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FINAL DESIGN REPORT RADON MITIGATION & DOME REINFORCEMENT PROJECT

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IT CORP. DOE-FN
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REPORT

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FINAL DESIGN REPORT

RADON MITIGATION & DOME REINFORCEMENT PROJECT

5975

From: J. T. Grumski

WMCO:WR:87-248

Date: August 25, 1987

Subject: **FINAL DESIGN REPORT FOR K-65 SILO RADON MITIGATION AND DOME REINFORCEMENT PROJECT**

To :

D. A. Fleming
C. E. Gamm
R. L. Gardner
S. L. Hinnefeld
R. W. Lippencott
T. A. Poff
R. M. Rogers
J. L. Trujillo

The purpose of this memo is to request a review of the attached documents relating to the K-65 Silo Radon Mitigation and Dome Reinforcement Project. Although all of the documents may not be necessary for your review, I have included them for completeness.

Because of the high site priority on K-65 Silo remediation, please complete your review by September 9, 1987 and call me so that I may pick up the comments in person and avoid any delay.

Thank you for your cooperation.

cc:

w/o Attachment

G. E. Bennett
L. C. Bogar
W. H. Britton
R. C. Kispert
K. A. Solomon
W. A. Weinreich

INTERNATIONAL TECHNOLOGY CORPORATION

Regional Office
312 Directors Drive
Knoxville, Tennessee 37923

ENGINEERING STUDY OF THE K-65 STORAGE SILO RADON MITIGATION AND DOME REINFORCEMENT PROJECT AT THE FEED MATERIALS PRODUCTION CENTER.

Submitted By:

IT Corporation - Nuclear Services
312 Directors Drive
Knoxville, Tennessee 37923

for

Advanced Sciences, Incorporated
107-F Jefferson Avenue
Oak Ridge, Tennessee 37830

August 20, 1987

5975

From: R. A. Vogel

WMCO:SR(WR):88-163

Date: May 2, 1988

Subject: **INDUSTRY REVIEW OF K-65 FOAMING PROJECT**

To : R. C. Kispert

An investigation of foam characteristics was undertaken as the result of questions which were raised by a potential foam applicator. These questions were in regard to the exothermic potential of flexible foam. As WREE did not have this information, these questions were asked of the authors of the Final Design Report of the K-65 Radon Mitigation and Dome Reinforcement Project. After several weeks without a specific answer regarding the exothermic potential, it was decided to contact industry representatives for this information.

Industry contacts were made through the Society of Plastics Industry and the Polyurethane Foam Association. As a result, telephone conversations were held regarding the basic concepts of the foaming project. The objective was to obtain a timely response regarding the initial question of exotherm.

These discussions covered the area of exothermic potential of both flexible and rigid foams, with the consensus of opinion that in our application rigid foam may be more of an exothermic problem than flexible. The unexpected conclusion of all of the industry representatives, however, was the general agreement that beyond inherent exothermic potential of urethane foam, a much more immediate limitation was control of application of the foam. The potential problem of excessive expansion was also raised. As a result of these initial responses, it was decided to send copies of the Technical Summary of the K-65 Interim Stabilization Project for review and comment.

The individuals who were involved in commenting on the K-65 foaming design were representatives of two trade associations, two large manufacturers (consisting of department managers and their technical staffs), a consultant from the academic sector, and an applicator familiar with the silos (from having applied the external foam to the silos). There were also comments made by a systems house representative (a systems house is the industry link between the manufacturer and the applicator).

After a period of review, comments were received from these industry representatives. There was again a consensus of opinion from the individuals involved regarding application as the most limiting aspect of the proposed foaming project. This was due to the fact that method and rate of application controls most of the potential variables of the foaming process. It immediately effects the quality of the foam unit controlling volume, potentially causing voids and bridging over if applied too rapidly or inconsistently. It is directly related to the exothermic potential of the foam, too fast an application rate will result in more heat being generated than can be dissipated. (This is especially relevant to the enclosed silo environment.) The method and rate of application also defines the volume of expansion before curing. (Volume changes after curing are a different phenomenon.) As a result, in order to control the exothermic potential and the potential for excessive expansion, application must be a precisely controlled process.

Most comments resulted from the unique restrictions to application within the silos. Many of these were based on the inability to enter the silo itself. As most applications involve an applicator in close proximity to the area to be foamed, the reliance upon a video system for visual contact presents unique problems. A comment from an applicator focused on one of these. He stated that heat rising from the foam as it was being applied would resemble heat rising from a roadway on a hot day. His concern was that to rely on the video system for the visual cues necessary to control application would be questionable when considering these heat waves.

A comment from a large manufacturer of foam materials provided a different perspective. He felt that due to the confined nature of the application within the silos, water vapor and fluorocarbons would form what he described as a dense fog. Another comment from the systems house representative expanded on the concept. He felt that the water vapor would quickly become steam due to the heat generated by the process. He also was concerned that even without these obstructions to clear vision, it would be difficult using the video camera to perceive the subtle color shifts which indicate changes in the curing process.

Most comments regarding application focused on the difficulty of applying a continuous layer of foam over so large of an area considering the limited access to the silos (manways). There is the problem of reaching those areas outside of the foam circle of application which can be transcribed from the four manways. This point was made by an applicator who suggested that a telescoping extension to the applicator wand might be a solution to this difficulty. As the length and weight of the applicator wand at present are such that it is difficult to handle, especially through the confines of the manways, there remains a question about the degree of precision of application possible with such a system.

The degree of precision of application which is necessary to control exothermic potential and expansion is definable. The temperature limit which has been recommended to be maintained is 250°F. at maximum, preferably 225°F. This is desirable since the autoignition point of rigid foam varies from 350° to 450°F., depending upon formulation, when the foam is exposed to sustained heat. The ignition point for foam not exposed to sustained heat is normally higher, but since the foam generates and retains heat so well, it must be understood to be at sustained elevated temperatures soon after application has begun. As ignition and subsequent burning of the foam is not acceptable, especially in our application, some guidelines have been suggested to avoid excessive temperature accumulation.

These guidelines are in terms of thicknesses of application which may be applied in order to prevent excessive temperature accumulation. Although estimation of safe thicknesses varied, most comments focused on 5-6 inches of expanded foam as a limit of application safety. This amount is the estimated thickness for the particular constraints of the K-65 application. These constraints on heat dissipation are the enclosed nature of the silo (limited heat loss to the air) and the sheer mass of the foam involved. Since these factors are not normally encountered in foam applications, the suggested thicknesses are estimates based on the reviewers understanding of the silo environment. It may be important to note that one reviewer stated that he would not be able to calculate heat loss for our application. As he represented a large manufacturer of foam components in the capacity of ensuring that these components met the needs of customers, such a calculation would normally be predictable. Due to the uncertainties and the size of our application, he would not attempt a calculation. This is seemingly the basis for variation among reviewers in estimated thicknesses of application. This same individual gave the most conservative estimate, he recommended beginning application of 2 inches with temperature monitoring. If no excessive temperature accumulation was noted, he then suggested going to 4-5 inches of application.

In order to achieve these suggested thicknesses, the degree of control of application of foam components is crucial. Using an expansion ratio of 1:30, it would be necessary to restrict application thickness to .2 inches in order to produce an expanded layer of 6 inches. If the 2 inch expanded layer is used, it will be necessary to maintain no more than .067 inches of component application thickness. The significance of these numbers is that considering the visual limitations mentioned above as well as the cumbersome nature of the application device, it would be difficult to achieve this degree of application control.

There were suggested solutions to the problem stated above. An automated spray unit has been suggested to maintain a controlled rate of application. It would require a relatively flat residue surface (unknown at present), a method of support other than the dome of the silo, and the design and testing

necessary to apply automated spray technology to our silo situation. An air handling system was suggested to overcome the visual difficulties mentioned above. This system would have an added benefit of cooling the foam surface, thus reducing the exotherm problem. There is, however, the problem of design and construction cost of such a system for this limited application, especially when radon daughters on the underside of the dome and sidewall are considered. There is also the limited benefit of this system until a layer of foam covers the residue surface.

A system of temperature monitoring during application was uniformly suggested. This has no obvious negatives other than cost and effort of installation, a potential problem associated with temperature monitoring is the possibility of obstruction to movement of the application tool. As it is the primary method of determining application rate, however, it should be considered essential if foaming is chosen as an alternative. The other frequently mentioned suggestion was the use of a mock-up test to determine if the limitations mentioned by industry representatives can be overcome.

The mock-up test should be as close to scale as possible (a quarter of the silo has to be suggested) due to problems which are essentially the result of the mass of material involved. It is important that the key limitations of access through a manway and visual guidance dependent upon a video system are also tested. The conclusion of several industry representatives was that only through such a test would it be possible to understand the particular restrictions of the silo application to the point of predictability.

Industry comments were consistent in questioning the design as proposed in the Technical Summary. They in general rejected a role for flexible foam in achieving filling of the silo space without excessive pressure. Most suggested a redesign, focusing on a layer of rigid foam of perhaps 3 feet in thickness. All reviewers suggested not proceeding until specifications could be developed from which a potential bidder could judge the requirements of this application. The frequently recommended mock-up test would provide the basis for these specifications.

RAV/ksv

cc: S. W. Heisler

FMPC

ENVIRONMENT, SAFETY & HEALTH DEPARTMENT

DOCUMENT REVIEW AND RECORD FORM

ORIGINATING DEPARTMENT:	DOCUMENT ORIGINATOR	COMMENTS DUE BY:	REVIEWING DEPARTMENT: (Name & Date Received)
Waste Remediation	Joe Gramski Jr.		Health Physics

DOCUMENT TITLE AND IDENTIFYING NUMBER: Final Design Report for K-65 Silo Radon Mitigation

REVISION DATE:

ITEM NO.	REVIEWER'S NAME	DOC. PAGE OR SEC. NO.	SRC *✓	COMMENT	COMMENT RESOLUTION
	Scott Walker		✓	1. Wooden boxes will not suffice for shielding around the filtration system enclosure. The shield should be made of wooden forms filled with soil. (Probably a minimum of 24 inches thick).	
		DH-6(1)	✓	2. The system is designed to dessicate air at 100% humidity at 40°F. Since warm air holds much more ~~moisture~~ moisture, the system should be designed for 80% humidity at 80°F to insure adequate dehumidification.	
		DH-11	✓	3. The proposed radon monitoring instrument ~~will not perform~~ is too sensative to adequately measure radon at existing concentrations. A different instrument must be chosen followed up by a direct grab sample measurement.	
		B1\A1-K-65 Silo RM		Section seven is not applicable.	
		DH-2(1)	✓	The HEPA	

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* Checked Comments must be resolved as "SIGNIFICANT REVIEW COMMENTS".

Comment Resolutions(s) Accepted By: _____ REVIEWER OR REVIEWING DEPARTMENT REPRESE[illegible] _____ DATE

(Signature required on SRC * comm[illegible]y)

FMPC-ES&H-2[illegible]38)

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SECTION 1.0
EXECUTIVE SUMMARY

1.0 EXECUTIVE SUMMARY

IT Corporation, as a subcontractor to ASI, has prepared a functional design package for the reduction of radon from the air space of two silos in the K-65 area of the Feed Material Production Center located in Fernald, Ohio. IT has also developed an application approach and functional specification for filling the air spaces in the silos with polyurethane foam. Filling with foam reduces the probability of radon release to the atmosphere and provides structural support to the roof.

The report presents the product of work performed on the radon reduction system and the foam applications. The radon reduction system material is presented in Section 3.0, while the foam application material is presented in Section 4.0. Both of these applications represent best available technology.

Radon reduction is to be accomplished in a system designed to remove 1000 cfm of air from a silo and pass it through a calcium sulfate dehumidifier and activated carbon. The radon is retained on the carbon and the air with a reduced radon concentration returned to the silo. Specially fabricated manway adapters will be used to provide connections for the ventilation system. Up to ten air space volumes will be passed through the carbon adsorption system to reduce radon to a target of 1 Ci in the silo. Any concentration below 4 Ci is acceptable. Section 3.0 of this report presents a description of this system and a narrative on its operation. Specifications for equipment to be purchased, and installation, testing and operating procedures are included. Drawings developed to support the design and utilities lists are also included. Because meeting the desired operational schedule requires the purchase of off-the-shelf items, a vendor list has been provided for system components.

Foam application is to be accomplished using a system supplied by an applications service vendor. Section 4.0 of this report presents a description of the vendor's system and a narrative on its operation. Functional specifications for equipment to be supplied by the vendor and operating and application procedures are included. Because of schedule constraints, a suggested vendor has been indicated even though a vendor list has been provided.

In addition to these design packages, supporting documentation has also been provided. Section 5.0 provides a toxic chemical review. This review indicates potential chemical hazards and a means of mitigating the consequences of personnel exposure. Material Safety Data Sheets (MSDSs) are also included.

Potential radiological hazards and their control in the project are discussed in the ALARA review presented in Section 6.0 of this report. The ALARA review has evaluated the work scope to be performed and recommended methods of reducing exposure of workers. The anticipated man-rem exposure for work to be performed on the project is 15.26.

Because the silos will require openings to be exposed to the atmosphere following radon reduction, an assessment of the impact of the foaming application on air quality has been made. This air quality assessment has been made a part of this report, and is included as Section 7.0.

Prior to proceeding with the installation of equipment and finalizing operational procedures to accomplish the work proposed, a permit must be obtained from the Ohio EPA. A Permit To Install (PTI) document has been prepared for submittal, which is made a part of this report as Section 8.0.

An appendix is included as a part of this report. It contains copies of reference material obtained to support the design basis for the radon reduction system and the foam application.

It is the intention of this report to provide complete response to all aspects of the scope of work outlined for this project. The functional aspects of systems required to perform the work are presented in adequate detail to allow the radon reduction and foam application to be performed in accordance with the October 1987 schedule.

SECTION 2.0
INTRODUCTION

2.0 INTRODUCTION

This report presents the results of an engineering and design effort performed to achieve sealing of the air space and support of the domes of the two K-65 storage silos. Radon reduction is to be carried out prior to opening the silos for introduction of polyurethane foam material. The foam placement will seal the surface of the radium-bearing sludge in the silos, which through radioactive decay is contributing the radon to the air space. The foam will also provide structural support for the concrete roof domes of the silos. Engineering analysis has indicated that little structural integrity remains in center portions of these roofs. The foam will help support them until the silos and contents are removed for final disposal in 3 to 5 years. This application is considered best available technology supporting the project scope of work.

The engineering and design effort is intended to support a project performance date of October 1987. In order to meet supplier delivery schedules, it has been necessary to identify standard components which are stock or shelf items which can be assembled into functional units. The design provides functional details of these items for field assembly to accomplish the radon reduction. Following this, a vendor will apply the foam in the silos as a service.

SECTION 3.0
RADON SYSTEM

SYSTEM DESCRIPTION
RADON REMOVAL SYSTEM

1.0 OBJECTIVE

The objective of this document is to describe a system to be installed to remove radon gas from the vapor space of two solid waste silos located at the Feed Materials Production Center in Fernald, Ohio. A description of the function, sizing, and operation of this system is provided. The radon reduction system supports a larger program to be carried out on the silo vapor space. Once radon concentrations have been reduced, silo openings will be employed to completely fill the present vapor space with a polyurethane foam material which will seal the silo, preventing leakage or release of radon gas to the environment.

2.0 SCOPE

The radon system to be supplied is complete and capable of stand-alone operation with nothing more than electrical supply in support of operations. The system is a temporary unit designed for an operating life of 5 years. To the extent possible, the components selected for use on the system are off-the-shelf manufacturers standard.

3.0 DEFINITIONS

3.1 DEHUMIDIFICATION

Process for the removal of moisture from air. In the present application, it is assumed that the air in equilibrium with sludge in closed silos is saturated with moisture at the prevailing gas temperature (100 percent relative humidity). A device containing the dehumidification agent calcium sulfate, is placed in the line to react with moisture and reduce the concentration present in the air.

3.2 CARBON ADSORPTION

The process of assimilating a substance such as radon present in a gas stream on a solid carbon matrix thereby effectively concentrating the radon in the solid phase and removing it from the recirculated gas.

4.0 DESCRIPTION

The radon removal system is designed with the following components:

4.1 SUCTION CONNECTION

Each silo containing radon gas to be processed can be thought of as a closed container with radon in the gas space in equilibrium with radium in the sludge. The gas must be removed from the silo through available connections. The silos have five manways suitable for this purpose. Each manway is 20 inches in diameter and is presently closed with a flanged and bolted cover. It is proposed to modify the manway covers at the top of the silos with new covers, each containing a 6-inch duct type connection. The details of this fixture are shown in sketch "A" on Drawing 303317.A.001. Suction will be taken from two of these 6-inch connections. The two connections will attach to a 12-inch suction header which directs flow to the radon removal system.

4.2 SYSTEM CONNECTIONS

The suction line for transport of gas from the silo suction connections will be 12-inch diameter and will be routed as shown on Drawing 303317.G.01.

4.3 RADON REMOVAL SYSTEM

4.3.1 Dehumidification

Moisture removal is accomplished by passing the gas removed from a silo through vessels loaded with calcium sulfate which reacts with moisture in the air, thereby accomplishing the required moisture removal. For the system supplied, the calcium sulfate is loaded in two canisters. The canisters are 48 inches in diameter by approximately 72 inches high. Flow enters the bottom of the bed through a flow distributor and exits from the top of the canister. Each canister is capable of processing up to 500 cfm of air. The system is therefore designed to treat up to 1000 cfm.

4.3.2 Carbon Adsorption

Radon is collected on activated carbon. The carbon is loaded in canisters similar to those used in dehumidification. Because the 48-inch by 72-inch canisters are rated at 500 cfm, processing would normally be at 500 cfm

through one canister. The desired process rate of 1000 cfm is achieved by operation of two canisters in parallel. Processing would be carried out until inlet and outlet radon concentrations indicate carbon capacity is being approached. Calculations indicate flow will be diverted through additional canisters in sequence during the air recirculation operation to achieve required reduction of radon from 37.4 Ci to about 1 Ci in the recirculated gas. Four trains of carbon beds are provided to achieve required adsorption capacity.

4.4 FAN

A fan is installed in the system to take suction from the silo(s) and to draw gas through the dehumidifiers and carbon beds. The fan is located downstream of the process to reduce the possibility of excessive untreated gas escaping into the environment. After passing air through the adsorption process the fan returns the air to the silo(s). The return line is 12 inches in diameter from the fan discharge to the silo dome. At the silo dome, the 12 inch line splits into connections which are 6 inches in diameter. The 6 inch lines are attached to special manway adapters which deliver treated air flow back to the silo.

4.5 DAMPERS

The radon adsorption system is designed to operate with one set of carbon vessels at a time. When one parallel pair of units is operating, all other vessels are isolated. Isolation is accomplished through the use of isolation dampers located at the inlet of the carbon units. The dampers selected must be capable of operation with reach rods and designed with bar seals or EPT seals which limit air leakage.

4.6 INSTRUMENTATION

Process control is accomplished using on-line monitoring of radon gas concentrations. The radon concentrations at the process inlet and process outlet are monitored. These process measurements are to be made using on-line measurements with an instrument such as the Eberline Model RGM-2 Radon Gas Monitor or equal.

5.0 DESCRIPTION OF OPERATION

The radon removal system is designed to operate at up to 1000 cfm gas flow to reduce radon levels in each of the two silos from 37.4 Ci to less than 1 Ci. Given gas volumes of 48,700 cubic feet in silo 1 and 38,700 cubic feet in silo 2, turnover times are 49 and 39 minutes respectively. Assuming 10 volume turnovers will be required to dilute radon concentrations to the level desired for start of foam application work, the total process times will be 500 minutes (8½ hours) and 400 minutes (7 hours) for silo and 1 and silo 2 respectively. In actual practice, it is anticipated this system as proposed will allow radon levels to be reduced to desired levels in two shifts.

The system is operated by opening the inlet damper to a pair of carbon beds. A flow path is verified from the silo to be processed, through the dehumidifiers and the carbon vessels to the fan. The fan is then started and air flow established through the system. The radon concentration is monitored at the process inlet and at the process outlet. Data available on carbon indicates removal efficiency for radon is between 85 and 99 percent. As inlet concentration is reduced and carbon capacity is being used, it is anticipated that flow will be diverted to a second set of carbon beds to achieve radon reduction to the final effluent concentration. The second silo will be processed by directing the initial flow through the partially expended bed from final processing of the first silo. The process will continue until inlet and outlet concentrations dictate a new bed must be placed in service. The new beds to be operated must have inlet dampers opened and flow established before isolating the expended units.

RADON REMOVAL SYSTEM

(Narrative)

A radon treatment system is proposed using the best available technology which is to be capable of safely removing accumulated and continuously generated radon gas within the K-65 silos. Primary system components include carbon beds, dehumidification beds, a fan for circulation and two continuous radon gas monitors. The general arrangement allows for circulation of contaminated air between the K-65 silos and the dehumidifiers/carbon beds located at the base of the berm.

Research was done to determine the most effective method for removing the radon gas from the air space of the silos. Literature data on Radon removal from air spaces tended to support carbon adsorption as being the most effective. Based on a system airflow of 1000 cfm, an initial curie content of 37.4 Ci, and 10 volume turnovers, the minimum curie content that can be achieved in the silos (due to continuous generation of radon gas) is approximately 0.4 Ci. A targeted final curie content for each K-65 silo is 1 Ci; however, an acceptable pre-foaming level is 4 Ci. The total amount of carbon required to "hold" 36.4 Ci (based on target curie content) is estimated at 4000 lbs. The selected carbon bed arrangement for radon removal uses two beds sized for 500 cfm operated in parallel to process 1000 cfm. Four trains of carbon beds are provided to achieve the required adsorption capacity.

Radon adsorption onto the carbon beds is much more efficient when the air moisture content is low. Thus, dehumidification will be provided by circulation of the contaminated air through 2 drums (500 cfm/drum) containing calcium sulfate capable of reducing the moisture level. The amount of calcium sulfate required (4000 lbs) was based on the assumption that the relative humidity of the air in each silo is 100 percent at 40 degrees F.

A fan is included in the system to draw gas from the silos through the dehumidifiers and carbon adsorption beds. It is located downstream of the process to reduce the possibility of untreated air escaping the closed system. Exhaust from the fan returns to the silos as treated air. Sampling and analysis of the circulating gas is provided by continuous radon

gas monitors located up and downstream of the dehumidification and carbon adsorption beds. Consistent readings of the targeted curie concentrations of 7.2×10^5 pCi/L for silo 1 and 9.1×10^5 PCi/L for silo 2 will justify terminating the radon removal process and beginning the foaming process. Levels of 3.1×10^6 pCi/L for silo 1 and 4×10^6 pCi/L for silo 2 are the maximum allowable concentrations prior to beginning the foaming process.

SPECIFICATION NO. 303317-RRS-01

SPECIFICATION FOR RADON REMOVAL SYSTEM

Prepared for:

FEED MATERIALS PRODUCTION CENTER
WESTINGHOUSE MATERIALS COMPANY OF OHIO
FERNALD, OHIO

AUGUST, 1987

ASI COMPANY

PREPARED BY: _____ DATE: _____

CHECKED BY: _____ DATE: _____

APPROVED BY: _____ DATE: _____

APPROVED BY: _____ DATE: _____

WESTINGHOUSE MATERIALS COMPANY OF OHIO

APPROVED BY: _____ DATE: _____

APPROVED BY: _____ DATE: _____

APPROVED BY: _____ DATE: _____

DEPARTMENT OF ENERGY

APPROVED BY: _____ DATE: _____

APPROVED BY: _____ DATE: _____

NEW:DH-8(2)

SPECIFICATION FOR RADON REMOVAL SYSTEM

for

THE K-65 SILO AREA

of

FEED MATERIALS PRODUCTION CENTER
FERNALD, OHIO

1.0 SCOPE

1.1 These Specifications cover the furnishing and delivery of a radon removal system as described herein. The radon removal system shall provide humidity removal, carbon adsorption for radon removal, and a fan for recirculating the air being treated. The carbon adsorption units shall treat the air and reduce radon levels to concentrations suitable for opening the K-65 silos. Since the contaminated air in the silos will be recirculated, a per pass reduction of at least 80 percent is required to ensure reduction of the radon level to below 1 Ci in each silo in two work shifts.

The equipment, complete with all controls, will be installed in a temporary building to be erected adjacent to the K-65 silos.

1.2 The attached drawings, 303317.M.001, 303317.F.01 show the arrangement and capacity for operation of the equipment.

2.0 RADON REMOVAL SYSTEM

2.1 HUMIDITY REDUCTION

2.1.1 The Contractor shall furnish a suitably sized humidity reduction unit to treat a flow of air of 1000 cfm. The unit should be sized to treat a total of 1,500,000 ft^3 of air saturated with water vapor at 40°F. The humidity reduction unit should employ calcium sulfate as the removal media and reduce relative humidity of the recirculated air below 40 percent.

2.2 RADON REMOVAL - CARBON ADSORBER

2.2.1 The Contractor shall furnish suitably sized radon removal units based on the use of activated charcoal. The charcoal units should be sized for a nominal per unit flow rate of 500 cfm.

2.2.2 Carbon adsorption units must be sized to reduce the radon content of 37.4 Ci contained in each of two silos. The volume (air space with 37.4 Ci of radon in equilibrium) of silo 1 is 48,700 ft^3 and silo 2 is 38,700 ft^3. The final targeted concentration of radon in the silos at the termination of the removal process must be less than or equal to 1 Ci. Based on a minimum of 80 percent reduction per volume pass, no more than 10 volume turnovers shall be required.

2.2.3 The Contractor shall supply the activated carbon for the radon removal system. The Contractor shall clearly delineate the carbon type and size he is proposing to supply. The literature shows much higher radon adsorption coefficients for coconut basis carbons, however, limited data show variability in capacity. The Contractor shall support his charcoal selection and quantity of material to be supplied for Purchaser's evaluation.

2.3 FAN

2.3.1 The Contractor shall supply a fan to recirculate radon containing air from the silo being treated through the radon removal system. The fan shall be sized to provide a minimum flow of 1000 cfm through the carbon adsorbers and the dehumidifier. See drawing 303317.F.01.

2.3.2 The Contractor shall supply an electric motor and all auxiliaries to provide a complete and operable air mover unit. The motor should be rated for 480 volt, 3 phase service. The Contractor is to indicate the motor horsepower rating selected. Motor starters, heater, fuses and remote start-stop capability are to be provided by the Contractor.

2.4 DAMPERS

2.4.1 The Contractor shall provide isolation dampers in the air recirculation system as shown on drawings 303317.F.01, 303317.M.001. The dampers selected shall have bar or EPT seals to limit leakage across closed dampers to no more than 3 percent of rated system flow. The dampers selected must be designed to operate at the system full flow pressure drop when in the closed position. Dampers shall have position indicators fitted to allow operators to readily determine if the damper is open or closed.

2.4.2 The Contractor shall supply reach rods for remote operation of dampers. Reference should be made to Drawing 303317.M.001 for details of reach rod operation.

2.5 DUCT WORK

2.5.1 The Contractor shall supply duct work to connect the components of the radon removal system together as shown in Drawing 303317.M.001. Galvanized sheet metal, PVC, fiberglass or other material can be employed. The Contractor shall specify duct work material for Purchaser's review and approval.

2.5.2 Contractor shall provide properly sized duct work to connect the radon removal system to the manway adapters on the silo. The Contractor can specify solid duct work as in 2.5.1 or flexible duct. Contractor is to specify duct work material for Purchaser's review and approval.

2.6 ELECTRIC MOTORS

2.6.1 Motors shall be totally enclosed, non-ventilated, construction and manufactured by General Electric, Westinghouse, Allis-Chalmers, or other Purchaser approved Supplier. Motors above three horsepower shall be for 480 volt, 3 phase, 60 cycle current. All motor starting equipment will be furnished by the Purchaser and mounted in a remotely located Vendor supplied load center. Motor enclosures and insulation shall be suitable for outdoor installation in southern Ohio. Motors shall conform to the requirements of

current SEEE and NEMA Standards covering such motors.

2.6.2 All instrumentation shall be subject to the approval of the Purchaser.

2.7 COMPONENTS IDENTIFICATION

2.7.1 All equipment furnished by the Contractor, including fans, dampers, piping, fittings, hangers, instrumentation, miscellaneous parts, assemblies and other process units shall be described in materials lists. All items shall be marked with proper identification by the Contractor or his Supplier in order that there shall be no confusion at the time of erection of the equipment. Material lists shall be supplied to the Purchaser prior to shipment of material to the site.

2.8 SHIPPING POINT

2.8.1 All materials and systems will be shipped to the Purchaser's plant site.

2.9 DELIVERY

2.9.1 Delivery of the equipment to the Purchaser's plant shall be on or about September 30, 1987.

SPECIFICATION NO. 303317-RRS-02

SPECIFICATION FOR FABRICATED MANWAY ADAPTERS

Prepared for:

FEED MATERIALS PRODUCTION CENTER
WESTINGHOUSE MATERIALS COMPANY OF OHIO
FERNALD, OHIO

AUGUST, 1987

NEW:DH-12(1)

ASI COMPANY

PREPARED BY: _____ DATE: _____

CHECKED BY: _____ DATE: _____

APPROVED BY: _____ DATE: _____

APPROVED BY: _____ DATE: _____

WESTINGHOUSE MATERIALS COMPANY OF OHIO

APPROVED BY: _____ DATE: _____

APPROVED BY: _____ DATE: _____

APPROVED BY: _____ DATE: _____

DEPARTMENT OF ENERGY

APPROVED BY: _____ DATE: _____

APPROVED BY: _____ DATE: _____

SPECIFICATION FOR FABRICATED MANWAY ADAPTERS

for

THE K-65 SILO AREA

of

FEED MATERIALS PRODUCTION CENTER
FERNALD, OHIO

1.0 SCOPE

1.1 This Specification covers the fabrication, and delivery of four fabricated adapters for manway openings located on K-65 storage silos of the Feed Materials Production Center, Fernald, Ohio.

1.2 The manway adapters shall be fabricated of materials as specified on Drawing 303317.A.001, and assembled by welding and bolting.

2.0 MANWAY ADAPTERS

2.1 The Contractor shall supply four manway adapters fabricated as shown on drawing 303317.A.001. The manway plate shall be fabricated from 1/2 inch carbon steel cut as shown on drawing 303317.A.001. The plate shall be 26 inch in diameter and shall contain 20-3/4 inch diameter drilled holes equally spaced on a 23 inch diameter bolt circle. The center of the plate shall be cut to accept a nominal 6 inch schedule 10S pipe.

2.2 A 6 inch diameter pipe shall be welded to the manway plate as shown in drawing 303317.A.001. The drawing calls for the use of T304 stainless steel schedule 10S carbon steel can be supplied as an acceptable substitute.

2.3 The Contractor shall provide a 6 inch - 90° close radius elbow butt welded to the 6 inch pipe assembly as shown on drawing 303317.A.001. This elbow shall be of the same material as the pipe. The top of the manway plate shall be stamped to mark the direction of the outlet of the elbow.

2.4 The Contractor shall provide a flanged connection on the opposite end of

the 6 inch pipe suitable for connection of a 6 inch damper. Details of the damper arrangement are shown on attached vendor data.

2.5 The Contractor shall fabricate the temporary manway adapters using good commercial practice. All carbon steel surfaces shall be grit blasted to a white metal finish, primed, and painted.

2.6 SHIPPING POINT

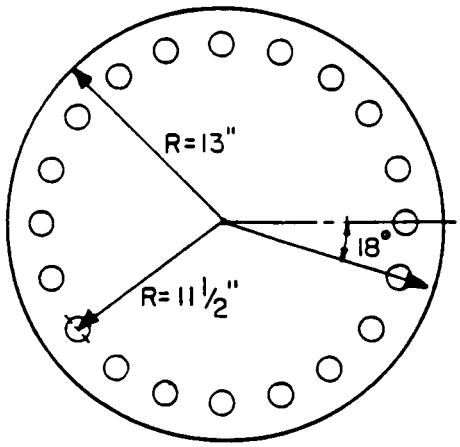
2.6.1 The temporary manway adapters shall be shipped to the Purchaser's plant site.

2.7 DELIVERY

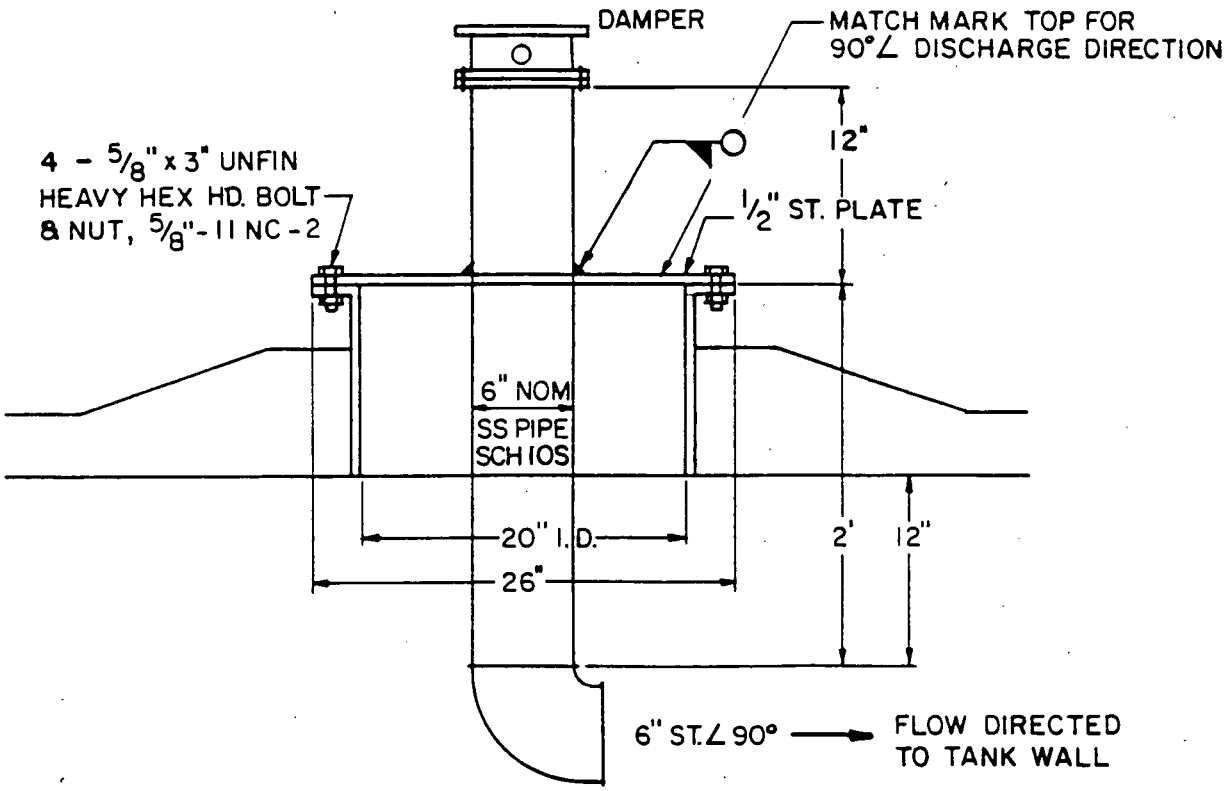
2.7.1 Delivery of the equipment to the Purchaser's plant shall be on or about September 30, 1[illegible]

BRUNING 44-132 67120

DRAWING NO.	A. 001
PROJECT NO.:	303317.09
INITIATOR: K. ATWOOD	
PROJ. ENGR.: D. HARMER	
DATE LAST REV.:	
DRAWN BY:	
STARTING DATE: 8-4-	
DRAWN BY: W. McGILL	



USE 4 BOLTS FOR TEMPORARY COVER WITH RED RUBBER GASKET.

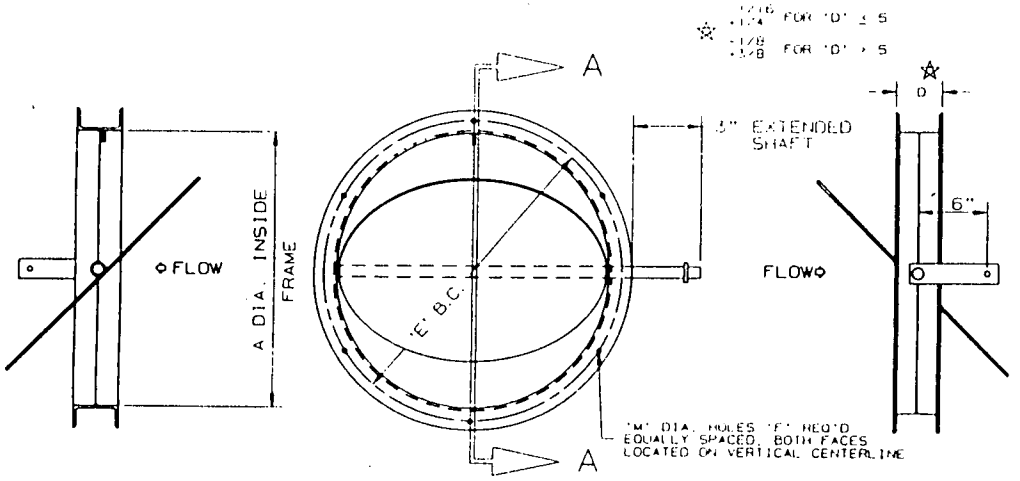


WESTINGHOUSE MATERIALS COMPANY OF OHIO
FMPC FERNALD, OHIO
TEMPORARY MANWAY COVER (4 REQ'D)
K-65 SILO PROJECT

© IT CORPORATION
ALL COPYRIGHTS RESERVED

IT ... Creating a Safer Tomorrow

"Do Not Scale This Drawing"



SECTION A-A

FACE VIEW

FLOW ENTERING SIDE

END VIEW

SHOWN WITH STD. LEVER ARM (SHIPPED LOOSE)

VC-561 STANDARD SPECIFICATIONS

MAX. FACE VELOCITY:	3900 FPM
MAX. DIFF. PRESSURE:	5" WG
MAX. TEMPERATURE:	150 DEG. F (WITH SEALS) 250 DEG. F (WITHOUT SEALS)
DAMPER SIZE RANGE:	3-1/16" TO 11-1/8" DIAMETER
AIR QUALITY:	CLEAN

FRAME: 7/8" X 1" X 11 GA. MIN. STL ANGLES, 1-3/4" DEEP, (3-1/16" DIA.)
15/16" X 1" X 11 GA. MIN. STL ANGLES, 1-7/8" DEEP, (4-1/16" DIA.)
1" X 1" X 11 GA. MIN. STL ANGLES, 2" DEEP, (5-1/16" & 6-3/32" DIA.)
1" X 1-1/8" X 11 GA. MIN. STL ANGLES, 2" DEEP, (7-1/8" & 8-1/8" DIA.)
1-1/8" X 1-1/4" X 11 GA. MIN. STL ANGLES, 2-1/4" DEEP, (9-1/8" DIA.)
1-1/4" X 1-3/8" X 11 GA. MIN. STL ANGLES, 2-1/2" DEEP, (10-1/8" & 11-1/8" DIA.)

SLEEVE: 16 GA. STL. (USED WITH OPTIONAL EXTENDED FRAME)

BLADE: 14 GA. STEEL, WELDED TO AXLE.

AXLE: 1/2" DIA. STEEL, FULL LENGTH

BEARINGS: OIL IMPREGNATED BRONZE

STOPS: PIN STOP

SEALS: (OPTIONAL SEE SCHEDULE)

FINISH: ONE COAT OF MAGNUS P-300 SERIES PRIMER.

ACTUATOR: EXTENDED SHAFT WITH LEVER ARM IS STANDARD. (SEE SCHEDULE FOR OPTIONS)

NOTES

1). SEE REVERSE SIDE FOR LEAKAGE, TORQUE, & PRESSURE DROP CHARTS.

DATE: _____

CUSTOMER: _____

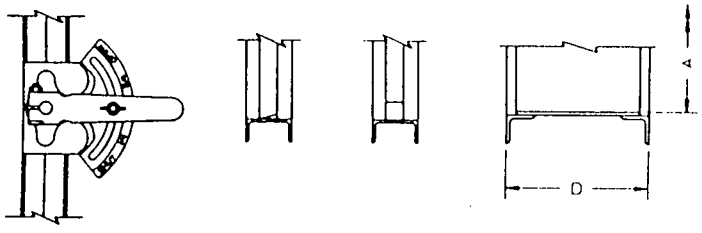
ARCH/ENGR.: _____

CUSTOMER ORDER NO.: _____

AGENT ORDER NO.: _____

AWV PRODUCTION NO.: _____

AVAILABLE OPTION DETAILS



MANUAL QUAD

EPT SEAL

BAR SEAL

EXTENDED FRAME

ITEM NO.	QTY.	DIMENSIONS							AVAILABLE OPTIONS					TAGGING
		'A' DIA. STD. FRM.	'D' DEPTH STD. FRM.	'A' DIA. EXT. FRM.	'D' DEPTH EXT. FRM.	'E' BOLT CIRCLE	'M' HOLES	'F' HOLES	MANUAL QUAD.	EPT SEAL	BAR SEAL	FRAME TYPE STD.	FRAME TYPE EXT.	
1		3-1/16	1-3/4	2-7/8	3	4-5/16	9/32	6			N/A			
2		4-1/16	1-7/8	3-7/8	4	5-5/16	9/32	6			N/A			
3		5-1/16	2	4-7/8	5	6-5/16	9/32	6			N/A			
4		6-3/32	2	5-7/8	6	7-5/16	9/32	6			N/A			
5		7-1/8	2	7	7	8-1/2	3/8	6						
6		8	2	8	8	9-9/16	3/8	6						
7		[illegible]	2-1/4	9	9	10-5/8	7/16	6						
8		10-1/8	2-1/2	10	10	11-13/16	7/16	6						

REVISION	DATE	DRN	APPD

AMERICAN WARMING AND VENTILATING INC.

1310 INDIAN WOOD CIRCLE MAUMEE, OHIO

VC-561 VOLUME CONTROL [illegible]

(3-1/16" THRU 11-1/8" DIA.)

CKD. BY RCG	APPD. BY ELP	
DRN BY	DWG NO	REV

SPECIFICATION NO. 303317-RRS-03

SPECIFICATION FOR RADON MONITORING INSTRUMENTATION

Prepare For:
Feed Materials Production Center
Westinghouse Materials Company of Ohio
Fernald, Ohio

August 1987

ASI COMPANY

Prepared By _____ Date _____

Checked By _____ Date _____

Approved By _____ Date _____

Approved By _____ Date _____

WESTINGHOUSE MATERIALS COMPANY OF OHIO

Approved By _____ Date _____

Approved By _____ Date _____

Approved By _____ Date _____

DEPARTMENT OF ENERGY

Approved By _____ Date _____

Approved By _____ Date _____

SPECIFICATION FOR RADON MONITORING INSTRUMENTATION

FOR

THE K-65 SILO AREA

OF

FEED MATERIALS PRODUCTION CENTER
FERNALD, OHIO

NEW:DH-11-cov

1.0 SCOPE

1.1 These specifications cover the furnishing and delivery of three complete radon monitoring instruments as described herein. The instruments shall provide on-line measurement of radon concentration on samples which are continuously removed from a process air stream.

2.0 RADON MONITORING INSTRUMENT

2.1 Detector - The radon monitoring instrument shall have a one-liter metal enclosed detector which is coated on the inside with zinc sulfide. The detector shall be mounted with a 5-inch diameter photomultiplier tube which is contained in a light-tight metal housing. Sensitivity at equilibrium should be 4 counts per minute (cpm) at a ^{222}Rn concentration of 1 pCi/l. The background of a new detector shall not exceed 0.25 pCi/l and shall be automatically subtracted from indicated and recorded measurements.

2.2 Microcomputer - The radon monitoring instrument shall have a microcomputer capable of providing the following:

- Day-of-year and time-of-day printed with each status change, calibration parameter change, and data printout
- Hourly and daily averages printed in pCi/l
- Test mode where data may be printed at selected intervals ranging from 1 to 9 minutes
- Instrument number, calibration factor, background subtraction, and alarm set point printed with each daily average
- Monitoring of status of power, sample flow, and alarm condition
- An alarm status print which indicates the maximum concentration in pCi/l that occurred during the alarm condition.

2.3 Printer - Alphanumeric, 21 characters per line , electric writing.

2.4 High Voltage - The radon monitor shall have voltage regulated and adjustable by an internal control to about 1700 V. The supply shall be a plug-in module for ease of maintenance.

2.5 Amplifier - The radon monitor amplifier shall have a charge sensitive input followed by a dc-coupled amplifier with feedback for stability. Overall sensitivity shall be adjustable by an internal control. The amplifier shall be a plug-in module for ease of maintenance.

2.6 Low Voltage Power Supply - Low voltage power shall be supplied with regulators for all supply voltages which are required by the instrument. Back-up batteries are to be supplied for critical components to insure data acquisition during interruptions of primary power. The instrument shall automatically recharge batteries when power is restored.

2.7 Power - Unit shall operate on 115V, 50/60 Hz line power at about 24 VAC or 12 Vdc at about 1A.

2.8 Temperature - The radon detection instrument shall be designed for operation between 0°F and 110°F (-18°C to 45°C). The unit shall also be capable of operation for extended periods at lower temperatures.

2.9 Environmental Capabilities - The radon detection instrument shall be of a size and design that will allow the unit to operate unattended in an outdoor environment in Southern Ohio. The instrument shall be installed in the equivalent of a NEMA3R enclosure and shall be self supporting.

2.10 Component Identification - All equipment furnished by the Contractor, including instrument packages, supporting devices, instruction manuals, calibration devices, etc. shall be described in materials lists. All items shall be marked with proper identification by the Contractor or his Supplier in order that there shall be no confusion when the instrument packages arrive on site. Material lists shall be supplied to the Purchaser prior to shipment of instruments to the site.

2.11 Shipping Point - All material shall be shipped to the Purchaser's plant site.

2.12 Delivery - Delivery of the instruments to the Purchaser's plant shall be on or about September 30, 1987.

3.0 Recommended Instrument - Eberline model RGM-2 or equivalent.

SPECIFICATION NO. 303317-RRS-04

SPECIFICATION FOR PORTABLE BUILDINGS

Prepared for:

FEED MATERIALS PRODUCTION CENTER

WESTINGHOUSE MATERIALS COMPANY OF OHIO

FERNALD, OHIO

AUGUST, 1987

NEW:DH-7(1)

ASI COMPANY

PREPARED BY: _____ DATE: _____

CHECKED BY: _____ DATE: _____

APPROVED BY: _____ DATE: _____

APPROVED BY: _____ DATE: _____

WESTINGHOUSE MATERIALS COMPANY OF OHIO

APPROVED BY: _____ DATE: _____

APPROVED BY: _____ DATE: _____

APPROVED BY: _____ DATE: _____

DEPARTMENT OF ENERGY

APPROVED BY: _____ DATE: _____

APPROVED BY: _____ DATE: _____

NEW:DH-7(2)

SPECIFICATION FOR PORTABLE BUILDINGS

for

THE K-65 SILO AREA

of

FEED MATERIALS PRODUCTION CENTER
FERNALD, OHIO

1.0 SCOPE

1.1 This specification covers the furnishing, delivery, and placement of temporary buildings. One building will be used to provide a weather cover for a process system designed for radon removal. The second structure will be used as a control house where electrical equipment and control and recording instrumentation will be located.

1.2 The portable buildings shall be of a free standing type designed for placement on a concrete slab provided by the Purchaser. The attached drawing 303317.G.01 shows the location of the concrete slab and the proposed location of the portable buildings.

2.0 PORTABLE BUILDINGS

2.1 ADSORPTION SYSTEM BUILDING

2.1.1 The Contractor shall supply a portable building with inside open dimensions which are at least 22' x 24'. The building shall be constructed in two halts for final assembly in the field.

2.1.2 The Contractor shall supply the portable building constructed with 4" x 6" pressure treated base timbers. The timbers will rest on the Purchaser supplied concrete pad. The building provided shall be constructed with no floor or other internal bracing once properly erected. The Contractor shall brace the structure halfs as required for structural integrity during shipping.

2.1.3 The Contractor shall employ 2" x 4" x 8' framing material for side walls and shall be spaced no more than 24 inches on centers.

2.1.4 The Contractor shall provide roofing support constructed with 2" x 4" truss design or other suitable structural design. Snow load for Southern Ohio must be considered in the design.

2.1.5 The Contractor shall cover the roof and sides of the building with aluminum materials designed for this service. The aluminum supplied shall be at least 0.021 inch in thickness and applied and fostered in a commercially acceptable manner.

2.1.6 In accordance with the attached drawing 303317.M.001, the building shall contain a door which shall be located as shown. The door shall be of standard design for outdoor use and sized at 4.0 x 6.8.

2.1.7 The Contractor shall construct the building in two halves of a nominal 11' x 24' size. The Contractor shall deliver the building halves to the job site and placed as shown in drawing 303317.M.001.

2.1.8 After the Contractor has located the building, he shall attach building halves and perform any leveling required.

2.1.9 The design life of the building shall be 5 years and materials and workmanship not specified in detail in this document shall be suitable for this building life considering the environment in Southern Ohio.

2.2 <u>Control Building</u>

2.2.1 The Contractor shall supply a portable building with inside open dimensions which are 10' x 14'. The building shall be constructed as a single complete structure and fabricated following specification items 2.1.2, 2.1.3, 2.1.4, 2.1.5, 2.1.6, and 2.1.7. If Contractor standard construction includes a built-in floor, it shall be provided with this building.

2.2.2 After delivery and placement of the building, the Contractor shall perform any leveling required.

2.3 Component Identification

2.3.1 All equipment and items furnished by the Contractor shall be described in materials lists and all items marked with proper identification by the Contractor in order that there shall be no confusion at the time of erection of the buildings. Material lists shall be supplied to the Purchaser prior to shipment of the building to the site.

2.4 Shipping Point

2.4.1 The portable buildings will be shipped to the Purchaser's plant site.

2.5 Delivery

2.5.1 Delivery of the equipment to the Purchaser's plant shall be on or about September 30, 1987.

Utilities List

1.0 Foam Operation

• Air Compressor	60 - 100 gallons diesel

2.0 Radon Removal

• Fan and Spare	480 Volt, 3 phase, 60 Hz, 10 bhp, 150A starting Rated kVA = $\sqrt{3}$ * 480V * 300A/1000 = 250 kVA
• Radon Instruments (2)	115 Volt, 60 Hz, 1A 2 * 115 * 1A/1000 = .230 kVA
• Lighting (1000 W)	110 Volt, 60 Hz 1000 VA/1000 = 1.0 kVA
• Spares (500 W)	110 Volt, 60 Hz 500 VA/1000 = .5 kVA
	Total kVA ≈252 kVA

SUGGESTED VENDOR LIST

Dampers

American Warming & Ventilating, Inc.
1310 Indian Wood Circle
Maumee, OH 43537

Air-Rite, Inc.
Pittsburgh, PA

Industrial Dampers Company
Cincinnati, OH

Effox, Inc.
Cincinnati, OH

Dehumidifiers and Carbon Adsorption Systems

General Dynamics Services Company
14 Holmes Street
Mystic, CT 06355

Purefil, Inc.
P.O. Box 80434
Atlanta, GA 30360

Baron-Blakeslee, Inc.
17 West 6th. Street
Cincinnati, OH 45202

Tigg Corporation
Box 11661
Pittsburgh, PA 15228

Radon Instrumentation

Eberline Instrument Corporation
P.O. Box 2108
Santa Fe, NM 87501

NRC Industries
Division of Nuclear Research Corporation
125 Titus Avenue, P.O. Box H
Warrington, PA 18976

Fans

Phelps Fan Manufacturing Company, Inc.
P.O. Box 9588/9417 New Benton Highway
Little Rock, AR 72219

Hertzell Fan, Inc.
Piqua, OH 45356

Portable Buildings

Fay Portable Buildings, Inc.
6400 Kingston Pike
Knoxville, TN

Foam Applicators

Foam Enterprises, Inc.
[illegible]0 Watertower Circle
[illegible]eapolis, MN 55441

[illegible]ern Foam Systems, Inc.
[illegible]dwin Street
[illegible]eport, CT 06607

Two-[illegible]bile [illegible]adios

Communication Specialists, Inc.
3044 Sutherland Avenue
Knoxville, TN

SECTION 4.0
FOAM APPLICATION

SPECIFICATION NO. 303317-FA-01

SPECIFICATION FOR POLYURETHANE
FOAM APPLICATION

FOR

THE K-65 SILO AREA

OF

ED MATERIALS PRODUCTION CENTER
FERNALD, OHIO

August 1987

NEW:DH-9-cov

ASI COMPANY

PREPARED BY: _____ DATE: _____

CHECKED BY: _____ DATE: _____

APPROVED BY: _____ DATE: _____

APPROVED BY: _____ DATE: _____

WESTINGHOUSE MATERIALS COMPANY OF OHIO

APPROVED BY: _____ DATE: _____

APPROVED BY: _____ DATE: _____

APPROVED BY: _____ DATE: _____

DEPARTMENT OF ENERGY

APPROVED BY: _____ DATE: _____

APPROVED BY: _____ DATE: _____

SPECIFICATION NO. 303317-FA-02

SPECIFICATION FOR CAMERA AND COMMUNICATION SYSTEMS

for

THE K-65 SILO AREA

of

FEED MATERIALS PRODUCTION CENTER
FERNALD, OHIO

AUGUST, 1987

ASI COMPANY

PREPARED BY: _____ DATE: _____

CHECKED BY: _____ DATE: _____

APPROVED BY: _____ DATE: _____

APPROVED BY: _____ DATE: _____

WESTINGHOUSE MATERIALS COMPANY OF OHIO

APPROVED BY: _____ DATE: _____

APPROVED BY: _____ DATE: _____

APPROVED BY: _____ DATE: _____

DEPARTMENT OF ENERGY

APPROVED BY: _____ DATE: _____

APPROVED BY: _____ DATE: _____

CAMERA AND COMMUNICATION SYSTEMS FOR
K-65 SILO FOAM APPLICATION

1.0 CAMERA SYSTEM

A remote viewing camera is necessary to assure the foam application process is performed in a manner as planned to provide maximum radon attenuation and structural support for the K-65 silos. The sketch included in this section shows a simple design that would allow sufficient capability for monitoring the foaming process.

1.1 CAMERA

A recommended camera which is readily available and is also functional in radiation areas is Photosea System Inc's model TV-100S. It is a black and white camera and can be purchased from surplus at General Public Utilities, Three Mile Island Nuclear Plant, Unit 2, Middletown, PA. Contact in TMI Purchasing is Mr. Art Farr. Two cameras (1 as a spare) should be taken to the site.

1.2 POWER SUPPLY

A recommended power supply for the aforementioned camera is model TP-1000. This unit is also available from Photosea. A spare should be brought to the site.

1.3 MONITORS

Black and white monitors are normally readily available from many vendors. Photosea's model VM09 is a monitor that mates very easily with the above camera and power supply. A spare monitor should be brought to the site.

1.4 LIGHTING

Lighting for the television monitoring system must be capable of illuminating the walls across 50 feet of airspace in the dome. It is highly recommended that the light be attached to the camera in a manner that makes the light directional with the view of the camera. Contact Remote Ocean Systems for proper lighting fixtures. (Spare lights recommended.)

1.5 PAN AND TILT

The pan and tilt mechanism is critical to the viewing capability of the camera. It should provide a pan of 360° and tilt of 90°.

1.6 VENDORS

• Power Supplies • Monitors		Photosea Systems, Inc.* 6377 Nancy Ridge Dr. Attn: Mr. Tom Olkowski Phone: 619-452-8903
• Lighting • Pan and Tilt		Remote Ocean Systems* 5111 Santa Fe St., Suite L San Diego, CA 92109 Attn: Mr. Bob Acks Phone: 619-483-3902

1.7 A VHS-VCR unit should be installed to record the foaming process. The VCR is an item that may be rented; however, the VHS blank cassettes must be purchased. Total recording time is approximately 140 hours.

2.0 COMMUNICATIONS

2.1 The communication between the foam operator and lead engineer during foam application will be extremely important for quick and thorough coverage of the K-65 silo residue during the initial phases of the work. The system must be reliable and operate in such a way that foaming progress is not impeded.

2.2 PORTABLE TWO-WAY RADIOS

2.2.1 A portable two way radio with a throat microphone/speaker is recommended. This system requires no manual operations by the user for communicating. Foam operator and lead engineer will have their hands free to perform any required tasks during the foam application.

*Note: Above two vendors have worked together in the past. They seem to be anxious to put a system together for the K-65 project.

2.2.2 G.E. model P5F58 portable radios have the required features and are readily available for this project.

2.2.3 <u>VENDOR</u>

2.2.3.1 Communication Specialists, Inc.
3044 Sutherland Avenue
Knoxville, TN.

REFERENCES

"Properties of Rigid Urethane Foams," Freon Product Information BA-13, E.I. DuPont De Nemours & Co. (Inc.).

Grumski, J. T., "K-65 Storage Silo Radon Mitigation and Dome Reinforcement Study, Conceptual Design Report", Westinghouse Materials Company of Ohio, Waste System Engineering, May 13, 1987.

Foam Enterprises, Inc., "MG2-B Rigid Urethane Barge Foam Industrial Flotation" technical data sheet.

Foam Enterprises "Technical Data Sheet for FE 7053," 8/7/87.

"Tests of Polyurethane Foam; Material, Equipment, and Procedure Evaluation" Twin City Testing and Engineering Laboratory, Inc., June 3, 1977.

Foam Enterprises, Inc., Excerpts from a question and answer session between Dennis Holbert, a Nigeria, Africa Customer, and their consulting engineer, May 1977.

Foam Enterprises Research, Inc., Letter directed to Dr. Harmer of IT Corporation from David C. Dressel of Foam Enterprises, Inc., July 30, 1987.

"Toxic Chemical Review for Polyurethane Foam System" prepared by IT Corporation for Advanced Sciences Inc., August 12, 1987.

DEFINED SAFETY SYSTEMS INVOLVED: ___ YES _X_ NO

1. DESCRIPTION OF EQUIPMENT AND OPERATION

1.1 Field production of polyurethane foam involves a continuous blending and pouring process. The principal foam reactants usually a polyisocyanate, a polyol, and a blowing agent are pumped through separate hoses to a mixing manifold on the butt of an application tool. The foam components begin to react as they mix and once applied will expand and set-up in a matter of minutes. The maximum application rate is about 100 lbs/min of foam. Other support operations in the foam system include pumping of a chlorinated solvent to the application lance for clearing out foam reactants, and compressed air for pump operation and blowing solvent out of the lance.

1.2 The polyurethane foam will be applied to fill the head space in the K-65 silos for the purposes of radon attenuation and to enhance the structural integrity of the concrete domes of the silos. The foam fill will involve the use of three different polyurethane products to be applied in a five phase operation with an optional sixth phase. General arrangement drawings are attached for foam application equipment and system layout. Also attached is an illustration for the application scheme for the foam fill. The operational phases are described as follows:

1.2.1 Elastomer precoat - An initial layer of special elastomer will be applied. This layer will attenuate radon and will provide a primer surface for application of subsequent foam layers.

1.2.2 Rigid foam sealing layer - This close-cell foam will be applied in a 18-30 inch layer for the purpose of providing a secondary seal for

radon attenuation.

1.2.3 Elastomer caulking - A second application of elastomer is performed around the border of the rigid foam layer for extra sealing assurance.

1.2.4 Flexible foam fill - Flexible open-cell foam will be applied between the rigid foam and the dome leaving space at the center of the silo for a rigid foam core. The flexible foam will provide some structural support for the dome while cushioning the expansion and contraction of the entire foam composite.

1.2.5 Rigid foam core - A second rigid foam application is designed to provide structural support for the center 20 foot diameter area of the silo dome.

1.2.6 Optional protective outer foam coating - A 2-inch thick protective foam barrier is sprayed on top of the dome. This barrier will provide weather protection and insulate the dome. Thermal expansion and contraction and freeze/thaw damage to dome will be reduced significantly.

2. ENVIRONMENTAL CONSIDERATIONS

At the present time, radon gas is escaping to the atmosphere through the K-65 silo dome at a rate of 60 Ci/yr. During the foam filling process, a maximum of 8 curies of radon will be displaced to the atmosphere. After the foam fill, random escape should be virtually eliminated.

3. INDUSTRIAL HEALTH AND SAFETY REQUIREMENTS

3.1 Normal process clothing and safety glasses shall be worn at all times.

3.2 Chemical goggles and chemical resistant gloves will be worn when working on or about hoses or pumps containing foam components.

3.3 An additional chemical respirator with organic vapor cartridges will be required for the foam application operation. Fans will be placed at the foam injection point for dispersing radon and other organic vapors away from the operator.

3.4 Foam components are combustible and emit toxic fumes when burning. No smoking, matches, or open flame is allowed. There will be a designated smoking area provided at a safe distance from the process.

3.5 A portable eyewash station and a continuous water supply shall be provided in case of chemical exposure.

3.6 Refer to the Toxic Chemical Review section of the design report for further information and MSDS for each of the chemicals to be used in the foaming process.

3.7 To minimize man-rem exposure, work on the K-65 silo must be well planned and performed such that no more time than necessary is spent on the dome.

3.8 Any action which results in intake of radioactive materials or over-exposure to foaming chemicals will be immediately reported to a supervisor.

4. PROCEDURE

4.1 PREPARATION

4.1.1 A remote video camera will be installed at the center manway. The radon treatment system may continue to operate during installation.

4.1.2 Operation of camera and lighting will be checked.

4.1.3 Foaming equipment will be prepared for Phase 1 application.

4.1.4 A review of safety precautions and operational procedures will be conducted by the lead engineer of the foam crew. All personnel involved with the project will attend the meeting.

4.1.5 The foam crew will walk-through the procedural steps for applying the foam.

4.1.6 Operation of safety equipment and two-way radio will be checked.

4.2 Phase 1 - Elastomer System

4.2.1 Hold point - When the radon measuring equipment on the radon treatment system indicates a level of 7.2×10^5 pCi/l or lower for silo #1 or 9.1×10^5 or lower for silo #2, the decision is made to proceed with the foam operation.

4.2.2 Ventilation system duct and cover are removed from a manway.

4.2.3 Using the video monitor, foam operator is instructed by the lead engineer in application of elastomer through the manway. Surfaces are covered as quickly as possible in all directions about the manway.

Note: Operating time on the dome surface must be minimized in every phase of this work.

4.2.4 When application at this manway is nearly complete, duct and cover from a second manway will be removed.

4.2.5 Temporary cover is placed over the first manway. The cover consists of a 26 inch diameter, 3/4 inch thick plywood disc with 4 holes drilled to match manway bolt holes.

4.2.6 Elastomer will quickly be applied on surfaces through second manway.

4.2.7 Steps 6.2.1 - are repeated for the third and forth manways.

4.2.8 Upon completion of Phase 1, the lance is cleared using solvent and air supplied to lance. Drums for waste solvent are located on berm for this operation.

Note: Solvent used to clean lance is not to be blown through manways.

4.2.9 Quality of the elastomer layer is visually evaluated and a touch-up operation is performed if necessary.

4.2.10 Using a measuring stick or other devise, the distance from the elastomer surface to the dome is measured at nine or more equally spaced access points.

4.3 <u>Phase 2 - Rigid Foam Seal</u>

4.3.1 The changes in reaction components will be made for rigid foam production.

4.3.2 A foam test will be performed to ensure good quality foam. A sample of the foam will be retained for WMCO.

4.3.3 The first temporary manway cover is removed.

4.3.4 Using the video monitor, the foam operator is instructed in application of the foam in a 18-30 inch layer over the elastomer.

4.3.5 When foaming is nearly complete through first manway, the cover from a second manway is removed.

4.3.6 The foam operation is continued through second manway. The first temporary manway cover #1 is replaced.

4.3.8 Steps 6.3.3 - 6.3.7 are repeated for the third and forth manways.

4.3.9 The foam lance is cleared using solvent and air.

4.3.10 Allow at least a 1 hour cure time before Phase 3.

4.3.11 Inspection of foam progress. Using the same technique as in 4.2.10, measure the distance from the top of the rigid foam to the dome. Using these measurements, determine the thickness of the rigid foam. More foam must be added where the the thickness is less than 18 inches.

4.4 <u>Phase 3 - Elastomer Caulking</u>

4.4.1 Foam components are changed for elastomer production.

4.4.2 Foam test and quality check are performed. Retainer sample is taken for WMCO.

4.4.3 The first temporary manway cover is removed.

4.4.4 Elastomer is applied to interior side walls of silo and in between the walls and the rigid foam layer. Remote camera is used to direct the application.

4.4.5 Second manway cover is removed and first cover replaced.

4.4.6 Steps 6.4.4 and 6.4.5 are repeated for the third and forth manways. Smaller 2 inch openings may be used to apply elastomer if necessary.

4.4.7 Visual evaluation of elastomer caulking is performed.

4.5 Phase 4 - Flexible Foam Fill

4.5.1 Foam components are changed for flexible foam foam production.

4.5.2 Foam test and quality check are performed. Retainer sample is taken for WMCO.

4.5.3 Flexible hose extensions are placed in all dome injection points with connections readily available for attachment to lance.

4.5.4 Lance is attached to a hose extension near the perimeter of the dome

and foam flow is established.

4.5.5 The lance is left on the dome with foaming in progress while the foam operator takes a position off the dome surface but near the lance.

4.5.6 As the foam fills the space between the rigid foam and the dome, the lance will be moved to other locations around the perimeter and towards the center of the dome. A space with dimensions of about 20-30 ft in diameter and 6-8 feet deep will be left at the center top of the silo.

4.5.7 Inspection of flexible foam. The same technique used in step 4.3.10 is used here to determine the thickness of the flexible foam. The foam must be at least 3 feet thick at the center manway.

4.6 Phase 5 - Rigid Foam Core

4.6.1 Foam components are changed for rigid foam production.

4.6.2 Foam test and quality check are performed. Retainer sample is taken for WMCO.

4.6.3 Remote camera is removed from center manway.

4.6.4 Foam lance with extension is situated at center manway for remote foaming and foam flow is established.

4.6.5 Foam operator leaves lance and takes a position off the dome as foaming continues.

4.6.7 Foam progress is monitored by remote camera, now positioned outside of

the center manway, or by periodic manual inspection. Position of foam lance is changed as necessary fill the void space at the top of the silo.

4.6.8 When foaming is complete, foam lance is cleared with solvent and air.

4.6.9 Foam overflow is removed from dome surfaces, flexible lance extensions are cut off, and all covers are replaced on dome openings.

4.7 Phase 6 - Optional Protective Dome Cover

4.7.1 Spraying equipment is prepared and foam components changed for rigid foam application.

4.7.2 Test spray is performed. Retainer sample is taken.

4.7.3 Starting at the dome center and moving quickly to outer surfaces, a 2-inch layer of rigid foam is applied. Manways and other dome protrusions are not coated in this step.

4.7.4 Spray attachments are cleared with solvent and air.

4.7.5 Foam components are changed to production of polyurethane weather barrier coating.

4.7.6 Test spray is performed and retainer sample is taken.

4.7.7 Barrier coating is applied to the dome on top of the rigid foam layer.

4.7.8 Final inspection of foam results.

PROCEDURE FOR INTERRUPTION OF FOAM APPLICATION FOR K-65 SILOS

REFERENCES: None.

DEFINED SAFETY SYSTEMS INVOLVED _____Yes __X__No

1.0 DESCRIPTION OF EQUIPMENT AND OPERATION

1.1 Equipment and operational procedures for foam application at the K-65 silos are described in SOP-303317-02. The operation of the radon treatment system described in SOP-303317-01 is designed to eliminate the accumulated radon gas in the K-65 silos. The radon gas, however, is generated continuously from the K-65 residue, therefore, it is important that the radon attenuation layer of foam be applied quickly. Should a breakdown of the foam equipment occur, or any other situation which would interrupt the application of foam, decisive action must be taken to seal the dome and prevent radon release while diverting attention to the other problem. In addition, a procedure must be available for restarting the foam process after the delay.

1.2 In the foam application procedure, only one manway is open to the atmosphere at any one time during the performance of Phases 1, 2, and 3. If the work is interrupted during this time, a temporary cover will be immediately placed on the manway through which the operator was working. If the work is delayed for more than one work shift, radon monitoring equipment will be used to determine radon level in the silo head space. If radon level exceeds 2.9×10^6 pCi/ ℓ in silo No. 1 or 3.65×10^6 pCi/ ℓ in silo No. 2, the radon treatment system will be reinstalled and accumulated radon removed before foaming is continued.

1.3 Once Phases 1-3 are complete, there will be no need for the radon treatment system during the rest of the foam application. If a delay occurs during Phases 4 or 5, any opening in the dome will be closed immediately until the work can be continued. In Phase 6 of the foaming, the dome is sealed from the start so radon exposure is not an issue. However, it will necessary to leave the dome area immediately if problems arise during Phase 6 operations.

2.0 ENVIRONMENTAL CONSIDERATIONS

See SOP-303317-02 for radon gas considerations.

3.0 INDUSTRIAL HEALTH AND SAFETY REQUIREMENTS

Nothing additional to those noted in SOP-303317-02.

4.0 PROCEDURE

4.1 INTERRUPTION OF PHASE 1, 2, OR 3

4.1.1 It is determined that the operation must be delayed to correct a problem. Foam operator leaves the dome area immediately.

4.1.2 Cover for manway is replaced, sealing dome.

4.1.3 Delay was less then one work shift and the decision is made to continue foaming.

4.1.4 Cover for manway is removed and foaming is continued per SOP-303317-02.

4.1.5 Duration of delay was greater than one shift and radon monitoring

Utilities List

1.0 Foam Operation

• Air Compressor	60 - 100 gallons diesel

2.0 Radon Removal

• Fan and Spare	480 Volt, 3 phase, 60 Hz, 10 bhp, 150A starting Rated kVA = $\sqrt{3}$ * 480V * 300A/1000 = 250 kVA
• Radon Instruments (2)	115 Volt, 60 Hz, 1A 2 * 115 * 1A/1000 = .230 kVA
• Lighting (1000 W)	110 Volt, 60 Hz 1000 VA/1000 = 1.0 kVA
• Spares (500 W)	110 Volt, 60 Hz 500 VA/1000 = .5 kVA
	Total kVA ≈252 kVA

SUGGESTED VENDOR LIST

Dampers

American Warming & Ventilating, Inc.
1310 Indian Wood Circle
Maumee, OH 43537

Air-Rite, Inc.
Pittsburgh, PA

Industrial Dampers Company
Cincinnati, OH

Effox, Inc.
Cincinnati, OH

Dehumidifiers and Carbon Adsorption Systems

General Dynamics Services Company
14 Holmes Street
Mystic, CT 06355

Purefil, Inc.
P.O. Box 80434
Atlanta, GA 30360

Baron-Blakeslee, Inc.
17 West 6th. Street
Cincinnati, OH 45202

Tigg Corporation
Box 11661
Pittsburgh, PA 15228

Radon Instrumentation

Eberline Instrument Corporation
P.O. Box 2108
Santa Fe, NM 87501

NRC Industries
Division of Nuclear Research Corporation
125 Titus Avenue, P.O. Box H
Warrington, PA 18976

Fans

Phelps Fan Manufacturing Company, Inc.
P.O. Box 9588/9417 New Benton Highway
Little Rock, AR 72219

Hertzell Fan, Inc.
Piqua, OH 45356

Portable Buildings

Fay Portable Buildings, Inc.
6400 Kingston Pike
Knoxville, TN

Foam Applicators

Foam Enterprises, Inc.
13630 Watertower Circle
Minneapolis, MN 55441

Eastern Foam Systems, Inc.
1-T Edwin Street
Bridgeport, CT 06607

Two-Way Mobile Radios

Communication Specialists, Inc.
3044 Sutherland Avenue
Knoxville, TN

SECTION 5.0
ALARA REVIEW

5.0 ALARA REVIEW

A review of the work being engineered on the K-65 silos was made from a radiation control standpoint. The following outlines the assumptions made and the results obtained in this review.

5.1 STATEMENT OF WORK

In order to minimize releases of radon gas to the environment and to help structurally support the silo tops, WMCo has decided to insert a series of foams into the void air space at the top of both silos. A ventilation system will first be installed that will reduce the concentration of radon gas in the void air space. Then a two inch elastomer layer will be poured onto the surface of the residues in the tank. A two foot thick layer of rigid foam will then be sprayed in the silos. A "caulking" layer of elastomer will then be applied around the edges of the two foot thick rigid foam insert. The silos will then be filled to within two feet of the top in the center with flexible foam. Finally, the small remaining void will be filled with rigid foam.

5.2 ASSESSMENT

Researching various documents concerning the K-65 silos and discussing the conditions as assessed by WMCo with project personnel, existing parameters were assumed for a silo that represents a mean condition. Table 5.2.1 describes the assumed existing conditions.

By inserting the parameters of Table 5.2.1 into a dose estimating program, MICROSHIELD®, with the varying elastomer and foam levels, the dose rate at a point 81 cm above the center point of the idealized silo was calculated for the following conditions. (For details, see Appendix).

1. Existing sludge
2. Existing airspace
3. Airspace evacuated, elastomer in place
4. Air space evacuated, 2' rigid in place
5. Air space evacuated, 6' flexible in place
6. All foam in place
7. All foam in place, new equilibrium of Rn daughters

A summary of the dose rates, both measured currently and calculated by MICROSHIELD® are given in Table 5.2.2.

In reviewing the draft operating procedures and design criteria for equipment, equipment placement and shielding placement, the ALARA considerations given in Table 5.2.3 were used as guidelines. Based on these dose rates and a review of the draft procedures for foam installation, a man-millirem budget was calculated and is given as Table 5.2.4.

TABLE 5.2.1
PARAMETERS FOR SILO DOSE RATE CALCULATIONS

Basis:

There are 1404.2 Ci radium in sludge and 37.4 Ci radon in 50% equilibrium (with daughters) in the void air space. Dimensions and densities are as follows:

a. 1005.8 cm height from silo bottom to exposure point
b. 609.6 cm depth of sludge at 1.6 grams/cc
*c. 304.8 cm height of air at 0.00129 grams/cc
d. 10.2 cm thickness of silo dome concrete at 2.300 grams/cc
e. 81.2 cm air between silo dome and observation at 0.00129 grams/cc
f. 1220 cm silo radius
g. 2440 cm silo diameter

Calculation Cases:

1. 609.6 cm of sludge

2. c 304.8 cm air at 0.00129 g/cc

3. c 5.1 cm elastomer at 0.715 g/cc
   c' 299.7 cm air at 0.00129 g/cc

4. c 5.1 cm elastomer at 0.715 g/cc
   c' 60.96 cm foam at 0.0318 g/cc
   c" 238.7 cm air at 0.00129 g/cc

5. c 5.1 cm elastomer at 0.175 g/cc
   c' 243.84 cm foam at 0.05560 g/cc
   c" 55.82 cm air at 0.00129 g/cc

6. c 5.1 cm elastomer at 0.715 g/cc
   c' 304.8 cm foam at 0.05085 g/cc

7. Same shielding as Case 6.

*Note: c, c', c" - represents air heights after stages of foam placement.

TABLE 5.2.2

RADIATION DOSE RATES ON CENTER OF SILO

MEASURED - 250 MR/HR. @ CONTACT
150 MR/HR. @ 3'

CALCULATED - 191 MR/HR. @ 80 CM

CALCULATED WITH ELASTONER IN PLACE - 86 MR/HR.

CALCULATED WITH ALL FOAM IN PLACE - 34.1 MR/HR.

CALCULATED WITH ALL FOAM IN PLACE AND EQUILIBRIUM RE-ESTABLISHED - 78.9 MR/HR.

TABLE 5.2.4
MAN MILLIREM ESTIMATE

Construction		
Silo #1		
Install Containments	800	
Remove Covers	1200	
Install Covers	800	
	2800	2800
Silo #2		2800
Install Ducting		240
Install TV Camera		700
Operation		
Test of Rn System		360
Radon System Operation		300
Silo #1		
Ventilate	360	
Elastomer	1150	
Inspection	200	
Rigid Foam	500	
Inspection	190	
Caulk	400	
Flexible	600	
Rigid	80	
Cleanup	150	
Dome Protect	350	
	3980	3980
Silo #2		3980
Waste Transport		50
Demobilization		50
		15,260

TABLE 5.2.3

ALARA CONSIDERATIONS

ENVIRONMENT

- o CARBON ABSORPTION SYSTEM
- o FOAM RADON ATTENUATOR
- o FOAM RADIATION ATTENUATOR

WORKERS

- o TIME REDUCTION
  - PRE-JOB ENGINEERING
  - PRE-ASSEMBLE AS MUCH AS POSSIBLE OFFSITE
  - USE OF QUALITY WORKMEN
  - PRE-PLAN JOB TO MINIMIZE WORKER TIME ON SILOS
- o DISTANCE
  - REMOVE RADON FROM SILO TO CARBON FOR FOAMING OPERATIONS
  - KEEP WORKERS OFF DOMES TO THE MAXIMUM EXTENT PRACTICABLE
  - KEEP FOAM TRUCKS, OPS TRAILER, CONTROL ROOM AWAY FROM RADIATION AREAS
  - REMOTE TV VIEWING
- o SHIELDING
  - INSTALL SOILBOX SHIELDING AROUND VENTILATION BUILDING

BALANCE QUALITY (REDUCE REWORK) VS. DOSE REDUCTION

SECTION 6.0

TOXIC CHEMICAL REVIEW

TOXIC CHEMICAL REVIEW
FOR POLYURETHANE FOAM SYSTEM

Chemicals: MDI, Diphenylmethane diisocyanate
Polyol
Dichlorodifluoromethane
Methylene chloride
Polyurethane foam finished product

The following discussion of hazardous properties for the foam chemicals was derived from the attached references 1-6. The information is believed to be accurate; however, it is possible that it does not reflect the most current information available for the materials. Nonetheless, it can serve as a guideline for the recognition of potential hazards.

Each of the chemicals to be used in the foaming operation can be hazardous if handled improperly; however, with the correct personnel protective equipment, careful handling procedures, and conscientious attitudes, the foaming operation can be performed safely.

MDI, DIPHENYLMETHANE DIISOCYANATE

Of the materials used in the foaming operation, MDI is the principal contributor to toxicity. Inhalation of MDI vapors or mists must be avoided. According to the Upjohn Bulletin 107, symptoms of overexposure can range from coughing and respiratory irritation to chemical pneumonia, depending on the level of exposure. The Threshold Limit Value (TLV) for MDI is 0.02 parts per million (ppm). In the range of 0.02 to 0.1 ppm some individuals will experience irritation. At 0.1 to 1.0 ppm respiratory irritation will occur in most cases. Above 1.0 ppm acute toxic effects are probable.

Skin contact should also be avoided. MDI can cause redness, swelling, and blistering if not removed promptly.

MDI is only slightly toxic if ingested. The Upjohn Bulletin gives an LD_{50} for rats of 5.8 grams per kilogram of body weight.

The flash point of MDI is 425°F, and MDI is considered a Class III B combustible material by the National Fire Protective Association (NFPA). MDI

will burn if exposed to a preexisting fire, producing isocyanate vapors and toxic fumes. MDI decomposes rapidly at temperatures above 450°F to hazardous products such as HCN and benzene.

Contact of MDI with water, ammonia, alcohols, amines, and alkalis must be avoided. Resultant reactions and polymerization of MDI occur quickly when contacted with these materials. Gaseous products produced will rupture a closed MDI storage container. The Foam Enterprises MSDS recommends that spills be cleaned up by covering with an absorbent material such as vermiculite or sawdust, then treating in an open top container with aqueous ammonium hydroxide. The area must be well ventilated during treatment.

PROTECTIVE EQUIPMENT

For froth/pour operations such as those at the K-65 silo operation, it is unlikely that MDI mist will be generated. In the vapor space of the silo, however, the vapor concentrations of MDI could exceed 0.04 ppm. Operators will be working outside the silo manway; however, a chemical respirator with an organic vapor cartridge will be necessary if MDI vapor concentration exceeds 0.02 ppm at the manway. Chemical goggles or a face shield should be worn for eye protection. Normal protective clothing is necessary, including gloves if hand contact is likely.

The following emergency procedures are summarized from Upjohn Chemicals Bulletin 107.

Persons exhibiting signs of overexposure to MDI vapor should be moved to fresh air immediately. If breathing is labored, oxygen should be administered by trained personnel. If breathing stops, apply artificial respiration. Get medical attention in any case.

If MDI is splashed in eyes, flush with copious amounts of water for at least 15 minutes and obtain medical attention. If contact occurs from a major spill, remove contaminated clothing and shower with water. Wipe affected areas with rubbing alcohol and follow with soap and water. For minor contact, wipe off with rubbing alcohol and wash with soap and water. Skin may show a

harmless brown discoloration which is temporary. Seek medical attention if reddening and swelling occur.

POLYOL

Upjohn reports that polyols used in polyurethane formulas "are believed to be relatively innocuous and present no known significant physiological risk." They also report that "since toxicological data on polyols are limited, they should be handled with caution."

Minor irritation will result with eye contact and no ill effects are associated with skin contact.

Foam Enterprises reports that their polyol MG2-B is stable under normal working conditions. Its flash point is greater than 300°F; however, it will burn and carbon monoxide will be produced.

Chemical goggles and rubber gloves are recommended for handling the material. If eye contact occurs, eyes should be flushed for 5 minutes with water and medical attention received if irritation persists. Soap and water will remove polyols from the skin. If ingested, induce vomiting and seek medical attention.

For spill cleanup, soak up with absorbent material and dispose of by incineration.

DICHLORODIFLUOROMETHANE

The blowing agent used in these foams is dichlorodifluoromethane, sometimes called Fluorocarbon 12. Concentrations used in the foams vary to control density. Light density foams use about 4 percent by weight blowing agent according to vendor information.

Fluorocarbon 12 is a gas above -20°F and is toxic in relatively high concentrations. The TLV for this material is 1000 ppm. Exposure to high concentrations can cause loss of feeling, unconsciousness and possibly death in extreme cases. The fluorocarbon is heavier than air and can displace air in low lying areas.

The Allied Corporation Product Safety Data Sheet reports that if Fluorocarbon 12 is handled as a liquid, exposure to skin and eyes could lead to frostbite. When handling the liquid, rubber gloves and chemical goggles are recommended. Respiratory protection is not necessary unless handling in a closed or low lying area, in which case self-contained breathing apparatus should be used.

Fluorocarbon 12 is not flammable but will decompose at high temperatures to harmful products such as phosgene. Welding and smoking must be avoided in areas where this material is in use.

Dichlorodifluoromethane has an EPA hazardous waste number of U075 and reportable spill quantity of 5000 pounds. The amount to be used as a blowing agent for the foam process will be 8,000-12,000 pounds. It is unlikely that a significant percentage of this will escape into the atmosphere.

METHYLENE CHLORIDE

Methylene chloride is used as a solvent to clear the foaming lance of polyurethane reactants after a foaming operation. It is a non-flammable, colorless liquid with a low boiling point (104°F) and high vapor pressure (340 mm Hg at 20°C).

Overexposure to methlyene chloride vapors causes narcotic effects and chemical asphyxia in extreme cases. The latest information reports a TLV of 100 ppm in air. Repeated skin contact can cause irritation. Eye contact is painful and irritating although corneal damage is not likely to occur. The LD_{50} for ingestion by rats is 1.6 gm/kilogram which translates to about 3 ounces for a 150-pound person.

In case of contact with eyes and skin, wash with water thoroughly and if irritation persists, get medical attention. In case of inhalation overexposure, remove person to fresh air and get medical attention. If ingested, induce vomiting and get medical attention.

Methylene chloride is chemically stable under normal conditions. Exposure to heat sources could result in release of carbon monoxide, HCl vapors, and phosgene gas. Small spills should be cleaned up with an absorbent material, which will then be moved outdoors where it can evaporate safely. Large spills should be diked and transferred to closed metal containers.

The EPA hazardous waste number for methylene chloride is U080 and its reportable spill quantity is 1,000 pounds. The use of methylene chloride for this project is limited to the amounts necessary to clear the foaming lance after system shutdowns. 50 to 100 gallons of methylene chloride waste may be generated during the job.

POLYURETHANE FINISHED PRODUCT

Extensive testing results reported in the Upjohn Bulletin have shown the polyurethane foam product to be non-hazardous with respect to eye and skin contact and ingestion. Inhalation of polyurethane dust should be avoided but consequences are no more serious than inhalation of dust from any non-hazardous source. A wealth of information has been reported by Upjohn and Mobay Corporation on risks of polyurethane fires. The major risk of the polyurethane product is combustibility and resultant thermal decomposition products. The autoignition temperature of most polyurethane foams is 600 to 700°F. Carbon monoxide is the major decomposition product released in polyurethane fires. Smaller amounts of carbon dioxide, nitrogen oxide, and hydrogen cyanide are produced. Carbon monoxide, because of its higher concentration, is considered the principal toxicant in these fires.

Self-contained breathing apparatus should be worn by anyone fighting fires involving polyurethane. Water is the best extinguishing media because it penetrates the foam most effectively. Other extinguishing media such as carbon dioxide, dry chemical, or foam are effective for small-scale fires.

REFERENCES

1. "Precautions for the Proper Usage of Polyurethanes, Polyisocyanurates, and Related Materials," Technical Bulletin 107, 2nd Edition, The Upjohn Company, Chemical Division, 1980.

2. "Fire Safety Guidelines and Related Information for Polyurethane Foams," Mobay Corporation, Polyurethane Division, 1985.

3. Product Safety Data Sheet, Genetron® 12 Dichlorodifluoromethane, Allied Corporation Chemicals Sector, March 1982.

4. Material Safety Data Sheet, MDI Polymethylene Polyisocyanate FE 801A, Foam Enterprises, Inc., May 1972.

5. Material Safety Data Sheet, MG2-B Polyol, Foam Enterprises, Inc., May 1982.

6. Material Safety Data Sheet, Methylene Chloride, Ashland Chemical Company, November 1985.

DICHLOROMETHANE

DCM

Common Synonyms			
Methylene chloride Methylene dichloride	Watery liquid	Colorless	Sweet, pleasant odor
	Sinks in water. Irritating vapor is produced.		

Stop discharge if possible.
Avoid contact with liquid and vapor
Isolate and remove discharged material
Notify local health and pollution control agencies

Fire

Not flammable.
POISONOUS GASES ARE PRODUCED WHEN HEATED.
Wear goggles and self-contained breathing apparatus.
Cool exposed containers with water.

Exposure

CALL FOR MEDICAL AID.

VAPOR
Irritating to eyes, nose and throat.
If inhaled, will cause nausea and dizziness.
Move to fresh air.
If breathing has stopped, give artificial respiration.
If breathing is difficult, give oxygen.

LIQUID
Irritating to skin and eyes.
Harmful if swallowed.
Remove contaminated clothing and shoes.
Flush affected areas with plenty of water.
IF IN EYES, hold eyelids open and flush with plenty of water.
IF SWALLOWED and victim is CONSCIOUS, have victim drink water or milk.

Water Pollution

Effect of low concentrations on aquatic life is unknown.
May be dangerous if it enters water intakes

Notify local health and pollution control officials
Notify operators of nearby water intakes.

1. RESPONSE TO DISCHARGE

(See Response Methods Handbook)

Disperse and flush

2. LABEL

2.1 Category: None
2.2 Class: Not pertinent

3. CHEMICAL DESIGNATIONS

3.1 CG Compatibility Class: Halogenated hydrocarbon
3.2 Formula: CH_2Cl_2
3.3 IMO/UN Designation: 9.0/1593
3.4 DOT ID No.: 1593
3.5 CAS Registry No.: 75-09-2

4. OBSERVABLE CHARACTERISTICS

4.1 Physical State (as shipped): Liquid
4.2 Color: Colorless
4.3 Odor: Pleasant, aromatic; like chloroform; sweet, ethereal

5. HEALTH HAZARDS

5.1 Personal Protective Equipment: Organic vapor canister mask, safety glasses, protective clothing.
5.2 Symptoms Following Exposure: INHALATION: anesthetic effects, nausea and drunkenness. CONTACT WITH SKIN AND EYES: skin irritation, irritation of eyes and nose.
5.3 Treatment of Exposure: INHALATION: remove from exposure. Give oxygen if needed. INGESTION: no specific antidote. CONTACT WITH SKIN AND EYES: remove contaminated clothing; wash skin or eyes if affected.
5.4 Threshold Limit Value: 100 ppm
5.5 Short Term Inhalation Limits: 500 ppm for 30 min.
5.6 Toxicity by Ingestion: Grade 2; LD_{50} = 0.5 to 5 g/kg
5.7 Late Toxicity: None
5.8 Vapor (Gas) Irritant Characteristics: Vapors cause moderate irritation such that personnel will find high concentrations unpleasant. The effect is temporary.
5.9 Liquid or Solid Irritant Characteristics: Minimum hazard. If spilled on clothing and allowed to remain, may cause smarting and reddening of the skin.
5.10 Odor Threshold: 205-307 ppm
5.11 IDLH Value: 5,000 ppm

6. FIRE HAZARDS

6.1 Flash Point: Not flammable under conditions likely to be encountered.
6.2 Flammable Limits in Air: 12%-19%
6.3 Fire Extinguishing Agents: Not pertinent
6.4 Fire Extinguishing Agents Not to be Used: Not pertinent
6.5 Special Hazards of Combustion Products: Dissociation products generated in a fire may be irritating or toxic
6.6 Behavior in Fire: Not pertinent
6.7 Ignition Temperature: 1184°F
6.8 Electrical Hazard: Not pertinent
6.9 Burning Rate: Not pertinent
6.10 Adiabatic Flame Temperature: Data not available
6.11 Stoichiometric Air to Fuel Ratio: Data not available
6.12 Flame Temperature: Data not available

7. CHEMICAL REACTIVITY

7.1 Reactivity With Water: No reaction
7.2 Reactivity with Common Materials: No reaction
7.3 Stability During Transport: Stable
7.4 Neutralizing Agents for Acids and Caustics: Not pertinent
7.5 Polymerization: Not pertinent
7.6 Inhibitor of Polymerization: Not pertinent
7.7 Molar Ratio (Reactant to Product): Data not available
7.8 Reactivity Group: 36

8. WATER POLLUTION

8.1 Aquatic Toxicity: Not pertinent
8.2 Waterfowl Toxicity: Not pertinent
8.3 Biological Oxygen Demand (BOD): Not pertinent
8.4 Food Chain Concentration Potential: None

9. SHIPPING INFORMATION

9.1 Grades of Purity: Aerosol grade; technical grade
9.2 Storage Temperature: Data not available
9.3 Inert Atmosphere: Inerted
9.4 Venting: Data not available

10. HAZARD ASSESSMENT CODE

(See Hazard Assessment Handbook)

A-P-X

11. HAZARD CLASSIFICATIONS

11.1 Code of Federal Regulations: ORM-A
11.2 NAS Hazard Rating for Bulk Water

Transportation: Category	Rating
Fire	1
Health	
Vapor Irritant	2
Liquid or Solid Irritant	1
Poisons	2
Water Pollution	
Human Toxicity	2
Aquatic Toxicity	1
Aesthetic Effect	2
Reactivity	
Other Chemicals	2
Water	1
Self Reaction	0

11.3 NFPA Hazard Classification:

Category	Classification
Health Hazard (Blue)	2
Flammability (Red)	0
Reactivity (Yellow)	1

12. PHYSICAL AND CHEMICAL PROPERTIES

12.1 Physical State at 15°C and 1 atm: Liquid
12.2 Molecular Weight: 84.93
12.3 Boiling Point at 1 atm: 104°F = 39.8°C = 313.0°K
12.4 Freezing Point: −142°F = −96.7°C = 176.5°K
12.5 Critical Temperature: 473°F = 245°C = 518°K
12.6 Critical Pressure: 895 psia = 60.9 atm = 6.17 MN/m²
12.7 Specific Gravity: 1.322 at 20°C (liquid)
12.8 Liquid Surface Tension: Not pertinent
12.9 Liquid Water Interfacial Tension: Not pertinent
12.10 Vapor (Gas) Specific Gravity: 2.9
12.11 Ratio of Specific Heats of Vapor (Gas): 1.199
12.12 Latent Heat of Vaporization: 142 Btu/lb = 78.7 cal/g = 3.30 X 10⁵ J/kg
12.13 Heat of Combustion: Not pertinent
12.14 Heat of Decomposition: Not pertinent
12.15 Heat of Solution: Not pertinent
12.16 Heat of Polymerization: Not pertinent
12.25 Heat of Fusion: 16.69 cal/g
12.26 Limiting Value: Data not available
12.27 Reid Vapor Pressure: 13.9 psia

NOTES

JUNE 1985

DICHLOROMETHANE

12.17 SATURATED LIQUID DENSITY	
Temperature (degrees F)	Pounds per cubic foot
—70	91.320
—60	90.700
—50	90.080
—40	89.450
—30	88.830
—20	88.200
—10	87.580
0	86.959
10	86.330
20	85.709
30	85.080
40	84.459
50	83.830
60	83.209
70	82.589
80	81.959
90	81.341
100	80.709

12.18 LIQUID HEAT CAPACITY	
Temperature (degrees F)	British thermal unit per pound-F
35	.274
40	.275
45	.276
50	.277
55	.278
60	.279
65	.279
70	.280
75	.281
80	.282
85	.283
90	.284
95	.284
100	.285

12.19 LIQUID THERMAL CONDUCTIVITY	
Temperature (degrees F)	British thermal unit-inch per hour-square foot-F
—110	1.205
—100	1.192
—90	1.179
—80	1.166
—70	1.154
—60	1.141
—50	1.128
—40	1.115
—30	1.102
—20	1.090
—10	1.077
0	1.064
10	1.051
20	1.038
30	1.025
40	1.013
50	1.000
60	.987
70	.974
80	.961

12.20 LIQUID VISCOSITY	
Temperature (degrees F)	Centipoise
	N O T P E R T I N E N T

12.21 SOLUBILITY IN WATER	
Temperature (degrees F)	Pounds per 100 pounds of water
68.02	1.380

12.22 SATURATED VAPOR PRESSURE	
Temperature (degrees F)	Pounds per square inch
—10	.866
—5	1.013
0	1.180
5	1.370
10	1.586
15	1.830
20	2.105
25	2.414
30	2.762
35	3.151
40	3.585
45	4.068
50	4.606
55	5.201
60	5.860
65	6.588
70	7.389
75	8.270
80	9.237
85	10.300

12.23 SATURATED VAPOR DENSITY	
Temperature (degrees F)	Pounds per cubic foot
—10	.01525
—5	.01763
0	.02031
5	.02333
10	.02671
15	.03050
20	.03472
25	.03941
30	.04462
35	.05039
40	.05676
45	.06378
50	.07149
55	.07996
60	.08922
65	.09934
70	.11040
75	.12240
80	.13540
85	.14960

12.24 IDEAL GAS HEAT CAPACITY	
Temperature (degrees F)	British thermal unit per pound-F
0	.126
10	.129
20	.131
30	.133
40	.135
50	.137
60	.139
70	.142
80	.144
90	.145
100	.147
110	.149
120	.151
130	.153
140	.155
150	.156
160	.158
170	.159
180	.161
190	.163
200	.164
210	.165
220	.167
230	.168
240	.169
250	.171

MATERIAL SAFETY DATA SHEET

(APPROVED BY THE U.S. DEPARTMENT OF LABOR AS—"essentially similar" to form OSHA-20)

FORM No. 100-546

Section 1—NAME & PRODUCT

Manufacturer's Name	City, State and Zip Code	Emergency Phone No. 24 hours
DOW CHEMICAL U.S.A.	Midland, Michigan 48640	517-636-4400

Date this form written: January 30, 1975

INORGANIC CHEMICALS DEPARTMENT

Trade Name: Methylene Chloride, Technical

Synonyms

Section 2—INGREDIENTS—TYPICAL VALUES

WT. %

Methylene chloride, essentially

Section 3—PHYSICAL DATA

BOILING POINT (°F.)	104 (39.8°C)	SOLUBILITY IN WATER	2.0g/100g at 25°C
VAPOR PRESSURE (mm Hg at 20°C)	340	SPECIFIC GRAVITY (H_2O : 1)	1.320 at 25/25°C
VAPOR DENSITY (air : 1)	2.93	% VOLATILE BY VOLUME	100 (essentially)

APPEARANCE: Colorless liquid

Section 4—FIRE AND EXPLOSION HAZARD DATA

Flash Point (and method used): °F

Flammable Limits (STP in air)—Vol. %: L.F.L. U.F.L.

EXTINGUISHING MEDIA: ☐ Water Fog ☐ Foam ☐ Alcohol Foam ☐ CO_2 ☐ Dry Chemical ☐ Other

Special Fire Fighting Protection Equipment and Hazards

Self-contained respiratory equipment.

Section 5—REACTIVITY DATA

STABILITY (Normal Conditions): X STABLE ☐ UNSTABLE

Conditions to avoid: See Journal of Chemical and Engineering Data *17* (1) 89-93 (1972) for flammat limits at other than standard temperature and pressure.

INCOMPATIBILITY — Materials to avoid: ☐ Water ☐ Acid ☐ Base ☐ Corrosive ☐ Oxidizing Material

Other: ☐

Hazardous Decomposition Products: Open flames and welding arcs can cause thermal degradation with the evolution of hydrogen ch and very small amounts of phosgene and chlorine.

HAZARDOUS POLYMERIZATION: ☐ MAY OCCUR X WILL NOT OCCUR

Conditions to avoid:

Section 6—SPILL OR LEAK PROCEDURES—USE PROPER PROTECTIVE EQUIPMENT

Steps to be taken in case material is released or spilled

Small spills: mop up, wipe up or soak up immediately. Remove to out of doors.
Large spills: evacuate area. Contain liquid; transfer to closed metal containers. Keep out of water supply.

Disposal Method

Send solvent to a reclaimer. In some cases it can be transported to an area where it can be placed on the ground and allowed to evaporate safely. Refer to Chemical Safety Data Sheet SD-86, Manufacturing Chemists Association, 1825 Connecticut Avenue, Washington, D.C. 20009.

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Section 7—HEALTH HAZARD DATA

5975

Ingestion

Low LD_{50} (rats) 1.6 g/kg. It is estimated that a dose of one ounce to one pint may be fatal to a 150 pound person.

Eye Contact

Painful and slight irritation. Corneal injury unlikely.

Skin Contact

Short contact – no irritation. Prolonged or frequently repeated contact – possible irritation. If confined to skin – may caus a burn.

Skin Absorption

Very low. Hazard not significant.

Inhalation

TLV: Proposed TLV is 100 ppm (1974)

Effects of Overexposure

Increasing signs of anesthesia above 300 ppm in the atmosphere.

FIRST AID PROCEDURE

EYES AND SKIN: Flush with plenty of water. Get medical attention if irritation develops.

INHALATION: If illness occurs, remove patient to fresh air, keep him quiet and warm. Get medical attention. If breathing stops, start artificial respiration.

INGESTION: Induce vomiting. Call a physician immediately.*

CAUTION: With some solvents, drinking alcohol shortly before, during or after exposure may cause undesirable effects.

CAUTION: Never give fluids or induce vomiting if patient is unconscious or having convulsions

Section 8—SPECIAL PROTECTION INFORMATION

Ventilation

Limit concentration in air to TLV.

Respiratory Protection Below 100 ppm – none; respiratory protection required in the absence of environmental control. For levels up to 2 percent for 1/2 hour or less, a suitable full-face mask with organic canister should be used. Above 2 percent and for emergencies, use a self-contained breathing apparatus.

Protective Clothing

No special protective clothing needed.

EYE PROTECTION	Not normally necessary	Safety glasses without side shields	Safety glasses with side shields	Chemical workers' goggles
	☐	☒	☐	☐

☐ Gas tight goggles or equivalent ☒ Other Eye wash stations and safety showers should be readily available.

Section 9—SPECIAL PRECAUTIONS OR OTHER COMMENTS

Exercise reasonable care and caution. Avoid breathing vapors. Store in cool place.

*NOTE TO PHYSICIAN: Overexposure to many of the chlorinated solvents, especially if accompanied by anoxia, may tempor. increase cardiac irritability. Maintain adequate oxygenation until recovery. Avoid sympatomimetic amines, such as epinephrine, which may precipitate arrhythmias.

OTICE: The information herein is given in good faith but no warranty, express or implied, is made.

U.S. DEPARTMENT OF LABOR
Occupational Safety and Health Administration

Form Approved
OMB No. 44-R1387

MATERIAL SAFETY DATA SHEET

Required under USDL Safety and Health Regulations for Ship Repairing, Shipbuilding, and Shipbreaking (29 CFR 1915, 1916, 1917)

SECTION I

MANUFACTURER'S NAME: FOAM ENTERPRISES, INC.	EMERGENCY TELEPHONE NO.: Chemtrec 800-424-9300
ADDRESS (Number, Street, City, State, and ZIP Code): 13630 WATERTOWER CIRCLE, MPLS., MN. 55441	
CHEMICAL NAME AND SYNONYMS: MDI Polymethylene Polyisocyanate	TRADE NAME AND SYNONYMS: FE 801 A
CHEMICAL FAMILY: Aromatic Isocyanate	FORMULA: $OCN-C_6H_4-CH_2-C_6H_4-NCO (C_{15}H_{10}O_2N_2)$

SECTION II - HAZARDOUS INGREDIENTS

PAINTS, PRESERVATIVES, & SOLVENTS	%	TLV (Units)	ALLOYS AND METALLIC COATINGS	%	TLV (Units)
PIGMENTS			BASE METAL		
CATALYST			ALLOYS		
VEHICLE			METALLIC COATINGS		
SOLVENTS			FILLER METAL PLUS COATING OR CORE FLUX		
ADDITIVES			OTHERS		
OTHERS					

HAZARDOUS MIXTURES OF OTHER LIQUIDS, SOLIDS, OR GASES	%	TLV (Units)
Diphenylmethane Diisocyanate	~50	0.02 PPM

SECTION III - PHYSICAL DATA

BOILING POINT (°F.)	406	SPECIFIC GRAVITY (H_2O=1)	1.24
VAPOR PRESSURE (mm Hg.) @ 25°C	<0.0001	PERCENT, VOLATILE BY VOLUME (%)	Nil
VAPOR DENSITY (AIR=1)	8.6	EVAPORATION RATE (_____ =1)	Nil
SOLUBILITY IN WATER	Nil		
APPEARANCE AND ODOR	Dark Brown viscous liquid. Very slight aromatic odor.		

SECTION IV - FIRE AND EXPLOSION HAZARD DATA

FLASH POINT (Method used): 425° F. (C) C)	FLAMMABLE LIMITS	Lel	Uel
EXTINGUISHING MEDIA: CO_2 - Dry Chemical - Chemical Foam			
SPECIAL FIRE FIGHTING PROCEDURES: The usual fireman's body protection should be worn as well as self-contained breathing apparatus to protect from vapors from product.			
UNUSUAL FIRE AND EXPLOSION HAZARDS: None			

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(Continued on reverse side)

SECTION V · HEALTH HAZARD DATA

THRESHOLD LIMIT VALUE
0.02

EFFECTS OF OVEREXPOSURE
Irritation of respiratory tract resulting in sinusitis, bronchitis and asthma.

EMERGENCY AND FIRST AID PROCEDURES
Inhalation: Treat symptomatically; vaso-dilators; oxygen, call physician. Skin contact: Wash with soap and water. Alcohol helpful. Eye contact: Flush with water at least 15 Minutes. Call physician.

SECTION VI · REACTIVITY DATA

STABILITY			CONDITIONS TO AVOID
	UNSTABLE		Water contamination. 450° F. or higher.
	STABLE	X	

INCOMPATABILITY *(Materials to avoid)*
Water, strong bases, metal compounds, amines.

HAZARDOUS DECOMPOSITION PRODUCTS
CO_2, benzene, toluene, oxides of nitrogen, HCN, acetaldenyne, acetone

HAZARDOUS POLYMERIZATION			CONDITIONS TO AVOID
	MAY OCCUR		
	WILL NOT OCCUR	X	May form CO_2 gas pressure.

SECTION VII · SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED
Cover with absorbent material (sawdust). Place in open top container or plastic sheet and treat with aqueous ammonium hydroxide and/or alcohol. Ventilate area. Evacuate personnel.

WASTE DISPOSAL METHOD
Bury expended absorbent material in a chemical land fill area after wetting with water in an open area.

SECTION VIII · SPECIAL PROTECTION INFORMATION

RESPIRATORY PROTECTION *(Specify type)*
Self contained breathing apparatus or gas masks for organic vapors.

VENTILATION	LOCAL EXHAUST	SPECIAL
	Minimize vapors to TLV.	
	MECHANICAL *(General)*	OTHER

PROTECTIVE GLOVES	EYE PROTECTION
Rubber or PVC	Chemical goggles.

OTHER PROTECTIVE EQUIPMENT

SECTION IX · SPECIAL PRECAUTIONS

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORING
Must be stored in tightly closed containers and protected from moisture. Avoid temperatures above 90°F. or below 60° F.

OTHER PRECAUTIONS

U.S. DEPARTMENT OF LABOR
Occupational Safety and Health Administration

Form Approved
OMB No. 44-R1387

MATERIAL SAFETY DATA SHEET

Required under USDL Safety and Health Regulations for Ship Repairing, Shipbuilding, and Shipbreaking (29 CFR 1915, 1916, 1917)

SECTION I

MANUFACTURER'S NAME: FOAM ENTERPRISES, INC.	EMERGENCY TELEPHONE NO.: Chemtrec 800424-9300
ADDRESS (Number, Street, City, State, and ZIP Code): 13630 WATERTOWER CIRCLE, MPLS., MN. 55441	
CHEMICAL NAME AND SYNONYMS: Polyols or Resin	TRADE NAME AND SYNONYMS: MG2-B
CHEMICAL FAMILY: Polyether & Polyester Triol	FORMULA: Mixture & Proprietary

SECTION II · HAZARDOUS INGREDIENTS

PAINTS, PRESERVATIVES, & SOLVENTS	%	TLV (Units)	ALLOYS AND METALLIC COATINGS	%	TLV (Units)
PIGMENTS			BASE METAL		
CATALYST Primary Amine	<1	10	ALLOYS		
VEHICLE		PPM	METALLIC COATINGS		
SOLVENTS Fluorocarbon 11B	<30	1,000	FILLER METAL PLUS COATING OR CORE FLUX		
ADDITIVES		PPM	OTHERS		
OTHERS					

HAZARDOUS MIXTURES OF OTHER LIQUIDS, SOLIDS, OR GASES	%	TLV (Units)

SECTION III · PHYSICAL DATA

BOILING POINT (°F.)	>300°F.	SPECIFIC GRAVITY (H_2O=1)	~1.2
VAPOR PRESSURE (mm Hg.) @ 70° F.	<700	PERCENT, VOLATILE BY VOLUME (%)	<30
VAPOR DENSITY (AIR=1)	<5.85 1/g	EVAPORATION RATE (_____=1)	N/A
SOLUBILITY IN WATER	>50%		
APPEARANCE AND ODOR	Amber liquic with a slight odor.		

SECTION IV · FIRE AND EXPLOSION HAZARD DATA

FLASH POINT (Method used): >300°F. Open Cup	FLAMMABLE LIMITS	Lel	Uel
EXTINGUISHING MEDIA: Water Fog - CO_2 - Dry Chemical - Foam			
SPECIAL FIRE FIGHTING PROCEDURES: DO NOT BREATH SMOKE WHEN BURNING			
UNUSUAL FIRE AND EXPLOSION HAZARDS			

SECTION V - HEALTH HAZARD DATA

THRESHOLD LIMIT VALUE: NONE

EFFECTS OF OVEREXPOSURE

EYE CONTACT: Minor irritation, but no corneal injury.

SKIN CONTACT: Essentially no irritation.

EMERGENCY AND FIRST AID PROCEDURES

EYES: Flush with plenty of water for five minutes.

SKIN: Wash with soap and water.

INGESTION: Induce vomiting and get medical help.

SECTION VI - REACTIVITY DATA

STABILITY			CONDITIONS TO AVOID
	UNSTABLE		
	STABLE	XX	STABLE UNDER NORMAL HANDLING CONDITIONS

INCOMPATABILITY *(Materials to avoid)*: QXIDIZING MATERIAL AND STRONG ACIDS

HAZARDOUS DECOMPOSITION PRODUCTS: CO and CO_2

HAZARDOUS POLYMERIZATION			CONDITIONS TO AVOID
	MAY OCCUR		
	WILL NOT OCCUR	XX	

SECTION VII - SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED

APPLY OBSORBENT MATERIAL SUCH AS SAWDUST. RINSE AREA WITH DETERGENT SOLUTION AND WATER.

WASTE DISPOSAL METHOD: INCINERATE

SECTION VIII - SPECIAL PROTECTION INFORMATION

RESPIRATORY PROTECTION *(Specify type)*

VENTILATION	LOCAL EXHAUST	SPECIAL
	MECHANICAL *(General)* ACCEPTABLE	OTHER

PROTECTIVE GLOVES: RUBBER OR P.V.C.

EYE PROTECTION: CHEMICAL GOGGLES

OTHER PROTECTIVE EQUIPMENT: EYE BATH AND SAFETY SHOWER

SECTION IX - SPECIAL PRECAUTIONS

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORING

AVOID SKIN AND EYE CONTACT.

OTHER PRECAUTIONS

ENGINEERING STUDY OF THE K-65 STORAGE SILO RADON MITIGATION AND DOME REINFORCEMENT PROJECT AT THE FEED MATERIALS PRODUCTION CENTER.

Submitted By:

IT Corporation - Nuclear Services
312 Directors Drive
Knoxville, Tennessee 37923

for

Advanced Sciences, Incorporated
107-F Jefferson Avenue
Oak Ridge, Tennessee 37830

August 20, 1987

SECTION 7.0

AIR QUALITY ASSESSMENT AS DEFINED BY PTI

For Office Use Only
Check Appropriate Box(es)

X Air Discharge

___ Water Discharge to New Source Treatment Works

___ Solid Waste Disposal Facility

___ Hazardous Waste Disposal Facility

For Office Use Only

PTI Application No. _____

Date Received _____

Premise No. _____

OHIO ENVIRONMENTAL PROTECTION AGENCY
Application for Permit to Install

U. S. Department of Energy, Feed Materials Production Center
Applicant's Name

P. O. Box E
Mailing Address

Oak Ridge		TN	37831	615/576-0845
City	County	State	Zip Code	Telephone Number

Ms. Margaret Wilson, Environ. Engineer, Environmental Protection Division 615/576-0845
Person to contact (Name and Title and Telephone Number)

The facility will be located within the production area of the DOE.
Location of Proposed Facility (State the location as completely and precisely as possible)*

Feed Materials Production Center, 7400 Willey Road

Fernald	Hamilton	45030
City or Township	County	Zip Code

Directions: A Permit to Install is required for new or modified sources of pollution under the provisions of OAC Rule 3745-31. An application cannot be considered complete unless all applicable questions are answered and the required information has been submitted. This application must be signed in accordance with OAC Rule 3745-31-04(B) or it cannot be accepted.

Applicants for permits involving air emissions or wastewater treatment facilities will be required to pay a permit to install fee as shown in Section 3745.11(B) and (C) of the Ohio Revised Code. This fee is payable fifteen days after the date of final issuance of the permit.

Name of new or modified source or facility: K-65 Silo (storage tank)

Product of new or modified source/facility: K-65 & Australian Radium Cake

Will the proposed source/facility involve any of the following: Check all that apply.

A. ___ Air Discharge

B. ___ Wastewater Treatment Works

C. ___ Solid Waste Disposal Facility

D. ___ Hazardous Waste Disposal Facility

*Example: "The source will be constructed on a 20 Acre plot to be located on Franklin Township Road No. 17, approximately 1 1/4 miles north of

MPA 3150

Under OAC 3745-31-04, these signatures shall constitute personal affirmation that all statements or assertions of fact made in the application are true and complete, comply fully with applicable state requirements, and shall subject the signatory to liability under applicable state laws forbidding false or misleading statements.

Authorized Signature (for facility) Date

James A. Reafsnyder (DOE)
Site Manager
Title

U. S. Department of Energy
Oak Ridge Operations Office
P. O. Box E
Oak Ridge, Tennessee 37831
Address

OHIO ENVIRONMENTAL PROTECTION AGENCY
Application for Permit to Install

US DOE Feed Materials Production Center
Fernald, OH

K-65 Storage Tank Modification

FOR ALL PERMITS TO INSTALL

1. Describe the product or service to be produced by the applicant along with a description of the proposed source/facility.

Previously installed and currently operating storage tanks at the USDOE FMPC, Fernald, OH are to be modified to provide radon emission control and structural reinforcement. The tanks (K-65-1 and K-65-2) contain residue principally resulting from the processing of pitchblend ore. The tanks have been found to need repair. The repair procedure, simply stated, involves filling the void above the residue with several layers of polyurethane foam to provide structural reinforcement. The procedure will also provide for removal of the radon gas in the silos, and the foam will greatly reduce emanation of radon continually generated by the residues.

2. List the name and quantity of all materials and chemicals (solid, liquid, or gaseous) that will be used or produced by the source/facility.

The residue from the pitchblend processing contains Radium-226, which produces the noble gas Radon-222. The Radon gas is in a semi-equilibrium state, in which radon is produced and routinely emitted to the atmosphere through the silo domes.

It is estimated that there are approximately 37 Curies of radon with associated daughter products in the air space in each silo. Following the application of a closed-cycle filtration system, this quantity will be reduced to approximately 0.4 to 4.0 Curies per silo. When the void above the residue is filled with foam, the gaseous mixture containing the remaining radon will be forced from the silos, temporarily creating a source of radioactive emissions. However, following the foaming procedure, the emissions from the silos should be virtually eliminated.

3. State the reason for the application. Is this a new installation, modification to an existing source/facility, reconstruction of an existing source/facility, or startup of a source/facility that has been permanently shutdown for _____ years?

This is a modification to an existing permitted source.

4. Has a previous Ohio EPA application or plan submission been filed for this source/facility? If so, state the date and type of the application previously submitted.

An application for a Permit to Operate each tank was filed on 5/1/85. PTO's were issued by OEPA on 2/14/86.

5. Will the proposed source/facility comply with all rules, laws, and regulations of Ohio EPA and US EPA?

The proposed modification of the facility has been designed to comply with all applicable rules, laws and regulations of the Ohio EPA and the US EPA.

FOR AIR POLLUTION SOURCES

6. State the amount of each air contaminant (actual emissions) from each source in pounds per hour and tons per year at maximum and average conditions.

The modification process will produce an intermittant emission of Radon-222 (and associated daughter products) in response to the foam filling process. The emission rates are estimated to be as follows:

Hourly (Ci/hr)

Average: 0.02 Ci/hr
Maximum: 0.31 Ci/hr

Annually (Ci/yr)

Average: 8 Ci/yr
Maximum: 8 Ci/yr

7. Are the proposed sources required to comply with the following federal requirements?

i. New Source Performance Standards (NSPS)
ii. National Emission Standards for Hazardous Air Pollutants (NESHAP)
iii. Prevention of Significant Deterioration (PSD)
iv. Appendix "S" - Emission Offset Policy

Radioactive sources are required to comply with Federal requirements under NESHAP; however, the principle constituant of concern will be Radon, which is exempt.

None of the other listed requirements apply.

8. Will the proposed sources employ best available technology?

The source will employ BACT to control the emissions. The gaseous effluent will be filtered in a closed-loop charcoal adsorbent system to reduce the amount of radioactivity in each silo from about 37 Ci to between 0.4 and 4 Ci, which is 1.5% - 15% of the original quantity, prior to any release to the atmosphere.

9. Will the proposed sources cause the significant degradation of air quality?

No.

10. Will the proposed sources interfere with the attainment and maintenance of the ambient air quality standards?

No.

11. Describe any source monitoring, emission monitoring, or control equipment monitoring devices to be installed by the applicant.

Monitoring will be performed at several stages of the process. Historically, monitoring was conducted from 20 Sep 84 to 5 Feb 85 in the environs of the K-65 Silos by Monsanto-Mound. Time integrated measurements of Radon in air around the K-65 silos were conducted utilizing charcoal canisters and Passive Environmental Radon Monitors (PERMs). In addition, a Radon-222 and Radon-220 (thoron) monitoring program, utilizing alpha sensitive plastic detectors, has been implemented by the FMPC for the fenceline and offsite environs.

Prior to the foam injection process, a closed-cycle radon gas treatment/circulation system will be used to minimize the amount of Radon gas to be released to the environment during the foaming operation. The Radon treatment system will have upstream and downstream monitors to determine the efficiency of the treatment system.

The Radon monitoring program currently in operation will be used to determine ambient concentrations resulting from the modification process.

12. Will the proposed sources involve the use of asbestos, benzene, beryllium, mercury, or vinyl chloride?

No.

13. Complete and attach an anticipated construction schedule for each proposed source.

See attached.

14. Please include the estimated cost of any air pollution control equipment to be installed on the proposed sources.

The closed-loop Radon treatment system will cost about $200,000, and the foam injection process, including labor and materials, will cost about $600,000.

15. An appendix for each air contaminant source must accompany this application. From the following description of the appendices, determine which should accompany your application.

Appendix A. Process Data is attached.

OHIO ENVIRONMENTAL PROTECTION AGENCY

INSTALLATION SCHEDULE

TO ACCOMPANY APPLICATION FOR PERMIT TO INSTALL

THIS FORM CONSTITUTES PART OF THE APPLICATION OF:

FACILITY NAME: Feed Materials Production Center

ADDRESS: 7400 Willey Road, Fernald, OH 45030

FOR A PERMIT TO INSTALL THE FOLLOWING AIR CONTAMINANT SOURCE:

IDENTIFICATION: **K-65 Silo Modification**

DESCRIPTION: **Radon Mitigation and Dome Reinforcement**

THE INSTALLATION OF THE ABOVE AIR CONTAMINANT SOURCE IS PLANNED TO FOLLOW THE TIME SCHEDULE DESCRIBED BELOW:

		DATE
1.	EQUIPMENT ORDERED	7 Aug. - 21 Sept. 87
2.	COMMENCE CONSTRUCTION	21 Sept. 87
3.	STARTUP	21 Oct. 87
4.	PERFORMANCE TESTING	15-21 Oct. 87

or Official Use Only

remise No. ___/___/___/____
ource No. ___/_____
pplication No. ___/_____

APPENDIX A, PROCESS

PROCESS DATA

5975

. Name of process Modification of FMPC Storage Tanks

. End product of this process Foamfill & Sealant

. Primary process equipment Foam Injection System

Your identification N/A Year Installed 1987

. Manufacturer N/A Make or model N/A

. Capacity of equipment (lbs./hr): Rated N/A Max. N/A

. Method of exhaust ventilation: ☐ Stack ☐ Window fan ☐ Roof vent
☐ Other, describe

Are there multiple exhausts? ☒ Yes ☐ No

OPERATING DATA

7. Normal operating schedule: 24 hrs./day, 7 days/wk., 2 wks./year.

3. Percent annual production (finished units) by season:
Winter ____ Spring ____ Summer ____ Fall ____

. Hourly production rates (lbs.): Average 6000 Maximum 6000

nual production (indicate units) 373,000 lbs foam & elastomer
rojected percent annual increase in production N/A

1. Type of operation: ☐ Continuous ☒ Batch

2. If batch, indicate Minutes per cycle 420 (average) Minutes between cycles 60

3. Materials used in process:

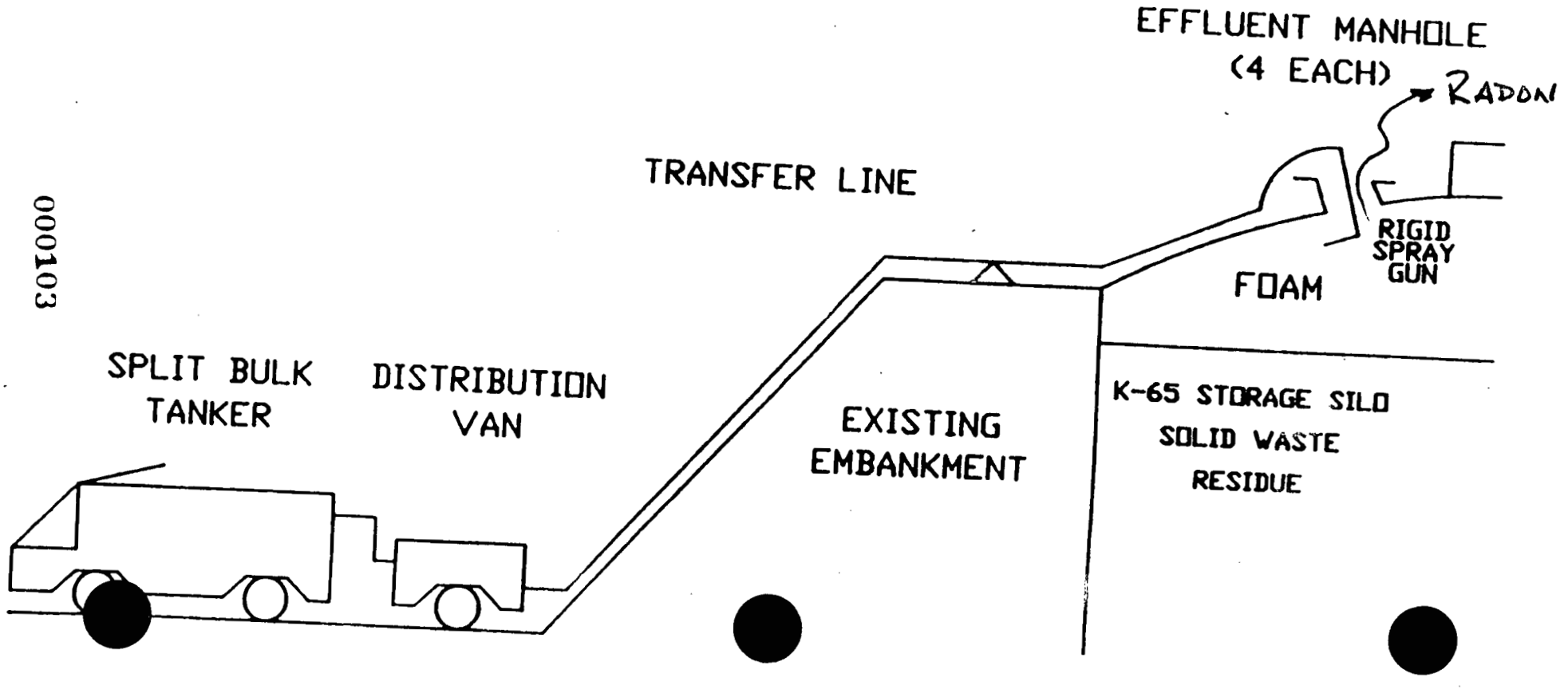
List of Raw Materials	Principal Use	Amount (lbs./hr.)
Flexible polyurethane foam	sealant	6000#/hr worst case (25 CFM)
Rigid foam	fill	6000#/hr (50 CFM)
Elastomer	sealant	6000#/hr (2.2 CFM)

4. A PROCESS FLOW DIAGRAM MUST BE INCLUDED WITH THIS APPENDIX. Show entry and exit points of all raw materials, intermediate products, by-products and finished products, Label all materials including airborne contaminants and other waste materials. Label the process equipment and control equipment.

See attached

FIGURE 1

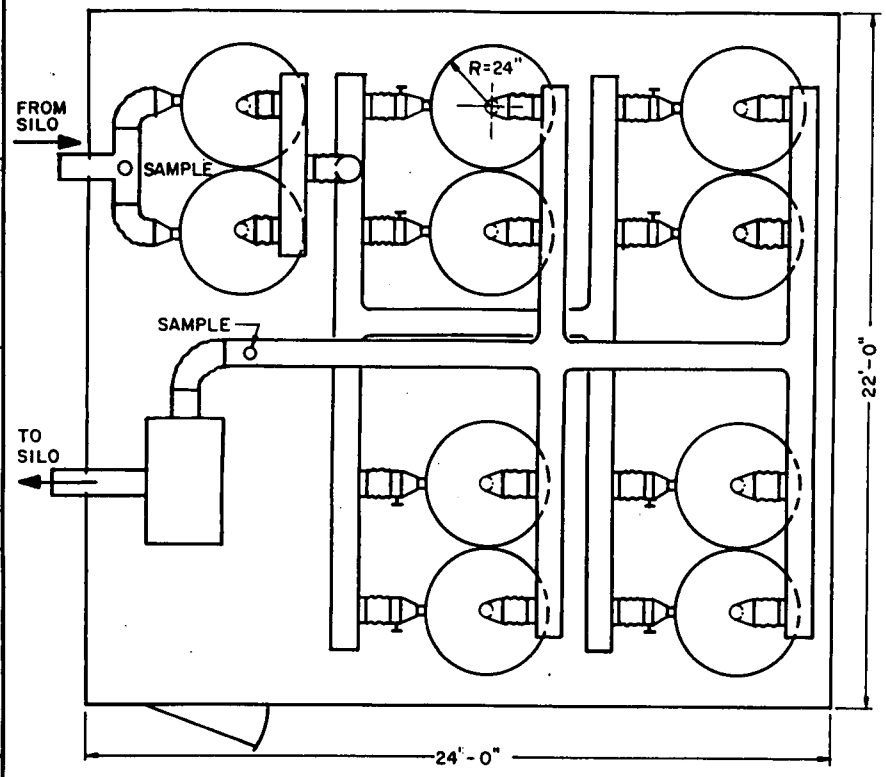
PROPOSED K-65 SILO FOAM FILLING SYSTEM



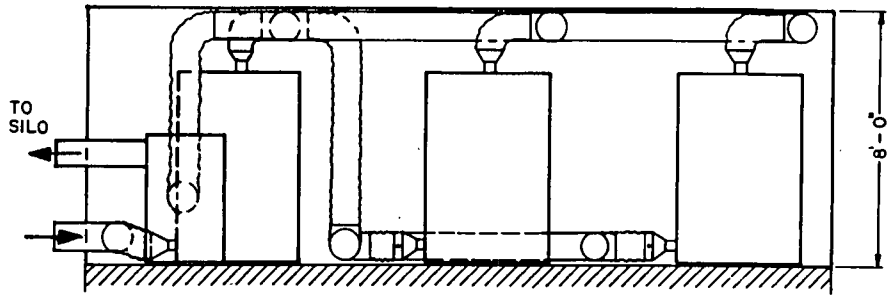
000103

5975

STARTING DATE: 8-11-87	DATE LAST REV.:	INITIATOR: K. ATWOOD	DRAWING NO.: 303317.B.002
DRAWN BY: W. McGILL	DRAWN BY:	PROJ. ENGR.: D. HARKER	PROJECT NO.: 303317.09



PLAN
SCALE: 1/4" = 1'-0"



ELEVATION
SCALE: 1/4" = 1'-0"

WESTINGHOUSE MATERIALS COMPANY OF OHIO
FMPC FERNALD, OHIO
GENERAL ARRANGEMENT FOR CALCIUM SULFATE/
CARBON BEDS AND ELEVATION
K-65 SILO PROJECT

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SOURCE EMISSION CALCULATION

Following treatment, the maximum amount of Radon-222 remaining will be no more than 4 Ci in each of the K-65 silos. Refering to Table 1. below, the concentration in each silo is calculated as a function of the volume of the space above the residue. As the foam is injected into the silo, it will displace the radon gas, forcing it out the four (4) open manways and into the ambient atmosphere. The maximum foam injection rate is 50 cfm, which will take place for limited (about seven hour) periods. This will result in a maximum emission rate of about 6.8×10^{-5} Ci/sec from silo 1 and about 8.6×10^{-5} Ci/sec from Silo 2.

Table 1. Worst Case Emission Calculations

ITEM	UNITS	SILO 1	SILO 2
Radon Present	Ci	4	4
Tank Volume	ft^3	48,700	38,700
Concentration	Ci/ft^3	8.2×10^{-5}	10.3×10^{-5}
Foam Injection Rate	ft^3/min	50	50
Emission Rate	Ci/sec	6.8×10^{-5}	8.6×10^{-5}

The maximum allowable on-site ambient radon concentration is listed in 10CFR20, Appendix B, Table I as 3×10^{-8} Ci/m^3. The following worst-case meteorological conditions were used to represent a conservative estimate of atmospheric dillution (dispersion).

Wind Speed = 0.5 m/s
Stability Class = F

Dispersion model calculations indicate that the maximum annual average on-site concentration would occur at a distance of about 450 meters, and would be 5.31×10^{-10} Ci/m^3. This concentration is less than two percent (< 2%) of the ambient standard of 10 CFR 20.

The maximum allowable annual off-site ambient radon concentration is listed in 10CFR20, Appendix B, Table II as 3×10^{-9} Ci/m^3. The same worst-case meteorological conditions were used to represent a conservative estimate of atmospheric dillution (dispersion).

Dispersion model calculations indicate that the annual average off-site concentration at the nearest fenceline (700m) would be 3.96×10^{-10} Ci/m^3. This concentration is 13 percent of the ambient standard of 10 CFR 20.

CONTROL EQUIPMENT

Control Equipment Code:

5975

(A) Settling chamber
(B) Cyclone
(C) Multiple cyclone
(D) Electrostatic precipitator
(E) Fabric filter
(F) Spray chamber
(G) Cyclonic scrubber
(H) Impingement scrubber
(I) Orifice scrubber
(J) Venturi scrubber
(K) Plate or tray tower
(L) Packed tower
(M) Adsorber
(N) Condenser
(O) Afterburner - catalytic
(P) Afterburner - thermal
(Q) Other, describe _____

15. Control Equipment data:

Item	Primary Collector	Secondary Collector
(a) Type (See above code)	Charcoal adsorber	
(b) Manufacturer	N/A	
(c) Model No.	N/A	
(d) Year installed	1987	
(e) Your identification	N/A	
(f) Pollutant Controlled	Radon	
(g) Controlled pollutant emission rate (if known)	unk	
(h) Pressure drop	11.5 in H_2O	
(i) Design efficiency	85-99%	
(j) Operating efficiency	N/A	

STACK DATA

16. Your stack identification K-65 tank vents

Are other sources vented to this stack? ☐ Yes ☒ No
If yes, identify sources _____

18. Type: ☒ Round, top inside diameter dimension 20 inches
☐ Rectangular, top inside dimensions (L) _____ x (W) _____

19. Height: Above roof 0.3 ft., above ground 27 ft.

20. Exit gas: Temp. Ambient °F, Volume 2 to 50 ACFM, Velocity 5.73 max ft./min.

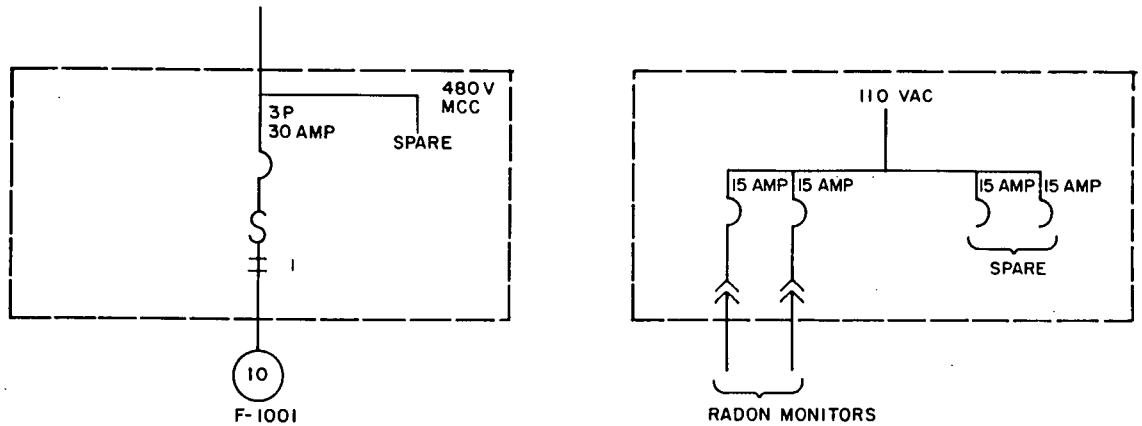
21. Continuous monitoring equipment: ☒ Yes ☐ No
If yes, indicate: Type Alpha Track-etch, Manufacturer FMPC
Make or Model N/A, Pollutant(s) monitored ambient radon

22. Emission data: Emissions from this source have been determined and such data is included with this appendix: ☒ Yes ☐ No
If yes, check method: ☐ Stack Test ☐ Emission factor ☒ Material balance

Completed by M. Gary Verhotek Date 20 Aug 87
IT Corp.

5975

STARTING DATE: 8-7-87	DATE LAST REV.:	INITIATOR: K. ATWOOD	DRAWING NO.: 303317. B. 001
DRAWN BY: W. McGILL	DRAWN BY:	PROJ. ENGR.: D. HARMER	PROJECT NO.: 303317.09



000108

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FMPC FERNALD, OHIO
ELECTRICAL ONE LINE DIAGRAM
K-65 SILO PROJECT

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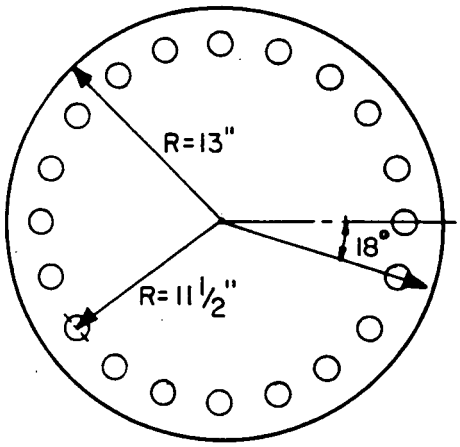
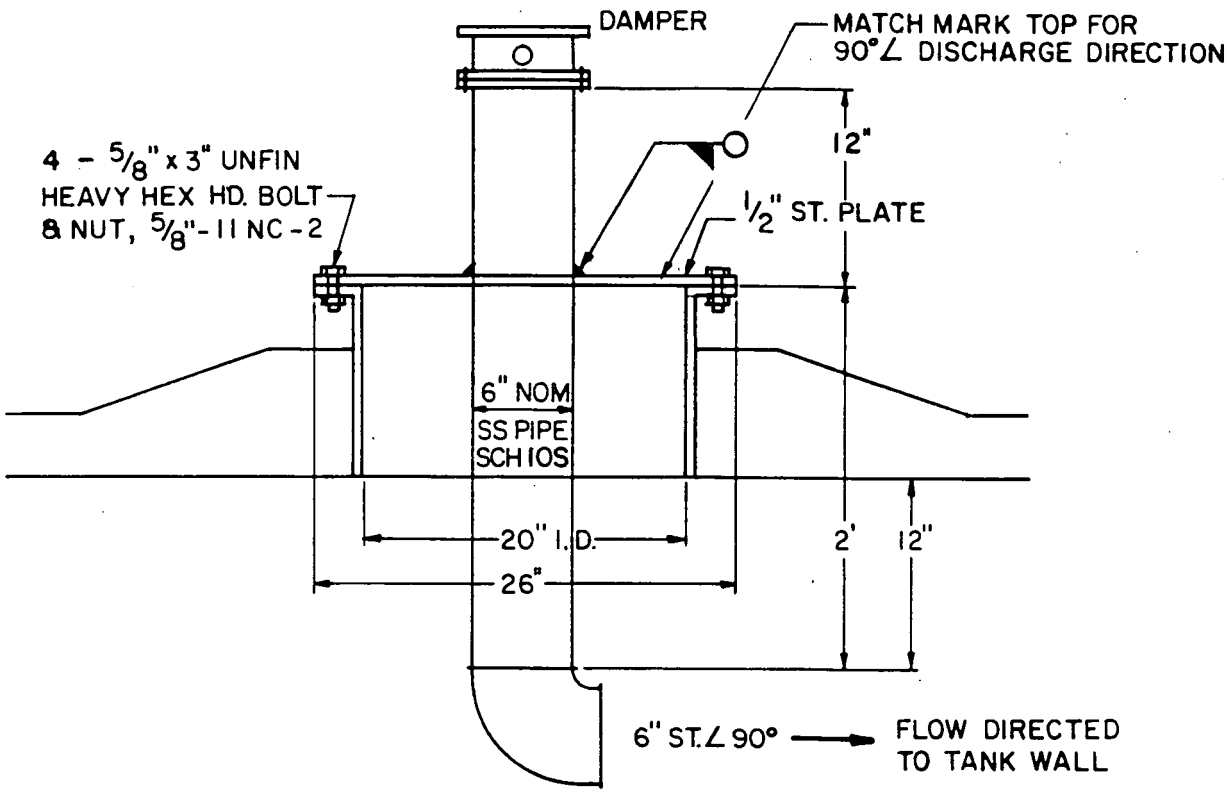


USE 4 BOLTS FOR TEMPORARY COVER WITH RED RUBBER GASKET.



WESTINGHOUSE MATERIALS COMPANY OF OHIO
FMPC FERNALD, OHIO
TEMPORARY MANWAY COVER (4 REQ'D)
K-65 SILO PROJECT

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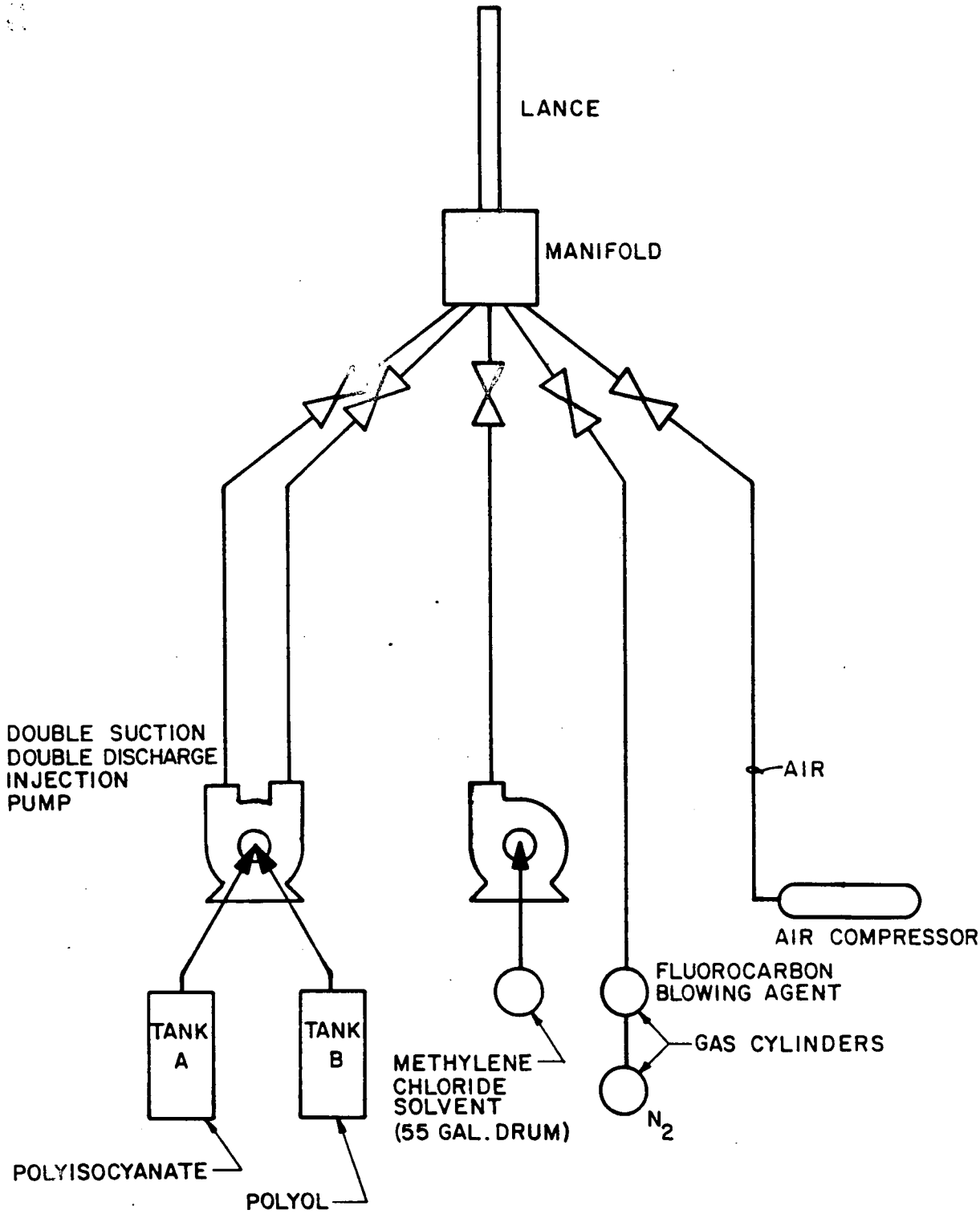
STARTING DATE: 8-
DRAWN BY: W. MC
DATE LAST REV.:
DRAWN BY:
INITIATOR: K. ATWO
PROJ. ENGR.: D. HARME
DRAWING NO: 317. A. 001
PROJECT #: 317.09

BRUNING 44-132 67120

STARTING DATE: 8-4 of 7	DATE LAST REV.:
DRAWN BY: W. MCGILL	DRAWN BY:
INITIATOR: K. ATWOOD	DRAWING NO. J3317.A.002
PROJ. ENGR.: D. HARMER	PROJECT NO.: 303317.09



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FMPC FERNALD, OHIO
POLYURETHANE FROTH/POUR SYSTEM
K-65 SILO PROJECT

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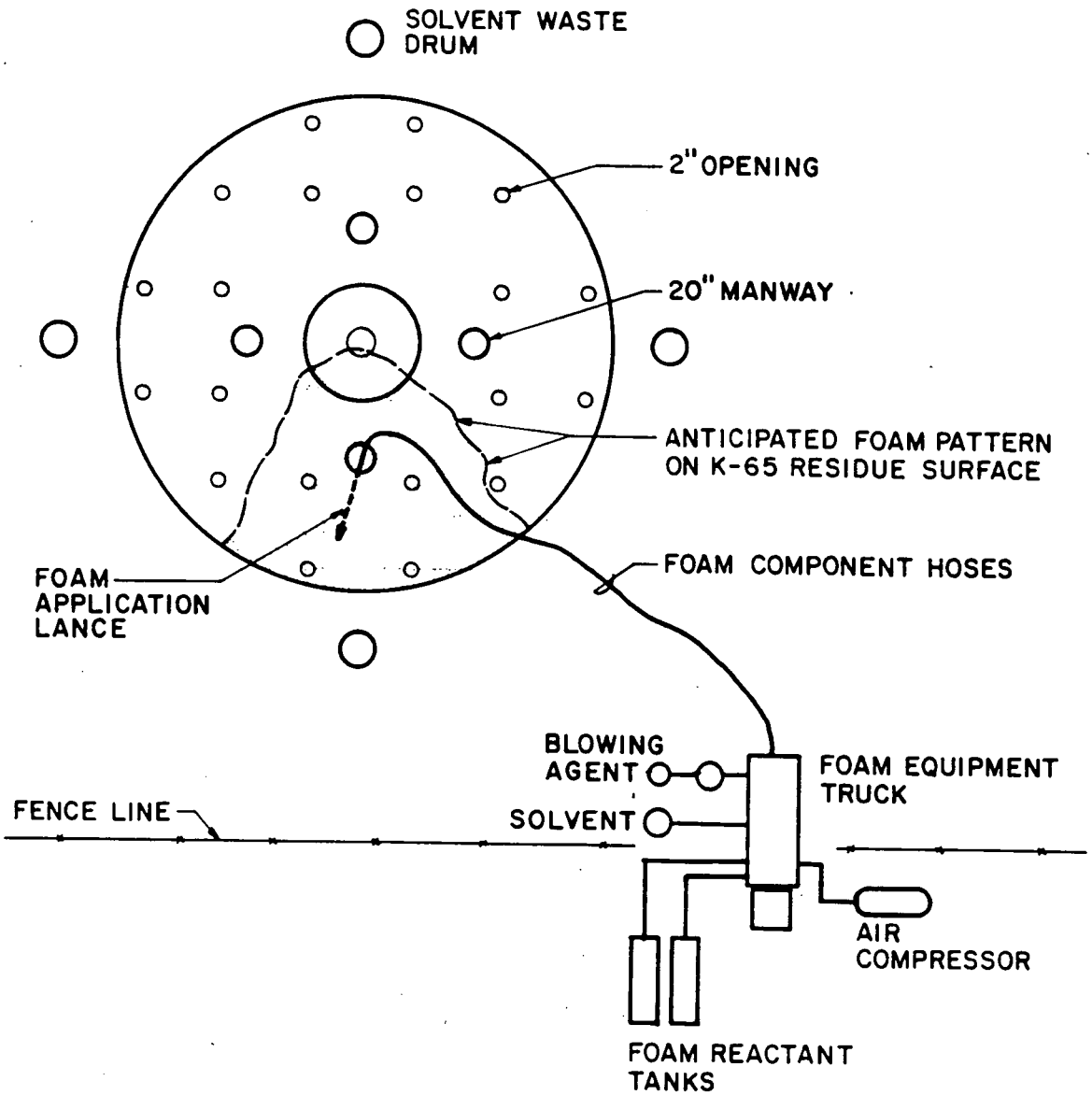
'59 75



WESTINGHOUSE MATERIALS COMPANY OF OHIO
FMPC FERNALD, OHIO
TYPICAL FOAM APPLICATION ARRANGEMENT FOR
K-65 SILO PROJECT

STARTING DATE: 8-
DRAWN BY: W. MC
DATE LAST REV.:
DRAWN BY:
INITIATOR: K. ATWOOD
PROJ. ENGR.: D. HARMER
DRAWING N 317.A.003
PROJECT N 317.09

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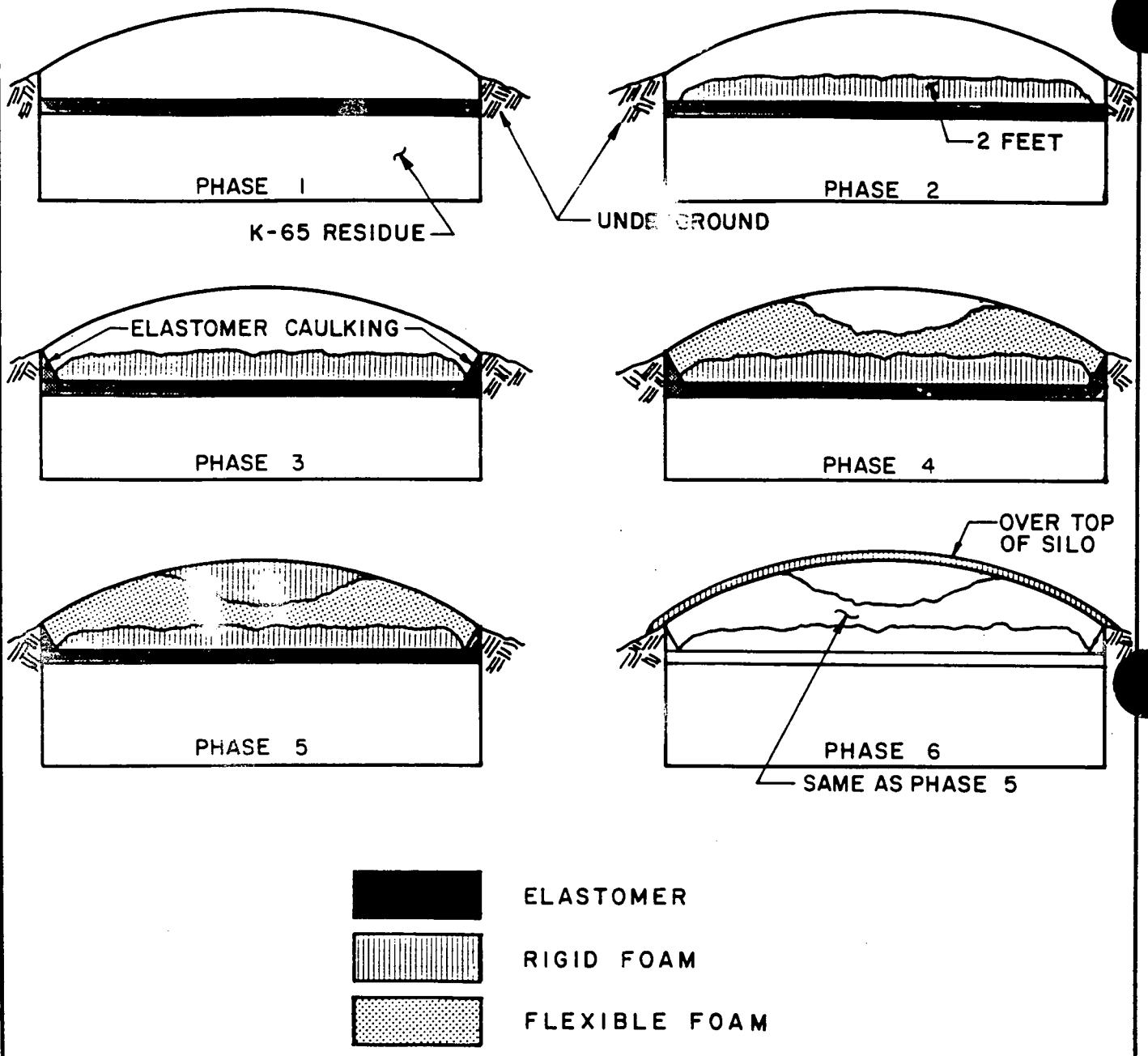
DRAWING NO 3317.A.004
PROJECT NO. 3317.09
INITIATOR: K. ATWOOD
PROJ. ENGR.: D. HARMER
DATE LAST REV.:
DRAWN BY:
STA
DRAWN BY: W. MCG



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FMPC FERNALD, OHIO
SEQUENCE OF FOAMING OPERATION
K-65 SILO PROJECT

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BRUNING 44-132 67120

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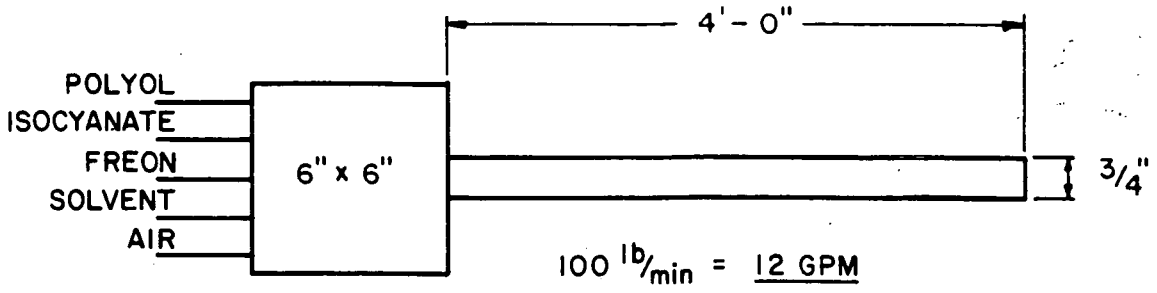
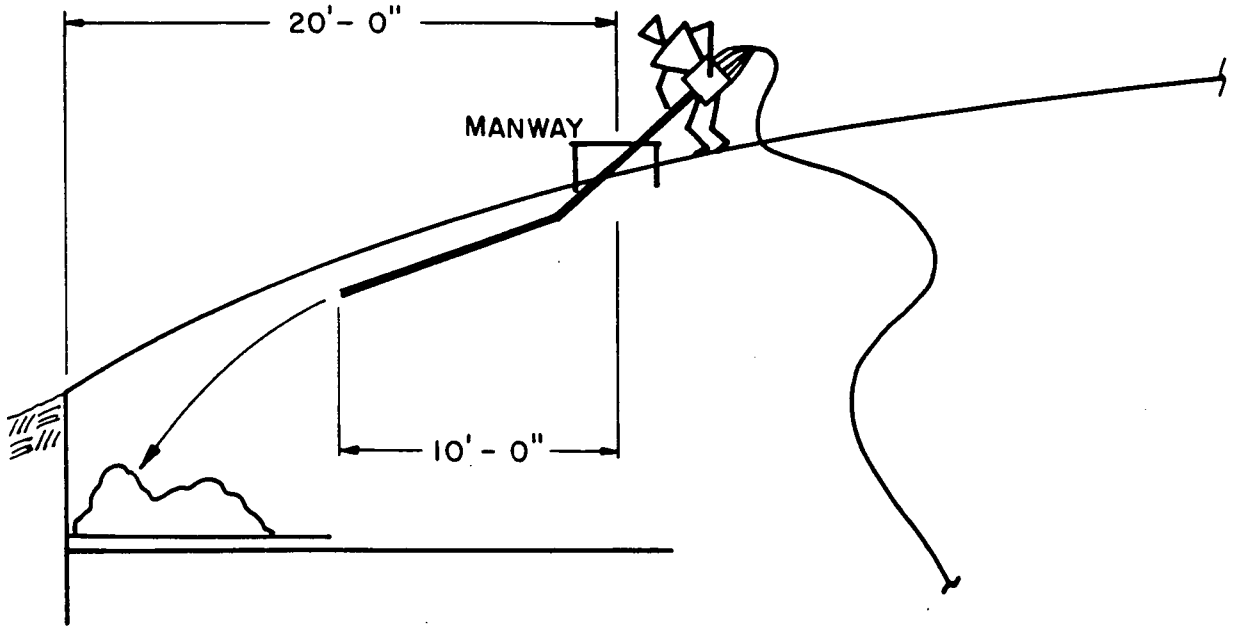
DRAWING NO.: 303317.A.005	
PROJECT NO.: 303317.09	
INITIATOR: K. ATWOOD	
PROJ. ENGR.: D. HARMEY	
DATE LAST REV.:	
DRAWN BY:	
STARTING DATE: 8-1	
DRAWN BY: W. McGILL	



FOAM APPLICATOR



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FMPC FERNALD, OHIO
FOAM APPLICATION ILLUSTRATION
K-65 SILO PROJECT

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BRUNING 44-132 67120

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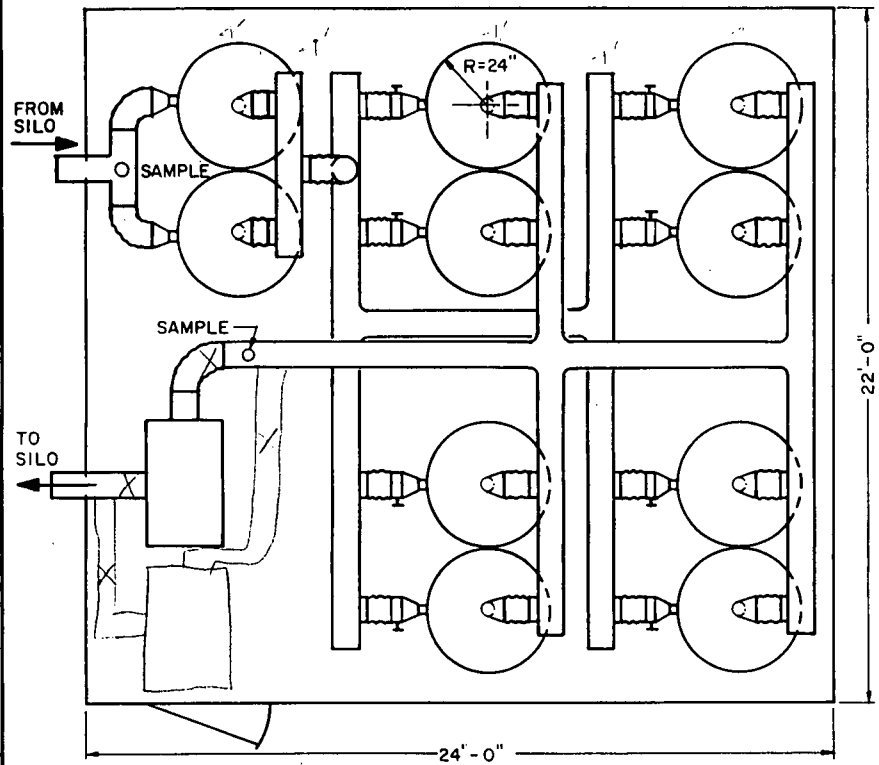
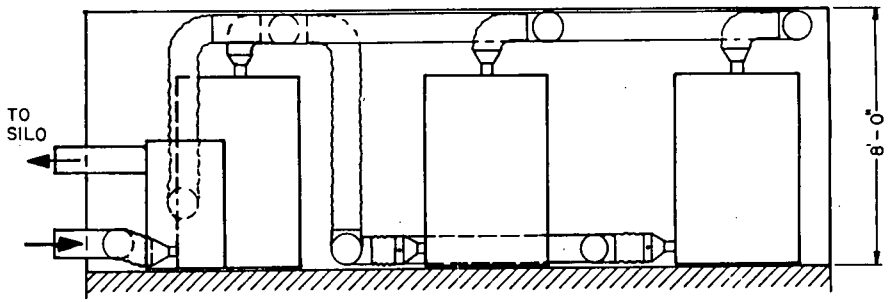
DRAWING NO.: 303317.B.002	INITIATOR: K. ATWOOD
PROJECT NO.: 303317.09	PROJ. ENGR.: D. HARMER
DATE LAST REV.:	
DRAWN BY:	
STARTING DATE: 8-11-87	
DRAWN BY: W. McGILL	



PLAN
SCALE: 1/4" = 1'-0"



ELEVATION
SCALE: 1/4" = 1'-0"

WESTINGHOUSE MATERIALS COMPANY OF OHIO
FMPC FERNALD, OHIO
GENERAL ARRANGEMENT FOR CALCIUM SULFATE/
CARBON BEDS AND ELEVATION
K-65 SILO PROJECT

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APPENDIX - Carbon System Supplier Brochure

ad • sorb *vt:* **1** to take up and hold by the adsorption process
2 effective, versatile purification method with TIGG systems

ad • sor • bent *adj:* **1** the capacity to adsorb
2 characteristic of all TIGG filters

ad • sorp • tion *n:* **1** adhesion of gas or solute molecules to solids
2 the speciality of TIGG equipment

. . . By any definition, TIGG Corporation products provide the unique advantages of adsorption in highly cost effective designs.

NIXTOX® *MODULAR ADSORBERS FOR AIR POLLUTION CONTROL, PROCESS GASES*

CANSORB® *MODULAR ADSORBERS FOR WATER POLLUTION CONTROL, PROCESS LIQUIDS*

ENVIROSORB® *LABORATORY, INDUSTRIAL AND MEDICAL WORK SPACE AIR FILTERS*

TIGG

TIGG CORPORATION

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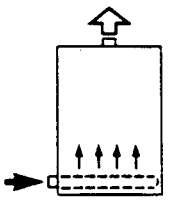
NIXTOX® *MODULAR ADSORBERS FOR AIR POLLUTION CONTROL, PROCESS GASES*

- **Tank/Separator Vents**
- **Air Exhausts**
- **Vacuum Pump Exhausts**
- **Drumming Stations**
- **Process Air Intakes**
- **Sewage Odors**

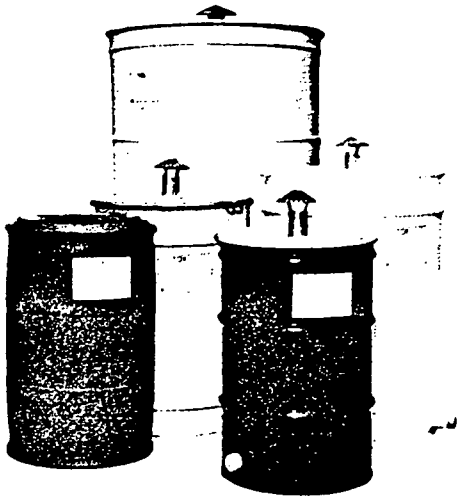
Models N100, N100 XP, N150, N250, N500 DB, N1500 DB

Shown at right are part of the NIXTOX family of modular activated carbon adsorbers. These deep bed models treat flows up to 1500 CFM per unit. All feature TIGG's unique* vapor distributors to deliver full adsorbent utilization and peak removal efficiency, at low pressure drop and low operating costs. For example, the N100 (55 gallon) contains 40% more active carbon than competitive models with gravel bed supports, giving N100 improved performance and service life, but operating at about half the flow resistance. Cost effectiveness is improved about 50%. The unique larger flow NIXTOX models offer similar design advantages.

Model numbers designate maximum flow in CFM. Rain shields and condensate drains are standard, eliminating need to provide a rain diverter and permitting filter drainage without disconnecting. For appropriate applications, optional visual saturation indicators show when the unit is about 70% exhausted. Standard construction is corrosion-resistant steel with stainless steel screen distributor. For extraordinarily corrosive situations, N100 XP is built entirely of cross-linked high density polyethylene, PVC and fiberglass. All models may be refilled or discarded after saturation. The N100 converts to a D.O.T. 5B hazardous waste disposal drum.



Standard Flow Pattern N100-N1500DB

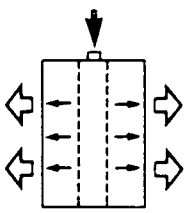


Left to right: (Foreground) N100 XP, N100; (Middle) N150, N250; (Rear) N500 DB Larger N1500 DB is not shown.

Front to rear: N500, N1000, N3000. N1500, with the same external appearance and size as N1000, is not shown. Similar larger N5000, N8000 are not shown

Models N500, N1000, N1500, N3000, N5000, N8000

For flows to 500, 1000, 1500, 3000, 5000 and 8000 CFM, respectively. These radial bed design units treat large flows at very low pressure drop, although the 5-18" bed depths are normally sufficient for long life and high efficiency. The radial design also results in a very compact adsorber, often requiring no more floor space than panel filters with an inch or less adsorbent bed depth. Typical flow is from a central stainless steel screened distributor*, outward through adsorbent, exhausting through external stainless screened ports. Flow is reversible if preferred. Units in the N500-8000 series are normally recharged, with parallel arrangements of smaller flow units used if vessel disposal is desired after adsorbent saturation. Vessel construction is corrosion-resistant steel, with other vessel materials available on custom order. The larger N5000 and N8000 units have similar flow patterns, but are shipped in segments for field assembly.

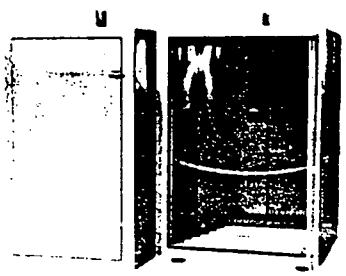


Standard Flow Pattern N500-N8000

*U.S. PATENT 4,379,750
CANADA PATENT 1,197,075

Accumulator Cabinets

These accessories collect flow from Models N500-N3000, above, when direct exhaust is not appropriate. Flow may be directed to an exhaust stack or to downstream processing as required. External floor ribs and handles facilitate positioning, and internal roller conveyors or pallet slides (N3000) assist in adsorber placement. Doors are fully gasketed. Cabinets are complete with adsorber retainer chain, inlet and outlet stacks, rupture disc, and flex hose connection for adsorber inlet. Construction is steel finished with two coats of catalyzed epoxy. Similar cabinets for N5000 and N8000 are field assembled.



Accumulator Cabinets for N500, left, and N1000/1500. The cabinet for N3000 is of similar appearance but of larger size.

See *Specifications and Properties* page for detail on NIXTOX Models.

000117

CANSORB® *MODULAR ADSORBERS FOR WATER POLLUTION CONTROL, PROCESS LIQUID PURIFICATION*

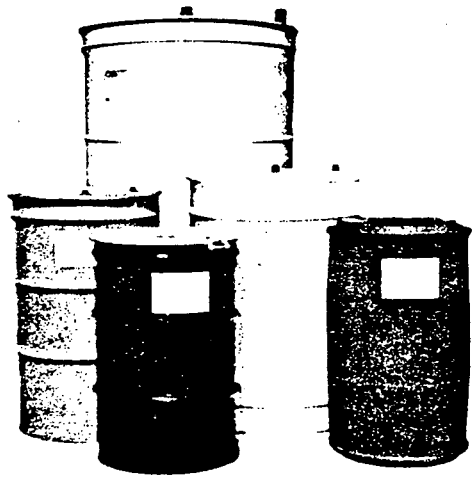
- **Waste Water/Wash Water**
- **Radioactive Waste Water**
- **Laboratory Wastes**
- **Process Streams/Solvents**
- **Spill Control**
- **Protect IX, RO Units**

Models C15, C15 XP, C20, C25, C50, C100

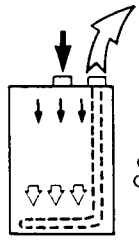
Part of the selection of CANSORB Modular Activated Carbon Adsorbers is shown at right. Model numbers give maximum recommended GPM for water and other low viscosity liquids. Maximum flow may be lower for viscous liquids or for removing impurities with low adsorption potential, or to obtain ultralow impurity levels by maximizing adsorbent:liquid contact time. Units employ a proprietary* liquid collection system that promotes even flow distribution for effective purification, maximum adsorbent utilization efficiency and low flow resistance.

Construction is double epoxy/phenolic or double phenolic lined steel as standard. The C15 XP vessel is cross-linked, high density polyethylene with PVC and fiberglass internals for highly corrosive duty. Standard units have full open heads for replacing adsorbent, but can be provided in closed head versions as needed.

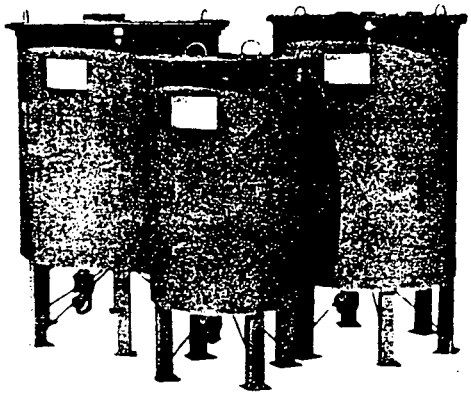
For disposal of hazardous wastes, the saturated C15 converts to a D.O.T. 5B drum. Conversion capability is of interest with non-carbon sorbents as well, for example in nonregenerable uses of ion exchange materials to isolate radioactive wastes.



Left to right: (Foreground) C15, C15 XP; (Middle) C20, C25, (Rear) C50. The larger C100 is not shown.



Standard Flow Pattern — All CANSORB and CANSORB HDS Units



Left to right: CANSORB C50 HDS, C25HDS, C35 HDS. C75 HDS, C100 HDS, and C200 HDS, not pictured, are similar units of successively larger size.

CANSORB HDS Models C25, C35, C50, C75, C100, C200

Units at left are designed for permanent installation/reuse and extra convenience in refilling. Liquid underdrains are designed with unique* collectors as described above, with similar effectiveness in flow geometry and low pressure drop. Model number refers to maximum water viscosity GPM per unit. (Also see contact time comment above.)

Standard construction is heavy steel shell with bolted flange top, completely lined with 1/4 inch thick high density polyethylene. Adsorber tops and bottoms are reinforced as needed to suppress flexing in service. Internals are stainless steel, PVC and fiberglass. Separate fittings allow adsorbent discharge and replacement without disconnecting liquid piping or removing top. Short legs assist in positioning and accommodate a bottom-mounted, side-discharging ball valve for removing spent adsorbents.

See *Specifications and Properties* page for details on CANSORB and CANSORB HDS models.

*U.S. PATENT 4,379,750
CANADA PATENT 1,197,075

CAUTIONS

NIXTOX filters are normally entirely trouble free in use. However, certain airborne materials can undergo oxidation, polymerization or other chemical reactions with, or in the presence of, activated carbon (active carbon), often with the liberation of heat. The use of NIXTOX filters to control substances such as ozone, methyl-ethyl ketone (MEK), and concentrated oxidant streams such as oxygen are not recommended for these reasons. If there is any doubt concerning the compatability of activated charcoal with your air or gas stream, TIGG Corporation will be happy to comment or to supply a sample of its adsorbent for appropriate tests. In the event the NIXTOX unit is to be connected to a storage tank or other source of flammable material, the precautionary use of a suitable flame arrester in the connection line is recommended.

CANSORB filter piping should be pressure relieved, particularly if the adsorbers are fed by a positive displacement pump or other potential sources of high system pressure in upset conditions. Similarly, CANSORB units should be vented during extended shut-downs, to relieve gases that might result from biological action on adsorbates.

ENVIROSORB LAB SENTRY, BENCH SENTRY and ODOR MAGNET filters are *designed to reduce concentrations* of adsorbable odors and other undesirable adsorbable gases and vapors. *This largely esthetic purpose is not intended to substitute for good safety or ventilation practices, nor to substitute for devices such as individual respirators or filters designed to remove poorly adsorbed substances such as carbon monoxide.*

WARRANTY

TIGG Corporation warrants these products to be in accordance with specifications and descriptions herein. Due to the wide variety of possible applications and conditions of use, no additional express or implied warranty is made for performance or suitability for particular purpose.

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ENVIROSORB®

LABORATORY, INDUSTRIAL AND MEDICAL WORK SPACE AIR FILTERS

.5975

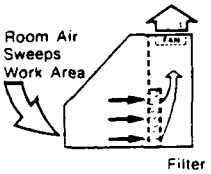
ENVIROSORB LAB SENTRY™ LABORATORY ADSORBENT AIR FILTER

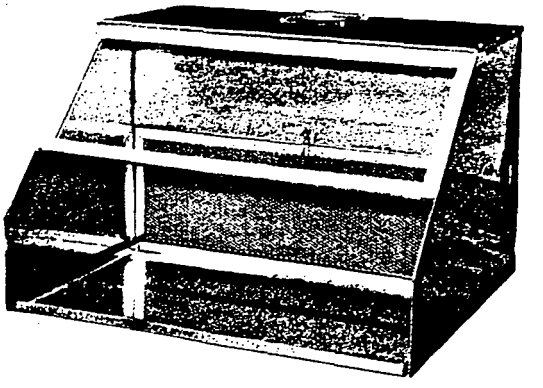
LAB SENTRY is designed for laboratories in which dedicated fume ventilation is not available, or in which adsorbable undesirable vapors require control prior to the regular chemical hood system.

The filter may be placed on counter or bench top, under a standard chemical hood, or can be fitted with connections (Parts EL-2A, EL-3A) to an exhaust duct.

Construction is lightly brushed stainless steel, with tempered safety plate observation window. The unit includes work light, switch, electrical plug and cord, spill tray, filter grille, rinsable particulate filter and TIGG's unique ADSORBOND filter panel - see below. An electronic fan assures efficient air movement without disturbing normal conversation.

LAB SENTRY AIR PATTERN





The EL-2 LAB SENTRY model is pictured. The larger EL-3 BENCH SENTRY™ for electronic soldering and other work stations, is of similar design

Specifications on other side of this page.

TIGG ADSORBOND™ BONDED ADSORBENT PANEL FILTERS

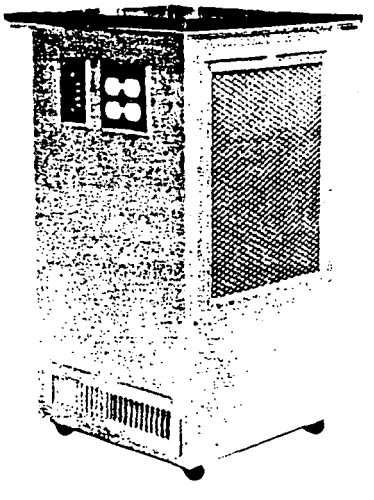
ENVIROSORB laboratory and room air filters are available with a highly innovative adsorbent system, in which the exclusive TIGG ADSORBOND process unites adsorbent particles into a porous panel. The result is a *lighter, dust free filter* with *lower flow resistance*, yet with *no loss in saturation adsorption capacity*.

Panels are faced both sides with fiber media, and framed in pressed paper board. The *adsorbent never requires handling*, since the entire ADSORBOND panel is *fully disposable*. For added disposal safety and convenience, ADSORBOND panels are *fully combustible*; permitting a *"hands-off" incineration option* for disposal - helpful if a LAB SENTRY filter had been used to isolate highly toxic chemicals, or an ODOR MAGNET™ unit had been used in an infectious medical setting. Replacement ADSORBOND panels, or steel-framed punched plate panels for loose adsorbent particles, are available from TIGG.

Standard ADSORBOND panels are made of bonded activated carbon granules or pellets. ADSORBOND panels can also be provided with special purpose sorbents. Thus ADSORBOND can control the hundreds of gases and vapors normally controlled with activated carbon, plus difficult materials such as ammonia, formaldehyde, mercury vapor and radioactive gases.

ENVIROSORB ODOR MAGNET™ ROOM/WORK SPACE AIR FILTER

—A customer put it best: "It's like opening a window, but without the energy loss."

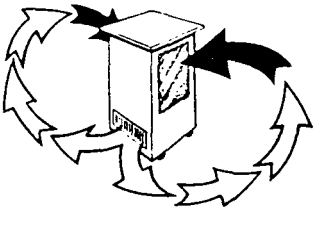


ENVIROSORB ODOR MAGNET
Shown with night light/outlet option.

See reverse of this page for specifications.

The ODOR MAGNET is designed for spaces in which odor sources can overwhelm air fresheners or filters with modest activated carbon contents. Typical applications include areas in which workers are exposed to chemical, flavor or perfume odors, or general indoor pollution common to energy-conserving buildings. In medicine, ODOR MAGNET can suppress environmental levels of certain anesthetics and prep supplies, as well as attenuate odors in rooms of incontinent patients; or those with severe infections, burns or advanced malignancies.

Construction is pebbled aluminum with a stainless steel top for work or shelf surface. Multidirectional casters provide easy movement over carpeted floors. A resiliant bumper avoids damaging walls or furniture. A rheostatic fan switch allows choices of fan speed and air movement. Operation will not interfere with normal conversation. The unit has two rinsable dust filters and two ADSORBOND active carbon filter panels, contained behind louvered doors for easy access. A unique air pattern focuses filtration where the room is occupied, producing effective air exchange and odor control at minimal power and noise level. A night light and electrical convenience outlet are available options.



ODOR MAGNET
AIR EXCHANGE PATTERNS
Indicated Flow Duplicated
On Other Side Of Unit

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SPECIFICATIONS and PROPERTIES

- TIGG products use no recycled vessels or reactivated adsorbents.
- Standard adsorbents are activated carbons. Treated carbons, ion exchange materials, molecular sieves, activated alumina, silica gel, c[illegible] sulfate and mixed sorbent media adsorbers are also offered.
- Installation and Operating Instructions are sent with each unit.

Unit	Design Maximum CFM (GPM)	psig. [a]	°F	Connections NPT (Duct)	Diameter/ Height, Inches [b]	Adsorbent, Cubic Feet	Minimum Contact. [c] Sec. (Min.)	Shipping [b],[d] Pounds
NIXTOX [e]								
N100	100	10	350	2"M	24/35	7	2.2	270
N100XP	100	10	165	2"M	24/38	7	2.2	228
N150	150	10	350	2"M	27/40	10	2.2	385
N250	250	8	350	2"M	32/44	14	1.8	510
N500DB	500	6	350	3"M	48/74	63	3.9	2275
N1500DB	1500	6	350	(6")	82/67	190	3.9	8600[f]
N500	500	Open	350	(4")	24/35	7	0.5	300
N1000	1000	Open	350	(6")	32/44	14	0.5	565
N1500	1500	Open	350	(7")	32/44	10	0.3	475
N3000	3000	Open	350	(10")	48/70	52	0.7	1950
N5000/8000	See separate specification sheet							
CANSORB								
C15	(15)	12	230	3/4"F	24/35	6	(2.1)	220
C15XP	(15)	12	165	3/4"F	24/37	6	(2.1)	,180
C20	(20)	12	230	1"F	27/40	9	(2.3)	310
C25	(25)	8	230	1 1/4"F	32/44	12	(2.5)	415
C50	(50)	6	230	2"F	48/72	63	(7.2)	2120
C100	(100)	6	230	3"F	66/72	115	(6.1)	4900[f]
C25HDS	(25)	12	165	1 1/4"M	33/58	12	(2.5)	675
C35HDS	(35)	12	165	1 1/2"M	41/64	22	(3.4)	1195
C50HDS	(50)	12	165	2"M	47/64	31	(3.4)	1525
C75HDS	(75)	12	165	2 1/2"M	57/79	59	(4.1)	2965
C100HDS	(100)	10	165	3"M	73/93	115	(6.1)	5490[f]
C200HDS	(200)	8	165	4"M	91/100	230	(6.1)	9100[f]

(a) Per Unit. Series pressures additive on upstream units.
(b) For fan-equipped: add 18" and 50 lbs. (N100-500); 25" and 80 lbs. (N1000, 1500); 29" and 190 lbs. (N3000).
(c) At maximum flow. Superficial contact about 50% greater.
(d) Active carbon basis. Higher if prewetted or other adsorbents.
(e) Available with nonsparking fans; all motor types/voltages/ phases.
(f) Adsorbent normally shipped separately to fill on-site.

ENVIROSORB

Model	CFM [a]	Voltage/ Cycles, Hz [a]	Fan Amps	Cord, ft.	Switch	L/W/H Inches	Shipping [b] Pou[illegible]
LAB SENTRY	25	115; 50/60	0.1	6	Rocker on/off	22/20/15	4[illegible]
BENCH SENTRY	45	115; 50/60	0.2	9	Rocker on/off	30/28/20	58
ODOR MAGNET	125	115; 50/60	1.0	9	Rheostatic	18/18/31	48

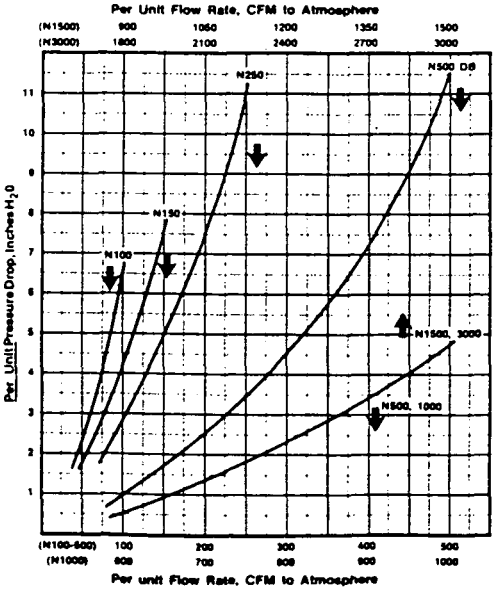
(a) 20% less CFM at 50 Hz.
(b) Including filter panels – two with ODOR MAGNET.

STANDARD ACTIVATED CARBONS

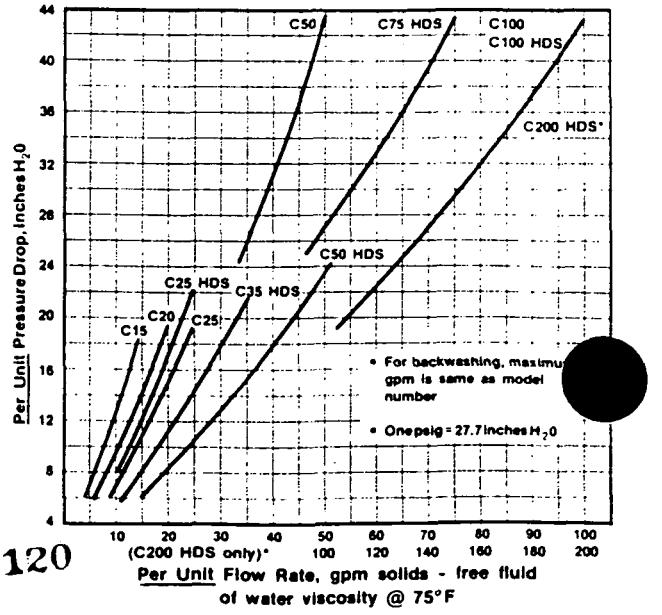
Type	Iodine No. mg./g. min.	Carbon Tetrachloride Weight % min.	Molasses No. min.	U.S. Sieve 90% min.	Bulk Density lbs./cu. ft. approx.
TIGG 5C 0410 (NIXTOX)	1050	60	—	4 X 10	30
TIGG 5D 1240 (CANSORB)	1000	—	230	12 X 40	26
ENVIROSORB/ADSORBOND	1050	60	—	4 X 8, 10	30
ENVIROSORB/Steel Frame	1050	60	—	4 X 8, 10	30

FLOW RESISTANCE

NIXTOX MODELS



CANSORB MODELS



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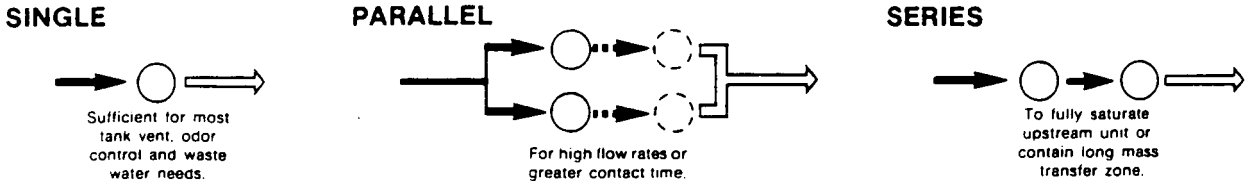
OPERATIONAL NOTES

• *ACCESSORIES/OPTIONS*

NIXTOX and CANSORB models are available with fan/motor or pump/motor combinations, rigid or flex prepiping, valves, quick disconnects, prefilters, postfilters, totalizers, rotometers, flame arrestors, temperature and pressure gauges, adsorbents prewetted with water or other process fluids, specialized adsorbents and chemisorbents. ENVIROSORB ODOR MAGNET options are night light and electrical outlet.

• *INSTALLATION/OPERATION*

All NIXTOX, CANSORB and ENVIROSORB models include the initial adsorbent fill and arrive ready for operation. After inlet and outlet fittings are connected, NIXTOX units typically go on stream immediately, while CANSORB models are usually liquid backfilled and then put in service. ENVIROSORB models need only be unpacked and plugged into an electrical outlet. Detailed instructions are sent with each unit. For NIXTOX and CANSORB, common adsorber configurations are:



• *REPLACEMENT/RECHARGING*

The smaller NIXTOX and CANSORB models may be replaced when permitted by economics of extended service life or for added convenience in disposing of wastes. Upflow NIXTOX and all CANSORB units may be completely sealed when spent. Additionally, N100 and C15 convert to D.O.T. 5B hazardous waste containers. NIXTOX and CANSORB have no gravel, screens or other loose components to complicate removing spent adsorbent or refilling vessels. The larger NIXTOX and CANSORB units are most conveniently emptied by water/adsorbent slurry or vacuum wand. Make-up adsorbents are available from TIGG.

Replacement of ENVIROSORB filters is simply a matter or removing the spent filter panel and replacing (ADSORBOND or steel) or refilling (steel-framed) it. The entire ADSORBOND panels are fully combustible, providing a variety of convenient disposal methods.

Spent adsorbent may be discarded, added to boiler coal or otherwise incinerated, or may justify reactivation if available in sufficient volume. The disposal method may be governed by the nature of adsorbate(s) on the spent material.

SPECIAL PRODUCTS/SERVICES

In addition to the standard products described in this bulletin, TIGG has the capability to design, fabricate and assemble products with ***custom modifications*** or to work with firms that may need ***unique adsorption products or systems.*** These individualized products have ranged from one-of-a-kind adsorbers to solve unusual or particularly challenging purification problems, to large scale, ***private label production of highly specialized adsorption systems.*** Systems and units designed and built by TIGG have won IR 100 and *Pollution Engineering's* 5-Star Product Advancement Awards. Our new ***ADSORBOND adsorbent bonding process*** creates additional possibilities for innovative adsorbent products and adsorption devices. Please write or call if these capabilities might help you solve a problem or attain a marketing goal.

NIXTOX, CANSORB and ENVIROSORB filters are shipped F.O.B TIGG Southcentral Operations, Heber Springs, Arkansas. This modern facility is dedicated solely to the fabrication of adsorbent products, modular adsorbers, and adsorption systems.

TIGG CORPORATION
BOX 11661
PITTSBURGH, PA 15228

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APPENDIX - Reference Material for [illegible] Adsorption on Carbon

DYNAMIC ADSORPTION OF RADON ON ACTIVATED CARBON

Kaye P. Strong and Desmond M. Levins
Australian Atomic Energy Commission
Research Establishment, Lucas Heights,
Sydney, N.S.W. 2232 Australia.

Abstract

The adsorption of ^{222}Rn from air onto activated carbon was studied over the range 0-55°C. A sharp pulse of radon was injected into an air stream that flowed through a bed of activated carbon. The radon concentration in the exit from the column was continuously monitored using a zinc sulfide α-scintillation flow cell. Elution curves were analysed to determine the dynamic adsorption coefficient and the number of theoretical stages.

Five types of activated carbon were tested and the dynamic adsorption coefficient was found to increase linearly with surface area in the range 1000-1300 m^2g^{-1}. The adsorptive capacity of activated carbon was reduced by up to 30 per cent if the entering gas was saturated with water vapor and the bed was initially dry. If the bed was allowed to equilibrate with saturated air, the adsorptive capacity was too low to be of practical use.

The minimum height equivalent to a theoretical stage (HETS) was about four times the particle diameter and occurred at superficial velocities within the range 0.002-0.02 m s^{-1}. For superficial velocities above 0.05 m s^{-1}, the HETS was determined by the rate of mass transfer. The application of these results to the design of activated carbon systems for radon retention is discussed.

I. Introduction

Three isotopes of radon occur in nature - ^{222}Rn (half-life = 3.8 days) in the uranium-238 decay chain, ^{220}Rn (half-life = 56 s) or thoron from the thorium decay chain, and ^{219}Rn (half-life = 4 s) from the actinium decay chain. Radon isotopes are not a significant radiological hazard in themselves but, because of their mobility as gases, they act as vehicles for dispersal of their alpha-emitting daughters. Radon-222 is the most significant isotope of radon both in terms of occupational exposure in uranium mines and public exposure resulting from its dispersal. The present approach to radon control in underground mines is to reduce the concentration to acceptable levels by forced ventilation. As easily accessible uranium is mined out, there will be a trend towards deeper mines where the technical problems and costs of forced ventilation could be prohibitive. An alternative approach would be to extract the radon from mine air in the vicinity of the working face. An assessment of radon removal processes[1] concluded that adsorption on activated carbon at ambient temperature was the most promising approach in terms of technical feasibility and cost.

This study of radon adsorption on activated carbon was undertaken to obtain more detailed and accurate mass transfer data than are currently available[2]. Specifically, the results are of value in the design of:

- Large scale equipment to remove radon from underground mine air by adsorption at ambient temperature[1,3].
- Gas masks or canisters containing activated carbon for short-term use in atmospheres containing very high radon concentrations

such as unventilated stopes[4].

- Apparatus used in the analysis of ^{222}Rn and ^{226}Ra by methods that involve the collection of radon on activated carbon[5,6].

- Systems for delay of ^{220}Rn that is released during reprocessing of high-temperature gas-cooled reactor (HTGR) fuels[2,7].

II. Experimental Procedure

Figure 1 shows the experimental set-up. Medically pure air was supplied at the required flow rate and humidity to a bed of activated carbon. The temperatures of the carbon bed and the inlet air temperature were controlled to ±1°C by electrical heating. Humidity was adjusted by diverting all or part of the air through a 75 mm diameter column filled with water and packed to a depth of 0.37 m with 5 mm Raschig rings. The moisture content of the air was determined by diverting the air through a silica gel trap and measuring the weight gain. Before commencement of most experiments, the activated carbon was conditioned by passing dry air through the bed for 16 hours. In a few experiments, the bed was heated to 60°C and evacuated overnight. Except where indicated, experiments were conducted at standard conditions:- superficial velocity = 0.087 m s^{-1}, temperature = 25°C, relative humidity = 0%, weight of carbon = 50 g and column diameter = 17 mm.

At the beginning of each experiment, air was momentarily diverted through a bed containing 200 g of high grade (about 30% U) uranium ore, resulting in the injection of a sharp pulse of radon into the carbon bed. Typically, about 0.5 μCi of ^{222}Rn was extracted from the ore bed with each milking. Zinc sulfide, α-scintillation flow cell detectors located at the inlet and outlet of the adsorption bed monitored both the pulse input and the subsequent elution of radon from the bed. Hold-up times on the activated carbon varied from about 30 min to 24 h. Counts from the outlet detector were integrated using a ratemeter with a time constant of 40 s and graphically recorded. The data from the chart recorder were punched on cards for processing by a computer.

Five types of activated carbon were tested for their efficiency in adsorbing radon. Variables investigated included air velocity (0.002-0.3 m s^{-1}), temperature (0-55°C), relative humidity (0-100%), bed depth (0.09-0.9 m) and column diameter (17-75 mm).

III. Flow Cell Detectors

The design of the radon flow cell detectors is shown in Figure 2. The detectors were a modified version of a scintillation cell used in the analysis of ^{226}Ra by emanation of ^{222}Rn. The cells, machined from Lucite (trademark of E.I. du Pont de Nemours & Co. Inc.), had internal volumes of 165 mℓ, and could be easily dismantled for cleaning or decontamination. A central Lucite baffle directed the flow to prevent short-circuiting and to minimise dead regions within the cell. All internal surfaces including the Lucite top and baffle were coated with a thin layer of high purity ZnS(Ag) scintillant. The coating was applied by greasing all surfaces lightly with vacuum grease and adding a few grams of ZnS(Ag) powder. The scintillant was then tumbled in the cell until a uniform surface coating was obtained. Excess powder was removed from the cell. Besides directing the flow, the central baffle improved the counting geometry by reducing the average path length that an α-particle could travel before striking a surface coated with scintillant. The flow cell was sealed by O-rings and placed, without optical coupling, on top of the photo-multiplier tube. The whole assembly was housed in

a light-tight enclosure. When freshly coated with scintillant, the background of the detectors was less than one count per minute while the efficiency for detection of radon and its α-emitting daughters was over 90 per cent.

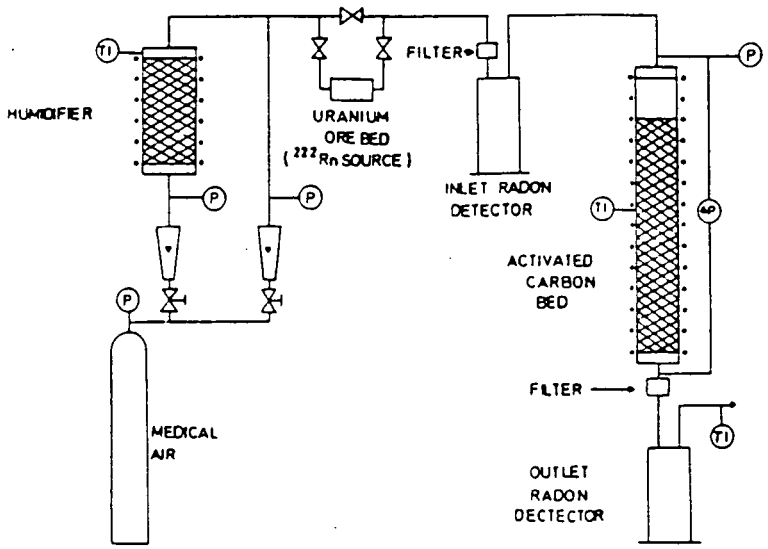

Figure 1. Experimental set-up.

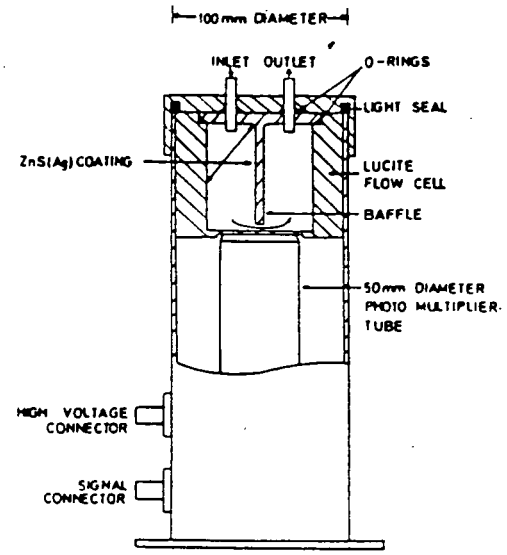

Figure 2. Radon flow cell detector

The inlet of each flow cell contained a glass fiber filter (Whatman GF/B) to remove any radon daughters from the gas stream. Nevertheless, ^{218}Po (RaA) was formed during passage of radon through the flow cell and some was deposited within the cell. The extent of deposition of radon daughters was determined by measuring the rate of decrease in the count rate following passage of a pulse of radon through the inlet detector. The percentage of ^{218}Po deposited varied from 60 per cent to almost 100 per cent and increased as flow rate was decreased. A computer program was written to convert the count rate from the detector to the radon concentration by taking account of the continual deposition and decay of ^{218}Po and the subsequent ingrowth of ^{214}Po. The efficiency of detection of the β-emitter ^{214}Bi was assumed to be zero.

IV. Mathematical Analysis

There are two conventional methods of analysing chromatographic adsorption data. The first approach, borrowed from distillation theory, assumes that a column can be divided into a number of stages of equal volume in which equilibrium always exists between the fluid and the adsorbent. The second approach acknowledges that equilibrium is never actually reached at any point in the column and explains performance in terms of the rate of diffusion and other mass transfer processes. Most descriptions of chromatographic separation rely on the equilibrium stage concept and accordingly this approach is adopted here. The response of N equilibrium stages to a change in concentration of adsorbing species can be determined by solving N first order differential equations that describe the mixing on each stage. For a pulse input in the adsorbing species and assuming a linear isotherm, the elution curve is[8,9]

$$C = \frac{N^N T^{N-1} e^{-NT}}{(N-1)!} \qquad (1)$$

where T is dimensionless time normalised to the mean residence time, τ; $T = t/\tau$; and C is dimensionless concentration normalised so that $\int_0^\infty C\, dT = 1$. The mean residence time is given by

$$\tau = \frac{k_a m}{F} \tag{2}$$

where F = flow rate ($m^3(STP)s^{-1}$), k_a = dynamic adsorption coefficient ($m^3(STP)kg^{-1}$) and m = mass of adsorbent in bed (kg). Equation (1) is asymmetric for small N and the maximum in the elution curve occurs at[2]

$$T_{max} = \frac{F\, t_{max}}{k_a\, m} = \frac{N-1}{N} \tag{3}$$

For large N, Equation (1) approaches the Gaussian distribution[10]

$$C = \sqrt{\frac{N}{2\pi}}\; e^{\frac{-N\,(T-1)^2}{2}} \tag{4}$$

and the models based on equilibrium stage theory and diffusion rates coincide.

In practice, the dynamic adsorption coefficient can be determined from the mean residence time or, more simply, from the maximum in the elution curve using Equation (3). A number of methods have been proposed to determine the number of theoretical stages including moment analysis, calculation of the variance, the ratio of peak height to area and the method of tangents[11, 12]. One of the simplest yet accurate methods is to measure the width of the elution curve half-wa up the peak ($\Delta t_{\frac{1}{2}}$). Peak widths were determined numerically from Equation (1) and found to satisfy the following relation,

$$\left(\frac{t_{max}}{\Delta t_{\frac{1}{2}}}\right)^2 = 0.180\, N - 0.194 \tag{5}$$

Since the number of theoretical stages depends on column length (L) and the diameter of the packing (d_p), the HETS and the reduced height of a theoretical plate (h) are frequently quoted as indices of column performance[13]. These terms are defined by the equation,

$$h = \frac{HETS}{d_p} = \frac{L}{N\, d_p} \tag{6}$$

V. Results and Discussion

Shape of the Elution Curves

The radon elution curves were processed by computer to determine the dynamic adsorption coefficient from Equation (3) and the number of theoretical stages from Equation (5). For the packed beds used in these experiments, the number of theoretical stages generally varied between ten and one hundred. The theoretical elution curves were calculated from Equation (1) and compared with the experimental curves.

Figure 3 compares a series of experiments using varying bed depths of Pittsburgh PCB activated carbon. In general, the experimental elution curves fitted the theoretical curves quite closely even when the number of theoretical

stages was so low that the asymmetry in the elution curves was obvious. A slight degree of tailing was noted in the experiments using Sutcliffe-Speakman type 207C activated carbon.

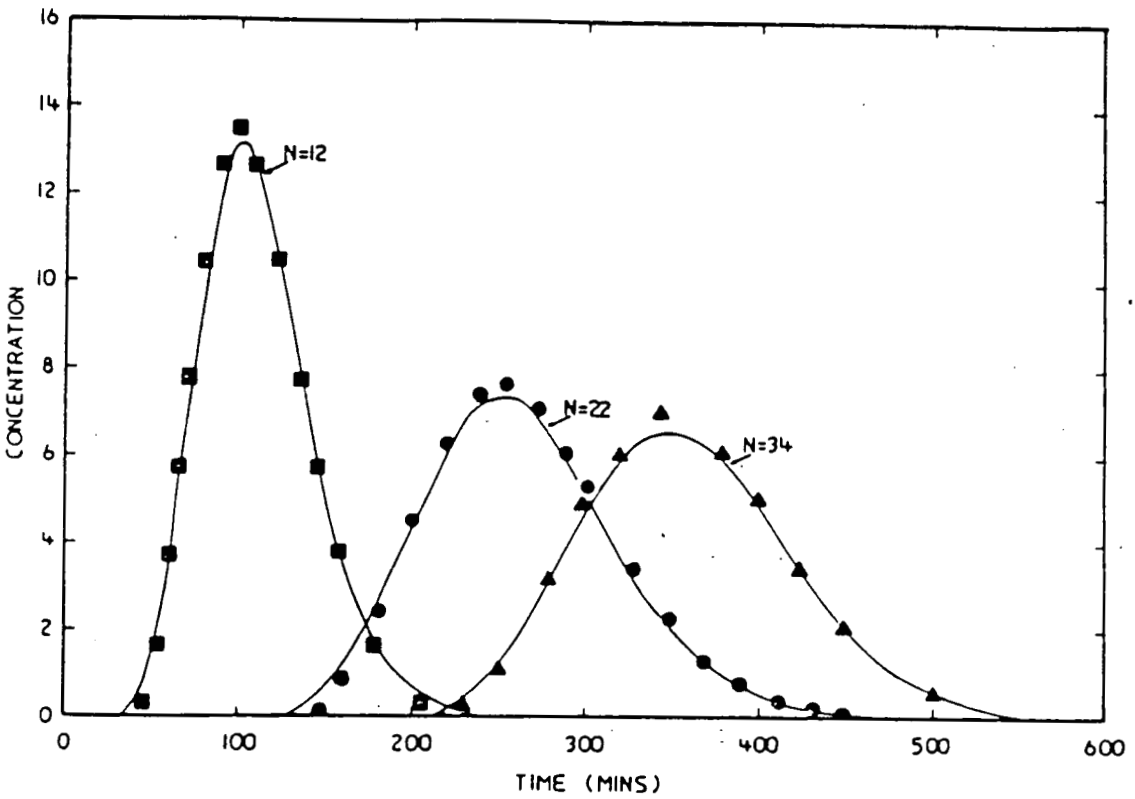

Figure 3. Shape of elution curves.

Air Velocity

As expected, the dynamic adsorption coefficient was found to be independent of air flow rate. Figure 4 shows the effect of superficial air velocity on the HETS for Sutcliffe-Speakman type 207C activated carbon. The minimum HETS was about four times the particle diameter. For velocities above 0.05 m s^{-1}, the HETS increased linearly with velocity.

The shape of Figure 4 agrees with the van Deemter equation for the effect of carrier gas velocity on HETS[14].

$$\text{HETS} = A + \frac{B}{u_s} + C\,u_s \qquad (7)$$

where u_s is the superficial gas velocity. A, B and C are, respectively, the coefficients due to eddy diffusion, longitudinal diffusion and resistance to mass transfer which occurs primarily within the adsorbent particle. The value of the constants in Equation (7) that give the best fit to the experimental data are $A = 2.7 \times 10^{-3}$m, $B = 7.3 \times 10^{-6} m^2 s^{-1}$, $C = 0.12$ s. For Sutcliffe-Speakman 207C carbon, Equation (7) can be expressed in dimensionless form as,

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$$h = \frac{\text{HETS}}{d_p} = 2.2 + \frac{0.73}{Pe} + 0.84\,Pe \qquad (8)$$

where Pe = Peclet number based on superficial velocity ($d_p u_s/D$) and D = diffusion coefficient of adsorbate ($D \sim 10^{-5} m^2 s^{-1}$ for radon). The constants in Equations (7) and (8) are similar to published data for other noble gases[2, 12, 13, 15].

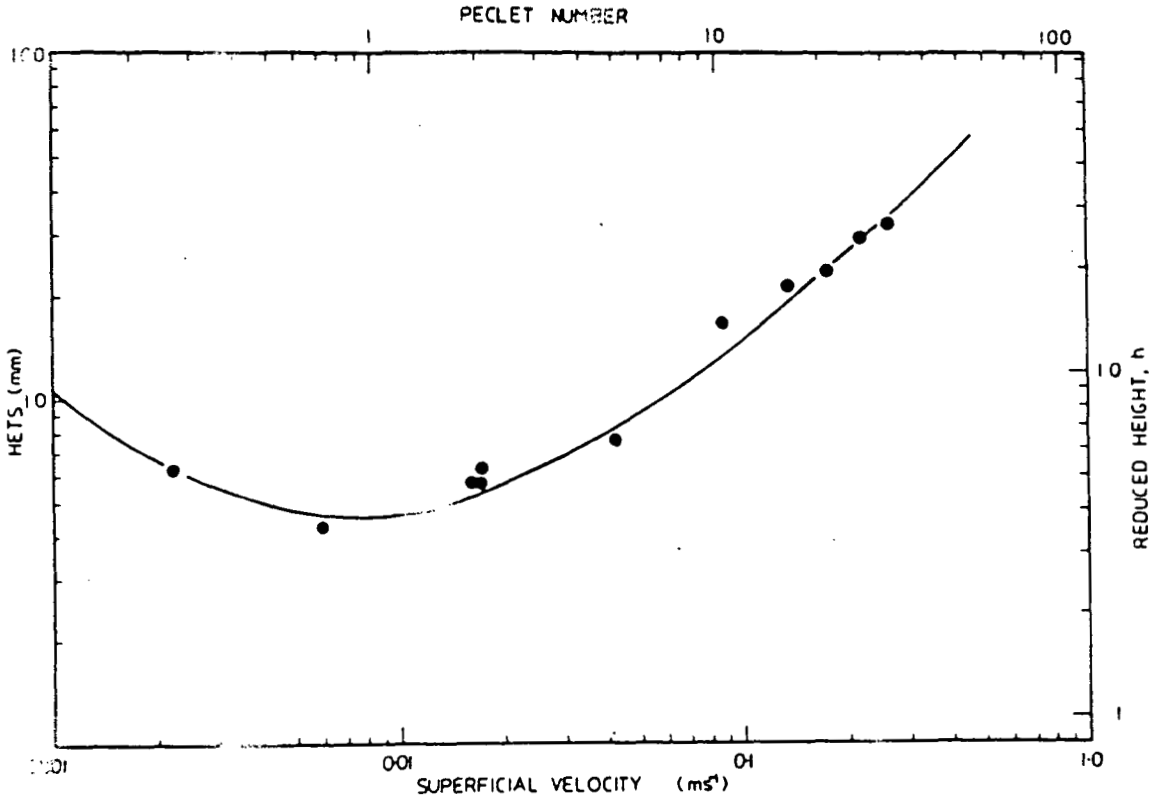

Figure 4. Effect of superficial velocity on HETS (temperature = 25°C)

Temperature

Figure 5 shows that within the temperature range 0-55°C the dynamic adsorption coefficient follows the Arrhenius equation. The calculated heat of adsorption is 6.9 kcal mol^{-1} (29 kJ mol^{-1}) which compares well with values in the range 6.1-7.1 kcal mol^{-1} (26-30 kJ mol^{-1}) reported in the literature[1, 2].

Figure 6 shows the effect of temperature on HETS for Sutcliffe-Speakman type 207C carbon at constant molar flow rate. The HETS increased with temperature in a similar way to that previously reported for adsorption of krypton and xenon on activated carbons[13]. The theoretical effect of temperature on HETS is complex since the effects due to changes in the diffusion coefficient, gas velocity and the dynamic adsorption coefficient often act in different directions[11]. The data in Figure 6 correspond to the case in which mass transfer makes the major contribution to HETS. In this case, for a rise in temperature, the diffusion coefficient increases thus tending to decrease the HETS, whereas the increase in gas velocity and the fall in the dynamic adsorption coefficient tend to increase the HETS. The biggest effect is caused by the change in dynamic adsorption coefficient since this affects the relative times that the adsorbing species spends in the adsorbed state and undergoing mass transfer. Overall the performance should improve (i.e. the HETS should fall) as temperature is decreased[11].

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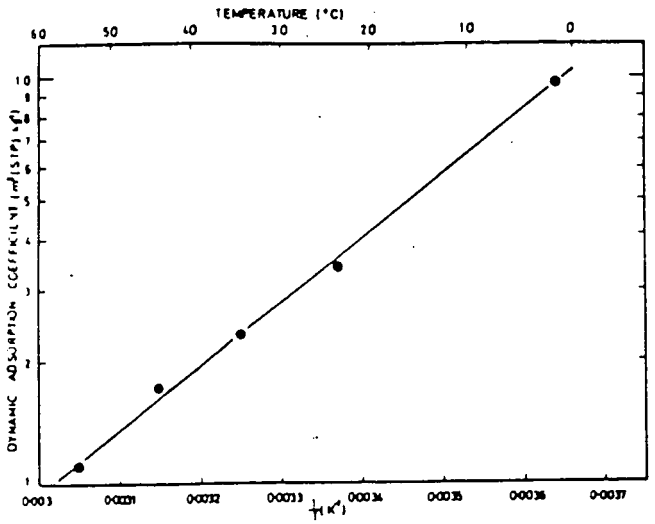

Figure 5. Temperature dependence of the dynamic adsorption coefficient

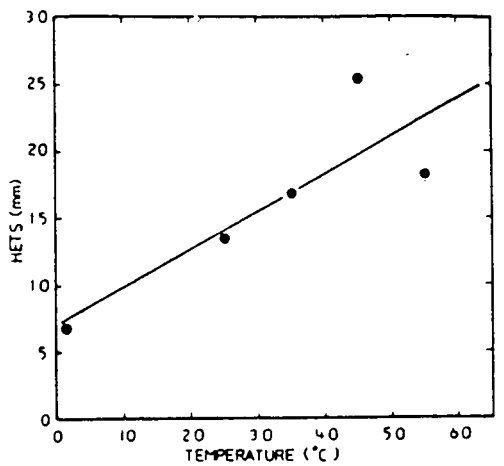

Figure 6. Effect of temperature on HETS

Type of Carbon

A comparative study was made of five commercial grades of activated carbon at the same superficial velocity (0.087 m s^{-1}) and otherwise identical conditions. There was a wide variation in performance as shown in Table 1. The measured dynamic adsorption coefficients ranged from 3.53-5.69 $m^3(STP)kg^{-1}$ compared with values ranging from 0.90-7.50 $m^3(STP)kg^{-1}$ in the published literature[1,2]. Figure 7 shows a positive correlation between the dynamic adsorption coefficient and specific surface area. This is in contrast with the results of Kovach[16] for adsorption of krypton and xenon on activated carbon where the dynamic adsorption coefficient passed through a maximum at a surface area of 900 m^2g^{-1}

Table I. Properties and performance of activated carbons

Type	Source	Shape	Mass Mean Diameter (mm)	Surface Area (N_2, BET) (m^2g^{-1})	k_a $m^3(STP)kg^{-1}$	HETS (mm)	h
Sutcliffe-Speakman 207C	Coconut shell	flakes	1.2	1000	3.53	14.9	12.4
Norit RFL3	Peat	extruded cylinders	4.7	1150	4.61	66.9	14.2
Norit RL111	Peat	extruded cylinders	4.7	1200	4.66	67.9	14.4
Ultrasorb SC2	Coconut shell	chips	0.7	1200	5.00	5.6	8.0
Pittsburgh PCB	Coconut shell	flakes	2.5	1300	5.69	22.9	9.2

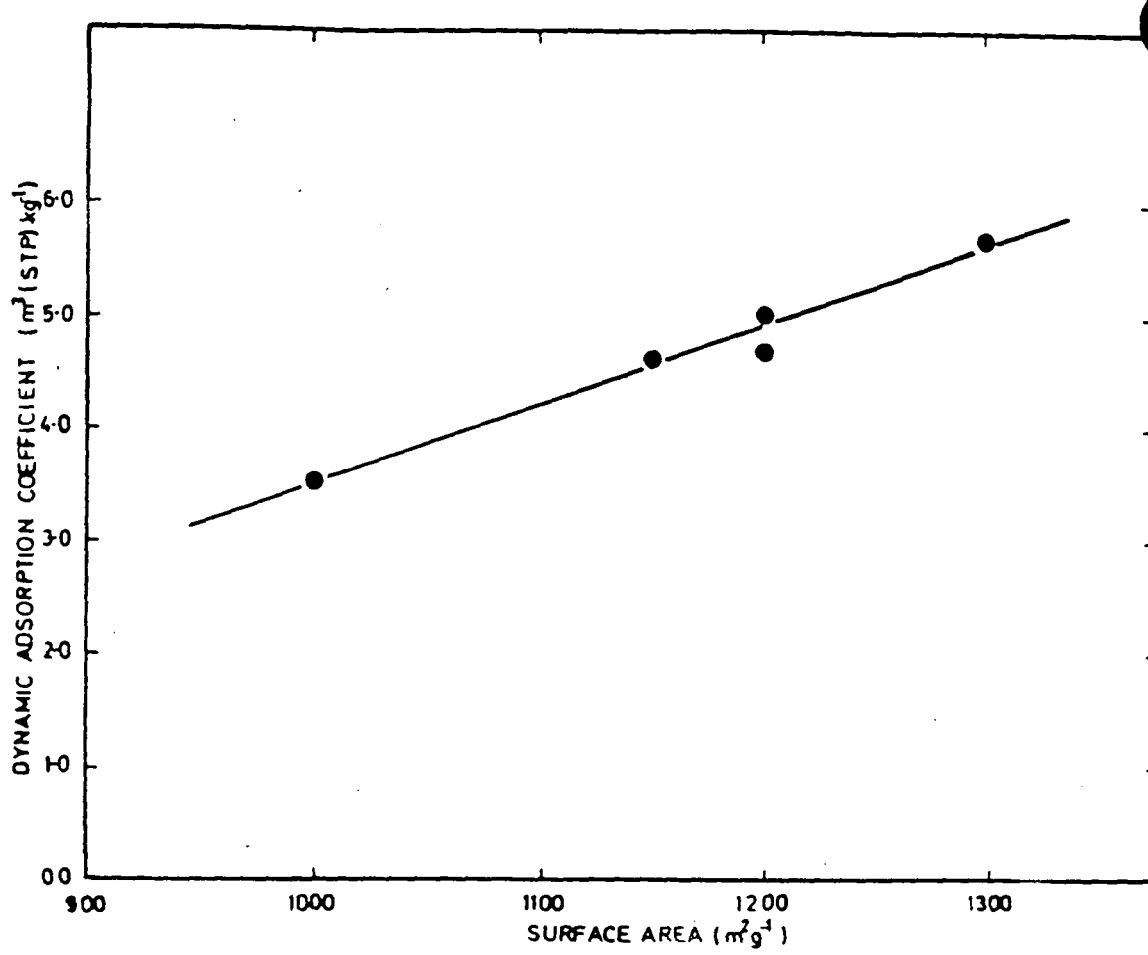

Figure 7. Relation between surface area and dynamic adsorption coefficient

Particle size is the most significant factor affecting the HETS. There appears to be a residual correlation between reduced height of a theoretical stage and both particle diameter and k_a but these effects are difficult to unravel. Prediction of k_a using Equation (8), which strictly only applies to Sutcliffe-Speakman 207C carbon, gives reasonable agreement with the experimental data except for the two Norit carbons. For these extruded cylindrical carbons it is difficult to define an effective diameter for use in the Peclet number, and the predicted values of h using the mass mean diameter are about twice the experimental values.

Bed Height

Four experiments were carried out with bed heights ranging from 90-900 mm but with otherwise identical conditions. The dynamic adsorption coefficient was constant but, as shown in Figure 8, the HETS increased slightly as height was raised. This is a well-known phenomenon in chromatographic columns which has generally been explained in terms of the change in velocity through the bed due to the pressure drop[10, 11]. In the present case, this does not appear to be the explanation since the pressure drop was only 1 kPa per meter of packing. A more plausible explanation for the deterioration in performance as bed height is raised is the progressive increase in channeling in the area of high voidage near the wall. This effect has been observed in other mass transfer equipment and can be remedied in very deep beds by installation of redistributors at regular intervals along the column.

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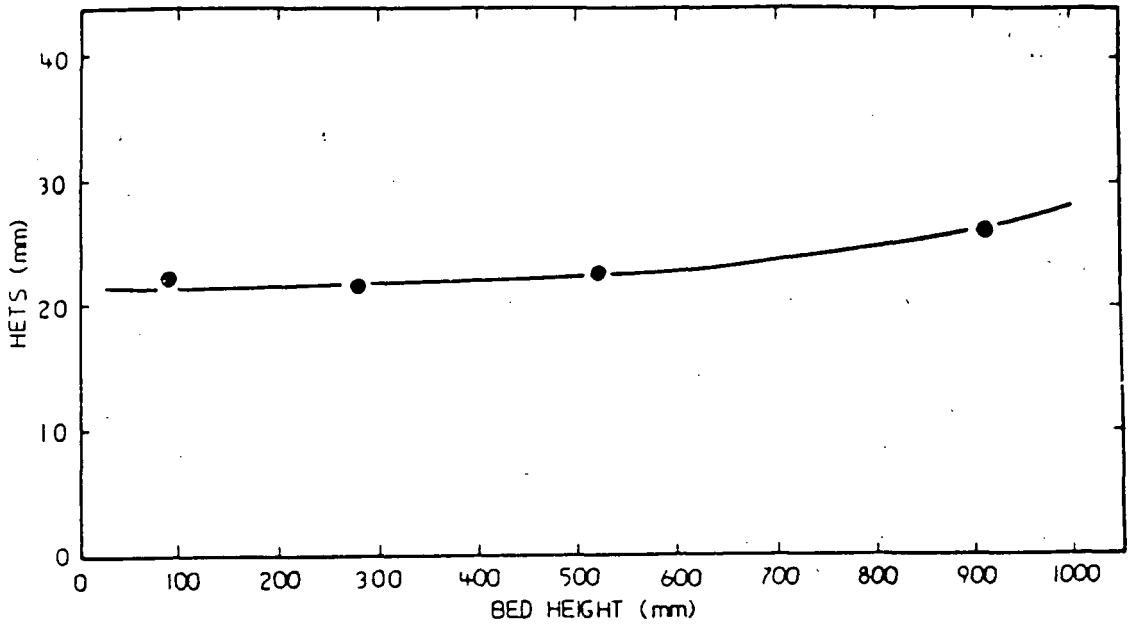

Figure 8. Effect of bed height on HETS (Pittsburgh PCB carbon, temperature = 25°C, superficial velocity = 0.087 m s^{-1})

Column Diameter

A reduction in performance with increase in diameter of chromatographic columns has been reported by many workers and is usually attributed to an uneven flow profile across the column[11]. To determine the effect of column diameter on performance, three experiments were conducted with column diameters ranging from 17 to 75 mm at constant superficial velocity. Each column was carefully packed to the same bulk density (0.47 kg ℓ^{-1}) with Sutcliffe-Speakman 207C activated carbon. The experimentally measured HETS was 5.7 mm for both 17 mm and 38 mm diameter columns and slightly higher (6.4 mm) for the 75 mm column. This variation in HETS was probably within experimental error and these experiments do not indicate a significant effect of column diameter on performance.

Humidity

The effect of water vapor on radon adsorption was studied in two series of experiments. In the first series, the activated carbon bed was first equilibrated with water vapor by passing humidified air through the bed at the test conditions for 16 hours. When equilibrated in this way, the performance of the bed was satisfactory at low relative humidities (<15%) but deteriorated rapidly for higher humidities. The dynamic adsorption coefficient was reduced to 50 per cent of its initial value at 30 per cent relative humidity. The reduction in k_a was matched by a corresponding rise in HETS. A few experiments were carried out at 100 per cent humidity but the retention time was too low to be of practical use. There was considerable scatter in the results of these experiments and local condensation of water was suspected.

In the second series of experiments, humidified air was passed into a dry bed at a temperature of 25°C and a superficial velocity of 0.087 m s^{-1}. Figure 9 shows that the dynamic adsorption coefficient decreased by 30 per cent for an increase in relative humidity from 0-100 per cent. This relatively small effect is explained by the observation that the radon penetrates the bed at a faster rate than water

vapor. Hence, for most of its travel, the radon passes through a dry bed. Near the inlet, the combined effects of temperature rise due to the heat of adsorption of water and the competition with water vapor for active sites tends to reduce the dynamic adsorption coefficient for radon. A computer program is being developed to solve the equations for heat and mass transfer during adsorption of water vapor on activated carbons. Initial results suggest that the effect of temperature rise on k_a is more important than co-adsorption of water vapor.

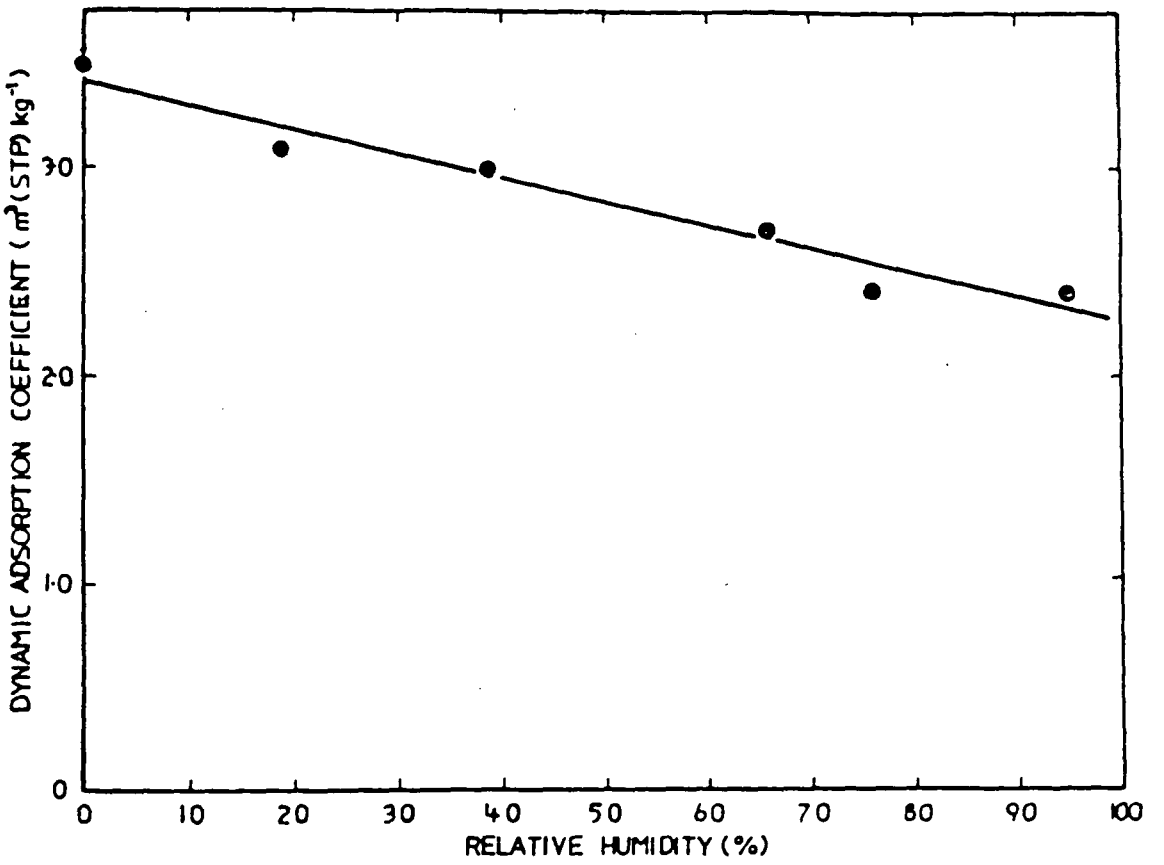

Figure 9. Effect of humidity on the dynamic adsorption coefficient (Sutcliffe-Speakman 207C carbon)

The results reported here are in contrast to the work of Thomas[4] who reported that deterioration in performance of gas mask canisters was most marked when the activated carbon was initially dry. The canister tested by Thomas had a diameter of 0.1 m and a depth of only 31 mm so inlet effects, particularly the sharp initial rise in temperature, would be expected to dominate under these conditions.

Ageing and Regeneration

The activated carbon bed was usually regenerated between experiments by passing dry air through the bed at a superficial velocity of 0.1 m s^{-1} for 16 hours. In a few cases the bed was heated to 60°C and evacuated overnight. This did not improve the adsorption properties of any of the carbons with the exception of Sutcliffe-Speakman type 207C where a slight increase in k_a was observed. Many experiments were conducted with the same carbon bed over several months without deterioration in performance due to ageing.

VI. Application of Results

Since the mass of radon adsorbed on an activated carbon bed for all practical cases is infinitesimal, the performance of a bed is independent of radon concentration and its capacity is determined by the total volume of air that passes through it. In most practical instances, the radon enters the bed as a step change in concentration rather than as the radon pulse used in these experiments. The response to a step change can be simply calculated by integrating the elution curve for a pulse input (Equations (1) or (4)).

For optimum performance, a radon adsorption bed should be sufficiently deep (at least 0.2 m is suggested) so as to contain a large number of stages and minimise broadening of the breakthrough front. The superficial velocity should ideally be in the range 0.002-0.02 m s^{-1}, which will minimise the HETS (see Figure 4) and ensure a low pressure drop. Unfortunately these requirements are not always consistent. This can be seen by expressing Equation (2) in the form,

$$\tau = \frac{T\, k_a \rho_b\, L}{273\, u_s} \qquad (9)$$

where ρ_b = bulk density of the carbon bed, typically about 450 kg m^{-3}. Substituting k_a = 5 m^3(STP)kg^{-1} at T = 298 K in this equation gives

$$\tau = \frac{2500\, L}{u_s} \quad (s) \qquad (10)$$

For the recommended limits, L = 0.2 m and u_s = 0.02 m s^{-1} then τ = 7 h. This means that, unless the bed is designed for a retention time of 7 h or longer, some departure from optimum conditions must be made. In practice, the velocity should be increased rather than the column length reduced because this results in a larger number of theoretical stages.

The design of an activated carbon adsorption process to remove radon from underground mine air was considered by Arthur D. Little Inc.[1]. This design was based on k_a = 4 m^3(STP)kg^{-1} which is consistent with the results reported here after allowing for the effects of humid air on performance. A sharp breakthrough front was assumed and no allowance was made for broadening due to a finite number of stages. The equipment was designed to process 2.36 $m^3 s^{-1}$ (5000 SCFM) at a bed superficial velocity of 0.4 m s^{-1}. For these conditions, the HETS would be approximately 50 mm (see Figure 4) and the bed depth of 0.82 m would be equivalent to only 16 theoretical stages. Broadening of the breakthrough front would be significant and the capacity of the bed would be reduced accordingly. Even with optimistic assumptions, the study found that removal of radon from underground mine air was not competitive with conventional forced ventilation on economic grounds. The major cost was not the carbon adsorber itself but that of ancillary equipment such as blowers, heat exchangers and heating costs associated with thermal regeneration to desorb radon from the exhausted bed. If a simple and cheap method of bed regeneration were devised, adsorption on activated carbon could become a feasible method of removing radon from mine air.

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Thomas[4] has demonstrated that portable canisters containing activated carbon can provide short-term protection (up to 1 h) from exposure to very high radon concentrations such as might occur in unventilated mine stopes. The breakthrough data presented by Thomas have been reanalysed to determine the dynamic

adsorption coefficient and values ranging from 3.8-5.7 $m^3(STP)kg^{-1}$ at room temperature have been estimated for the most effective carbon tested[1, 2]. The Mil Army gas mask canister has a depth of only 31 mm which violates the design criteria discussed above. As a consequence, some breakthrough of radon occurs after a very short interval and this canister is not recommended. The Scott-Acme canister has a greater capacity, and being longer (15 cm), it is a more satisfactory design.

Activated charcoal traps are frequently used to collect radon for analytical purposes. Two common applications are atmospheric sampling for ^{222}Rn in the vicinity of uranium mines and mills, and determination of ^{226}Ra in solutions by ingrowth and subsequent de-emanation of ^{222}Rn[5, 6]. In most applications it is recommended that activated carbon traps be cooled with liquid nitrogen or dry ice. Calculations of adsorber capacity based on the mass of carbon and the volume of air that is passed through the trap frequently show that it is not essential to cool the traps, although in some cases the geometry of the bed needs to be modified. Adsorption of radon at ambient temperatures would simplify procedures particularly in situations that require field work.

Another possible application for activated carbon is the removal of ^{220}Rn from the off-gas stream during reprocessing of HTGR fuel[2, 8]. Since ^{220}Rn has a half-life of only 56 s, only 20 minutes is sufficient for essentially complete retention. Activated charcoal has 10-20 times the adsorptive capacity of molecular sieves and about 200 times that of silica gel[1, 2]. As with other applications for activated carbon, the major disadvantage is the fire hazard.

VII. Conclusions

Over the temperature range, 0-55°C, the dynamic adsorption coefficient for radon on activated carbons with specific surface areas (S) in the range 1000-1300 m^3g^{-1} can be estimated from the equation

$$k_a(m^3(STP)kg^{-1}) = (0.0070S - 3.51)e^{-\frac{6.9 \times 10^3}{RT}} \qquad (11)$$

The presence of water vapor in air decreases the dynamic adsorption coefficient. For an initially dry bed of activated carbon at ambient temperature, the dynamic adsorption coefficient decreases by about 30 per cent for an increase in relative humidity from 0-100 per cent. If the bed allowed to equilibrate with saturated air, the adsorptive capacity is too low to be of practical use.

The minimum height equivalent to a theoretical stage (HETS) occurs at superficial velocities in the range 0.002-0.02 m s^{-1}. This minimum value is typically about four times the particle diameter. For superficial velocities above 0.05 m s^{-1}, the HETS is governed by the rate of mass transfer.

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DISCUSSION

TADMOR: Dr. Levins, as you rightly mentioned, radon is a problem in the mining of uranium, but it may be also a long term problem from the long term release of radon from tailings and other residual materials from mining. Do you have data, or would you venture to make some predictions, on the adsorption of radon on soil and underground material which may be used to cover the tailings produced in mining or milling of uranium?

LEVINS: We haven't a lot of evidence on the adsorption of radon on soil materials. My general observation would be that it wouldn't be very strong. There is one exception: silica, that may appear in tailings, may adsorb the radon weakly, but I don't think it would be a significant factor in retarding the release of ra-

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CLEANUP OF RADON INHALATION STUDY EFFLUENTS*

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Abstract

This report discusses a limited amount of experimental data on radon retention by activated carbon. The data collected were used to design a system for retention of 99% of the radon leaving an inhalation exposure chamber. A flow diagram, shielding considerations for the carbon beds, and operating characteristics of the proposed system are presented. A successful test of the prototype retention system indicated that 40 cubic meters of air would be decontaminated of radon by one kilogram of PCB (6 x 10 mesh) activated carbon under experimental conditions of 0 ±2°C and 330 cm/min superficial velocity or 660 cm/min true velocity with 50% void.

Introduction

Studies of the effects in animals of inhalation of radon and its daughter products, in progress in the Battelle-Northwest laboratory for several years, have resulted in continuous release to the environment of approximately 300 μCi of ^{222}Rn per minute. A recent change in the physical location of these studies to a less isolated area, the ERDA Manual Chapter 0511 requirements[1], and as low as practicable (ALAP) considerations[2], required development of a radon retention system capable of decontaminating 4,000 cubic meters of moist, radon-bearing air per month.

140,000 ft³

Very limited information exists in the literature for radon effluent retention systems. Since radon is a noble gas, work on effluent treatment systems for krypton and xenon in reactors may be applicable. Relevant information is found in the proceedings of the AEC Air Cleaning Conferences [3,4,5]. The work by Jess W. Thomas [6] of the Health and Safety Laboratory in evaluation of activated carbon canisters for radon protection of workers in uranium mines contains a review of the variables involved in radon retention. The variables considered were radon concentration, flow rate, humidity, carbon dioxide concentration, temperature and carbon type.

Based upon these variables, extrapolated data suggested that the radon effluent could be retained at the flows required for about 15 days in 20 cubic feet of activated carbon cooled to zero degrees centigrade. To pinpoint a more exact adsorption capacity of activated carbon beds, some simple experiments were designed utilizing a radon generator and commercially available carbon.

Experiment

Using the apparatus shown schematically in Figure 1, tests were conducted to determine the amount of air that could be decontaminated of ^{222}Rn per kilogram of Pittsburgh PCB (6 x 16 mesh) activated carbon** under the conditions described below. The activated carbon had an apparent bulk density of 0.44 g/cm³ and 50% voids in a dense packed column. Two experiments used a 43 cm long column (0.59 kg) of activated carbon, while one experiment used a 21.5 cm long column (0.29 kg) of activated carbon. The superficial velocity in the charcoal bed was calculated to be 330 cm/minute from the 6.2 cm column diameter and the 10 ℓ/min flow rate. The radon-bearing air entering the freezer and the air leaving the freezer were monitored using alpha air monitoring equipment. The radon was generated at about 90 μCi/min, diluted with room air to a flow rate of 10 ℓ/min, cooled to approximately 7°C to remove some of the moisture and passed through a drierite bed for further dehumidification before introduction into the freezer. In the freezer, which was held at a temperature of 0 ±2°C, the radon-bearing air was cooled in a copper coil before introduction into the charcoal bed. Flow through the system was maintained until radon was detected by the downstream alpha air monitor.

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*Based on work performed under Contract E(45-1):1830 with United States Energy Research and Development Administration.

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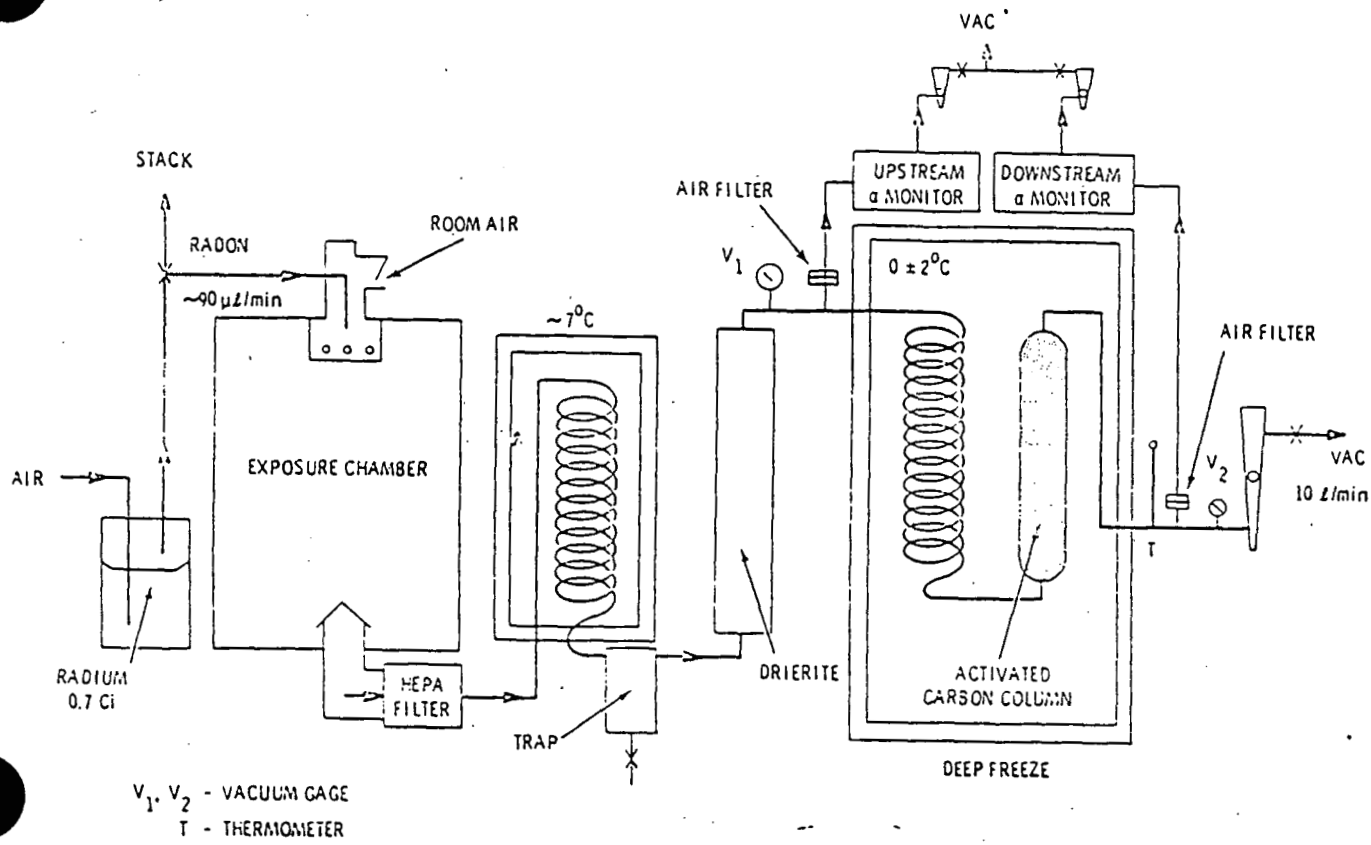

Fig. 1 Experimental radon retention apparatus

From the results of the three runs (shown in Table 1), a reasonable assumption is that 40 cubic meters of air would be decontaminated of radon by one kilogram of PCB (6 x 16 mesh) activated carbon under the experimental conditions of 0±2°C and 330 cm/min superficial velocity (or 660 cm/min true velocity considering 50% voids).

Table 1: Retention of Radon by Activated Carbon (PCB, 6 x 16 mesh)

Run No.	Column Lg (cm)	Column Wt (kg)	Time to Rn Breakthrough (hrs)	Vol. of Air Decontaminated (m^3)	Radon Retained (mCi)	Retention Efficiency (m^3/kg)
1	43	0.59	42.0	25.2	227	42.7
2	43	0.59	40.0	24	216	40.7
3	21.5	0.29	17.5	10.5	95	36.2
					Average	39.9 ±3.3

Design of Radon Retention System

The radon retention system required is visualized as 1) the equipment to dry and precool the air stream and 2) two activated carbon filters, each with the capacity to decontaminate at least one month's output of radon-bearing air. When one filter becomes "loaded" with radon (i.e., when radon first shows at the outlet of the filter), the air stream would be valved to the second filter. By the time the second filter is loaded, the radon retained in the first filter would have decayed away, and the filter would be ready for use again.

Figure 2 is a schematic diagram of the retention system that has been designed and is now under construction. All of the air treatment equipment is commercially available except for the activated carbon filter. A dual system was designed for failure protection with the exception of the cold room which contains the dual activated carbon

ter. The carbon bed and massive shielding will remain at low temperatures for substantial time periods in event of refrigeration failure. Reduced flows may be required even though the radon-bearing air is cooled to approximately 0°C before entry to the carbon. The air handling system is designed to process up to 1.0 m^3/min of air. Actual flow rates will vary from 1×10^{-1} to 0.5 m^3/min initially, with higher flow rates likely in the future.

A more detailed drawing of the dual, activated carbon filters in Figure 3 shows the required shielding and capability to replace the activated carbon if necessary. The carbon filter is a dual unit with each bed consisting of . 110 kg of activated carbon packed in two columns that are 31.5 cm diameter and 145 cm tall. Either half of the unit may be used with the radon-bearing air entering the chamber at the bottom and passing up through the two activated carbon columns simultaneously. The activated carbon is expected to process about 4,000 cubic meters of air per month.

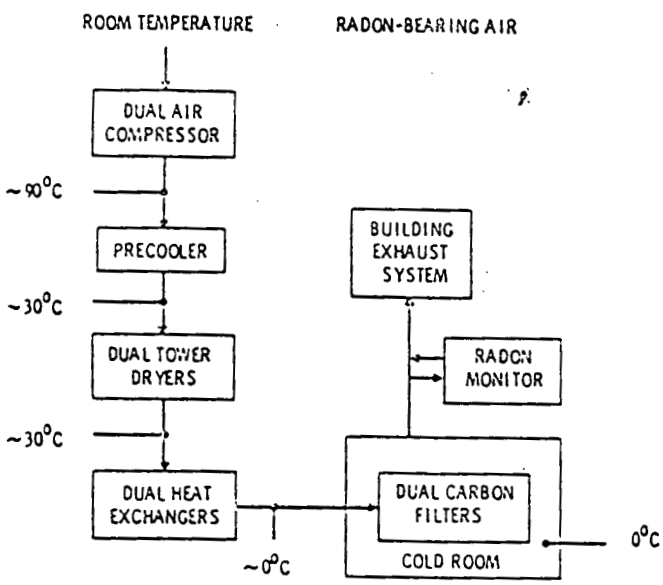

Fig. 2. Flow Schematic - Radon Retention System

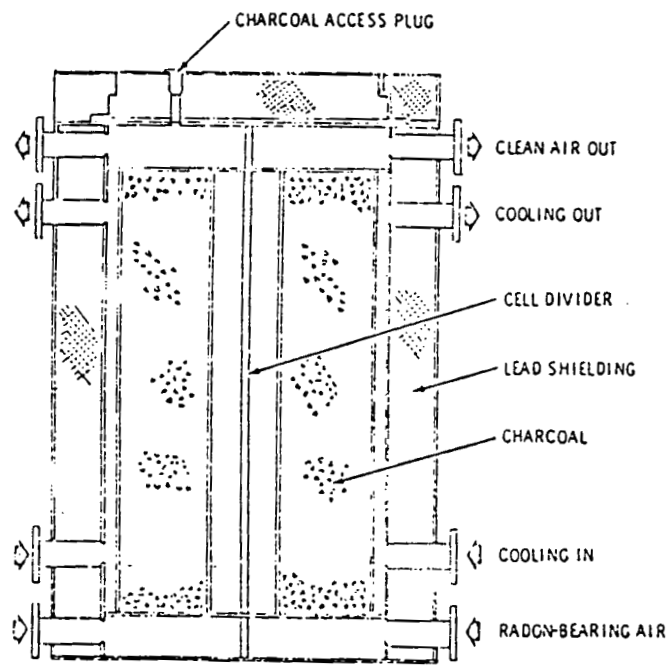

Fig. 3. Dual Activated Carbon Filter

Shielding Conditions

A six-inch lead shield was designed around the carbon filter. The maximum continuous input of radon was specified as 300 μCi per minute. When equilibrium is reached in the carbon filter, about 2.4 curies of radon are expected to be present. Table 2 briefly reviews the radon decay chain and shows only the gamma energies and yield.

Table 2: Radon-222 Decay Series

Nuclide	Half-Life	Gamma Energy (MeV)	Yield %
^{222}Rn	3.8 d	0.510	0.07
^{218}Po	3.05 m	--	--
^{214}Pb	26.8 m	0.295	19
		0.352	36
^{214}Bi	19.7 m	0.609	47
		1.120	17
		1.764	17
^{214}Po	164 μs	0.8	0.014
^{210}Pb	21 y	0.047	4

When considering shielding needs, ^{214}Pb and ^{214}Bi contribute almost all of the gamma rays of concern. A calculated six inches of lead would be expected to reduce the maximum dose rate to less than 1 mrem/hr at the outside surface of the shield. The shielding has four access plugs on the top that would permit replacement of the carbon if some unforeseen contaminant reduces the adsorption capacity. The radon and daughters would be permitted to decay before replacing the carbon. The residual ^{210}Po which would build up gradually in the carbon has a low yield (4%) gamma emission of low energy (0.047 MeV) which is not expected to cause any severe exposure problems.

Conclusions

A prototype retention system for radon and its daughters has been successfully tested. The prototype test indicated 40 cubic meters of air would be decontaminated of radon by one kilogram of PCB (6 x 16 mesh) activated carbon under the experimental conditions of 0 ±2°C and 330 cm/min superficial velocity or 660 cm/min true velocity considering 50% void.

A final design was completed and the system is expected to be installed and operational by January 1, 1976. Details of the testing of this system will be reported if available at the scheduled oral presentation of this paper.

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Sent for 2/4/86..

Health Physics Vol. 45, No. 2 (August), pp. 501-508, 1983
Printed in the U.S.A.

0017-9078/83 $3.00 + .00
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THEORY AND PRACTICE OF RADON MONITORING WITH CHARCOAL ADSORPTION

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Abstract—Because of interest in charcoal adsorption as an inexpensive radon monitoring technique that may be suitable for mass data collection, the theory of radon adsorption from air by a charcoal bed is developed, giving numerical estimates at all stages. The method is practical down to air concentrations of about 0.1 pCi/l. A simple charcoal bed is limited by the fact that its response is highly sensitive to [illegible] time interval before termination of the exposure, but two simple methods of av[illegible]ing this problem are developed. Simple methods for determining the diffusion consta[illegible] for the charcoal being used, and for optimizing the depth of the charcoal bed, are presented.

INTRODUCTION

A NUMBER of methods for monitoring radon gas concentrations in air have been developed in recent years. They encompass a variety of experimental techniques with a wide range of sensitivities and time integration properties. Time integration is especially important here because health effects presumably depend on long time averages, and radon concentrations are known to fluctuate rapidly. It is therefore now widely recognized that measurements of instantaneous radon levels by "grab sampling" is far from an optimal approach for determining exposures.

Many techniques have been developed and used for integrating radon levels over periods of hours, days, weeks or even a year or more. It is our purpose here to evaluate a new technique, based on adsorption of radon in charcoal and measuring the quantity adsorbed by counting the γ-rays from the decay of radon daughters. This collection-detection method has been widely used for several years for measurement of radon emanation rates from surfaces (Co76). But only recently has it been used for measuring radon concentrations in air (Ge81).

The potential advantages of this method arise largely from the facts that charcoal samples cost less than $1 (and can be re-used many times by baking the radon out) and that analysis could be automated so as to require little human effort. In principle, large numbers of people could be given jars of activated charcoal for exposure in their homes and return to analytical laboratories, permitting rapid and massive data collection on environmental radon levels.

EQUILIBRIUM ADSORPTION

At concentrations corresponding to partial pressures well below one atmosphere, which would always be applicable for radon, adsorption of gases by charcoal is governed by Henry's Law (Br43).

$$v = kp, \tag{1}$$

where v is the volume of gas adsorbed per mass of charcoal (cm^3 at STP per g) at equilibrium, p is the partial pressure (cm^3-STP of gas per cm^3 of space), and k is the adsorption coefficient (cm^3 of space per g). Values of k for radon at room temperature have been reported in the range 2000–6000 cm^3/g

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(Un81; St81); we will use 4000 cm^3/g as a typical value in calculations. An equivalent expression, using the same adsorption coefficient k, writes the activity adsorbed per unit mass as

$$Q/m = kC, \qquad (2)$$

where Q is the adsorbed activity (pCi), m is the mass of charcoal (g), C is the airborne radon concentration (pCi/l.), and

$$k = 4000\ cm^3/g = 4\ l./gm \text{ or } pCi/(g\text{-}pCi/l.). \qquad (3)$$

Therefore, in the equilibrium situation, each g of radon has adsorbed the radon present in 4 l. of air, resulting in 4 pCi of radon for each pCi/l. of radon in air.

If carbon of mass M is placed in a closed volume V containing an initial concentration C_0, the adsorption reduces the concentration to

$$C = C_0 - Q/V, \qquad (4)$$

assuming equilibrium is reached in a time that is short compared with the radon half life. Solving equations (2) and (4) simultaneously gives

$$Q = kmC_0 \Big/ \left(1 + \frac{km}{V}\right). \qquad (5)$$

If the volume V is much less than 4 l./g of carbon present, the first term in the denominator is negligible and (5) reduces to

$$Q = C_0 V \qquad V \text{ small}, \qquad (6)$$

i.e. the carbon adsorbs essentially all of the radon. For example, in an emanation experiment, we might have $V = 5$ l., $m = 100$ g, whence $km/V = 80$, which is much larger than 1, so all but 1/80 of the emanating radon is adsorbed. As another practical example, a closed 1-l. jar containing 250 g of charcoal would have $km/V = 4 \times 250/1 = 1000$, so all but one-thousandth of the radon is adsorbed.

On the other hand, if V is very large, as in an open room ($\sim 10^5$ l.), the second term in the denominator is much less than 1, so (5) reduces to

$$Q = kmC_0 \qquad V \text{ large}. \qquad (7)$$

and a measurement of Q plus a knowledge of k (or a calibration with a known C_0) gives a determination of C_0. This, of course, is the object of our application.

At this point it is of interest to consider the practicality of measuring the adsorbed radon. For our 3- × 3-in. NaI (Tl) scintillation crystal, we constructed a Marinelli beaker which holds 250 g of carbon. Measurements with a calibrated ^{133}Ba source indicate that it detects 0.35 MeV γ-rays with an efficiency of 10.5% for counts under the photoelectric peak. Since 36% of Rn decays are followed by the 0.35 MeV γ-ray from ^{214}Pb, we may expect from 1 pCi of adsorbed radon $0.105 \times 0.36 \times 3.7 \times 10^{-2}$ counts/sec = 0.083 counts/min. From equation (2), at equilibrium the 250 g of carbon would contain 1000 pCi of radon, yielding 83 counts/min per pCi/l. in air. Inside our $1\frac{1}{2}$-in. thick lead shield, the background with the Marinelli beaker filled with freshly baked out charcoal has no peak at 0.35 MeV, and the total within the limits used for detecting the peak is about 32 counts/min. Thus a radon level of 0.1 pCi/l. would give counts 25% above background and would be easily detectable. Sensitivity can be further enhanced by using other peaks in the spectrum, although they also contain contributions from thoron decay.

Returning to equation (7), it must be understood that this simple expression is valid only when equilibrium has been reached, which is the case only when all of the charcoal is in intimate contact with the air. This could be realized by having the individual grains of charcoal spread out over a surface, but there are two practical problems with this approach. Firstly, unless the surface is very large, there would not be enough charcoal to adsorb sufficient radon to measure with γ-ray counting; and secondly, this gives an instantaneous measurement of radon concentration, equivalent to a grab sample, and hence does not integrate over time. The last point is not strictly correct as it

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takes a few minutes for equilibrium to be reached even between a single grain of charcoal and the surrounding air, so there is a few minutes of time integration, but this is hardly sufficient for our purposes. In order to avoid these two problems, we must consider a bed of charcoal of appreciable depth.

DIFFUSION OF RADON INTO A CHARCOAL BED OF INFINITE DEPTH

Boundary conditions for the diffusion equation

In this section we treat the mixture of charcoal, air and radon as a continuous medium with each microscopic volume in equilibrium as described by equation (2), i.e. with 4 pCi/g (of carbon) adsorbed for each pCi/l. of radon in the surrounding air. We consider the one-dimensional problem of diffusion perpendicular to the charcoal–air interface, with displacement variable x equal to zero at the interface and increasing with depth into the bed. We take $y(x, t)$ as the concentration of radon in the continuous medium in pCi/cm^3, with t being the time in seconds.

Fick's law of diffusion states that the flux, J, the rate at which the diffusing substance crosses an area, is proportional to the concentration gradient, i.e.

$$J = -D\frac{\partial y}{\partial x}, \tag{8}$$

where D is the diffusion constant. For a substance that decays with a rate constant λ (2.1×10^{-6} sec^{-1} for radon), conservation of mass and application of (8) leads directly to the diffusion equation,

$$\frac{\partial y}{\partial t} = D\frac{\partial^2 y}{\partial x^2} - \lambda y. \tag{9}$$

For the case where the charcoal bed is exposed at time zero, this differential equation is to be solved with the initial condition that

$$\text{at } t = 0,\ y = 0 \text{ for } x > 0. \tag{10}$$

The boundary condition at the air–charcoal interface requires that the concentration of radon in the air, C, be the same on both sides. If the porosity of the bed is f, a volume dV of it at the surface contains $f\,dV$ cm^3 of air and $\rho\,dV/g$ of carbon, where ρ is the measured density of the bed (which includes the effect of the porosity). The quantity of radon in dV, $y\,dV$, is then $Cf\,dV$ in the air plus $kC\rho\,dV$ in the carbon, using equation (2). The latter greatly exceeds the former which we therefore ignore, giving the boundary condition

$$\text{at } x = 0,\ y = k\rho C(t). \tag{10a}$$

In this section, we consider a bed of infinite depth, so the other boundary condition is

$$\text{at } x = \infty,\ y = 0. \tag{10b}$$

The diffusion constant, D

Before proceeding with solutions, it is useful to have a value for D. A method for estimating diffusion constants is given by Underhill (Un77), who used it for obtaining D for krypton and xenon. His formula is $D = (\gamma\epsilon' D_g/\rho k)$, where D_g is the diffusion constant for the gas in air, γ is a tortuosity factor for the charcoal, ϵ' is the fractional interparticle void volume, ρ is the density of the charcoal, and k is the adsorption coefficient. D depends on atomic sizes, masses, and thermodynamic properties not readily available for radon, but all of these are slowly varying functions of atomic weight for noble gases. Underhill derives $D_g = 0.173$ cm^2/sec for Kr and 0.138 for Xe, from which we extrapolate $D_g \simeq 0.12$ cm^2/sec for radon.

Underhill estimates $\gamma = 0.6$, $\epsilon' = 0.45$, $\rho = 0.5$ g/cm^3 as typical properties of charcoal. Using these and taking our typical $k = 4000$ cm^3/g gives $D = 1.6 \times 10^{-5}$ cm^2/sec. Underhill's best estimates of D for Kr and Xe were about 20% smaller than those derived from this calculation, so we apply the same correction to our estimate for radon, which gives

$$D = 1.3 \times 10^{-5}\ \text{cm}^2/\text{sec}. \tag{11}$$

Note that this is based on our assumed value for k, and varies in inverse proportion to it.

Solutions for diffusion equation

We now consider solutions for the diffusion equation (9) with boundary conditions equation (10). Solutions for some cases can be obtained analytically if we ignore the effect of radioactive decay by setting $\lambda = 0$ in (9). Such solutions are valid for times short in comparison with the 3.8-day half life of ^{222}Rn. It is most instructive to consider the behavior of a short (in time) pulse of radon concentration in air. This is represented mathematically by choosing $C(t)$ in equation (10a)

$$C(t) = C_0 \tau \delta(t), \tag{12}$$

where $\delta(t)$ is a function which is zero [illegible] except at $t = 0$ and satisfies

[illegible]

This gives [illegible] exposure, $\int_0^\infty C\,dt$ [illegible] concentration [illegible] (Vol. [illegible]), the boundary conditions [illegible]

$$\text{at } x = 0,\ y = A\delta(t), \text{ where } A = k\rho C_0 \tau. \tag{14}$$

The solution of equation (9) with boundary condition equation (14) is readily obtained by use of La Place transforms as

$$y = \frac{Ax}{2\sqrt{(\pi D t^3)}}\, e^{-x^2/4Dt}. \tag{15}$$

The total quantity of radon adsorbed in the charcoal bed, Q, is

$$Q = \int_0^\infty y\,dx$$

$$= A\sqrt{\left(\frac{D}{\pi}\right)}\, t^{-1/2}. \tag{16}$$

This indicates that the contribution of a pulse to Q is inversely proportional to the square root of the time after exposure, assuming t is small compared with the half life of radon.

Since (9) is a linear differential equation, solutions are additive and the radon concentration in air as a function of time, $C(t)$, may be thought of as a continuous series of these pulses. For example, for $C(t)$ constant ($= C_0$) over the entire measurement, we consider a series of pulses of height C_0 and duration dt (i.e. $\tau \to dt$) giving a contribution dQ from (16) and (14) as

$$dQ = k\rho C_0 \sqrt{\left(\frac{D}{\pi}\right)}\, t^{-1/2}\, dt.$$

Integrating this from $t = 0$ to t gives

$$Q(t) = 2k\rho C_0 \sqrt{\left(\frac{D}{\pi}\right)}\, t^{1/2}, \tag{17}$$

which indicates that the radon accumulation increases as the square root of the exposure time, now represented by t.

Other time dependences of $C(t)$ could be inserted to obtain $Q(t)$ in similar fashion, but it is perhaps most convenient to think of $C(t)$ as a constant leading to (17) plus short spikes, either positive or negative, whose effects are added by use of (16).

Since $C(t)$ is not ordinarily known, a measurement of Q would be interpreted in terms of an average level C_0 obtained by use of (17); i.e. for an exposure time T_1 for which the measured accumulation is $Q(T_1)$, the average radon level would be taken to be

$$C_0 = Q(T_1) \Big/ \left[2k\rho \sqrt{\left(\frac{D}{\pi}\right)}\, T_1^{1/2}\right]. \tag{18}$$

This interpretation would be correct assuming T_1 is much shorter than 3.8 days if the concentration in air were constant throughout the measurement. The question is, how closely does this reflect the actual average concentration?

In extreme situations, it can be highly inaccurate. For example, if the actual $C(t)$ is due to a single short pulse, the difference between its occurrence 15 and 1500 min (1 day) before termination of the exposure, according to equation (16), is a factor of 10. In general, $Q(T)$, the contribution of a concen-

tration occurring time T prior to termination of the exposure is

$$Q(T) = A\sqrt{\left(\frac{D}{\pi}\right)}T^{-1/2},$$

a function whose behavior is shown by curve (a) in Fig. 1.

This large variation with T corresponds to a large possible inaccuracy due to the time integration. In fact the large peak near $T = 0$ leaves this type of measurement with most of the limitations of grab sampling. It would be highly advantageous to reduce these limitations and produce measured results which more closely reflect the average concentration during exposure time.

Methods for improving time integration

(1) *Added adsorber method.* One method for reducing the above problem is to have a period of time T_0 at the end of the exposure during which $C = 0$. This can be approximated by inserting a fresh sample of activated charcoal over the bed and then closing the jar, since the fresh sample would rapidly adsorb all the radon out of the entrapped air, and would continue for some time to adsorb the radon diffusing out of the bed. This should generally be valid for T_0 much shorter than T_1, the initial exposure time.

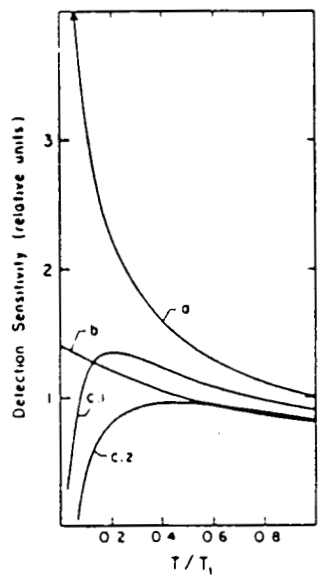

FIG. 1. Detection sensitivity vs time before the end of exposure (T), assuming a total exposure time T_1. (a) Simple charcoal bed, (b) added adsorber method, (c) skimming method with $b^2/4DT_1 = 0.1$ (c.1) and 0.2 (c.2).

The contribution to Q at the end of T_0 from various times T before termination of the exposure is then

$$Q(T) = A\sqrt{\left(\frac{D}{\pi}\right)}(T + T_0)^{-1/2}. \qquad (19)$$

A plot of this for $T_0 = 1/2T_1$ is shown by curve (b) of Fig. 1. Clearly this situation is much more favorable than that for curve (a); the sensitivity to T varies by only a factor of 1.7 between the extremes of a pulse occurring near the beginning and near the end of the exposure.

For the case of constant $C = C_0$ during T_1, the quantity present after $T_1 + T_0$ is just the difference between a constant exposure for time $T_1 + T_0$ and the same constant exposure for T_0. From (17), this is Q_f given by

$$Q_f = 2k\rho C_0\sqrt{\left(\frac{D}{\pi}\right)}[(T_1 + T_0)^{1/2} - T_0^{1/2}].$$

The measured Q_f would then be used to determine C_0 by solving this, which gives

$$C_0 = Q_f \Big/ 2k\rho\sqrt{\left(\frac{D}{\pi}\right)}[(T_1 + T_0)^{1/2} - T_0^{1/2}]. \qquad (20)$$

The logistics of this method might be to give participants two jars, one containing the bed, and another with a separate charcoal sample attached to the lid and contained by a screen. The participant removes the lid of the first jar, exposes it for a time T_1, then removes the lid of the second jar and screws it on the first jar, lets it remain in that condition for a time T_0, and then removes that lid and screws on the original lid. Until this time it is important not to shake or disturb the bed, but once the original lid is replaced, there is no problem in shaking it as all radon in that jar will be adsorbed into the charcoal. In fact,

it is necessary to shake it thoroughly before transfer into the counting beaker because the detection efficiency varies considerably with location in the dish, and we assume that the adsorbed radon is uniformly distributed through it.

(2) *Skim-off method.* An alternative method for improving the time integration over that represented by curve (a) in Fig. 1 is by skimming-off the top part of the charcoal bed at the end of the exposure period. This could be done by having the top part of the bed contained by a screen material so that it can be easily removed. The participant would then be instructed to remove this piece before screwing the lid back on. This could be simpler for the participant since his activities would be confined to two operations at different times (starting and stopping the exposure) rather than requiring three as in the added adsorber method.

In this situation, the quantity of radon left in the bed differs from that calculated from (16) in that the integration is not from $x = 0$ to infinity, but rather from $x = b$ to infinity where b is the skimming depth. The integration then gives

$$Q(T) = A\sqrt{\left(\frac{D}{\pi}\right)}T^{-1/2}e^{-b^2/4DT} \qquad (21)$$

where we have replaced t by T since both are actually the time interval between occurrence of the pulse and the end of the exposure. Plots of $Q(T)$ from (21) are shown in Fig. 1 for $b^2/4DT_1 = 0.1$ (curve c.1) and 0.2 (curve c.2). We see that these do indeed flatten the dependence of the accumulated radon on time of pulse occurrence. They also remove all sensitivity to radon concentrations occurring near the end of the exposure, but this is not an important problem since one can simply consider the exposure to be somewhat shorter than T_1, and in fact, this would be automatically taken into account in calibrating with a known constant radon concentration. It is certainly much preferable to the opposite situation encountered in curve (a) where a relatively small pulse of radon very near the end of the exposure can grossly distort the measurement.

From Fig. 1, it appears that an optimum skimming depth is about $b^2/4DT_1 = 0.2$. With our typical $D = 1.3 \times 10^{-5}\,\mathrm{cm^2/sec}$, $b = 1\,\mathrm{cm} \times T^{1/2}$ (days). It should be emphasized that the skimming must be done immediately at the end of the exposure. If it is delayed, the radon in the top layers will diffuse down into the bed and the method is no longer valid.

SOLUTIONS FOR FINITE BEDS

In the previous sections, we have used the approximations that the depth of the charcoal bed is infinite and that the radioactive decay of radon can be ignored ($\lambda = 0$ in (9)). In order to solve the basic differential equation (9) without these approximations, a computer program was prepared. The radioactive decay is taken into account by simply using the correct value for λ in equation (9), 2.1×10^{-6}/sec. A finite depth (or height) of the bed, h, is introduced by changing the boundary condition (10b) to

$$\text{at } x = h,\ J = 0 = \frac{\partial y}{\partial x} \qquad (10b')$$

Results of calculating the total radon accumulated in charcoal beds of various depth are shown in Fig. 2 for exposures of 1, 2 and

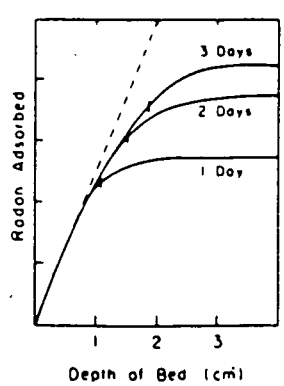

FIG. 2. Total radon accumulated as a function of bed depth for exposures of 1, 2 and 3 days. Cross marks on the curves are the values of $\sqrt{(DT_1)}$ discussed in the text. These curves are calculated for $D = 1.3 \times 10^{-5}\,\mathrm{cm^2/sec}$, but they are applicable to other D by multiplying the abscissa scale by $(D/1.3 \times 10^{-5})^{1/2}$. Dashed line represents infinite exposure and no radioactive decay as represented by equation (7).

3 days with our typical value of D. The dashed line represents an infinite exposure with no radioactive decay, as represented by equation (7).

According to (15), diffusion may crudely be viewed as a spreading out over a distance of about

$$x = 2\sqrt{(Dt)}. \tag{22}$$

When the diffusion front reaches the bottom of the bed, it is reflected from the container surface, so the reflected front comes back to the top of the bed after travelling a distance $2h$. After that, the adsorption is approximately in equilibrium, as gas diffuses out of the top surface as fast as it diffuses in (ignoring radioactive decay). The time required to reach this equilibrium, t_{eq}, is obtained by setting x in (22) equal to $2h$, which gives

$$t_{eq} \approx h^2/D \tag{23}$$

Clearly of little use to expose the charcoal for a time much longer than t_{eq}, so the depth of the bed should be not much deeper than

$$h \approx \sqrt{(DT_1)} \tag{24}$$

where T_1 is the exposure time. The values of h from equation (24) are shown by cross marks on the curves in Fig. 2. We see that bed depths given by equation (24) collect about 85% as much radon as an infinite bed depth with the same exposure.

Determination of D *and bed depth*

In order to choose the depth of charcoal bed from equation (24), it is necessary to know the diffusion constant, D; variations of D with charcoal type are much too large to accept our typical value.

A simple method for determining D is to expose the same quantity of charcoal in dishes of various areas and hence, of various depth. After exposure for some time period (1–3 days), the quantity of radon adsorbed is determined by γ-ray counting to determine the quantity per unit surface area, q. According to Fig. 2, for large depths q is independent of h whereas for small depths it is proportional to h. By plotting, or simply by inspecting the data, one determines the value of h for which q is 85% of its value for large depths. Inserting this value of h in (24) gives D.

As an example, we made determinations for Calgon Type PCB 12 × 30 charcoal. Samples weighing 250 g were baked out at 110°C overnight and then placed in four dishes of differing areas (sample D was used to measure background before it was exposed).

After 3 days, the samples were transferred to closed jars and shaken up thoroughly so as to eliminate correlations between position in the bed and position in the counting beaker. They were then transferred in turn to the latter and counted for 80 min with a multichannel analyzer. The number of counts under the 0.35 MeV peak were determined from the spectrum, and after subtracting background (5100 counts), the values listed in Table 1 were obtained. Dividing these by the area gives the values of q in that Table.

One would not expect sample A to have a smaller q than sample B, or sample C to have more than twice the q value of sample D, but these problems are presumably due to statistical fluctuations, fluctuations of radon levels in the room, or experimental errors. From the data presented it would seem that the infinite bed depth q value is about 1300. Following our prescription, 85% of this is 1100. From the q value for sample C, this corresponds to h a little larger than 1.9 cm. The q value for sample D is 46% of that for infinite depth; from Fig. 2, the 46% height on a 3-day exposure is reached for $h = 0.8$ cm whereas $\sqrt{(DT_1)}$ is 1.95 cm, so we might expect our $\sqrt{(DT_1)}$ to be 1.95/0.8 times the depth of sample D (0.9 cm), or 2.2 cm. From our data on sample B, $\sqrt{(DT_1)}$ must be very much less than 3.1 cm. All of this is consistent with $\sqrt{(DT_1)} \approx 2.2$ cm. Since $T_1 = 2.6 \times 10^5$ sec (3 days), this corresponds to $D = 1.86 \times 10^{-5}$ cm²/sec. A reasonable choice for bed depth is about 2.2 cm.

Once D is determined, it might be useful to convert the curves in Fig. 2 to that basis. It is

Table 1. Data on calgon type PCB 12 × 30 charcoal

Sample	dish area	depth	counts-Bq	q(Cts/Area)
A	75 cm^2	6.7cm	1590	1190
B	162	3.1	2230	1380
C	264	1.9	2820	1070
D	550	0.9	2800	510

evident from our basic equation (9) that if one transforms the units of displacement by

$$x' = x/\sqrt{(D)}, \qquad (25)$$

equation (9) becomes

$$\frac{\partial y}{\partial t} = \frac{\partial^2 y}{\partial x'^2} - \lambda y,$$

which is independent of D. If this transformation is also applied to the boundary conditions, all results become independent of D, including Fig. 2. Since Fig. 2 was calculated for $D = 1.3 \times 10^{-5}$, to convert it to our charcoal, the abscissa must be multiplied by $\sqrt{(1.86/1.3)} = 1.2$. It would be equally valid to multiply it by the ratio of $\sqrt{(DT_1)}$ to that shown by the cross marks in Fig. 2, $(2.2/1.8) = 1.2$.

Acknowledgments—The authors are grateful to D. W. Underhill (Univ. of Pittsburgh), A. C. George (Environmental Measurements Laboratory, New York), C. R. Phillips and C. Porter (EPA, Montgomery), I. Kanter (Westinghouse Research Lab), and J. Wetzel and P. Boron (Calgon-Pittsburgh) for helpful discussions.

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Health Physics Vol. 50, No. 4 (April), pp. 457–463, 1986
Printed in the U.S.A.

0017-9078/86 $3.00 + .00
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Pergamon Press Ltd.

A DIFFUSION BARRIER CHARCOAL ADSORPTION COLLECTOR FOR MEASURING Rn CONCENTRATIONS IN INDOOR AIR

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(*Received* 7 *January* 1985; *accepted* 22 *August* 1985)

Abstract—Development of a practical detector for collecting Rn by adsorption in charcoal with a time integration of 2 d or more, achieved by use of a diffusion barrier through which Rn enters, is described. The sensitivity is adequate for monitoring Rn levels in houses. It is easily sent and returned by mail, and instructions for use are simple enough for any householder to follow. The cost per measurement is apparently well below that for competitive techniques.

INTRODUCTION

ADSORPTION on charcoal is a simple and inexpensive method for collecting Rn and it is well suited to simple γ-ray counting for determination of the quantity adsorbed. However, an important limitation of this method is that Rn desorbs from a charcoal bed as well as sorbing onto it, making the contribution to the total quantity adsorbed from the end of the exposure period much more important than that from the beginning (Co83). As a result, measuring Rn concentrations in air by charcoal adsorption has more the character of a "grab sample" which gives an instantaneous concentration rather than the average over an appreciable time period. However, since health effects of Rn are proportional to exposures integrated over time, one is usually interested in time-averaged Rn levels rather than instantaneous levels. This problem is aggravated by the facts that Rn concentrations often have diurnal variations, and also frequently undergo irregular short-term up and down variations by as much as an order of magnitude (Co84). Time averaging over a few days is therefore a highly desirable feature for a Rn collection device.

Prichard and Marien pointed out that time averaging can be extended in charcoal adsorption devices by interposing a diffusion barrier between the charcoal and the ambient air being sampled (Pr83). As long as the charcoal adsorbs the Rn as fast as it leaves the diffusion barrier, the Rn concentration in the air inside the detector, C_i, is much less than that in the outside ambient air, C_o, so the concentration gradient across the diffusion barrier is just proportional to C_o. In quantitative terms with Q equal to the quantity of Rn in the collector, the rate at which Rn passes through the diffusion barrier, dQ/dt, is given by diffusion theory as

$$\frac{dQ}{dt} = JA = D\frac{dC}{dx}A = \frac{DA}{L}(C_o - C_i) \cong PC_o \quad (C_i \ll C_o), \qquad (1)$$

where

J	is the diffusion current, usually expressed in pCi/cm^2-sec (Bq/cm^2-s);
A	is the cross-sectional area of the barrier;
dC/dx	is the concentration gradient;
D	is the diffusion constant defined by $J = D\,dC/dx$; for Rn in air, D is about 0.1 cm^2/s at room temperature (Li41);
L	is the length of the diffusion barrier; and
P	$= DA/L$ (2)

and the second line is derived from the first by noting that conservation of mass requires that $dJ/dx = 0$ whence dC/dx is constant.

From the last form of eqn (1) we see that Rn

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enters linearly with time, which is the requirement for a time-averaging device. However, the requirement $C_i \ll C_o$ places a limitation on the sensitivity of a detector. The adsorption coefficient of charcoal (St81) for Rn k is about

$$k = 4000 \text{ pCi/g–charcoal per pCi/cm}^3 \text{ in air}$$
$$(=4000 \text{ Bq/g–charcoal per Bq/cm}^3 \text{ in air}). \quad (3)$$

Thus, if a mass m of charcoal were directly exposed to the ambient air, the quantity of Rn it would adsorb, Q', would be

$$Q' = kmC_o,$$

whereas the quantity it adsorbs with the barrier, Q, is

$$Q = kmC_i. \quad (4)$$

The condition $C_i \ll C_o$ thus implies $Q \ll Q'$ which means that the amount of Rn collected for measurement is greatly reduced, and hence sensitivity is being severely sacrificed.

The most important present application of these techniques is for monitoring of Rn levels in homes, cheaply and conveniently. For this purpose, sensitivity is an important limitation, so compromises are called for.

A practical device consists of a charcoal bed which air can enter only through a diffusion barrier. We next consider the design of each of these.

DESIGN CONSIDERATIONS—CHARCOAL BED

The goal is to develop a collector which can be sent by mail, deployed by the resident following very simple instructions, returned by mail, and measured by placing it against a γ-ray detector capable of quantifying the amount of Rn from the characteristic γ rays of the Rn decay chain. One way to increase sensitivity is to increase the mass of charcoal, m. Since most γ-ray detectors are only about 7 cm in diameter, it does not pay to make the diameter of the charcoal container much larger than that.

Figure 1 (Co83) shows the quantity of Rn adsorbed by a charcoal bed as a function of bed depth and time; the dashed line represents ex-

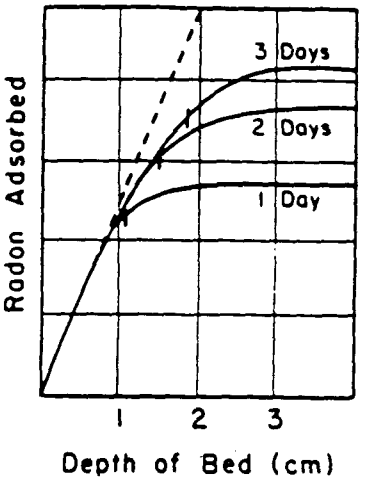

FIG. 1. Total Rn accumulated in a charcoal bed vs bed depth for exposures of 1, 2, and 3 days. Dashed line represents infinite exposure with no radioactive decay (from Co83).

pectations from eqn (4). We see from Fig. 1 that the quantity of Rn adsorbed by a charcoal bed does not increase much as the depth is increased beyond about 1.5 cm; the diffusion rate is such that radioactive decay negates the increased adsorption beyond that depth. Deeper charcoal beds also reduce γ-ray counting efficiency by moving the Rn further from the detector and absorbing γ rays, and they increase the bulkiness and postage costs of the package. Container availability is also a consideration here; it is important to have a low-cost, gas-leak-proof container with a tight-fitting lid. Metal "ointment cans" accommodating charcoal beds 1.5 cm and 3.5 cm deep were tested, and the former, containing 25 g of charcoal, were chosen as the best compromise. The charcoal beds are covered by a fine mesh screen held in place by RTV cement.

DESIGN CONSIDERATIONS—DIFFUSION BARRIER

We now consider the design of the diffusion barrier. Its purpose is to extend the integration time for the Rn collection without greatly reducing the total accumulation of Rn at the end of exposure, since this determines the sensitivity. First, we apply a theoretical approach.

The time constant, t_a, for a charcoal bed to

adsorb Rn in air within 1 cm of its surface may be estimated from eqn (17) of Co83 as

$$t_a = \frac{\pi}{4k^2\rho^2 D},$$

where ρ is the density of the charcoal bed, ~0.5 g/cm^3, and D is the diffusion constant for Rn in it, 1.3×10^{-5} cm^2/s. With eqn (3) this gives t_a to be a fraction of a second. While this estimate takes into account only the diffusion into the bed and does not consider adsorption dynamics, or the diffusion through the 1 cm of air, it is clear that on a time scale of hours or days, equilibrium between a charcoal bed and the air within 1 cm of its surface is essentially instantaneous. This applies to the air inside our Rn collector.

From the standpoint of the diffusion barrier, the inside of the collector is therefore equivalent to a volume of air, $V(t)$, given by

$$V = \frac{Q}{C_i}, \tag{5}$$

where Q is the quantity of Rn adsorbed in the charcoal.

From the well-known solutions of the diffusion equation (e.g. eqn (15) of Co83), the time constant, t_c, for reaching the equilibrium value of Q given by eqn (4) is about

$$t_c = \frac{h^2}{4D},$$

where h is the depth of the charcoal bed. For $h = 1.5$ cm, this gives $t_c = 12$ h; this could also be estimated from Fig. 1.

Note that both t_a and t_c are much smaller than the time constant we are designing into our collector, ~60 h, which is basically the time constant for the diffusion barrier, $Q/(dQ/dt)$. It is therefore a reasonably accurate approximation to take $t_a = t_c = 0$. This has the advantage of greatly simplifying the mathematics and one's thinking. This approximation has been used previously (Pr85). With it V becomes independent of t, and from eqn (4),

$$V = km. \tag{6}$$

There are two factors affecting dQ/dt, entrance of Rn through the diffusion barrier as given by eqn (1), and radioactive decay. Thus,

$$\frac{dQ}{dt} = P(C_o - C_i) - \lambda Q.$$

Inserting eqn (5), this becomes

$$\frac{dC_i}{dt} = -\left(\frac{P}{V} + \lambda\right)C_i + \frac{P}{V}C_o. \tag{7}$$

Equation (7) is the form familiar from production of a radioactive isotope, or with $C_o = 0$, simple radioactive decay with decay constant, τ, given by

$$\frac{1}{\tau} = \frac{P}{V} + \lambda. \tag{8}$$

The well-known solution for $C_i = 0$ at $t = 0$ is

$$C_i = C_o \frac{P/V}{P/V + \lambda}(1 - e^{-t/\tau})$$
$$= C_o(1 - \lambda\tau)(1 - e^{-t/\tau}). \tag{9}$$

For $C_i = C_{io}$, $C_o = 0$ at $t = 0$, the solution of eqn (7) is

$$C_i = C_{io}e^{-t/\tau}. \tag{10}$$

Equation (10) provides an experimental method for determining τ; it is only necessary to expose the detector to a high Rn concentration for a day or so to get the charcoal well loaded with Rn, close the detector for a day or so to assure that the Rn becomes equally distributed through the charcoal, and then expose the detector in an area of low Rn concentration and follow the decay of the count rate.

Equation (10) is also the key to understanding the integration time constant for the detector. Since the equations governing the diffusion through the barrier and into the charcoal bed are linear, solutions are additive. The effect of a short exposure leading to collection of a quantity of Rn, ΔQ, at a time T before the end of the exposure gives a contribution to Q at the end of exposure of $\Delta Qe^{-T/\tau}$. In the parlance of electronic circuitry, τ is the "integration time constant."

According to eqn (4), C_i/C_o is equal to Q/Q_{max} where Q_{max} is the accumulation with an infinitely fast and efficient diffusion barrier, $P = \infty$. Plots of Q/Q_{max} from eqn (9) are shown in Fig. 2. We see there that by sacrificing half of the sensitivity, our detector can have an integration time constant of about 2.5 d; if we are only willing to sacrifice one-fourth of the sensitivity, we can achieve an integration time of about 1.3 d, whereas if we are willing to settle for only one-fourth the maximum sensitivity, we can have an integration time of over 4 d.

Setting $\tau = 50$ h $= 1.8 \times 10^5$ s, $V = km = 4000 \times 25 = 1 \times 10^5$ cm^3, $\lambda = 2.1 \times 10^{-6}$/s in eqn (8) gives $P = 0.35$ cm^3/s, whence, from eqn (2)

$$\frac{DA}{L} = 0.35 \text{ cm}^3/\text{s}.$$

If our diffusion barrier is to be made with a thin film of some sort, for which $D \sim 10^{-7}$ cm^2/s, we require $A/L \cong 10^7$ cm. The maximum value of A is the area of our detector lid, about 40 cm^2, so the thickness of the film would have to be about 10^{-5} cm thick; no such films are available. The alternative is to use diffusion through air for which $D \cong 0.1$ cm^2/s. The distance from the lid to the charcoal bed is 1 cm, which requires $A = 3.5$ cm^2, a 2.1-cm-diameter hole. The simplest approach would then be to punch a hole of that diameter in the lid.

One problem with this is that convection could have an important effect on the passage of air through the barrier. To avoid this, the hole was covered by two pieces of fine mesh (0.001-inch openings) nylon screen separated by a 2-mm-thick cardboard ring, all glued together and to the inside of the lid. If one blows hard on one side of this assembly, no draft can be felt on the opposite side. This would seem to solve the problem of convection.

There are some inaccuracies in the calculation given above. The cross section of the flow area expands from a 2.1-cm diameter at the lid to a 7-cm diameter at the surface of the charcoal, 1 cm below. The length of the diffusion path is not simply 1 cm in that geometry. Moreover, the cross-sectional area is affected by the screens which have only 50% open area. The best approach in this situation is empirical. Holes of different sizes were punched in lids, nylon screen assemblies were attached, charcoal beds were exposed to Rn, and the decay of the γ-ray count rates was followed for several days. The count rates vs time were reasonably well fitted by straight lines on semi-log paper as expected from eqn (10). Examples are shown in Fig. 3. The values of τ derived from the slopes of these lines are plotted vs the diameter of the holes in the lids in Fig. 4. Also shown there, by the dashed line is the value calculated from eqns (8) and (2) with $L = 1$ cm and A = area of the hole. The agreement is as good as can be expected considering the problems in the calculation discussed above. The hole size chosen to give the desired 50-h integration constant was 1.9 cm ($\frac{3}{4}$ inch) in diameter.

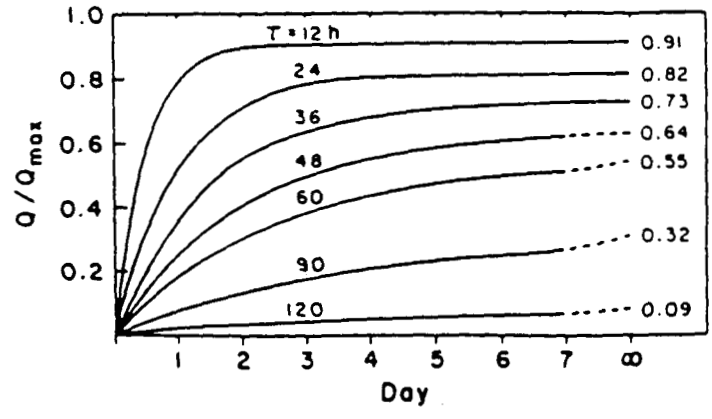

FIG. 2. Radon accumulation, Q, vs time for various values of τ according to eqn (9). Q_{max} is Q for $\tau = 0$, an infinitely fast diffusion barrier.

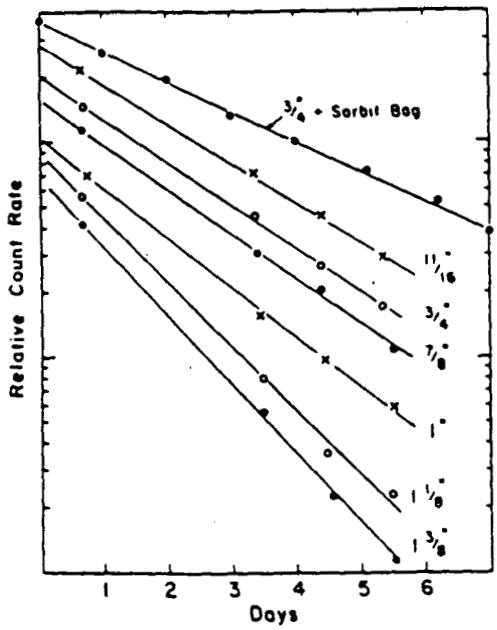

FIG. 3. Count rate vs time for collectors with various diffusion barriers. All but top data are for double nylon screen with a hole in the lid of the diameter stated. Top data are for a ¾-inch hole in the lid covered by a single nylon screen and a sorbit bag taped below.

HUMIDITY PROBLEMS

Charcoal is an excellent adsorber of many gases other than Rn, including water vapor. It is well known that the quantity of Rn adsorbed is therefore reduced as humidity increases, because some of the adsorption sites are taken up by water molecules, making them unavailable for Rn. Typical data in the literature indicate that high humidity reduces the Rn adsorption to about half of that at low humidity. This problem is usually addressed by determining the mass increase of the charcoal during exposure, and using this as a measure of humidity to derive a correction. This requires additional time and effort, and introduces additional uncertainty into the results. It seemed reasonable to hope that these could be avoided by including a desiccant as part of the diffusion barrier.

It is interesting to note that even without desiccant, the diffusion barrier itself does a lot to ce moisture uptake. The double nylon screen ier typically reduces the moisture uptake to one-third of its value with an open charcoal can (no barrier).

Insertion of a desiccant raises two questions: how will it affect the diffusion of Rn, and how will it reduce the moisture uptake of the charcoal. At the outset, it seemed obvious that the second problem would be trivial—adding desiccant is bound to reduce moisture uptake by the charcoal—while the first problem seemed to be the major one. The situation turned out to be quite the opposite.

Insertion of desiccant introduced little problem with diffusion. Many different configurations were used, including various types of desiccants in various type bags (and in a few cases without bags), in various geometries, but in no case was the diffusion of Rn retarded greatly. Bags made of heavy brown kraft paper introduced appreciable retardation, but that was easily compensated by increasing the size of the hole in the lid. None of the other four bag types tested made enough difference to warrant this action.

On the other hand, introducing desiccant was not nearly as effective as expected in reducing moisture uptake by the charcoal. Replacing the double nylon screen by a desiccant bag as a covering over the hole in the lid typically reduced the mass gain of the charcoal by 20%. Only by filling the entire 1-cm-high × 7-cm-diameter space above the charcoal retaining screen with loose desiccant could the mass gain of the char-

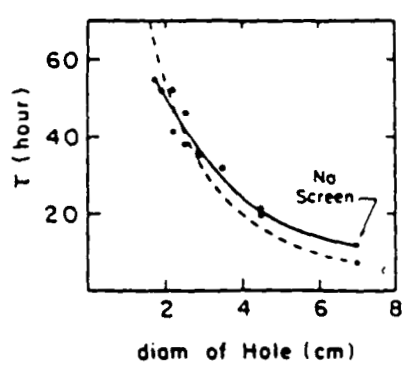

FIG. 4. Values of τ from measurements of Rn loss vs diameter of hole in detector lid. In all cases but the one marked, holes were covered by a double nylon screen. Dashed line shows the values calculated from eqns (8) and (2) with L = 1 cm and A = area of hole.

coal under high humidity conditions be reduced to half of that with the double nylon screen alone and this involved substantial extra effort, weight and cost. The most practical scheme involving desiccant was taken to be taping a tightly packed, fine-grained bag (3-g "sorbit" bag) over the hole in the lid. These bags cost 3¢ each and take only few seconds to install or remove. With a ¼ inch hole, they extend τ to 3.1 d (cf. Fig. 3). A considerable amount of monitoring was done with these. One advantage is that the variation of Rn collection with humidity is somewhat less than for the double nylon screen barrier. On the other hand, it is still desirable to measure mass gain by weighing. In one study of 165 houses over a period of several months, corrections based on mass gain were all within ±10%.

DURATION OF EXPOSURE

It is evident from Fig. 2 that, for a 3.1-d time constant, there is little advantage in extending an exposure to more than about 7 d. In fact, there is some disadvantage in longer exposure because the moisture pick-up is increased. For measurements done by members of the general public, there are advantages in a one-week exposure. Many aspects of every day life have a one-week periodicity, making it easier to remember when to terminate an exposure. With a one-week exposure, it makes less difference if the exposure is mistakenly made a day longer or a day shorter. A householder, being aware of the detector's presence, might change his relevant habits (e.g. keeping doors or windows open or closed) for the first few days, but would be less likely to continue to do so for a full week. It was therefore decided to standardize on a one-week exposure.

Of course, the first few days of exposure contribute little to the result in this case, but there is no *a priori* reason why that should raise or lower the result. The goal of these measurements is to derive a random (in time) sample of Rn levels averaged over a period of a few days, and a one-week exposure achieves that end.

LOGISTICS

All materials for the detector are available commercially: metal "ointment cans," 3-inch-diameter × 1-inch-high, with tight-fitting lids (25¢–50¢); cocoanut charcoal size 12 × 30 ($2 per pound)—size 4 × 10 was also tried and performed equally well; fine mesh wire screen to retain the charcoal, cut to size and cemented in place; and very fine mesh nylon screen and desiccant bags to form the diffusion barrier. Holes were punched in the can lids with electronics chassis punches. Double nylon screen diffusion barriers were glued in place, while the desiccant bags were taped. A complete detector and its mailing box costs about $1, and takes less than 15 min to assemble, so lost detectors are not a problem. The charcoal is baked out to remove moisture and weighed (25 g) in assembling the detector. For each use, the detector is baked out overnight at 120°C with the lid off to eliminate adsorbed Rn. Shortly after the oven is switched off, the lid is installed, the detector is removed from the oven, and after a few minutes of cooling, the lid is sealed to the can by wrapping with black rubber electrical tape. The diffusion barrier is normally closed by an Al foil covering the hole and sealed to the lid by a piece of gray duct tape to which it is stuck. Exposures are started and stopped by simply removing and re-attaching this gray tape.

The detector is weighed and packed in a 3½ × 3½ inch cardboard box with an instruction sheet, a tape for resealing the box for return, and a return address label. The entire package weighs 3½ ounces. The instruction sheet includes advice on locating the detector and on starting and stopping the exposure, a data sheet with name, address, start time, and stop time to be returned with the detector, and a warning that it must be returned promptly by first class mail.

When the returned detector is received, it is promptly counted with a 3-inch-diameter NaI γ-ray detector measuring the activity in the 220–390 keV and 550–680 keV energy ranges for 30 min. A detector exposed to 1 pCi/liter (37 Bq/m^3) and counted after one half-life of decay (3.8 d) would have a total of 200 and 60 counts in these energy ranges, with about 1200 and 400 counts of background, respectively, giving a result with a 17% standard deviation. For Rn levels well below 1 pCi/liter (37 Bq/m^3), statistical accuracies are poor, but good accuracy is seldom of interest in that range.

After counting, the detector is weighed, untaped to remove the lid, baked out, and put through another cycle. Radon levels are determined by comparing the γ-ray counts with those

from detectors exposed in a chamber with known Rn concentration. The humidity correction, calculated from the mass increase, is determined by varying the humidity in the Rn chamber by inserting quantities of water-glycerin mixtures.

All operations involved in a single measurement require a total of less than 15 min from a student assistant when the work is done in batch quantities. The postage costs are 73¢ each way plus the cost of letters to arrange for the measurement and to give the result. Since each detector and mailing box is used many times, they add little to the cost. In a large program, it therefore seems that the total cost per measurement should be about $10, well below the cost of competitive techniques.

These detectors are now being used in Rn monitoring programs involving thousands of houses.

Acknowledgments—The authors are greatly indebted to Andreas George of the Environmental Measurements Laboratory, New York, NY, for providing many exposures in his well-calibrated Rn chambers.

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RADIUM (L. *radius*, ray) Ra; at. wt. (226); at. no. 88; m.p. 700°C; b.p. <1737°C; sp. gr. 5?; valence 2. Radium was discovered in 1898 by M. and Mme. Curie in the *pitchblende* or *uraninite* of North Bohemia, in which it occurs. There is about 1 gm. of radium in 7 tons of pitchblende. The element was isolated in 1911 by Mme. Curie and Debierne by the electrolysis of a solution of pure radium chloride, employing a mercury cathode; on distillation in an atmosphere of hydrogen this amalgam yielded the pure metal. Originally, radium was obtained from the rich pitchblende ore found at Joachimsthal, Bohemia. The *carnotite* sands of Colorado furnish some radium, but richer ores are found in the Belgian Congo and in the Great Bear Lake region of Canada. Radium is present in all uranium minerals, and could be extracted, if desired, from the extensive wastes of uranium processing. Large uranium deposits are located in Ontario, New Mexico, Utah, Australia, and elsewhere. Radium is obtained commercially as the bromide or chloride; it is doubtful if any appreciable stock of the isolated element now exists. The pure metal is brilliant white when freshly prepared, but blackens on exposure to air, probably due to formation of the nitride. It exhibits luminescence, as do its salts; it decomposes in water and is somewhat more volatile than barium. It is a member of the alkaline-earth group of metals. Radium imparts a carmine red color to a flame. Radium emits alpha, beta, and gamma rays and when mixed with beryllium produces neutrons. Thirteen isotopes are now known; radium-226, the common isotope, has a half-life of 1620 yrs. One gram of radium produces about 0.0001 milliliter (stp) of emanation, or radon gas, per day. This is pumped from the radium and sealed in minute tubes, which are used in the treatment of cancer and other diseases. One gram of radium yields about 1000 cal. of heat per year. Radium is used in producing self-luminous paints, neutron sources, and in medicine for the treatment of disease. Some of the more recently discovered radioisotopes, such as Co^{60}, are now being used in place of radium. Some of these sources are much more powerful, and others are safer to use. Radium loses about 1% of its activity in 25 yrs., being transformed into elements of lower atomic weight. Lead is a final product of disintegration. The study of radium has greatly altered our ideas of the structure of the atom. Radium is a radiological hazard. (Stored radium should be ventilated to prevent build-up of radon.) Inhalation, injection, or body exposure to radium can cause cancer and other body disorders. The recommended maximum allowable concentration for total body content is 0.1 microgram and exposure to 2 roentgens/mo. Radium in the form of the chloride or bromide is available without A.E.C. permit at a cost of about 25 dollars to 50 dollars/milligram, plus service charges.

RADON (from *radium;* called *niton* at first, L. *nitens*, shining), Rn; at. wt. (~222); at. no. 86; m.p. −71°C; b.p. −61.8°C; density of gas 9.73 gms/l; sp. gr. liquid 4.4 at −62°C, solid 4; valence 0. The element was discovered in 1900 by Dorn, who called it *radium emanation*. In 1908 Ramsay and Gray, who named it *niton*, isolated the element and determined its density, finding it to be the heaviest known gas. It is inert and occupies the last place in the zero group of gases in the Periodic Table. Since 1923, it has been called radon. Eighteen isotopes are known. Radon-222, coming from radium, has a half-life of 3.823 days and is an alpha emitter; radon-220, emanating naturally from thorium and called *thoron*, has a half-life of 54.5 seconds and is also an alpha emitter. Radon-219, emanates from actinium and is called *actinon*. It has a half-life of 3.92 seconds and is both an alpha and gamma emitter. It is estimated that every square mile of soil to a depth of 6 inches contains about 1 gm of radium, which releases radon in tiny amounts to the atmosphere. On the average, one part of radon is present to 1 sextillion parts of air. At ordinary temperatures radon is a colorless gas; when cooled below the freezing point, radon exhibits a brilliant phosphorescence which becomes yellow as the temperature is lowered and orange-red at the temperature of liquid air. It has been reported that fluorine reacts with radon, forming radon fluoride. Radon is still produced for therapeutic use by a

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few hospitals by pumping it from a radium source and sealing it in minute tubes, called seeds or needles, for application to patients. This practice is now largely discontinued as hospitals can order the seeds directly from suppliers, who make up the seeds with the desired activity for the day of use. Radon is available at a cost of about 4 dollars/millicurie. Care must be taken in handling radon, as with other radioactive materials. The main hazard is from inhalation of the element and its solid daughters, which are collected on dust in the air. The permissible level in air has been given at 10^{-6} microcuries/milliliter. Good ventilation should be provided where radium, thorium, or actinium is stored to prevent buildup of this element.

RHENIUM (L. *Rhenus*, Rhine), Re; at. wt. 186.2; at. no. 75; m.p. 3180°C; b.p. 5627°C (est.); sp. gr. 21.02 (20°C); valence −1, 2, 3, 4, 5, 6, 7. Discovery of rhenium is generally attributed to Noddack, Tacke, and Berg, who announced in 1925 they had detected the element in platinum ores and *columbite*. They also found the element in *gadolinite* and *molybdenite*. By working up 660 kg. of molybdenite they were able in 1928 to extract 1 gm of rhenium. The price in 1928 was 10,000 dollars/gm. Rhenium does not occur free in nature or as a compound in a distinct mineral species. It is, however, widely spread throughout the earth's crust to the extent of about 0.001 ppm. Commercial rhenium in the U.S. today is obtained from molybdenite roaster-flue dusts obtained from copper-sulfide ores mined in the vicinity of Miami, Arizona, and elsewhere in Arizona and Utah. Some molybdenites contain from 0.002 to 0.2% rhenium. Some 100 lbs. of rhenium are now being produced yearly in powder and fabricated forms by one U.S. company. The total estimated free-world reserve of rhenium metal is 100 tons. Rhenium metal is prepared by reducing ammonium perrhenate with hydrogen at elevated temperatures. The element is silvery white with a metallic luster; its density is exceeded only by that of platinum, iridium, and osmium; and its melting point is exceeded only by that of tungsten and carbon. It has other useful properties. The usual commercial form of the element is as a powder, but it can be consolidated by pressing and resistance-sintering in a vacuum or hydrogen atmosphere. This produces a compact shape in excess of 90% of the density of the metal. Annealed rhenium is very ductile, and can be bent, coiled, or rolled. Rhenium is used as an additive to tungsten and molybdenum-based alloys to impart useful properties. It is widely used for filaments for mass spectrographs and ion gages. Rhenium-molybdenum alloys are superconductive at 10°K. Rhenium is also used as an electrical contact material as it has good wear resistance and withstands arc corrosion. Thermocouples made of Re-W are used for measuring temperatures up to 2200°C, and rhenium wire is used in photoflash lamps for photography. Rhenium powder sells for about 2 dollars/gm or 600 dollars/lb. Fabricated rhenium strip sells for about 800 dollars to 1500 dollars/lb.

RHODIUM (Gr. *rhodon*, rose), Rh; at. wt. 102.905; at. no. 45; m.p. 1966 ± 3°C; b.p. 3727 ± 100°C; sp. gr. 12.41 (20°C); valence 2, 3, 4, or 5. Wollaston discovered rhodium in 1803–4 in crude platinum ore he presumably obtained from South America. Rhodium occurs native with other platinum metals in river sands of the Urals and in North and South America. It is also found with other platinum metals in the copper-nickel sulfide ores of the Sudbury, Ontario, region. Although the quantity occurring here is very small, the large tonnages of nickel processed makes the recovery commercially feasible. The metal is silvery white and at red heat slowly changes in air to the sesquioxide. At higher temperatures it converts back to the element. Rhodium has a higher melting point and lower density than platinum. Its major use is as an alloying agent to platinum. Such alloys are used for furnace windings, thermocouple elements, bushings for glass fiber production, electrodes for aircraft spark plugs, and laboratory crucibles. It is useful as an electrical contact material as it has a low electrical resistance, a low and stable contact resistance, and is highly resistant to corrosion. Plated rhodium, produced by electroplating or

PHYSICAL CONSTANTS OF INORGANIC COMPOUNDS (Continued)

No.	Name	Synonyms and Formulas	Mol. wt.	Crystalline form, properties and index of refraction	Density or spec. gravity	Melting point, °C	Boiling point, °C	Solubility, in grams per 100 g: Cold water	Hot water	Other solvents
	Potassium									
p619	uranyl sulfate	$K_2SO_4.UO_2SO_4.2H_2O$	576.39	yel, monocl	3.363[20/4]	$-2H_2O$, 130		s		
p620	urate, acid	$KHC_5H_3N_4O_3$	206.21	wh powd				sl s		
p621	metavanadate	KVO_3	138.04	col cr				sl s	s	sl s KOH; i d
p622	vanadium sulfate	Potassium vanadium alum. $KV(SO_4)_2.12H_2O$	498.35	violet rubie	1.783[20]	20	$-12H_2O$, 230	1964[20]		
p623	ethylxanthate	KC_2H_5OCSS	160.30	wh to pa yel cr or cr powd	1.558[20/4]	d>200		v s	d	s al; i eth
p624	Praseodymium (α form)	Pr	140.907	pa yel, met, hex up to 798	6.782	935, tr to β form 798	3127	d		s a
p625	(β form)	Pr	140.907	sub	6.64	935	3127	d		s a
p626	acetate	$Pr(C_2H_3O_2)_3.3H_2O$	372.09	grn need				v s		
p627	acetylacetonate	$Pr(C_5H_7O_2)_3$	438.24	cr ppt		146				s CCl_4
p628	bromate	$Pr(BrO_3)_3.9H_2O$	686.77	grn, hex		56.5	$-7H_2O$, 170	196[20]		
p629	bromide	PrBr$_3$	380.63	grn cr powd		691	1547	d, sl s		
p630	carbide	PrC_2	164.92	yel cr	5.10	d		d	d	s dil s
p631	carbonate	$Pr_2(CO_3)_3.8H_2O$	605.96	grn silky pl		$-6H_2O$, 100		i		s a
p632	chloride	PrCl$_3$	247.27	bl grn need	4.02[20]	786	1700	103.9[20]	[illegible]	v s al; 2.4 [illegible] i abl, eth
p633	chloride, hepta-hydrate	$PrCl_3.7H_2O$	373.37	grn, triel	2.25[20]	115		334[20]	[illegible]	s al, HCl
p634	hexantipyrine perchlorate	$(Pr(C_{11}H_{12}N_2O)_4)(ClO_4)_3$	1568.65	grn, hex leaf		d 286–291				
p635	iodide	PrI$_3$	521.63	gr cr, hygr		737		v s		
36	molybdate	$Pr_2(MoO_4)_3$	761.63	green-green tetr	4.84	1030				
37	oxalate	$Pr_2(C_2O_4)_3.10H_2O$	726.03	lt grn cr				i		s a
38	oxide, di-	PrO_2	173.91	br-bl powd	6.82	>550 tr to Pr_6O_{11}				
39	oxide, sesqui-	Praseodymia. Pr_6O_{11}	329.81	yel-grn, amorph	7.07	d		0.000020[20]		s a
40	selenate	$Pr_2(SeO_4)_3$	710.69		4.30[20]			36[0]	2[100]	
41	sulfate	$Pr_2(SO_4)_3$	570.00	lt grn powd	2.72[20]			23.7[0] 17.7[20]	1.02[100]	
42	sulfate, octahydrate	$Pr_2(SO_4)_3.8H_2O$	714.12	grn, monocl, 1.540, 1.549, 1.561	2.827[15/4]			17.4[20]	sl s	
43	sulfate, pentahydrate	$Pr_2(SO_4)_3.5H_2O$	660.08	monocl pr	3.176[15]				1.85[20]	
44	sulfide	PrS$_2$	278.01	br powd	5.042[18]	d		i	d	s dil s
45	Protactinium	Pa	231.10	gray met, tetrag	15.37	~1230(?)				
46	chloride	PaCl$_5$	372.91	yel-grn, tetrag		subl 400 in vac		s		s dil HCl
47	fluoride	PaF$_5$	307.09	monocl				i		
48	oxide, di-	PaO_2	263.10	blk, sub						
49	oxide, pent-	Pa_2O_5	542.20	wh, sub						s dil HF
r1	Radium	Ra	226.00	silver wh met	5(?)	700	<1737	d, ev H_2O		d a
r2	bromide	RaBr$_2$	385.82	col-yelsh, monocl	5.79	728	subl 900	s	s	s al
r3	bromide dihydrate	$RaBr_2.2H_2O$	421.85	wh, monocl		$-2H_2O$, 100		s	s	
r4	carbonate	$RaCO_3$	286.01	wh, or sl brnsh, monocl				i		d a
r5	chloride	RaCl$_2$	296.91	col-yelsh, monocl	4.91	1000		s	s	s al
r6	chloride, dihydrate	$RaCl_2.2H_2O$	332.94	wh, monocl, discol		$-2H_2O$, 100		s	s	s HCl
r7	iodate	$Ra(IO_3)_2$	575.81					0.0175[0]	0.170[100]	
r8	nitrate	$Ra(NO_3)_2$	350.01	cr				13.9[20]		
r9	sulfate	RaSO$_4$	322.06	col, rhomb				0.000002[20]	0.000003[100]	i a
r10	Radon	Niton, Radium emanation. Rn	222.00	col gas, opaque cr	gas 9.73 g/l liq 4.4[-62] sol 4.0	−71	−61.8	51.0[0] cm³ 22.4[20] cm³	13.0[0] cm³	sl s al, eth [illegible]
r11	Rhenium	Re	186.2	met lust, hex	20.53	3180	5627	i	i	s dil HNO_3, H_2O_2; d s [illegible] i HCl
r12	bromide	ReBr	425.93	grn-blk cr		subl 500, vac				s dil H_2SO_4, HBr, [illegible]
r13	carbonyl, penta-	$[Re(CO)_5]_2$	652.51	col, sub cr		d 250				v sl s org [illegible]
r14	chloride, penta-	ReCl$_5$	363.47	dk grn to blk	4.9	d	d	d	d	s HCl, [illegible]
r15	chloride, tetra-	ReCl$_4$	328.01	blk (amor. ?)			500	s, d	s, d	s HCl
r16	chloride, tri-	ReCl$_3$	292.56	dk red, hex			>550	s	s	s a, alk, [illegible] sl; sl s eth
r17	fluoride	ReF$_6$	262.19	dk grn	5.383[20]	124.5	d 500	d		s a
r18	fluoride, hexa-	ReF$_6$	300.19	pa yel, v hygr	liq 6.1573, sld 3.616[20/4]	18.8	47.6	s, d	s, d	d HNO_3, [illegible]
r19	iodide pentacarbonyl	ReI.5CO	453.16	yel, rhombd		200	d 400, subl vac 90	i		s bz
r20	oxide, di-	Re_2O_3	318.20	blk	11.4[0]	d 1000		i	i	s conc HCl, [illegible]
r21	oxide, hept-	Re_2O_7	484.40	yel pl or hex cr powd, hygr	6.103	297	subl 250	v s	v s	v s al; s alk; d s [illegible]
r22	oxide, per-	ReO_3(?)	500.40	wh	8.4	145		v s	v s	s alk; d s [illegible]

No.	Name
	Rhenium
r23	oxide, sesqui-
r24	oxide, tri-
r25	oxybromide, tri-
r26	oxychloride, tri-
r27	oxytetrachloride
r28	oxytetrafluoride
r29	oxydifluoride, di-
r30	sulfide, di-
r31	sulfide, hepta-
r32	Rhodium
r33	amminechloride, hexa-
r34	carbonylchloride, hexa-
r35	chloride, tri-
r36	chloride, tri-
r37	fluoride, tri-
r38	iodide, tri-
r39	nitrate
r40	oxide, di-
r41	oxide, di-, dihyd
r42	oxide, sesqui-
r43	oxide, sesqui-, pentahydrate
r44	sulfate
r45	sulfate
r46	sulfate
r47	sulfide, hydro-
r48	sulfide, mono-
r49	sulfide, sesqui-
r50	sulfite
r51	Rubidium
r52	acetate
r53	aluminum sulfate
r54	azide
r55	borofluoride
r56	borohydride
r57	bromate
r58	bromide
r59	bromide, tri-
r60	bromochloroiodide
r61	bromoiodide, di-
r62	carbonate
r63	carbonate, acid
r64	chlorate
r65	perchlorate
r66	chloride
r67	
r68	chlorobromide, di-
r69	chlorodibromide
r70	chloroiodide, di-
r71	chloroplatinate
r72	chloroplatinite, he
r73	chromate
r74	dichromate
r75	chromosulfate

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BNWL-SA-5541

CLEANUP OF RADON INHALATION STUDY EFFLUENTS*

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Abstract

This report discusses a limited amount of experimental data on radon retention by activated carbon. The data collected were used to design a system for retention of 99% of the radon leaving an inhalation exposure chamber. A flow diagram, shielding considerations for the carbon beds, and operating characteristics of the proposed system are presented. A successful test of the prototype retention system indicated that 40 cubic meters of air would be decontaminated of radon by one kilogram of PCB (6 x 16 mesh) activated carbon under experimental conditions of 0 ±2°C and 330 cm/min superficial velocity or 660 cm/min true velocity with 50% void.

Introduction

Studies of the effects of inhalation in animals of radon and its daughter products, in progress in the Battelle-Northwest laboratory for several years, have resulted in continuous release to the environment of approximately 300 μCi of ^{222}Rn per minute. A recent change in the physical location of these studies to a less isolated area, the EPDA Manual Chapter 0511 requirements[1], and as low as practicable (ALAP) considerations[2], required development of a radon retention system capable of decontaminating 4,000 cubic meters of moist, radon-bearing air per month.

Very limited information exists in the literature for radon effluent retention systems. Since radon is a noble gas, work on effluent treatment systems for krypton and xenon in reactors may be applicable. Relevant information is found in the proceedings of the AEC Air Cleaning Conferences [3,4,5]. The work by Jess W. Thomas [6] of the Health and Safety Laboratory in evaluation of activated carbon canisters for radon protection of workers in uranium mines contains a review of the variables involved in radon retention. The variables considered were radon concentration, flow rate, humidity, carbon dioxide concentration, temperature and carbon type.

Based upon these variables, extrapolated data suggested that the radon effluent could be retained at the flows required for about 15 days in 20 cubic feet of activated carbon cooled to zero degrees centigrade. To pinpoint a more exact adsorption capacity of activated carbon beds, some simple experiments were designed utilizing a radon generator and commercially available carbon.

Experiment

Using the apparatus shown schematically in Figure 1, tests were conducted to determine the amount of air that could be decontaminated of ^{222}Rn per kilogram of Pittsburgh PCB (6 x 16 mesh) activated carbon** under the conditions described below. The activated carbon had an apparent bulk density of 0.44 g/cm^3 and 50% voids in a dense packed column. Two experiments used a 43 cm long column (0.59 kg) of activated carbon, while one experiment used a 21.5 cm long column (0.29 kg) of activated carbon. The superficial velocity in the charcoal bed was calculated to be 330 cm/minute from the 6.2 cm column diameter and the 10 ℓ/min flow rate. The radon-bearing air entering the freezer and the air leaving the freezer were monitored using alpha air monitoring equipment. The radon was generated at about 90 μCi/min, diluted with room air to a flow rate of 10 ℓ/min, cooled to approximately 7°C to remove some of the moisture and passed through a drierite bed for further dehumidification before introduction into the freezer. In the freezer, which was held at a temperature of 0 ±2°C, the radon-bearing air was cooled in a copper coil before introduction into the charcoal bed. Flow through the system was maintained until radon was detected by the downstream alpha air monitor.

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*Based on work performed under Contract E(45-1):1830 with United States Energy Research and Development Administration.

**Pittsburgh Activated Carbon
Division of Calgon Corporation
Subsidiary of Merck & Co., Inc.
Box 1346
Pittsburgh, PA 15230

filter. The carbon bed and massive shielding will remain at low temperatures for substantial time periods in event of refrigeration failure. Reduced flows may be required even though the radon-bearing air is cooled to approximately 0°C before entry to the carbon. The air handling system is designed to process up to 1.0 m^3/min of air. Actual flow rates will vary from 1 x 10^{-4} to 0.5 m^3/min initially, with higher flow rates likely in the future.

A more detailed drawing of the dual, activated carbon filters in Figure 3 shows the required shielding and capability to replace the activated carbon if necessary. The carbon filter is a dual unit with each bed consisting of a 110 kg of activated carbon packed in two columns that are 31.5 cm diameter and 145 cm tall. Either half of the unit may be used with the radon-bearing air entering the chamber at the bottom and passing up through the two activated carbon columns simultaneously. The activated carbon is expected to process about 4,000 cubic meters of air per month.

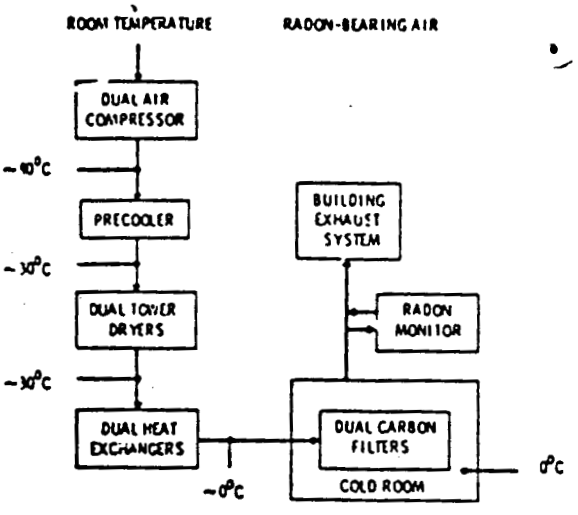

Fig. 2. Flow Schematic - Radon Retention System

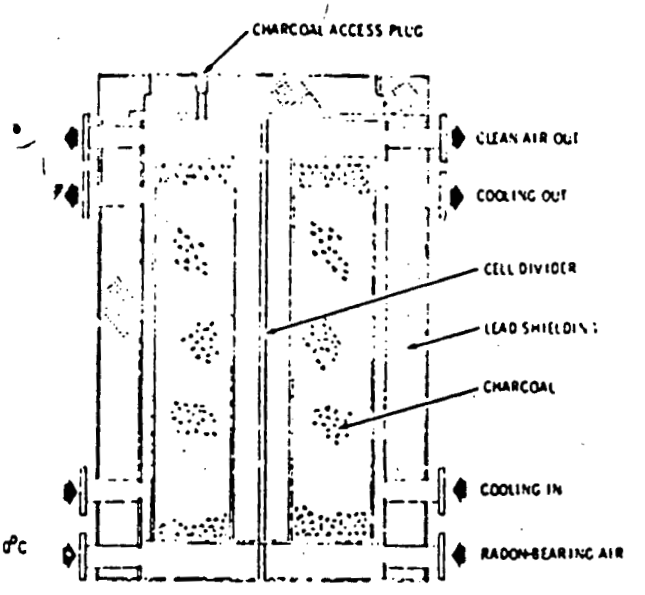

Fig. 3. Dual Activated Carbon Filter

Shielding Conditions

A six-inch lead shield was designed around the carbon filter. The maximum continuous input of radon was specified as 300 uCi per minute. When equilibrium is reached in the carbon filter, about 2.4 curies of radon are expected to be present. Table 2 briefly reviews the radon decay chain and shows only the gamma energies and yield.

Table 2: Radon-222 Decay Series

Nuclide	Half-Life	Gamma Energy (MeV)	Yield %
^{222}Rn	3.8 d	0.510	0.07
^{218}Po	3.05 m	--	--
^{214}Pb	26.8 m	0.295	19
		0.352	36
^{214}Bi	19.7 m	0.609	47
		1.120	17
		1.764	17
^{214}Po	164 us	0.8	0.014
^{210}Pb	21 y	0.047	4

When considering shielding needs, ^{214}Pb and ^{214}Bi contribute almost all of the gamma rays of concern. A calculated six inches of lead would be expected to reduce the maximum dose rate to less than 1 mrem/hr at the outside surface of the shield. The shielding has four access plugs on the top that would permit replacement of the carbon if some unforeseen contaminant reduces the adsorption capacity. The radon and daughters would be permitted to decay before replacing the carbon. The residual ^{210}Po which would build up gradually in the carbon has a low yield (4%) gamma emission of low energy (0.047 MeV) which is not expected to cause any severe exposure problems.

Conclusions

A prototype retention system for radon and its daughters has been successfully tested. The prototype test indicated 40 cubic meters of air would be decontaminated of radon by one kilogram of PCB (6 x 16 mesh) activated carbon under the experimental conditions of 0 ±2°C and 330 cm/min superficial velocity or 660 cm/min true velocity considering 50% void.

A final design was completed and the system is expected to be installed and operational by January 1, 1976. Details of the testing of this system will be reported if available at the scheduled oral presentation of this paper.

References

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MEASUREMENT OF DYNAMIC ADSORPTION COEFFICIENTS FOR NOBLE GASES ON ACTIVATED CARBON

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Abstract

Experimental techniques and analytical procedures were developed to measure the noble gas dynamic adsorp coefficients on activated carbon with a continuous inlet noble gas flow rather than the normal radioactive tracer p injection method. Nonradioactive krypton or xenon was blended with dry air to a concentration of 1 to 10 ppm by vol and continuously fed to the inlet of the test adsorber. The adsorber effluent was divided to permit sample storage as we real-time analyses. The experimental work was performed with 1-1/4- or 2-in. diameter adsorber columns 2 to 8 ft l

To measure a few parts per million of krypton or xenon in air, special analytical techniques were developed pre-concentrate the samples. The breakthrough curves were established by quantitatively measuring the adsort concentration in the carbon adsorber effluent with an ultrasonic detector gas chromatograph. The dynamic adsorp coefficients (k_d) were calculated from:

$$k_d = F\, t_m/M$$

where k_d = dynamic adsorption coefficient [cc(20°C, 1 atm ≡ STP)/gm]; F = gas flow rate [cc(STP)/min]; t_m = adsorb mean residence time (min); M = mass of dry carbon (gm).

The experimentally determined dynamic adsorption coefficients were in close agreement with those previou reported in the literature for other carbons. The equilibrium stage theoretical model adequately described the measu breakthrough curves.

I. Introduction

Removal of noncondensable gases from the turbine condensers in thermal generating plants is genera accomplished with steam jet air ejectors (SJAE). In nuclear generating plants, the radioactive noble gases Kr and Xe are potential source of radioactivity in the plant gaseous effluents. Unless properly treated, the noble gases could become a ma source of off-site radiation. Since most Kr and Xe radioactive isotopes have relatively short half-lives, systems which delay t noble gases can be used effectively to reduce the total activity by radioactive decay.

The SJAE effluent (offgas) from a boiling water reactor is composed primarily of hydrogen and oxygen from th radiolysis of reactor water and air from condenser in-leakage, but also contains trace amounts of radioactive noble gase General Electric is offering recombiner – activated carbon systems designed to delay the noble gases and also is developin methods for the removal and storage of these gases. Measurements of the noble gas concentrations in the recombined offg (normally 0.5 to 1.5 ppm by volume) and evaluation of different noble gas delay or removal systems required th development of new analytical and experimental methods. These methods and their application to the evaluation of activate carbon as an adsorbent for Kr and Xe are discussed.

II. Theory

The dynamic adsorption process is one in which a gaseous species in a flowing carrier gas stream is physicall adsorbed onto the surface of a solid adsorbent. Although the adsorbate is not bound permanently to the adsorbent, its ex from the adsorption bed is delayed with respect to the carrier gas. Several theoretical treatments have been used t characterize the dynamic adsorption process, and the one developed at the Oak Ridge National Laboratory (ORNL) has bee adopted for this paper.[1] In this approach, the packed adsorber column is assumed to be divided into a number o theoretical chambers in series. The gas flow into each chamber is instantly distributed and brought to adsorption equilibrium

A mass balance for the adsorbate across each of the N stages is

$$\frac{dy_i}{dt} = -\frac{FN}{k_d M}(y_i - y_{i-1}) \tag{1}$$

where

y_i = Volume fraction of adsorbate in gas phase leaving the ith stage at time t;
F = Total gas flow rate [cc(20°C, 1 atm ≡ STP)/gm]
M = Total charcoal mass on dry basis (gm);
N = Number of theoretical equilibrium stages;
t = Time (min).
k_d = Dynamic adsorption coefficient [cc(STP)/gm]

Solution of the series of N differential equations with the appropriate adsorbate initial boundary conditions yields the effluent concentration profile from the Nth stage. For a unit input pulse at t = 0, this solution is

$$y_N = \frac{N^N F^{N-1} t^{N-1}}{(N-1)!\,(k_d M)^N} \exp\left(\frac{-NFt}{k_d M}\right). \tag{2}$$

By differentiating Equation (2) with respect to time and setting the result equal to zero ($y_N' = 0$) the time, t_{max}, required for the concentration to reach a maximum, y_{max}, is

$$t_{max} = \frac{(N-1)\,k_d M}{NF}. \tag{3}$$

It has been shown that for a linear adsorption isotherm, which should apply at low adsorbate concentrations, the mathematical solution to a step change (constant input) initial boundary condition is equivalent to the integral of the solution for a square wave (pulse) boundary condition;[2] i.e.,

$$z_N = \int_0^t y_N\,dt \tag{4}$$

where z_N provides the effluent concentration profile for a step constant input.

Thus, the time required to reach the peak maximum for the pulse case, t_{max}, (obtained from $y_N' = 0$) can be equated to the time to the inflection point in concentration for constant input (since $z_N'' = y_N'$). For the near-symmetrical effluent distribution function described by Equation (2), this time can be denoted by t_m, the mean residence time of the adsorbed species in the column, without serious error.

For long, well-packed beds, N will be a large number, so that (N-1)/N will be approximately unity. The assumption of large N and substitution of t_m for t_{max} in Equation (3) yields

$$t_m = k_d M/F. \tag{5}$$

This result shows that a characteristic residence time of an adsorbed species in a dynamic adsorption column of mass M and at carrier-gas flow rate F is defined by the proportionality constant, k_d. Once the effect of those system parameters which affect k_d are known, the mean delay time for any given total flow (F) and adsorber size (M) can be calculated by using Equation (5).

A computer program was written to integrate Equation (2) numerically. The number of equilibrium stages (N) was calculated by using the revised correlation proposed by Vermeulen, as described by Robell and Merrill.[2] Effluent profiles were calculated by integrating Equation (2) after substituting the experimental conditions and the value of N found above. The profiles agreed well with the experimentally measured curves over a wide range of conditions (Section V), which lends credence to the application of the equilibrium stage theory to dynamic noble gas adsorption on carbon.

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III. Analytical Technique

Analytical Equipment

An analytical instrument capable of detecting the noble gases in air at the parts per million level and belo needed for analyzing actual and simulated reactor offgas. Since the instrument would be used both in the laboratory the field, it also had to be somewhat portable. A survey of available analytical techniques indicated that a gas chromatc (GC) with a helium ionization detector (HID) or an ultrasonic detector (UD) could probably meet these requirements.

The HID is at least an order of magnitude more sensitive than the UD. However, the high sensitivity of th requires the chromatographic system be extremely clean and free from leaks, i.e., water vapor or air can swamp the det In fact, the sensitivity of the HID to leaks precludes the use of any valving between the sample inlet and HID. Pr experience with an HID GC showed the detector was easily poisoned and required hours of bake-out time after maintenance or instrument modifications (e.g., column changes). In addition, the instrument was quite delicate and sub shipping damage. The UD has the advantages of a wide dynamic range (10^6); freedom from single carrier gas require i.e., the HID requires ultra-pure helium carrier; flexibility, since column switching valves can be used; and predi calibration. Based on these comparisons, it was decided to purchase a GC with the more rugged and flexible UD.

The UD system measures the changes in the speed of sound in gas mixtures by comparing the phase shift of a traversing the mixture to a reference signal. The characteristics of the UD have been discussed by Noble, et al.,[3] Too DeBord,[4] and Grice and David.[5] As shown by Grice and David,[5] the peak area for a particular sample compon degree-seconds (A) for a given detector can be approximated by

$$A = Kn(M - M_c)/PF_c$$

where

- K = Detector constant;
- n = Moles of component in sample;
- M = Molecular weight of component;
- M_c = Molecular weight of carrier;
- P = Pressure of gas in detector cell; and
- F_c = Carrier flow rate.

For a given set of chromatographic conditions, the pressure and flow rate are constant. Thus, the response per is a function of the molecular weight difference, $M - M_c$. Equation (6) indicates that when using hydrogen or helium carrier gas, a single calibration curve can be used without appreciable error for all samples except those of very low mole weight. The data reported by Grice and David[5] illustrate these predictions are valid.

Column Development

As shown in Figure 1, it is not difficult to separate Kr from air with a 5A molecular sieve (MS) column wher relative concentrations of O_2, N_2, and Kr are within a few orders of magnitude of each other. However, the quantit determination of 1 ppm Kr in air (Figure 2) presents a more difficult problem. The Kr peak appears on the tail of the peak and is too small for accurate quantitative measurements. An experimental investigation of several GC column pac materials and operating conditions was conducted to optimize the separation of trace quantities of Kr and Xe from air. results of this program (Table 1) indicated that Carbosieve-B provided good separation between air, Kr, and Xe, but suff from interference of CH_4 and CO_2. Porapak-T appeared capable of separating Xe from CO_2, CH_4, and air. Type 5A-M subambient temperature (-10 to 10°C) was the best for the Kr analysis. In the final analytical scheme, a Carbosieve-B colu was incorporated to eliminate most of the N_2 and O_2 from the sample, followed by a 5A-MS column for Kr analysis Porapak-T column for Xe analysis.

Analytical Procedure

A Tracor Model MT-150 GC equipped with a dual UD (Figure 3) is used to detect the sample components, and corresponding peak areas are measured with an Autolab System IV computing integrator. The required sensitivity is obta by using 20 cc air samples. Most of the air is separated from the sample in a cutting column; the final separation is effectec

one of two analytical columns (Figure 4). Helium carrier gas (99.995% purity) is first passed through a 1/4-in. diam[illegible] 10-ft long activated carbon column maintained at liquid nitrogen temperature to remove any remaining conta[illegible] Valve V1 is used to select a sample either from a 20 cc sample loop or from the sample storage system descri[illegible] in Section IV. The sample is injected into a Carbosieve-B cutting column. The Kr and Xe are preferentially retained on the Carbosieve-B, and the bulk of the air is vented through valve V3 and needle Valve N3. After venting the air, valve V3 is used to direct the flow through valve V2 to the 5A-MS column and Detector-A for the Kr analysis, and to the Porapak-T column and Detector-B for the Xe analysis.

The pressures and flows throughout the system are balanced to minimize flow disturbances caused by the valve switching operations during the analysis. The GC operating conditions are shown in Table 2. The normal analysis time is 18 to 20 minutes. As shown in Figure 5, good separation is achieved between the Kr and N_2 peaks. Figure 6 shows that a reasonably sharp Xe peak is also obtained.

TABLE 1. Gas Chromatograph Column Development
(Carrier Gas – Helium)

Packing Material	Carrier Flow [cc(STP)/min]	Column Temperature (°C)	Column Length (ft)	Comments
Activated Carbon	80	27 to 80	2	CH_4 in air interferes with Kr peak.
Carbosieve-B	35 to 60	30	4	CH_4 interferes with Kr, and CO_2 interferes with Xe.
5-A Molecular Sieve	30	−15 to 95	8 to 12	At −10 to 10°C, can be used for Kr. Interference from H_2O and CO_2 for Xe.
Porapak-Q	25 to 70	−40 to 27	8 to 12	Insufficient separation between air and Kr. Water and CO_2 interfere with Xe.
Porapak-T	40 to 70	27 to 120	12	Insufficient separation between air and Kr. Good for separating Xe from air, CO_2 and CH_4.

TABLE 2. Gas Chromatograph Operating Conditions

	Krypton	Xenon
Carrier Flow, cc(STP)/min.	60	60
Detector		
Pressure, psig	30	30
Temperature, °C	120	120
Cutting Column		
Length, inches	9	9
Inside Diameter, inches	0.17	0.17
Packing	Carbosieve-B	Carbosieve-B
Mesh Size	140/200	140/200
Analytical Columns		
Length, ft	8	12
Inside Diameter, inches	0.10	0.10
Packing	5A-MS	Porapak-T
Mesh Size	60/80	50/80
Temperature, °C	−10 to +10	0 to 30

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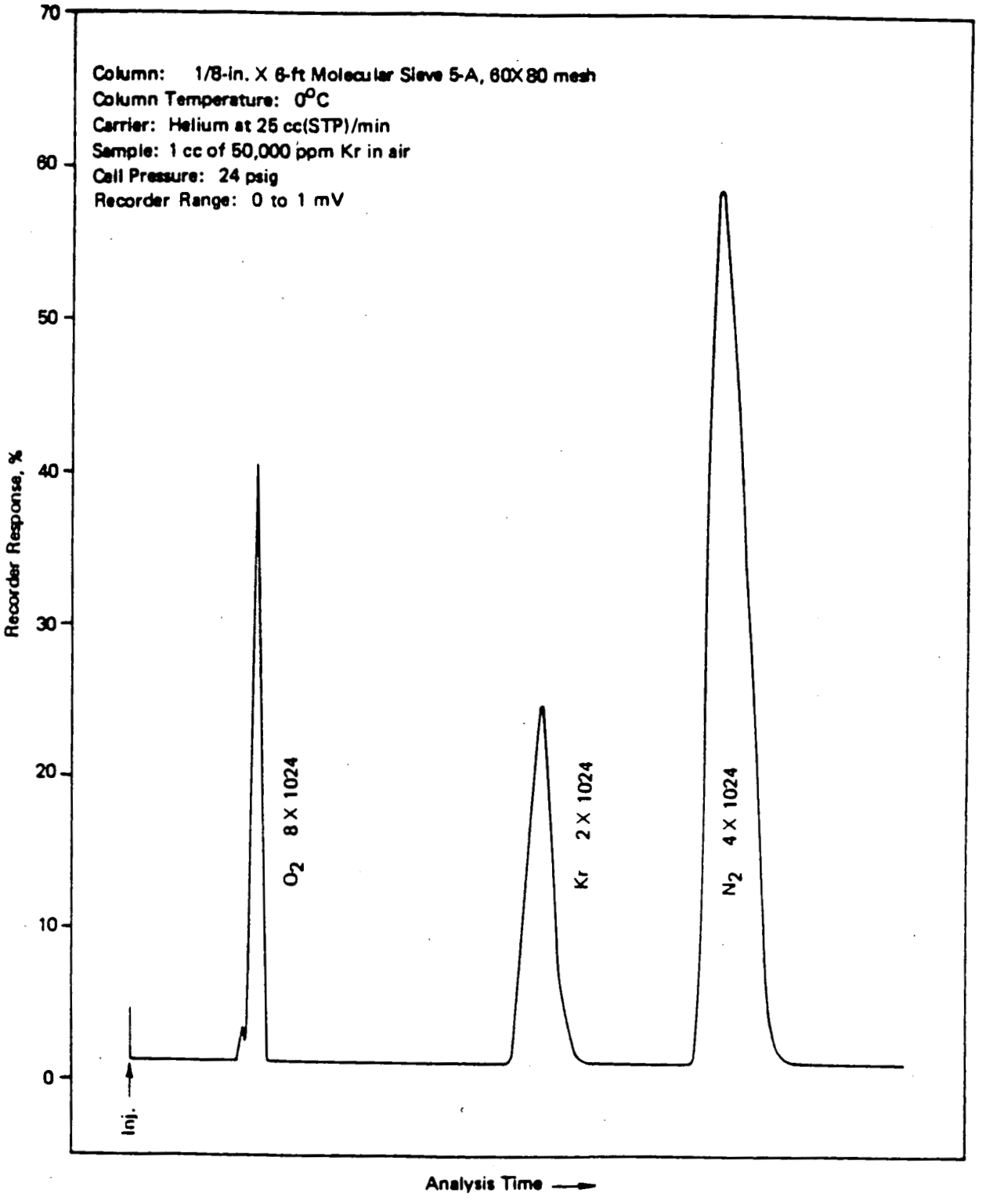

FIGURE 1. SEPARATION OF OXYGEN, KRYPTON, AND NITROGEN

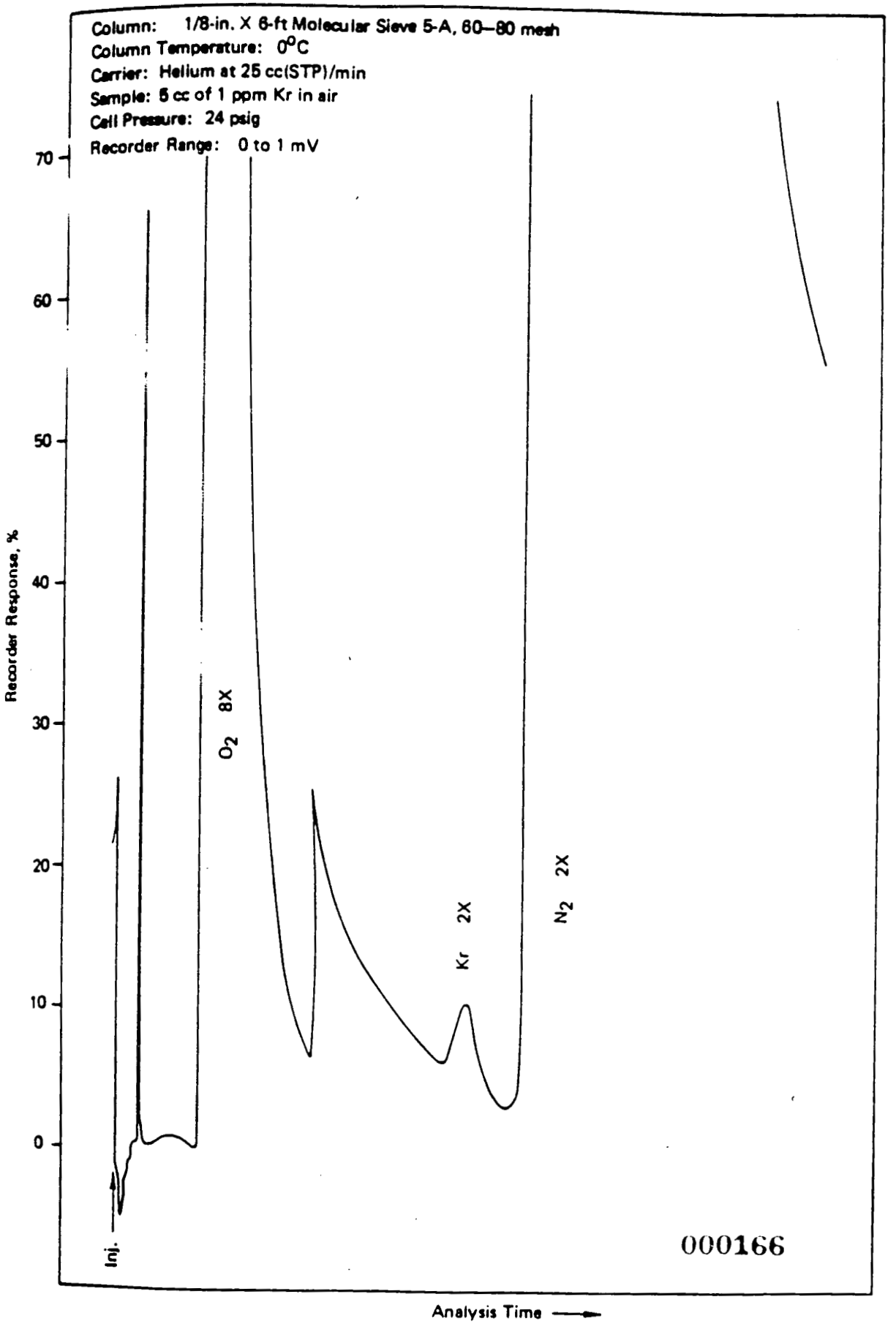

FIGURE 2. DETERMINATION OF 1 ppm KRYPTON IN AIR

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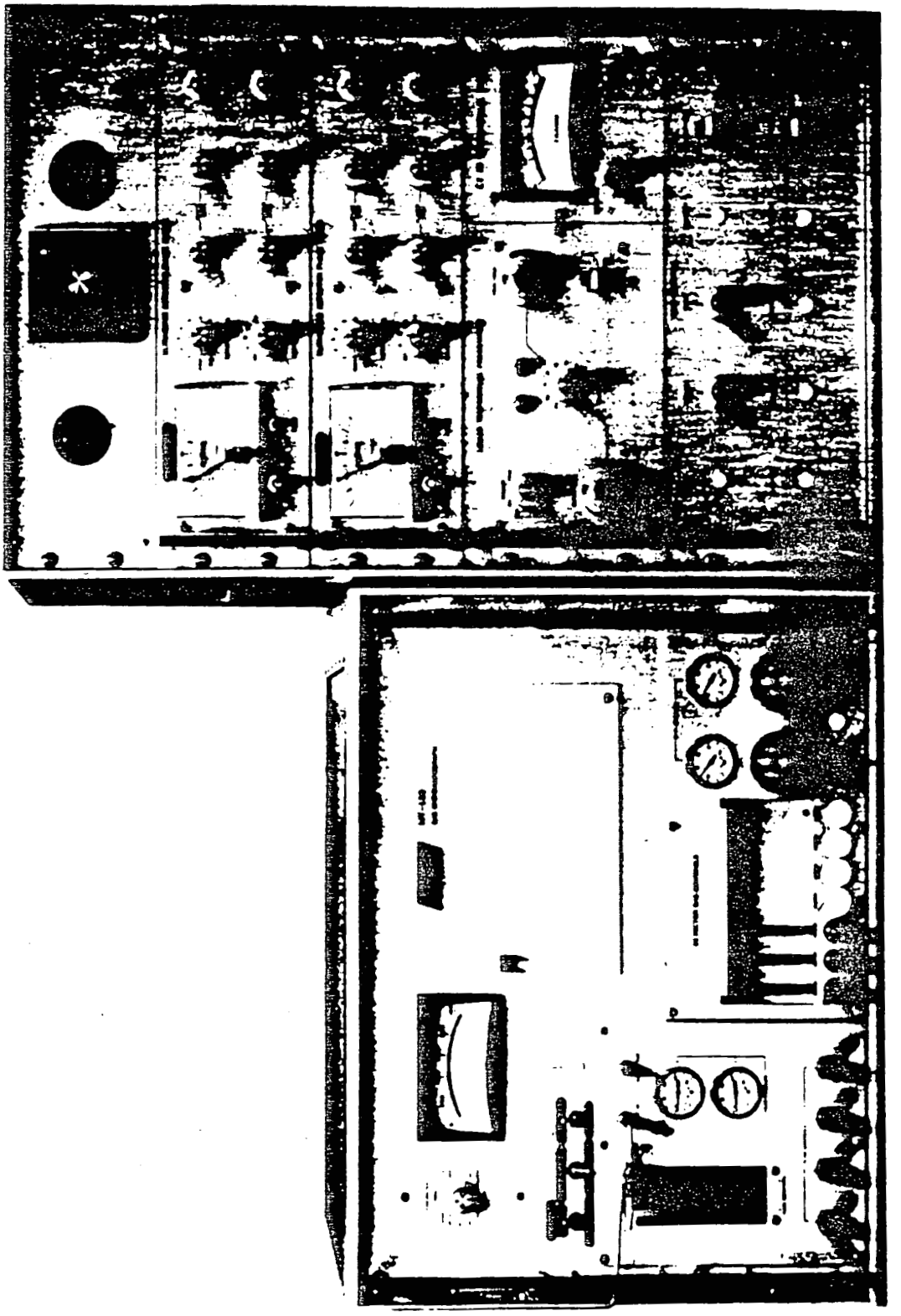

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FIGURE 3. TRACOR MT-150 GAS CHROMATOGRAPH

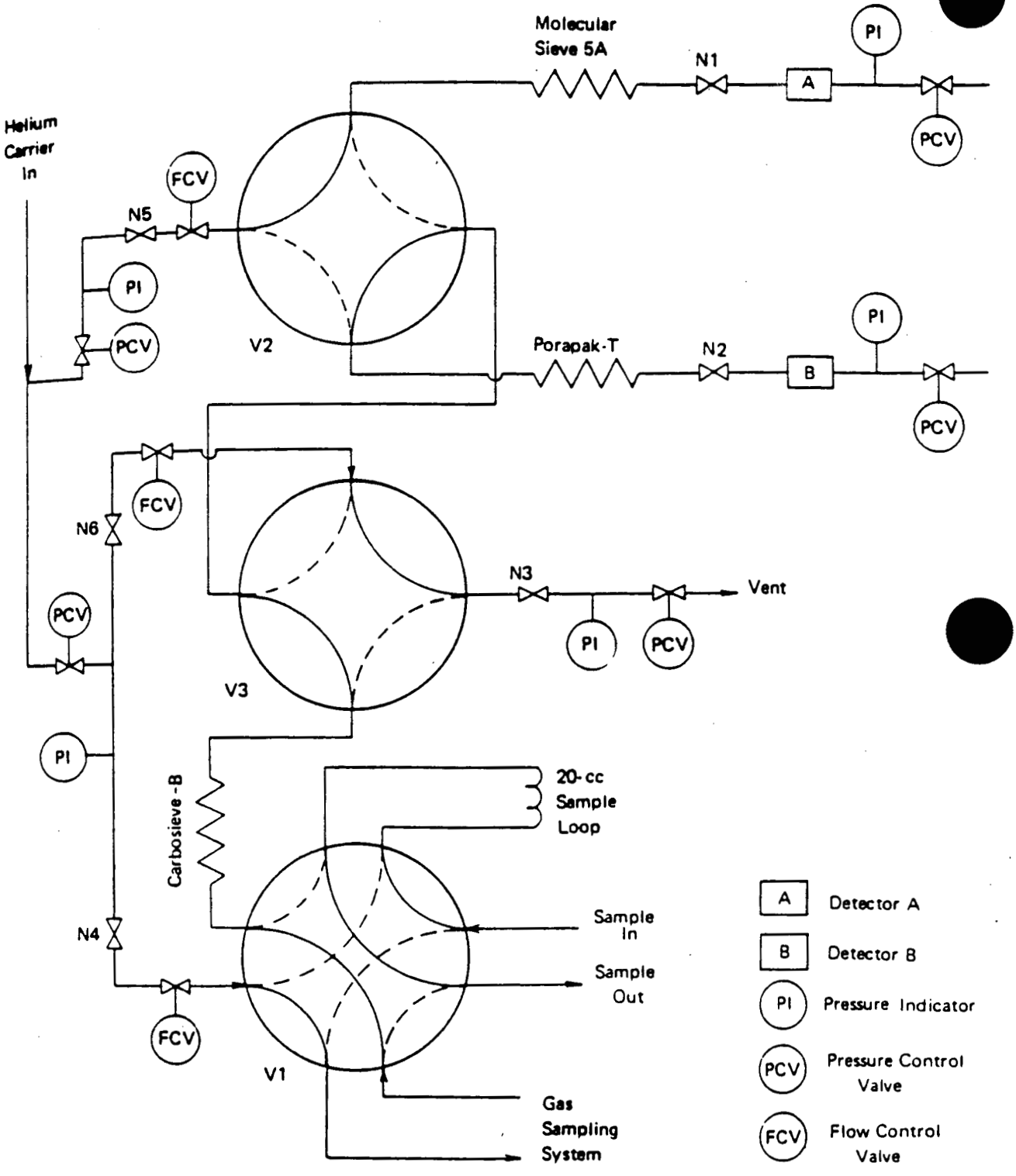
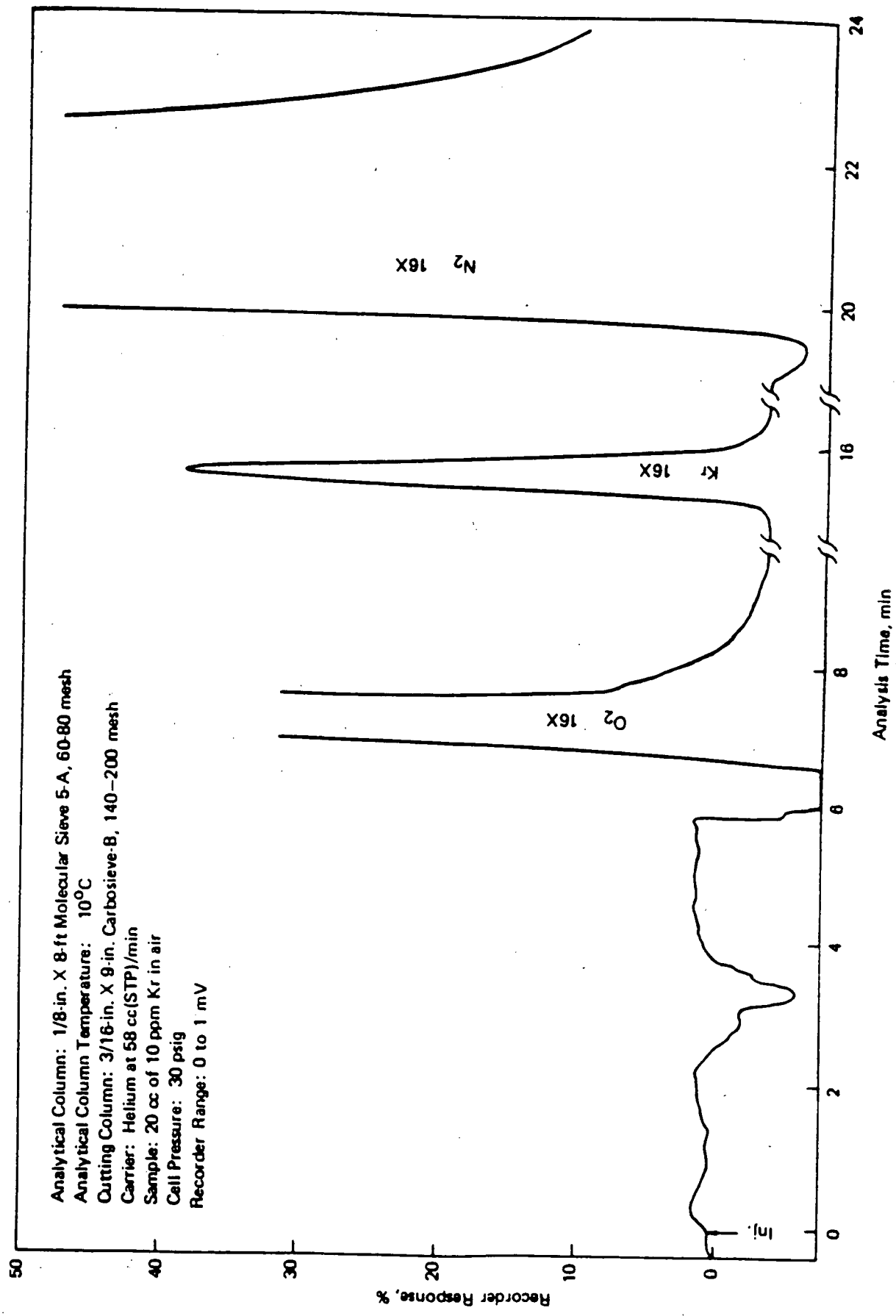


FIGURE 4. GAS CHROMATOGRAPH FLOW DIAGRAM


Analytical Column: 1/8-in. X 8-ft Molecular Sieve 5-A, 60-80 mesh
Analytical Column Temperature: 10°C
Cutting Column: 3/16-in. X 9-in. Carbosieve-B, 140–200 mesh
Carrier: Helium at 58 cc(STP)/min
Sample: 20 cc of 10 ppm Kr in air
Cell Pressure: 30 psig
Recorder Range: 0 to 1 mV
Inj.
O2 16X
Kr 16X
N2 16X
Analysis Time, min
Recorder Response, %
0
2
4
6
8
16
20
22
24
10
20
30
40
50

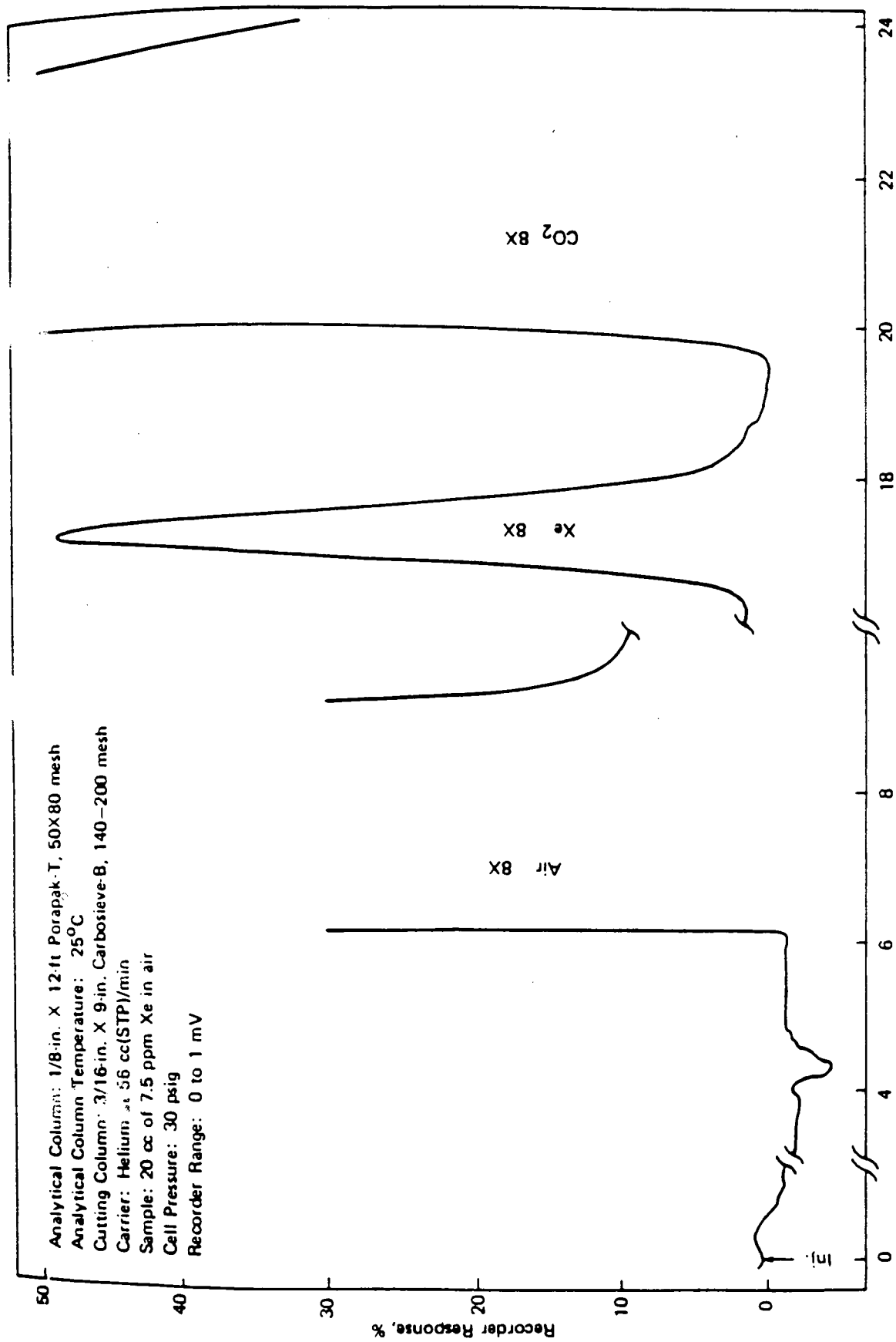


FIGURE 6. TYPICAL XENON ANALYSIS

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IV. Experimental Apparatus

Flow System

The dynamic adsorption experiments have been performed with the equipment shown schematically in Fig Compressed or cylinder air is dried to an inlet dewpoint of -70°C (< 3.5 ppm moisture) with Type 3A-MS (to prevent h of CO_2) and is cleaned of trace hydrocarbons with an activated carbon filter before being blended with a prepared ru containing 100 to 500 ppm of Kr or Xe in zero-grade air (< 2 ppm hydrocarbon content). The two gas flows are indivi metered through critical flow orifices to give noble gas concentrations of 1 to 10 ppm at the adsorber inlet. Provisior easily be made to add moisture or gaseous contaminants to the flowing carrier gas stream.

Three adsorbers (either 1-1/4- or 2-in. inside diameter aluminum columns) are located within a Webber, temperature chamber in which a constant temperature (± 1°C) can be maintained (Figure 8). The columns can be individually or in series to provide adsorber lengths of 2 to 8 ft. The gas flow path contains in-line probes for contin remote monitoring of the gas temperature and humidity. Humidity measurements are made with a Panametrics, Model-1000 aluminum oxide hygrometer capable of measuring gas dewpoints over the range of -110 to +20°C. The s pressure is controlled with a backpressure regulator located in the gas sampling system and is measured at the entrance c chamber. The total gas flow rate is continuously monitored at the same location with a calibrated laminar flow element.

Gas Sampling System

The adsorber column effluent flows to the gas sampling system (Figure 9). The total effluent gas flow is div into parallel streams so that a portion of the stream can be analyzed in real time at the GC and other fractions can be s for subsequent analysis. Two 15-loop sample storage valves (S1, S2) are used to store up to thirty 20 cc samples. The vol of the connecting lines between the GC sample valve (V1) and the 8-port switching valves (C1, C2) have been adjuste 20 cc to provide a second sample loop for real-time GC analyses. Before the storage valves are indexed to the next sa loop, solenoid valves (E1, E2) are energized to close the inlet lines and enable the loop pressures to bleed dow atmospheric pressure. Check-valves in each of the parallel sample lines prevent the high pressure carrier gas contained w previously analyzed sample loops from diluting subsequent samples. Flows of 40 to 60 cc(STP)/min are maintained thr each of the sample loops, requiring a minimum adsorption system backpressure of 1.5 to 2.0 psig.

V. Experimental

Experimental Conditions

Samples of activated carbon from several vendors were evaluated for Kr and Xe adsorption at a variety of conditions. For all these tests, the carbon was first dried in a 120°C oven purged with dry air to a moisture content of than 0.3% by weight before loading into the adsorber columns. The carbon was transferred from the oven to a tared adso column in less than 2 minutes to minimize moisture pickup. The columns were packed by vibrating the column wall w maintaining a head of several inches of excess carbon above the column top. The columns were then sealed and reweighed.

Before starting a test, the carbon was flushed with dry air(-70°C dewpoint) until the inlet and outlet humidities w equal. After the Kr or Xe run mix was added to the carrier air stream, the column effluent was sampled and analyzed for or Xe. Plotting the measured outlet concentration versus time gives an S-shaped adsorption breakthrough curve (Figure 1 The time axis in Figure 10 is normalized with respect to the mean breakthrough time and the concentration axis with resp to the inlet concentration. The total gas flow rates used in the test program were such that the superficial gas velocity ranged from 0.8 to 3.2 ft/min. The combination of column lengths and flow rates was chosen so that complete breakthro of the noble gas occurred in a reasonable period of time. For example, at 25°C and at a superficial velocity of 1.6 ft/m mean holdup times of approximately 25 to 30 minutes and 7 to 8 hours were found for Kr and Xe adsorption, respective in a 2-ft long adsorber bed.

Reproducibility

Early in the experimental program, a series of adsorption runs was made to determine error limits and experimen accuracy. Five months later, in tests made with a sample of the same type carbon but which was obtained at a later da lower values obtained for the adsorption coefficient led to retesting the original carbon sample. Thus, experiments have be run with different columns and column lengths, with columns that had been reloaded with previously tested carbon, as w

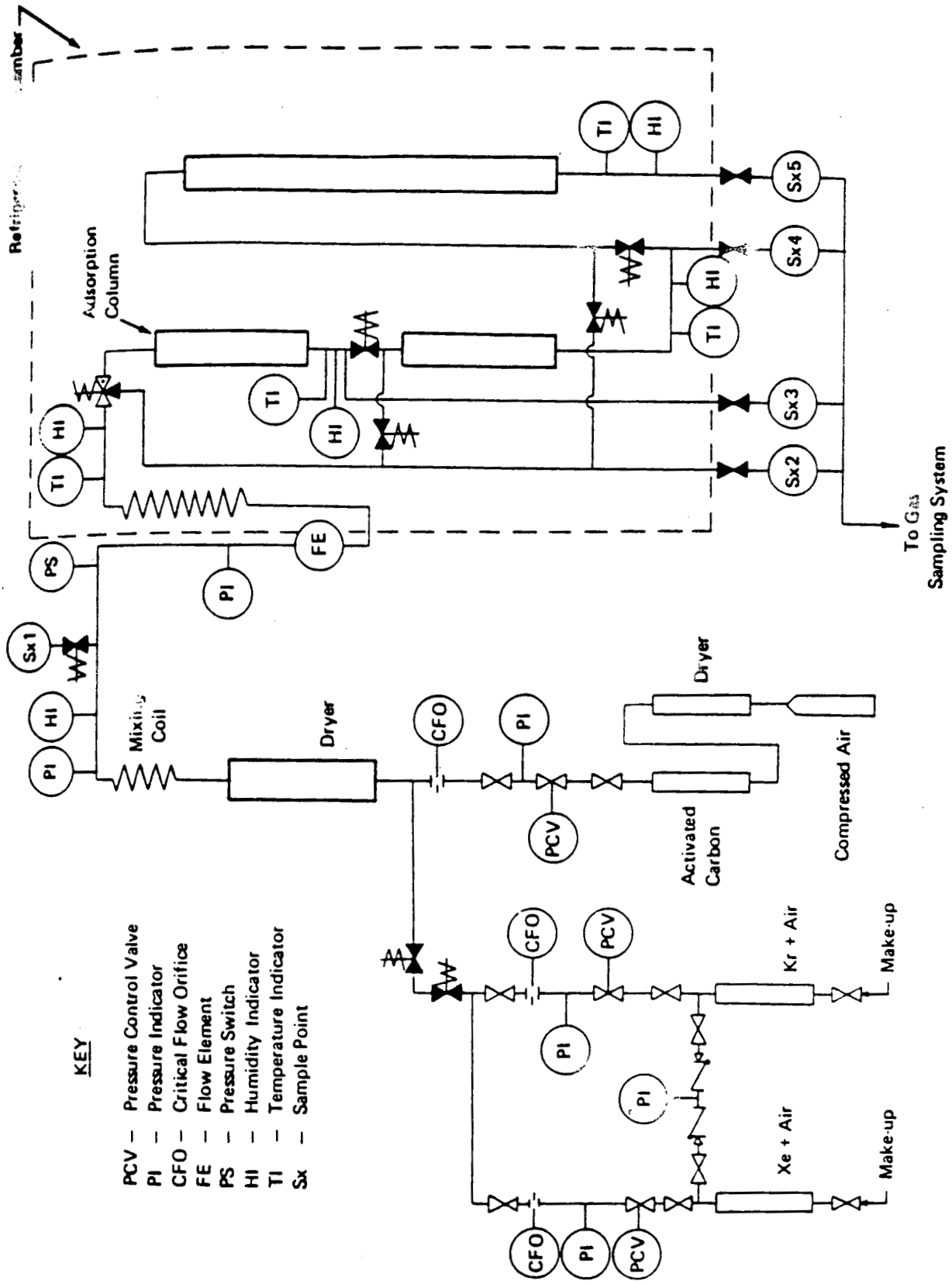

FIGURE 7. EXPERIMENTAL SYSTEM FOR DYNAMIC ADSORPTION MEASUREMENTS

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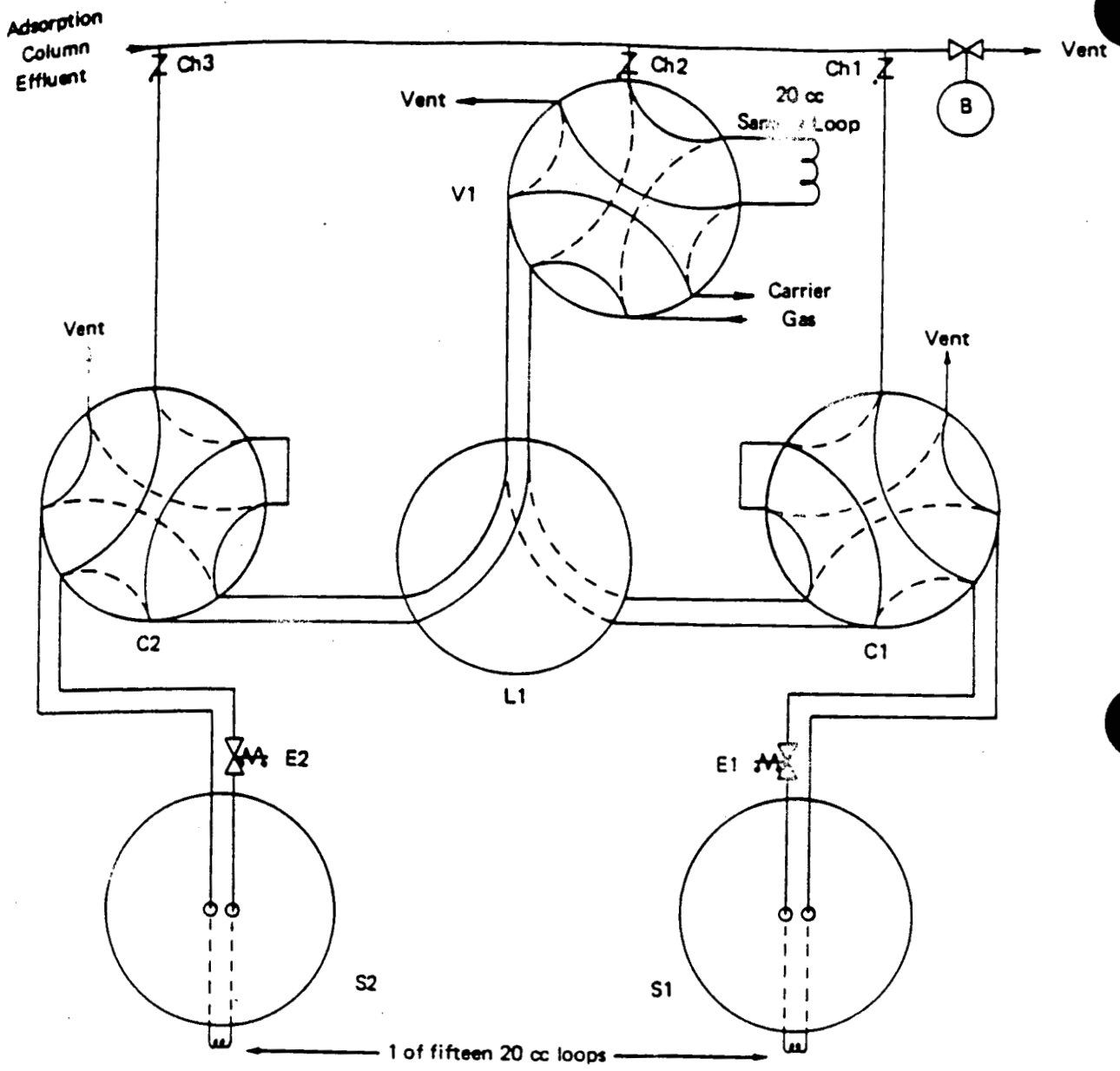
FIGURE 8. ADSORPTION COLUMNS IN CONTROLLED TEMPERATURE CHAMBER



S – 15-loop sample storage valve
C – 8-port switching valve
L – 6-port switching valve
V – 8-port GC sampling valve
Ch – Check valve
E – 2-way solenoid valve
B – Back pressure regulator

FIGURE 9. GAS SAMPLING SYSTEM

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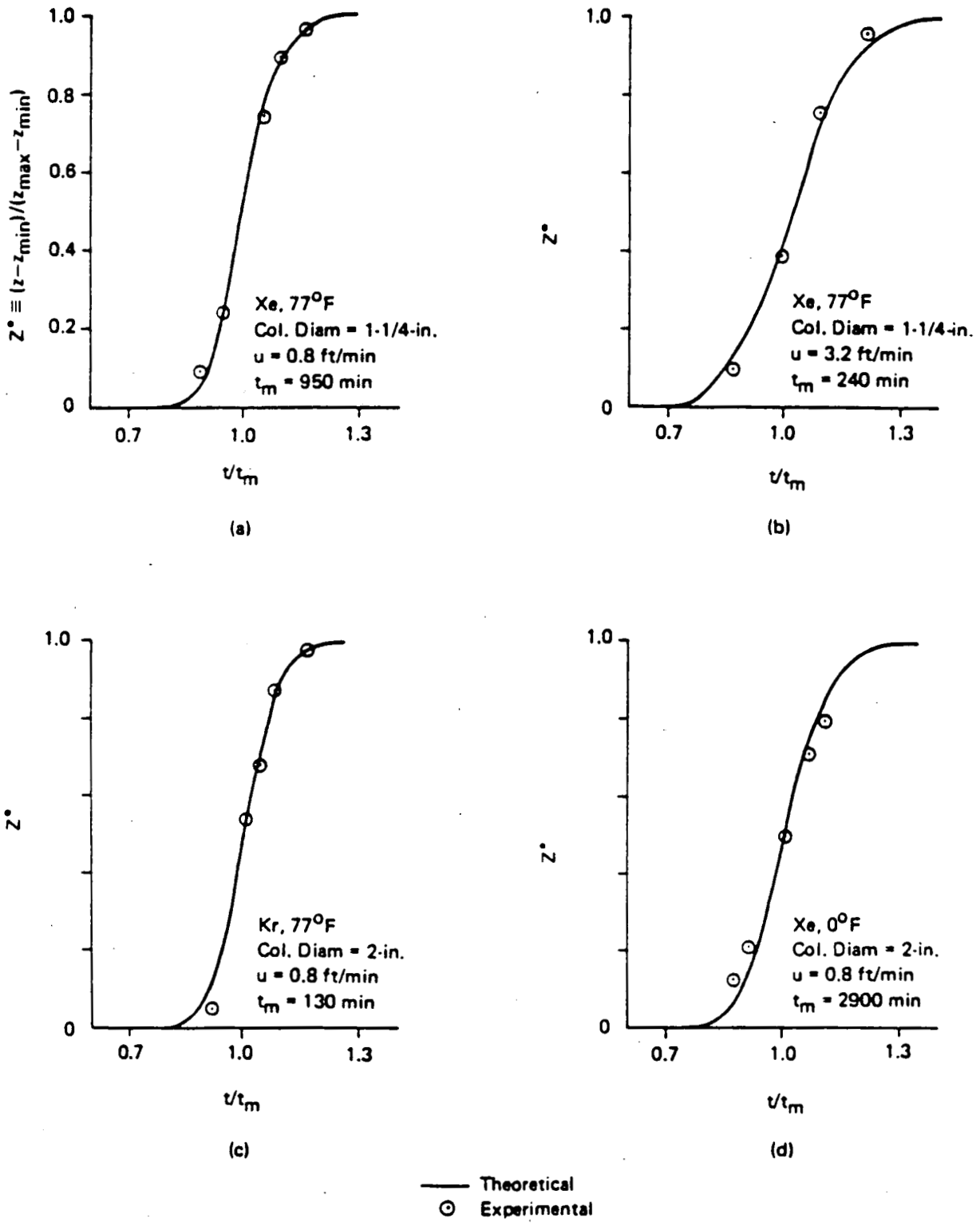

FIGURE 10. CALCULATED VERSUS EXPERIMENTAL BREAKTHROUGH CURVES

as with carbon of the same type received at different times. The results, presented in Table 3, show the combined experimental errors cause less than a ± 3% standard deviation in the calculated dynamic adsorption coefficient.

As shown in Table 3, there was no detectable effect on the dynamic adsorption coefficient of a fourfold change in flow rate (0.8 to 3.2 ft/min) or a twofold change in column cross-sectional area (1-1/4- to 2-in. inside diameter columns). The shape of the breakthrough curves resulting from the different experimental conditions is predicted well by the theory (Figure 10).

TABLE 3. Experimental Reproducibility

Conditions			
Column Size (inches)	Flow Velocity (ft/min)	k_d(Kr)* [cc(STP)/gm]	k_d(Xe)* [cc(STP)/gm]
Coconut Base Carbon A – Sample 1			
1-1/4 X 48	1.6	57.5	
1-1/4 X 96	1.6	55.0	
1-1/4 X 96	1.6	54.0	
1-1/4 X 24	1.6		900
1-1/4 X 48	1.6	55.0	
1-1/4 X 24 (Rerun 5 months after above experiments)	3.2		890
Coconut Base Carbon A – Sample 2			
2 X 48	0.8	52.6	
2 X 24	0.8		775
1-1/4 X 24	0.8		760
1-1/4 X 24	3.2		815
1-1/4 X 24	3.2		790

*k_d measured at 25°C, 16.2 to 16.7 psia and normalized to STP.

Effect of Adsorbate Concentration

One of the goals of this program was to determine the noble gas dynamic adsorption coefficients at conditions approximating those expected in the recombined offgas (primarily air) of an operating BWR. Adsorption experiments were conducted at noble gas concentrations of 1 and 10 ppm. Since atmospheric air contains 1.14 ppm Kr, the columns were first flushed with nitrogen for the low concentration experiments. Changing the noble gas concentration from 1 to 10 ppm produced no noticeable effect on the dynamic adsorption coefficient. Therefore, most experiments were performed with noble gas concentrations of about 10 ppm to simplify the experiments and afford better accuracy.

Effect of Temperature

The capabilities of the controlled temperature chamber containing the adsorber columns permitted experiments to be made over a wide range of temperatures. Although most of the experiments were run at 25°C, some tests were performed at lower temperatures. A comparison of the experimentally measured effect of temperature on the adsorption coefficient for one coconut base carbon with literature data[6-8] (a compilation of several carbon types) is given in Figure 11. It can be seen the experimental and literature adsorption coefficients agree reasonably in absolute value.

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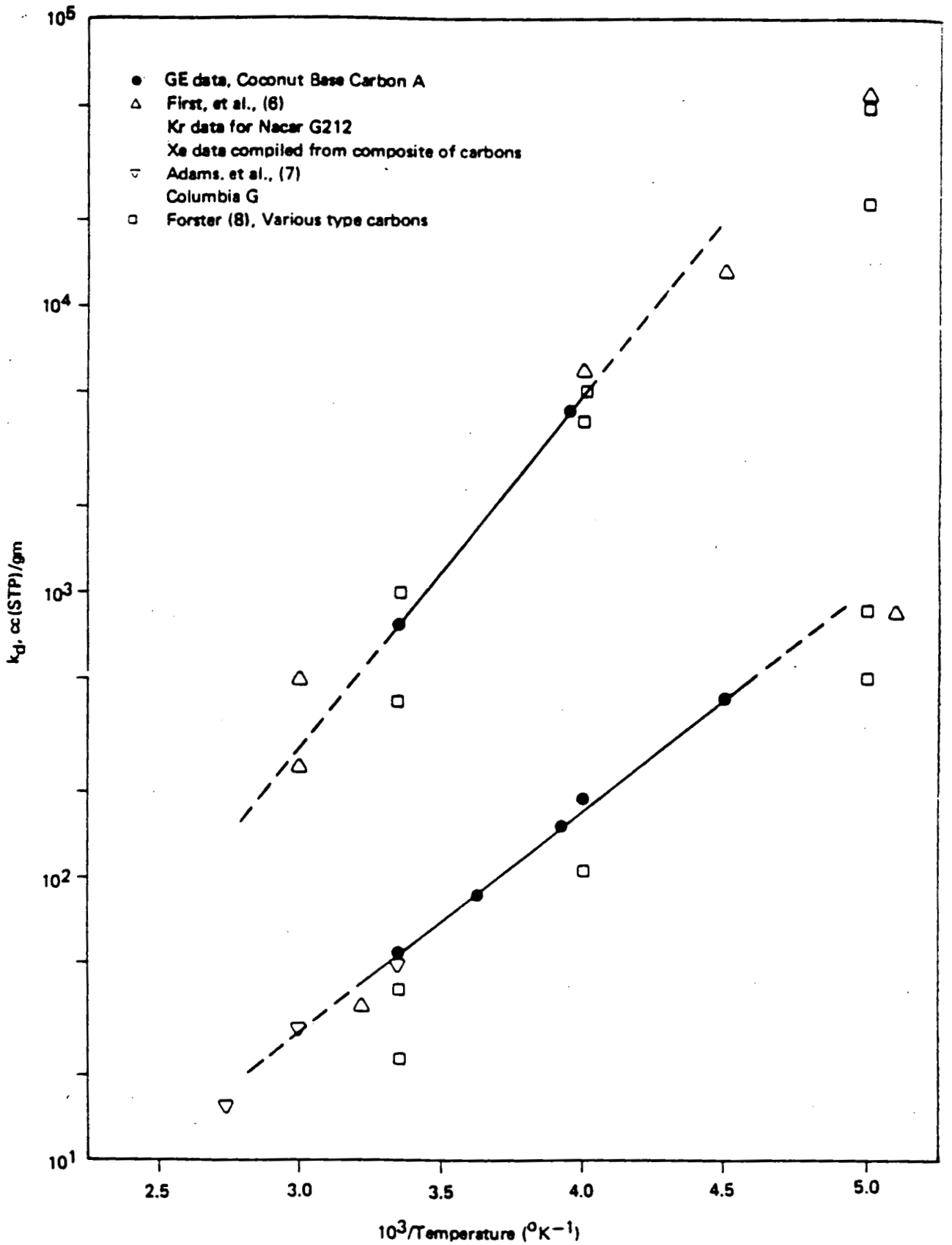

FIGURE 11. DYNAMIC ADSORPTION COEFFICIENT VERSUS TEMPERATURE

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Carbon Comparison

The dynamic adsorption coefficients for Kr and Xe have been measured at 25°C on ten different activated carbons. The samples tested included coconut, coal, and petroleum base carbons. As shown in Table 4, the coconut base carbons generally had higher adsorption coefficients. Also, since the ratio of the Xe and Kr dynamic adsorption coefficients for this grouping of carbon samples was fairly constant, a fair prediction of both coefficients might be made on the basis of a single adsorption experiment on each carbon.

TABLE 4. Dynamic Adsorption Coefficients for Selected Carbons
(25°C, Dry Carbon)

	$k_d(Kr)^*$	$k_d(Xe)^*$	$k_d(Xe)/k_d(Kr)$
	[cc(STP)/gm]		
Coconut Base			
Carbon A	55.3 – 52.6**	910 – 785**	16.4 – 15.8
Carbon B	50.2	770	15.4
Carbon C	57.7	925	16.0
Carbon D	55.5	970	17.4
Carbon E	44.0	690	15.7
Petroleum Base			
Carbon F	47.2 – 46.5**	680 – 655**	14.4 – 14.1
Carbon G	47.7	620	13.1
Carbon H	45.0	720	16.0
Coal Base			
Carbon I	41.9	680	16.3
Carbon J	34.4	460	13.5

*k_d measured at 25°C, 16.7 psia and normalized to STP.
**k_d measured on carbon samples received at different times.

VI. Conclusions

Analytical and experimental techniques have been developed to determine noble gas dynamic adsorption coefficients on activated carbon at concentration levels approximating those in the offgas of an operating BWR. The data obtained agree well with values obtained by other techniques.[6-8] The versatility of the system and procedures developed will enable dynamic adsorption experiments to be conducted with a variety of adsorbate and adsorbent combinations and experimental conditions. The use of nonradioactive gases precludes the need for special safety and monitoring facilities or procedures.

Acknowledgment

The authors wish to acknowledge the efforts of W. R. Kassen and E. J. Jacklitsch in the procurement of the analytical and experimental equipment and of F. A. Arlt and L. R. Powell who assembled the experimental system. In addition, the contribution of F. A. Arlt in conducting the individual tests and maintenance of the equipment is gratefully appreciated.

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Health Physics Vol. 38 (January), pp. 83–85
Pergamon Press Ltd., 1980. Printed in the U.S.A.

Radon Adsorption in a Gas Flow by Activated Charcoal

(*Received* 12 *October* 1978; *accepted* 19 *April* 1979)

WE STUDIED the radon adsorption characteristics of a commercial charcoal as a function of time, temperature, gas velocity and radon concentration. We chose a peat-based material because of its relatively low radon content. The charcoal was composed of small cylinders about 1.2 mm long and 0.2–0.5 mm in diameter with a density of 0.43 g/cm^3.

Theoretically the distribution of ^{222}Rn in an adsorption media can be described by a three-zone model (Jü76). The first zone is saturated with radon and the adsorption and desorption processes are in equilibrium. The next region, the adsorption zone, is characterized by active uptake of radon. The amount of adsorption is related logarithmically to the zone thickness. The last region, the non-burden zone, shows no appreciable radon adsorption.

The experimental procedure is described as follows: The charcoal is divided into 30 fractions in an adsorption tube (length, 27.8 cm; diameter, 4.5 cm; distance between two fractions, 0.6 cm; thickness of each fraction, 0.2 cm; and mass of each fraction, 1.4 g). Nitrogen gas with a known ^{222}Rn concentration flows through the adsorption tube. The quantity of ^{222}Rn adsorbed in each of the 30 charcoal fractions is measured by γ-spectrometry (RaC'). We made our tests with gas velocities of 1.5, 4.4 or 29 cm/sec and temperatures of 293, 273 or 194.5 K.

The duration of the adsorption varied from 1 min to 1 hr. The radon concentration varied from 5.1 μCi/l. to 9.1 nCi/l. During each adsorption test all the parameters remained constant.

The results of these tests are shown in Figs. 1–3. These figures show the quantity of ^{222}Rn adsorbed in each carbon fraction as a function of the fraction number, in a semilogarithmic scale. The quantity of adsorbed ^{222}Rn is normalized to the activity concentration of ^{222}Rn of the gas flow, to compare the results.

Figure 1 shows the effect of the temperature in adsorption. These data were made at a gas velocity of 4.4 cm/sec and an adsorption time of 1 hr. The curve with an adsorption temperature of 194.5 K is significant. This curve shows no zone of saturation and the decrease at the adsorption zone is very sharp. Increasing gas velocities show similar results.

Figure 2 shows the influence of gas velocity in adsorption at a temperature of $T = 273$ K. Each test lasted 10 min. The quantity of ^{222}Rn adsorbed in the first fraction is always the same. The gas velocity influences the decrease in the adsorption zone only.

Figure 3 shows the distribution of the ^{222}Rn as a function of adsorption time. Four tests were conducted at a temperature of 293 K and a gas velocity of 4.4 cm/sec. Longer adsorption times flattened the decrease of the adsorption curves in the adsorption zone and increased the maximum of ^{222}Rn adsorbed in the first fraction. This indicates that more than one adsorption process with different kinetics may be taking place (Gu55; Wi40).

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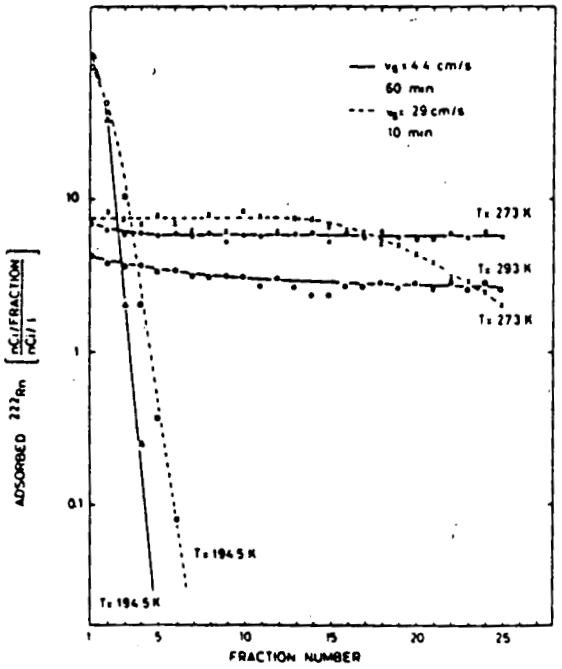

FIG. 1. Quantity of ^{222}Rn adsorbed in an adsorption layer for different temperature.

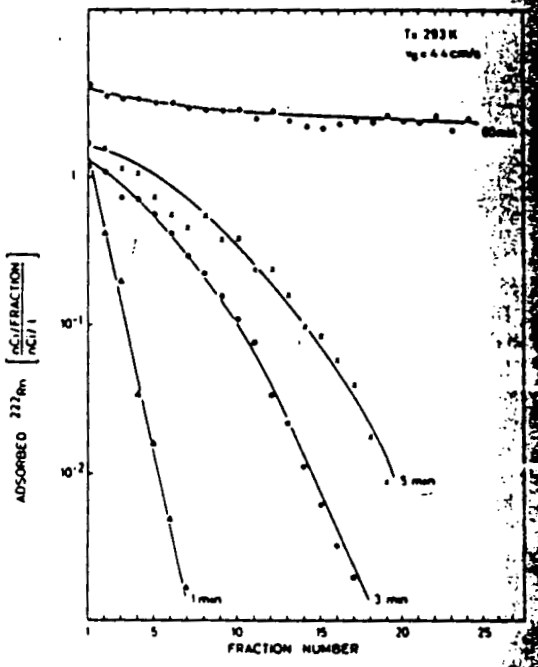

FIG. 3. Quantity of ^{222}Rn adsorbed in an adsorption layer for different adsorption times.

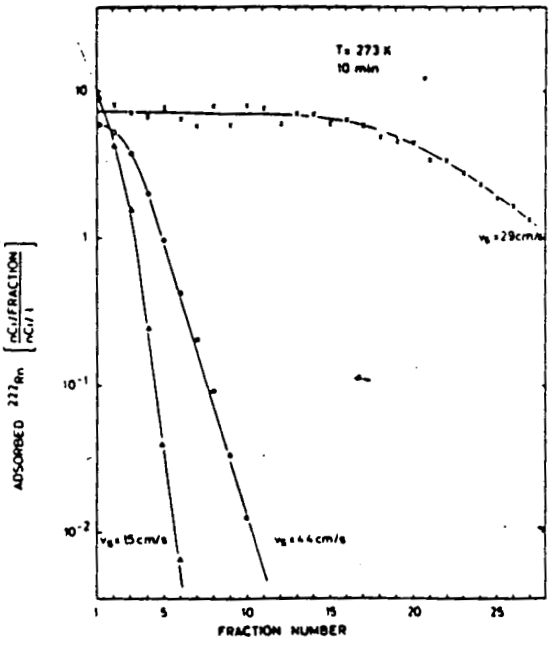

FIG. 2. Quantity of ^{222}Rn adsorbed in an adsorption layer for different gas velocities.

From the quantity of ^{222}Rn adsorbed in the saturation zone for the 1-hr tests, it is possible to determine the Freundlieh adsorption coefficient (Cr51).

This can be stated as

$$n = ap^b$$

where n = quantity of ^{222}Rn adsorbed; p = pressure (partial pressure); a = adsorption coefficient; b = constant. We were able to show that for very low pressures or partial pressures the constant b becomes 1. The experimental values of the adsorption coefficient are 0.43 and 0.13 mol/g bar at 273 and 293 K, respectively. These values compare favorably to those obtained by Gübeli and Störi using charcoal of lime wood at atmospheric pressure. They obtained adsorption coefficients of 0.56 and 0.28 mol/g bar at 273 and 293 K, respectively (Gu54).

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EVALUATION OF ACTIVATED CARBON CANISTERS FOR RADON PROTECTION IN URANIUM MINES

January 1974

Health and Safety Laboratory (AEC)
New York, New York

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EVALUATION OF ACTIVATED CARBON CANISTERS FOR RADON PROTECTION IN URANIUM MINES

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January 1974

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U. S. Atomic Energy Commission
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ABSTRACT

The protection against radon gas afforded by several types of activated carbon gas mask canisters was determined, since uranium mine personnel are occasionally exposed to radon concentrations in the thousands of pCi/ℓ range, and calculations showed that 3300 pCi/ℓ of radon was equivalent to the permissible level of 0.3 WL of radon daughters on the basis of potential alpha energy release in the respiratory tract. The canisters were tested at radon concentrations from about 1500 to 40,000 pCi/ℓ and flow rates from 8 to 64 ℓ/min. Other variables studied were test air humidity, water content of the carbon, and temperature. Results indicated that a canister containing about 900 ml of dry, high-grade activated carbon, used at a breathing rate of 16 ℓ/min, would provide almost 100% protection against radon for a period of one hour at a temperature of 25°C and an air humidity of about 9 mg/ℓ. Protection would be provided for a longer period at the lower temperatures existing in uranium mines.

INTRODUCTION

Concentration limits for the exposure of uranium miners are expressed in terms of radon daughters, which constitute the predominant inhalation hazard compared to radon gas. Mine atmospheres normally are ventilated to maintain radon daughters below prescribed limits. However, in certain restricted locations such as abandoned workings and exploratory drifts, ventilation may be deficient or absent. This can give rise to extremely high concentrations of both radon and its daughters, often comparable to values of 50,000 pCi/ℓ reported by Holaday et al.[1] in their early investigations. During the occasional brief entries to these areas that are required for exploration or maintenance, personnel should be equipped with respiratory protection against both radon and radon daughters, since exposure to radon itself can be hazardous. To define more accurately when protection is needed, an MPC is required for radon-222 gas in the absence of its daughters. This has not been set in the standard radiation protection handbooks. However, an estimate may be obtained by considering the MPC for radon-222 to be that concentration which will result in the same energy release in the respiratory tract that would be given by a radon daughter concentration corresponding to the current limit of 0.3 working levels (WL).

One WL is defined as that quantity of radon daughters per liter of air which will result in the eventual release of 1.3×10^5 MeV of alpha energy. Hence, 0.3 WL would result in the eventual release of 0.4×10^5 MeV of alpha energy per liter of air. To calculate the alpha energy release in the respiratory tract due to inhalation of air at 0.3 WL, it is necessary to assume values for fractional respiratory deposition and for breathing rate (minute volume).

George and Breslin[2] reported deposition values from 23 to 45% in uranium mines varying with mine location, individual tested, and tidal volume. Most of their results were obtained for sedentary subjects having low tidal volumes. They also found that increased tidal volume resulted in increased deposition. For mine workers doing moderate work, tidal volume would be higher than for the sedentary position. Hence, it seems reasonable to assume a round value of 50% for the purposes of this calculation. The breathing rate adopted by the ICRP[3] for the quantity of air inhaled during an eight hour day, 10^7 cm^3, is used. This value corresponds approximately to 20 ℓ/min.

With these assumptions of fractional respiratory deposition and breathing rate, the deposition of potential alpha energy in

the respiratory tract per minute for 0.3 WL is (0.4×10^5) (0.50) (20) = 4×10^5 MeV/min. Accordingly, to calculate the MPC for radon-222, it is necessary to find the radon concentration which would result in the deposition of 4×10^5 MeV/min of potential alpha energy in the respiratory tract. This type of calculation has been done by Holaday et al.[1], who assumed a lung volume of 2.75 liters and complete retention of the radon daughters formed by decay of radon while in the respiratory tract. The assumption of complete retention was presumably made because the freshly formed RaA would be unattached and hence would diffuse rapidly to body surfaces. Their calculation showed that a radon concentration of 1 pCi/ℓ would release 116.7 MeV in the respiratory tract. Hence, the MPC for radon would be (0.3) $(1.3 \times 10^5)/(1.17 \times 10^2)$ = 3300 pCi/ℓ. Respiratory protection against radon in absence of its daughters is therefore indicated when the radon gas concentration exceeds about 3000 pCi/ℓ.

At present, the only feasible method of providing this respiratory protection is with supplied air respirators. A typical device of this kind might weigh 20 pounds and last for about 20 minutes. Reduction of this weight and/or increase of servicable time obviously would be highly desirable. Since it is known that activated carbon has a limited capacity to absorb radon even at room temperature[4,5], it appeared that a gas mask canister containing carbon might provide worthwhile protection. The purpose of this work was to investigate the degree of radon protection afforded by the small M11 Army gas mask canister, and a larger commercial canister, the Scott-Acme type 184.

THE M11 AND SCOTT-ACME CANISTERS

The M11 Army gas mask canister, a component of the M9 gas mask, was developed by the Army Chemical Corps during World War II and has been described by West[6]. It was manufactured in large quantities for issuance to Army personnel. The canister contains a pleated, high efficiency filter which should remove radon daughters with very nearly 100% efficiency regardless of their degree of attachment. The canister weighs about 260 grams and is mounted on one side of the gas mask facepiece, a convenient and comfortable arrangement.

The Scott-Acme canisters (Acme Products, South Haven, Mich.) were the manufacturer's types 184-OV and 184-OVWC. The canisters are mounted on the wearer's body and are connected to the facepiece by a corrugated hose. Their size is roughly 2½" × 4½" × 7", and weight about 1½ pounds. The canisters do not contain a high

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efficiency filter, and hence would not provide protection against particulate radon daughters. Canisters containing both activated carbon and a high efficiency filter, however, are available from Scott-Acme and other companies.

Some of the properties of the carbon beds of the M11 and the Scott-Acme canisters are listed below.

Property	Scott-Acme	M11
Carbon volume, cm^3	900	270
Area of carbon layer, cm^2	60	87
Thickness of carbon layer, cm	15	3.1
Void fraction	0.72	0.70
Mesh size	6-16	12-30

The quantities in the listing above were determined in this laboratory by simple methods or obtained from the manufacturer and must be considered as approximate. An emission spectrographic analysis was also done on carbon from the M11 and the two types of Scott-Acme canisters. The M11 carbon, known to be the impregnated "ASC" type[7], showed about 0.1% silver, 1.0% chromium, and 0.5% copper by weight. The values for the Scott-Acme 184-OVWC carbon were about 0.1% silver, and 0.8% chromium, and 0.7% copper. It appears, within the limits of the analysis, that the Scott-Acme 184-OVWC canisters and the M11 canisters both contain "ASC" impregnated carbon. Carbon from the Scott-Acme 184-OV canisters contained no detectable silver, chronium or copper, and was assumed to be unimpregnated.

APPARATUS AND PROCEDURE

The canisters were tested by passing a radon-air mixture into them at a known flow rate, radon concentration and humidity, and determining the radon transmission vs. time. The dimensionless fractional transmission T is defined as the concentration of radon in the carbon bed effluent divided by the influent concentration at any time. Details of the test apparatus are shown in Figure 1. Radon was generated by bubbling air saturated with water at 1 ℓ/min through a radium chloride solution. Several different solutions were used, with radium contents in the range of 0.2 to 5 mCi. High efficiency filter paper was used downstream of the bubbler to remove any entrained aerosol from the radium bubbler. The main air supply for the apparatus entered through flowmeter F-1

at various flow rates from about 20 to 70 ℓ/min and was humidified when desired, by one or more of the humidifying tubes shown in the figure. When very dry air was needed, the humidifying tubes were replaced by a silica gel dryer. The total flow into the canister test chamber was set at a higher value than any of the flows to be withdrawn through the test canisters, to provide an excess. The radon concentrations obtained varied from about 1500 to 40,000 pCi/ℓ. Canisters were tested at 8, 16, 32 or 64 ℓ/min, the canister flow being maintained by two flowmeters; F-4 at 8 ℓ/min, and F-3 at the rate needed to make up the total flow. The 8 ℓ/min flow line was arranged to measure radon concentrations in the effluent from the test canister. This line was provided with a bypass so that the flow could be maintained constant whether or not a concentration sample was being obtained.

To prepare for an adsorption test, the air flow was maintained for about 2 or 3 hours to establish equilibrium conditions. The waiting period allows accumulated radon in the radium bubbler to be swept out into the hood, and allows the water in the humidifier to reach an equilibrium temperature. It was found that after the waiting period the apparatus would produce a constant (± 5%) radon concentration for days or weeks. Immediately prior to the test, the input radon concentration was measured at 8 ℓ/min using the two-filter method[8], sampling from line 1 of the figure. Samples were taken for three minutes using 934AH paper (Reeve-Angel Co., Clifton, N. J.) with a 530 ml two-filter tube and were counted from ½ to 6½ minutes after the end of the sampling with an alpha scintillation counter. Usually four determinations were taken prior to a test, and four after completion of the test. After establishing the input radon concentration, the canister was attached to line 2 of the figure and the radon concentration in the canister output determined repeatedly at three minute intervals. The average transmission obtained over the three-minute sampling period was considered to be the instantaneous transmission at the midpoint of the sampling period.

The humidity of the air stream, in milligrams of water vapor per liter of air, was determined when needed by drawing a sample from line 1 at 3 ℓ/min through silica gel (Tell-Tale, Fisher Scientific Co., No. S-160) contained in a sampling tube about 2 cm in diameter and 12 cm long. Such a tube will completely adsorb about 2 grams or more of water vapor at 3 ℓ/min.

In two of the canister tests, CO_2 was introduced at a concentration of 2% by volume. This was done by means of a CO_2 tank and auxiliary flowmeter set at 400 ml/min, not shown in Figure 1. Since it was not known whether CO_2 would have an effect on the two-filter method for radon, a few tests were done at a constant

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radon concentration with and without the CO_2. Concentration values obtained with CO_2 were a few percent higher than those obtained without CO_2, but since the effect was small it was ignored.

RESULTS AND DISCUSSION

The primary data were obtained in the form of transmission vs. time curves, Figures 2 to 9. From these curves, the canister life to any fractional transmission could be obtained and, by integration, the fraction of input radon adsorbed to a given test time calculated. The principal variables studied were radon concentration, air flow rate, test air humidity and canister water content. Some information was also obtained on the effect of carbon dioxide, the relative efficiency of different carbons, and the effect of temperature.

Effect of Radon Concentration

Theoretically, the transmission of a noble gas through a carbon bed is independent of the gas concentration when the gas is present in low concentration. This has been verified for krypton and xenon[9], and should also apply to radon. To confirm this, dry M11 canisters were tested at radon concentrations of about 1600 and 38,000 pCi/ℓ, with all other conditions being held as nearly constant as possible. The transmission curves are shown in Figures 3 and 4, and the results summarized in Table 1 for intercomparison. The table shows that radon concentration has no detectable effect on the rate of radon adsorption, and in subsequent work the radon concentration was set as high as feasible, to improve the precision of the tests.

Effect of Flow Rate

From theory[9,10] flow rate has a pronounced effect on noble gas transmission through carbon beds. Results are shown in Figures 2 to 9. From these figures a comparison may be obtained of the life of the canisters to, e.g., 10% transmission at flow rates differing by a factor of two, as indicated in Table 2. The table shows that within the range studied, the life of the canister increases by about a factor of 2.5 with halving of the flow rate.

Effect of Water

The effect of water on radon adsorption was studied in two

different ways. In the first method initially dry canisters were used and the test humidity varied from nearly zero to about 18 mg/ℓ. In this case, one has co-adsorption of water and radon, and the water content of the canisters varies with time.

In the second method the canisters were first equilibrated with air at different humidities, and then a radon test was done with air at the same humidity. In this method there is very little or no co-adsorption of water during the radon test, and the canisters had essentially the same water content before and after the radon test. The water content of the canisters was arbitrarily defined, for experimental convenience, as the weight of the canisters after equilibration minus their weight when equilibrated with air at about 1.4 mg/ℓ humidity.

Tests done on M11 canisters according to the first method are shown in Figures 2, 3, and 4. The figures show the deleterious effect of air humidity on dry M11 canisters. Tests were also done using the second method, with canisters equilibrated at various test humidities. Figure 10 shows a comparison of results obtained by the two different methods. It is apparent from the figure that water adsorbed during the test is more harmful to canister radon adsorption efficiency than water added before the test. To find the reason for the difference, air at about 15 mg/ℓ humidity was passed into a dry carbon bed containing a thermometer. A temperature rise of about 7°C was immediately noted. This qualitative test showed that the poorer performance with co-adsorption of water is caused by the effect of higher temperature on radon adsorption.

The Scott-Acme canisters were tested using the pre-equilibration method only, and some of the transmission curves obtained for different water contents are shown in Figures 5, 6, and 7. The effect of water content is shown directly in Figure 11, where the canister life to 2% transmission is compared at the three flow rates for different canister water contents.

Integration of the transmission curves permitted calculations of the fraction of total input radon that is adsorbed by the canister during a 60 minute test as a function of canister water content, Figure 12. In this figure there are several data at "zero" water content and also at a water content of about 2 to 3 grams. The data at zero water content were for canisters equilibrated and tested at about 1.4 mg/ℓ humidity; the data at 2 to 3 grams water content were for canisters equilibrated and tested at 9 mg/ℓ humidity. Comparison of the results shows differences in the fraction of radon adsorbed to be of the order of 5% or less. This shows that humidities of about 9 mg/ℓ do not seriously

decrease the fraction of radon adsorbed compared to dry conditions, at least at room temperatures (25°C = 77°F).

Effect of Carbon Dioxide

Results of tests at a volumetric concentration of 2% CO_2 are given in Figure 9. It is apparent that CO_2 has a somewhat deleterious effect. However, considering that the CO_2 concentration used in the test was greater by at least one order of magnitude than the concentrations which would be expected in mines, it appears that there need be no concern over the effect of normal CO_2 levels on radon adsorption.

Effect of Temperature

The effect of temperature was studied by varying the room temperature from 25 ± 1°C to 20° + 1°C. In these tests, the radon concentration was about 11,000 pCi/ℓ, the flow rates were 16, 32 and 64 ℓ/min, and the test humidity was about 11 mg/ℓ. The same Scott-Acme canister was used for all tests with desorption of the canister between each test. A series of tests at the three flow rates was done at 20°C, next at 25°C, and then repeated at 20°C, to confirm that the desorption was adequate, and the tests reproducible. The tests were not considered very accurate because of relatively poor temperature control. However, a definite temperature effect was found as shown in Figure 8. The results of these tests in terms of the fraction of radon adsorbed, and the total radon adsorbed in a 60 minute test are given in Table 3. The results are corrected for small variations in water content of the carbon, which averaged about 28 grams. The ratios of radon adsorbed at 20°C compared to 25°C, averaging the two tests at about 20°C, were 1.13 at 16 ℓ/min, 1.14 at 32 ℓ/min, and 1.21 at 64 ℓ/min.

The temperature effect found can be compared, to a limited extent, with that predicted by the Fusamura et al.[11] equation. According to this equation, the "saturated radon adsorption" value, As, over the temperature range 275°K to 305°K, and for one type of activated carbon, may be expressed as

$$As = 6000 \left(\frac{288}{T}\right)^{12.7} Cs$$

where Cs is the radon concentration in μCi/cm³ and T is the absolute temperature. Writing this equation for 20°C (293°K) and 25°C (298°K) and dividing one by the other gives

$$\frac{As\ (20\ C)}{As\ (25\ C)} = \left(\frac{298}{293}\right)^{12.7} = (1.017)^{12.7} = 1.24$$

Hence, the equation predicts 24% more radon adsorbed at 20°C than at 25°C. The experimental results show a somewhat smaller effect, averaging 16%. However, the present results are for unsaturated carbon, as the tests were stopped while the carbon was still adsorbing radon. Also, the type of carbon and water content of the carbon were different than used by Fusamura et al.[11].

Effect of Carbon Type

The Scott-Acme type 184 canisters tested had three different lot numbers, 1381, 1711, and 1478, and were filled with three different types of carbon. According to Scott-Acme, the canisters in lot 1381 contained type 337 carbon, manufactured by Witco Chemical Company. This carbon had a surface area of about 1300 square meters per gram. The carbon of lot 1711 was stated to be type-WV-H, manufactured by Westvaco Corp. and had a surface area of about 1000 square meters per gram. No information was available on the carbon of lot 1478 (OVWC canisters).

Results of a comparison of the different carbons are given in Table 4. The table shows that the 184-OV (lot 1711) canisters had very nearly the same adsorptive capacity as the impregnated OVWC type. The 184-OV (lot 1381) canisters, however, were definitely superior both to the 184-OV (lot 1711) and the OVWC canisters. It appears that high carbon surface area is very desirable, and that ASC impregnation probably has a deleterious effect on radon adsorption.

Canister Regeneration

It was found early in the work that canisters used for radon adsorption could easily be regenerated by passing air through them. Consequently it was possible to make repeated tests using the same canister, with regeneration between tests. All of the transmission curves obtained in Figure 5, for example, were obtained using the same Scott-Acme type 184-OV canister, which was regenerated between tests by passing air at about 1.4 mg/ℓ humidity through it for two to three hours at 70 ℓ/min. The tests were run within the span of a few days in the following sequence: 32 ℓ/min, 64 ℓ/min, 16 ℓ/min, 32 ℓ/min, 64 ℓ/min, and finally 16 ℓ/min. Inspection of the results showed that there was little or no difference between the first and second tests

at the same flow rate, which proved that the regeneration was adequate. The results shown in Figures 6 and 7, obtained with higher canister water content and test humidity, confirmed that two to three hours regeneration at 70 ℓ/min was adequate. In the latter two cases the humidity of the air used for regeneration was about 11 and 14 mg/ℓ, respectively; hence it appears that the humidity used for regeneration is not critical. It was also found that much less regeneration air was needed if the canister was heated, e.g., to 100°C.

Regeneration tests were also done using a M11 canister. The data are shown in Figure 13 and the desorbing conditions are given in Table 5. In contrast to the results obtained with the unimpregnated carbon in the Scott-Acme type 184-OV canisters, there was a slight drop off in radon adsorption efficiency with repeated tests. The reason for this is not known, but may be related to the presence of ASC impregnated carbon in the M11 canister. On one of the tests listed in Table 5, the canister was merely stored for 18 days, 4.7 radon half-lives, without passage of air through the canister. Decay of radon was sufficient to regenerate the canister.

PROTECTION AFFORDED BY CANISTERS IN MINES

This work has shown that activated carbon canisters will remove radon efficiently even at room temperatures. However, the radon removed is concentrated in the canister carried near the wearer's body, which could cause an external radiation hazard. For example, if a canister were used for one hour at a breathing rate of 16 ℓ/min and a radon concentration of 50,000 pCi/ℓ, and essentially all radon was removed, about 50 μCi of radon would accumulate in the canister, plus the daughter products removed by the particulate filter.

If we assume that the average loading over the one hour period is 25 μCi of radon in equilibrium with its daughters, and that the radiation from the counter is equivalent to that from a point source at the canister half thickness, 3 cm, it may be calculated[12] that the radiation intensity at the canister surface would average about 25 mr/hr over the one hour period. Hence it may be desirable to position the canister away from the body, or replace it when its radiation level is judged excessive. It appears that the external radiation problem, if significant, may be handled by simple precautions.

All of the radon adsorption test results herein were obtained at about 20 to 25°C, under various humidity conditions. It is difficult to estimate accurately the useful life of a canister at mine conditions, where the temperature would be considerably lower than 20° or 25°C, but where air relative humidities might approach 100%. Also, the life of the canister would depend on the initial water content of the canister, the type of carbon used in the canister and the breathing rate of the wearer. Nevertheless, let us assume that the mine temperature is 10°C and make the pessimistic assumption that the relative humidity is 100%, corresponding to about 9 mg/ℓ humidity at 10°C. Figure 12 shows that a Scott-Acme 184-OV canister, with a water content 2 to 3 grams, which corresponds to equilibration at 9 mg/ℓ, would adsorb about 95% of the input radon if used for an hour at 25°C and a breathing minute volume of 16 ℓ/min. At 10°C, the canister would adsorb more water than at 25°C. If a dry canister were used for an hour at 16 ℓ/min, 9 mg/ℓ humidity, the maximum water adsorption possible would be (16) (60) (9)/1000 = 8.6 grams. Referring to Figure 12, it seems that this water content would not greatly affect the fraction of radon adsorbed, and, in view of the temperature effect found, Figure 8, it seems virtually certain that the protection afforded by canisters at mine conditions would be higher than that provided at 25°C.

CONCLUSIONS

Results of this work show that it is feasible to provide protection against radon by use of gas mask canisters containing activated carbon. The protection provided is independent of radon concentration, increases with decreasing temperature, and decreases with increasing flow rate and humidity or canister water content.

Initially dry M11 canisters which contain about 270 ml of ASC impregnated carbon and a high efficiency particulate filter, provide almost complete protection against radon at room temperature for about 5 to 15 minutes at a flow rate of 16 ℓ/min, depending on test humidity. The larger Scott-Acme canisters, which contain 900 ml of carbon but no high efficiency filter, provide considerably higher protection against radon. Scott-Acme type 184-OV canisters, when filled with unimpregnated dry carbon having a surface area of 1300 m^2/g, were found to remove about 99% of influent radon for a one-hour period at a flow rate of 16 ℓ/min, a humidity of 9 mg/ℓ and a temperature of 25°C. Protection would be expected to be higher at the lower temperature existing in uranium mines.

The use of activated carbon to provide radon protection appears to offer an advantage of at least a factor of 10 over self-contained supplied air respirators, with respect to the weight of the equipment. Another advantage is that the canisters may be regenerated by simply passing air through them overnight. Gas mask canisters containing both activated carbon and a high efficiency filter are recommended for protection against radon and daughters in uranium mines.

ACKNOWLEDGMENT

The author expresses his appreciation to Robert Sladowski, student trainee from Pratt Institute, Brooklyn, N. Y., who carried out most of the tests of the Scott-Acme canister.

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TABLE 1

EFFECT OF RADON CONCENTRATION ON LIFE OF M11 CANISTERS*

Radon Concentration (pCi/ℓ)	Temperature (°C)	Humidity (mg/ℓ)	Canister Life (min) Transmission			
			2%	10%	30%	50%
1,640	24	0.2	13	17	22	27
37,250	23	0.2	13	18	23	27
1,650	23	5.0	9	13	17	22
39,100	23	5.3	10	13	17	21
1,590	23	18.0	4	7	10	12
37,050	23	17.0	5	8	11	13

*Flow rate was 16 ℓ/min.

TABLE 2

EFFECT OF FLOW RATE

Canister Type	Moisture Conditions	Relative life to 10% transmission		
		8 ℓ/min / 16 ℓ/min	16 ℓ/min / 32 ℓ/min	32 ℓ/min / 64 ℓ/min
Scott-Acme	"Zero" water content (Fig. 5)	-	2.3	2.5
Scott-Acme	Medium water content (Fig. 6)	-	2.9	2.5
Scott-Acme	High water content (Fig. 7)	-	2.7	2.5
M11	Fresh dry canister, tested at 0.2 mg/ℓ humidity (Figs. 2 and 3)	2.3	-	-
M11	Fresh dry canister, tested at 9.4 mg/ℓ humidity (Figs. 2 and 3)	2.2	-	-

TABLE 3

EFFECT OF TEMPERATURE ON EFFICIENCY OF SCOTT-ACME CANISTERS

Test No.	Temp. (°C)	Flow Rate (ℓ/min)	Water Content (grams)	Fraction Radon Adsorbed		Radon Adsorption (pCi)
				Observed	Corrected*	
74	20	16	25.6	0.928	0.911	9.62×10^6
79	21	16	25.9	0.897	0.882	8.47×10^6
77	25	16	27.7	0.835	0.833	8.00×10^6
73	19	32	23.0	0.653	0.618	13.05×10^6
80	21	32	29.5	0.555	0.566	11.95×10^6
76	25	32	29.8	0.508	0.521	11.00×10^6
75	20	64	28.8	0.412	0.414	17.49×10^6
81	20	64	33.8	0.354	0.365	15.42×10^6
78	26	64	27.2	0.323	0.321	13.56×10^6

Time of test, 60 minutes.

Radon concentration, about 11,000 pCi/ℓ.

Test humidity, about 10 mg/ℓ.

*All results corrected to a water content of 28 grams per canister.

TABLE 4

COMPARISON OF SCOTT-ACME TYPE 184 CANISTERS

Canister Type	Lot	Water Content (grams)	Test Humidity (mg/ℓ)	Life to 2% Transmission (min)	Fraction Radon Adsorbed	
					1 hour	2 hours
184-OV	1381	0	9	50	0.99	0.86
184-OV	1381	4	9	53	0.99	0.86
184-OV	1711	0	1	38	0.97	-
184-OV	1711	0	1	37	0.97	-
184-OV	1711	3	9	35	0.96	-
184-OV	1711	3	9	32	0.95	-
184-OVWC	1478	0	9	36	0.96	0.73
184-OVWC	1478	9	9	37	0.96	0.70

Flow rate 16 ℓ/min, temperature 25 ± 1°C in all tests.

Radon concentration 38,000 pCi/ℓ for tests of 184-OV (Lot 1381) and 184-OVWC canisters and 11,000 pCi/ℓ for tests of 184-OV (Lot 1711) canisters.

TABLE 5

DESORBING CONDITIONS FOR REPEATED RADON TESTS ON A M11 CANISTER

Before Test No.	Canister Treatment
1	None (fresh canister)
2,5	5 hrs at 1.5 mg/ℓ humidity, 20 ℓ/min
3,4,6,8,9,11	16 hrs at 1.5 mg/ℓ humidity, 20 ℓ/min
7,10	16 hrs at <0.1 mg/ℓ humidity, 20 ℓ/min
12	No regeneration, stored 18 days
13,14	16 hrs at 4.5 mg/ℓ humidity, 20 ℓ/min

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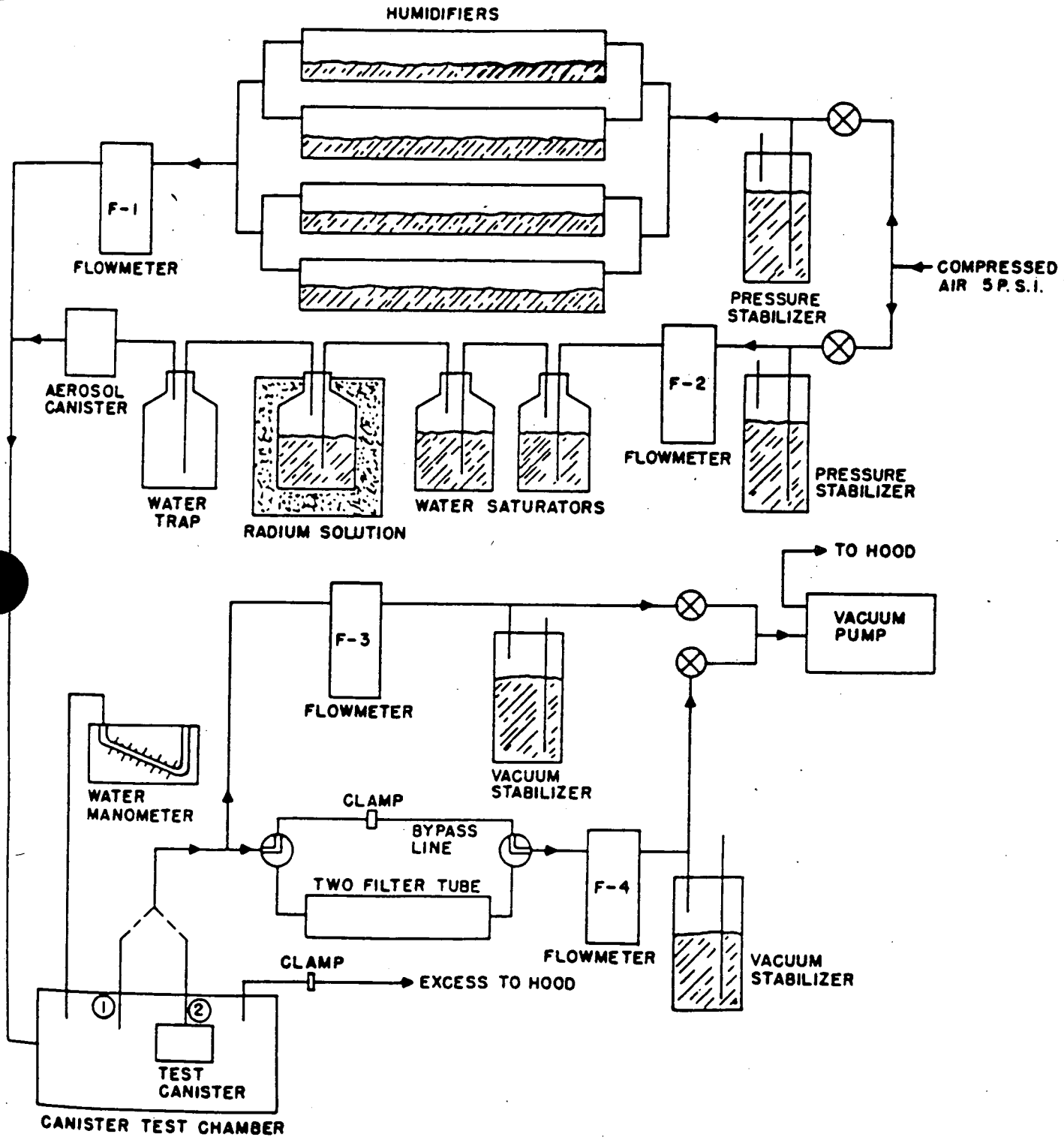

Figure 1. Radon canister test apparatus.

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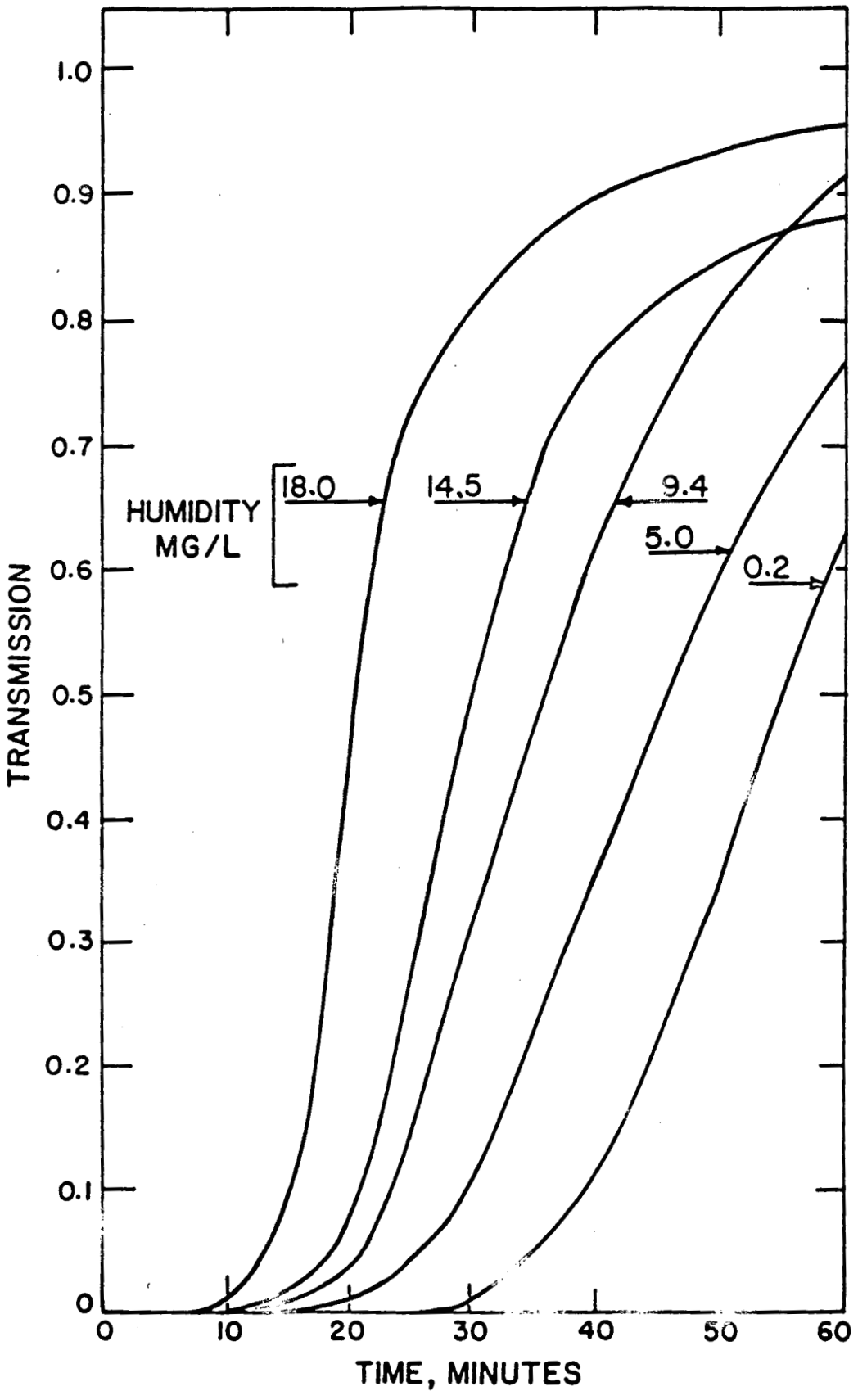

Figure 2. Test of initially dry M11 canisters at 1600 pCi/ℓ radon. Flow rate 8 ℓ/min, temperature 22°C, various test humidities.

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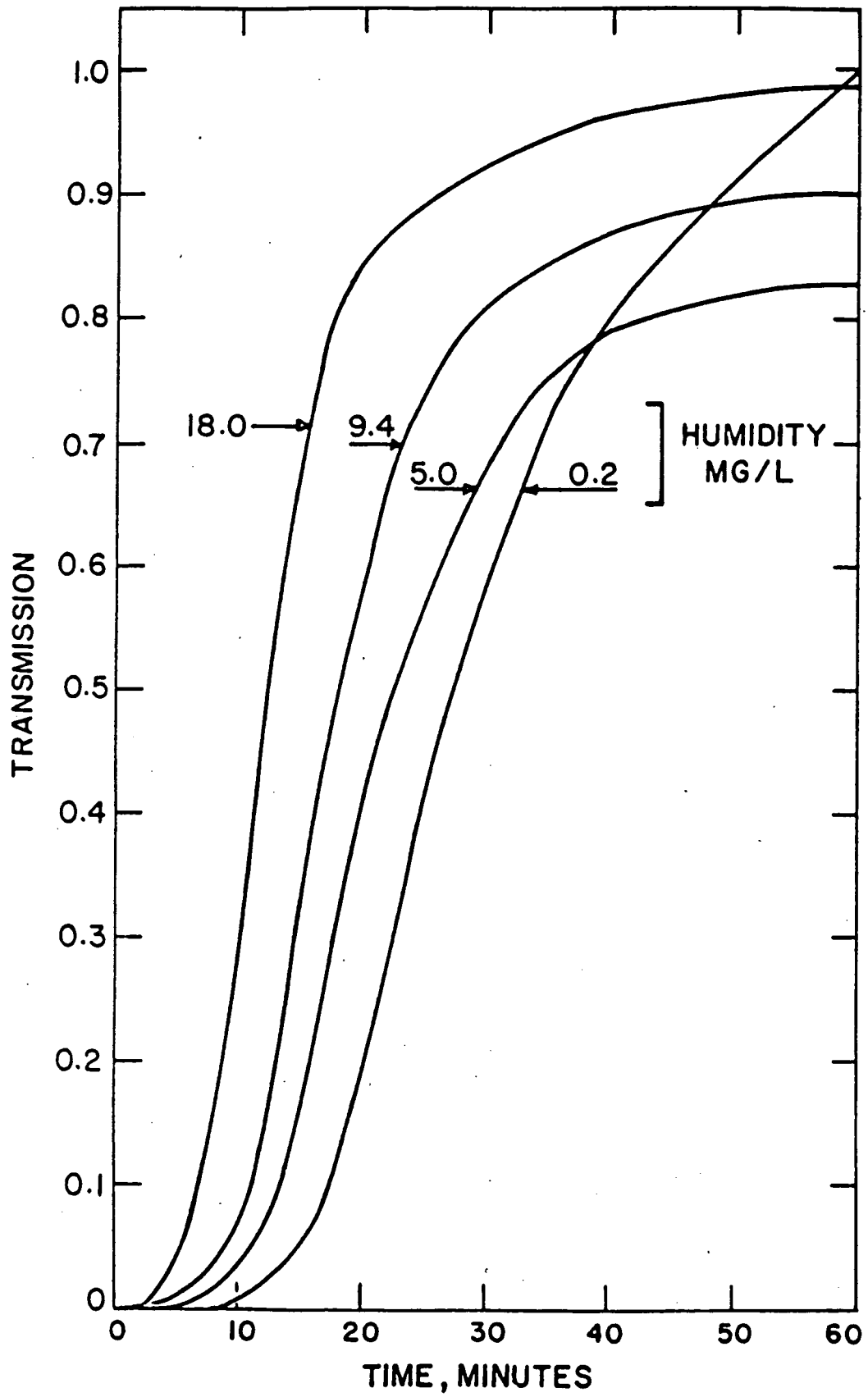

Figure 3. Tests of initially dry M11 canisters at 1600 pCi/ℓ radon. Flow rate 16 ℓ/min, temperature 22°C, various test humidities.

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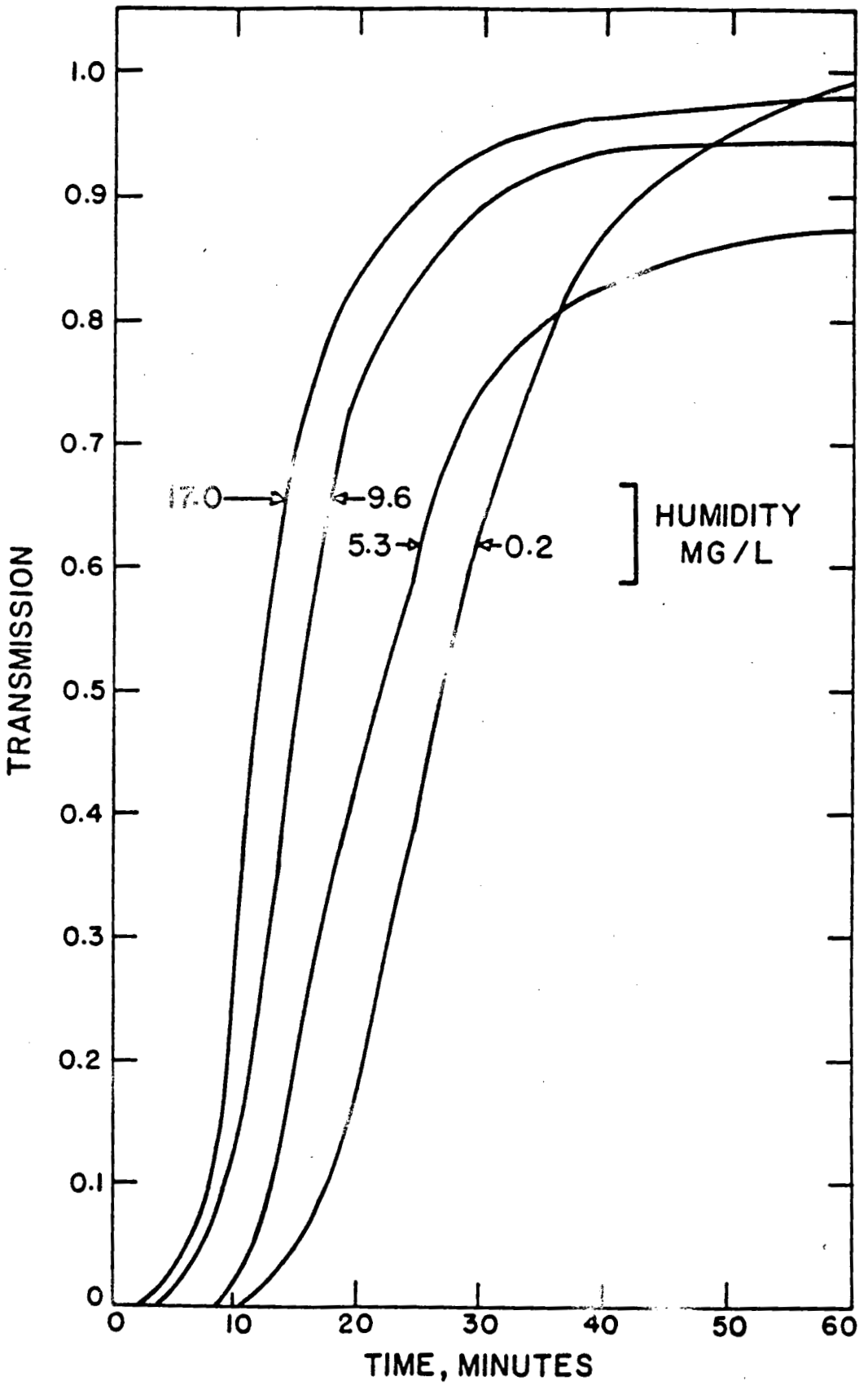

Figure 4. Test of initially dry M11 canisters at 38,000 pCi/ℓ radon. Flow rate 16 ℓ/min, temperature 22°C, various test humidities.

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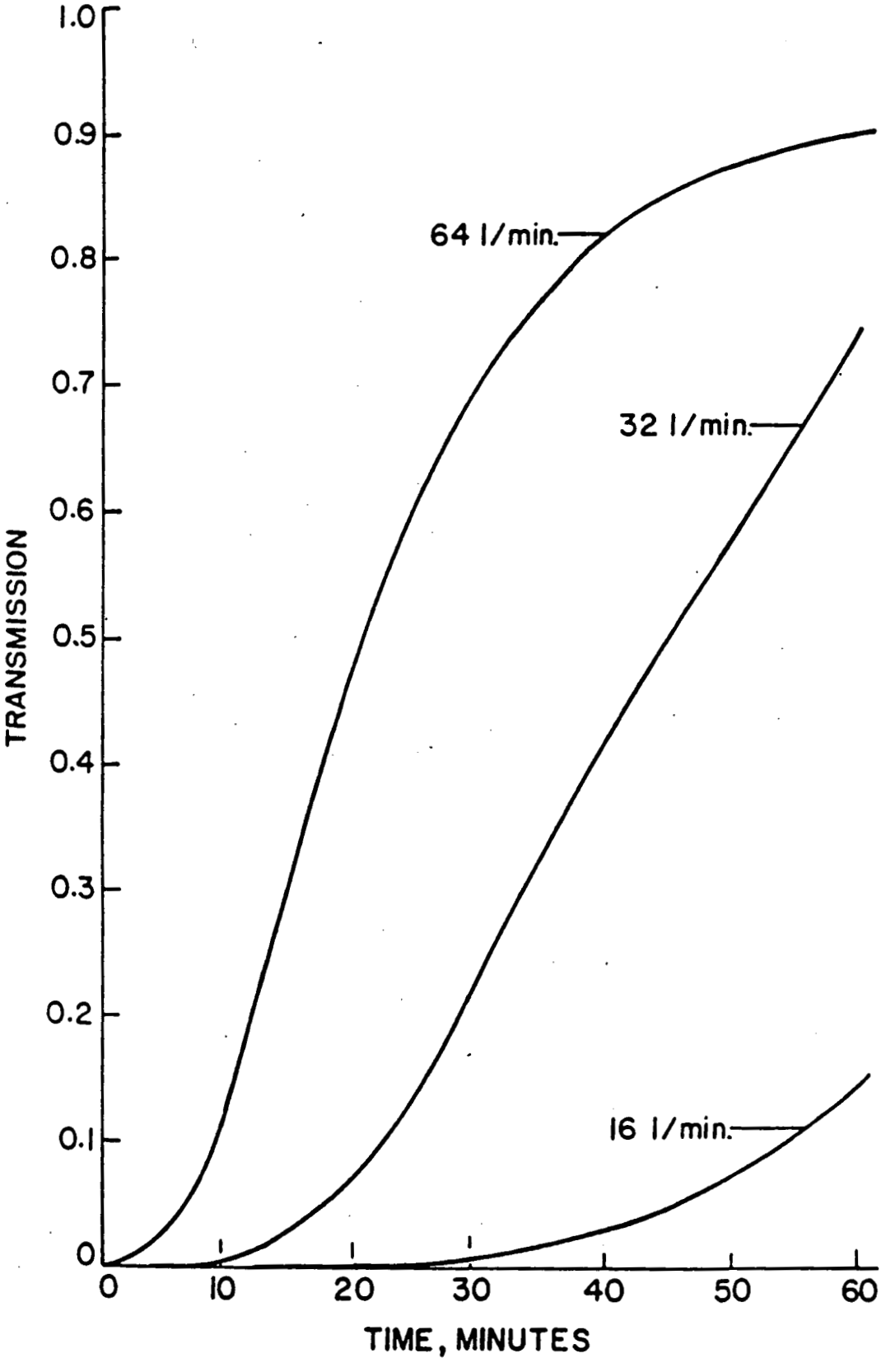

Figure 5. Test of a Scott-Acme 184-OV (lot 1711) canister at 11,000 pCi/ℓ radon. Equilibrated and tested at about 1.4 mg/ℓ humidity, temperature 25°C.

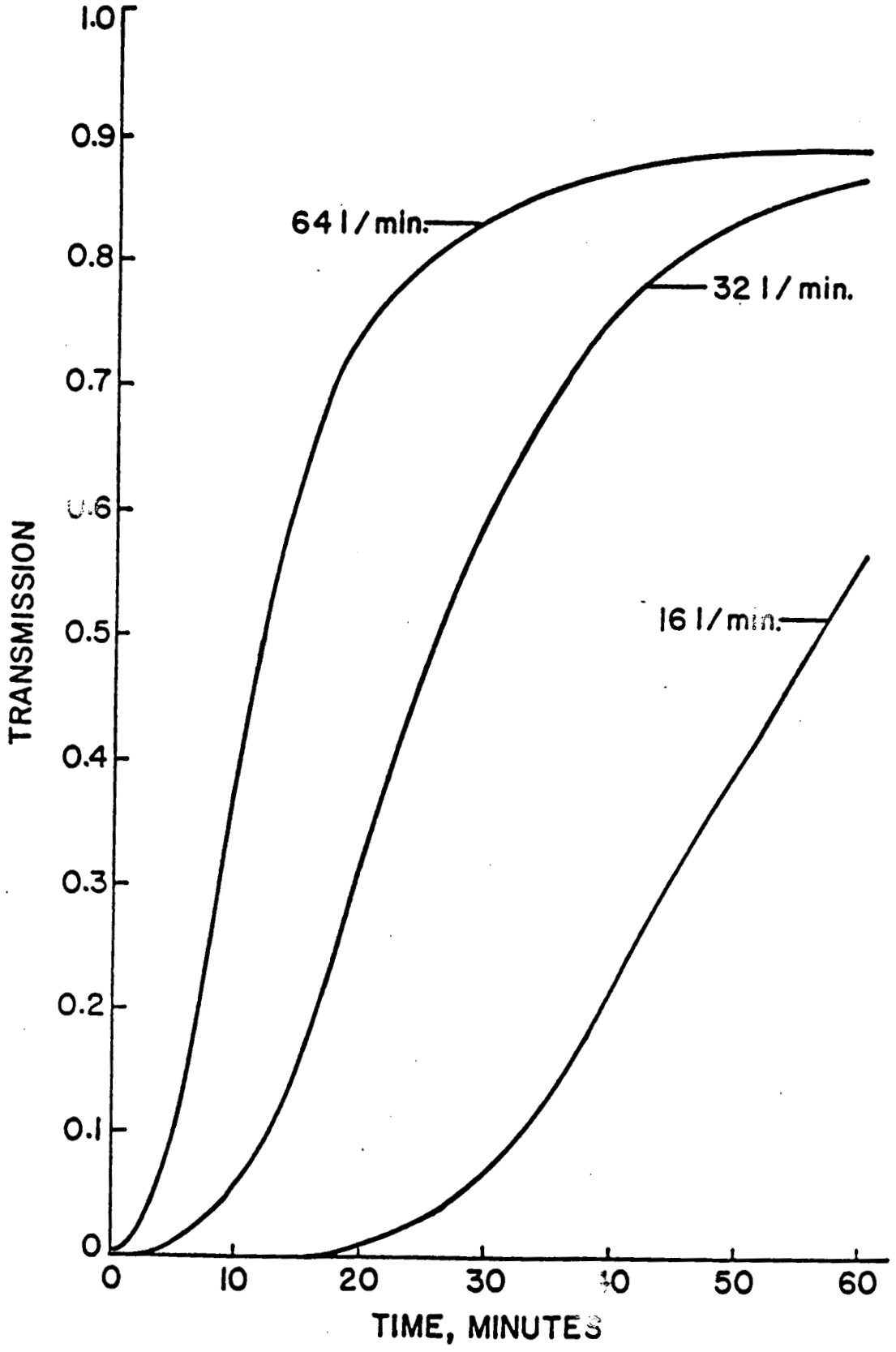

Figure 6. Tests of a Scott-Acme 184-OV (lot 1711) canister at 11,000 pCi/ℓ radon, intermediate water content (about 28 grams). Equilibrated and tested at about 11 mg/ℓ humidity, temperature 25°C.

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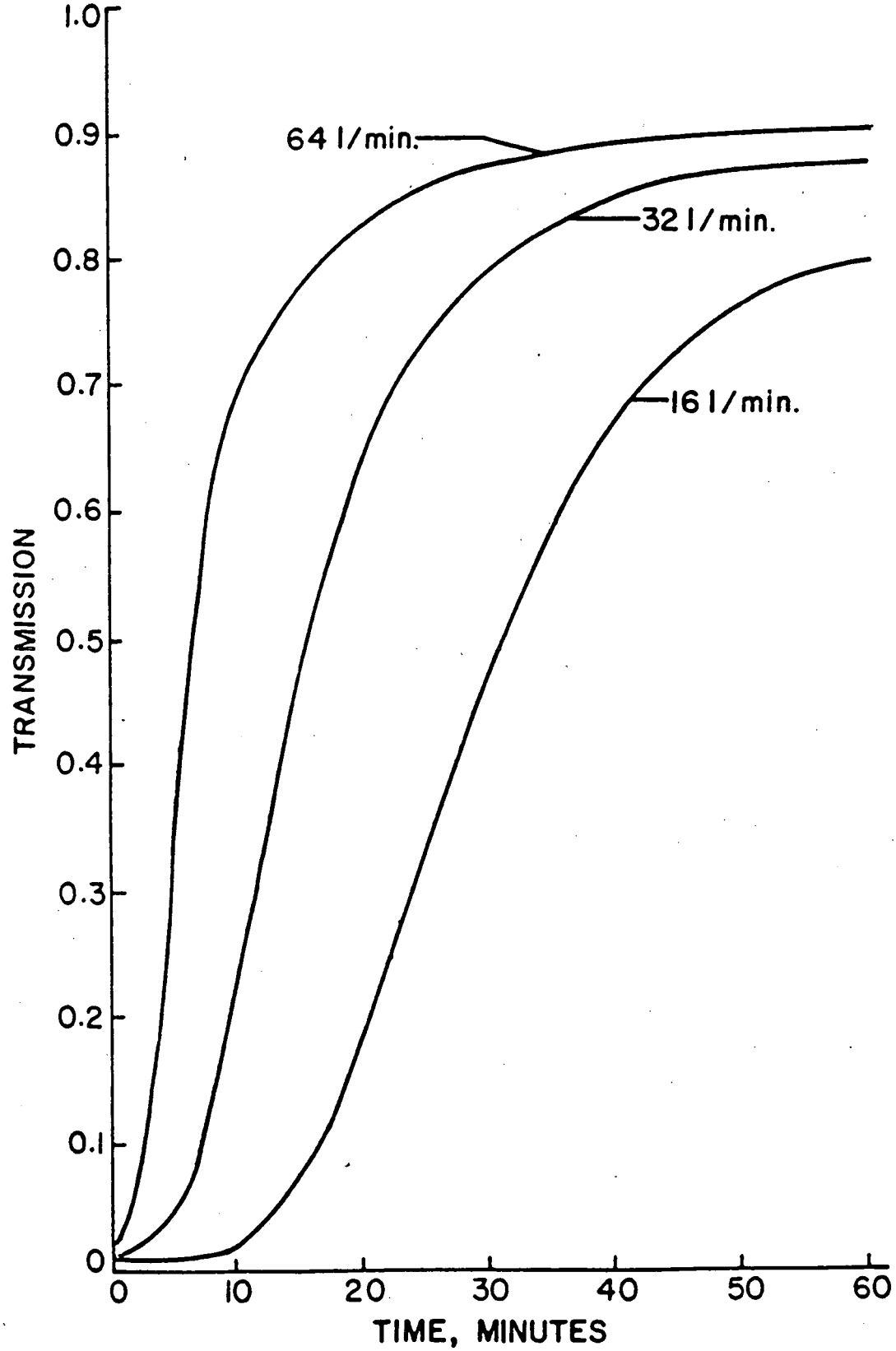

Figure 7. Tests of a Scott-Acme 184-OV (lot 1711) canister at 11,000 pCi/ℓ radon, high water content (about 57 grams). Equilibrated and tested at about 14 mg/ℓ humidity, temperature 25°C.

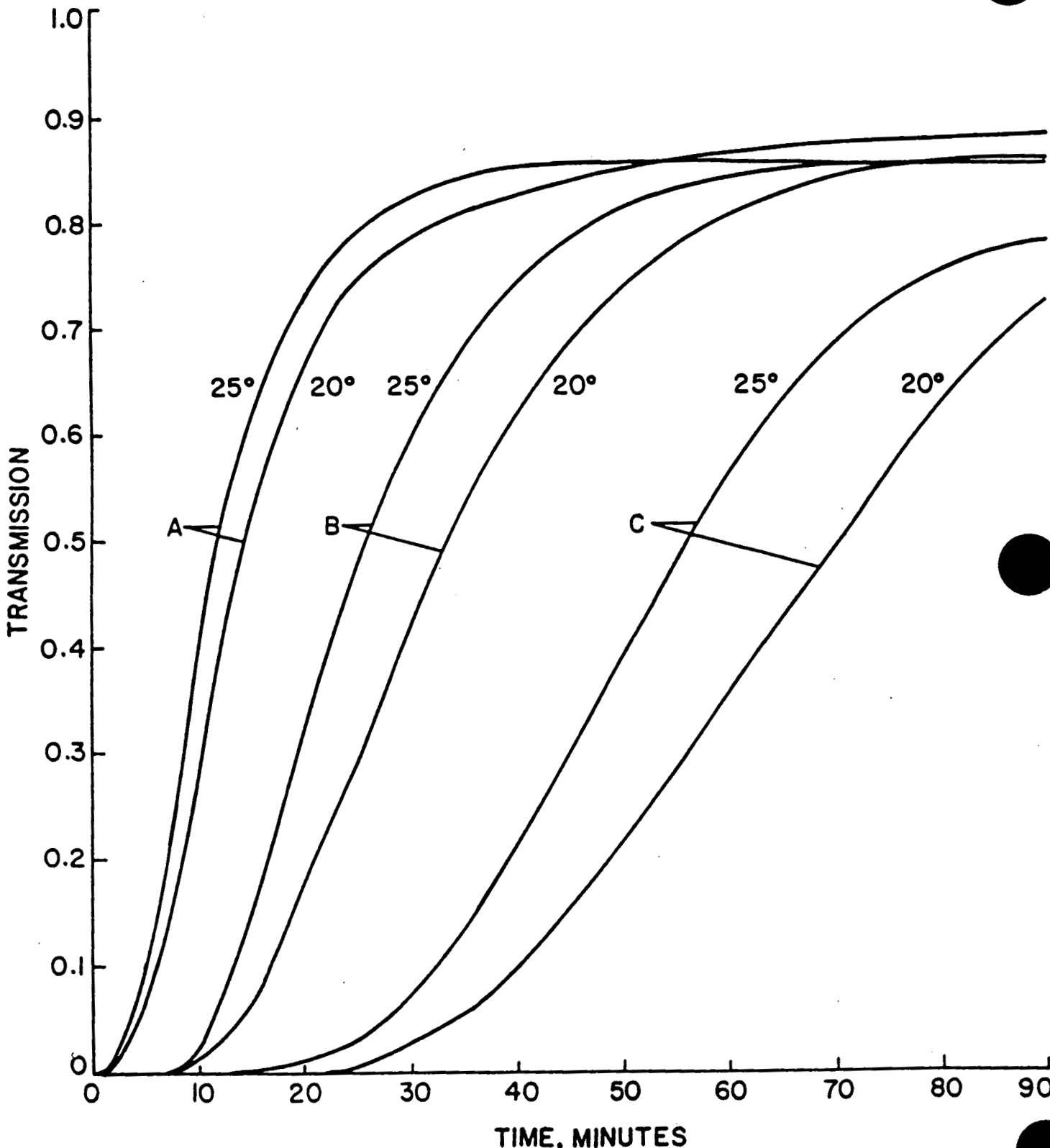

Figure 8. Tests of a Scott-Acme 184-OV (lot 1711) canister at 11,000 pCi/ℓ radon, at temperatures of 20°C and 25°C. Equilibrated and tested at about 11 mg/ℓ humidity, water content about 28 grams. Flow rates 64 ℓ/min (A); 32 ℓ/min (B); and 16 ℓ/min (C).

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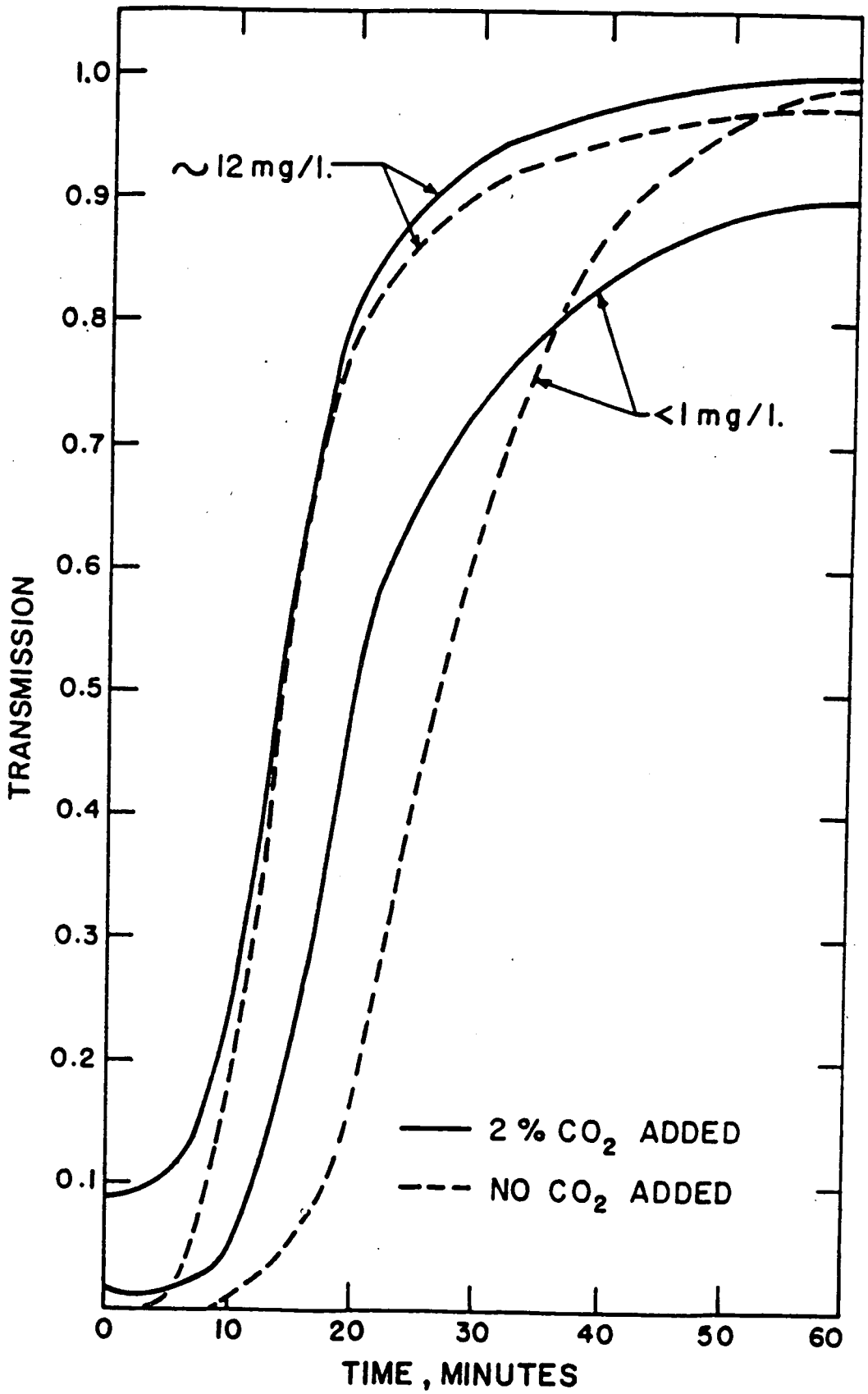

Figure 9. Effect of CO_2 on radon transmission by initially dry M11 canisters, at 38,000 pCi/ℓ radon, two test humidities. Flow rate 16 ℓ/min, temperature 22°C.

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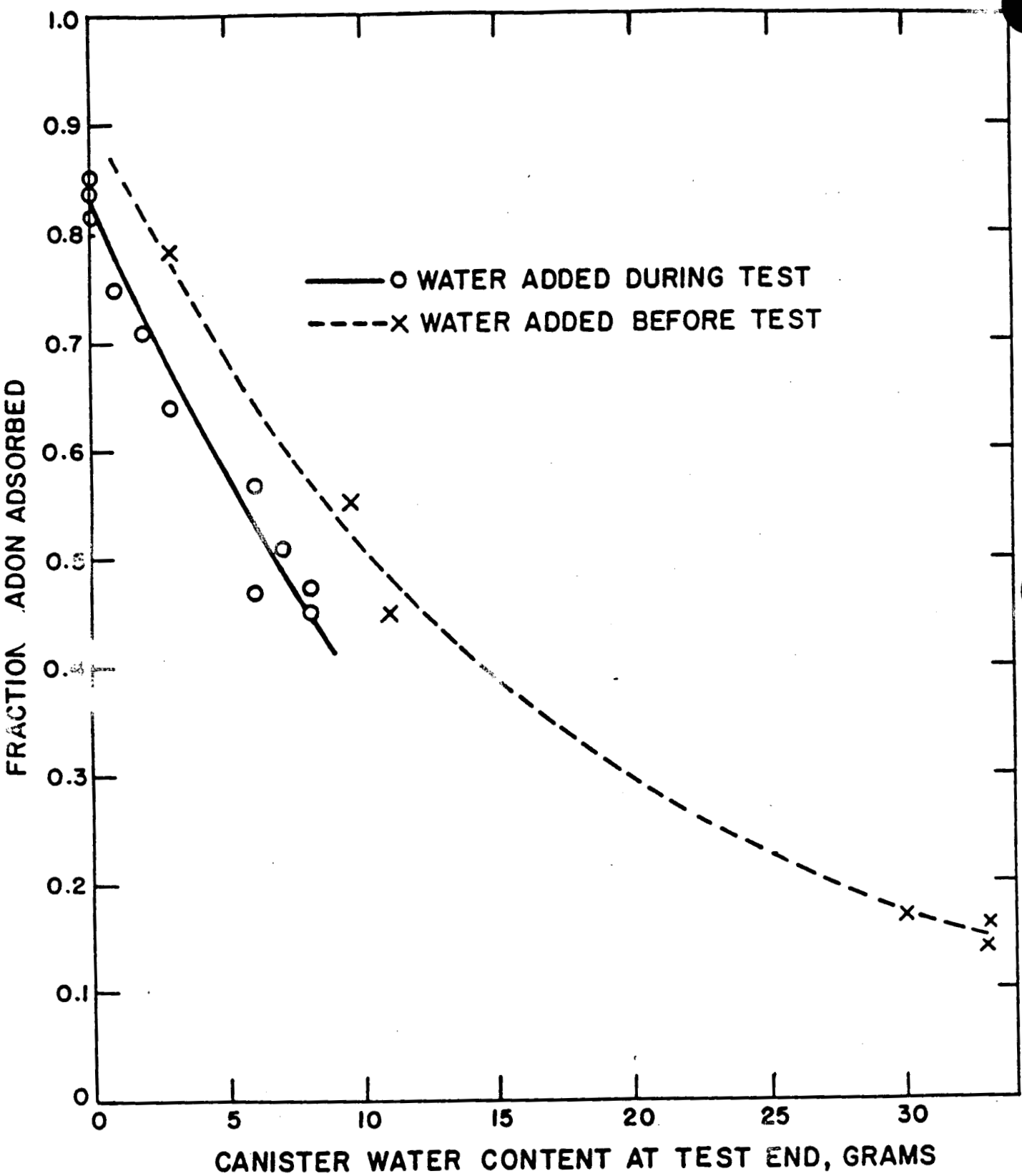

Figure 10. Effect of carbon water content on fraction of input radon absorbed by M11 canisters. 30 minute test time, flow rate 16 ℓ/min, radon concentration 38,000 pCi/ℓ.

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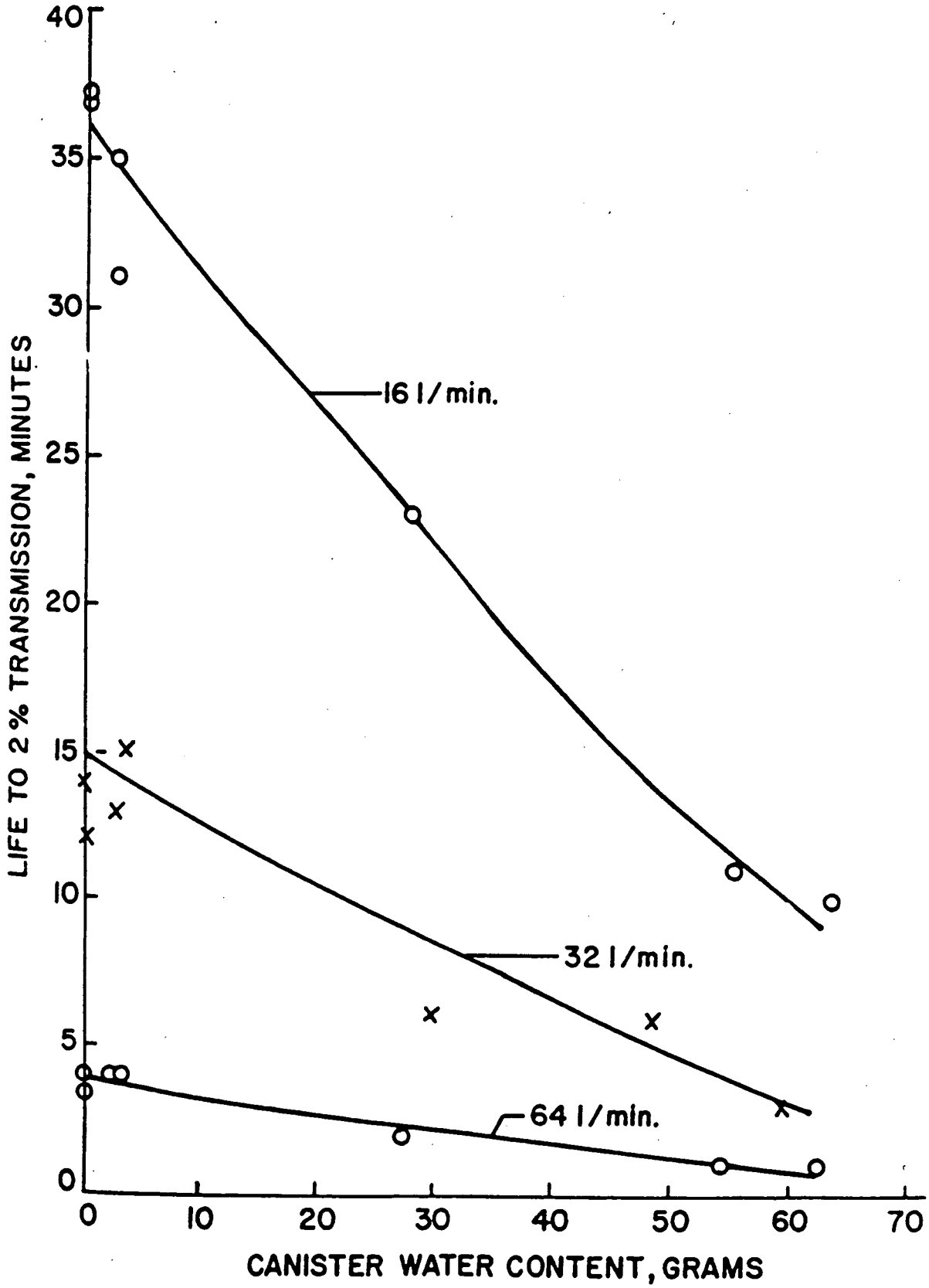

Figure 11. Effect of water content on transmission curves of Scott-Acme 184-OV (lot 1711) canisters. Radon concentration 11,000 pCi/ℓ, temperature 25°C.

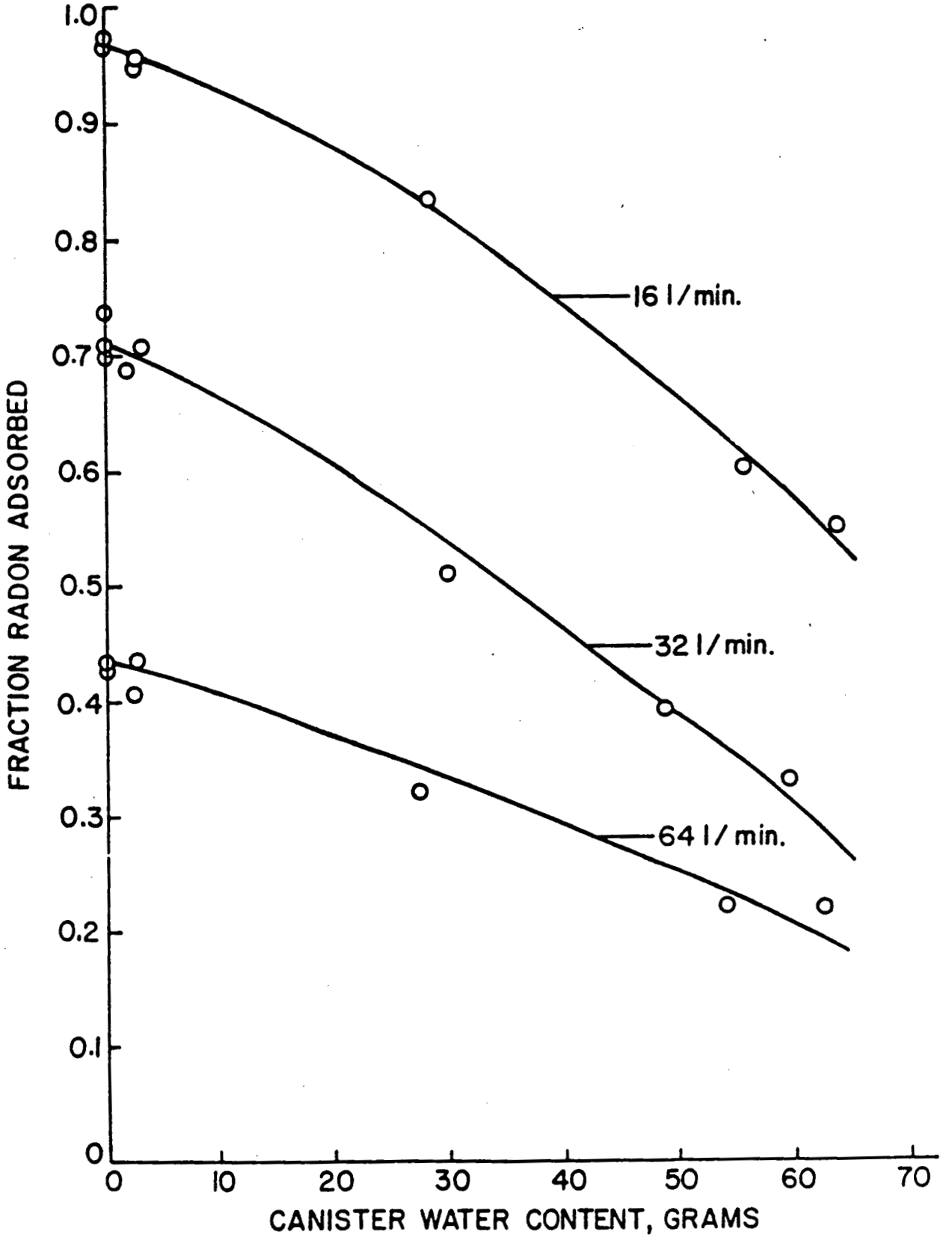

Figure 12. Fraction of input radon adsorbed in a 60 minute test time for Scott-Acme (lot 1711) canisters. Radon concentration 11,000 pCi/ℓ, temperature 25°C.

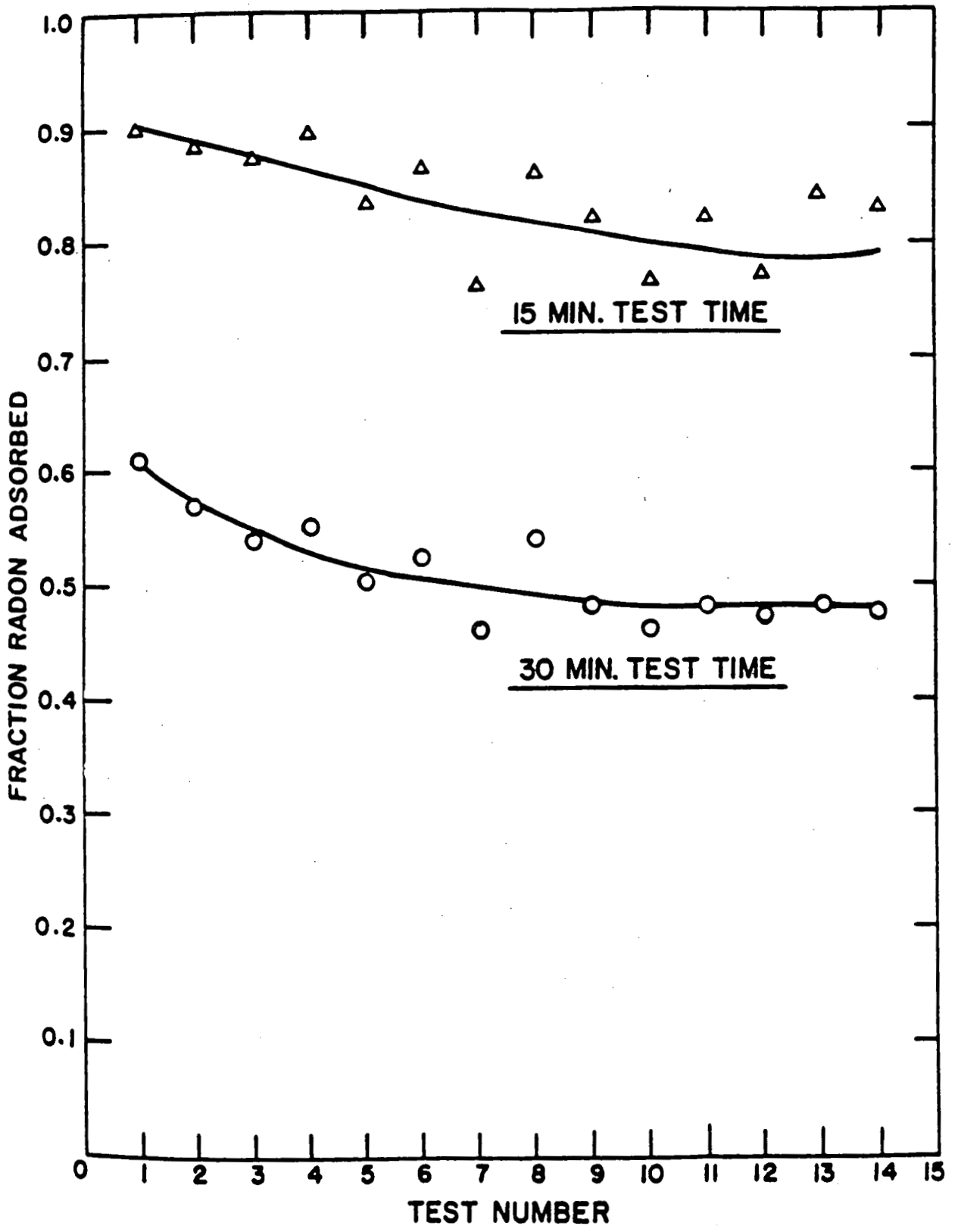

Figure 13. Repeated radon tests on a M11 canister; fraction of radon adsorbed in 15 and 30 minute test times. Flow rate 16 ℓ/min, humidity 9 mg/ℓ, radon concentration 38,000 pCi/ℓ, temperature 23°C.

PENDIX - Reference Material on Foam Selection

FOAM ENTERPRISES, INC.

13630 Watertower Circle
Minneapolis, MN 55441
(612) 559-3266
(800) 328-3342

The following are excerpts from a question and answer session between Dennis Holbert, a Nigeria, Africa customer, and their consulting engineer.

This meeting took place in May 1977, which eventually resulted in the foaming of 13 barges in Nigeria that fall.

The meeting was opened by agreeing that foaming of the African company barges is necessary and time is of the essence.

They said that ultimately 13 80 x 30 barges will be completely foamed and 41 of the balance of 47 would only have the rake sections foamed pursuant to an engineering survey conducted by them. They noted that it may be necessary later to consider completely foaming the entire fleet. They said that for the present, the African company will purchase material for 13 barges together with the necessary equipment.

Mr. Holbert noted that rakes frequently are the most leaky section of a barge but 30 year old barges probably are full of pinholes and the bottom is probably so porous that daylight could be seen through the entire bottom.

In response to questions, Mr. Holbert gave the following answers with the consultant's reactions noted.

Q. Will foam stand up to tropical conditions?

A. I have no personal knowledge of Nigerian conditions, but the foam stands up to Gulf Coast weather. Only acids are known to break down the foam.

Consultant: It is likely that in sealed holds the foam will endure the Nigerian conditions for years. Constant exposure to heat and humidity will slowly deteriorate the surface. However, the closed cell foam structure inhibits any penetration and I think the danger is small to a properly formulated isocyanate polyurethane foam. However, the foam will nourish tropical molds if there is exposure and the material is not inhibited.

Q. Will foam be applied in layers?

A. Yes. Two inch holes will be drilled in the deck at about 6' intervals to inject the foam. Three pours are anticipated. After the last pour, someone will stand on a board over the hole to retain the foam in the hold. About 3 to 4 hours per layer is the practice. No voids are anticipated. Listing will not be a problem and may be a help.

Consultant: This follows the practice I suggested in our early discussions of foaming.

Q. What about exothermic heat?

A. This is controlled by the formulation of the foam and by the pouring in layers. A temperature of 130F will probably be the highest attained during reaction. The hazard of creating heat generated voids by excess exotherm is known.

Consultant: This is the present state of the art and is entirely a matter of the formulation which Mr. Holbert did not disclose.

Q. What is the time for the foam to rise after being mixed and poured?

A. The cream time is 3 minutes.

Q. What about fire resistance?

A. The foam will have the fire retardance of MIL-SPEC-P-21929B (ASTM D-1692). This is accomplished by incorporating 3½ percent of Fyrol-6. While the foam will not be ignited by tossed match, it can be ignited by a cutting torch. The foam will pass the "hot nut" (simulating welding sparks) test.

Consultant: It should be recognized that polyurethane foam will burn if ignited by a sufficient ignition source. However, the circumstances of normal use do not present much hazard. When a barge is to be welded or cut, special precautions should be taken to avoid burning the foam. The fumes from combustion are quite toxic and we have had more than enough sad history with the Nigerian crew. A casual approach can lead to tragedy. Mr. Holbert promised to furnish a safety manual as well as an operating manual. I would like to review the manuals.

Q. What prefoam cleanup procedure do you recommend?

A. The barge should be free of ponding water and loose material. Do not scrape the rust!

Consultant: Wherever the surface is damp or wet, the foam will be substandard. If there is steady influx of water the hole should be plugged unless the foam, by itself, will plug the hole. A new barge should be prepared so that the foam will adhere to the steel and protect it from future rusting from the inside besides strengthening the structure. The 30 year old barges will suffer more harm than derive good from rust removal. However, pinholes will be plugged by the foaming process and it should not be surprising to see it exudate from the orifices. The foam will find all openings.

Q. What about the use of Freon 12 in the foaming process?

A. About 4% of Freon 12 is used in the formula. This is a blowing agent. The Freon is introduced through the mixing valve and compressed nitrogen is necessary to push it into the system. Operator skill is required to make sure that an appropriate amount of Freon 12 is metered in.

Consultant: Note that compressed nitrogen must be available at the foaming site

Consultant (continued) The Freon 12 boils at -21.6 F. and will cause the bubbles to form during the creaming. Special care will be necessary in handling this material. A skilled technician is required for the taking of samples, weighing them, and calculating the density to regulate the Freon content.

Q. What are the requirements for compressed air for this process?

A. 150 CFM at 80 psig.

Consultant: This will require a sturdy air compressor with adequate capacity. A spare is indicated for this essential part of the system.

Q. What is the procedure for uncompartmented barges as in those barges where the superstructure is unreliable.

A. Transcript not readable at this point.

Q. How do you measure the amount of material per fill?

A. By eyeball and a watch.

Consultant: More operator skill is involved.

Q. There are five connections on your mixing valve. One is for solvent. What are we talking about?

A. Cellusolve solvent (Methyl ethyl ketone or xylol will also work). This is to clean the mixer gun when operations are temporarily halted, otherwise the mixer will plug. This will stop operations.

Consultant: This is another material that must be provided in Nigeria. Can Mr. Holbert mean Cellosolve, a well known paint and lacquer thinner? We, however, talked about a petroleum fraction.

Q. How much labor is involved?

A. We would supply a skilled technician foamer; unskilled help will be expected to be available locally. Our proposal will cover this point.

Consultant: There is a considerable amount of material handling involved. 100 drums of foam chemicals must be opened and used per barge. The proposed rate of 150 lbs. per minute means that about 20 drums per hour will be handled, opened, emptied, and disposed of. The logistics should be carefully examined to be sure that the planned procedure is feasible. Personnel protection must be carefully provided for. The used drums should be carefully and properly disposed of. In the hands of an unsophisticate there is a real serious hazard.

Q. What about strengthening the barge by foaming?

A. Although the compressive strength of the foam is about 20 psi, no assurance can be given of strengthening.

Consultant: This is true except in the case of a new barge where the foam adheres strongly to the metal. In this case substantial strength occurs.

Q. Why should not all new barges be foamed?

A. They should be, but the initial cost is a deterrent.

Consultant: It takes a while for a technology advance to take hold. This advance has about 10 years to go before it becomes commonplace. This is an African company opportunity.

I will not comment on the discussion of material costs, machine costs, shipping except to say that Mr. Holbert seems to be quite competitive based on my discussions with two other foamers of barges.

In general, I have the distinct impression that Mr. Holbert has real world experience, has met and overcome most of the problems that have arisen in the U.S., and has a can-do spirit.

FOAM ENTERPRISES

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TECHNICAL DATA SHEET FOR FE 7053

1703 Crosspoint
Houston, Texas 77054
(713) 796-9743

FE 7053 is a polyurethane elastomer system formulated for spray application. FE 7053 is designed for below ground application as a secondary container barrier for fuel spills. This barrier is intended as a temporary containment after a fuel spill.

The ground area is first sprayed with the FE 502 foam system at a thickness of 1/2 to 3/4 inch. The FE 7053 is then applied over the FE 502 at a 1/8 to 3/16 inch thckness.

APPLICATION:

EQUIPMENT: Graco (Viscount II) variable ratio Hydra-Cat and Foam-Cat heater with a 35:1 Senator (954-517) resin pump and a #2 Cylinder (207-862) isocyanate pump. A Binks 43P spray gun modified with a dynamic shear mixer before the 0.029 spray tip is recommended.

Pumping pressures of 1700-2500 psi with a preheat and hose temperature range or 115-125°F. are recommended. A calibrated weight ratio of 100 B component to 56 A component is required.

PHYSICAL PROPERTIES

PROPERTY	TEST	RESULTS
Density, pcf	Immersion	40 - 50
Tensile, psi	ASTM D-412	200 - 400
Elongation, %	ASTM D-412	100 - 210
Tear Strength, PLI	ASTM D-1004	65 - 85
MVT, Perm	ASTM E-398	0.75 - 0.95
Hardness	Shore A	48 - 60
Scaling Resistance, 80 Cyles	ASTM C-672-76	"O", No Scaling
Abrasion Resistance	ASTM D-4060 (1)	
Wear Index		0.20 - 0.26
Weight Loss		0.20 - 0.26
Wear Cycles/Mil (2)		135 - 145

Strips of FE 7053 were immersed in water and thirty weight oil (separately) for six months. The strips were evaluated as follows:

PROPERTY	TEST	RESULTS
Tensile, psi	ASTM D-412	200 - 400
Elongation, %	ASTM D-412	100 - 210
Weight Change, %	FETP #16	
Water		+15 to +30
Oil		+7 to +9

(1) Utilized an H-18 abrasion wheel, 100 gm. weight and 1000 rpm.

(2) Number of cycles of abrasion required to wear a film through to the substrate per mil (0.001 inches) or film thickness.

GENERAL INFORMATION

The recommended application and handling procedures for the specific product being used should be known and followed by the foam applicator. A small "test area" of spray foam should be applied and inspected prior to commencing the project. This simple, low-cost test area can indicate inadequate adhesion, improper surface preparation and/or primer, surface contamination, improper substrate and/or ambient temperature, equipment malfunctions, material contamination or improper application technique. A simple visual inspection of a sample cut from a test and periodic job samples can reveal potential problems that may be due to one or more of the above conditions.

CAUTION

The use of foamed plastic in interior applications on walls or ceilings may present an unreasonable fire hazard unless the foam is protected by an approved, fire-resistive thermal barrier which has a finish-rating of not less than 15 minutes.

The information herein is to assist customers in determining whether our products are suitable for their applications. Our products are intended for sale to industrial and commercial customers. We request that customers inspect and test our products before use and satisfy themselves as to contents and suitability. We warrant that our products will meet our written specifications. Nothing herein shall constitute any warranty express or implied, including any warranty of mercantability or fitness, nor is protection from any law or patent to be inferred. All patent rights are reserved. The exclusive remedy for all proven claims is replacement of our materials and in no event shall we be liable for special, incidental or consequential damages.

FOAM ENTERPRISES, INC
13630 WATERTOWER CIRCLE
MINNEAPOLIS, MN 55441
(612) 559-3266 (800) 328-334

twin city testing
and engineering laboratory, inc.
662 CROMWELL AVENUE
ST PAUL MN 55114
PHONE 612/646-3801

REPORT OF: TESTS OF POLYURETHANE FOAM

PROJECT: MATERIAL, EQUIPMENT AND PROCEDURE EVALUATION

DATE: June 3, 1977

REPORTED TO: Foam Enterprises, Inc.
13630 Watertower Circle
Plymouth, Minnesota 55441
Attn: Mr Dennis Holbert
President

FURNISHED BY:

COPIES TO:

LABORATORY No. 7-7280

INTRODUCTION:

This report presents the results of a series of tests conducted on Class I polyurethane foam, nominal density (open mold) 2.0 pounds per cubic foot The tests were performed at the request of Mr. Dennis Holbert, President, Foam Enterprises, to satisfy his contract with Marinette Marine Corp, Marinette, Wisconsin, to provide foam in place flotation as per Navsea Drawing 191-5014996 (MMC Drawing 1240-001-191). This material is to meet the requirements of Mil-P-21929B, Class I. Mil-P-29129B is the Military Specification, Plastic Material, Cellular Plyurethane, Foam-In-Place, Rigid, 2 and 4 Pounds Per Cubic Foot, dated 11, August, 1969.

SUMMARY OF TEST RESULTS:

Property	Class I Requirement	Tested Value
Density	2.0 ± 0.5 pcf	2.28 pcf
Compressive Strength (@ 10% deformation)	20 psi min.	26.2 psi
Humidity Aging		
Volume change, % of original	±10	+5.07%
Compressive Strength change, % of original, max.	20	Less than 1%
Compressive Set. % max.	3.5	2.0%
Water Absorption, lb./ft^2 of cut surface area, max.	0.12	0.07 lb./ft^2
Resistance	no softening or visible change	No evidence of softening or visible degradation
Fire Resistance	non-burning and no flaming droplets	All specimens either self-extinguished or did not ignite, therefore, material is non-burning. There was [illegible]

000223

MIXTURE AND DISPENSING OF CHEMICALS:

The chemicals used to produce the foam meet the F.E.- MG2A and MG2B specifications. F.E. -MG2A covers the isocyanate and MG2B covers the resin. During the foam production, the chemicals were used in a 1:1 ratio (by volume).

Equipment used for foaming was the F.E.- GV60 air powered pumping system, which is of Empro design and manufacture. It is equipped with two equally sized proportioning fluid pistons powered by a reciprocating air motor. At the dispensing head, the materials are manifolded into a static mixer which introduces air for dynamic mixing, and blowing agents for the frothing and cooling of the reacting chemicals.

During the foaming of the material in the laboratory, temperature control of the MG2A and MG2B was maintained, as well as the method of introducing them into the proportioning pumps. The compressed air pressure was controlled to the pump and the mixing head. The correct amounts of blowing agents, which are necessary to quality and density, were controlled by the operator.

The basic chemicals, equipment and procedures, when applied together by foam technicians under the guidance of Dennis Holbert, resulted in the foam meeting the requirements of MIL-P-21929B for Class I material.

INTIAL TEST PREPARATION:

Two test molds were fabricated for preparation of two free-rise samples of the polyurethane foam. The molds measured 13" x 13" x 25" inside dimensions, and were fabricated from ½" aluminum plate, with bolted connections on all corners and edges for ease of removal of the sample block from the mold. After two unsuccessful attempts to attain the correct density in the sample blocks, the blocks were foamed at 60°F and 80°F, which were the temperature extremes expected to be encountered on the job site.

The two aluminum molds were pre-conditioned for a minimum of 4 hours on March 7, 1977 before the sample blocks were foamed. Then both the 60°F and the 80°F sample blocks were foamed and held for a minimum of 48 hours before the samples blocks were removed from the molds.

twin city testing
and engineering laboratories, inc.
ST PAUL, MN 55114

REPORT OF: TESTS OF POLYURETHANE FOAM

DATE: June 3, 1977

LABORATORY No. 7-7280

INITIAL TEST PREPARATION:

The post-cured densities of the two blocks were:

60°F sample - 2.65 pcf.

80°F sample - 2.28 pcf.

At this time, it was decided between Foam Enterprises & Marinette Marine Corp. to test only the 80°F block, since the 60°F sample was our of spec for density.

TESTS:

Color and Odor -

The sample block did conform to color and odor requirements.

Density -

After removal from the mold, the 80°F sample block was trimmed of surface skin to a block size of 11.75" x 11.75" x 22.75". The weight of this block was determined to be 4.154 lb., giving a density of 2.28 pounds per cubic foot.

Homogeneity of Cured Foam -

The sample block was sliced into twelve 1" thick (nominal) layers. The remainder of the block was set aside for future use, if necessary. A visual examination of both faces of each of the twelve layers comprising the test specimen revealed that the cured foam was free of non-foamed, or soft and tacky particles. The foam was composed of smal

cells of approximately the same size. Blow holes were encountered during the visual examination, but none were larger than ¼" and not more than one occurred in any projecte area of 6" x 6". Also, no more than 3 blow holes were present in any 3 adjacent 1" thic layers.

Compressive Strength -

Three 4" x 4" specimens were tested in accordance with procedure A of ASTM D-1621. The tests specimens were selected from layers 3, 9 and 12.

Specimen Number	Area, in.^{2}	Density, pcf.	Load at 10% Deformation, lb.	Compressive Strength, psi.
3	16.32	2.24	450	27.6
9	16.36	2.37	415	25.4
12	16.44	2.19	420	25.5
			Average -	26.2 psi

Humidity Aging -

Six specimens measuring 4" x 4" were subjected to humidity aging, three of which were tested afterwards for change in compressive strength.

Volume Change

Specimen Number	Original Volume, in.^{3}	Volume Change After 1 day	Volume Change After 7 days
3-1	16.52	+4.54%	+5.57%
6-1	16.61	+4.52%	+4.52%
9-1	18.00	+2.22%	+5.11%
		Average -	+5.07%

No reversion was detected during the 7-day conditioning period at 140°F and 100% R.H.

Compressive Strength Change

Specimen Number	Area, in.^{2}	Density, pcf.	Load at 10% Deformation, lb.	Compressive Strength, psi.
3-1	16.81	2.23	455	27.1
6-1	16.81	2.21	430	25.6
9-1	17.22	2.27	435	25.3

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REPORT OF: TESTS OF POLYURETHANE FOAM

DATE: June 3, 1977

LABORATORY No. 7-7280

Compression Set -

Three specimens measuring 2.250" diameter were subjected to a static load of 5 psi at 158°F for 24 hours. After a 30 minute recovery period, the thicknesses were remeasured.

Specimen Number	Original Thickness, in.	Final Thickness, in.	Compression Set, %
1	1.250	1.230	1.6
2	1.150	1.120	2.6
3	1.150	1.130	1.7
		Average -	2.0%

Water Absorption -

Water absorption was determined in accordance with ASTM D-2127 except specimens were immersed in distilled water at 4.35 psi for 48 hours.

Specimen Number	Cut Surface Area, ft^2	Original Weight, g.	Final Weight, g.	Water absoprtion lb/ft^2 of cut surface area
3	0.33	9.55	17.87	.056
6	0.34	10.60	20.82	.067
9	0.30	9.60	21.42	.076
			Average -	0.066 lb/ft^2

Oil Resistance -

Four specimens measuring 1.129" x 1" thick (nominal) were immersed for 70 hours in ASTM #2 reference oil at 70°F and 50% R.H. Four control specimens were held at 70°F and 50% R.H. for comparison after the test. After 70 hours, the specimens were removed from the oil, the excess oil was blotted away, and the specimens were examined. No evidence of softening or visible degradation was detected.

Fire Resistance -

Fire resistance of the foam was tested both before and after aging at 140°F and 100 R.H. for seven days. Specimen size was ½" x 2" x 6". Procedures outlined in ASTM D-1692 were followed for the test. Applied flame time for all specimens was 60 seconds

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PHONE 612-646-2884

REPORT OF: TESTS OF POLYURETHANE FOAM

DATE: June 3, 1977

LABORATORY No. 7-7280

PAGE: 6

Specimen Number	Burn Time, sec.	Burn Length, in.	Burn Rate, in/sec.	Remarks
Before conditioning:				
1	130	4.0	.03	Self-extinguished
2	81	1.5	.02	Self-extinguished
3	60	0.5	.01	Did not ignite
4	60	0.5	.01	Did not ignite
5	60	0.5	.01	Did not ignite
After conditioning:				
1	72	1.5	.02	Self-extinguished
2	60	1.0	.02	Did not ignite
3	65	2.0	.03	Self-extinguished
4	70	2.3	.03	Self-extinguished
5	80	2.3	.03	Self-extinguished

All specimens either self-extinguished or did not ignite during the fire resistance test. Therefore, the material is non-burning. Also, we observed no evidence of flaming droplets during the test.

REMARKS:

We hereby certify that this polyurethane foam when produced under the above conditions, meet the specified requirements of Mil-P-21929B for Class I material.

TWIN CITY TESTING AND ENGINEERING
LABORATORY, INC.

Ward A Blandin, M.E.

FOAM ENTERPRISES, INC.

13630 Watertower Circle
Minneapolis, MN 55441
(612) 559-3266
(800) 328-3342

MG2-B

RIGID URETHANE BARGE FOAM

INDUSTRIAL FLOTATION

DESCRIPTION:

MG-2.0-B is formulated for use in industrial (barge) flotation applications with large "froth/pour" equipment.

The foam exhibits below normal exothermic heat generation during the "froth/pour" (using R-12) operation and has excellent flowing characteristics.

PROCESSING CHEMICAL PROPERTIES:

	Test Temp. °F.	ASTM Meth.	Test Unit	"A" Component	"B" Componen
Viscosity	77°F.	D-1638	cps	250-350	900-100
Specific Gravity	77°F.	D-1638	gr/cc	1.24	1.21
Ratio (Parts by Weight)				50	50
Cream Time (no R-12)	77°F.			25-30 seconds	
Rise Time				2 minutes, 50 seco	
Tack Free Time				3 minutes, 15 seco	
Density (no R-12)	77°F.		lbs/ft^2	2.0 ± 0.1	

FOAM PHYSICAL PROPERTIES:

Nominal Density	77°F.	D-1622	lbs/ft^3 (with R-12)	1.8 ± 0.1
k-Factor(BTU/ft^2-hr-°F/inch)		D-177		0.15 aged
Compressive strength	77°F.	D-1621	psi(10% deflection)	24.0
Closed cell percent		D-1940	o/o	92
Water Absorption	74°F.	D-2127	lbs/ft^2	0.1
Dimensional Stability		D-2126	(% volume change)	
4 Weeks	158°F.	at	100% RH	+ 16
3 Weeks	158°F.	at	100% RH	+ 16
2 Weeks	158°F.	at	100% RH	+ 14
1 Week	158°F.	at	100% RH	+ 12
4 weeks	-30°F.			-1.5
24 hours	30°F.		Dry cold	no change

Shelf-life 6 months from manufacturing date

(See reverse side)

*This numerical flame spread rating is not intended to reflect hazards presented by this or any other material under actual fire conditions.

The information herein is to assist customers in determining whether our products are suitable for their applications. Our products are intended for sale to industrial and commercial customers. We request that customers inspect and test our products before use and satisfy themselves as to contents and suitability. We warrant that our products will meet our written specifications. Nothing herein shall constitute any other warranty express or implied, including any warranty of mercantability or fitness, nor is protection from any law or patent to be inferred. All patent rights are reserved. The exclusive remedy for all proven claims is replacement of our materials and in no event shall we abe liable for special, incidental or consequential damages.

SPECIFY: RIGID URETHANE FOAM

Buoyancy
62.0 lbs /sea water
60.4 lbs /fresh water

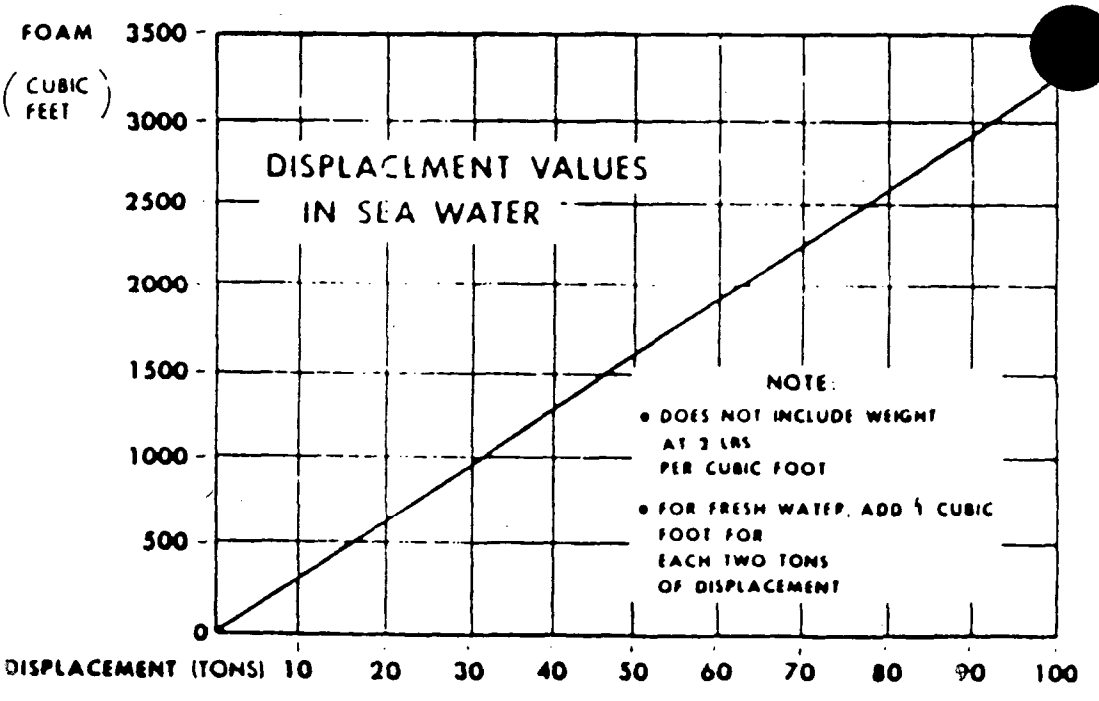
Water Absorption
2% maximum

Reduces Impact Damage
Force is distributed through out foam mass

Easily Repaired
Easy, quick repairs can be made if damage occurs

No Deterioration, No Corrosion
Not affected by water, brine, vermin or crustaceans

Non toxic
Practically chemically inert



Two liquid components applied into a boyancy chamber expands into a closed-cell, monolithic urethane foam conforming to the chamber configuration and adhering to every surface. It can be applied while the vessel is in the water—no necessity for dry-dock. The foam sets immediately, the vessel can go into immediate service. Formulation Meets Specification MIL-P-219298 Amendment 1.

The urethane material will seal all faulty weld seams, loose rivets and holes of less than 1" diameter. (Patch larger holes. Even small ruptures are sealed and the common problem of taking on water is eliminated for more positive trim control

The urethane foam system is versatile. Its resiliency permits the urethane foam to flex with movements of the vessel without cracking or loosening. Its superior insulating value makes urethane ideal for heat control applications, and it can also serve as an "above water" moisture-proofing agent.

See Reverse Side for General Specifications and Physical Data

5975

FOAM ENTERPRISES RESEARCH, INC.

1703 Crosspoint
Houston, Texas 77054-3707
713-796-9743

July 30, 1987

I.T. Corp.
312 Directors Drive
Knoxville, TN 37922
ATTN: Dr. David Harmer

Dear Dr. Harmer;

In reference to sealing the K-65 silo structure, we recommend the following composite of foamed polymer materials:

1. The first application should be four to eight inches of FE 611-6.0 hydrophobic polyurethane foam system. This foam product processes with minimal interaction with soil bound moisture and would provide a rigid foam base to protect the remainder of the foam applications from moisture contamination.

2. The second application should be six to ten inches of FE FLEX-281WH as a flexible foam seal to insure the seal at the foam/wall interface. This product exhibits a minimal percent elongation of 110% together with a thick integral surface skin.

3. The resultant void would be filled to within one to three feet of the ceiling with a 2.0-2.5 pcf rigid foam system designated FE MG-2B. The typical range of compressive modulus of FE MG-2B is 300-800 psi.

4. The remainder of the void would be "topped off" and filled with the FE FLEX-281WH system.

We also propose that a rigid polyurethane foam insulation topped with an elastomeric coating membrane be applied to the exterior of the concrete dome. This composite would protect the concrete dome from further weatherability regression (ie. freeze - thaw). The exterior insulation would also reduce the movement of the concrete relative to temperature changes. This protective roofing composite would be applied as follows:

1. The concrete surface should be cleaned and primed with an epoxy polyamide sealant.

2. The FE 302-2.5 (or -2.7) rigid polyurethane foam insulation would be spray applied at a thickness of one to two inches.

3. F ra Flex 500 e tomeric coating would then be applie t a thickness of 5-40 m ls.

4. The composite would then be topped with the weather resistant Futura Flex 550 coating at a thickness of 10-15 mils.

Sincerely,

David C. Dressel
Technical Director

DCD:lkg

cc: D. Holbert
C. White
J. Andersen

5975

FOAM ENTERPRISES

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Minneapolis, MN 55441
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(713) 796-9743

CHEMICAL SYSTEM UPC 281

DESCRIPTION: INTEGRAL SKIN FLEXIBLE FOAM

UPC-281 is a MDI based, two component chemical system. This medium low density, open-celled foam has excellent and tough integral skin when cast in metal or plastic molds. It exhibits excellent energy absorption properties over a wide temperature range from 0°F to 150°F. This moderately firm foam is used to package very expensive objects, where flexible cushioning characteristics are needed to dampen shock and resonant frequency encountered in most shipping. It is also recommended for molding arm or head rests for use in furniture, aircraft or automobiles.

CHEMICAL PROPERTIES: (@ 77°F)

Viscosity, CPS	
A-Component: 100	B-Component: 500-600
Specific Gravity	
A-Component: 1.23	B-Component: 1.10
Reactivity Profile	
Cream time, sec.	15-18
Rise time, sec.	30-35
Tack free, sec.	35-40
Mixing Ratio (By Weight) A/B	25/75
Processing Temperature, °F	75-80
Mold Temperature, °F	80-90
Demold Time, min.	10

PHYSICAL PROPERTIES:

Core Density (Free Rise) LB/Ft^3	4
Tensile Strength, PSI	15
Tear Strength, PLI	1.2
Elongation, %	110-120
Resiliency, % ball rebound	60-64
4" ILD, LBS/50 in^2 (based on 4" free rise foam)	
25% Deflection	45 (core)
65% Deflection	98 (core)
Air Flow	3.2

MATERIAL HANDLING PRECAUTIONS:

Component A contains reactive isocyanates: Avoid contact with skin, eyes, or clothing. Wear chemical resistance rubber or plastic gloves. When pouring in confined areas, provide ventilation to maintain vapor concentration below established TLV of 0.02 ppm Toluene Diisocyanate. Avoid breathing vapors. The use of a respirator is impressive in confined areas.

In case of contact with the eyes, flush immediately with copious amounts of clean water for at least fifteen minutes. Get immediate medical attention.

Component B contains polyether polyol, amine catalyst and silicone surfactant. Since its vapor pressure is low, there is no significant hazard to health under usual circumstances of handling or use.

STORAGE INFORMATION:

Component A will react with moisture which liberates heat and carbon dioxide. This could result in rupture of closed container. Component A should be stored between 60°F and 80°F in sealed containers.

Component B should be stored between 60° - 80°F. When opening a container, partially unscrew the cap or vent the bung to relieve any pressure before opening fully. Reseal the container as soon as the required amount of material is removed to prevent unnecessary loss of chemicals.

SHELF LIFE:

Six months in sealed, unopened containers.

The information herein is to assist customers in determining whether our products are suitable for their applications. Our products are intended for sale to industrial and commercial customers. We request that customers inspect and test our products before use and satisfy themselves as to contents and suitability. We warrant that our products will meet our written specifications. Nothing herein shall constitute any other warranty express or implied, including any warranty of mercantability or fitness, nor is protection from any law or patent to be inferred. All patent rights are reserved. The exclusive remedy for all proven claims is replacement of our materials and in no event shall we abe liable for special, incidental or consequential damages.

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FOAM ENTERPRISES RESEARCH, INC.

1703 Crosspoint
Houston, Texas 77054-3707
713-796-9743

TECHNICAL DATA SHEET

FE 611-6.0

The FE 611-6.0 rigid polyurethane foam system exhibits hydrophobic characteristics during and after foaming. This product is designed for in-ground, structural applications.

LIQUID COMPONENT PROPERTIES

PROPERTY	TEST	FE 800	FE 611-6.0
Mix Ratio	By Volume or Weight	1.0	1.0
Specific Gravity	ASTM D-1638	1.23-1.25	1.15-1.20
Viscosity, cps	Brookfield RVF (75°F)	150-220	2700-2900

PROCESSING CHARACTERISTICS

PROPERTY	HAND MIX A & B AT 75°F
Cream Time, Sec.	34 - 44
Gel Time, Sec.	60 - 75
Rise Time, Sec.	75 - 95
Tack Free time, Sec.	75 - 95
Core Density, PCF	5.7 - 6.0

*This numerical flame spread rating is not intended to reflect hazards presented by this or any other material under actual fire conditions.

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FOAM ENTERPRISES, INC.
Corporate Office & Plant: 13630 Watertower Circle, Minneapolis, MN 55441 (612) 559-3266
Research & Plant: 1703 Cross Point, Houston, TX 77054 (713) 797-0405
Telex 910 576 0008 Toll Free (800) 328-3342

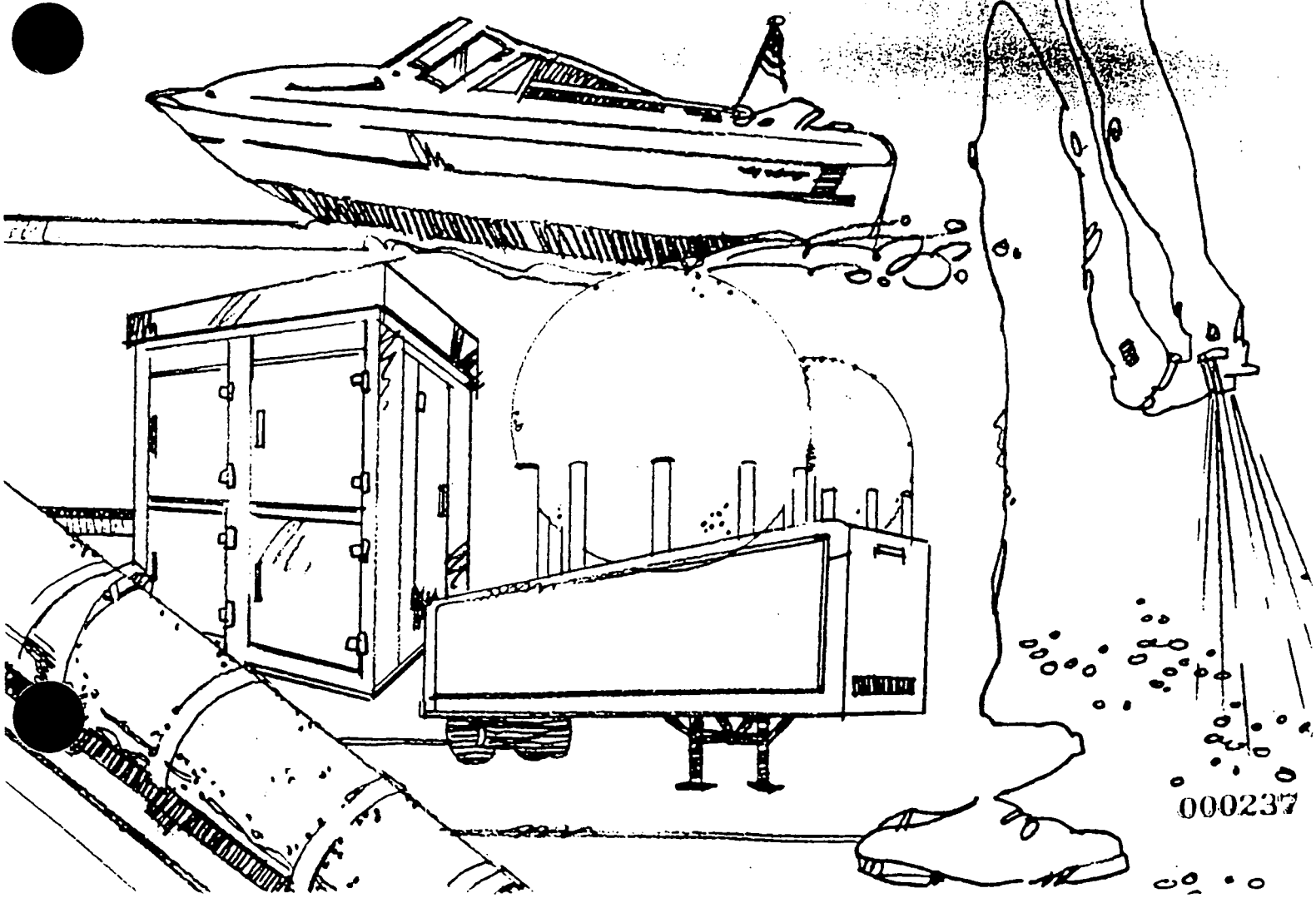
FOAM ENTERPRISES TECHNICAL DATA FE-302-2.5

With increasing awareness stemming from the energy crisis and the soaring costs of fuel and energy bills, energy conservation has become a national priority.

Foam Enterprises manufactures the highest quality U.L. rated and non-rated spray-on urethane roof systems. They offer energy saving insulation and with proper top coatings, stay waterproof for numerous years of service under movement and other variable conditions such as temperature, rain or snow, thermal shock and radiation.

Urethane foam is the most thermally efficient insulating material available. Furthermore, it forms a monolithic, seamless jacket that is totally adhered to 100% of the surface. Sprayed directly in place and protected with an elastomeric coating, Foam Enterprises, Inc. provides an aesthetically pleasing finished appearance that will provide years of service.

From Thermo-insulation panels to roofing systems to Marine floatation. To underground/water pipe insulation, Foam Enterprises, Inc. can do the job.



Foam Enterprises, Inc. 302-2.5 system is a smooth skin polyurethane spray foam designed for thermal insulation of roof and storage tanks. FE302-2.5 is classified by Underwriters Laboratories Inc. per UL723 (ASTM E84)* testing, also UL790 (ASTM-E10 Class A.

FLAMMABILITY CHARACTERISTICS

[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
Smoke Developed	Over 450 @ 2"

*UL 723, ASTM-E84 (This numerical flame spread is not intended to reflect hazards presented by this or any other material under actual fire conditions.)

CHEMICAL PROPERTIES

	A	B
[illegible]	[illegible]	[illegible]
[illegible]	250-60	550-650
[illegible]	[illegible]	[illegible]

RATIO

	A	B
Weight	50	50
Volume	50	50

Reaction times are influenced by equipment efficiency, temperatures of materials "A" & "B", ambient conditions, temperature or substrate and thickness of the foamed mass. The following charts are guidelines, and are intended to be used as such. Temperatures and reaction profiles are estimates and can vary slightly.

REACTION PROFILE

PROPERTY	75°F (HAND MIX)			SPRAYED		
	Normal	Fast	Winter	Normal	Fast	Winter
Cream Time	3-5 Sec.	2-3 Sec.	Less Than 12 Sec.	Approx. 3 Sec.	Approx. 2	Approx. 1
Tack Free Time	12-16 Sec.	10-14 Sec.	7-10 Sec.	8-12 Sec.	3-8 Sec.	3-6 Sec.
Cure Time	2 Hr.	2-3 Hr.	4-6 Hr.	2 Hr.	2-3 Hr.	4 Hr.
Temp. Range	—	—	—	80°-110°	55°-90°	40°-65°

CURED PHYSICAL PROPERTIES

[illegible]	[illegible]	[illegible]
[illegible]	ASTM [illegible]	[illegible]
Overall core density	ASTM D-1622	[illegible]
Tensile, lb/in²	ASTM [illegible]	[illegible]
Tensile, psi	ASTM [illegible]	[illegible]
COMPRESSIVE STRENGTH		
Parallel to rise	ASTM [illegible]	[illegible]
Perpendicular to rise	ASTM [illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
Water absorption	ASTM D-2842	[illegible]
Closed cell content	ASTM D-2856	[illegible]

MVT

MOISTURE	TEST METHOD	WATER VAPOR TRANSMISSION
Vapor transmission	ASTM E-96	[illegible]

DIMENSIONAL STABILITY

ASTM D-2126

Days	°F	% RH	%
7	158°F	100%	[illegible]
28	158°F	100%	+7.8
7	200°F	Dry	−2.3
28	200°F	Dry	−3.4
7	−20°F	Dry	−1.0
28	−20°F	Dry	−1.5

First Aid Considerations:

VAPOR INHALATION problems are characterized by coughing, shortening of breath and tightness in the chest. Anyone exhibiting these type symptoms should be immediately removed from the workplace and administered oxygen or fresh air. If the condition is prolonged or extreme, SUMMON "EMERGENCY TRAINED" MEDICAL ATTENTION IMMEDIATELY.

SKIN CONTACT with liquid components can result in a rash or other irritation. Wash any affected skin area with water. Wipe residual liquid from the skin with a clean cloth then wipe the affected area with a 30% solution of rubbing alcohol. Follow the alcohol wipe with repeated washings with soap and water. If a rash or other irritation developes, SEE A PHYSICIAN.

EYE CONTACT with liquid or sprayed components can result in corneal burns or abrasions. Upon exposure, eyes should be flushed with water for an extensive period. SUMMON "EMERGENCY TRAINED" MEDICAL ATTENTION IMMEDIATELY.

Chemical Exposure

Polyurethane foams should not be exposed to liquids, vapors, or residue of any chemicals or solvents that will soften or degrade the foam or affect it in any other manner. Because of the variety of solvents and the various concentration levels involved, each condition becomes specialized and should be individually considered.

Safety, Health & Toxicity Data

A MATERIAL SAFETY DATA SHEET (MSDS) HAS BEEN PREPARED ON FE302-2.5 ALL PERSONNEL WHO WILL COME IN CONTACT WITH THE PRODUCT SHOULD READ AND UNDERSTAND THE MSDS.

Protective Equipment:
Since the FE302-2.5 is atomized into a very fine, particle distribution during spray application, it is essential that maximum effort is made to protect the spray mechanic and others near the work place from undue exposure. FE800A is a polymeric isocyanate and, as such, can be very sensitizing, particularly from the standpoint of VAPOR INHALATION. Some other ingredients may be sensitizing from the standpoint of SKIN CONTACT OR EYE CONTACT. Proper safety equipment should be worn as called for by the material safety data sheets.

Protection of the Workplace
The overspray from system FE302-2.5 can carry considerable distances and care should be taken to do the following:

1) Post warning signs a minimum, of 100 ft. from the work area.
2) Cover all intake vents near the work area.
3) Set up wind breaks when needed.
4) Minimize or exclude all personnel not directly involved with the spray application.
5) NO WELDING, SMOKING OR OPEN FLAMES.

Shelf Life
Shelf life of FE302-2.5 A and B Components is 6 months from the date of manufacture when stored in original unopened containers at temperatures between 50°F and 74°F

Freight Classification
Liquid Plastic Materials - NOIBN

Drum Disposal
Drums can be re-cycled by your local drum reconditioner. Make sure you empty them completely. If you need to locate one, contact National Barrel & Drum Association, Inc., 1030 Fifteenth Street N.W., Suite 130, Washington, D.C. 20005. Phone number 202-296-8028.

General Requirements and Special Conditions

The successful design, installation, and operation of a sprayed polyurethane foam roof insulation system is heavily dependent upon a wide variety of factors combining technology, experience, and common sense. These interdependent factors must be thoroughly evaluated and considered to eliminate potential problems that can occur in any type of project. Factors to be given specific consideration include foam application, unique and/or local weather conditions, maintenance and periodic inspection, and other special conditions.

Foam Application
The successful application of sprayed polyurethane foam is heavily dependent upon the experience, common sense, and attention to detail exercised by the Contractor's personnel. Experience has shown that the use of certain simple techniques and visual inspections can pinpoint potential problems so that they can be identified and remedied.

The recommended application and handling procedures for the specific product being used should be known and followed by the foam applicator. A small "test area" of sprayfoam should be applied and inspected prior to commencing the project. This simple, low-cost test area can indicate inadequate adhesion, improper surface preparation and/or primer, surface contamination, improper substrate and/or ambient temperature, equipment malfunctions, material contamination, or improper application technique. A simple visual inspection of a sample cut from a test area and periodic job samples can reveal potential problems that maybe due to one or more of the above conditions.

The basic visual and physical indicators of conditions to be corrected are as follows: irregular and/or rough surface texture; irregular and/or large cell structure; excessive pinholes; a thin, low-density and lighter-colored layer of foam at foam interface; a higher-density layer of foam at foam interface; erratic or "streaky" foam color; poor interface adhesion; inadequate adhesion to substrate; foam overspray under a foam layer; and delamination and/or inadequate adhesion of the underlying coating and/or primer. These are indicators and not causes of conditions to be corrected when compared to an acceptable sample of the same foam.

Industry application standards should be followed as explained in U.F.C.A. or S.P.I. guidelines.

Caution
The use of foamed plastic in interior applications on walls or ceilings may present an unreasonable fire hazard unless the foam is protected by an approved, fire-resistant thermal barrier which has a finish-rating of not less than 15 minutes.

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FOAM ENTERPRISES, INC.

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FUTURA COATINGS INC.

TECHNICAL DATA

FUTURA-FLEX 500

Aromatic Urethane

PRODUCT DESCRIPTION

Futura-Flex 500 is a two component, hydrolytically stable aromatic urethane elastomer designed for long term protection of polyurethane foam. The high solids and thixatropic nature of the coating, when properly mixed, permit application of a uniform high build film on either horizontal or vertical surfaces. The cured film has an exceptional combination of high tensile strength and elongation, providing a tough and impact resistant protective membrane. It is available in a one to one mixing ratio (by volume) for premix or plural component spray equipment to insure trouble free, economical applications.

FEATURES

Versatility

The Futura-Flex 500 System is a separate base coat/finish coat system. Supplied in a tan base coat and a gray aromatic topcoat, this system has excellent durability; however, slight chalking and color change will occur. When maximum color and gloss retention, aesthetics, and ease of cleanability are of prime importance, Futura-Flex 550 aliphatic urethane is recommended as a finish coat.

Toughness

The high tensile and elongation of Futura-Flex 500 provide superior resistance to mechanical and hail damage.

Weatherability

The Futura-Flex 500 system has good resistance to ultraviolet radiation, temperature extremes, oxidation and all forms of water.

Fire Retardance

Futura-Flex 500 carries a UL790 Class A approval over numerous polyurethane foams.

High Build/High Solids

The high solids (by volume), thixatropic nature of Futura-Flex 500 enables the applicator to apply a uniform film thickness of 15-25 mils with ease, even on rough or vertical surfaces without pinholing or sagging. Higher solids also allow faster application rates with increased coverage, providing reduced labor and material costs.

Visichrome®

Allows the applicator to recognize instantly when the coating is applied off-ratio. The "A" and "B" components are manufactured in separate colors, that when mixed, produce a distinctive third color. Should a problem occur in the mixing of the coating, this third color will show a definite change towards either the "A" or "B" side color. Visichrome® saves wasted time and materials without added cost.

Chemical Resistance

Futura-Flex 500 has high resistance to many dilute acids, alkalis, salts, and solvents.

Convenient Mixing Ratio

Formulated in a 1:1 mixing ratio, Futura-Flex 500 can be conveniently pre-mixed and sprayed with standard airless or plural component equipment.

TECHNICAL SPECIFICATIONS

Technical Data

Physical and performance proper-

TABLE 1: TYPICAL PROPERTIES (WET)

Property	Specifications	Value	
		Futura-Flex 500 Base	Futura-Flex 500 Finish
Weight (#/gal):	ASTM D 1475		
Component A		9.2 ± 0.5	9.2 ± 0.5
Component B		13.0 ± 0.5	13.5 ± 0.5
Mixing Ratio:	A:B — by Volume	1:1	1:1
Solids (mixed):			
by Weight	ASTM D 1353	86% ± 2	86% ± 2
by Volume	Calculated	72% ± 1	72% ± 1
Flash Point:	Pensky-Martens Closed Cup	80°F (26°C)	80°F (26°C)
Storage Stability	40°F (-10°C) to 100°F (37.8°C)		
Component A		6 months	6 months
Component B		1 year	1 year

TABLE 2: TYPICAL PERFORMANCE PROPERTIES OF CURED MEMBRANE

Physical Properties	Test Method	Results
Tensile	ASTM D 412 (Die C at 20 inches per min)	1600 PSI ± 25
Elongation at 75°F	ASTM D 412 (Die C at 20 inches per min)	450% ± 25
100% Modulus	ASTM D 412	408 PSI ± 25
Tear Resistance	ASTM 624 (Die A at 20 inches per min)	290 PLI ± 25
Permeability	ASTM E 96 Procedure B (@ 20 mils)	0.65 U.S. Perms 0.61 Metric Perms 0.013 Perm inches
Hardness	ASTM D 2240 Shore A	80 ± 5
Accelerated Weathering Q-UV Accelerated Weathering Tester	ASTM G-53-77 Cycling Procedure: 8 hours intense UV @ 160°F 4 hours condensation @ 105°F	There was no checking, cracking, delamination or loss of flexibility after 6,000 hours of testing.
Ultraviolet Resistance Atlas Carbon Arc Weatherometer	ASTM D 822 Continuous UV and water spray cycling	There was no checking, cracking, delamination or loss of flexibility after 6,000 hours of testing. There was a slight change of color and chalking on surface of film.
EMMAQUA UV Radiation	ASTM E 838	Futura-Flex 500 retained an excellent appearance after over 2,000,000 langleys of radiation. There was slight evidence of chalking and color loss with no delamination or loss of flexibility.
Water Absorption	ASTM D 471 3 days @ 75°F (23.8°C)	1.5% max.
Accelerated Heat Aging	ASTM D 573 30 days @ 185°F (85°C)	No significant change in physical properties.
Low Temperature Flexibility	ASTM D 2136 180° bend @ -50°F (-45.5°C)	Passes
High Temperature Resistance	ASTM D 573 Continuous Intermittent	200°F (93°C) 225°F (107°C)
Abrasion Resistance	ASTM C 501 CS-17 wheel 1000 rev. with 1000 gram weight	29 mg ± 2 mg

ties of Futura-Flex 500 may be found in Tables 1 and 2, respectively.

Theoretical Coverage

Futura-Flex 500 Base — 1154 mil sq. ft./gallon

Futura-Flex 500 Finish — 1154 mil sq. ft./gallon

Recommended Thickness

30-40 mils (Total System)

2.6 - 3.5 gallons per square, depending on specification.

Typical Example:

Per 100 square feet of surface

1.73 Gallons No. 500 Base	20 Mils
0.87 Gallon No. 500 Finish	10 Mils
Total	30 Mils

Topcoated with Futura-Flex 550 Finish

1.73 Gallons No. 500 Base	20 Mils
0.96 Gallon No. 550 Finish	10 Mils
Total	30 Mils

(These figures are approximations only. Also see Estimating Allowances.)

Number of Coats

Depending upon the service and dry film thickness specifications, a Futura-Flex 500 system will require a total of 2-3 coats. When using Futura-Flex 550 as the finish, 1 or 2 coats of Futura-Flex 500 base coat and one coat of Futura-Flex 550 is recommended.

Colors

Base Coat: Tan (Standard)

Intermediate Coat (Optional): Tan (Standard), Tinting available

Finish Coat: Gray (Standard) Other colors available in quantity on special order.

Compatibility with Other Elastomers

Obtain specific recommendat[illegible] from Futura's Technical Dep[illegible]ment or Customer Service Representative.

Estimating Allowances

Allow 10-20% additional material for irregularity of surface and con-

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tingency factors when estimating quantities.

PERFORMANCE PROPERTIES

Resistance to Hail and Mechanical Damage

Due to it's high tensile and elongation, Futura-Flex 500 has superior resistance to hail and mechanical damage. An 18 ounce steel ball dropped from a height of 20 feet does not produce surface cracking or rupturing of the coating. (Twenty mils of coating sprayed on 2.5 PCF density polyurethane foam.)

Flexibility

Futura-Flex 500 demonstrates excellent flexibility over a range of extreme temperatures. Even at sub-zero temperatures, Futura-Flex 500 exhibits exceptional flexibility as reflected by passing a 180° bend at minus 50°F.

Ponding Water Resistance and Hydrolytic Stability

Futura-Flex 500 is unaffected by long-term immersion in water. Six months immersion in distilled water at 75°F (23.9°C) indicates negligible changes in physical properties of the membrane.

Cold Temperature Impact Resistance

Futura-Flex 500 has excellent low temperature impact resistance. An 18 ounce steel ball dropped from a height of 15 feet at 0°F (-17.8°C) does not produce cracking or rupturing of the membrane.

ORDERING INFORMATION

Container Size

10 Gallon Kit — 5 Gallon Pails
110 Gallon Kit — 55 Gallon Drums

Approximate Shipping Weight

	Base	Finish
10 Gallon Kit	121 lbs.	125 lbs.
110 Gallon Kit	1331 lbs.	1401 lbs.

Freight Classification

Paint Compound
NOIBN
Flammable Liquid, Red Label required

ADDITIONAL INFORMATION AVAILABLE

Chemical Tests
Specifications
Roofing
Hot Tanks
Cold Tanks
Coolers and Freezers
Current UL Classification Listing
Warranty
Distributor and Sales Office Locations

FUTURA APPLICATION INSTRUCTIONS

METHOD

Futura-Flex 500 is designed for airless or conventional spray equipment. A brush or roller is acceptable for touch up.

EQUIPMENT AND MIXING

A) **Batch Mix Using Standard Airless Equipment**

Pump Ratio — 30:1 or greater
Tip Size — .025 to .035 inch
Fan Angle — 60° - 80°
Hose Diameter — 3/8 inch (High pressure hose)

B) **Plural Component Application Using Static Mixing/Standard Airless Gun**

A plural 1:1 ratio proportioning unit, which develops a minimum spray pressure of 2400-3000 PSI, should be used. The proportioning pump should be fed by 2:1 or greater transfer pumps. Both "A" and "B" components are pumped in individual hoses by the proportioning pump to a three inlet manifold and through an 18 element, 24 inch static mixer with removable/replaceable elements (or equivalent). A standard airless spray gun with a 15 foot whip hose (maximum) should be attached to the exit of the mixer. A high pressure solvent line is attached to the manifold to facilitate flushing the whip and gun when spraying is stopped for more than 15 minutes. The solvent pump should be at least a 10:1 ratio pump.

C) **Totally Plural Component Sprayed**

A plural 1:1 proportioning unit, which can develop 2400-3000 PSI in heated or unheated systems, is used. The proportioning pump should be fed by 2:1 transfer pumps. The material temperature to the gun should not be lower than 75°F or greater than 110°F. The spray gun should be a plural component internal mixing gun designed to spray pigmented coatings with a flat spray pattern and rated at a minimum pressure of 2000-3000 PSI, such as Glas-Craft's "Prober" gun with post-chamber static mixer or Gusmer's "AB-A" gun.

SPRAYING

Futura-Flex 500 is formulated to spray directly without thinning or heating. A spray pressure of 2800-3000 PSI and a 60° to 80° wide angle spray tip .025 to .035 will provide good atomization and a uniformly applied application. Using a 3-6 inch overlap to insure an evenly coated surface, walk the roof, making complete passes of the roof surface.

APPLICATION TEMPERATURES

	Material	Surface
Minimum	45°F	45°F
Maximum	110°F	160°F

POT LIFE TEMPERATURE/TIME

55°F — 2-1/2 - 5 Hours
75°F — 1-1/2 - 2-1/2 Hours
95°F — 3/4 - 1-1/2 Hours
115°F — 1/2 - 3/4 Hours

Do no[illegible] ore material than can be used within the pot life of the material.

NOTE: Dark hoses on dark roof surfaces absorb tremendous quantities of heat. Do not leave mixed material in fluid lines for more than a few minutes when spraying is stopped.

THINNING

Do not thin the "A" or "B" component when using plural component application equipment. For premix applications, thinning is normally not required, however, a change of viscosity is possible in opened containers. For these instances, use up to 10% No. 50 Urethane Thinner when necessary.

INTERCOAT SCHEDULE

The recommended recoat schedule for all Futura urethane coatings is as follows:

FAST SET URETHANES
(1-15 minute cure)
Recoat the same day or within 24 hours.

MODERATE FAST SET URETHANES
(1-3 hour cure)
As soon as cured and within 3 days.

STANDARD CURE
(4-8 hour cure)
As soon as cured and within 5 days.

NOTE: Recoat is based on sunlit days. Clouds or rain would lengthen the recoat schedule proportionally. Coat as soon as weather permits.

CLEAN-UP

Equipment — For best results, [illegible] Thinner No. 50, a mixture of XYLOL and MEK (50/50), or XYLOL.

STORAGE

Store materials in a dry environment or with a minimum temperature of 30-40°F and a maximum temperature of 100°F. The shelf life of component "A" is 1/2 - 1 year in unopened containers which are purged with nitrogen. The shelf life of component "B" is 1 - 2 years in unopened containers. If the component "A" is opened, it should be purged with nitrogen and resealed or filled into smaller containers to their maximum volume in order to eliminate polymerization in the can.

APPLICATION GUIDELINES

1) DO NOT apply over w[illegible] substrates or when inc[illegible]nt weather is imminent.
   DO NOT apply when the temperature is below 45°F or greater than 120°F.
3) CAUTION: Prior to application of Futura-Flex 500, the system should be purged to eliminate all solvent remaining in hoses before applying to roof.
4) DO NOT apply w[illegible]out adequate air exchange a[illegible]ntilation in enclosed areas.

GENERAL SAFETY, TOXICITY AND HEALTH DATA

Material Safety Data Sheets are available on this coating material. Any individual who may come in contact with these products should read and understand the Material Safety Data Sheet.

WARNING: Contact with skin or inhalation of vapors may cause an allergic reaction. Avoid eye contact of the liquid or spray mist.

Eye Protection: Safety glasses, splash goggles, or face shield is recommended.

Skin Protection: Chemical resistant gloves are recomme[illegible] Cover as much of the ex[illegible] skin area as possible with appropriate clothing.

Respiratory Protection: Use a respirator approved for isocyanates and/or organic vapors. Consider the application and environmental concentrations in deciding if add[illegible]nal protective measures are ne[illegible]ssary.

Ingestion: Do not take internally. It is believed ingestion of TDI, MDI, or polymeric isocyanates would not be fatal to humans but may cause in[illegible]ammation of the mouth and stomach tissue. Do not take internally or swallow.

Flammability: This coating contains solvents. Do not use near open flame or spark producing sources. Store away from heat. Use only approved explosion proof equipment.

NOTE: Solvent fumes are heavier than air and may travel along the ground. Eliminate any poss[illegible] ignition source in the gen[illegible] work area.

Have available CO_2 or dry chemical fire extinguishers. DO NOT USE WATER.

For detailed safety instructions, consult the Futura-Flex 500 container labels which are designed according to guidelines established by the National Paint and Coatings Association, or contact Futura's Technical Department.

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REP: Futura-Flex 500 810[illegible]

Our data is based on information from lab[illegible] Coatings, Inc.'s control. We do not ass[illegible] replacement of products [illegible]ests which are believed to be accurate b[illegible] liability or responsibility of the product [illegible] recommendations are made without warranty, since the conditions of use are beyond Futura [illegible]e to coverage, performance, or injury resulting from its use. Liability, if any, is limited to

FUTURA COATINGS INC.

TECHNICAL DATA

FUTURA-FLEX 550

Aliphatic Urethane Finish

PRODUCT DESCRIPTION

Futura-Flex 550 is a two component, fire retardant, aliphatic urethane which exhibits long-term color and gloss retention. It is a premium grade elastomeric coating which is recommended when an aesthetically appealing and an exceptionally durable exterior finish is desired.

Futura-Flex 550 is primarily designed for use over polyurethane foam as a finish coat but may also be used over concrete, masonry, wood and metal substrates where a flexible, high gloss and color retentive coating is required.

FEATURES

Superior Color and Gloss Stability

Due to its aliphatic chemical structure, Futura-Flex 550 provides long-term color stability even after years of exposure to weather and ultraviolet attack. In addition, Futura-Flex 550 has excellent gloss and resists chalking, which provides total film integrity throughout the entire service life.

Super Tough

The high tensile and elongation of Futura-Flex 550 provides superior resistance to mechanical and hail damage.

Weatherability

Futura-Flex 550 has excellent resistance against ultraviolet degradation, extreme temperatures, oxidation and all forms of water.

Fire Retardance

Futura-Flex 550 has UL790 Class A approvals over numerous polyurethane foams.

High Volume Solids

Futura-Flex 550 contains more volume solids than most aliphatic urethane elastomers which allows excellent build and coverage. This results in higher application rates, reduced labor costs, and high film deposition for optimum film integrity.

Chemical Resistance

Futura-Flex 550 has excellent resistance to many dilute acids, alkalis, salts, and solvents.

Convenient Mixing Ratio

Formulated in a one to one (1:1) mixing ratio, Futura-Flex 550 can be conveniently sprayed with plural component equipment.

TECHNICAL SPECIFICATIONS

Theoretical Coverage

1,042 mil sq. ft./gal.

Recommended Thickness

10 dry mils (1 gallon). Typical specification recommendation is a 30 mil combination system of a Futura Urethane Base Coat and Futura-Flex 550.

Practical Coverage

(See Estimating Comments)

1 gallon per square

Compatibility with Other Elastomers

Futura-Flex 550 may be used as a finish coat for almost all of Futura's line of urethane base coatings and butyl rubber. (Obtain specific recommendations

TABLE 1: TYPICAL PROPERTIES (WET)

Property	Specifications	Value
Weight (#/gal):	ASTM D 1475	
Component A		8.5 ± 0.5
Component B		14.0 ± 0.5
Mixing Ratio:	A:B — by Volume	1:1
Solids (mixed):		
by Weight	ASTM D 1353	75% ± 2
by Volume	Calculated	65% ± 1
Flash Point:	Pensky-Martens Closed Cup	85°F
Storage Stability	40°F (-10°C) to 100°F (37.8°C)	
Component A		6 months
Component B		1 year

JUNE 1985

MEMBRANE ROOFING fluid applied roofing

TABLE 2: TYPICAL PERFORMANCE PROPERTIES OF CURED MEMBRANE

Physical Properties	Test Method	Results
Tensile	ASTM D 412 (Die C @ 20 inches per min)	2700 PSI ± 50
Elongation at 75°F	ASTM D 412 (Die C @ 20 inches per min)	275% ± 25
Tear Resistance	ASTM 624 (Die C @ 20 inches per min)	275 PLI ± 25
Permeability	ASTM E 96 Procedure B (@ 20 mils)	0.48 U.S. Perms 0.31 Metric Perms 0.01 Perm Inches
Hardness	ASTM D 2240 Shore A	75 ± 5
Accelerated Weathering Q-UV Accelerated Weathering Tester	ASTM G-53-77 Cycling Procedure: 8 hours intense UV @ 160°F; 4 hours condensation @ 105°F	Futura-Flex 550 retained an excellent appearance after 6,000 hours of accelerated weathering. There was no evidence of chalking, checking, delamination or loss of flexibility.
Ultraviolet Resistance Atlas Carbon Arc Weatherometer	ASTM D 822 Continuous UV and water spray cycling	Futura-Flex 550 retained an excellent appearance after 6,000 hours with only slight loss of gloss. There was no chalking, checking, delamination or loss of flexibility.
EMMAQUA UV Radiation	ASTM E 838	Futura-Flex 550 retained an excellent appearance after over 2,000,000 langleys of radiation. There was slight evidence of chalking and color loss with no delamination or loss of flexibility.
Water Absorption	ASTM D 471 3 days @ 75°F (23.8°C)	1.5% max
Accelerated Heat Aging	ASTM D 573 30 days @ 185°F (85°C)	No significant change in physical properties.
Low Temperature Flexibility	ASTM D 2136 180° bend @ -50°F (-45.6°C)	Passes
High Temperature Resistance	ASTM D 573 Continuous Intermittent	 200°F (93.3°C) 225°F (107.2°C)
Abrasion Resistance	ASTM C-501 CS - 17 wheel 1000 rev. with 1000 gram weight	33 mg ± 2

from Futura's Technical Service Department).

Estimating Allowance

Allow 10-20% additional material for irregularity of surface and contingencies when estimating quantities.

PERFORMANCE PROPERTIES

Resistance to Hail and Mechanical Damage

Due to the high tensile and elongation of Futura-Flex 550, it has superior resistance to hail and mechanical damage. An 18 oz. steel ball dropped from a height of 20 feet does not produce surface cracking. (20 mils of coating sprayed on 2.5 PCF density polyurethane foam.)

Flexibility

Futura-Flex 550 demonstrates excellent flexibility over a range of extreme temperatures. It exhibits exceptional flexibility as reflected by passing a 180° bend at minus 50°F (ASTM D 2136).

Ponding Water Resistance and Hydrolytic Stability

Futura-Flex 550 is unaffected by long-term immersion in water. After six months immersion in distilled water at 75°F (23.9°C), there were negligible changes in physical properties.

Cold Temperature Impact Resistance

Futura-Flex 550 has excellent low temperature resistance. An 18 oz. steel ball dropped at a height of 15 feet at 0°F (-17.8°C) does not produce cracking or rupturing the film.

ORDERING INFORMATION

Container Size

10 gallon kits (5 gallon pails)
110 gallon kits (55 gallon drums)

Approximate Weight
10 gallon kit — 122 lbs.
110 gallon kit — 1342 lbs.

Freight Classification
Paint Compound
NOIBN
Flammable Liquids

ADDITIONAL INFORMATION
*Chemical Tests
*Specifications
Roofing
Hot Tanks
Cold Tanks
Coolers and Freezers*
*Current UL Classification Listing
*Warranty
*Distributor and Sales Office Locations

FUTURA APPLICATION INSTRUCTIONS

METHOD

Futura-Flex 550 is designed for airless or conventional spray equipment.

EQUIPMENT AND MIXING

A) Batch Mix Using Standard Airless Equipment

Pump Ratio — 30:1 or greater
Tip Size — .020 to .030 inch
Fan Angle — 60° - 80°
Hose Diameter — 3/8 inch (high pressure hose)

B) Plural Component Application Using Static Mixing/Standard Airless Gun.

A plural 1:1 ratio proportioning unit, which develops a minimum spray pressure of 2400-3000 PSI, should be used. The proportioning pump should be fed by 2:1 or greater transfer pumps. Both "A" and "B" components are pumped in individual hoses by the proportioning pump to a three inlet manifold and through an 18 element, 24 inch static mixer with removable/replaceable elements (or equivalent). A standard airless spray gun with a 15 foot whip hose (maximum) should be attached to the exit of the mixer. A high pressure solvent line is attached to the manifold to facilitate flushing the whip and gun when spraying is stopped for more than 15 minutes. The solvent pump should be at least a 10:1 ratio pump.

C) Totally Plural Component Sprayed

A plural 1:1 proportioning unit, which can develop 2400-3000 PSI in heated or unheated systems, is used. The proportioning pump should be fed by 2:1 transfer pumps. The material temperature to the gun should not be lower than 75°F or greater than 110°F. The spray gun should be a plural component internal mixing gun designed to spray pigmented coatings with a flat spray pattern and rated at a minimum pressure of 2000-3000 PSI, such as Glas-Craft's "Prober" gun with post chamber static mixer or Gusmer's "AB-A" gun.

POTLIFE

55°F — 2½ - 5 hours
75°F — 1½ - 2½ hours
95°F — ¾ - 1½ hours
115°F — ½ - ¾ hours

Batch Mixing

Do not mix more material than can be used within the pot life of the material.

NOTE: Dark hoses on dark roof surfaces absorb tremendous quantities of heat. Do not leave mixed material in fluid lines for more than a few minutes when spraying is stopped. A black hose on a black deck may reach 140°F. If the hose is very long, the coating will pick up temperature above ambient. It is advisable if warm temperatures are anticipated, to insulate the hose with Armorflex or equivalent. When mixed (catalyzed) material is introduced into a hot hose, the pot life will be significantly reduced. Winter grades available on special request.

Storage

Store materials in a dry environment with a minimum temperature of 40°F and a maximum temperature of 100°F. The shelf life of component "A" is ½-1 year in unopened containers which are purged with nitrogen. The shelf life of component "B" is 1-2 years in unopened containers. If the component "A" is opened, it should be purged with nitrogen and resealed or refilled into smaller containers to their maximum volume in order to eliminate polymerization in the can.

THINNING

Do not thin the "A" or "B" component when using plural component application equipment. For premix applications, thinning is normally not required, however, a change of viscosity is possible in opened containers. Use up to 10% of No. 50 Urethane Thinner only when necessary.

APPLICATION TEMPERATURES

	Material	Surface
Minimum	45°F	45°F
Maximum	110°F	160°F

CURE SCHEDULE

The cure time will vary depending on temperature and humidity. Use this information as a general guide:

Temperature	Dry Time	Complete Cure
35°F	24-48 hrs	5 days
50°F	18-24 hrs	4 days
75°F	6-8 hrs	3 days
90°F	4-6 hrs	2 days

SPRAYING

Futura-Flex 550 is formulated to

pressure 2800-3000 PSI and a 60° to 80° wide angle spray tip 0.020 to 0.030 will provide good atomization and uniformly applied application. Using a 3-6 inch overlap to insure an evenly coated surface, walk the roof, making complete passes of the roof surface.

CLEAN-UP

Equipment — For best results, use Thinner No. 50 or a mixture of XYLOL and MEK (50/50) or XYLOL is acceptable.

APPLICATION GUIDELINES

1) DO NOT apply over wet substrates or when inclement weather is imminent.
2) DO NOT apply when the temperature is below 45°F or greater than 120°F.
3) CAUTION: Prior to application of Futura-Flex 550, the system should be purged to eliminate all solvent remaining in hoses before applying to roof.
4) DO NOT apply without adequate air exchange and ven-

GENERAL SAFETY, TOXICITY AND HEALTH DATA

Material Safety Data Sheets are available on this coating material. Any individual who may come in contact with these products should read and understand the Material Safety Data Sheet.

WARNING: Contact with skin or inhalation of vapors may cause an allergic reaction. Avoid the contact of the liquid or spray.

Eye Protection: Safety glasses, splash goggles, or face shield is recommended.

Skin Protection: Chemical resistant gloves are recommended. Cover as much of the exposed skin area as possible with appropriate clothing.

Respiratory Protection: Use a respirator approved for isocyanates and/or organic vapors. Consider the application and environmental concentrations in deciding if additional protective measures are necessary.

Ingestion: Do not take internally. It is believed ingestion of TDI, MDI or polymeric isocyanates would not be fatal to humans but may cause inflammation of the mouth and stomach tissue. Do not take internally or swallow.

Flammability: This coating contains solvents. Do not use near open flame or spark producing sources. Store away from heat. Use only approved explosion proof equipment.

NOTE: Solvent vapors are heavier than air and may travel along the ground. Eliminate any possible ignition source in the general work area.

Have available CO2 or dry chemical fire extinguishers. DO NOT USE WATER.

For detailed safety instructions, consult the Futura-Flex 550 container labels which are designed according to guidelines established by the National Paint and Coatings Association or contact Futura's Technical Department.

000248

REP: Futura-Flex 550 81010

FUTURA COATINGS, INC. • 9200 LATTY AVE. • HAZELWOOD, MO 63042 • (314) 521-4100 • TWX# 910-760-1622

Our data is based on information from laboratory tests which are believed to be accurate but all recommendations are made without warranty, since the conditions of use are beyond Futura Coatings, Inc.'s control. We do not assume any liability or responsibility of the product relative to coverage, performance or injury resulting from its use. Liability is limited to replacement of products.

ELASTOMERIC COATING SYSTEMS FOR POLYURETHANE FOAM

FUTURA
COATINGS INC.

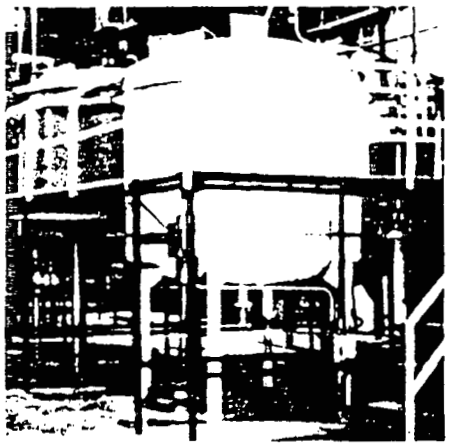
FUTURA COATINGS

Sprayed-in-place urethane foam and elastomeric coating is rapidly developing into the choice for modern roofing. It is lightweight, 100% bonded to the substrate on application, monolithic and absolutely seamless. It is capable of withstanding severe extremes of cyclic weather and still retains full functionality. The development of high quality, long term performance elastomers has made all of this possible.

Futura Coatings, Inc. has been deeply involved in the industry since its inception and has been a leader in the development of these performance elastomers. Futura represents a continuum of a decade and a half in the formulation and sales of elastomers developed specifically for the protection of sprayed-in-place urethane foam. Our product line is uniquely complete offering an array of products designed to meet a broad range of properties that are required in roofing and tank applications.

ADVANCED TECHNOLOGY

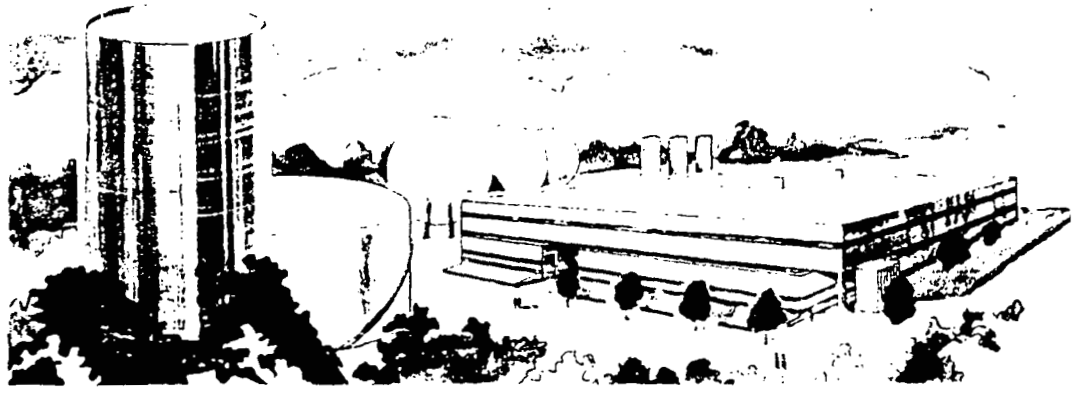
Modern polymer development begins with research in well equipped laboratories. Out of the hundreds of evolved formulae, few make it past rigorous accelerated test programs. Those that do, become candidates for inclusion into Futura's product line and receive even more extensive testing and development to insure performance in the field.



We are primary in manufacturing of many of the resins and chemicals used in our products. This back integration permits us to develop and manufacture elastomers with very precise end properties. Quality control is stringently maintained from the beginning of the resin manufacturing process through completion of the end product.

Manufacturing is done in a semi-automated 100,000 square foot facility in St. Louis. Advance planning and engineering preparation has permitted portions of the facility to become fully automated with computer controlled production.

URETHANE FOAM AND ELASTOMERIC COATINGS



AN ULTRA MODERN INSULATION AND ROOFING MATERIAL

MONOLITHIC CONSTRUCTION

Futura's elastomeric coating and sprayed-in-place urethane foam forms a virtually inseparable composite system from bottom to top and edge to edge. No seams, joints or layered construction to transmit water laterally through the system. Sprayed-in-place foam is closed cell and, therefore, resists the transmission of water even from one cell to the next.

100% SEAMLESS AND BONDED

Sprayed-in-place foam and elastomeric coatings are 100% seamless and because they are applied initially as a liquid, they bond tenaciously to the surface to which they are applied. There are no seams to let go or glue to fail. They eliminate the 1000's of mechanical fasteners that puncture the deck and protrude through the insulation.

SPRAY APPLIED AND SELF—FLASHING

The spray application of foam and elastomeric coatings permit the system to be easily and rapidly applied to extremely complex geometric shapes. Because it is spray applied as a liquid it bonds to the substrate. This eliminates all of the problems associated with mechanical bonding and flashing. These facts are true of both the insulation and the weather barrier coating.

EFFICIENT LIGHTWEIGHT SYSTEM

Sprayed-in-place polyurethane foam and elastomeric coatings are unsurpassed in insulation values. Weight and loading of structural members are critical factors in engineering designs. Per square, few materials are capable of competing with polyurethane foam insulation and elastomeric coatings for its ultra low weight factor and high strength.

ELEMENTS IN SELECTING A COATING SYSTEM

Elastomeric coatings are unique in the world of coatings. One of the primary differences is their ability to elongate to 150% of their original length then return to their initial dimension. They are coatings designed for long service lives and they must be capable of operating through an extremely wide latitude of temperatures and environments. Critical operating parameters are outlined below.

CLIMATE The local environment plays an important part in the coating selection. For example, cold, northern climates require a coating with low temperature flexibility, sunbelt areas may need greater ultraviolet resistance, and rainy regions usually require coatings with low permeability.

OPERATING TEMPERATURES The interior temperature of the structure must be considered in relationship to the possible exterior ambient temperatures and humidity levels. The moisture vapor drive is always from warm to cold and increases proportionately with the difference in temperature. To resist vapor drive in coolers, freezers, and cryogenic vessels, use low permeable coatings.

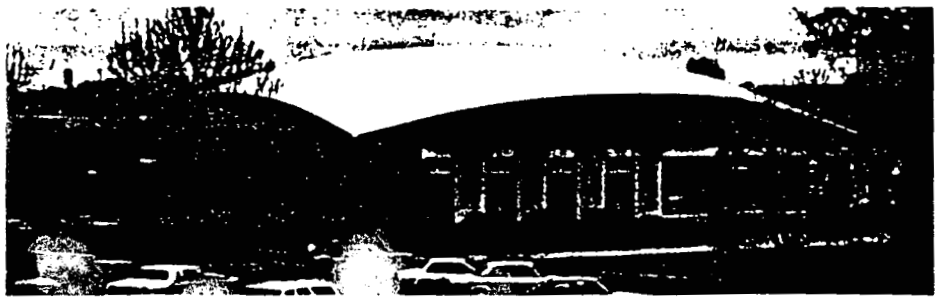
PONDING WATER On flat, or near flat roofs where water stands one inch deep over 100 square feet after 48 hours, special consideration is required. While all Futura coatings have good film integrity under ponding water conditions, we recommend using a coating with a permeability less than one perm. Coatings with permeability greater than one perm, allow more moisture transmission into the insulation, decreasing the insulational value, and increasing the risk of the foam blistering.

ULTRAVIOLET RESISTANCE Regions with extensive ultraviolet exposure such as the sunbelt and high elevation areas, require a coating that insures added protection from ultraviolet radiation.

AESTHETICS Highly visible projects such as domes, sloped roofs, and tanks may necessitate a coating that has excellent color, gloss retention, and good dirt release.

IMPACT RESISTANCE This is the most important consideration in the majority of projects. The severity of roof traffic and mechanical damage, along with hail, dictate the requirement for tough coatings. Impact resistance is inherent in coatings with high tensile and elongation properties.

FUTURA'S ELASTOMERIC COATINGS



UR THAN S...TOM ORROWS COATING TODAY!

Over the last decade great strides have been made in elastomeric urethane coatings technology. As a result, better and better materials have made their way from t aboratory to the field. The most apparent r is their long term performance. Futura C ngs has long been a leader in this area. Deve ental emphasis has simultaneously progr along two separate paths. They are, performance standards of the coatings and their application properties. Only when both requisites are addressed can truly lon erm high performance coatings be attained. Elastomeric membrane coatings are frequently applied at thicknesses of 45 mils with 30 to 35 mil films being the m mum dustry standard for all generic classes.

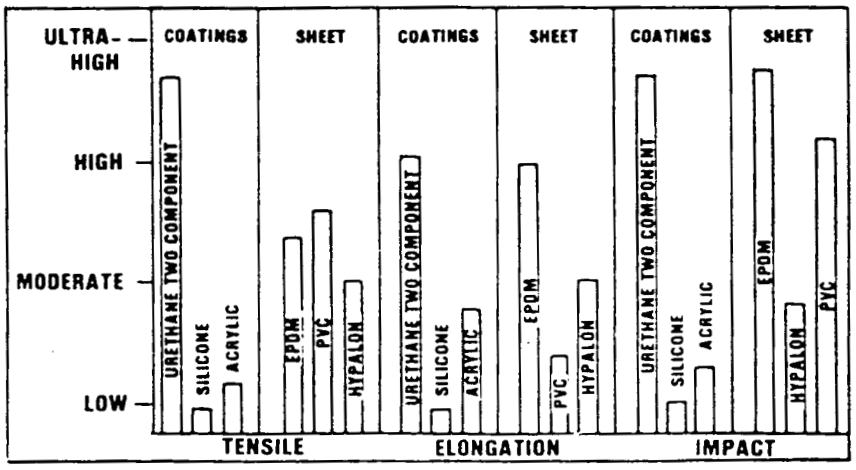
COMPARISON OF PHYSICAL PROPERTIES TO OTHER ELASTOMERS

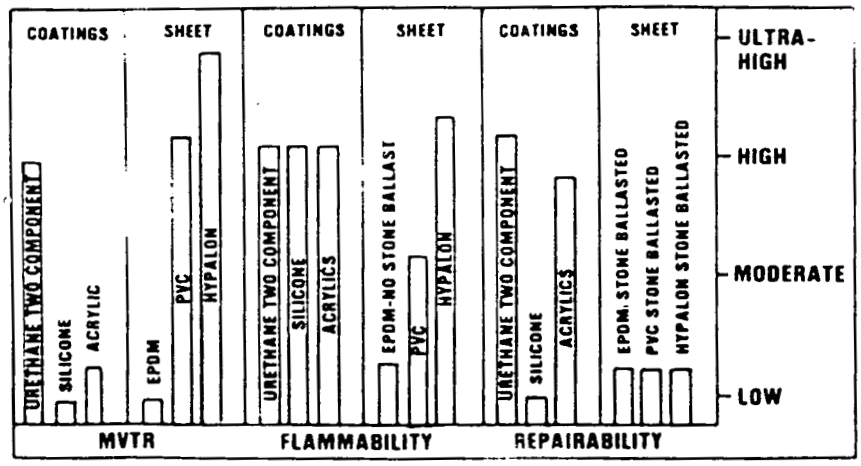
COMPARATIVE

TENSILE STRENGTH
Tensile strength is the amount of force developed necessary to cause a permanent break or rupture of a coating.

ELONGATION
Is the maximum amount of "stretch" exhibited by the coating and is measured as a percent of its original length at the moment of break.

IMPACT RESISTANCE
Is the ability of a material to move suddenly and not rupture or break even though the substrate may be totally deformed or destroyed by impact. This ability is a combined function of tensile strength and elongation.





PROPERTIES

MOISTURE VAPOR TRANSMISSION RESISTANCE
MVTR is the ability of a material to resist the transmission of water in vapor form. This is a critical factor in keeping the insulation dry.

FLAMMABILITY WITHOUT GRANULES OR ROCK BALLAST
All Futura elastomeric coatings systems are rated U.L. 790 Class "A" without the requirement for rocks or granules.

REPAIRABILITY
Careful selection of elastomeric membrane materials can eliminate complex and unnecessary effort and cost when maintenance of the roofing system eventually becomes necessary. Most sprayed-in-place elastomers, with the exception of silicone type materials, are easily maintained and repaired.

FUTURA'S FAMILY OF URETHANE COATINGS

Futura's family of urethane coatings are broken into three distinct groups. The basic distinction between each group is the speed of cure and solids content of the materials. The properties of each are outlined below.

STANDARD CURE MATERIALS are designed with a sufficient pot life to permit application with standard airless spray equipment. Pot life of the various materials will range from 60 minutes to 2 hours at 75° F. The resulting cure rate is 4 to 8 hours at temperatures of 75° F to 80° F.

MODERATE CURE MATERIALS are designed for application through modified plural component spray equipment. They require a high pressure plural component proportioner, plural hoses and a manifold mixer. These materials are unique in that they are applied with a standard high pressure airless spray gun. The pot life of these types of materials are 20-30 minutes. This results in a cure rate of 1 to 3 hours at 75° F to 80° F.

FAST CURE MATERIALS Futura's fast cure urethanes are true elastomers with high tensile strengths but just as important, high elongation. All materials meet the U.F.C.A. definition of a true elastomer. These materials require plural component spray equipment from the metering pump to the gun. The pot life of this type of material is 15 to 45 seconds. This results in a cure rate of 2 to 6 minutes.

STANDARD CURE URETHANES

BASE COAT NUMBER	TYPE	RECOMMENDED ELASTOMERIC FINISH	VISICHROME® COLOR	TENSILE (PSI)	ELONGATION (PERCENT)	U.S. PERM	VOLUMETRIC SOLIDS
500	AROM	500, 550	Desert Tan	1600 ± 25	450 ± 25	.65	72% ± 1
522	AROM	501	Gray	1025 ± 25	480 ± 25	.32	80% ± 1
FINISH COAT NUMBER	**TYPE**	**RECOMMENDED BASE MEMBRANE**	**STANDARD COLOR**	**TENSILE (PSI)**	**ELONGATION (PERCENT)**	**U.S. PERM**	**VOLUMETRIC SOLIDS**
500 FIN	AROM	Any Urethane Base	Gray	1600 ± 25	450 ± 25	.65	72% ± 1
501	AROM	522	Metallic Gray	700 ± 25	275 ± 25	.45	65% ± 1
550	ALIP	Any Urethane Base	White	2710 ± 50	275 ± 25	.48	65% ± 1

MODERATE CURE URETHANES

BASE COAT NUMBER	TYPE	RECOMMENDED ELASTOMERIC FINISH	VISICHROME® COLOR	TENSILE (PSI)	ELONGATION (PERCENT)	U.S. PERM	VOLUMETRIC SOLIDS
524	AROM	Any Urethane Finish	Beige	1450 ± 50	350 ± 25	.66	85% ± 1
FINISH COAT NUMBER	**TYPE**	**RECOMMENDED BASE MEMBRANE**	**STANDARD COLOR**	**TENSILE (PSI)**	**ELONGATION (PERCENT)**	**U.S. PERM**	**VOLUMETRIC SOLIDS**
524 FIN	AROM	5000, 524, 500	Gray	1600 ± 50	300 ± 25	.66	85% ± 1
5550	ALIP	Any Urethane Base	White	1800 ± 50	380 ± 25	.56	85% ± 1

FAST CURE URETHANES

BASE COAT NUMBER	TYPE	RECOMMENDED ELASTOMERIC FINISH	VISICHROME® COLOR	TENSILE (PSI)	ELONGATION (PERCENT)	U.S. PERM	VOLUMETRIC SOLIDS
5000	AROM	500, 524 550, 5550	Brown	2250	350 ± 25	.61	100%
5007	AROM	500,524, 550, 5550	Med. Gray	3450	175 ± 25	.61	100%

VISICHROME®

Is a special bi-color spray check designed specifically to tell you when your pump/meter system is malfunctioning or when there is an inadequate level of mixing occurring at the gun. The telltale indicator is evidenced when color favors the color of the "A" component or the "B" component.

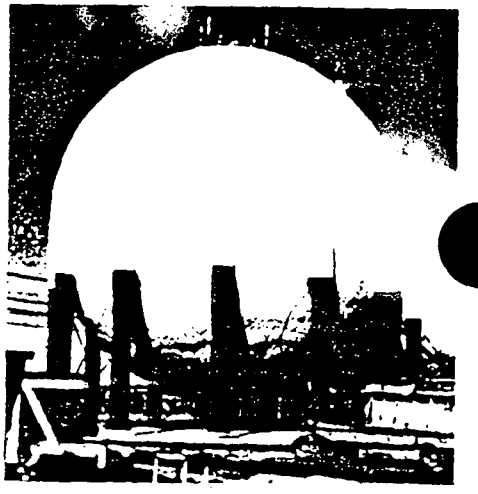
ACRYLIC ELASTOMERS

Futura Coatings manufactures two acrylic elastomeric membrane systems. They offer the applicator the convenience of a single package material with the ease of clean up of a water ba system. They can be an excellent choice of materials where weather is moderate and not susceptible to extremes and where surfaces are well drained.

ACRO-BOND ACRYLIC SYSTEM					
SYSTEM NO.	NO. OF COATS	TENSILE (PSI)	ELONGATION (PERCENT)	U.S. PERMS	VOLUMETRIC SOLIDS
440/442	1 EACH	300 ± 25	290 ± 10	2.8	60%
444	2	175 ± 25	275 ± 10	1.4	65%

BUTYL ELASTOMERS

Butyl rubber based elastomers are unsurpassed in their resistance to moisture vapor permeation. They are used as a base membrane in thicknesses from 30 to 60 mils to resist severe vapor drives encountered in cryogenic tanks and freezer/cooler applications. Butyls are generally overcoated with urethane finish membranes or urethane systems to achieve greater resistance to mechanical damage and impact.



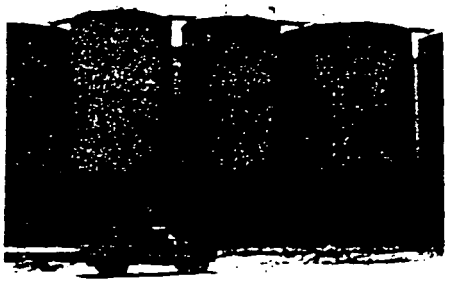
ELASTO-BOND BUTYL SYSTEM					
SYSTEM NO.	NO. OF COATS	TENSILE (PSI)	ELONGATION (PERCENT)	U.S. PERM	VOLUMETRIC SOLIDS
801 OR 801 FS	1 OR 2	375 ± 25	180 ± 25	.02	60%

SYNTHETIC RUBBER ELASTOMERS

Elasto-Bond 875 System is based on a proprietary synthetic rubber compound. It is a single package elasticized material that has a number of outstanding properties. It is an extremely low permeance material with excellent U.V.

ELASTO-BOND SYNTHETIC RUBBER SYSTEM					
SYSTEM NO.	NO. OF COATS	TENSILE (PSI)	ELONGATION (PERCENT)	U.S. PERM	VOLUMETRIC SOLIDS
875	2	800 ± 25	550 ± 25	.11	40%

HYPALON ELASTOMERS



Hypalon elastomers provide several special properties occasionally desired by designers. They have extremely low moisture vapor transmission rates and, as a result, are frequently used as a finish coat elastomer in conjunction with butyl rubber. They also exhibit the best overall fire performance and are used alone as a membrane system when flammability is an overriding consideration.

ELASTO-BOND HYPALON SYSTEM					
SYSTEM NO.	NO. OF COATS	TENSILE (PSI)	ELONGATION (PERCENT)	U.S. PERM	VOLUMETRIC SOLIDS
850	1 TO 4	800 ± 25	250 ± 25	.15	30%

PRIMERS

Although urethane foams exhibit a high order of adhesion to most materials, they benefit greatly when applied over substrate oriented primers, bonding agents, or corrosion resistant primers.

EPOXO-BOND 300 (metal primer)—is a chemically set polyamide-epoxy primer with balanced inhibiting pigments for maximum corrosion protection over steel surfaces. It bonds tenaciously to either steel or concrete surfaces and is supplied in a one to one mixing ratio. It is an excellent primer for most spray urethane coatings as well as urethane foam.

EPOXO-BOND 307 (concrete and masonry primer)—is a catalyzed clear penetrating sealer for concrete, masonry, and wood surfaces. It may be used alone, or in combination with other Futura coatings. It has excellent adhesion and chemical resistance which makes it an ideal primer or sealer for factories, warehouses, and food processing plants.

FUTURA-BOND 502 (general primer)—is a catalyzed urethane penetrating primer that adheres to steel, concrete and masonry surfaces, wood, glass, and old built-up roofs. It ties up any loose materials, blocks moisture from the substrate, and provides for maximum adhesion of urethane foam. This primer is an ideal material when repairing previously coated and/or degraded urethane foam.

FUTURA-BOND 702 (non-ferrous primer) -is a two component equal volume mix wash primer which gives outstanding adhesion and anti-corrosive properties over smooth or sandblasted steel and non-ferrous surfaces. It is compatible with most generic finishes which enhances the corrosion protection of the total system.

SPECIFYING AND ENGINEERING

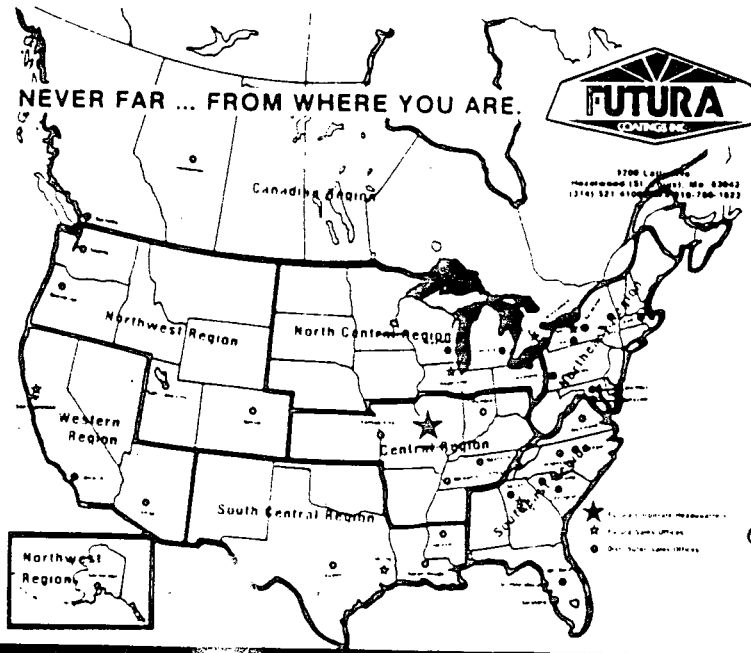
To obtain additional information on the use and design of sprayed-in-place polyurethane foam insulation and elastomeric weather barrier membranes, call or write us today. Futura Coatings, Inc. also offers at no cost a roof energy survey for building owners and operators. To avail yourself of this service, contact your nearest Futura Coatings representative.

The following programs and data are also available:

• *Technical Bulletins on Each Product* • *Technical Specifications* • *Plural Component Spray Application Guide* • *Product Warranty Program*

OTHER SPECIALTY ELASTOMERIC COATING SYSTEMS

In addition to the coatings outlined in this brochure, Futura Coatings manufactures a full line of elastomeric coatings for architectural waterproofing applications, waterproofing and wear abrasion resistance on traffic and pedestrian decks. Should you wish information on either of these systems, please contact us requesting information on your area of interest.



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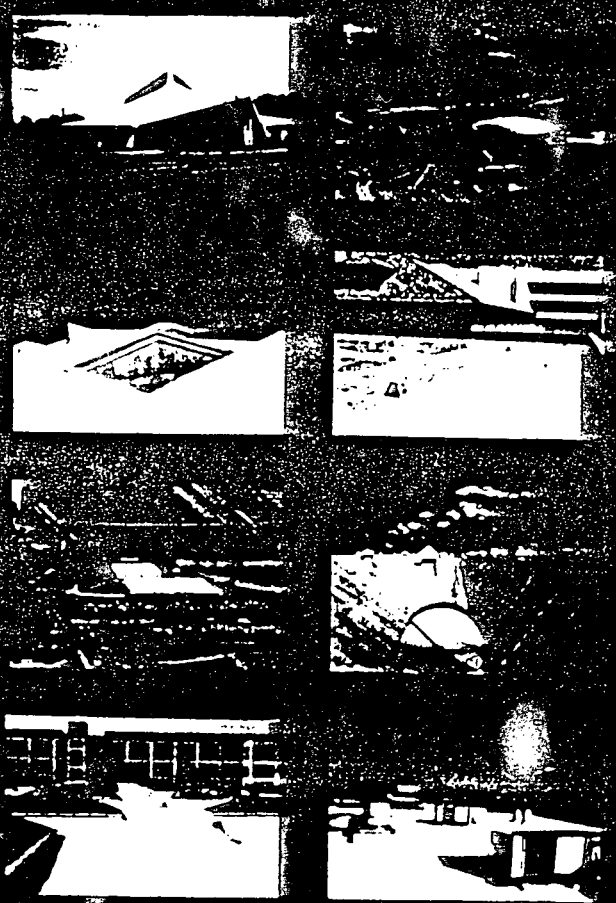

- Aeroquip
- Dupont Corp.
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APPENDIX - Supporting Data for ALARA Review

****** MICROSHIELD 2.02 ******

File : K65SLDGO.OUT
Saved: 10:51:33
: 08-12-1987

File Ref: _____
Date: ___/___/___
By: _____
Checked: _____

****** CASE TITLE ******
DOSE RATE AT 81 cm ABOVE SHIELD WITH 1404.2 Ci of Ra

****** GEOMETRY (centimeters) ******

CYLINDER - VIEW FROM END.....SLAB

Locating dimensions
X = 1005.8

Source dimensions
radius = 1220
length = 609.6

Shields
t(2) = 304.8
t(3) = 10.2
t(4) = 81.20001

Integration parameters
radial increment = 30.48
lateral intervals = 11

Source volume (cubic centimeters) = 2.850E+09

****** SHIELD MATERIAL DENSITIES (g/cc) ******
(Buildup is based on the properties of shield 3.)

Material	Source	Shield 2	Shield 3	Shield 4
Air		0.00129		0.00129
Concrete	1.600		2.300	

****** MICROSHIELD 2.02 ******

File : K65SLDGO.OUT
Saved: 10:51:33
: 08-12-1987

File Ref: _____

****** CASE TITLE ******
DOSE RATE AT 81 cm ABOVE SHIELD WITH 1404.2 Ci of Ra

****** SOURCE STRENGTH ******

Isotope	Activity (Curies)
Bi 214	1.386E+03
Pb 210	1.386E+03
Pb 214	1.386E+03
Po 214	1.386E+03
Ra 226	1.404E+03
Rn 222	1.367E+03
Th 230	1.900E+00
U 234	1.900E+00

****** RESULTS ******

Photon group energy (MEV)	Activity (photons/sec)	Dose point flux (MEV/sq cm/sec)	Dose rate (R/hr)
0.10 - 0.20	1.845E+12	1.976E+01	3.415E-05
0.20 - 0.30	1.236E+13	6.522E+02	1.278E-03
0.30 - 0.40	1.845E+13	2.668E+03	5.497E-03
0.40 - 0.55	1.573E+12	3.987E+02	8.134E-04
0.55 - 0.75	2.279E+13	7.183E+03	1.494E-02
0.75 - 0.90	4.260E+12	1.859E+03	3.719E-03
0.90 - 1.10	1.640E+12	1.150E+03	2.219E-03
1.10 - 1.35	1.179E+13	1.004E+04	1.847E-02
1.35 - 1.60	5.434E+12	6.337E+03	1.115E-02
1.60 - 1.80	9.791E+12	1.454E+04	2.486E-02
1.80 - 2.00	1.384E+12	2.839E+03	4.713E-03
2.00 - 2.20	1.230E+12	2.916E+03	4.666E-03
2.20 - 2.40	2.666E+12	7.018E+03	1.081E-02
2.40 - 2.60	8.202E+11	2.511E+03	3.817E-03
2.60 - 2.80			
2.80 - 3.20			
3.20 - 4.00			
4.00 - 5.00			
5.00 - 6.00			
6.00 - 7.20			
7.20 - 10.00			
Totals:	9.604E+13	6.013E+04	1.070E-01

****** MICROSHIELD 2.02 ******

File : K65VOID0.OUT
Saved: 11:02:11
: 08-12-1987

File Ref: _____
Date: ___/___/___
By: _____
Checked: _____

****** CASE TITLE ******
DOSERATE AT 90 cm ABOVE SHIELD WITH 37.4 Ci Rn & 50% EQUIL.

****** GEOMETRY (centimeters) ******

CYLINDER - VIEW FROM END.....SLAB

Locating dimensions	Source dimensions	Shields
X = 406.4	radius = 1220	t(2) = 1
	length = 304.8	t(3) = 10.2
		t(4) = 90.39999

Integration parameters
radial increment = 30.48
lateral intervals = 11

Source volume (cubic centimeters) = 1.425E+09

****** SHIELD MATERIAL DENSITIES (g/cc) ******
(Buildup is based on the properties of shield 3.)

Material	Source	Shield 2	Shield 3	Shield 4
Air	0.00129	0.00129		0.00129
Concrete			2.300	

****** MICROSHIELD 2.02 ******

File : K65VOID0.OUT
Saved: 11:02:11
: 08-12-1987

File Ref: _____

****** CASE TITLE ******
DOSERATE AT 90 cm ABOVE SHIELD WITH 37.4 Ci Rn & 50% EQUIL.

****** SOURCE STRENGTH ******

Isotope	Activity (Curies)
Bi 214	1.870E+01
Pb 210	1.870E+01
Pb 214	1.870E+01
Po 214	1.870E+01
Rn 222	3.740E+01

****** RESULTS ******

Photon group energy (MEV)	Activity (photons/sec)	Dose point flux (MEV/sq cm/sec)	Dose rate (R/hr)
0.10 - 0.20			
0.20 - 0.30	1.667E+11	6.438E+02	1.262E-03
0.30 - 0.40	2.491E+11	2.585E+03	5.325E-03
0.40 - 0.55	2.173E+10	3.844E+02	7.842E-04
0.55 - 0.75	3.075E+11	6.708E+03	1.395E-02
0.75 - 0.90	5.750E+10	1.657E+03	3.314E-03
0.90 - 1.10	2.214E+10	9.482E+02	1.830E-03
1.10 - 1.35	1.591E+11	8.147E+03	1.499E-02
1.35 - 1.60	7.334E+10	4.858E+03	8.551E-03
1.60 - 1.80	1.322E+11	1.077E+04	1.841E-02
1.80 - 2.00	1.868E+10	1.931E+03	3.206E-03
2.00 - 2.20	1.661E+10	1.929E+03	3.086E-03
2.20 - 2.40	3.598E+10	4.582E+03	7.057E-03
2.40 - 2.60	1.107E+10	1.587E+03	2.412E-03
2.60 - 2.80			
2.80 - 3.20			
3.20 - 4.00			
4.00 - 5.00			
5.00 - 6.00			
6.00 - 7.20			
7.20 - 10.00			
Totals:	1.272E+12	4.673E+04	8.418E-02

****** MICROSHIELD 2.02 ******

File : K65ELASO.OUT
Saved: 11:35:00
: 08-12-1987

File Ref: _____
Date: ___/___
By: _____
Checked: _____

****** CASE TITLE ******
DOSERATE AT 81 cm ABOVE THE SHIELD WITH ELASTOMER IN PLACE

****** GEOMETRY (centimeters) ******

CYLINDER - VIEW FROM END.....SLAB

Locating dimensions	Source dimensions	Shields
X = 1005.8	radius = 1220	t(2) = 5.1
	length = 609.6	t(3) = 299.7
	Integration parameters	t(4) = 10.2
	radial increment = 30.48	t(5) = 81.20001
	lateral intervals = 11	

Source volume (cubic centimeters) = 2.850E+09

****** SHIELD MATERIAL DENSITIES (g/cc) ******
(Buildup is based on the properties of shield 4.)

Material	Source	Shield 2	Shield 3	Shield 4	Shield 5
Water		0.71500			
Air			0.00129		0.00129
Concrete	1.600			2.300	

****** MICROSHIELD 2.02 ******

File : K65ELAS0.OUT
Saved: 11:35:00
: 08-12-1987

File Ref: _____

****** CASE TITLE ******
DOSERATE AT 81 cm ABOVE THE SHIELD WITH ELASTOMER IN PLACE

****** SOURCE STRENGTH ******

Isotope	Activity (Curies)
Bi 214	1.386E+03
Pb 210	1.386E+03
Pb 214	1.386E+03
Po 214	1.386E+03
Ra 226	1.404E+03
Rn 222	1.367E+03
Th 230	1.900E+00
U 234	1.900E+00

****** RESULTS ******

Photon group energy (MEV)	Activity (photons/sec)	Dose point flux (MEV/sq cm/sec)	Dose rate (R/hr)
0.10 - 0.20	1.845E+12	1.208E+01	2.087E-05
0.20 - 0.30	1.236E+13	4.301E+02	8.430E-04
0.30 - 0.40	1.845E+13	1.848E+03	3.807E-03
0.40 - 0.55	1.573E+12	2.868E+02	5.851E-04
0.55 - 0.75	2.279E+13	5.464E+03	1.137E-02
0.75 - 0.90	4.260E+12	1.428E+03	2.857E-03
0.90 - 1.10	1.640E+12	8.994E+02	1.736E-03
1.10 - 1.35	1.179E+13	8.008E+03	1.474E-02
1.35 - 1.60	5.434E+12	5.267E+03	9.271E-03
1.60 - 1.80	9.791E+12	1.194E+04	2.041E-02
1.80 - 2.00	1.384E+12	2.354E+03	3.907E-03
2.00 - 2.20	1.230E+12	2.435E+03	3.896E-03
2.20 - 2.40	2.666E+12	5.903E+03	9.091E-03
2.40 - 2.60	8.202E+11	2.127E+03	3.233E-03
2.60 - 2.80			
2.80 - 3.20			
3.20 - 4.00			
4.00 - 5.00			
5.00 - 6.00			
6.00 - 7.20			
7.20 - 10.00			
Totals:	9.604E+13	4.840E+04	8.576E-02

****** MICROSHIELD 2.02 ******

File : K65RIGIO.OUT
Saved: 11:44:23
: 08-12-1987

File Ref: _____
Date: _____
By: _____
Checked: _____

****** CASE TITLE ******
DOSE RATE AT 81 cm ABOVE SHIELD WITH 2' RIGID IN PLACE

****** GEOMETRY (centimeters) ******

CYLINDER - VIEW FROM END.....SLAB

Locating dimensions	Source dimensions	Shields
X = 1005.8	radius = 1220	t(2) = 5.1
	length = 609.6	t(3) = 60.96
	Integration parameters	t(4) = 238.7
	radial increment = 30.48	t(5) = 10.2
	lateral intervals = 11	t(6) = 81.2399[illegible]

Source volume (cubic centimeters) = 2.850E+09

****** SHIELD MATERIAL DENSITIES (g/cc) ******
(Buildup is based on the properties of shield 5.)

Material	Source	Shield 2	Shield 3	Shield 4	Shield 5	[illegible]
Water		0.71500				
Air			0.03180	0.00129		0.001
Concrete	1.600				2.300	

****** MICROSHIELD 2.02 ******

File : K65RIGIO.OUT
Saved: 11:44:23
: 08-12-1987

File Ref: _____

****** CASE TITLE ******
DOSE RATE AT 81 cm ABOVE SHIELD WITH 2' RIGID IN PLACE

****** SOURCE STRENGTH ******

Isotope	Activity (Curies)
Bi 214	1.386E+03
Pb 210	1.386E+03
Pb 214	1.386E+03
Po 214	1.386E+03
Ra 226	1.404E+03
Rn 222	1.367E+03
Th 230	1.900E+00
U 234	1.900E+00

****** RESULTS ******

Photon group energy (MEV)	Activity (photons/sec)	Dose point flux (MEV/sq cm/sec)	Dose rate (R/hr)
0.10 - 0.20	1.845E+12	9.651E+00	1.668E-05
0.20 - 0.30	1.236E+13	3.554E+02	6.966E-04
0.30 - 0.40	1.845E+13	1.560E+03	3.213E-03
0.40 - 0.55	1.573E+12	2.462E+02	5.022E-04
0.55 - 0.75	2.279E+13	4.721E+03	9.821E-03
0.75 - 0.90	4.260E+12	1.265E+03	2.530E-03
0.90 - 1.10	1.640E+12	8.027E+02	1.549E-03
1.10 - 1.35	1.179E+13	7.212E+03	1.327E-02
1.35 - 1.60	5.434E+12	4.784E+03	8.420E-03
1.60 - 1.80	9.791E+12	1.091E+04	1.865E-02
1.80 - 2.00	1.384E+12	2.160E+03	3.586E-03
2.00 - 2.20	1.230E+12	2.244E+03	3.590E-03
2.20 - 2.40	2.666E+12	5.455E+03	8.401E-03
2.40 - 2.60	8.202E+11	1.972E+03	2.997E-03
2.60 - 2.80			
2.80 - 3.20			
3.20 - 4.00			
4.00 - 5.00			
5.00 - 6.00			
6.00 - 7.20			
7.20 - 10.00			
Totals:	9.604E+13	4.369E+04	7.724E-02

****** MICROSHIELD 2.02 ******

File : K65FLEX0.OUT
Saved: 11:58:27
: 08-12-1987

File Ref: _____
Date: ___/___/__
By: _____
Checked: _____

****** CASE TITLE ******
DOSE RATE AT 81 cm ABOVE SHIELD WITH 6' FLEX IN PLACE

****** GEOMETRY (centimeters) ******

CYLINDER - VIEW FROM END.....SLAB

Locating dimensions	Source dimensions	Shields
X = 1005.8	radius = 1220	t(2) = 5.1
	length = 609.6	t(3) = 243.84
	Integration parameters	t(4) = 55.82
	radial increment = 30.48	t(5) = 10.2
	lateral intervals = 11	t(6) = 81.24005

Source volume (cubic centimeters) = 2.850E+09

****** SHIELD MATERIAL DENSITIES (g/cc) ******
(Buildup is based on the properties of shield 5.)

Material	Source	Shield 2	Shield 3	Shield 4	Shield 5	Shield
Water		0.71500				
Air			0.05560	0.00129		0.001
Concrete	1.600				2.300	

****** MICROSHIELD 2.02 ******

File : K65FLEX0.OUT
Saved: 11:58:27
: 08-12-1987

File Ref: _____

****** CASE TITLE ******
DOSE RATE AT 81 cm ABOVE SHIELD WITH 6' FLEX IN PLACE

****** SOURCE STRENGTH ******

Isotope	Activity (Curies)
Bi 214	1.386E+03
Pb 210	1.386E+03
Pb 214	1.386E+03
Po 214	1.386E+03
Ra 226	1.404E+03
Rn 222	1.367E+03
Th 230	1.900E+00
U 234	1.900E+00

****** RESULTS ******

Photon group energy (MEV)	Activity (photons/sec)	Dose point flux (MEV/sq cm/sec)	Dose rate (R/hr)
0.10 - 0.20	1.845E+12	2.443E+00	4.221E-06
0.20 - 0.30	1.236E+13	1.101E+02	2.158E-04
0.30 - 0.40	1.845E+13	5.492E+02	1.131E-03
0.40 - 0.55	1.573E+12	9.598E+01	1.958E-04
0.55 - 0.75	2.279E+13	1.920E+03	3.993E-03
0.75 - 0.90	4.260E+12	5.999E+02	1.200E-03
0.90 - 1.10	1.640E+12	3.990E+02	7.701E-04
1.10 - 1.35	1.179E+13	3.789E+03	6.972E-03
1.35 - 1.60	5.434E+12	2.649E+03	4.662E-03
1.60 - 1.80	9.791E+12	6.268E+03	1.072E-02
1.80 - 2.00	1.384E+12	1.274E+03	2.115E-03
2.00 - 2.20	1.230E+12	1.356E+03	2.170E-03
2.20 - 2.40	2.666E+12	3.357E+03	5.170E-03
2.40 - 2.60	8.202E+11	1.239E+03	1.883E-03
2.60 - 2.80			
2.80 - 3.20			
3.20 - 4.00			
4.00 - 5.00			
5.00 - 6.00			
6.00 - 7.20			
7.20 - 10.00			
Totals:	9.604E+13	2.361E+04	4.120E-02

****** MICROSHIELD 2.02 ******

File : K65FULL0.OUT
Saved: 16:19:48
: 08-12-1 -87

File Ref: _____
Date: ___/___
By: _____
Checked: _____

****** CASE TITLE ******
DOSE RATE AT 81 cm ABOVE SHIELD WITH ALL FOAM IN PLACE

****** GEOMETRY (centimeters) ******

CYLINDER - VIEW FROM END.....SLAB

Locating dimensions	Source dimensions	Shields
X = 1005.8	radius = 1220	t(2) = 5.1
	length = 609.6	t(3) = 299.7
	Integration parameters	t(4) = 10.2
	radial increment = 30.48	t(5) = 81.20001
	lateral intervals = 11	

Source volume (cubic centimeters) = 2.850E+09

****** SHIELD MATERIAL DENSITIES (g/cc) ******
(Buildup is based on the properties of shield 4.)

Material	Source	Shield 2	Shield 3	Shield 4	Shield 5
Water		0.71500			
Air			0.05720		0.00129
Concrete	1.600			2.300	

****** MICROSHIELD 2.02 ******

File : K65FULL0.OUT
Saved: 16:19:48
: 08-12-1987

File Ref: _____

****** CASE TITLE ******
DOSE RATE AT 81 cm ABOVE SHIELD WITH ALL FOAM IN PLACE

****** SOURCE STRENGTH ******

Isotope	Activity (Curies)
Bi 214	1.386E+03
Pb 210	1.386E+03
Pb 214	1.386E+03
Po 214	1.386E+03
Ra 226	1.404E+03
Rn 222	1.367E+03
Th 230	1.900E+00
U 234	1.900E+00

****** RESULTS ******

Photon group energy (MEV)	Activity (photons/sec)	Dose point flux (MEV/sq cm/sec)	Dose rate (R/hr)
0.10 - 0.20	1.845E+12	1.598E+00	2.761E-06
0.20 - 0.30	1.236E+13	7.663E+01	1.502E-04
0.30 - 0.40	1.845E+13	3.975E+02	8.189E-04
0.40 - 0.55	1.574E+12	7.171E+01	1.463E-04
0.55 - 0.75	2.279E+13	1.454E+03	3.024E-03
0.75 - 0.90	4.262E+12	4.765E+02	9.531E-04
0.90 - 1.10	1.641E+12	3.216E+02	6.207E-04
1.10 - 1.35	1.179E+13	3.108E+03	5.718E-03
1.35 - 1.60	5.436E+12	2.208E+03	3.886E-03
1.60 - 1.80	9.795E+12	5.285E+03	9.037E-03
1.80 - 2.00	1.385E+12	1.083E+03	1.798E-03
2.00 - 2.20	1.231E+12	1.161E+03	1.858E-03
2.20 - 2.40	2.667E+12	2.891E+03	4.452E-03
2.40 - 2.60	8.205E+11	1.074E+03	1.632E-03
2.60 - 2.80			
2.80 - 3.20			
3.20 - 4.00			
4.00 - 5.00			
5.00 - 6.00			
6.00 - 7.20			
7.20 - 10.00			
Totals:	9.606E+13	1.961E+04	3.410E-02

****** MICROSHIELD 2.02 ******

File : K65REGRO.OUT
Saved: 11:22:29
: 08-19-1987

File Ref: _____
Date: ___/___
By: _____
Checked: _____

****** CASE TITLE ******
DOSE RATE AT 81cm FROM REGROWTH ONLY

****** GEOMETRY (centimeters) ******

CYLINDER - VIEW FROM END.....SLAB

Locating dimensions	Source dimensions	Shields
X = 397.2	radius = 1220	t(2) = 5.1
	length = 1	t(3) = 299.7
	Integration parameters	t(4) = 10.2
	radial increment = .1	t(5) = 81.2
	lateral intervals = 11	

Source volume (cubic centimeters) = 4.676E+06

****** SHIELD MATERIAL DENSITIES (g/cc) ******
(Buildup is based on the properties of shield 4.)

Material	Source	Shield 2	Shield 3	Shield 4	Shield 5
Water		0.71500			
Air			0.05720		0.00129
Concrete	1.600			2.300	

****** MICROSHIELD 2.02 ******

File : K65REGRO.OUT
Saved: 11:22:29
: 08-19-1987

File Ref: _____

****** CASE TITLE ******
DOSE RATE AT 81cm FROM REGROWTH ONLY

****** SOURCE STRENGTH ******

Isotope	Activity (Curies)
Bi 214	3.740E+01
Pb 214	3.740E+01
Po 214	3.740E+01

****** RESULTS ******

Photon group energy (MEV)	Activity (photons/sec)	Dose point flux (MEV/sq cm/sec)	Dose rate (R/hr)
0.10 - 0.20			
0.20 - 0.30	3.335E+11	1.243E+02	2.436E-04
0.30 - 0.40	4.982E+11	6.412E+02	1.321E-03
0.40 - 0.55	4.151E+10	1.111E+02	2.267E-04
0.55 - 0.75	6.151E+11	2.295E+03	4.774E-03
0.75 - 0.90	1.150E+11	7.278E+02	1.456E-03
0.90 - 1.10	4.428E+10	4.575E+02	8.830E-04
1.10 - 1.35	3.183E+11	4.364E+03	8.029E-03
1.35 - 1.60	1.467E+11	2.938E+03	5.171E-03
1.60 - 1.80	2.643E+11	6.800E+03	1.163E-02
1.80 - 2.00	3.736E+10	1.276E+03	2.118E-03
2.00 - 2.20	3.321E+10	1.328E+03	2.125E-03
2.20 - 2.40	7.196E+10	3.261E+03	5.022E-03
2.40 - 2.60	2.214E+10	1.169E+03	1.777E-03
2.60 - 2.80			
2.80 - 3.20			
3.20 - 4.00			
4.00 - 5.00			
5.00 - 6.00			
6.00 - 7.20			
7.20 - 10.00			
Totals:	2.541E+12	2.549E+04	4.477E-02

Lowest Responsive Responsible Bidder

- Performance Specs

IFB or RFP

Schedual Info

Level I QA

Need QA plan
Dan Sager

IFB pre award survey

FASTER

Technical Data Requirement

Construction Safety ≈ green sheet

- Westing house supplied equipment
  they need respirators

- Drawing Review
  - Concepts
  - Fabrication drawings

☆ - Recom / not to advertise based on urgency - Letter

- Safety Specs
- Repairs
- Specify potential for contamination; we buy at market price

~~Water Separel~~

- Payments

INTERNATIONAL TECHNOLOGY CORPORATION

October 19, 1987

Joe Grumski
Westinghouse Materials Company
P. O. Box 398704
Cincinnati, Ohio 45239

Dear Joe:

This letter is confirmation of some responses to questions which were handled by telephone during the past few days.

You asked about the advisability of moving the damper valves from the inlets to the outlets of the carbon and Drierite beds. I checked with Ken Atwood on this matter and he confirmed that the inlet position had been specified as a matter of conventional engineering practice, but for the K-65 application there should be no problem in locating them at the outlets.

The other inquiry was concerned with a requested decrease in size of plastic pipe within the filter house from 12 inch to 6 inch size. The path from the exit of the $CaSO_4$ beds through the carbon beds to the entrance of the fan was calculated using a configuration leading to the greatest probable pressure drop. The configuration required determinations for the following segments:

1. 13 ft. of 6 inch piping with 500 cfm
2. 36 ft. of 6 inch piping with 1000 cfm
3. 3 ells of 6 inch ID with 500 cfm
4. 4 ells of 6 inch ID with 1000 cfm

The approximate total pressure drop is represented by the sum of the above, and is just under 1 inch of water (0.82 in. a calculated). Perry's Chemical Engineer's Handbook, Section 5, was used to obtain the appropriate equations and graphs for this task.

I hope your current work on the project is progressing well and can keep ahead of the early winter weather.

Best regards.

Dave Harmer

Dr. David E. Harmer
Manager of Applied Technology

DEH/lt

cc: Brian Frederick

INTERNATIONAL TECHNOLOGY CORPORATION

October 8, 1987

Joe Grumski
Westinghouse Materials Company
P. O. Box 398704
Cincinnati, Ohio 45239

Dear Joe:

In the course of the review being done by ASI, a few typographic errors have been turned up. These were the result of a change in drawing numbering systems which occurred when we sent our rough copies to the drafting group. To correct these, I am enclosing "Rev. 1" pages which should be used to replace those pages in your copies of the report which bear the same number. Please discard the old pages.

Best regards,

Dave Harmer

Dr. David E. Harmer
Manager of Applied Technology

DEH/lt

Enclosure

cc: Bryan Frederick

000274

Regional Office
312 Directors Drive • Knoxville, Tennessee 37923 • 615-690-3211

SPECIFICATION FOR RADON REMOVAL SYSTEM

for

THE K-65 SILO AREA

of

FEED MATERIALS PRODUCTION CENTER
FERNALD, OHIO

1.0 SCOPE

1.1 These Specifications cover the furnishing and delivery of a radon removal system as described herein. The radon removal system shall provide humidity removal, carbon adsorption for radon removal, and a fan for recirculating the air being treated. The carbon adsorption units shall treat the air and reduce radon levels to concentrations suitable for opening the K-65 silos. Since the contaminated air in the silos will be recirculated, a per pass reduction of at least 80 percent is required to ensure reduction of the radon level to below 1 Ci in each silo in two work shifts.

The equipment, complete with all controls, will be installed in a temporary building to be erected adjacent to the K-65 silos.

1.2 The attached drawings, 303317.GA.01, 303317.F.01 and 303317.B.002 show the arrangement and capacity for operation of the equipment.

2.0 RADON REMOVAL SYSTEM

2.1 HUMIDITY REDUCTION

2.1.1 The Contractor shall furnish a suitably sized humidity reduction unit to treat a flow of air at 1000 cfm. The unit should be sized to treat a total of 1,500,000 ft^3 of air saturated with water vapor at 40°F. The humidity reduction unit should employ calcium sulfate as the removal media and reduce relative humidity of the recirculated air below 40 percent.

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4.1 INSTALLATION OF RADON REMOVAL SYSTEM

4.1.1 Initiate installation of the radon removal system by placing a portion of the 4-foot by 4-foot by 8-foot boxes filled with soil in place.

4.1.2 Receive and locate one-half of the prefabricated cover (11-foot by 24-foot section) for the radon system.

4.1.3 Receive and locate dehumidifier and activated carbon canisters in accordance with drawing 303317.B.002.

4.1.4 Locate fan assembly per drawing 30[illegible]B002.

4.1.5 Locate the second half of the radon system cover (11-foot by 24 foot) and slide to mate with first half. Complete assembly of the building halves and jack and level as required.

4.1.6 Install ductwork and damper connecting the dehumidifiers, carbon adsorbers, and fan as shown on drawing 303317.B.002.

4.1.7 Install ductwork connecting silos and radon removal system as shown on drawing 303317.GA.01. Provide tie downs every 40 feet to ensure the integrity of the system.

4.[illegible]3 Make re[illegible]red electrical connections to power fan and instrumentation.

4.1.9 Install radon monitoring instruments.

4.1.10 Complete placement of containers to provide shielding.

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4.1.3 Receive and locate dehumidifier and activated carbon canisters in accordance with drawing 303317.B.002.

4.1.4 Locate fan assembly per drawing 303317.B002.

4.1.5 Locate the second half of the radon system cover (11-foot by 24 foot) and slide to mate with first half. Complete assembly of the building halves and jack and level as required.

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4.1.4 Locate fan assembly per drawing 303317.B002.

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4.1.4 Locate fan assembly per drawing 303317.B002.

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4.1.3 Rec[illegible] and locate dehumidifier an[illegible] activ[illegible]ed carbon canisters in acco[illegible] with drawing 303317.B.002.

4.1.4 Locate fan assembly per drawing 303317.B002.

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4.1 INSTALLATION OF RADON REMOVAL SYSTEM

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4.1.2 Receive and locate one-half of the prefabricated cover (11-foot by 24-foot section) for the radon system.

4.1.3 Receive and locate dehumidifier and activated carbon canisters in accordance with drawing 303317.B.002.

4.1.4 Locate fan assembly per drawing 303317.B002.

4.1.5 Locate the second half of the radon system cover (11-foot by 24 foot) and slide to mate with first half. Complete assembly of the building halves and jack and level as required.

4.1.6 Install ductwork and damper connecting the dehumidifiers, carbon adsorbers, and fan as shown on drawing 303317.B.002.

4.1.7 Install ductwork connecting silos and radon removal system as shown on drawing 303317.GA.01. Provide tie downs every 40 feet to ensure the integrity of the system.

4.1.8 Make required electrical connections to power fan and instrumentation.

4.1.9 Install radon monitoring instruments.

4.1.10 Complete placement of containers to provide shielding.

4.1 INSTALLATION OF RADON REMOVAL SYSTEM

4.1.1 Initiate installation of the radon removal system by placing a portion of the 4-foot by 4-foot by 8-foot boxes filled with soil in place.

4.1.2 Receive and locate one-half of the prefabricated cover (11-foot by 24-foot section) for the radon system.

4.1.3 Receive and locate dehumidifier and activated carbon canisters in accordance with drawing 303317.B.002.

4.1.4 Locate fan assembly per drawing 303317.B002.

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4.1.4 Locate fan assembly per drawing 303317.B002.

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4.1.6 Install ductwork and damper connecting the dehumidifiers, carbon adsorbers, and fan as shown on drawing 303317.B.002.

4.1.7 Install ductwork connecting silos and radon removal system as shown on drawing 303317.GA.01. Provide tie downs every 40 feet to ensure the integrity of the system.

4.1.8 Make required electrical connections to power fan and instrumentation.

4.1.9 Install radon monitoring instruments.

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4.1.2 Receive and locate one-half of the prefabricated cover (11-foot by 24-foot section) for the radon system.

4.1.3 Receive and locate dehumidifiers and activated carbon canisters in accordance with drawing 303317. .002.

4.1.4 Locate fan assembly per drawing 303317.B002.

4.1.5 Locate the second half of the radon system cover (11-foot by 24 foot) and slide to mate with first half. Complete assembly of the building halves and jack and level as required.

4.1.6 Install ductwork and damper connecting the dehumidifiers, carbon adsorbers, and fan as shown on drawing 303317.B.002.

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4.1.8 Make required electrical connections to power fan and instrumentation.

4.1.9 Install radon monitoring instruments.

4.1.10 Complete placement of containers to provide shielding.

SECTION 5.0
ALARA REVIEW

5.0 ALARA REVIEW

A review of the work being engineered on the K-65 silos was made from a radiation control standpoint. The following outlines the assumptions made and the results obtained in this review.

5.1 STATEMENT OF WORK

In order to minimize releases of radon gas to the environment and to help structurally support the silo tops, WMCo has decided to insert a series of foams into the void air space at the top of both silos. A ventilation system will first be installed that will reduce the concentration of radon gas in the void air space. Then a two inch elastomer layer will be poured onto the surface of the residues in the tank. A two foot thick layer of rigid foam will then be sprayed in the silos. A "caulking" layer of elastomer will then be applied around the edges of the two foot thick rigid foam insert. The silos will then be filled to within two feet of the top in the center with flexible foam. Finally, the small remaining void will be filled with rigid foam.

5.2 ASSESSMENT

Researching various documents concerning the K-65 silos and discussing the conditions as assessed by WMCo with project personnel, existing parameters were assumed for a silo that represents a mean condition. Table 5.2.1 describes the assumed existing conditions.

By inserting the parameters of Table 5.2.1 into a dose estimating program, MICROSHIELD®, with the varying elastomer and foam levels, the dose rate at a point 81 cm above the center point of the idealized silo was calculated for the following conditions. (For details, see Appendix).

1. Existing sludge
2. Existing airspace
3. Airspace evacuated, elastomer in place
4. Air space evacuated, 2' rigid in place
5. Air space evacuated, 6' flexible in place
6. All foam in place
7. All foam in place, new equilibrium of Rn daughters

A summary of the dose rates, both measured currently and calculated by MICROSHIELD® are given in Table 5.2.2.

In reviewing the draft operating procedures and design criteria for equipment, equipment placement and shielding placement, the ALARA considerations given in Table 5.2.3 were used as guidelines. Based on these dose rates and a review of the draft procedures for foam installation, a man-millirem budget was calculated and is given as Table 5.2.4.

TABLE 5.2.1
PARAMETERS FOR SILO DOSE RATE CALCULATIONS

Basis:

There are 1404.2 Ci radium in sludge and 37.4 Ci radon in 50% equilibrium (with daughters) in the void air space. Dimensions and densities are as follows:

a. 1005.8 cm height from silo bottom to exposure point
b. 609.6 cm depth of sludge at 1.6 grams/cc
*c. 304.8 cm height of air at 0.00129 grams/cc
d. 10.2 cm thickness of silo dome concrete at 2.300 grams/cc
e. 81.2 cm air between silo dome and observation at 0.00129 grams/cc
f. 1220 cm silo radius
g. 2440 cm silo diameter

Calculation Cases:

1. 609.6 cm of sludge

2. c 304.8 cm air at 0.00129 g/cc

3. c 5.1 cm elastomer at 0.715 g/cc
   c' 299.7 cm air at 0.00129 g/cc

4. c 5.1 cm elastomer at 0.715 g/cc
   c' 60.96 cm foam at 0.0318 g/cc
   c" 238.7 cm air at 0.00129 g/cc

5. c 5.1 cm elastomer at 0.175 g/cc
   c' 243.84 cm foam at 0.05560 g/cc
   c" 55.82 cm air at 0.00129 g/cc

6. c 5.1 cm elastomer at 0.715 g/cc
   c' 304.8 cm foam at 0.05085 g/cc

7. Same shielding as Case 6.

*Note: c, c', c" - represents air heights after stages of foam placement.

TABLE 5.2.2

RADIATION DOSE RATES ON CENTER OF SILO

MEASURED - 250 MR/HR. @ CONTACT
150 MR/HR. @ 3'

CALCULATED - 191 MR/HR. @ 80 CM

CALCULATED WITH ELASTONER IN PLACE - 86 MR/HR.

CALCULATED WITH ALL FOAM IN PLACE - 34.1 MR/HR.

CALCULATED WITH ALL FOAM IN PLACE AND EQUILIBRIUM RE-ESTABLISHED - 78.9 MR/HR.

RADON REMOVAL SYSTEM

(Narrative)

A radon treatment system is proposed using the best available technology which is to be capable of safely removing accumulated and continuously generated radon gas within the K-65 silos. Primary system components include carbon beds, dehumidification beds, a fan for circulation and two continuous radon gas monitors. The general arrangement allows for circulation of contaminated air between the K-65 silos and the dehumidifiers/carbon beds located at the base of the berm.

Research was done to determine the most effective method for removing the radon gas from the air space of the silos. Literature data on Radon removal from air spaces tended to support carbon adsorption as being the most effective. Based on a system airflow of 1000 cfm, an initial curie content of 37.4 Ci, and 10 volume turnovers, the minimum curie content that can be achieved in the silos (due to continuous generation of radon gas) is approximately 0.4 Ci. A targeted final curie content for each K-65 silo is 1 Ci; however, an acceptable pre-foaming level is 4 Ci. The total amount of carbon required to "hold" 36.4 Ci (based on target curie content) is estimated at 4000 lbs. The selected carbon bed arrangement for radon removal uses two beds sized for 500 cfm operated in parallel to process 1000 cfm. Four trains of carbon beds are provided to achieve the required adsorption capacity.

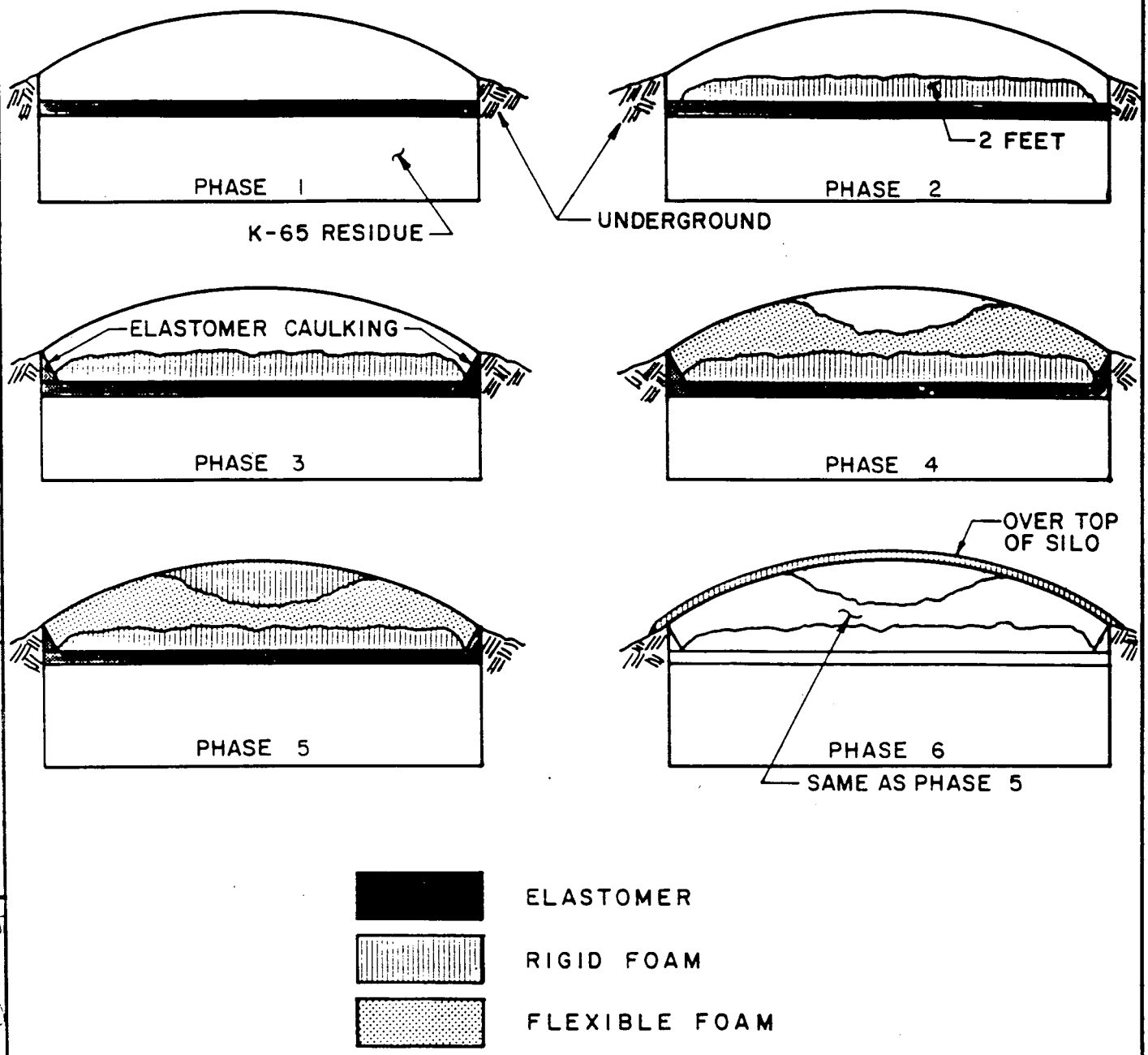
Radon adsorption onto the carbon beds is much more efficient when the air moisture content is low. Thus, dehumidification will be provided by circulation of the contaminated air through 2 drums (500 cfm/drum) containing calcium sulfate capable of reducing the moisture level. The amount of calcium sulfate required (4000 lbs) was based on the assumption that the relative humidity of the air in each silo is 100 percent at 40 degrees F.

A fan is included in the system to draw gas from the silos through the dehumidifiers and carbon adsorption beds. It is located downstream of the process to reduce the possibility of untreated air escaping the closed system. Exhaust from the fan returns to the silos as treated air. Sampling and analysis of the circulating gas is provided by continuous radon

gas monitors located up and downstream of the dehumidification and carbon adsorption beds. Consistent readings of the targeted curie concentrations of 7.2×10^5 pCi/L for silo 1 and 9.1×10^5 PCi/L for silo 2 will justify terminating the radon removal process and beginning the foaming process. Levels of 3.1×10^6 pCi/L for silo 1 and 4×10^6 pCi/L for silo 2 are the maximum allowable concentrations prior to beginning the foaming process.

5975

DRAWING 5317.A.004
PROJECT NO. 303317.09
INITIATOR: K. ATWOOD
PROJ. ENGR.: D. HARMER
DATE LAST REV.:
DRAWN BY:
STARTING DATE: 8
DRAWN BY: W. McGILL



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FMPC FERNALD, OHIO
SEQUENCE OF FOAMING OPERATION
K-65 SILO PROJECT

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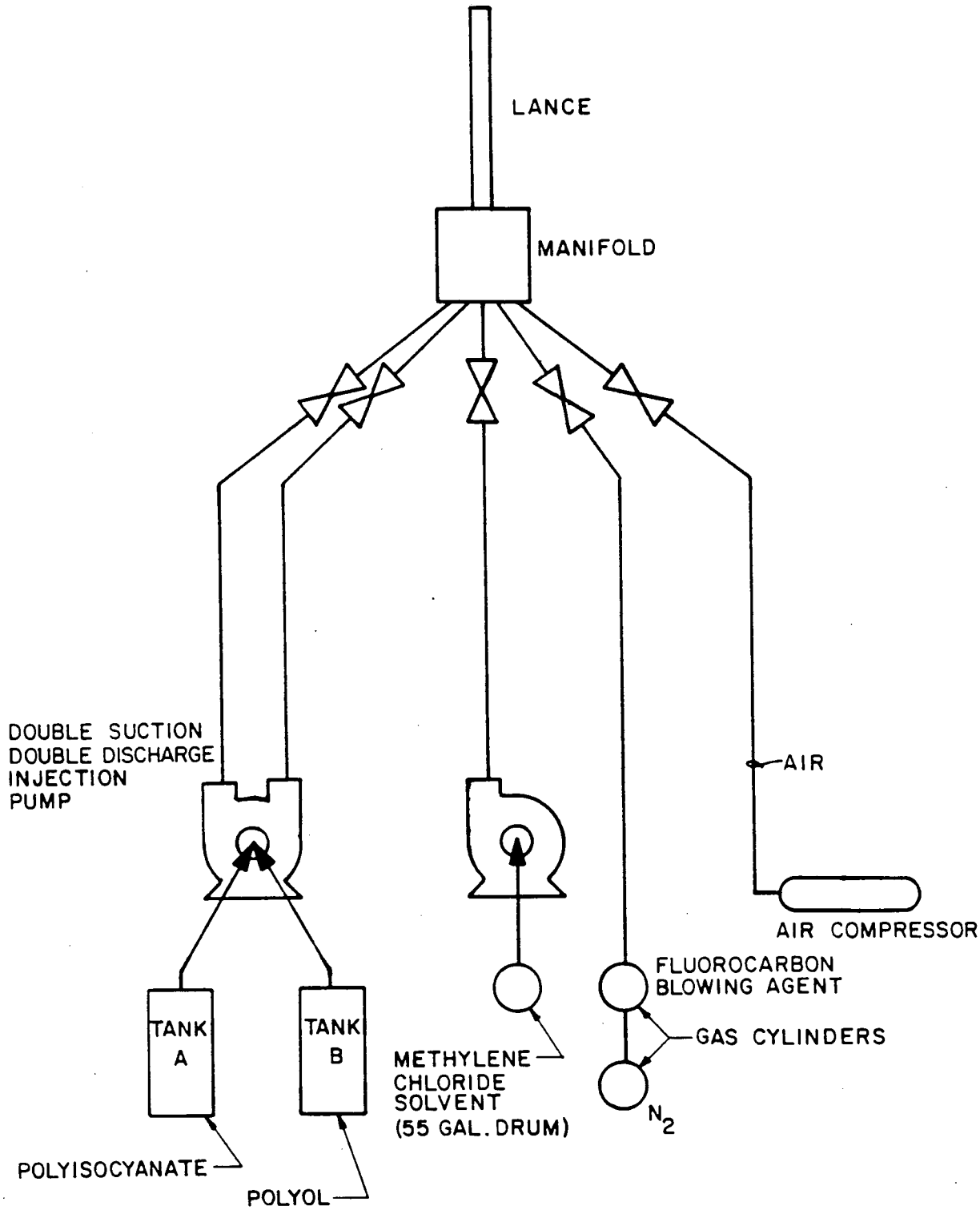
65360

BRUNING 44-132 67120

1317.A.002
3317.09
DRAWING
PROJECT
INITIATOR: K. ATWOOD
PROJ. ENGR.: D. HARMER
DATE LAST REV.:
DRAWN BY:
STARTING DATE:
DRAWN BY: W. M

5975



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FMPC FERNALD, OHIO
POLYURETHANE FROTH/POUR SYSTEM
K-65 SILO PROJECT

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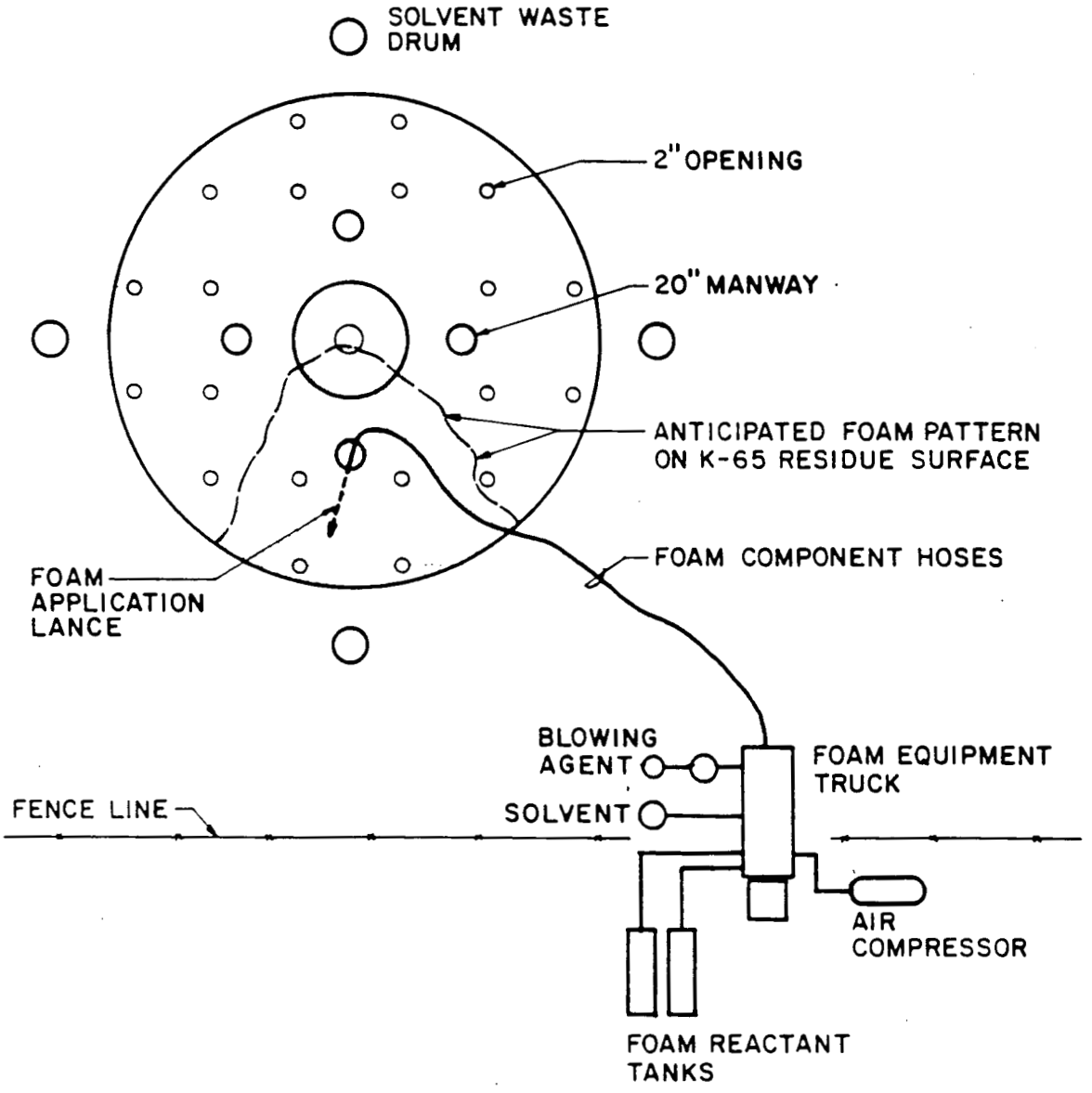
317.A.003
317.09
DRAWING
PROJECT
INITIATOR: K. ATWOOD
PROJ. ENGR.: D. HARMEY
DATE LAST REV.:
DRAWN BY:
STARTING DATE:
DRAWN BY: W. M.



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FMPC FERNALD, OHIO
TYPICAL FOAM APPLICATION ARRANGEMENT FOR
K-65 SILO PROJECT

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SYSTEM DESCRIPTION
RADON REMOVAL SYSTEM

1.0 OBJECTIVE

The objective of this document is to describe a system to be installed to remove radon gas from the vapor space of two solid waste silos located at the Feed Materials Production Center in Fernald, Ohio. A description of the function, sizing, and operation of this system is provided. The radon reduction system supports a larger program to be carried out on the silo vapor space. Once radon concentrations have been reduced, silo openings will be employed to completely fill the present vapor space with a polyurethane foam material which will seal the silo, preventing leakage or release of radon gas to the environment.

2.0 SCOPE

The radon system to be supplied is complete and capable of stand-alone operation with nothing more than electrical supply in support of operations. The system is a temporary unit designed for an operating life of 5 years. To the extent possible, the components selected for use on the system are off-the-shelf manufacturers standard.

3.0 DEFINITIONS

3.1 DEHUMIDIFICATION

Process for the removal of moisture from air. In the present application, it is assumed that the air in equilibrium with sludge in closed silos is saturated with moisture at the prevailing gas temperature (100 percent relative humidity). A device containing the dehumidification agent calcium sulfate, is placed in the line to react with moisture and reduce the concentration present in the air.

3.2 CARBON ADSORPTION

The process of assimilating a substance such as radon present in a gas stream on a solid carbon matrix thereby effectively concentrating the radon in the solid phase and removing it from the recirculated gas.

4.0 DESCRIPTION

The radon removal system is designed with the following components:

4.1 SUCTION CONNECTION

Each silo containing radon gas to be processed can be thought of as a closed container with radon in the gas space in equilibrium with radium in the sludge. The gas must be removed from the silo through available connections. The silos have five manways suitable for this purpose. Each manway is 20 inches in diameter and is presently closed with a flanged and bolted cover. It is proposed to modify the manway covers at the top of the silos with new covers, each containing a 6-inch duct type connection. The details of this fixture are shown in sketch "A" on Drawing 303317.A.001. Suction will be taken from two of these 6-inch connections. The two connections will attach to a 12-inch suction header which directs flow to the radon removal system.

4.2 SYSTEM CONNECTIONS

The suction line for transport of gas from the silo suction connections will be 12-inch diameter and will be routed as shown on Drawing 303317.G.01.

4.3 RADON REMOVAL SYSTEM

4.3.1 Dehumidification

Moisture removal is accomplished by passing the gas removed from a silo through vessels loaded with calcium sulfate which reacts with moisture in the air, thereby accomplishing the required moisture removal. For the system supplied, the calcium sulfate is loaded in two canisters. The canisters are 48 inches in diameter by approximately 72 inches high. Flow enters the bottom of the bed through a flow distributor and exits from the top of the canister. Each canister is capable of processing up to 500 cfm of air. The system is therefore designed to treat up to 1000 cfm.

4.3.2 Carbon Adsorption

Radon is collected on activated carbon. The carbon is loaded in canisters similar to those used in dehumidification. Because the 48-inch by 72-inch canisters are rated at 500 cfm, processing would normally be at 500 cfm

through one canister. The desired process rate of 1000 cfm is achieved by operation of two canisters in parallel. Processing would be carried out until inlet and outlet radon concentrations indicate carbon capacity is being approached. Calculations indicate flow will be diverted through additional canisters in sequence during the air recirculation operation to achieve required reduction of radon from 37.4 Ci to about 1 Ci in the recirculated gas. Four trains of carbon beds are provided to achieve required adsorption capacity.

4.4 FAN

A fan is installed in the system to take suction from the silo(s) and to draw gas through the dehumidifiers and carbon beds. The fan is located downstream of the process to reduce the possibility of excessive untreated gas escaping into the environment. After passing air through the adsorption process the fan returns the air to the silo(s). The return line is 12 inches in diameter from the fan discharge to the silo dome. At the silo dome, the 12 inch line splits into 2 connections which are 6 inches in diameter. The 6 inch lines are attached to special manway adapters which deliver treated air flow back to the silo.

4.5 DAMPERS

The radon adsorption system is designed to operate with one set of carbon vessels at a time. When one parallel pair of units is operating, all other vessels are isolated. Isolation is accomplished through the use of isolation dampers located at the inlet of the carbon units. The dampers selected must be capable of operation with reach rods and designed with bar seals or EPT seals which limit air leakage.

4.6 INSTRUMENTATION

Process control is accomplished using on-line monitoring of radon gas concentrations. The radon concentrations at the process inlet and process outlet are monitored. These process measurements are to be made using on-line measurements with an instrument such as the Eberline Model RGM-2 Radon Gas Monitor or equal.

5.0 DESCRIPTION OF OPERATION

The radon removal system is designed to operate at up to 1000 cfm gas flow to reduce radon levels in each of the two silos from 37.4 Ci to less than 1 Ci. Given gas volumes of 48,700 cubic feet in silo 1 and 38,700 cubic feet in silo 2, turnover times are 49 and 39 minutes respectively. Assuming 10 volume turnovers will be required to dilute radon concentrations to the level desired for start of foam application work, the total process times will be 500 minutes (8½ hours) and 400 minutes (7 hours) for silo and 1 and silo 2 respectively. In actual practice, it is anticipated this system as proposed will allow radon levels to be reduced to desired levels in two shifts.

The system is operated by opening the inlet damper to a pair of carbon beds. A flow path is verified from the silo to be processed, through the dehumidifiers and the carbon vessels to the fan. The fan is then started and air flow established through the system. The radon concentration is monitored at the process inlet and at the process outlet. Data available on carbon indicates removal efficiency for radon is between 85 and 99 percent. As inlet concentration is reduced and carbon capacity is being used, it is anticipated that flow will be diverted to a second set of carbon beds to achieve radon reduction to the final effluent concentration. The second silo will be processed by directing the initial flow through the partially expended bed from final processing of the first silo. The process will continue until inlet and outlet concentrations dictate a new bed must be placed in service. The new beds to be operated must have inlet dampers opened and flow established before isolating the expended units.

POLYURETHANE FOAM SYSTEM
NARRATIVE AND SYSTEM DESCRIPTION

NARRATIVE

Based on the conceptual design provided by WMCO and practical aspects of applying polyurethane foams for this type of treatment, a method has been generated using the best available technology to satisfy the main objectives of the project.

One of the main objectives of the foam application to the K-65 silos is to enhance the structural integrity of the tank domes by providing underlying support. However, rigid polyurethane foams, particularly low density foams, will expand and contract due to the physical and chemical nature of the materials. In fact, the compressive strength of the rigid foam is easily high enough to cause structural damage to the dome if expanded beyond the confines of the silo air space. In addition there is the concern that contraction of the foam could open avenues for the escape of radon past the foam layer.

The use of a composite foam system will satisfy both of these concerns. Rigid foam, flexible foam, and a polyurethane elastomer will be used in the composite. The flexible polyurethane foam will be used to fill the bulk of the silo void space and provide cushioning for expansion and contraction of the foam composite as a whole. The elastomer will be used to provide a reliable seal on the surface of the K-65 residue for radon attenuation. Rigid polyurethane foam will be applied in a 2 foot thick layer on top of the elastomer as a secondary Radon barrier. In addition a 20-30 foot diameter, 6-8 foot thick core of rigid foam will be applied at the top center of the dome to provide structural support. An illustration showing the sequence of foam application is provided in Drawing No. 303317.A.004.

An independent test performed by Twin City Testing on a 2.28 lb/ft^3 density rigid foam resulted in an expansion of 5.07 percent after a 7 day aging period. At a 6 percent expansion, a 15 foot thick layer of foam could expand to 15.9 feet. This foam has a compressive strength of 20 psi which is easily enough to lift the concrete dome of the silo. For this reason, a flexible

foam will be used as the primary fill material for the silo. For enhancing the structural integrity at the center of the dome, a 3000 to 4000 ft^3 core of rigid foam will be applied. The rigid foam core will be supported by a minimum 3 foot thickness of flexible foam.

The elastomer layer will provide the primary barrier for radon gas. It will be applied in a 2 inch thick layer on top of the K-65 residue. The material is moderately dense and elastic and is not likely to expand or contract significantly. In addition to the initial layer, the elastomer will be applied to caulk the outer perimeter of the 2 foot rigid foam layer.

In an optional operation, a 2-3 inch layer of rigid foam will be applied to the outside dome surface along with an elastomer weather barrier. This outer cover will insulate the silo and reduce thermal expansion and contraction of the fill foam as well as the dome concrete structure. Moisture uptake of the foam is also reduced and the dome structure is protected from environmental elements. Although the foam cover will add a small amount of weight to the dome lid, the compressive and tensile strength of the foam will help bridge some of the weak spots of the structure.

SYSTEM DESCRIPTION

Field production of the polyurethane foam to be used for this project will involve the mixing and pouring of several components which react and set-up within 5 minutes of application. The two reaction components, an aromatic isocyanate and a polyol, along with a fluorocarbon blowing agent are pumped through individual hoses to a static mixing chamber located on the butt of a pour lance. The aromatic isocyanate and polyol are combined in a 1:1 ratio and the fluorocarbon flow, usually 4 percent of the total mixture, is controlled to maintain the proper density foam. The mixture will begin to react immediately as it leaves the lance, but will continue to flow and rise for about 3 minutes after reaching the surface. Drawing No. 303317.A.002 illustrates the polyurethane froth/pour system.

The two reactants are pumped with an air powered pumping unit with two equally sized proportioning fluid pistons. The fluorocarbon is introduced into the mixing chamber using nitrogen pressure to push it in. The maximum rate of

foam delivery is about 100 pounds per minute. The volume of foam delivered will vary depending on the density of foam desired. For a 2 lb/ft^3 foam, a maximum volume of 50 ft^3/min can be expected.

The first step in the procedure will involve application of a fairly even 2 inch thick layer of elastomer. The material will be applied via the manways using the lance with an extension. The extension on the lance will be maneuvered through the manway such that it can be pointed in the desired direction by the operator from above the manway. The elastomer will be applied initially toward the silo wall, quickly working toward the center of the silo to establish a visible layer on as much surface area as possible. The operation is repeated for each of the four perimeter manways. The center manway will be used only if the center of the silo cannot be reached from the perimeter manways. Once the initial layer is applied, the operator will rework the surface if necessary to increase the thickness. Drawing 303317.A.003 shows the arrangement to be used for this operation.

To confirm thorough and even application of elastomer, a remote TV camera along with adequate lighting will be installed at the center manway. After applying the initial layer, the surface will be examined thoroughly by camera and any problem areas noted. The problem areas will be re-worked prior to switch-over to the next phase. After the touch-up operation, the distance between elastomer coating and the dome will be determined from various access points on the dome. These measurements will provide a baseline for determining the thickness of subsequent foam layers.

The rigid foam will be applied on top of the elastomer to a thickness of 18-30 inches. It will be applied in the same fashion as the elastomer covering as much surface as possible. The foam progress will be viewed and directed by remote TV camera. The same operation will be used to apply the elastomer caulking around the perimeter of the rigid foam layer. Measurements of distance between the rigid foam surface and the dome will be performed for determination of foam thickness.

In the next step of the process, flexible foam will be used to fill most of the silo head space. A void space at the center of the silo will be left

measuring 20 to 30 feet in diameter and 6 to 8 feet deep at the center of the dome. The flexible foam will be applied in a semi-remote fashion using disposable flexible hose extensions for the lance. Flexible hose will be placed in various openings of the dome in an arrangement such that the foam will fill the outer edge of the dome and expand toward the center. The foam lance will be attached to a flexible hose extension and left on the dome as the foaming progresses. As the space fills with foam, the lance will be moved to other injection points around the dome in a pattern which prevents the formation of void spaces. When the foaming is complete, the flexible hoses will be cut off flush to the openings of the dome.

The final core of rigid foam is also applied in semi-remote fashion from the center manway. Lance extensions will be used to ensure a complete pour with a minimum of void spaces. Once the foam application is complete, all manways and other dome openings will be covered.

The optional outer dome coating will be applied using special spray equipment. The rigid foam layer will be applied first, working from the center of the dome toward the perimeter. Once the rigid foam has cured, the thin elastomer layer can be applied.

SOURCE EMISSION CALCULATION

Following treatment, the maximum amount of Radon-222 remaining will be no more than 4 Ci in each of the K-65 silos. Refering to Table 1. below, the concentration in each silo is calculated as a function of the volume of the space above the residue. As the foam is injected into the silo, it will displace the radon gas, forcing it out the four (4) open manways and into the ambient atmosphere. The maximum foam injection rate is 50 cfm, which will take place for limited (about seven hour) periods. This will result in a maximum emission rate of about 6.8×10^{-5} Ci/sec from silo 1 and about 8.6×10^{-5} Ci/sec from Silo 2.

Table 1. Worst Case Emission Calculations

ITEM	UNITS	SILO 1	SILO 2
Radon Present	Ci	4	4
Tank Volume	ft^3	48,700	38,700
Concentration	Ci/ft^3	8.2×10^{-5}	10.3×10^{-5}
Foam Injection Rate	ft^3/min	50	50
Emission Rate	Ci/sec	6.8×10^{-5}	8.6×10^{-5}

TABLE 5.2.1
PARAMETERS FOR SILO DOSE RATE CALCULATIONS

Basis:

There are 1404.2 Ci radium in sludge and 37.4 Ci radon in 50% equilibrium (with daughters) in the void air space. Dimensions and densities are as follows:

a. 1005.8 cm height from silo bottom to exposure point
b. 609.6 cm depth of sludge at 1.6 grams/cc
*c. 304.8 cm height of air at 0.00129 grams/cc
d. 10.2 cm thickness of silo dome concrete at 2.300 grams/cc
e. 81.2 cm air between silo dome and observation at 0.00129 grams/cc
f. 1220 cm silo radius
g. 2440 cm silo diameter

Calculation Cases:

1. 609.6 cm of sludge

2. c 304.8 cm air at 0.00129 g/cc

3. c 5.1 cm elastomer at 0.715 g/cc
   c' 299.7 cm air at 0.00129 g/cc

4. c 5.1 cm elastomer at 0.715 g/cc
   c' 60.96 cm foam at 0.0318 g/cc
   c" 238.7 cm air at 0.00129 g/cc

5. c 5.1 cm elastomer at 0.175 g/cc
   c' 243.84 cm foam at 0.05560 g/cc
   c" 55.82 cm air at 0.00129 g/cc

6. c 5.1 cm elastomer at 0.715 g/cc
   c' 304.8 cm foam at 0.05085 g/cc

7. Same shielding as Case 6.

*Note: c, c', c" - represents air heights after stages of foam placement.

TABLE 5.2.2

RADIATION DOSE RATES ON CENTER OF SILO

MEASURED - 250 MR/HR. @ CONTACT
150 MR/HR. @ 3'

CALCULATED - 191 MR/HR. @ 80 CM

CALCULATED WITH ELASTONER IN PLACE - 86 MR/HR.

CALCULATED WITH ALL FOAM IN PLACE - 34.1 MR/HR.

CALCULATED WITH ALL FOAM IN PLACE AND EQUILIBRIUM RE-ESTABLISHED - 78.9 MR/HR.

TABLE 5.2.4
MAN MILLIREM ESTIMATE

Construction		
Silo #1		
Install Containments	800	
Remove Covers	1200	
Install Covers	800	
	2800	2800
Silo #2		2800
Install Ducting		240
Install TV Camera		700
Operation		
Test of Rn System		360
Radon System Operation		300
Silo #1		
Ventilate	360	
Elastomer	1150	
Inspection	200	
Rigid Foam	500	
Inspection	190	
Caulk	400	
Flexible	600	
Rigid	80	
Cleanup	150	
Dome Protect	350	
	3980	3980
Silo #2		3980
Waste Transport		50
Demobilization		50
		15,260

TABLE 5.2.3

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ALARA CONSIDERATIONS

ENVIRONMENT

- o CARBON ABSORPTION SYSTEM
- o FOAM RADON ATTENUATOR
- o FOAM RADIATION ATTENUATOR

WORKERS

- o TIME REDUCTION
  - PRE-JOB ENGINEERING
  - PRE-ASSEMBLE AS MUCH AS POSSIBLE OFFSITE
  - USE OF QUALITY WORKMEN
  - PRE-PLAN JOB TO MINIMIZE WORKER TIME ON SILOS
- o DISTANCE
  - REMOVE RADON FROM SILO TO CARBON FOR FOAMING OPERATIONS
  - KEEP WORKERS OFF DOMES TO THE MAXIMUM EXTENT PRACTICABLE
  - KEEP FOAM TRUCKS, OPS TRAILER, CONTROL ROOM - AWAY FROM RADIATION AREAS
  - REMOTE TV VIEWING
- o SHIELDING
  - INSTALL SOILBOX SHIELDING AROUND VENTILATION BUILDING

BALANCE QUALITY (REDUCE REWORK) VS. DOSE REDUCTION

TABLE 5.2.4
MAN MILLIREM ESTIMATE

5975

Construction		
Silo #1		
Install Containments	800	
Remove Covers	1200	
Install Covers	800	
	2800	2800
Silo #2		2800
Install Ducting		240
Install TV Camera		700
Operation		
Test of Rn System		360
Radon System Operation		300
Silo #1		
Ventilate	360	
Elastomer	1150	
Inspection	200	
Rigid Foam	500	
Inspection	190	
Caulk	400	
Flexible	600	
Rigid	80	
Cleanup	150	
Dome Protect	350	
	3980	3980
Silo #2		3980
Waste Transport		50
Demobilization		50
		15,260

POLYURETHANE FOAM SYSTEM
NARRATIVE AND SYSTEM DESCRIPTION

NARRATIVE

Based on the conceptual design provided by WMCO and practical aspects of applying polyurethane foams for this type of treatment, a method has been generated using the best available technology to satisfy the main objectives of the project.

One of the main objectives of the foam application to the K-65 silos is to enhance the structural integrity of the tank domes by providing underlying support. However, rigid polyurethane foams, particularly low density foams, will expand and contract due to the physical and chemical nature of the materials. In fact, the compressive strength of the rigid foam is easily high enough to cause structural damage to the dome if expanded beyond the confines of the silo air space. In addition there is the concern that contraction of the foam could open avenues for the escape of radon past the foam layer.

The use of a composite foam system will satisfy both of these concerns. Rigid foam, flexible foam, and a polyurethane elastomer will be used in the composite. The flexible polyurethane foam will be used to fill the bulk of the silo void space and provide cushioning for expansion and contraction of the foam composite as a whole. The elastomer will be used to provide a reliable seal on the surface of the K-65 residue for radon attenuation. Rigid polyurethane foam will be applied in a 2 foot thick layer on top of the elastomer as a secondary Radon barrier. In addition a 20-30 foot diameter, 6-8 foot thick core of rigid foam will be applied at the top center of the dome to provide structural support. An illustration showing the sequence of foam application is provided in Drawing No. 303317.A.004.

An independent test performed by Twin City Testing on a 2.28 lb/ft^3 density rigid foam resulted in an expansion of 5.07 percent after a 7 day aging period. At a 6 percent expansion, a 15 foot thick layer of foam could expand to 15.9 feet. This foam has a compressive strength of 20 psi which is easily enough to lift the concrete dome of the silo. For this reason, a flexible

foam will be used as the primary fill material for the silo. For enhancing the structural integrity at the center of the dome, a 3000 to 4000 ft^3 core of rigid foam will be applied. The rigid foam core will be supported by a minimum 3 foot thickness of flexible foam.

The elastomer layer will provide the primary barrier for radon gas. It will be applied in a 2 inch thick layer on top of the K-65 residue. The material is moderately dense and elastic and is not likely to expand or contract significantly. In addition to the initial layer, the elastomer will be applied to caulk the outer perimeter of the 2 foot rigid foam layer.

In an optional operation, a 2-3 inch layer of rigid foam will be applied to the outside dome surface along with an elastomer weather barrier. This outer cover will insulate the silo and reduce thermal expansion and contraction of the fill foam as well as the dome concrete structure. Moisture uptake of the foam is also reduced and the dome structure is protected from environmental elements. Although the foam cover will add a small amount of weight to the dome lid, the compressive and tensile strength of the foam will help bridge some of the weak spots of the structure.

SYSTEM DESCRIPTION

Field production of the polyurethane foam to be used for this project will involve the mixing and pouring of several components which react and set-up within 5 minutes of application. The two reaction components, an aromatic isocyanate and a polyol, along with a fluorocarbon blowing agent are pumped through individual hoses to a static mixing chamber located on the butt of a pour lance. The aromatic isocyanate and polyol are combined in a 1:1 ratio and the fluorocarbon flow, usually 4 percent of the total mixture, is controlled to maintain the proper density foam. The mixture will begin to react immediately as it leaves the lance, but will continue to flow and rise for about 3 minutes after reaching the surface. Drawing No. 303317.A.002 illustrates the polyurethane froth/pour system.

The two reactants are pumped with an air powered pumping unit with two equally sized proportioning fluid pistons. The fluorocarbon is introduced into the mixing chamber using nitrogen pressure to push it in. The maximum rate of

foam delivery is about 100 pounds per minute. The volume of foam delivered will vary depending on the density of foam desired. For a 2 lb/ft^3 foam, a maximum volume of 50 ft^3/min can be expected.

The first step in the procedure will involve application of a fairly even 2 inch thick layer of elastomer. The material will be applied via the manways using the lance with an extension. The extension on the lance will be maneuvered through the manway such that it can be pointed in the desired direction by the operator from above the manway. The elastomer will be applied initially toward the silo wall, quickly working toward the center of the silo to establish a visible layer on as much surface area as possible. The operation is repeated for each of the four perimeter manways. The center manway will be used only if the center of the silo cannot be reached from the perimeter manways. Once the initial layer is applied, the operator will rework the surface if necessary to increase the thickness. Drawing 303317.A.003 shows the arrangement to be used for this operation.

To confirm thorough and even application of elastomer, a remote TV camera along with adequate lighting will be installed at the center manway. After applying the initial layer, the surface will be examined thoroughly by camera and any problem areas noted. The problem areas will be re-worked prior to switch-over to the next phase. After the touch-up operation, the distance between elastomer coating and the dome will be determined from various access points on the dome. These measurements will provide a baseline for determining the thickness of subsequent foam layers.

The rigid foam will be applied on top of the elastomer to a thickness of 18-30 inches. It will be applied in the same fashion as the elastomer covering as much surface as possible. The foam progress will be viewed and directed by remote TV camera. The same operation will be used to apply the elastomer caulking around the perimeter of the rigid foam layer. Measurements of distance between the rigid foam surface and the dome will be performed for determination of foam thickness.

In the next step of the process, flexible foam will be used to fill most of the silo head space. A void space at the center of the silo will be left

measuring 20 to 30 feet in diameter and 6 to 8 feet deep at the center of the dome. The flexible foam will be applied in a semi-remote fashion using disposable flexible hose extensions for the lance. Flexible hose will be placed in various openings of the dome in an arrangement such that the foam will fill the outer edge of the dome and expand toward the center. The foam lance will be attached to a flexible hose extension and left on the dome as the foaming progresses. As the space fills with foam, the lance will be moved to other injection points around the dome in a pattern which prevents the formation of void spaces. When the foaming is complete, the flexible hoses will be cut off flush to the openings of the dome.

The final core of rigid foam is also applied in semi-remote fashion from the center manway. Lance extensions will be used to ensure a complete pour with a minimum of void spaces. Once the foam application is complete, all manways and other dome openings will be covered.

The optional outer dome coating will be applied using special spray equipment. The rigid foam layer will be applied first, working from the center of the dome toward the perimeter. Once the rigid foam has cured, the thin elastomer layer can be applied.

SECTION 5.0
ALARA REVIEW

5.0 ALARA REVIEW

A review of the work being engineered on the K-65 silos was made from a radiation control standpoint. The following outlines the assumptions made and the results obtained in this review.

5.1 STATEMENT OF WORK

In order to minimize releases of radon gas to the environment and to help structurally support the silo tops, WMCo has decided to insert a series of foams into the void air space at the top of both silos. A ventilation system will first be installed that will reduce the concentration of radon gas in the void air space. Then a two inch elastomer layer will be poured onto the surface of the residues in the tank. A two foot thick layer of rigid foam will then be sprayed in the silos. A "caulking" layer of elastomer will then be applied around the edges of the two foot thick rigid foam insert. The silos will then be filled to within two feet of the top in the center with flexible foam. Finally, the small remaining void will be filled with rigid foam.

5.2 ASSESSMENT

Researching various documents concerning the K-65 silos and discussing the conditions as assessed by WMCo with project personnel, existing parameters were assumed for a silo that represents a mean condition. Table 5.2.1 describes the assumed existing conditions.

By inserting the parameters of Table 5.2.1 into a dose estimating program, MICROSHIELD®, with the varying elastomer and foam levels, the dose rate at a point 81 cm above the center point of the idealized silo was calculated for the following conditions. (For details, see Appendix).

1. Existing sludge
2. Existing airspace
3. Airspace evacuated, elastomer in place
4. Air space evacuated, 2' rigid in place
5. Air space evacuated, 6' flexible in place
6. All foam in place
7. All foam in place, new equilibrium of Rn daughters

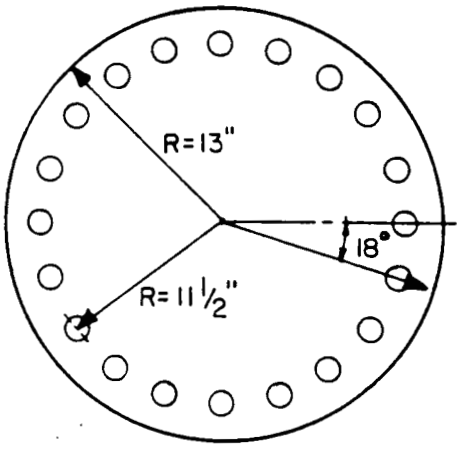
A summary of the dose rates, both measured currently and calculated by MICROSHIELD® are given in Table 5.2.2.

In reviewing the draft operating procedures and design criteria for equipment, equipment placement and shielding placement, the ALARA considerations given in Table 5.2.3 were used as guidelines. Based on these dose rates and a review of the draft procedures for foam installation, a man-millirem budget was calculated and is given as Table 5.2.4.

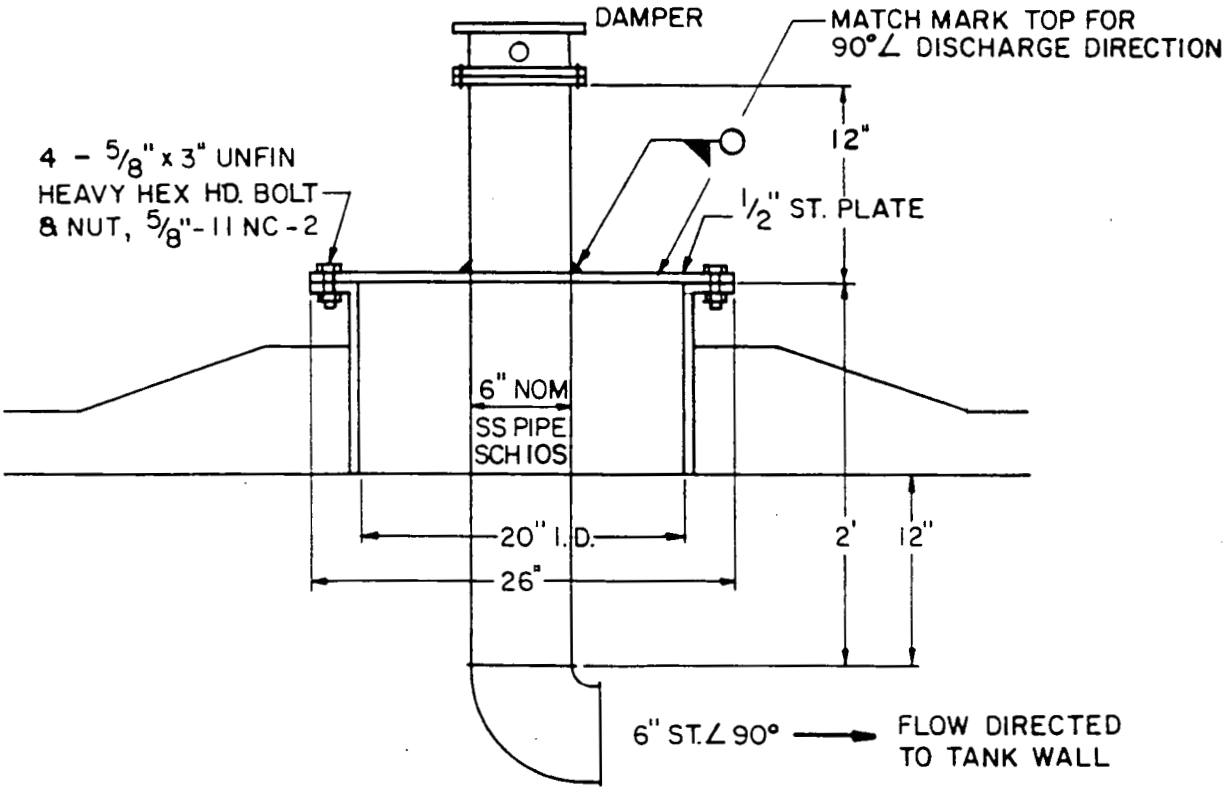
BRUNING 44-132 67120

5975

DRAWING: 317.A.001
PROJECT: 317.09
INITIATOR: K. ATWOOD
PROJ. ENGR.: D. HARMER
DATE LAST REV.:
DRAWN BY:
STARTING DATE:
DRAWN BY: W. K.



USE 4 BOLTS FOR TEMPORARY COVER WITH RED RUBBER GASKET.



WESTINGHOUSE MATERIALS COMPANY OF OHIO
FMPC FERNALD, OHIO
TEMPORARY MANWAY COVER (4 REQ'D)
K-65 SILO PROJECT

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"Do Not Scale This Drawing"

The maximum allowable on-site ambient radon concentration is listed in 10CFR20, Appendix B, Table I as 3×10^{-8} Ci/m^3. The following worst-case meteorological conditions were used to represent a conservative estimate of atmospheric dillution (dispersion).

Wind Speed = 0.5 m/s
Stability Class = F

Dispersion model calculations indicate that the maximum annual average on-site concentration would occur at a distance of about 450 meters, and would be 5.31×10^{-10} Ci/m^3. This concentration is less than two percent (< 2%) of the ambient standard of 10 CFR 20.

The maximum allowable annual off-site ambient radon concentration is listed in 10CFR20, Appendix B, Table II as 3×10^{-9} Ci/m^3. The same worst-case meteorological conditions were used to represent a conservative estimate of atmospheric dillution (dispersion).

Dispersion model calculations indicate that the annual average off-site concentration at the nearest fenceline (700m) would be 3.96×10^{-10} Ci/m^3. This concentration is 13 percent of the ambient standard of 10 CFR 20.

Addendum To

Engineering Study of The K-65 Storage Silo Radon Mitigation And Dome Reinforcement Project At The Feed Materials Production Center

Submitted By:

IT Corporation - Nuclear Services
312 Directors Drive
Knoxville, Tennessee 37923

For:

Advanced Sciences, Incorporated
107-F Jefferson Avenue
Oak Ridge, Tennessee 37830

August 31, 1987

Data sheet for the specification of a fan to provide circulation for the radon removal system.

1. Type: Pressure Blower
2. CFM: 1000 CFM (Nominal)
3. Static Pressure: 17 inches H_2O
4. RPM: 3057
5. Electrical Power: 3 phase, 60 H_z, 230/460 volt, TEFC
6. Arrangement: (Motor and fan bolted to frame, belt drive w/guard side inlet, horizontal outlet)
7. V-Belt/Direct Drive: V-Belt
8. Vibration Isolators: Not required but can be added.
9. Discharge Arrangement: Optional
10. Connection Type: Duct (Standard)
11. Horsepower: 4.47 bhp, 5 hp motor
12. Wheel size: 18 in.
13. Maximum Physical Size: L - 41 15/16 in., W - 16 11/16 in., H = 33 7/8 in.
14. Construction material: Aluminum housing and wheel for fan; steel base
15. Recommended Vendor: Cincinnati Fan and Ventilator Company
16. Model Number: PB18

*4 week lead time on this item

Data sheet for the specification of dampers for the radon removal system.

1. Type: Butterfly

2. Size: 8 at 12 in., 4 at 6 in.

3. Operator Type: Manually operated via reach rod

4. Flange Type and Size: Rolled steel angle, 12 in. and 6 in.

5. Length of Operator Shaft: Internal diameter of flange + 3 in. ± 1 in.

6. Construction Material

   - Sleeve: 16 GA STL
   - Frame: 11 GA STL
   - Blade: 14 GA STL
   - Axle: 1/2 in. diam. STL, full length
   - Seals: 1) EPT
     2) Bar Seal

7. Acceptable Leakage: 3% of rated system flow (30cfm)

8. Recommended Vendor: American Warming and Ventilating, Inc.
   P. O. Box 279
   1310 Indian Wood Circle
   Maumee, Ohio 43537
   419/893-5011

9. Model Number: VC-561

Data sheet for the specification of charcoal filters for radon adsorption at the K-65 silos.

1. CFM: 500/bed

2. Pounds of Charcoal: 1800-1900 lbs/bed (4000 lbs. total required)

3. Charcoal Characteristics: Calgon PCB 10x40 (Coconut shell base)

4. Inlet and Outlet Locations: See Drawing B.002

5. Pressure Drop: Approximately 12 in. H_2O

6. Maximum Physical Size: 48 in. x 72 in. (See Figure B.002)

7. Construction Material: Corrosion resistant steel with stainless steel screen distributor

8. Recommended Vendor: TIGG Corporation
   Box 11661
   Pittsburgh, PA 15228
   412/563-4300
   Contact: Don Tigglebeck

9. Model Number: N500 DB

Approximately 1 day to manufacture each unit.

Data sheet for the specification of the dehumidifier for the radon removal system.

1. Air Flow: 500 cfm/bed

2. Pressure Drop: Approximately 1-2 in. H_2O per bed

3. Operating Requirements: Dry 90,000 ft.^{3} of air saturated @ 40°F (100% RH)

4. Construction Material: Corrosion resistant steel with stainless steel screen distributor

5. Maximum Physical Size: 48 in. x 72 in. (See Figure B.002)

6. Type: 4 mesh Du-cal Drierite (Calcium Sulfate filler)

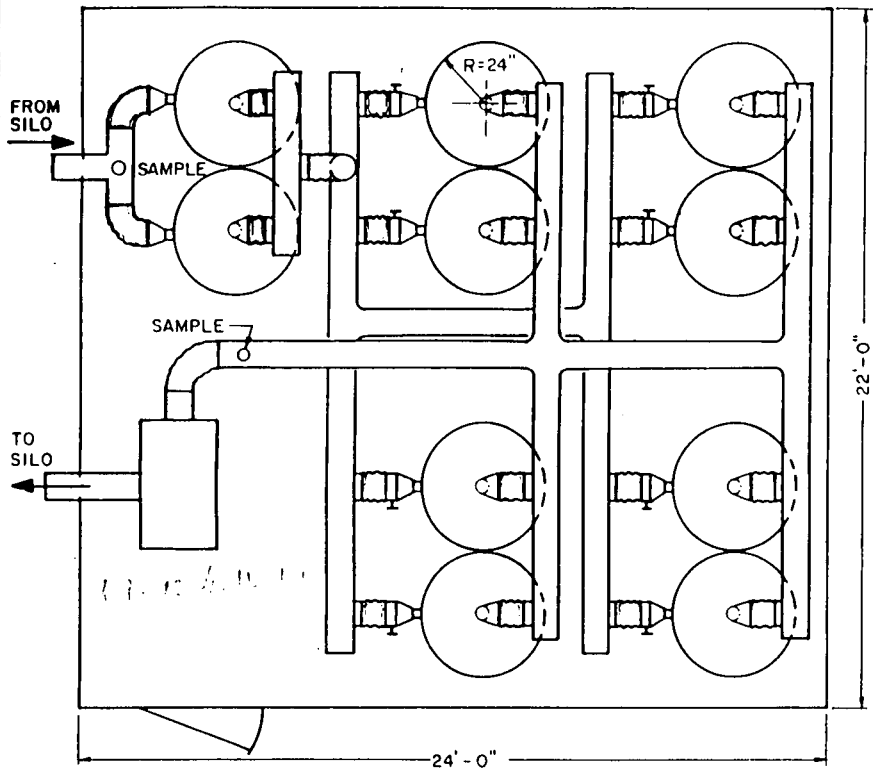
7. Recommended Vendor: Tigg Corporation
   Box 11661
   Pittsburgh, PA 15228
   412/563-4300
   Contact: Don Tigglebeck

8. Model Number: N500DB

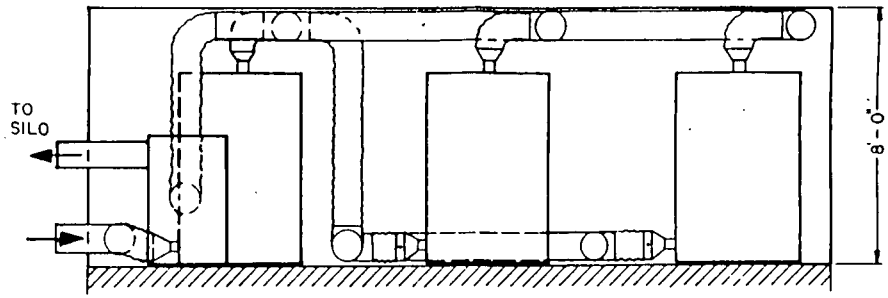
Approximately 1 day to manufacture each unit.

5975

STARTING DATE: 8-11-87	DATE LAST REV:	INITIATOR: K. ATWOOD	DRAWING NO.: 303317.B.002
DRAWN BY: W. McGILL	DRAWN BY:	PROJ. ENGR.: D. HARMER	PROJECT NO.: 303317.09



PLAN
SCALE: 1/4" = 1'-0"



ELEVATION
SCALE: 1/4" = 1'-0"

WESTINGHOUSE MATERIALS COMPANY OF OHIO
FMPC FERNALD, OHIO
GENERAL ARRANGEMENT FOR CALCIUM SULFATE/
CARBON BEDS AND ELEVATION
K-65 SILO PROJECT

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