metal that is consumed by the mill. Basis: See Section 3.2.3.

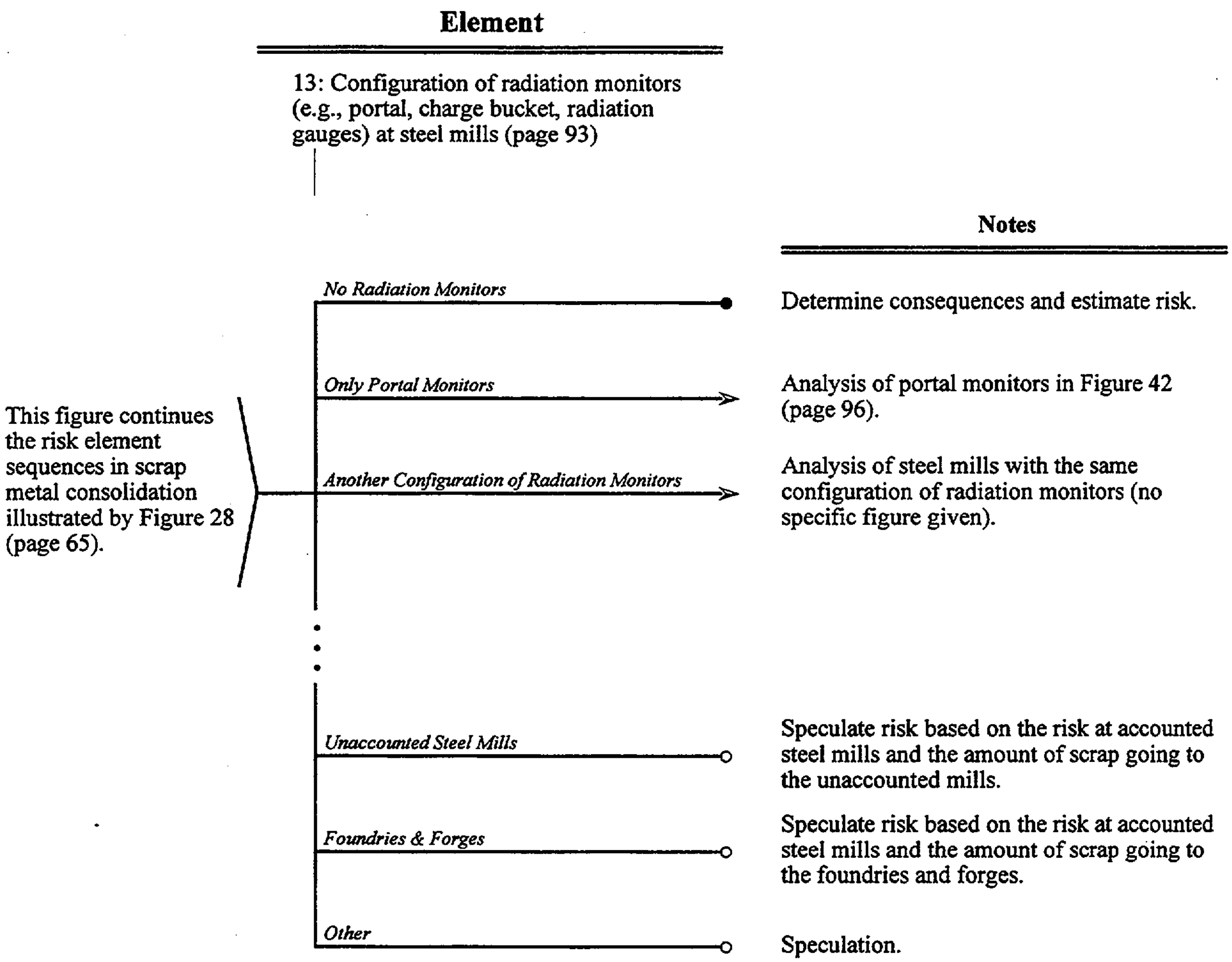


Figure 41 Analysis of the risk elements for the configuration of radiation monitors at steel mills. LEGEND: Single black lines are sequences. An arrow (➢) indicates that a sequence continues in a subsequent figure (e.g., Figure 42). A dot (○) indicates that a sequence is unresolved; it continues, but is not further developed.

Figure 42 illustrates the risk elements at the entrance to a steel mill. Single black lines are sequences of risk elements. For clarity, common elements of the sequences are illustrated in the inset; some of these sequences discontinue at –A⟩, then continue in the inset at –A⟩; other such sequences discontinue at –B⟩, then continue in another inset at –B⟩. An arrow (➢) indicates that a sequence continues in Figure 43. A dot (●) indicates the end of a sequence. An open dot (○) indicates that a sequence is unresolved; it continues, but is not developed further. Hazard terms are from the *U.S. Code of Federal Regulations* (Ref. 9). A gray box (▩) indicates that a concern is present in Elements 14 through 23 of a particular sequence. A white box (□) indicates that a concern is not present. The danger to life and property are as follows:

- When regulators are notified of a rejected load, sufficient controls are in place to remove danger to life and property. In these cases, sequences usually terminate. When only the supplier is notified, a potential remains for the load to be inappropriately addressed, improperly disposed, or sent to another steel mill where it might not be detected. The shutter of a gauge may be open or the sealed source may be dislodged, presenting a danger to life. If no one is notified, the load can go anywhere; nothing more can be said and the sequence remains unresolved.

- A reworked load gives rise to opportunities to find and secure a gauge. But if BC is also in a load, a radiation alarm may be attributed to it instead of a gauge; the gauge may be missed, thus, the sequence continues. A danger to life remains.

- If scrap metal is not scanned for radiation, there may be a danger to life. The shutter of a gauge may be open. The source may be dislodged.

- Between Elements 14 and 23, there is no danger to property. Nothing is happening to breach a sealed source because scrap metal is being transported into a mill, not processed.

Element 14: Scanning Scrap Metal for Radiation (Figure 42)

Scrap metal may not be *properly* scanned for radiation, even though a mill has a radiation monitor, for many reasons:

- The monitor is malfunctioning.

- The settings on the monitor have been altered to reduce the frequency of false alarms.

- The monitor has been deactivated because the alarms are annoying.

In Element 14, the phrase *proper scanning* also includes a proper response to a radiation alarm; the alarm is not ignored because it is annoying or arbitrarily attributed to BC.

Determining the availability of a monitor system at a given location is fraught with difficulties. Records of the out-of-service time are unlikely to be kept by the mills. Monitor vendors may have some records of unavailability through telecommunication links with their monitoring equipment, but not all monitors are linked to their vendors. Even if such information were available, associating it with a given site is unreasonable because vendors may be reluctant to disclose the identity of their customers and the survey for collecting information from steel mills is anonymous. Another difficulty in obtaining information about the availability of monitors is that deactivating monitors and ignoring alarms are sensitive matters; reliable responses from a survey would be doubtful.

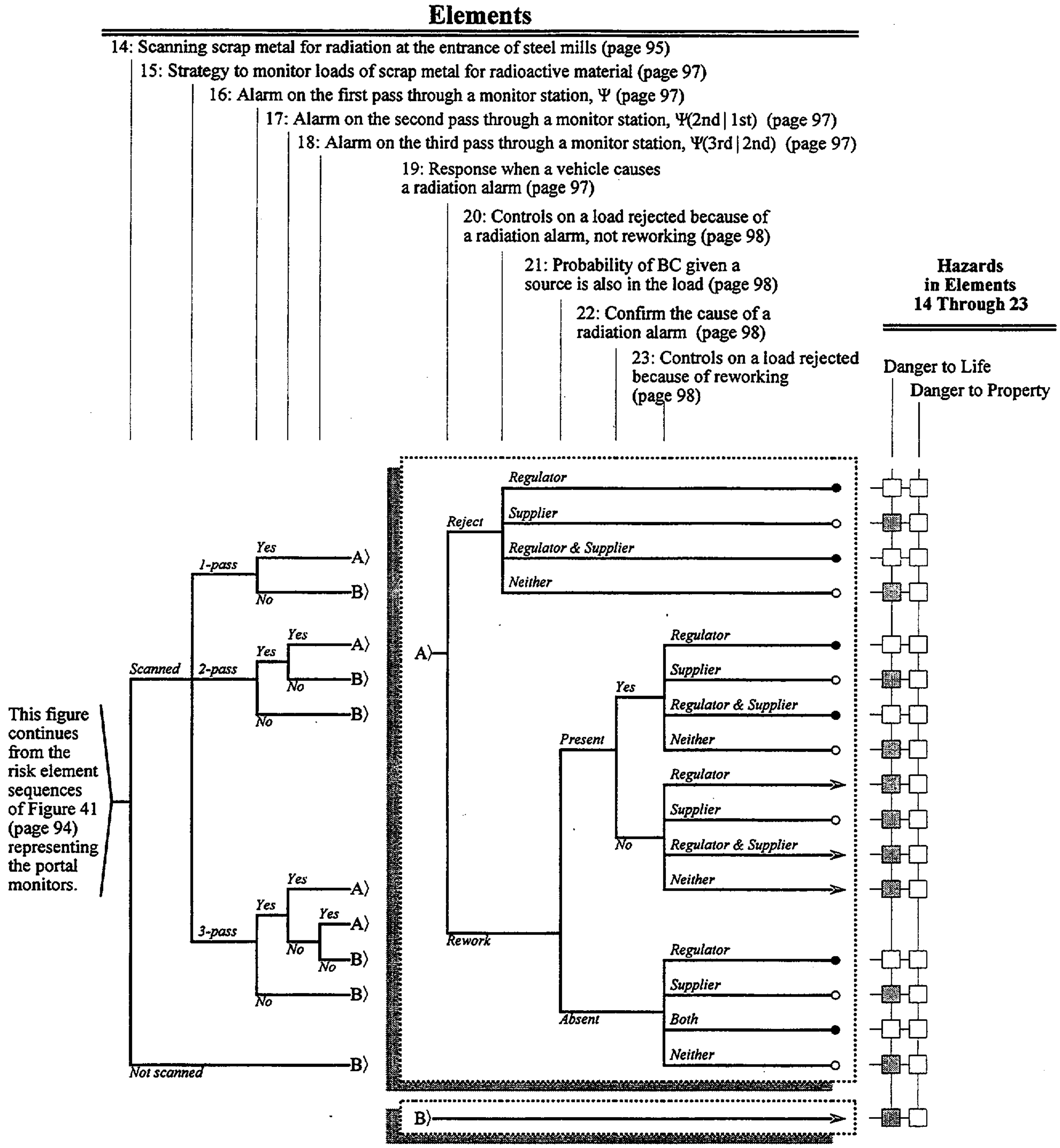


Figure 42 Analysis of the risk elements at the entrance of steel mills. LEGEND: Single black lines are sequences of risk elements. For clarity, common elements of the sequences are illustrated in the inset; some of these sequences discontinue at –A⟩ then continue at –A⟩; other such sequences discontinue at –B⟩, then continue at –B⟩. An arrow (➢) indicates that a sequence continues in Figure 43. A dot (●) indicates the end of a sequence. An open dot (○) indicates that a sequence is unresolved; it ends here, but not further developed. A black box (■) indicates that a concern is present in Elements 14 through 23 of a particular sequence. A shaded box (▩) indicates that a concern might be present. A white box (□) indicates that a concern is not present. Hazard terms are taken from the *U.S. Code of Federal Regulations* (Ref. 9).

More difficult to take into account than the unavailability itself is the use of the monitors at a given mill:

- A mill may draw on its inventory, not accepting additional scrap metal, while its monitor station is inoperative.
- Another mill may have several monitors; when one is out of service, vehicles are sent through the other monitor.
- Still another mill may have several monitors, but they are dedicated, one to trucks, the other for railcars. Rerouting scrap metal from a malfunctioning monitor may be impractical.
- Some mills that are closely tied to their supplier may take the risk of using unscanned scrap metal, relying on the radiation monitoring done by their supplier.

For a risk analysis, the issue is not the availability of the monitor nor the factors giving rise to scrap metal entering the mill without being properly scanned. The issue is the amount of scrap metal that is correctly scanned for radiation. The survey asks for an educated guess about the fraction of scrap metal that is correctly scanned for radiation.

Elements 15 through 18: Monitoring Strategies and Confirming a Radiation Alarm (Figure 42)

Three practices of sending a vehicle through a radiation monitor station are typically found in the steel industry (see Section 7.6):

- One-pass strategy. If there is a radiation alarm, then it is addressed according to the practices at a given mill. The one-pass strategy is represented in Figure 42 by Element 16.
- Two-pass strategy. If the first pass results in an alarm, then the vehicle is sent through the monitor station again. The two-pass strategy is represented in Figure 42 by Elements 16 and 17.
- Three-pass strategy. If the first pass results in an alarm and the second pass occurs without an alarm, then a third pass is used to confirm either the first or the second pass. If it confirms the first pass, then the alarm is addressed. If it confirms the second pass, then the load enters the mill. The three-pass strategy is represented in Figure 42 by Elements 16, 17, and 18. The uppermost branch of Element 17 is undeveloped because the second alarm confirms the first alarm, making a third pass unnecessary. Element 17 is developed in the case where an alarm occurs on the first pass and does not occur on the second pass.

One could argue that the monitoring strategy is of no concern; the only concern is the final outcome (i.e., accept, reject, or rework a load). While this treatment simplifies the risk analysis, it also limits the usefulness of the results. This study is an analysis of risk, not just an assessment. While the risk could be determined without considering the number of passes through a monitor station, the understanding of the risk estimates would be hampered. The empirical rejection probability will depend on the monitor strategy, the monitor characteristics, and the composition (metal, BC, sealed sources) of the load. An analysis is desired that separately accounts for these aspects.

Element 19: Response When a Vehicle is Rejected Because of a Radiation Alarm (Figure 42)

If the monitoring does not detect radiation, then the load is considered to be free of radioactive material and is accepted. If a radiation alarm suggests that radioactive material is present, then the load is either rejected or reworked. Several practices of reworking a load are found as discussed in Section 7.4. The various ways that a load can be rejected are not delineated; the only issue at this point is that a load is rejected.

Element 20: Controls on a Load Rejected Because of a Radiation Alarm (Figure 42)

Notifying local authorities ensures to various degrees that disposal is properly done. Sometimes regulators are called. Other times, police may be called if a truck driver refuses to remain at the mill until the reason for a radiation alarm is determined. Still other times, no one is called. Lacking controls means that a truck can go anywhere, as sometimes has been known to occur; an analogous situation does not exist on railroads because arrangements must be made with a carrier to have the rail car removed and sent to a specific destination. Some possibilities of how a nuclear gauge might be improperly disposed are discussed in Section 7.4. These possibilities could not be determined directly through a survey (see Section 4.3) The responses can be aggregated into distributions to assign to Element 20.

Element 21: Probability of Benign Contamination Given a Radioactive Source (Figure 42)

Many types of radioactive material can be detected with a radiation monitor. The plastic detectors of the monitors are unable to discriminate between a radioactive source and BC. Essentially, the only way to confirm the cause of an alarm is to rework the scrap metal in some way. The coincidence of BC with a nuclear gauge cannot be definitively analyzed. Instead, it is treated in a way to bound its effect on risk. Such an analysis need be done only at the portal monitors, not at later points of the risk model, such as at the charge bucket. A charge bucket itself will not have BC when it is monitored because radiation alarms would always be occurring. A mill owns the charge bucket and will have it cleaned. The same can be said when monitoring vehicles bringing scrap metal from the storage area to the furnace.

Element 22: Confirm the Cause of a Radiation Alarm (Figure 42)

A radiation alarm may occur for many reasons, including the presence of a nuclear gauge or many forms of BC. Monitors with plastic detectors are unable to discriminate sources of radiation. Various practices can be found in the steel industry to confirm the cause of an alarm:

- A load of scrap metal will not be accepted at a mill unless it can pass through a monitor station at the mill without causing an alarm. When a rejected load is returned to the supplier, it will pass through a portal monitor of the scrap yard. The alarm at the scrap yard may not occur for unknown reasons. But the lack of an alarm at the scrap yard may be irrelevant in light of the attitudes at the mill—monitor at the mill is the basis for the decision.

- A survey meter may be used to scan a vehicle. If the alarm of the portal monitor can be attributed to a structural member in the cargo hold of the transporting vehicle or to pipe scale on the scrap metal, then the load may be accepted.

- The load is reworked. Because of the difficulty in taking a load apart, sometimes a load will be partially reworked.

The only way of ensuring that a nuclear gauge is not in a load is to rework the load. Without knowing for sure, an implicit assumption is made—there is only one source of radiation in the load. Most of the time, this assumption is correct. But an assumption should not be made on the points of a matter that are at issue, in this case, the radioactive material in a load. Also, the financial consequences for being wrong are large. The other ways of "confirming" the cause of a radiation alarm do not confirm in and of themselves, but only because the implicit assumption happens to be correct for the suspected load of scrap metal.

Element 23: Controls on a Load Rejected Because it Was Reworked (Figure 42)

Reworking a load has different ramifications at different mills. Sometimes, reworking a load is tantamount to accepting the load and whatever radioactive material it may contain. Other times, a load is not fully accepted until a radiation alarm has been fully investigated. Because ramifications for reworking a load differ, the probabilities of what controls would happen differ.

Figure 43 illustrates the risk elements at the charge bucket of a steel mill. Single black lines are sequences of risk elements. For clarity, common elements of the sequences are illustrated in the inset; some of these sequences discontinue at –A⟩, then continue in the inset at –A⟩; other such sequences discontinue at –B⟩, then continue in another inset at –B⟩. An arrow (➢) indicates that a sequence continues in Figure 44. A dot (●) indicates the end of a sequence. An open dot (○) indicates that a sequence is unresolved; it continues, but is not developed further. Hazard terms are taken from the *U.S. Code of Federal Regulations* (Ref. 9). A gray box (▩) indicates that a concern is present in Elements 24 through 27 of a particular sequence. A white box (□) indicates that a concern is not present. The danger to life and property are similar to those discussed in Figure 41, the difference here being that a mill now owns the scrap metal and cannot simply reject a load. The following can be said about the sequences:

- If a nuclear gauge is detected and regulators are notified, the danger to life is removed; it will either be properly disposed or properly set aside (temporarily). If only the supplier is notified, there is a chance for danger to life and the sequence remains unresolved.

- The sequences other than disposal or set aside are unresolved; here, information is limited by what can be reliably collected with a survey of the steel industry. If a regulator is notified, a gauge will be properly secured. If only a supplier is notified, there is a chance that it will not be properly secured, giving rise to a danger to life.

- If scrap metal is not scanned at the charge bucket, there may be a potential for nearby employees to be exposed. The exposure may be brief if the nuclear gauge goes into the charge bucket. The exposure may be longer if it should happen to miss the charge bucket, falling to the ground, when scrap metal is loaded; if a radiation monitor is present, then the exposures may be brief because an alarm would activate.

- There is no danger to property between Elements 24 and 27 because scrap metal is only being moved.

Elements 24 Through 27: Charge Bucket/Box (Figure 43)

The analysis of charge bucket monitoring is similar in many respects to the analysis of the portal monitors and scanning a vehicle after reloading. The analysis of the charge bucket monitoring is illustrated in Figure 43. For many reasons, not all scrap metal is scanned (Element 24). Whether being scanned while being loaded or upon completion of the loading, the shielding from the scrap metal gives rise to a probability of an alarm of the radiation monitor (Element 25). At the charge bucket, the scrap metal is owned; it cannot be returned to the scrap dealer if radioactive material is found. Radioactive material can be disposed, set aside, or addressed in other unspecified ways (Element 26). The controls placed on the radioactive material give varying levels of assurance of proper disposal (Element 27).

Author's Note

The risk elements in rescanning scrap metal in the yard of a steel mill are analogous to those in the analysis of the charge bucket (Figure 43). For brevity, the risk elements for the yard are not discussed. Instead, the discussion resumes at the charge bucket.

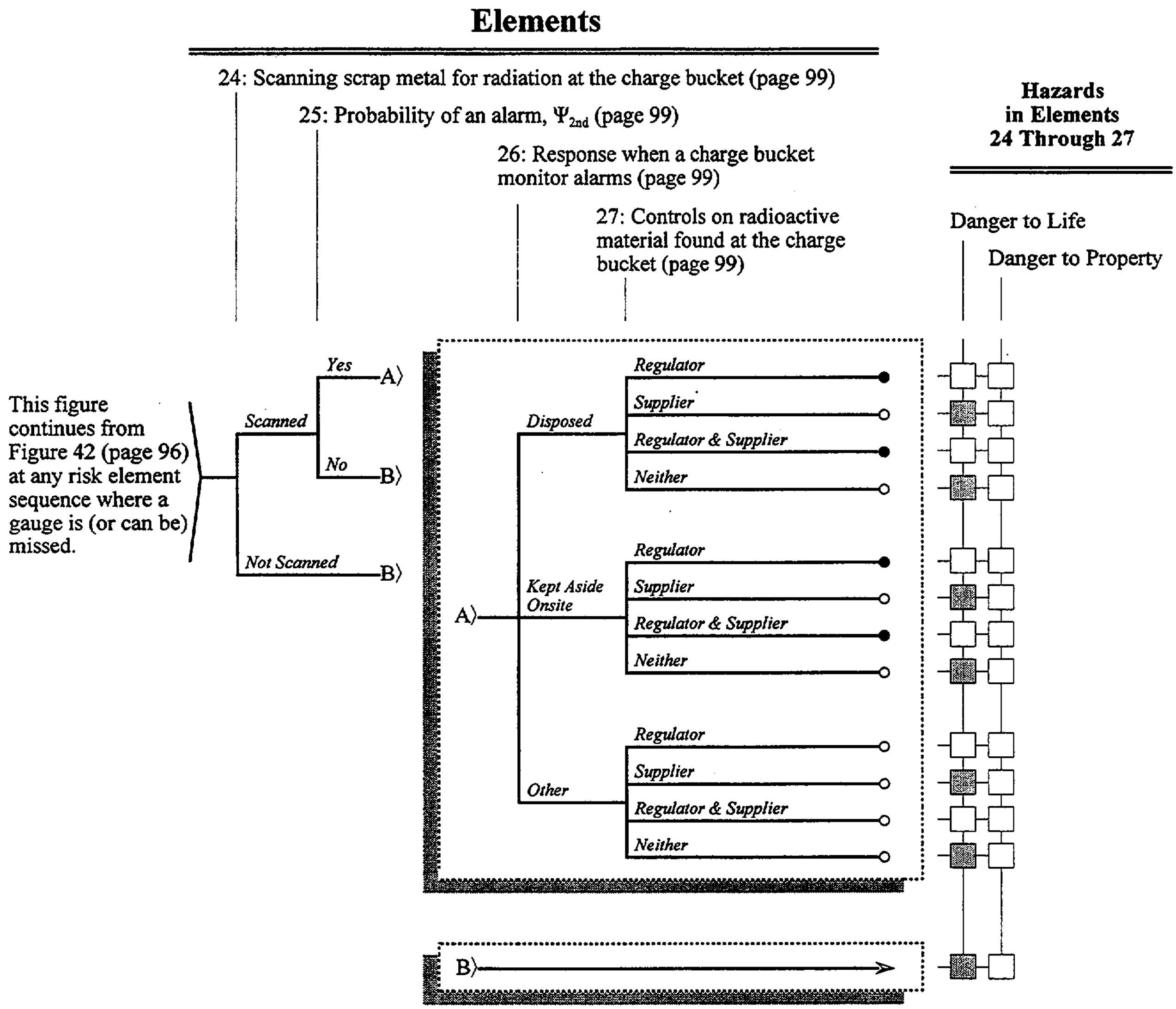


Figure 43 Analysis of the risk elements at the charge bucket of steel mills. LEGEND: Single black lines are sequences of risk elements. For clarity, common elements of the sequences are illustrated in the inset; some of these sequences discontinue at –A⟩ then continue in the inset at –A⟩, other such sequences discontinue at –B⟩, then continue in the inset at –B⟩. An arrow (➢) indicates that a sequence continues in Figure 44. A dot (●) indicates the end of a sequence. An open dot (○) indicates that a sequence is unresolved; it continues, but is not further developed. A black box (■) indicates that a concern is present in Elements 24 through 27 of a particular sequence. A shaded box (▩) indicates that a concern might be present. A white box (□) indicates that a concern is not present. Hazard terms are taken from the *U.S. Code of Federal Regulations* (Ref. 9).

A difficulty in the analysis is determining the composition of the scrap metal for evaluating the detection probability. The blend of scrap metal commodities of the scrap metal going from the storage area to the scrap bay or yard may change as scrap metal is sorted before being loaded into the charge bucket. But in the long run, limits on the changes occur because scrap metal does not accumulate at the storage area—it is all used. These changes are beyond the resolution of the risk calculations and the capability to collect information through a survey. Hence, the composition of the scrap metal entering a monitored charge bucket is studied in the risk analysis by exploring the effects on risk of plausible compositions. The difficulty can be addressed either by trying bounding values or by making an assumption.

Assumption: For the most part, the commodities of the scrap metal going into the charge bucket or box are similar to the commodities coming into the mill. Although sorting and blending are done at the yard, single commodities are used in bulk. Basis: The principal investigator observed charge buckets being filled. Also, scrap metal does not accumulate in the storage area because there are costs associated with storing and handling deferred scrap metal.

Figure 44 illustrates the risk elements of products and byproducts at steel mills. Single black lines are sequences of risk elements. A dot (•) indicates the end of a sequence. An open dot (○) indicates that a sequence is unresolved; it continues, but is not developed further. Hazard terms are taken from the *U.S. Code of Federal Regulations* (Ref. 9). A black box (■) indicates that a concern is present in Elements 28 through 35 of a particular sequence. A shaded box (▒) indicates that a concern might be present. The danger to life and property are as follows:

- Melted ^{137}Cs poses a small danger to life; employees at the mills may be exposed to small amounts of contaminated furnace dust that escapes the ventilation system of the melt shop. Property damage, in the form of lost production because equipment has to be decontaminated, occurs if radiation is detected. But radiation may not always be detected; the possibility for this is discussed in Section 2.3.

- Melted ^{60}Co poses a small danger to life for two reasons. First strong sources in nuclear gauges (a few curies) will be diluted in many tons of steel. Second, contaminated steel shields itself. The danger to life is not zero. Unnecessary exposures to low-level radiation will occur both at the mills and, for a longer time, to the public. Because steel is contaminated by ^{60}Co, property damage occurs. As in the case of ^{137}Cs, this type of property damage does not "occur" unless radiation is detected.

- Little is known about the phenomena when ^{241}Am is melted; nothing definite can be said, though there is the belief that it will reside in slag. There may be a danger to life. Property damage, taking the form of contaminated equipment, occurs. As with ^{137}Cs and ^{60}Co, property damage does not "occur" unless radiation is detected.

Element 28: Radionuclide Melted in Furnaces (Figure 44)

Three types of radioactive material commonly found in nuclear gauges are ^{137}Cs, ^{60}Co, and ^{241}Am. Cesium vaporizes and adheres to furnace dust. Although cobalt forms an alloy with steel, furnace dust and slag are also contaminated (Ref. 11) because these byproducts contain steel. Americium is treated as if it concentrates in slag. Element 28 of Figure 44 is the relative prevalence of gauges containing ^{137}Cs, ^{60}Co, and ^{241}Am.

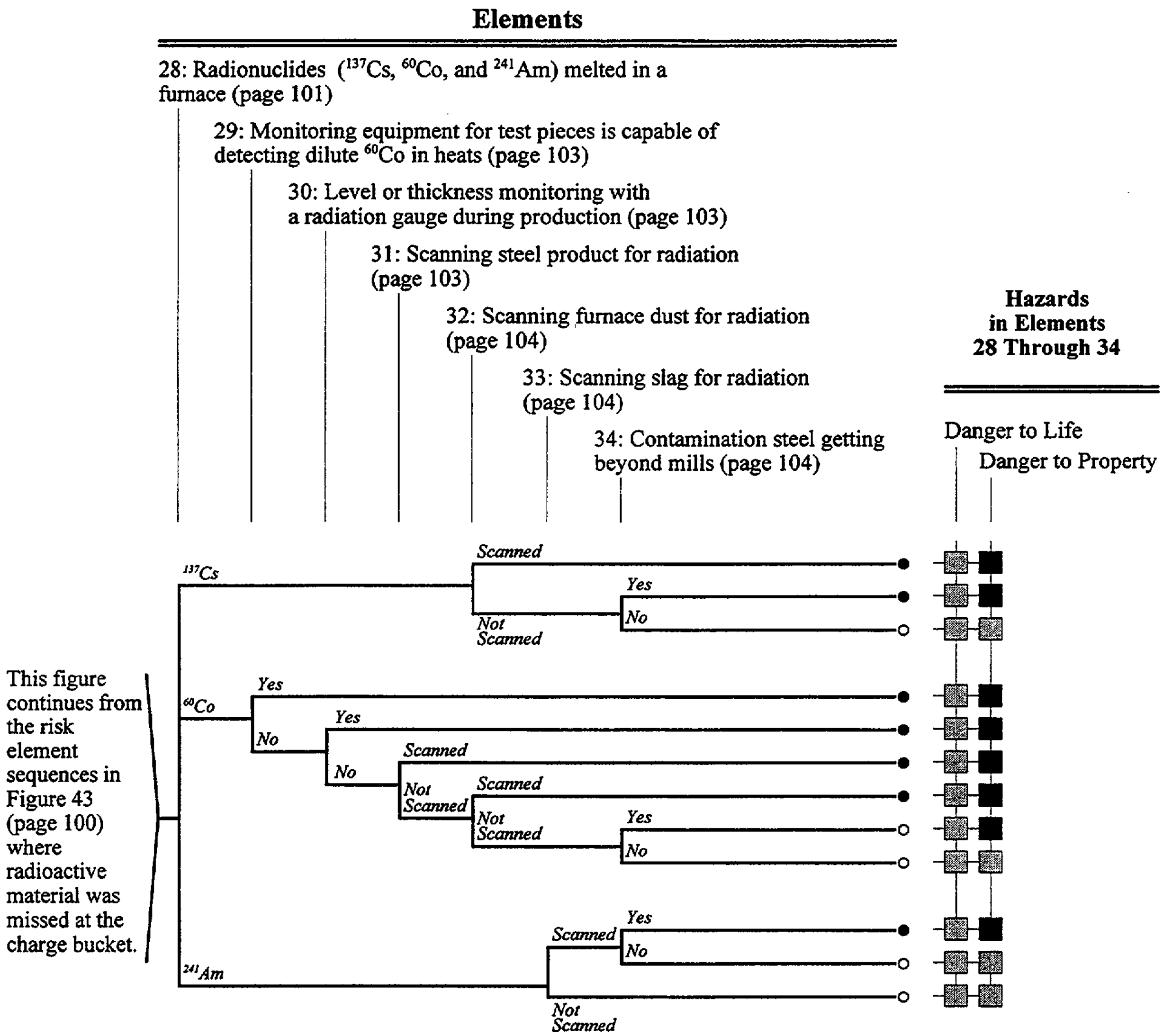


Figure 44 Analysis of the risk elements at product and byproduct monitoring at steel mills. LEGEND: Single black lines are sequences of risk elements. A dot (●) indicates the end of a sequence. An open dot (○) indicates that a sequence is unresolved; it continues, but is not further developed. A black box (■) indicates that a concern is present in Elements 28 through 34. A shaded box (▩) indicates that a concern might be present. A white box (□) indicates that a concern is not present. Hazard terms are taken from the *U.S. Code of Federal Regulations* (Ref. 9).

The ^{137}Cs, ^{60}Co, ^{241}Am prevalence ratio assigned to Element 28 would be most easily determined as the prevalence of the gauges that are distributed by the gauge vendors. Radionuclides may not be moving in this ratio through the recycling stream, for example, because some radionuclides are easier to detect in the recycling stream than others; hence, some gauges may be more selectively removed from the recycling stream than others. The selection can be taken into account in two ways: relative to Element 1, postulate changes in the prevalence ratio for Element 28; before Element 1, the prevalence of gauges containing ^{137}Cs, ^{60}Co, and ^{241}Am can be determined separately and risk can be estimated for each group of gauges.

Element 29: Scanning Heats for Radiation (Figure 44)

Element 29 branches from the middle branch of Element 28, which represents ^{60}Co because cobalt forms an alloy with steel. Cesium does not form an alloy with steel, hence, Element 29 does not branch from the upper branch of Element 28. The extent to which ^{241}Am will reside in steel is poorly understood, hence, as illustrated in Figure 44, Element 29 does not branch from the lower branch of Element 28. Figure 44 is to explain concepts; modifications can be made as more information about americium becomes available.

Element 29 represents the capability of the units for monitoring test pieces to detect contaminated steel. The element is used to bound risk estimates, postulating two cases to bound the effect on risk — always detected (probability of detection is one) and never detected (probability of detection is zero). The survey gives only a clue as to what the probability may be, but because it is a facet of risk, it must at least be acknowledged.

Elements 30: Level or Thickness Gauges (Figure 44)

Radiation gauges that are in the process line are represented by Element 30, which is developed when contamination is missed when monitoring the test pieces (Element 31). Element 31 is undeveloped when contaminated steel is detected by scanning test pieces because further processing has ceased.

A prohibitive amount of information about the characteristics of the radiation gauges and the arrangement of radiation gauges would be needed to evaluate Element 30. Nevertheless, because the element is a method for detecting melted radioactive material in steel, it is a facet of risk that needs to be taken into account. Element 30 is treated to bound its effects on risk.

Elements 31: Scanning Steel Product (Figure 44)

Element 31 represents steel product being scanned for radiation as it is transported in trucks or by rail out of the mills. The probability of detection is represented in a simple way, unlike the monitoring of scrap metal, where the heterogeneity of a load and the transporting vehicle shield radioactive material that itself may be in a highly shielded holder. In a steel product, ^{60}Co in the steel would be dispersed, bringing the radioactive material within view of a detector. Because of the dispersion, the concepts of detection areas developed in Section 7.5 do not apply here. The notion of the monitoring strategy (see Section 7.6) is a moot point; given that there is enough radioactive material to detect, the radiation will, for most concerns, always be or never be detected.

The same is not true of the gauges in the scrap metal. The fixed nuclear gauges of concern have enough radioactive material to be detected; the problem is the shielding from the housing, the vehicle, and the scrap metal.

> Assumption: If steel product is contaminated, then the probability of detecting the contamination with a radiation monitor is one. Basis: Steel product is homogeneous. The composition of steel does not change as steel is tapped from a furnace.

The assumption reduces the analysis product monitoring to the fraction of product that is scanned and unscanned; if steel product is scanned, then radioactive contamination will be detected.

Element 32: Scanning Furnace Dust for Radiation (Figure 44)

The element represents the fraction of the dust that is scanned, given that monitoring is done. The element is relevant for both ^{137}Cs and ^{60}Co. The low volatility of ^{137}Cs driving it from molten steel where it condenses on furnace dust has been discussed. Though ^{60}Co forms an alloy with steel, furnace dust contains iron; this explains the contaminated furnace dust reported in Reference 11. The contamination will be dispersed; hence, the same assumption and simplification given for Elements 30 and 31 with regard to product monitoring are made in the analysis of furnace dust monitoring.

Element 33: Scanning Slag for Radiation (Figure 44)

As in the analysis of product monitoring (Elements 30 and 31) and furnace dust (Element 32), here too, in the case of slag monitoring, the detection probability is treated as being one if the radioactive material is at all detectable. Element 33 is developed for both ^{241}Am and ^{60}Co. Also, because the contamination will be dispersed, the same assumption and simplification made with regard to product monitoring are made here.

Element 34: Contaminated Steel Getting Beyond Mills (Figure 44)

Contaminated steel has gotten beyond mills and into the public domain. Reference 1 discusses the first time this was known to occur. Reference 11 and the box in Section 7.4 entitled "An Incident of Radioactive Scrap Metal" suggests a potential for contaminated material to get into the markets.

7.8 Sources of Information

Tables 8, 9, and 10 summarize the sources of information for developing the inputs of the steel mill analysis. Along the top are the elements corresponding to the elements in Figures 41, 42, 43, and 44. Along the vertical are classes of information (see Section 4.2). A shaded box indicates that information is available; numbers refer to survey questions (see Appendix C); letters refer to notes following the table. A white box indicates that a particular class of information for a particular element is unavailable.

7.9 Observations and Insights

1. Research is needed to characterize the commodities of scrap metal and to determine the detection probability for each commodity, not just to determine the detection capabilities of specific systems as has been done. With a characterization of the commodities, the capabilities of equipment could then be predicted without having to conduct a field trial each time the technology changes. Field trials may still be necessary to validate predictions, but as yet, there is sparse quantitative basis for making predictions.

Author's Note

Observations and Insights resume on page 108 after Table 10.

Table 8 Sources of information supporting the analysis of risk elements in monitors at the entrance of steel mills (Figures 41 and 42). LEGEND: A shaded box indicates that information is available; a number in a shaded box indicates a question of the survey in Appendix C and a letter indicates a note following the table. A white box indicates unavailable information. Degrees of information are discussed in Section 4.2.

Elements

13: Configuration of radiation monitors (e.g., portal, charge bucket, radiation gauges) at steel mills (page 95)
14: Scanning scrap metal for radiation at the entrance of a steel mill (page 97)
15: Strategy to monitor loads of scrap metal for radioactive material (page 97)
16: Alarm on the first pass through a monitor station, Ψ (page 97)
17: Alarm on the second pass through a monitor station, Ψ (2nd|1st) (page 97)
18: Alarm on the third pass through a monitor station, Ψ (3rd|2nd) (page 97)
19: Response when a vehicle causes a radiation alarm (page 97)
20: Controls on a load rejected because a radiation alarm, not reworking (page 98)
21: Probability of BC given a source is also in the load (page 98)
22: Confirm the cause of a radiation alarm (page 98)
23: Controls on a load rejected because of reworking (page 98)

Degrees of Information (Section 4.2)	Source of Information	13	14	15	16	17	18	19	20	21	22	23
1st	Survey (page 135	A		B 13	C 8, 10	C 8, 10	C 8, 10					
2nd	Survey (page 135)	A 3, 4	D 9					E 16	E 17		E 14, 19	E 18
3rd	Plausible judgments									F		

Notes on Table 8

A. The analysis of the steel industry requires that the steel mills be grouped according to the location of radiation monitors. Each group is homogeneous, having mills with radiation monitors in the same location(s). Questions 2, 6, 7, 10, 12, 20, 21, 25, 26, 29, 34, 39, 40, 43, 44, 47, and 48 determine the location of radiation monitors. The replies to Questions 3 and 4 are used to emphasize configurations according to the amount of risk scrap metal that they consume; Reference 1 indicates that mills producing carbon steel are more at risk than mills producing stainless steel.

B. The number of times that a vehicle passes through the monitor station influences the risk of nuclear gauge entering the mill (see Section 7.6).

C. The placement of detector panels is one of many factors that determines the probability of detecting radioactive material in a load of scrap metal (see Section 7.5).

D. A mill is at higher risk of receiving radioactive material in proportion to the amount of scrap metal that is not scanned for radiation. Anecdotal information suggests that radiation monitors are sometimes turned off because the alarms are annoying or activate for superfluous reasons.

E. Question 16 determines the basis for rejecting a load of scrap metal. At some mills, a radiation alarm is sufficient for rejecting; at other mills, an alarm serves as a basis for further investigation. Questions 17 and 18 determine the controls that are placed on a load that is going to be rejected; in Question 17, the rejection is based only on an alarm (the load is only suspected of containing a nuclear gauge because the alarm may be due to BC); in Question 18, the rejection is based on reworking the load (a nuclear gauge was found). Question 14 refers scrap metal that has not been unloaded; Question 19 refers to scrap metal that has been unloaded.

F. Speculation may be done, based on Reference 1, and used in calculations to bound risk estimates.

OTHER NOTES: Questions 1, 38, and 39 are used to support the inferences discussed in Section 2.5. Question 53 is used to verify the burden estimates made during pilot tests.

Table 9 Sources of information supporting the analysis of risk elements in yard and charge bucket monitors at steel mills (Figure 43). LEGEND: A shaded box indicates that information is available; a number in a box indicates a question of the survey in Appendix C, and a letter indicates a note following the table. A white box indicates unavailable information. Degrees of information are discussed in Section 4.2.

Elements

Degrees of Information (Section 4.2)	Source of Information	Monitoring in the Yard: Scrap metal going directly to the melt shop area (page 99, "Author's Note")	Monitoring in the Yard: Scrap metal rescanned without unloading (page 99, "Author's Note")	Monitoring in the Yard: Scrap metal rescanned after reloading (page 99, "Author's Note")	Monitoring in the Yard: Monitor strategy (page 99, "Author's Note")	Monitoring in the Yard: Alarm on passing through a monitor station, Ψ_{2nd} (page 99, "Author's Note")	Monitoring in the Yard: Actions following an alarm (page 99, "Author's Note")	Charge Bucket Monitoring: Configuration of detectors around the charge bucket (page 93)	Charge Bucket Monitoring: Mode of scanning the charge bucket (page 93)	Charge Bucket Monitoring: 24: Scanning scrap metal for radiation at the charge bucket (page 99)	Charge Bucket Monitoring: 25: Probability of an alarm, Ψ_{2nd} (page 99)	Charge Bucket Monitoring: 26: Response when a charge bucket monitor alarms (page 99)	Charge Bucket Monitoring: 27: Controls on radioactive material found at the charge bucket (page 99)
1st	Survey (page 135)		shaded: A, 12	shaded: A, 21	shaded: B, 23	shaded: C, 20		shaded: D, 26	shaded: E, 29		shaded: F		
2nd	Survey (page 135)	shaded: G, 15		shaded: H, 22			shaded: I, 33			shaded: J, 31		shaded: I, 33	shaded: I, 33
3rd	Plausible judgments												

Notes on Table 9

A. Question 12 determines whether or not the secondary monitoring is done. Question 21 determines whether or not secondary monitoring is done after scrap metal is reloaded from the storage area.

B. The number of times that a vehicle passes through the monitor station influences the risk of a nuclear gauge entering the mill (see Section 7.6). Here, Question 23 refers to the strategy after reloading.

C. The question establishes the size of the transporting vehicle in sufficient detail for shielding calculations. In the context of a risk analysis, the difference between cross-sectional areas of tri-axle (or larger) trucks and railcars is insignificant.

D. The location of the detector panels will, in part, determine the detection areas in a load of scrap metal (see Section 7.5).

E. The mode of scanning a charge bucket influences the detection probability. Monitoring a charge bucket as it is filled allows small amounts of scrap metal to be scanned; a stationary bucket allows for more radiation to reach a detector than when the bucket is moving.

F. The detection areas for the detection probability are determined from Questions 25, 26, 27, and 28.

G. Question 15 distinguishes between the two routes shown in Figure 42: one route is to the storage and processing area, the other route is to the scrap bay/yard next to the melt shop.

H. The difference between monitoring again after reloading and monitoring without reloading is discussed in Section 7.6.

I. By this time in the recycling stream, the scrap metal, and whatever may be in the scrap metal, is owned by the mill. Radioactive material cannot simply be returned to the scrap dealer. The second part of the question asks what controls are placed on the material.

J. Charge bucket monitors are not always operational. The loading process is violent and the detector panels are fragile. The protection over the panels must be minimal and the detectors must be as close as possible to the charge bucket to take advantage of detection capabilities. Detection panels are sometimes damaged while the charge bucket is being loaded. A monitor can be off to the side of its mountings for no apparent reason. Scrap metal that is not scanned is more risky than scrap metal that is scanned.

Table 10 Sources of information supporting the analysis of risk elements in product and byproduct monitoring at steel mills (Figure 44). LEGEND: A shaded box indicates that information is available; a number in a shaded box indicates a question of the survey in Appendix C and a letter indicates a note following the table. A white box indicates unavailable information. Degrees of information are discussed in Section 4.2.

Degree of Information (Section 4.2)	Source of Information	28: Radionuclides (^{137}Cs, ^{60}Co, and ^{241}Am) melted in a furnace (page 101)	29: Monitoring equipment for test pieces is capable of detecting ^{60}Co levels expected in a heat (page 103)	30: Level or thickness monitoring with a radiation gauge during production (page 103)	31: Scanning steel product for radiation when leaving a mill (page 103)	32: Fraction of furnace dust that is scanned for radiation (page 104)	33: Scanning slag for radiation (page 104)	34: Contaminated steel getting beyond mills (page 104)
1st	Survey (page 135)		A 35, 36	B 2				
2nd	Survey (page 135)				C 49	D 40, 41	E 44, 45	
3rd	Plausible judgments	F		G 32				H

Notes on Table 10

A. Question 35 gives an indication of general practices and equipment. There is also an implication, although vague, as to the assurance that the monitoring is done. For example, when monitoring is done with a desktop unit, the sample of a heat may have been inadvertently skipped because the laboratory technician was fatigued or distracted. Question 36 is used to suggest the extent to which radioactive material that forms an alloy with steel can be detected.

B. Radiation gauges in the process line may act as a form of monitoring of the steel product, thus possibly giving assurance that contaminated steel will not leave the mill site.

C. Question 49 indicates the potential for contaminated steel to be detected as it leaves a mill.

D. If furnace dust is not scanned, then a melted ^{137}Cs source will go undetected. Question 40 is used for a subjective evaluation of the monitoring effectiveness. When weather is inclement, monitoring with a survey meter may not be done or an alarm from a portal monitor may not be investigated. Question 41 is used to suggest the potential for contaminated furnace dust to leave a mill site. Some mills have strict policies about monitoring everything entering and leaving the site. Other mills may not be so strict.

E. Slag may be used for road material or processed to recover iron. Question 44 suggests the rigor of the monitoring; Question 45 indicates the potential for contaminated slag to leave a mill.

F. Reference 1, records, and opinions from regulators may be used to determine plausible values of the relative prevalence of ^{137}Cs, ^{60}Co, and ^{241}Am.

G. The concentration of radionuclides in a furnace suggests the extent to which radiation gauges will detect melted radioactive material. Furnaces of different sizes may be used to different extents. For example, in a small furnace at a facility that is seldom used, the concentration of radioactivity in the melted steel would be high, but the chance of it being contaminated would be low.

H. Little is known about the extent to which contaminated steel has gone beyond mills into the markets. Only plausible judgments, based on a few reported incidents, are possible.

2. Figure 32 has important implications for the scrap yards and steel mills. If Area 2 is small, then the practice of passing a load through a monitor station multiple times is of no consequence. A nuclear gauge in Area 1 will always be detected. A nuclear gauge in Area 3 will never be detected, no matter how many times a load is passed through the monitor station. If Area 2 is large, then there is a chance that a nuclear gauge will be detected, and hence, multiple passes through a monitor station are useful.

3. Highly sophisticated monitors alone cannot be entirely relied on to detect radioactive material in scrap metal loads.

4. Proper use of monitors is important in ensuring a high probability of rejecting a load when radioactive material is present.

5. If the primary concern when monitoring scrap metal is detecting sealed sources, then the best of the strategies considered is the one-pass strategy. The decision to reject or accept a load would be based on the first pass through a monitor station. If the primary concern is false alarms, then the best of these strategies is the two-pass strategy. The three-pass strategy is a compromise between the one-pass and two-pass strategies.

6. When ^{137}Cs is melted, it adheres to the furnace dust. Most, but not all, of the dust is collected by the ventilation system of the melt shop. Some of the dust escapes into the melt shop. The amount varies from mill to mill. The amount of contaminated dust escaping into the melt shop is difficult to determine, depending on when the sealed source melts in relation to when the furnace is open and the capacity of the ventilation system to collect dust.

7. When a ^{60}Co source is melted, the cobalt forms an alloy with the steel. The radioactive material is at least somewhat diluted in the heat. The steel gives self-shielding. The furnace gives additional shielding until it is tapped. Some ^{60}Co gets into furnace dust, some of which escapes the ventilation system.

8. Little is known about what will happen when ^{241}Am is melted. The current understanding is that it will reside mostly in slag.

9. When a radiation alarm is to be confirmed to determine whether or not to allow the load of scrap metal into a mill, only reworking the load (i.e., by dumping the load and sorting through the scrap metal) gives adequate assurance about the cause of the alarm. Scanning a load with a survey meter and attributing an alarm to the rib of a vehicle or pipe scale assumes a nuclear gauge is not present in the load. Most, but not all, of the time, this assumption is correct. However, until further study is done, making the assumption is inappropriate considering the possible consequences (melting radioactive material) of being wrong.

10. Some methods for monitoring test pieces have much uncertainty in detecting when radioactive material has been melted in a furnace.

8 PUBLIC DOMAIN

8.1 Overview

Though nuclear gauges are physically a minuscule part of a process unit, often the gauges are critical, convenient, and irreplaceable for producing high-quality products at competitive prices. But the use of gauges also has consequences. People have been overexposed to radiation and equipment along the recycling stream has been contaminated.

The public domain is where the risk element sequences of the nuclear gauges end. Some sequences are short. Other sequences are long. All of the sequences end in consequences of some kind, from benign to hazardous:

- The consequences to health are usually expressed in terms of injury, disease, or dose. But in the study of nuclear gauges, a surrogate measure may be more practical because of the complex circumstances in which the consequences arise. Also, a gauge that is intact is still of concern, even though disease, injury, and dose are not occurring, because it has a potential to do so.

- The consequence to property is often expressed in terms of costs. Available cost estimates to the steel industry are poorly characterized. Little is known about what the cost estimates represent; it is unclear whether or not the estimates were adjusted to present dollars. The predicted damages from melting a gauge at an integrated mill lack a firm basis.

Accurate information, in a form that is suitable for a risk analysis, was unavailable for this study.

8.2 Importance in Risk

In this study, the public domain is that segment of the population in which the net effects to society from nuclear gauges are apparent. Most segments of the licensees (Section 5), scrap yards (Section 6), and steel mills (Section 7) are in the public domain because a *worker* is a person licensed to work with nuclear material (Ref. 9). Although a licensee can be a corporation, the definition of a worker in Reference 9 refers to only those people designated to handle nuclear material. Other people in a workplace in which nuclear material is used, who are not designated to handle nuclear material, are considered the public. These "non-workers" are most of the population in industrial facilities.

Changes in control mechanisms can affect various groups within the public domain in various ways. A positive consequence is a *benefit*; conversely, a negative consequence is a *cost*.

The relation of the public domain to other constituents of the risk analysis is shown in Figure 45.

Section 8

■ Danger to life
■ Danger to property
□ Transporting gauges
□ Markets

Figure 45 Topics taken into account in the analysis of the public domain. LEGEND: A black bullet indicates that a topic is comprehensively taken into account. A white bullet indicates that a topic is beyond the scope of the risk analysis. A gray bullet indicates that a topic is briefly taken into account. LEGEND: Black bullets indicate that a topic is rigorously taken into account in the risk analysis. Gray bullets indicate that a topic is briefly taken into account. White bullets indicate that a topic is beyond the scope of the risk analysis.

Some portions of the public domain are not taken into account:

- Transporting a nuclear gauge has negligible risk. When a nuclear gauge is transported, the gauge is deliberately sent to a specific destination, to a person expecting it, in a package that can withstand likely accident conditions. The delivery systems are reliable and usually have means of keeping account of packages to ensure that gauges arrive at their intended destinations.

- Markets (movement of materials and products among industries and consumers) are beyond the scope of this risk analysis. Their complexity precludes a meaningful analysis within the resources allocated to this study.

8.3 Concepts

Nuclear gauges allow industries to conveniently and precisely control processes that otherwise would be difficult to control. Although they are physically a minuscule part of production, for many industries gauges are critical for making high-quality products. Other devices measure attenuated radiation to control industrial processes without using a sealed source. A reasonable question to ask is why nuclear gauges are used at all. Indeed, radar and x-ray tubes use radiation at a lower spectrum energy than sealed source gauges containing ^{137}Cs, ^{60}Co, and ^{241}Am. The most popular replacement for a nuclear gauge is a radar gauge. However, even a radar gauge has limitations. A radar gauge is defeated by foaming and buildups in industrial processes and is more limited than a nuclear gauge in applications in high temperatures and pressures; also, the radar waves will pass through materials that have a low conductivity without being attenuated for measurements. Gauges that use x-rays are less precise compared to sealed source gauges because the broader (bremsstrahlung) spectrum of x-ray radiation is more difficult to measure than the relatively narrow spectrum from a sealed source. In principle, an x-ray type of device that emits gamma rays too would have a broad spectrum that hampers measurement; such a device has a nonradiological hazard from the high voltage needed to produce the gamma rays. The sealed source used in a nuclear gauge produces a comparatively narrow high-energy spectrum for precise measurements. At industrial facilities, there have been instances when nuclear gauges have been replaced with another type of measuring device that in turn, was replaced again with a nuclear gauge after a hazardous material overflowed a tank. These facilities have found that the radiological hazards and regulatory burden are often much more acceptable than the hazard of an awry industrial process requiring accurate and reliable control. At least in the short run, nuclear gauges are not only an integral part of some process units, but also an irreplaceable part.

Author's Note

The term *public domain* is defined in Figure 45 for use in this risk analysis. It is <u>not</u> a statutory term.

Gauges reliably, accurately, and precisely measure thickness, level, density, or consistency of materials under a variety of conditions—hot, corrosive, dusty, dirty, or humid. Nuclear gauges are used in many ways to control industrial processes. Some examples of the measurements made by the gauges include the following::

- level of steel as it is poured into a caster;

- thickness of steel that is rolled into sheets for cars, cans, and electronic components;

- height of liquid in industrial autoclaves for making graphite electrodes used in steel minimills;

- thickness of coatings on steel used to make food cans;

- thickness of tar in the production of roof shingles;

- level of molten glass in a furnace for producing fiberglass insulation;

- density of slurries in the air pollution control equipment of a fossil fuel power plant;
- density of fluids in pipes of a coal processing plant and paper mill;
- height of liquids in tanks of a chemical plant making industrial and commercial products;
- height of coal entering a coal crusher of a fossil fuel plant;
- height of lime rock entering a cooler after being made anhydrous for industrial uses;
- height of wood chips in tanks beginning the manufacture of pulp in a paper mill; and
- amount of recycled cardboard on a conveyor belt at a paper mill.

But gauges also can result in costs:

- Exposures to workers have occurred when tanks have been serviced while the shutter of a gauge was inadvertently left open.
- Exposures to workers have occurred when gauges have been removed while the shutter was inadvertently left open.
- Exposures to workers have occurred when improperly disposed gauges in the recycling stream have been processed at scrap yards.
- Millions of dollars have been spent to decontaminate steel mills that have inadvertently melted gauges.
- Radiation alarms at scrap yards and steel mills require the attention of employees who have other responsibilities for production. Most of the alarms seem to be caused by naturally occurring radioactive material (see Figure 2).
- Regulators are often called to assist in placing controls on a load of scrap metal that is suspected of containing radioactive material so that the load can be moved to a place where it can be safely taken apart to determine the cause of the radiation alarm.
- Resources have been expended to investigate and contain amounts of radioactive material that have no impacts on health.

8.4 Elements of Risk

In the public domain, the elements of risk are the consequences of the sequences in Sections 5.5, 6.4, and 7.7. Two types of consequences are impacts to health and the cost of restoring a facility after breaching a sealed source.

8.4.1 Danger to Life

Risk, in terms of danger to life, is usually expressed as injury, disease, or dose. In this study, the risk to life is expressed in terms of the activity of the sources because of the circumstances in which nuclear gauges can inflict consequences on life. The states of gauges (intact with the shutter closed, intact with the shutter open, dislodged source, breached source) and scrap metal consolidation create complex circumstances that are difficult to characterize for dose calculations. The necessary simplifications and assumptions would severely limit the usefulness of such risk estimates, complicating the way in which such risk estimates are interpreted.

A surrogate measure of consequences to health is the activity of sealed sources. This surrogate measure circumvents the problems of determining the dose under the complex and variable environment of a scrap yard and the populations in the surrounding area. The surrogate measure also covers intact gauges in the recycling stream, which though not causing exposures, are still a concern because they are beyond controls.

At present, a quantitative evaluation of the impacts to health from melting a nuclear gauge at a steel mill is difficult to perform. Three parameters are unknown: the furnace size, the partitioning of radionuclides between product and byproduct materials, and the collection effectiveness of the ventilation system in the melt shop. Qualitative statements can be made from the reported incidents of radioactive material melted at mills and are illustrated in Figure 46:

(1) Furnace size. A wide range of furnace capacities can be found across the steel industry; the principal investigator visited mills with furnace capacities ranging from 59 tonnes to 145 tonnes (65 tons to 160 tons). A large amount of steel, although contaminated, will give more shielding than a small amount of steel. Also, a large amount of steel means that the concentration of radioactive material (e.g., ^{60}Co) will be low in any product that is made.

(2) Partitioning. ^{137}Cs: the partitioning is well known. Cesium vaporizes from molten steel and slag and resides in the furnace dust. Contamination is not found in steel when cesium has been melted. ^{60}Co: some information is known, but this partitioning has not been characterized. Cobalt forms an alloy with steel. Because some steel is in the slag and furnace dust, these byproducts will also be contaminated (Ref. 11). ^{241}Am: little is known about the partitioning, but it is suspected to reside in slag.

(3) Collection efficiency. A ventilation hood in a melt shop collects dust from the furnace. At some mills, the furnace is ventilated while it is operating. When a furnace is opened, a plume of dust rises up to the hood, but not all of the plume enters the hood. Inhalation exposures are more than just a function of the collection efficiency. Predicted exposures are complicated by the rate at which radionuclides are purged from molten steel. Little is known about the purge rate.

In addition to the above points, predicting exposures from inhaling and ingesting radioactive material, as well as external exposures, is difficult owing to differences in facilities.

8.4.2 Danger to Property

The burden to industry from more stringent controls and the damage to property when a nuclear gauge is compromised can be conveniently expressed in a common term — costs.

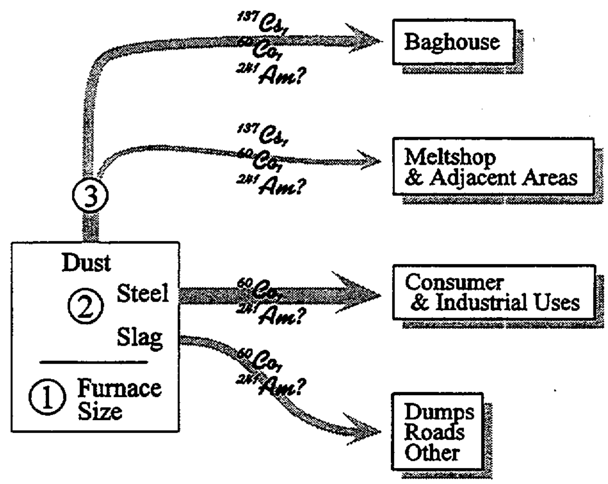


Figure 46 Difficulties in determining health impacts at a melt shop.

Licensees

Unless a facility has many nuclear devices, there is seldom one person whose only responsibility is the care of nuclear gauges. An employee who is responsible for nuclear gauges usually has other responsibilities. That person may be an environmental engineer, the chief electrical engineer, a production manager, or a safety engineer, having critical responsibilities in an expensive process. The time spent on administering regulations is time that is taken away from other safety concerns (e.g., chemicals, high-voltage lines, heavy loads, falls) and production. The expense to the facility is not just a licensing fee or the time of the person at an hourly wage; it is the cost of taking that person away from production matters that can affect the safety of employees and the populations surrounding a facility. While all of the aspects of costs may not be explicitly represented in an analysis, a comprehensive analysis will at least acknowledge their existence.

Scrap Yards and Steel Mills

When radioactive material has been accidentally melted, the costs to decontaminate a mill and dispose of contaminated products and byproducts has been reported to be from \$2 million to \$23 million (Ref. 10). Reference 3 (pages 263 through

270) states that costs are often difficult to use. Problems exist with the cited figures of financial damage:

- The costs by themselves are poorly characterized. Only a range of costs is given, sometimes with a vaguely defined average.

- Money has a value that changes over time. The costs of incidents need to be stated with respect to an applicable time frame.

- Costs are often misstated from the view of a systematic analysis because of accounting practices. Accounting practices usually do well in keeping track of receipts and expenses by placing costs into conventional categories, avoiding subjective appraisals of value. But the categories may be inappropriate for a risk analysis. For example, a nuclear gauge may have been melted shortly before a scheduled shutdown; attributing the entire cost of a shutdown to melting a nuclear gauge would overstate the consequences. The constituents of the cost figures must be known.

Accurate cost information, in a form that is compatible with a risk analysis, is essential for assessing financial risk. The costs expected in an integrated mill have not been rigorously determined, although figures have been stated (Ref. 10). Minimills that have not melted nuclear devices have expected costs too, but the estimates are poorly founded.[10]

8.5 Sources of Information

Table 11 is a summary of the sources of information for developing the inputs of the steel mill analysis. Shaded cells indicate that information is available. Numbers in cells refer to survey questions in Appendix C. Letters in cells are notes following the table about the information or lack thereof. White cells of the table indicate that a particular class of information for a particular element is unavailable at a reasonable cost.

8.6 Observations and Insights

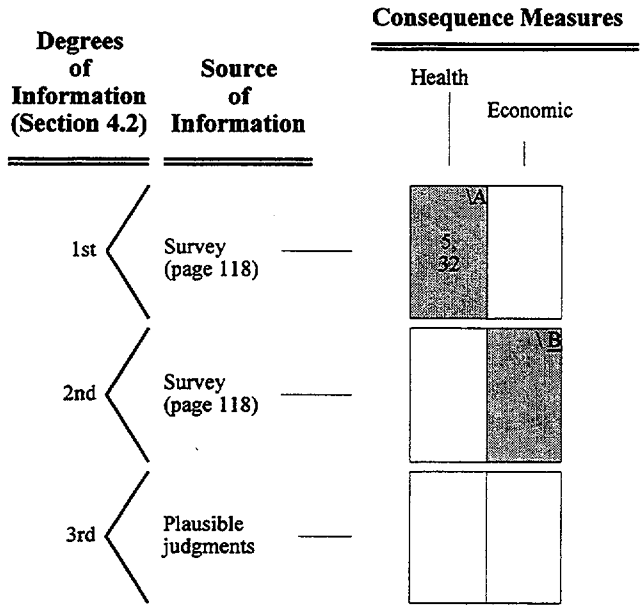
1. Nuclear gauges allow industries to conveniently and precisely control processes that otherwise would be difficult to control. Although they are physically a minuscule part of production, for many industries gauges are critical for making high-quality products with less risk from the processes themselves.

2. Use of nuclear gauges also have consequences. People have been overexposed to radiation when gauges have been improperly used or disposed of in the recycling stream. Property has been contaminated and financial losses have occurred when sealed sources have been breached within the recycling stream. Most of the people who are vulnerable to the consequences are members of the public; workers trained in the use of nuclear material are not considered the public.

3. An assessment of risk in terms of impacts to public health is hampered by a paucity of information on relevant parameters.

10/ This statement is based on pilot tests of the steel industry survey in Appendix C.

Table 11 Sources of information supporting the analysis of risk elements in the public domain. LEGEND: A shaded box indicates available information; a number in a shaded box indicates a survey question in Appendix C and a letter indicates a note following the table. A white box indicates unavailable information. Degrees of information are discussed in Section 4.2.



Notes on Table 11

A. Question 5: The type of processing of scrap metal that is done at a mill can influence health risk. Sorting, shearing, and cutting may dislodge a sealed source from its holder. Cutting may also breach the source. Currently, the information is used for qualitative purposes because such an element of risk would be difficult to quantify. Question 32: The size of the furnaces is used to compute the concentration of radionuclides in a heat when a nuclear gauge is melted. This will give an indication of activities to expect. From the activities, the hazard posed to workers in a melt shop can be postulated. Also, these concentrations may suggest the extent to which radiation gauges will detect melted radioactive material. Furnaces of different sizes may be used to different extents. For example, a small furnace at a facility may seldom be used; although the concentration of radioactivity in the melted steel would be high, the chance of it being contaminated would be low.

B. Question 51 directs respondents away from these cost questions at mills where there have been no meltings of radioactive material. While staff could be asked to predict costs, pilot tests of the survey revealed that predictions amount to guesses that have little quantitative merit and may even be incongruent with one another. The costs should not be strongly dependent on the strength of the sealed source in nuclear gauges; for most activities found in most nuclear gauges, the same decontamination procedures will occur regardless of the source strength. Question 52: Three costs are relevant: downtime, decontamination, and disposal. The year of the incurred costs is asked to adjust the costs to present value. The question is relevant to mills where radioactive material has been melted. Questions 11, 24, 30, 37, 42, 46, and 50 suggest the impacts to mills from having to monitor scrap metal; an impact to a mill is the rate of alarms, which a mill expends resources to investigate.

9 NEED FOR SURVEY INFORMATION TO ESTIMATE RISK

The need for survey (Appendices B and C) information to estimate risk is shown in Table 12. Gray boxes indicate the risk elements where at least some information from surveys is needed. White boxes indicate the risk elements where the surveys in Appendices B and C do not cover. Sources of information for all of the risk elements are discussed in Sections 5.6, 6.5, 7.8, and 8.5.

Table 12 Elements of risk requiring information from surveys of licensees and the steel industry. LEGEND: Gray box = at least some information from the surveys in Appendices B and C. White box= surveys in Appendices B and C do not cover.

Analysis	Elements											
Licensees	$\mathcal{P}$	1	2	3	4γ	4ε	5	6				
Scrap Metal Consolidation	7	8	9	10	11	12						
Steel Mills	13	14	15	16	17	18	19	20	21	22	23	24
	25	26	27	28	29	30	31	32	33	34	35	
Public Domain	C_H	C_F										

Element Identification for Table 12

Licensees

$\mathcal{P}$: prevalence of nuclear gauges (page 48)
1: States of facilities (page 48)
2: Work force changes (page 49)
3: Gauge locations (page 49)
4: At-risk potential for a gauge to get beyond controls (page 53)
5: State of a gauge at risk (page 56)
6: Disposition of a gauge at risk (page 56)

Scrap Metal Consolidation

7: Nuclear gauges enter the recycling stream (page 66)
8: Scanning scrap metal for radiation (page 66)
9: Radiation alarm before scrap metal is processed (page 67)
10: Type of scrap metal processing (page 67)
11: Effects of scrap metal processing on a nuclear gauge (page 67)
12: Radiation alarm when scrap metal after is processed (page 68)

Steel Mills

Entrance
13: Configuration of radiation monitors at steel mills (page 93)
14: Scanning scrap metal at the entrance of steel mills (page 95)
15: Strategy to monitor loads of scrap metal (page 97)
16: Alarm on the first pass through a monitor station (page 97)

Steel Mills; entrance (continued)

17: Alarm on the second pass through a monitor station (page 97)
18: Alarm on the third pass through a monitor station (page 97)
19: Response when a vehicle causes a radiation alarm (page 97)
20: Controls on a load rejected because of an alarm (page 98)
21: Probability of BC given a source is also in the load (page 98)
22: Confirm the cause of a radiation alarm (page 98)
23: Controls on a load rejected because of reworking (page 98)

Charge Bucket
24: Scanning scrap metal at the charge bucket (page 99)
25: Probability of an alarm (page 99)
26: Response when a charge bucket monitor alarms (page 99)
27: Controls on radioactive material found (page 99)

Products and Byproducts
28: Radionuclides melted in a furnace (page 101)
29: Capability of monitoring equipment for test pieces (page 103)
30: Level or thickness monitoring; radiation gauge (page 103)
31: Scanning steel product for radiation (page 103)
32: Scanning furnace dust for radiation (page 104)
33: Scanning slag for radiation (page 104)
34: Contamination steel getting beyond mills (page 104)

Public Domain

C_H: Health consequences (page 115)
C_F: Financial consequences (page 116)

10 CONCLUSIONS

General

The licensees, scrap yards, and steel mills take actions every day without explicitly analyzing their risk. The judgment of risk is clearly an intuitive one that is based on experience and working knowledge. The complexity of the system formed by the industrial environments and the control mechanisms, which is illustrated in Figure 6, suggests that an accurate assessment of the risk from nuclear gauges in the recycling stream needs a more careful analysis than can be done intuitively. In this study, risk analysis methods were applied to examine the subject of nuclear gauges in the recycling stream:

- An accurate assessment of risk was precluded by a paucity of data for the elements of risk. Nonetheless, the analysis yielded observations and insights of interest. To quantify risk, information from surveys about licensees (see Appendix B) and the steel industry (see Appendix C) is needed.

- Any assurance that changing controls will have the desired effect must be based on detailed knowledge of the system illustrated in Figure 6.

- Evaluating the effect of modifying a control mechanism or introducing a new one using empirical data will take years because of the time necessary to collect and analyze data. Furthermore, it will be difficult to evaluate the efficacy of the changed or new control mechanisms because the observed changes may depend on many changing and poorly understood factors that may not be readily taken into account. But with data from surveys and other sources, a risk analysis can be used to evaluate changes in risks to stakeholders from a modified or new control mechanism.

Licensees

Licensees are confronted with making business decisions to devise practices that provide immediate and continuous control (ICC). Such decisions must balance the predictable cost of maintaining control over nuclear gauges against a chance of inadvertently discarding gauges. ICC practices take three forms:

- Although not typically viewed as a control, a gauge in use, controlling production, cannot be removed and discarded without drawing attention.

- When a gauge must be removed from a process unit, storage in an area that is dedicated only for gauges reduces the chances of the gauge being discarded with scrapped materials and equipment.

- An unused gauge that has been returned to a vendor is not at risk of being discarded into the recycling stream.

The above practices place a gauge in a definite location from which it is unlikely to be removed unnoticed—risk, as far as the licensees are concerned, is kept to a minimum. These practices are collectively referred to as hard controls. Whatever reliance that is not placed on hard controls is typically placed on so-called soft controls, such as labels, semi-annual inventories, education and communication, and civil penalties. Soft controls are less effective than hard controls in providing ICC because they do not always gain enough attention at the right times and they can be degraded by conditions and circumstances at facilities. Redundancy in control mechanisms increases overall effectiveness because it compensates for control mechanisms becoming compromised.

The way to evaluate any control is to evaluate its capability to operate immediately and continuously when gauges are at risk to prevent them from being inadvertently removed from their intended places. From the concept of ICC, statements can be made about common forms of control:

- The extent to which high-level accountability, civil penalties, and license revocation provide ICC is unclear. The chance of these mechanisms being called upon (the remote possibility of losing a gauge at an unknown time in the future) is overshadowed by acute concerns and hazards at an industrial facility.

- The decrease in risk from moderate increases in the frequency of inspections appears to be small. Most of the time, gauges are not at risk to improper disposal—other control mechanisms (e.g., in use on an operating process line) are functioning. Because occasional inspections are unlikely to be done when gauges are at risk of improper disposal, moderately increasing them will have little effect on risk.

- Registering gauges enhances other controls that provide ICC, such as responsibility and accountability. Registration refreshes memory about the gauges; this is especially important when facilities are closed or when employees change professions or retire. A lack of a response alerts regulators to some forms of at-risk conditions, such as closed and abandoned facilities. Followup is necessary for registration to be effective.

- Responsibility for ICC, not for the gauges, is often difficult to assign in complex industrial organizations. The responsibilities of employees may be overlapping and changing to meet market demands and the state of a facility. The use of outside contractors during system shutdowns for extensive maintenance and overhauls exacerbates the difficulties in assigning responsibility for ICC.

Another important element of risk is the extent to which gauges are at risk of entering the recycling stream. The at-risk potential is a complex function determined by the gauge environment, the applicability of control mechanisms to each environment, the prevalence of the control mechanisms, and the effectiveness of the control mechanisms. Most nuclear gauges are not at risk because they are in use controlling industrial processes. Even when a gauge is at risk, it may not enter the recycling stream. The potential for a gauge to enter the recycling stream is represented in this analysis by the probability of a gauge being discarded.

Regulatory agencies do not continuously verify that licensees implement control mechanisms. Accordingly, an implicit assumption is being made that licensees will, can, and know how to assume their responsibilities. Reference 1 suggests that the assumption is not always valid.

A difficulty for licensees in maintaining accountability is that they lack the collective experience of what does and does not provide ICC. Because current regulations are broad and non-prescriptive, licensees have considerable leeway to devise their own control programs. Many licensees might benefit from learning about effective ICC practices.

Perfect control that eliminates the risk to life and property is impractical to require by regulatory agencies (i.e., the Nuclear Regulatory Commission or Agreement States) and implement at industrial facilities. Many factors placing the gauges at risk are outside the jurisdiction of regulatory agencies or cannot be completely controlled by licensees. Many of the control mechanisms are compromised in the complex, changing, and hazardous environments of industrial facilities. This leaves a regulatory agency with the task of devising and communicating ICC practices that can be efficiently implemented.

Recycling Industries

Scrap yards and the steel industry are confronted with making business decisions to invest in a level of protection against the danger of nuclear gauges in the recycling stream, balancing the predictable cost of protection against a chance of incurring consequences. The following practices are decisions to accept an unknown level of risk:

- Using radiation monitors throughout a scrap yard or a steel mill provides a level of protection against the consequences of processing a nuclear gauge. The level of protection depends on both the number and location of the monitors.

- Turning off radiation monitors because the alarms are annoying increases risk.

- Bringing scrap metal into a mill in large amounts and in highly packed forms to reduce costs compromises the protection given by radiation monitors.

- Rejecting a load of scrap metal suspected of containing nuclear material without notifying authorities may increase the risk of another scrap yard or steel mill. The load may be taken to another facility where it might be accepted because there the radiation alarms might not activate.

- Typically vehicles entering scrap yards or steel mills with scrap metal are passed through a radiation monitor station one, two, or three times. If the primary concern is to detect sealed sources, then the decision to reject or accept a load would be based on one pass through a monitor station. If the primary concern is false alarms, then decision would be based on the second pass, given an alarm on the first pass. The three-pass strategy is a compromise between the one-pass and two-pass strategies.

- Reworking a load of scrap metal suspected of containing radioactive material reduces risk. By dumping the load and sorting through the scrap metal, all possible causes of a radiation alarm can be assessed. Scanning a load with a survey meter and attributing an alarm to benign contamination (e.g., dirt in the rib of a vehicle or pipe scale) assumes a nuclear gauge is not present in the load. Most, but not all, of the time, this assumption is correct. However, until further study is done, making the assumption is inappropriate considering the possible consequences (dislodging, breaching, or melting a sealed source) of being wrong.

Research is needed to characterize the commodities of scrap metal and to determine the detection probability for each commodity, not just to determine the detection capabilities of specific systems as has been done. With a characterization of the commodities, the capabilities of equipment could then be predicted without having to conduct a field trial each time the technology changes. Field trials may still be necessary to validate predictions, but as yet, there is sparse quantitative basis for making predictions.

The probability of detecting a nuclear gauge in a load of scrap metal is poorly characterized, yet it has implications for the public, licensees, the steel industry, and regulatory agencies. If the detection probability is low when using state-of-the-art monitoring equipment, then stringent controls at the licensee facilities would be needed to control the risk, placing heavy burdens on both the gauge users and on the regulatory agencies. If the detection probability is high, then less stringent controls would be needed. Therefore, the detection probability should be determined and thoroughly understood.

The recycling industries sometimes place too much reliance on sophisticated radiation monitors alone instead of understanding the ramifications of using this technology. The basis for choosing to pass a vehicle through a radiation monitor one, two, or three times for deciding to accept or reject a load of scrap metal is seldom known. Some methods for monitoring samples from a furnace for contamination leave much uncertainty in detecting contaminated steel in a furnace.

Scrap Yards

- Scrap yards are often located near populated areas. Portions of these populations can be placed at risk of radiation exposure when a breached source is dispersed. The extent of the dispersal is difficult to predict.

- A health hazard from nuclear gauges may occur at the scrap yards. Here, shredding, shearing, and cutting (burning) scrap metal can dislodge and breach a sealed source. Installing radiation monitors near some of these processes might be an effective way to detect a dislodged or breached sealed source. But the use of radiation monitors may also be impractical for these processes. Supports for monitors must be placed where monitoring would be effective. High vibrations, shock waves from explosions (e.g., when a propane tank is accidently processed), and stray pieces of scrap metal (e.g., from loading shredders and balers) could damage a monitor. Individuals who cut scrap metal move around the yard.

- Information about the scrap yards is difficult to obtain. For example, which scrap yards supplying the mills use radiation monitors would be considered propriety information by the scrap metal industry. Other information might require costly experiments, for example, the probability of breaching a sealed source.

Steel Mills

- When ^{137}Cs is melted, it adheres to the furnace dust. Most, but not all, of the dust is collected by the ventilation system of the melt shop. Some of the dust escapes into the melt shop. The amount of contaminated dust escaping into the melt shop is difficult to determine, depending on when the sealed source melts in relation to when the furnace is open and the capacity of the ventilation system to collect dust.

- When a ^{60}Co source is melted, the cobalt forms an alloy with the steel. The radioactive material is at least somewhat diluted in the heat. The steel provides self-shielding. The furnace provides additional shielding until it is tapped. Some ^{60}Co gets into furnace dust, some of which escapes the ventilation system.

- Little is known about what will happen when ^{241}Am is melted. The current understanding is that it will reside mostly in slag.

- Accurate cost information, in a form that is compatible with a risk analysis, is essential for assessing financial risk. Trade associations report costs from melting nuclear material that range from $2 million to $23 million (Ref. 10). But these costs are poorly characterized. Only a range of costs is given, sometimes with a vaguely defined average. The damage expected in an integrated mill has not been rigorously determined, although figures have been stated (Ref. 10).

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APPENDIX A

ICC DETERMINATIONS

The analyses of the licensees are discussed in Section 5. There, the key concept of immediate and continuous control (ICC) was developed and applied to control mechanisms of nuclear gauges. In Appendix A, the reasons are given for determining whether or not a control mechanism can provide ICC in a given environment.

Figure 20 is reproduced and annotated as Figure 47. As before, the elements of risk are at the top left of Figure 47. Beneath the element titles the possibilities of each element are delineated. The left half of Figure 47 delineates the 33 industrial environments of the gauges. The right half of Figure 47 indicates the capability of the control mechanisms to provide ICC; a white cell indicates that the control mechanism cannot provide ICC over gauges; a shaded cell indicates that the control mechanism can provide ICC. Numbers in each of these cells refer to notes following Figure 47. These notes give reasons for stating that a control mechanism can or cannot provide ICC in a given environment.

Figure 47 shows the applicability of the control mechanisms to a gauge in a given environment. It does not show the logical relationships of the control mechanisms, which are shown in Figure 23.

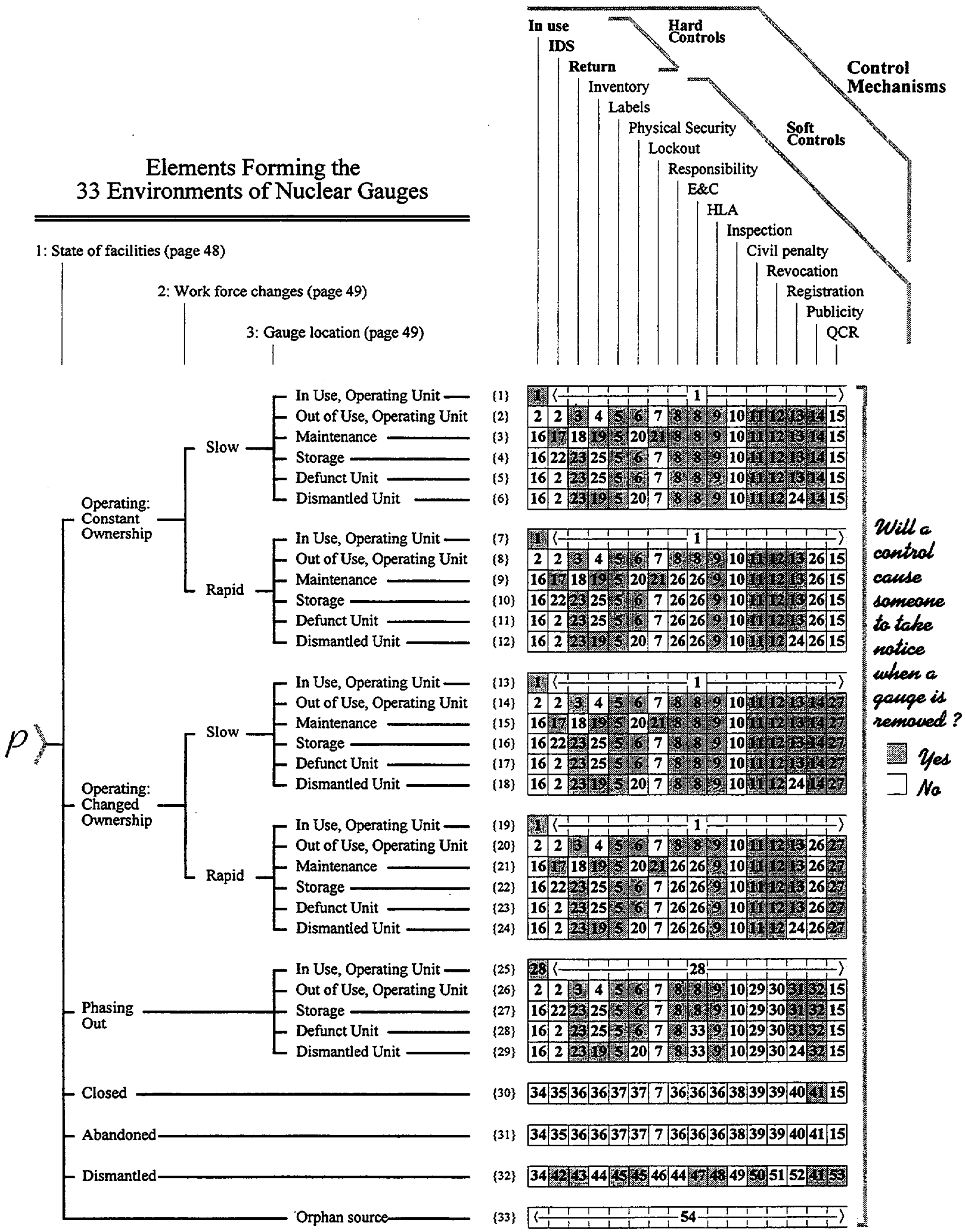


Figure 47 Reasons for stating that control mechanisms either can or cannot provide immediate and continuous control in a given industrial environment. LEGEND: A white box (□) indicates that a control cannot provide ICC in a given environment. A shaded box (▩) indicates that a control can provide ICC in a given environment. P = prevalence nuclear gauges; x = G for generally licensed gauges; x = S for specifically licensed gauges; x = T for both types of gauges. E&C = education and communication. HLA = high-level accountability. QCR = query at a change in responsibility.

Notes on Figure 47

1. Unlike the other environments, Environments 1, 7, 13, 19, and 25 are a control mechanism — in use. Nuclear gauges are controlling production. The gauges are not at risk of being discarded because they are in use. Some process units can operate without the gauges providing control signals, but when the process unit must be controlled manually there is still an awareness of the gauges or the lack thereof. When a gauge is in these environments, it is automatically under a hard control mechanism. Therefore, the soft controls are not an issue. The same cannot be said about the other environments. Interim dedicated storage (IDS) and return to vendor are applicable only when a gauge is not being used.

2. IDS is applicable for gauges that are normally in use, but must be removed while a process unit is serviced. A gauge cannot be in use and out of use.

3. A gauge that is not being used to control a process can be returned to its vendor.

4. The process unit is operating; employees are unlikely to remove a component from an operating unit. Inventory would have to be done after any servicing to provide ICC. Here, servicing is minor. An inventory is impractical for minor servicing because such servicing may be frequent and the servicing is localized.

5. Although a label is just a reminder, it is one of the few ways to identify a nuclear gauge. Shape and color are other ways, albeit much less conspicuous than a radiation trefoil. Labels can be effective in many environments. For example, during maintenance workers are focused on their tasks, not on gauges. While some storage areas are dedicated to nuclear gauges, storage areas are seldom dedicated and may be cluttered with other materials. When a process unit has been unused for a long time, labels remind people who have forgotten about the gauges and provide awareness as the work force changes.

6. Physical security, such as a chain, cage, or padlock, gives a warning that something should not be removed.

7. Lockout is applicable to a process unit that is being taken out of service for maintenance.

8. Someone close to the process units is knowledgeable of the gauges and can be held accountable for the day-to-day activities of the gauges. The person knows of the gauges wherever they are — in use, in storage, on defunct units, or on units that are about to be dismantled. A person has to be educated in ICC. Communications is necessary because a responsible person cannot know from one moment to the next which gauges are being placed at risk.

9. Holding upper management of a facility accountable prompts management to support the people who are close to the process units and responsible for the gauges. The process units may be operating, in service, defunct, or in the process of being dismantled. Management are still at a facility that is being phased out over a period that may be years.

10. Inspections are infrequent and brief. An inspection may coincide with persisting environments where gauges are at risk, but many of these environments may not be matters of compliance. Although these conditions may persist for extended periods, the moment when the gauges are being discarded may be brief. Maintenance and renovation activities are unlikely to coincide with inspections.

11. A civil penalty can be levied against a facility that is operating.

Notes on Figure 47

12. The gauges are often vital to the processing. If the gauges cannot be used responsibly, revoking a license is tantamount to closing down a profitable facility for a legitimate reason—to protect public health. Even when a facility is changing ownership, it is viable. The possibility of having the license revoked is a clear message to the management of the facility, who are accountable to their customers and stockholders.

13. Registration provides awareness, at least to some people, of gauges in a facility, regardless of where they are located. The awareness has the capability of providing at least some ICC. Through education and communication (E&C), registration provides awareness to contractors during maintenance or to hourly employees who might be removing scrap materials or cleaning out storage areas.

14. An image-conscious company draws stockholders to invest, skilled people for employment, and customers who can rely on a facility to supply products on demand.

15. Query at a change in responsibility is applicable when ownership is changing, not when ownership is constant. A closed facility may still be owned by a corporation. When a facility is abandoned, ownership is not being transferred.

16. Gauges that are in use on a process unit cannot be on a process unit that is undergoing maintenance or storage, on a defunct unit, or on a unit that is being dismantled.

17. In IDS, a gauge is in a known, definite, and well-marked location while it is not in use. The gauge is not subject to being forgotten, lost among clutter on a shop floor while maintenance is done, lost among clutter in general storage, or simply left on the side of a process unit or shop floor; in these situations, a gauge is at risk of being mistakenly discarded with other materials.

18. Process units are shut down for brief periods—too brief to have a gauge returned to its vendor.

19. An inventory done after maintenance or before materials leave a facility is ICC.

20. Chains, bolts, and welds are easily severed with a cutting torch. People servicing a process unit are busy, possibly overlooking physical security as a warning of something that should not be removed.

21. Lockout is a form of inventory that is done both before and, more importantly for ICC, after maintenance.

22. IDS is storage on an interim basis only, while a process unit is out of service for maintenance.

23. Returning a gauge that is in storage (other than IDS), on defunct units, or on units being dismantled removes the gauge from being at risk.

24. Annual registration operates through E&C to provide ICC. But dismantling is often done by a contractor, leaving a high potential for E&C to fail. A contractor representative may be informed of a gauge, but the employees dismantling a unit may not be informed or may not appreciate the information.

25. Storage in a room or on a defunct unit is continuous. Discarding a gauge occurs rapidly. Inventory is periodic and brief. Between inventories, a gauge may be discarded. Unless the inventory is frequent, ICC will not be provided.

Notes on Figure 47

26. During a rapid turnover of the work force, three control mechanisms are compromised in four environments in which employees are needed for control: ◇ A responsible person may not always be at the facility. ◇ E&C are compromised because few people stay long enough to maintain the memory of the gauges. ◇ Publicity is not a concern for employees who have little interest in the facility; publicity works when someone is at a facility to be held accountable to customers and stockholders.

27. When a facility changes ownership, regulatory agencies are contacted by the new owner before the title transfer is complete. Awareness is heightened so that gauges are not discarded when process units are renovated or dismantled.

28. A facility that is being phased out is still operating. The same points as in Note 1 are relevant here.

29. A civil penalty is essentially of no use at a facility that is being phased out. A large civil penalty pushes a facility closer to its inevitable ending. When a company is liquidated, a regulatory agency is treated as an unsecured creditor; secured creditors will be paid before the regulatory agency.

30. Revoking a license on a facility that is being phased out is meaningless. Revocation will only do what is inevitable. Yet gauges in storage, on defunct units, or on units being dismantled are at risk.

31. A facility that is being phased out is functioning. Registration provides awareness of the gauges.

32. Publicity is relevant to a facility being phased out if the facility is owned by an image-conscious corporation.

33. In a facility that is being phased out, attention will be on future employment and financial security, not on a facility that has no future. Little concern will be given for E&C.

34. The facility is no longer operating. The gauges are no longer in use for ICC.

35. IDS might serve as a warning because it is distinct. A gauge may have been in IDS at the time the facility closed. But closed and abandoned facilities are subject to being pillaged, which is not always done with discretion.

36. No one is in a closed facility. Controls (e.g., return, inventory, responsibility, E&C, and high-level accountability) requiring employees to perform ICC are irrelevant.

37. Labeling and physical security are relevant only when employees are in a facility. People in a closed or abandoned facility are likely to be thieve, looking for tools and scrap metal. Signs and physical security are not necessarily within their attention or concern. Labels are likely to be overlooked. Physical security is of little use against cutting torches.

38. Inspections are infrequent. A facility may be closed or abandoned for years before regulators are aware of it and can ensure that the gauges have been properly disposed. In the meantime, such facilities can be pillaged.

39. A civil penalty and revocation are irrelevant to facilities that are closed or abandoned.

40. In a closed or abandoned facility, no one is present to provide ICC by the increased awareness from registration. A regulator may eventually be alerted to something wrong when registration is not completed. But registration is too infrequent for ICC.

Notes on Figure 47

41. Publicity is relevant whenever a facility is owned by a corporation trying to stay in business. An abandoned facility has no owner. A closed facility is still owned and can be reopened. A dismantled facility may be owned, such as by a corporation.

42. IDS may be conspicuous enough to draw attention to a hazard when a facility is being dismantled. At least some demolition contractors evaluate environmental hazards before dismantling a facility.

43. A responsible demolition company may return a gauge. Any cost to the company would be a disincentive. But the control is still applicable.

44. The responsible person may not be present at a facility that is being dismantled to take an inventory. The demolition contractor is not responsible because title to the facility is not transferred or assumed.

45. Labels and physical security may serve as a warning when a facility is being dismantled by a responsible company.

46. Lockout is an activity done during maintenance.

47. E&C are relevant to demolition and salvage companies. The difficulty is in reaching *all* of the demolition companies and employees within those companies who dismantle the facilities.

48. Management at the corporate level may be held accountable for ensuring that a facility has been properly closed before being dismantled.

49. Inspections are too infrequent to occur with assurance when a facility is dismantled.

50. A civil penalty may be relevant when a facility is owned by a corporation.

51. Revoking a license is irrelevant because the facility is not operating.

52. Dismantling is done by a contractor, not an owner. The organization receiving the registration is not the organization causing a gauge to be discarded.

53. Regulations have an *assumption* that the gauges will be properly disposed. But no mechanisms exist to ensure that the gauges are properly disposed. An inquiry with a regulatory agency, asking what gauges are known to be in a facility, would alert demolition employees to look for the gauges.

54. Orphaned gauges are beyond regulatory control mechanisms and cannot be traced to their owner.

APPENDIX B

SURVEY OF LICENSEES

Letter to Industrial Facilities with Nuclear Gauges:

Nuclear gauges (typically devices for measuring thickness, density, level, or consistency of materials along process units) have been *inadvertently* discarded from facilities of many industries into the scrap metal recycling stream. Facilities can incur high costs to retrieve gauges known to have been lost or compensate other facilities that have been damaged when a lost gauge was processed with scrap metal. For regulatory controls to be effective, they have to address conditions as they are in industry, acknowledging the demands on employees, organizations, and facilities, which can be complex and changing.

The NRC is doing a comprehensive risk analysis of the use and storage of nuclear gauges. The gauges of interest are found on such places as pipes, tanks, vessels, channels, and along conveyor belts, and they use cesium, cobalt, or americium for radioactive material.

NRC records indicate that your facility has nuclear gauges. Please answer the attached questions about the nuclear gauges themselves and a few questions asking for very general information about your facility. The answers to your questions will be compiled with other replies for use in the analysis to estimate risk.

Your answers are important so that the analysis can account for the characteristics of a facility such as the one in which you work. The responses to the questions are voluntary and anonymous.

I recommend that the person who should complete the survey should be a radiation safety officer or someone else who has responsibility for the gauges, such as a plant engineer or plant manager.

These questions can be completed without looking through records. Please answer the questions based on your knowledge.

Please mail your answers in the enclosed prepaid envelope.

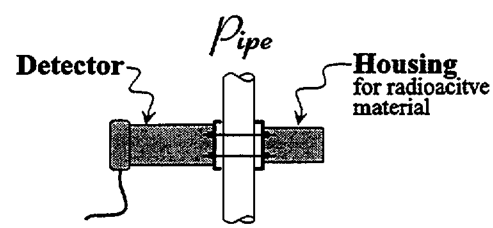
Your time and effort are very much appreciated.

Thank you.

Important Points

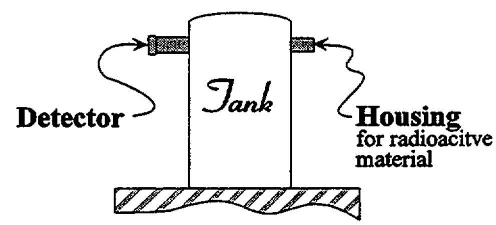
☞ **For this survey, a <u>facility</u> is a building or group of related buildings, under one plant manager. Please use a survey form for <u>each</u> facility.**

☞ **Complete this survey for nuclear gauges that ...**



- ✓ **are fixed onto pipes, tanks, vessels, channels, or on conveyor belts.**
- ✓ **contain cesium, cobalt, or americium**
- ✓ **measure the density, level, or consistency of materials or the thickness of metal foils and slabs.**

In general, a fixed nuclear gauge looks like this ... ➾ On a tank, the detector may also look like an unattached pipe.



☞ **Do not complete this survey...**

- ✗ **for nuclear equipment in a laboratory**
- ✗ **portable nuclear gauges**
- ✗ **gauges measuring the thickness of paper or non-metallic films**

☞ **If your facility never had or <u>no longer</u> has fixed nuclear gauges or has for some reason returned the housing containing the radioactive material, then discard this survey.**

(1) Typically, how many gauges are at the following locations?

_____ **gauges in use** on operating process units
_____ **gauges not in use**, but still on operating process units
_____ gauges on **unused process units**
_____ gauges in a storage **area (room)** that is used **only** for the gauges
_____ gauges in a storage **area (room)** that is also used to store other materials and equipment
NOTE: This is permitted by regulations.

(2) If no attention was given to a nuclear gauge, about how much time would you expect the radiation caution label on the gauge to remain visible?

☐ About ______________ days, weeks, months, indefinitely.
NOTE: You may specify a range. *Circle one*

☐ Don't know

(3) Who checks for the presence of the gauges, either as required by regulations or by your own practices? How often is the check done?

By process unit operators ... typically, about every _____ months, years.
Check ☐ if not applicable. *Circle one.*

By plant engineers or the person(s) responsible for the gauges ... typically, about every _____ months, years.
Check ☐ if not applicable. *Circle one.*

By staff from headquarters ... typically, about every _____ months, years.
Check ☐ if not applicable. *Circle one.*

(4) When else is the presence of the gauges checked?

Check all that apply.

☐ After a machine shutdown for maintenance
☐ After a machine shutdown for changing the product
☐ Before a process unit is relocated
☐ Before a process unit is dismantled for scrap or salvage
☐ Other ______________________________
Specify

(5) When are the following groups of people made aware of the gauges?
NOTE: Check all that apply.

People working on or around process units

- ☐ Never
- ☐ Soon after coming on site
- ☐ Once a year
- ☐ Other ______________ *Please specify.*
- ☐ Not sure

Plant Management

- ☐ Never
- ☐ Soon after coming on site
- ☐ Once a year
- ☐ Other ______________ *Please specify.*
- ☐ Not sure

Outside contractors working in buildings (shops) where gauges are located

- ☐ Never
- ☐ Before coming into the facility
- ☐ Other ______________ *Please specify.*
- ☐ Not sure

(6) What is done to maintain control of gauges in storage?

Short term

☐ Gauges are **not** kept in a storage area for a short time

- ☐ Open area off to side
- ☐ Fenced off area
- ☐ Storage box
- ☐ Room
- ☐ Cabinet

Check all that apply.

with

- ☐ verbal warnings
- ☐ signs
- ☐ ropes or tape
- ☐ locks

Check all that apply.

to remind people

Long term

☐ Gauges are **not** kept in a storage area for a long time

- ☐ Open area off to side
- ☐ Fenced off area
- ☐ Storage box
- ☐ Room
- ☐ Cabinet

Check all that apply.

with

- ☐ verbal warnings
- ☐ signs
- ☐ ropes or tape
- ☐ locks

Check all that apply.

to remind people

(7) Are there cages, chains, or locks on **gauges** themselves (not the shutter on the gauge) that are in use on process units?

- ☐ All of the gauges
- ☐ Some of the gauges
- ☐ None of the gauges

(8) Is the radiation safety officer or plant engineer responsible for the gauges kept informed of maintenance, renovation, and dismantling activities on process units ...

with nuclear gauges? ☐ No ☐ Yes

any process unit? ☐ No ☐ Yes

(9) Has the facility changed ownership in the last year?

☐ Never changed ownership.
☐ Yes

As far as you know or can remember, how many times has your facility changed ownership.

______ times in the past ______ years.

(10) Typically, for how much time is a process unit shut down for maintenance, calibration, or product change?

About ________ ☐hours ☐days ☐weeks ☐months in a typical ☐ day ☐ week ☐ month ☐ year

(11) In regards to the work force at the **facility** with nuclear gauges (not a site with many facilities) ...

- Approximately, how many people work in the facility? _______

- Where in the organization at the facility is the **radiation safety officer**?
  - ☐ Not applicable
  - ☐ First line supervisor
  - ☐ Middle management
  - ☐ Plant manager
  - ☐ Other ________________ *Specify.*

- Where in the company are **other people** with any responsibility for the care and control of the gauges?
  - ☐ Operators
  - ☐ First line supervisor
  - ☐ Middle management
  - ☐ Plant manager
  - ☐ Headquarters staff
  - ☐ Other ________________ *Specify.*

Check all that apply.

(12) Typically, ...

- how long has a process unit been dormant (mothballed, no plans to restart)?

  ☐ No process units have been dormant (mothballed)
  ☐ Weeks
  ☐ Months
  ☐ Years

- how much time is taken to dismantle a process unit for scrap or salvage?

  ☐ Less than a day
  ☐ Days
  ☐ Weeks
  ☐ Months
  ☐ Years
  ☐ Done as people are available

Thank you.

APPENDIX C

SURVEY OF THE STEEL INDUSTRY

Letter to Steel Mills:

Radioactive material is being found in and melted with scrap metal used by steel mills. Even the best radiation monitors can miss radioactive material deep within a load of scrap metal. Since 1983, steel mills have melted radioactive material 26 times; the cost of decontaminating the mill, disposing of contaminated products and byproducts, and lost revenue has ranged from $2 million to $23 million. A risk analysis is a technique to systematically understand and characterize all of the reasonable and possible routes from the industries that use the gauges to the steel mills. NRC is collecting necessary information for inputs to an analysis with the attached questions so that the steel industry can be accurately taken into account.

To answer the questions, please talk to the people at the mill who know about the radiation monitors and purchasing of scrap metal. **These questions can be completed without looking through records. Please answer the questions based on your knowledge.**

The responses from all mills are anonymous. I will compile the answers and make them available to the trade association.

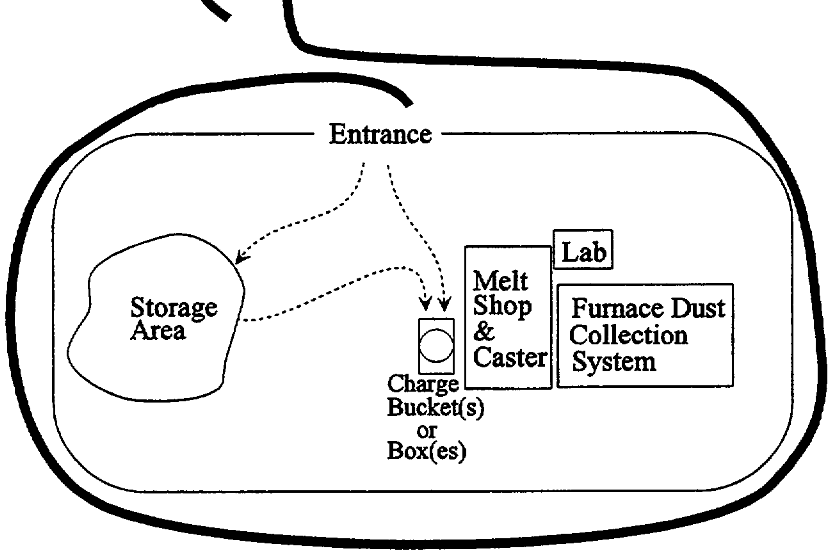
Please mail your answers in the enclosed prepaid envelope.

Your time and effort are very much appreciated.

Thank you.

DIRECTIONS

- **Do not look through records or measure anything, but answer the questions carefully.**
- **Talk to the people who know about the radiation monitors and purchasing of scrap metal.**
- **If you need additional space, then write in the margins or on the back of a page.**
- **Please write legibly.**
- **Questions refer to this as your site.**



A. DESCRIPTION OF THE STEEL MILL

(1) Which best describes your site as it is **currently operated**? (*Check one.*)

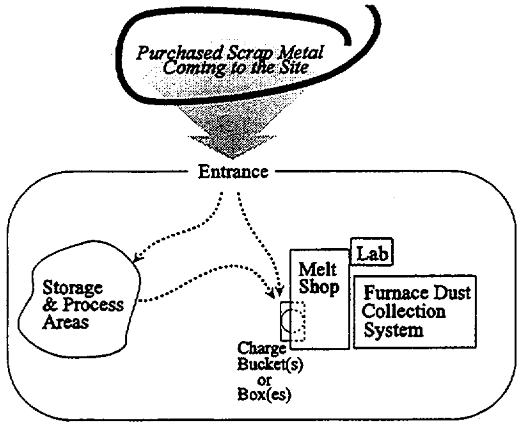
☐ Integrated mill
☐ Mini-mill
☐ Other ______________________________
(*Specify*)

(2) At your site, are radiation gauges (x-ray, radioactive material) used to directly measure the level or thickness of steel after it is taken from the furnace?

☐ Yes - Approximately, what is the total annual licensing fee? $____________
☐ No

(3) Typically, what percentage of your production is stainless, carbon, and alloy steel?

Type of Steel	**Percentage of Production**
Stainless	%
Carbon	%
Alloy	%



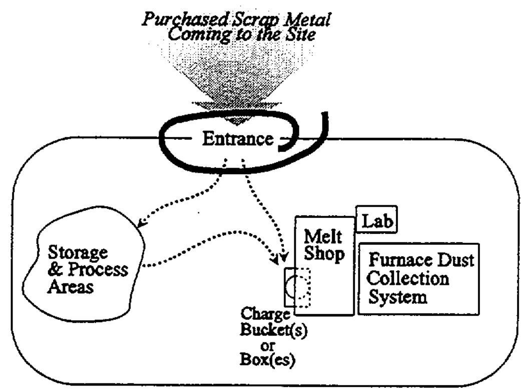
B. PURCHASED SCRAP METAL

(4) Estimate the amount of each commodity (grade) of purchased scrap metal used by your site in a typical amount of time.

Commodities (grade) of Purchased Scrap Metal	Typical Amount		Time Period (*Check one.*)
Bundles	______	Tons per	☐ month ☐ quarter ☐ year ☐ Other ________
Sheared scrap	______		
Plate and structural (P&S)	______		
Shredded scrap (frag)	______		
Heavy Melt	______		

(5) What kinds of processing are done to purchased scrap metal **at your site**? (*Check all that apply.*)

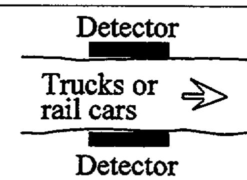
☐ Sorting
☐ Cutting
☐ Shearing
☐ Other ________________
Specify



C. OUTSIDE ONTO THE SITE

(6) At your site, is purchased scrap metal coming from the outside onto the site scanned for radiation?

☐ No - **Go To Page 146, Part E.**
☐ Yes



Example of 1 monitor station with 2 detector panels.

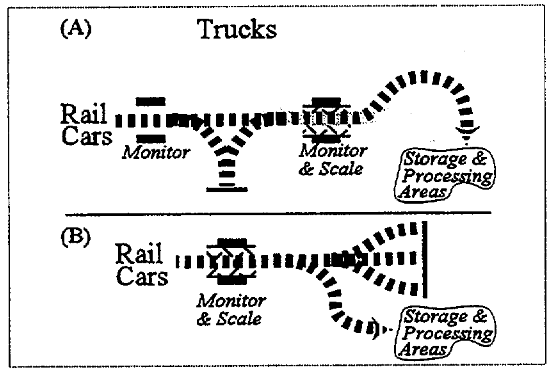
(7) How many monitor stations are there for scanning this scrap metal coming from the outside onto your site? ______

	Station No. 1	**Station No. 2**	**Station No. 3**
(8) How are the detectors mounted in relation to the trucks or railcars at each station?	☐ One side ☐ Both sides ☐ Top ☐ Bottom	☐ One side ☐ Both sides ☐ Top ☐ Bottom	☐ One side ☐ Both sides ☐ Top ☐ Bottom
(9) What percentage of **all** the purchased scrap metal **entering the site** passes through **each** of these stations?	______ %	______ %	______ %
(10) Are the vehicles (trucks or railcars) moving or stationary when being scanned?	☐ Moving ☐ Stationary	☐ Moving ☐ Stationary	☐ Moving ☐ Stationary
(11) About how often do radiation alarms occur at each station when purchased scrap metal material is being scanned?	___ per ______ *time*	___ per ______ *time*	___ per ______ *time*

C. Outside onto the Site (continued)

(12) **Along the way into** your site, do trucks or railcars pass through more than one radiation monitor or the same radiation monitor **without unloading**?
See figure for examples. ➫

☐ No **- Go To Question 13.**
☐ Yes , explain below.



Examples of railcars scanned several times without unloading: (A) Passing one monitor for railcars and another for both for railcars and trucks. (B) Passing through one station to be stored on spur tracks, then weighed, then brought into the site.

(13) After a vehicle passes through a monitor station and causes a radiation alarm, is the vehicle passed through the station again to confirm the alarm?

☐ No
☐ Yes, explain below.

(14) About what percentage of the time do you accept scrap metal, even though a radiation alarm continues to occur, because you attribute the alarm to benign sources of radiation in or around the scape metal, such as pipe scale, thorium in a weld, dirt or sand in a rib of the vehicle?

_____%: accept

(15) What percentage of the purchased scrap metal goes **directly** to the storage/processing area and the melt shop after passing through the radiation monitors?

___ % Storage/processing area
___ % Melt shop
100 % TOTAL

D. ACTIONS TAKEN BEFORE TAKING POSSESSION OF PURCHASED SCRAP METAL

(16) When a truck or railcar from the outside onto the site causes a radiation alarm and is **suspected** of containing radioactive material, how likely would the following events occur?

____% **Turn away** the truck or railcar based only on the radiation alarm(s)
____% **Poke** into the scrap metal to determine the cause of the alarm with a survey meter
____% **Unload** the scrap metal to investigate determine the cause of the alarm
100 % TOTAL

NOTE: Answer Question 17 if vehicles are TURNED AWAY without poking into or unloading scrap metal.

(17) How likely is it that the following events would happen after a radiation alarm occurs when a scrap metal is rejected?

____% Only authorities (regulators, police) are notified
____% Only the scrap metal supplier is notified
____% **Both** authorities (regulators, police) and supplier are notified
____% No one is notified
100 % TOTAL

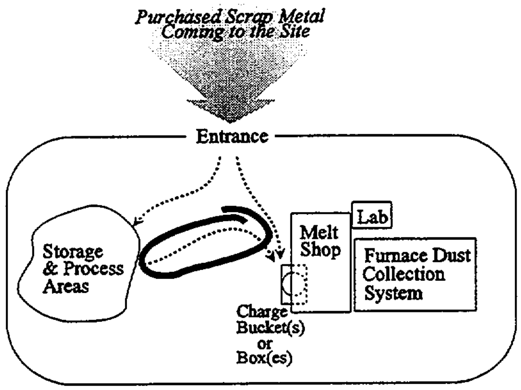
NOTE: Answer Questions 18 and 19 only if vehicles are POKED INTO or UNLOADED to investigate the cause of a radiation alarm.

(18) How likely is it that the following events would happen after poking into or reworking (dumping) a load taken from the **outside** to the **storage area** is suspected of containing radioactive material?

____% Only authorities (regulators, police) are notified
____% Only the scrap metal supplier is notified
____% **Both** authorities (regulators, police) and supplier are notified
____% No one is notified
100 % TOTAL

(19) How likely is it that you would accept scrap metal when a radiation alarm **continues** to occur because you have found what you believe is causing the alarm, such as dirt or pipe scale?

__________ %



E. BETWEEN THE STORAGE /PROCESS AREAS AND MELT SHOP

(20) How is scrap metal brought to the area near the melt shop?

☐ Scale (transfer) cars - **Go To Page 147, Part F.**
☐ Trucks or railcars

(21) **Along the way** from the storage/process areas and to the melt shop, is purchased scrap metal scanned for radiation?

☐ No - **Go To Page 147, Part F .**
☐ Yes - Explain below.

____
____
____

(22) What percentage of purchased scrap metal from the storage/process areas to the area next to the furnace would you guess is scanned for radiation? _______ %

(23) After a vehicle passes through a monitor station and causes a radiation alarm, is the vehicle passed through the station again to confirm the alarm?

☐ No - **Go to Question 24.**
☐ Yes - Explain below.

____
____
____

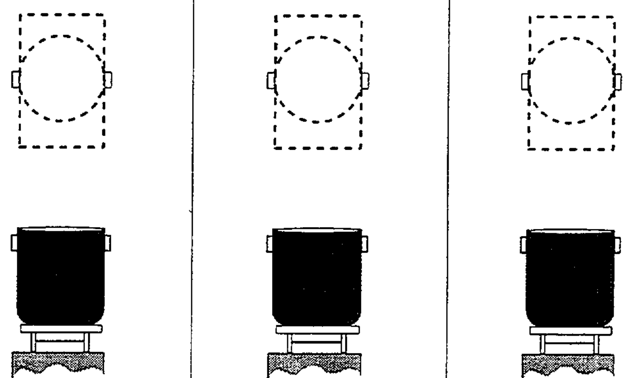
(24) How often do radiation alarms occur when purchased scrap metal is scanned when going from the storage/process area to the melt shop?

____ per ____________
(time period)

F. CHARGE BUCKET OR CHARGE BOX FOR ANY TYPE OF FURNACE

(25) Is the charge bucket or charge box scanned for radiation?

- ☐ Never - **Go To Page 148, Part G.**
- ☐ Sometimes
- ☐ Always

	1st Charge Bucket/Box	2nd Charge Bucket/Box	3rd Charge Bucket/Box
(26) On these sketches of charge buckets/ boxes, mark the location of the detectors around each charge bucket/box on the figures. Also, indicate the distance in **feet** from the bucket or box by marking the same diagram. **Top View** / **Side View**			
(27) Is a bucket or a box used to fill your furnace(s)?	☐ Charge bucket ☐ Charge box	☐ Charge bucket ☐ Charge box	☐ Charge bucket ☐ Charge box
(28) Approximately, what are the linear dimensions of the charge bucket or box?	________ feet *Linear dimensions*	________ feet *Linear dimensions*	________ feet *Linear dimensions*
(29) How is each charge bucket/box monitored? (*Check all that apply.*)	☐ While the bucket/ box is **being filled**? ☐ After loaded, while the bucket/box is **stationary**? ☐ After loaded, while the bucket/box is **moving**?	☐ While the bucket/box is **being filled**? ☐ After loaded, while the bucket/box is **stationary**? ☐ After loaded, while the bucket/box is **moving**?	☐ While the bucket/box is **being filled**? ☐ After loaded, while the bucket/box is **stationary**? ☐ After loaded, while the bucket/box is **moving**?
(30) How often do radiation alarms occur?			
(31) About what percentage of scrap metal passing through each charge bucket/box is scanned for radiation? Please account for times when a monitor is inoperative.	_____ %	_____ %	_____ %

Sum to 100%

G. FURNACE

(32) How large are the furnaces for melting scrap metal, how many of each size are at the site, how large are the charges of scrap metal, and what percentage of the production is made in each?

	Furnace # 1	Furnace # 2	Furnace # 3	Furnace # 4	Furnace # 5
Type of furnace	☐ EAF ☐ BOF	☐ EAF ☐ BOF	☐ EAF ☐ BOF	☐ EAF ☐ BOF	☐ EAF ☐ BOF
Rated capacity of each furnace (Tons)					
Size of charges (Tons) 1st, 2nd, 3rd, 4th, 5th					
Percent of total production made in each furnace	_____ %	_____ %	_____ %	_____ %	_____ %

Sum to 100%

H. ACTIONS TAKEN ONCE SCRAP METAL IS UNLOADED

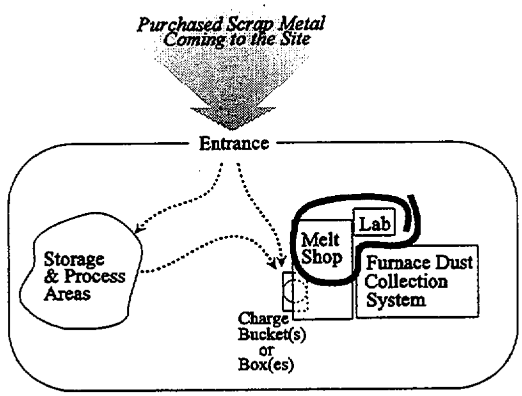
(33) When a radioactive source is found in unloaded scrap metal, how likely is it that the following events would occur in the long term to the radioactive source and to notify someone?.

Radioactive Source

- ____% Disposed of by the mill employees, consultant, or regulator
- ____% Kept in an unused area to deal with at an unknown time in the future
- ____% Other
- 100 % TOTAL

Notify Someone

- ____% Only authorities (regulators, police) are notified
- ____% Only the scrap metal supplier is notified
- ____% **Both** authorities (regulators, police) and supplier are notified
- ____% No one is notified
- 100 % TOTAL



I. SAMPLES (TEST PIECES) TAKEN FROM HEATS

(34) Are the samples taken from the heats to determine the composition also scanned for radiation?

- ☐ Never - **Go below to Page 151, Part J.**
- ☐ Sometimes
- ☐ Always

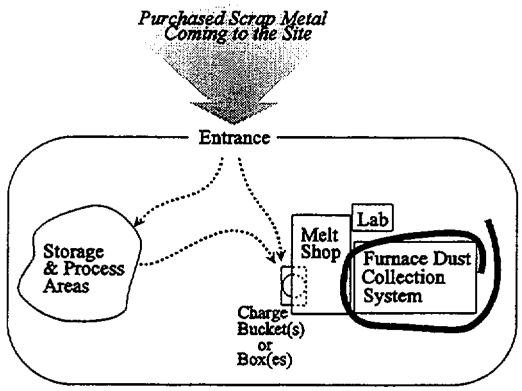
(35) Where is the radiation detector? *(Check all that apply.)*

- ☐ At the quench bucket
- ☐ In the chem lab, as part of the chemical analysis unit
- ☐ In the chem lab, separate from the chemical analysis unit.
- ☐ Other ______________________ *(Specify)*

(36) About what percentage of **heats** would you guess are scanned for radiation? _______ %

(37) How often have the radiation alarms occurred when samples (test pieces) are scanned?

____ per ____________ *(time period)*



J. FURNACE DUST

(38) **Currently**, what is done with furnace dust? (*Check all that apply.*)

EAF	BOP
☐ Bury at a disposal site	☐ Bury at a disposal site
☐ Send to a hazardous waste recycler **off site**	☐ Send to a hazardous waste recycler
☐ Process on site	☐ Sintering
☐ Other ______________ *Specify*	☐ Other ______________ Specify

(39) Is the furnace dust scanned for radiation before leaving the site?

- ☐ Never, **Go To Page 152, Part K.**
- ☐ Sometimes
- ☐ Always

(40) What best describes the radiation monitor used to scan the furnace dust for radiation? (*Check all that apply.*)

- ☐ Same monitor system used for scanning scrap metal coming into the site.
- ☐ Separate monitor dedicated for scanning the product
- ☐ Hand-held survey meter
- ☐ Along the dust collection ductwork going to the baghouse or pollution control system
- ☐ Inside of the baghouse or pollution control system
- ☐ While exiting the baghouse or pollution control system
- ☐ Other ____ *Specify*

(41) What percentage of furnace dust would you guess is scanned for radiation? _______ %

(42) How often do radiation monitors alarm when furnace dust is scanned? ____ per __________ *(time period)*

K. SLAG

(43) Is slag scanned for radiation **before** leaving the **site**?

☐ Never - **Go below to Part L.**
☐ Sometimes
☐ Always

(44) What best describes the radiation monitor used to scan the slag for radiation?

☐ Same monitor system used for scanning scrap metal coming into the site.
☐ Separate monitor dedicated for scanning the product
☐ Hand-held survey meter
☐ Other ______________________________
(*Specify*)

(45) What percentage of slag would you guess **is** scanned for radiation? ________ %

(46) How often do radiation alarms occur when slag is scanned? ____ per __________
(*time period*)

L. STEEL (BARS, SLABS, COILS, PLATES, FINISHED) PRODUCT

(47) Is the steel produced at this site scanned for radiation before leaving the site?

☐ Never - **Go to Page 153, Part M.**
☐ Sometimes
☐ Always

(48) What best describes the radiation monitor used to scan the steel product for radiation?

☐ Same monitor system used for scanning scrap metal coming into the site..
☐ Separate monitor dedicated for scanning the product.
☐ Hand-held survey meter.
☐ Other ______________________________
(*Specify*)

(49) What percentage of steel product would you guess **is** scanned for radiation? ________ %

(50) How often do radiation alarms occur when steel produced at the site is scanned?

____ per __________
(*time period*)

M. COSTS

(51) Was a radioactive source melted at your site?

☐ No - **Go To Question 53.**
☐ Yes

(52) At your site, what year was a radiative source melted and what were the down-time, decontamination, and disposal costs?

	1st Occurrence	**2nd Occurrence**
Year that the radioactive material was melted	19 ____	19 ____
Down time costs	$ ________	$ ________
Decontamination costs	$ ________	$ ________
Disposal of contaminated products and byproducts.	$ ________	$ ________

(53) **Optional.** About how much staff-time did people at your site spend gathering information and completing the survey?

__________ hours, __________ minutes

Thank you.

INDEX

NRC FORM 335 (2-89) NRCM 1102, 3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER (Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, if any.)

NUREG-1669

2. TITLE AND SUBTITLE

A Risk Analysis of Fixed Nuclear Gauges

3. DATE REPORT PUBLISHED

MONTH	YEAR
April	2000

4. FIN OR GRANT NUMBER

5. AUTHOR(S)

6. TYPE OF REPORT

Technical

7. PERIOD COVERED *(Inclusive Dates)*

1995-1998

8. PERFORMING ORGANIZATION - NAME AND ADDRESS *(If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)*

Division of Risk Analysis and Applications
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

9. SPONSORING ORGANIZATION - NAME AND ADDRESS *(If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)*

Same as above.

10. SUPPLEMENTARY NOTES

11. ABSTRACT *(200 words or less)*

Fixed nuclear gauges containing the radionuclides ^{137}Cs, ^{60}Co, or ^{241}Am are used in many industries to improve the quality and lower the costs of products for industrial, commercial, and private uses. But gauges that are improperly controlled during use and transfer can expose people to radiation and, upon entering the stream of recycled steel, can cause steel mills to spend millions of dollars to decontaminate equipment and dispose of contaminated materials. The risk to licensees and the recycling industries that nuclear gauges pose is incompletely understood. An analysis of fixed nuclear gauges was performed to study the risk to life and property, from facilities where the gauges are used to steel mills where the gauges might be melted. A risk analysis should be of interest to all stakeholders— agencies that promulgate regulations, licensees who must comply with the regulations, and the recycling industries who use scrap steel as a resource for making products. Although risk could not be estimated because data are lacking, observations and insights were made that can be used by all stakeholders to reduce their risk, even if the extent of the reduction is unknown.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

immediate and continuous control
nuclear gauge
risk analysis
scrap yard
steel mill

13. AVAILABILITY STATEMENT

unlimited

14. SECURITY CLASSIFICATION

(This Page)
unclassified

(This Report)
unclassified

15. NUMBER OF PAGES

16. PRICE

Printed on recycled paper

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NUCLEAR REGULATORY COMMISSION
WASHINGTON, DC 20555-0001

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