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Project Summary

Guidelines for Monitoring Indoor Air Quality

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This document provides guidelines for designing programs to measure indoor air quality. Brief summaries of past and current research and descriptions of indoor contaminants provide a background for developing the monitoring design. Factors that influence indoor air quality are discussed with the aid of mass balance models. An extensive review of measurement systems, including a listing of numerous instruments with their performance specifications, is presented.

Design considerations are discussed for two types of studies—applied research in indoor air quality and investigations of building-associated problems. A systematic approach for developing the design is also described. In addition, the document presents a format for data reporting and suggestions on quality assurance and quality control.

This Project Summary was developed by EPA's Office of Monitoring Systems and Quality Assurance, Washington, DC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The problem of indoor air pollution is receiving increased attention as buildings are constructed more tightly to conserve energy and as new methods are developed to detect a wider variety of pollutants at lower concentrations. The U.S. Environmental Protection Agency (EPA) is concerned with indoor air pollution because it contributes to human exposure to pollutants.

Measuring indoor pollutants sometimes requires different techniques than measuring outdoor pollutants. For example, high-volume pumps cannot be used because they could affect the flow pattern in an enclosed space. In fact, many of the bulky or noisy instruments currently used in outdoor measurements must be redesigned or totally replaced to be adequate for indoor use. Other requirements, such as measuring air exchange rates, are unique to the indoor environment, and have no counterpart in outdoor monitoring.

The present project was conceived to develop guidelines for the design and operation of indoor monitoring programs. An attempt was made to collect in one volume self-contained descriptions of the major measurement methods, equipment, design considerations, and data requirements needed by anyone contemplating an indoor monitoring program. The results should be useful for air pollution engineers; building engineers; building energy conservation experts; heating, ventilation, and air conditioning (HVAC) engineers; and students of environmental or building-related fields.

Organization of Report

Section 1—Introduction

Section 2—Indoor Air Quality Research

An historical perspective will familiarize the reader with research conducted in the field of indoor air quality. Ongoing research projects are also listed (Table 1).

Section 3—Pollutants and Other Factors Affecting Indoor Air Quality

Thirteen pollutants or pollutant groups and their indoor sources are summarized (Table 2). A generalized mass balance

Table 1. *A Partial Summary of Ongoing Research Related to Indoor Air Quality*

Area/brief title	*Pollutants*	*Study frame*	*Sponsoring organization*	*Principal investigator**
Characterization and Modeling				
Office buildings, homes for elderly, and schools	*Organics*	*Phase I: 1 building each Phase II: 2 buildings each*	*EPA*	*Phase I: E. Pellizzari, RTI Phase II: not selected*
Air transport within buildings	*Rn progeny*	*3-compartment chamber*	*DOE*	*D. Grimsrud, A. Nero, LBL*
Monitoring and modeling of energy use, infiltration, and indoor air quality	*CO, NO_2, IP, Rn and Rn progeny, HCHO*	*2 identical houses*	*EPRI*	*N.L. Nagda, GEOMET*
Pollutants in residential air	*CO, NO_2, HCHO, particulates, volatile vapors*	*40 homes*	*CPSC*	*T.G. Matthews, Oak Ridge National Laboratory*
Residential and commercial indoor air quality	*Rn, NO_2, HCHO, RSP, CO*	*40 homes for passive monitoring of pollutants; 2 homes subset for real-time*	*Niagara Mohawk/ NYERDA*	*R. O'Neil, Niagara Mohawk*
Effects of residential woodburning appliances on indoor air quality	*CO, CO_2, NO_2, particulates*	*Test homes*	*TVA/BPA*	*J. Harper, TVA*
Assessment of natural Rn and Rn progeny in U.S. single-family houses	*Rn and Rn progeny*	*40 representative homes*	*DOE*	*J. Rundo, Argonne National Laboratory*
Measurement of annual indoor and outdoor ^{222}Rn and its relationship to environmental variables	*Rn*	*Indoor/outdoor; detailed, long-term correlation for a small number of homes*	*DOE*	*N. Harley, New York University*
Studies of Rn in buildings	*Rn*	*140 homes*	*DOE*	*B. Cohen, University of Pittsburgh*
Residential ventilation	*Rn, HCHO, CO, NO_2*	*3 pairs of homes, to assess heat exchanger, weatherization, and occupancy*	*Pacific Power & Light/ Battelle Northwest*	*D. Zerba, Pacific Power & Light*
Influence of building design and other factors on indoor air quality	*CO, NO_2, SO_2, O_3, RSP, HCHO*	*4 homes*	*NSF*	*C. Davidson, Carnegie Mellon*
Emissions				
Emission from unvented combustion sources; from tobacco combustion; and occupancy and tobacco odor	*NO_2, CO, SO_2, CO_2, O_2 depletion; particulates, odor, CO, trace elements, organics; occupancy odor*	*Chamber*	*NIEHS*	*J.A.J. Stolwijk, B.P. Leaderer, W.S. Cain; John B. Pierce Foundation/Yale University*
Emission factors for several indoor sources	*NO_2, CO, SO_2, CO_2, O_2 depletion*	*Chamber*	*NIEHS*	*J.A.J. Stolwijk, B.P. Leaderer; John B. Pierce Foundation/Yale University*
Characterization of emissions from unvented gas stoves, wood stoves, and kerosene heaters	*CO, NO_2, SO_2*	*Research house*	*DOE and CPSC*	*D. Grimsrud, A. Nero, LBL*
Building materials	*Organics*	*Chamber*	*DOE*	*D. Grimsrud, A. Nero, LBL*
Characterization of emissions from unvented gas appliances, wood-	*All*	*Chamber*	*GRI*	*D. Moschandreas, IITRI*

**Addresses of principal investigators appear at the end of Table 1.*

Table 1. (concluded)

Area/brief title	Pollutants	Study frame	Sponsoring organization	Principal investigator*
burning devices, kerosene heaters, cooking, and cigarette smoking				
Emissions from kerosene heaters	CO, CO_2, NO_2, SO_2	*Chamber*	*CPSC*	*W. Porter, CPSC*
Formaldehyde content in various preserved wood products supplied by manufacturers	*HCHO*	*Chemical analysis of wood products*	*CPSC*	*T.G. Matthews, Oak Ridge National Laboratory*
Controls (Including Ventilation)				
Pollutant-specific removal techniques	*Rn, Rn progeny, particulates*	*3-compartment chamber*	*DOE*	*D. Grimsrud, A. Nero, LBL*
Behavior of heat exchangers	*None*	*Chamber*	*DOE EPA, BPA*	*D. Grimsrud, A. Nero, LBL*
Instrumentation				
Development and field evaluation of passive samplers	*HCHO, CO, particulates*	*Laboratory*	*DOE*	*D. Grimsrud, A. Nero, LBL*
Assessment of radioactive and chemically active air contaminants	*Rn, Rn progeny*	*Develop calibration facility, instrumentation, and methods for residential and public building sampling*	*DOE*	*E. Knutson, DOE*
Exposure Studies				
24-hour exposure of residents of Washington D.C., and Denver	*CO*	*1,000 person-days in each location*	*EPA*	*T. Hartwell, RTI; T. Wey, PEDCo*
24-hour exposure of residents of chemical-industrial cities	*18 volatile organics*	*500 person-days in two major industrial areas*	*EPA*	*E. Pellizzari, RTI*
Total exposure to emissions of unvented gas appliances	CO, NO_2	*Large multi-pollutant field study*	*GRI*	*J. Spengler, Harvard*
Characterization of 24-hour exposure of three population subgroups	*CO*	*200 person-days*	*EPRI*	*N.L. Nagda, GEOMET*
Assessing exposures and adverse health effects associated with alternative heat sources in residences	NO_2, CO, CO_2, SO_2, HCHO, O_2 depletion	*Field study*	*NIEHS/CPSC*	*J.A.J. Stolwijk, B.P. Leaderer; John B. Pierce Foundation/Yale University*
Pollutants, aero-allergens, and respiratory diseases	TSP, RSP, O_3, CO, NO_2, pollen bacilli, fungi, algae	*200 homes in 4 geographic clusters*	*EPA*	*M.D. Lebowitz, University of Arizona*
Data Evaluation				
Evaluation of indoor air quality data for making risk assessments	*All*	*Data from past studies*	*EPRI*	*J. Yocom, TRC; J. Spengler, Harvard*
Evaluation of risk of exposure to Rn for design of epidemiological studies	*Rn and Rn progeny*	*Data from past studies*	*DOE*	*A. Nero, D. Grimsrud, LBL*

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IIT Research Institute, 10 West 35th Street, Chicago, IL 60616, (312) 567-4310.
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Oak Ridge National Laboratory, Oak Ridge, TN 37830, (615) 574-6248.
Pacific Power & Light, Portland, OR 97204, (503) 243-4876.
Pierce, John B., Foundation, Yale University, 290 Congress Street, New Haven, CT 06519, (203) 562-9901.
PEDCo Environmental, Inc., 11499 Chester Road, Cincinnati, OH 45246, (513) 782-4700.
Research Triangle Institute, Research Triangle Park, NC 27709, (919) 541-6000.
Tennessee Valley Authority, Chattanooga, TN 37401, (615) 751-0011.
TRC Environmental Consultants, Inc., 800 Connecticut Boulevard, East Hartford, CT 06108, (203) 289-8631.
University of Arizona, University Health Sciences Center, College of Medicine, Tucson, AZ 65724, (602) 626-6379.
U.S. Department of Energy, Environmental Measurements Laboratory, 376 Hudson Street, New York, NY 10014. (212) 620-3570.

model relates various factors affecting indoor concentrations; an example illustrates the use of the model. Publications describing different aspects of indoor air quality research are highlighted.

Section 4—Measurement Systems

This section discusses measurement and instrumentation characteristics, operating principles, and sources of information. Instrumentation and methods for measuring pollutant concentrations and air exchange rates are summarized (Table 3).

Section 5—Design Considerations

A discussion of various design considerations, including selection of parameters, determination of sample size, and selection of a measurement system, will help the user systematically develop a monitoring program. Helpful hints on such specifics as probe placement are given, and feedback and iterative procedures for developing a design are emphasized. Approaches for addressing building-associated indoor quality problems are discussed.

Section 6—Data Reporting

Guidelines for data reporting will enable users and study investigators to understand the descriptors required to make useful data sets accessible to other users. Formats for reporting the scope and content of data are included.

Section 7—Quality Assurance and Quality Control

Quality assurance (QA) and quality control (QC) considerations, with references, are discussed.

Appendix A

This appendix categorizes and reviews commercial instruments suitable for measuring indoor air quality.

Table 2. *Sources and Exposure Guidelines of Indoor Air Contaminants*

Pollutant/sources	Guidelines
Asbestos and Other Fibrous Aerosols	
Friable asbestos: fireproofing, thermal and acoustic insulation, decoration. Hard asbestos: vinyl floor and cement products, automatic brake linings (O).†	*0.2 fibers/ml for fibers longer than 5 µm (based on ASHRAE* guidelines of 1/10 of U.S. 8-hour occupational standard).*
Biological Aerosols	
Human and animal metabolic activity products, infectious agents, allergens, fungi, bacteria in humidifiers, bacteria in cooling devices.	*None available.*
Carbon Monoxide	
Kerosene heaters, gas stoves, gas space heaters, wood stoves, fireplaces, smoking, and automobiles (O).	*9 ppm for 8 hours (NAAQS§); 35 ppm for 1 hour (NAAQS).*
Formaldehyde	
Particleboard, paneling, plywood, ceiling tile, urea-formaldehyde foam insulation, other construction materials.	*0.1 ppm (based on Dutch and West German guidelines as reported in ASHRAE Guidelines, 1981, and National Research Council report, 1981).*
Inhalable Particulates	
Smoking, vacuuming, combustion sources (O), industrial sources, fugitive dust (O), and other organic particulate constituents.	*55 to 110 $\mu g/m^3$ annual. #150 to 350 $\mu g/m^3$ for 24 hour.#*
Metals and Other Inorganic Particulate Contaminants	
Lead: old paint, automobile exhaust (O).	*1.5 $\mu g/m^3$ for 3 months (NAAQS).*
Mercury: old paint, fossil fuel combustion (O).	*2 $\mu g/m^3$ for 24 hours (ASHRAE).*
Cadmium: smoking, use of fungicides (O).	*2 $\mu g/m^3$ for 24 hours (ASHRAE).*
Arsenic: smoking, pesticides, rodent poisons.	*None available.*
Nitrates: Outdoor air.	*None available.*
Sulfates: Outdoor air.	*4 $\mu g/m^3$ annual, 12 $\mu g/m^3$ for 24 hours (ASHRAE).*
Nitrogen Dioxide	
Gas stoves, gas space heaters, kerosene space heaters, combustion sources (O), automobile exhaust (O).	*0.05 ppm annual (NAAQS).*
Ozone	
Photocopying machines, electrostatic air cleaners, outdoor air.	*Not exceeding 0.12 ppm once a year (NAAQS).*
Pesticides and Other Semivolatile Organics	
Sprays and strips, drift from area applications (O).	*5 $\mu g/m^3$ for chlordane (NRC).***

**ASHRAE—American Society of Heating, Refrigerating and Air-Conditioning Engineers.*
†(O) refers to outdoor sources.
§NAAQS—U.S. National Ambient Air Quality Standards.
#These numbers indicate the probable range for the new NAAQS for particulates of 10 µm or less in size. Based on "Recommendations for the National Ambient Air Quality Standards for Particulates—Revised Draft Paper," Strategies and Air Standard Division, Office of Air Programs, EPA, October 1981.
***National Research Council. 1982. "An Assessment of Health Risk of Seven Pesticides Used for Termite Control," National Academy Press, Washington, D.C.*

Table 2. (concluded)

Pollutant/sources	Guidelines
Polyaromatic Hydrocarbons and Other Organic Particulate Constituents	
Woodburning, smoking, cooking, coal combustion, and coke ovens (O).	*None available.*
Radon and Radon Progeny	
Diffusion through floors and basement walls from soil in contact with a residence, construction materials containing radium, untreated groundwater containing dissolved radon, combustion of natural gas used in cooking and unvented heating. Radon from local soil emanation (O).	*0.01 working level (ASHRAE guidelines).*
Sulfur Dioxide	
Kerosene space heaters, coal and oil fuel combustion sources (O).	*80 μg/m³ annual; 315 μg/m³ for 24 hours (NAAQS).*
Volatile Organics	
Cooking, smoking, room deodorizers, cleaning sprays, paints, varnishes, solvents and other organic products used in homes and offices, furnishings such as carpets and draperies, clothing, furniture, emissions from waste dumps (O).	*None available.*

Appendix B

Standard or accepted methods can be used for certain measurements when no off-the-shelf, commercial instrumentation is available. In some cases, these methods can serve as alternatives to the instrumentation summarized in Appendix A. Appendix B summarizes these methods.

Table 3. *Summary of Selected Pollutant Concentration Measurement Systems*

Pollutant	Operating principle	Personal, portable, or stationary	Active or passive	Analyzer or collector	Appendix cross-reference*
Asbestos and other fibrous aerosols	Induced Oscillation/Optical Scattering—Sample air passes through an oscillating electric field. Fibers are detected by detecting right-angle scattering pulses from larger illumination aligned with the fiber axis.	Portable	Active	Analyzer	A1-1
	Filtration—A laboratory analyzes the filters.	Personal	Active	Collector	B
Biologic aerosols	Impaction—Sample air passes through a series of selective stages (petri dish containing agar); inertial effects cause particles in size ranges of interest to collide with collector surface. Microbial colonies are incubated for 24 hours and counted manually.	Stationary	Active	Collector	A2-1, A2-2
Carbon monoxide	Nondispersive Infrared (NDIR)—Infrared radiation passes through parallel optical cells, one containing sample air, the other containing reference CO-free air. The difference in absorbance relates to CO concentration.	Stationary	Active	Analyzer	EPA Reference Method, Appendix A
	Gas Filter Correlation (GFC)—Infrared radiation passes through a spinning filter wheel that contains a sealed CO reference cell and a nitrogen reference cell. The IR beam then passes through a chamber containing sample air and is detected. The signal difference observed between the nitrogen cell and the CO cell relates to CO concentration.	Stationary	Active	Analyzer	EPA Equivalent Method, Appendix A
	Electrochemical Oxidation—Sample air passes into an electrochemical cell where oxidation of CO to CO_2 produces a signal related to the CO concentration.	Personal Personal Portable	Active Passive Active	Analyzer Analyzer Analyzer	A3-3 A3-2, A3-5 A3-1, A3-4

1 or B denotes the appendix where system is discussed; the numbers following A show instrument summary number.

Table 3 (continued)

Pollutant	*Operating principle*	*Personal, portable, or stationary*	*Active or passive*	*Analyzer or collector*	*Appendix cross-reference**
Formaldehyde	*Wet Chemical—HCHO is scrubbed from the sample airstream by a standard reagent solution. Addition of a second reagent forms a distinctive color whose intensity is related to HCHO concentration.*	*Portable*	*Active*	*Analyzer*	*A4-4 and B*
	Sorption/Spectrophotometry—HCHO is adsorbed onto treated substrate and subsequently desorbed and quantitated in the laboratory.	*Personal*	*Passive*	*Collector*	*A4-1, A4-2, A4-3, B*
Inhalable particulate matter	*Optical Scattering—Sample air passes through a size-selective inlet prior to entering an optical cell. Forward light scattering from controlled light source relates to IP concentration.*	*Personal* *Portable*	*Passive* *Active*	*Analyzer* *Analyzer*	*A5-1* *A5-2*
	Filtration—Sample air passes through a size-selective inlet. Particles in size range(s) of interest are retained on filter(s) for mass determination in laboratory.	*Stationary*	*Active*	*Collector*	*A5-3, A5-4, B*
	Impaction—Sample air passes through a series of selective stages; inertial effects cause particles in size range of interest to collide with collector surface.	*Personal*	*Active*	*Collector*	*A5-5*
	Piezoelectric Resonance—Sample air passes through a size-selective inlet. Particles within the size range of interest are electrostatically precipitated onto a quartz crystal. Alterations in oscillation frequency relate to collected mass.	*Portable* *Stationary*	*Active* *Active*	*Analyzer* *Analyzer*	*A5-6* *A5-6*
Metals and other inorganic particulate constituents	*Filter Collection/Laboratory Analysis—Inorganic constituents are collected by passing sample air through a suitable filter. Metals may be quantitated by atomic absorption spectroscopy, neutron activation analysis, proton-induced X-ray fluorescence. Nitrates and sulfates can be determined spectrophotometrically.*	*Personal* *Portable* *Stationary*	*Active* *Active* *Active*	*Collector* *Collector* *Collector*	*B*
Nitrogen dioxide	*Gas-Phase Chemiluminescence—Photon emission that accompanies reaction of NO with O_3 is monitored to simultaneously quantify NO and NO_x. NO_x is quantified by first reducing all oxides of nitrogen to nitric oxide, NO. NO_2 is the algebraic difference between NO_x and NO.*	*Stationary* *Portable*	*Active* *Active*	*Analyzer* *Analyzer*	*EPA Reference Method, Appendix A* *A6-1*
	Triethanol Amine (TEA) Adsorption—NO_2 is quantitatively sorbed onto treated substrate for subsequent quantitation in the laboratory.	*Personal*	*Passive*	*Collector*	*A6-3, A6-5*
	Wet Chemical—NO_2 reacts with a reagent system and is quantified colorimetrically.	*Portable* *Personal*	*Active* *Passive*	*Analyzer* *Collector*	*A6-4* *A6-2*
Ozone	*Gas-Phase Chemiluminescence—Photometric detection of the chemiluminescence resulting from the gas-phase reaction between ethylene and O_3.*	*Stationary* *Portable*	*Active* *Active*	*Analyzer* *Analyzer*	*EPA Reference Method, Appendix A* *A7-1*
	Gas-Solid Phase Chemiluminescence—Photometric detection of the chemiluminescence resulting from the reaction between O_3 and rhodamine-B.	*Stationary*	*Active*	*Analyzer*	*EPA Equivalent Method, Appendix A*
	Ultraviolet Absorption—Measurement of the difference in ultraviolet intensity between sample air and reference.	*Stationary*	*Active*	*Analyzer*	*EPA Equivalent Method, Appendix A*

**A or B denotes the appendix where system is discussed; the numbers following A show instrument summary number.*

Table 3. (continued)

Pollutant	Operating principle	Personal, portable, or stationary	Active or passive	Analyzer or collector	Appendix cross-reference*
Pesticides and other semivolatile organics	Sorbent Collection/Laboratory Analysis—Semivolatile organics are collected by passing sample air through polyurethane foam. In the laboratory, compounds are extracted for chromatographic quantitation.	Personal Portable Stationary	Active Active Active	Collector Collector Collector	B
Polyaromatic hydrocarbons and other organic particulate constituents	Filter Collection/Laboratory Analysis—Organic constituents are collected by passing sample air through a suitable filter. Organic constituent may be quantified through a number of chromatographic techniques.	Personal Portable Stationary	Active Active Active	Collector Collector Collector	B
Radon/radon progeny	Filtration/Gross Alpha Counting—Rn progeny collect onto a filter; consequent alpha activity relates to working level.	Stationary	Active	Collector	A8-2
	Electrostatic Collection/Thermoluminescent Dosimetry—Rn passes into a special chamber where subsequent progeny (ions) are electrostatically focused onto a thermoluminescent dosimeter (TLD) chip. Subsequent alpha disintegrations create metastable defects in the TLD, which is deactivated and quantified in the laboratory.	Stationary	Passive	Collector	A8-1, A8-6
	Grab Sample/Alpha Scintillation—Rn progeny collect in a filter; Rn is collected in a scintillation flask. Subsequent alpha activity relates to working level (filter sample) and to Rn concentration (scintillation flask).	Portable	Active	Analyzer	A8-3
	Filtration/Alpha Spectroscopy Coupled to Electrostatic Collection/Alpha Spectroscopy—Rn progeny (ions) are collected on a filter; subsequent alpha decay relates to working level. Rn passes into a special chamber where subsequent decay ions are electrostatically focused onto a detector; subsequent alpha decay relates to Rn concentration.	Stationary	Active	Analyzer	A8-4
	Filtration/Alpha and Beta Spectroscopy—Rn progeny are collected on a filter; subsequent alpha and beta activity relate to working level.	Stationary	Active	Analyzer	A8-5, A8-7
	TRACK ETCH™— Alpha-sensitive film registers damage tracks when chemically etched; average Rn concentration is related to the number of damage tracks per unit area.	Stationary	Passive	Collector	A8-8
	Sorption/Gamma Activity—Rn is absorbed onto activated charcoal; subsequent gamma activity is related to average Rn concentration.	Stationary	Active	Collector	B
Sulfur dioxide	Flame Photometric Detection (FPD)—Measurement of sulfur-specific emissions from hydrogen-rich air flame.	Stationary	Active	Analyzer	EPA Equivalent Method
	Pulsed Fluorescence—Measurement of the intensity of the ultraviolet fluorescence of SO_2 excited by a high-intensity light source.	Stationary	Active	Analyzer	EPA Equivalent Method
	Wet Chemical—SO_2 reacts with a reagent system and is quantified conductometrically or colorimetrically.	Stationary Portable	Active Active	Analyzer Analyzer	EPA Equivalent Method A9-3
	Electrochemical Oxidation—Sample air passes into an electrochemical cell where	Personal Personal	Active Passive	Analyzer Analyzer	A9-1 A9-2

*A and B denotes appendix where system is discussed; the numbers following A show instrument summary number.

Table 3 (concluded)

Pollutant	*Operating principle*	*Personal, portable, or stationary*	*Active or passive*	*Analyzer or collector*	*Appendix cross-reference**
	oxidation of SO_2 produces a signal proportioned to concentration.				
Volatile organics	*Sorbent Collection/Laboratory Analysis—Volatile organics are collected by passing sample air through a suitable absorbant column. In the laboratory, compounds of interest are desorbed for chromatographic quantitation.*	*Personal*	*Active*	*Collector*	*B*
		Portable	*Active*	*Collector*	
		Stationary	*Active*	*Collector*	

**A or B denotes the appendix where system is discussed; the numbers following A show instrument summary number.*

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The complete report, entitled "Guidelines for Monitoring Indoor Air Quality," (Order No. PB 83-264 465; Cost: $22.00, subject to change) will be available only from:

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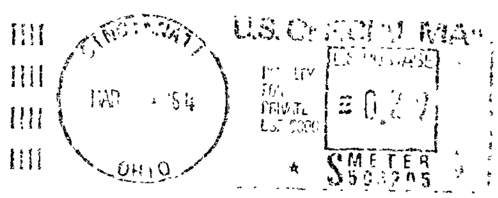

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