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# Proceedings of the 24th DOE/NRC Nuclear Air Cleaning and Treatment Conference

Held in Portland Oregon  
July 15-18, 1996

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4400 Glen Willow Lake Lane  
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Harvard School of Public Health  
The Harvard Air Cleaning Laboratory  
665 Huntington Avenue  
Boston, MA 02115-6021

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**ABSTRACT**

This report contains the papers presented at the 24th DOE/NRC Nuclear Air Cleaning and Treatment Conference and the associated discussions. Major topics are: (1) nuclear air cleaning issues, (2) waste management, (3) instrumentation and measurement, (4) testing air and gas cleaning systems, (5) progress and challenges in cleaning up Hanford, (6) international nuclear programs, (7) standardized test methods, (8) HVAC, (9) decommissioning, (10) computer modeling applications, (11) adsorption, (12) iodine treatment, (13) filters, and (14) codes and standards for filters and adsorbers.



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J. Dymont, *AWE Aldermaston, England*  
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Co-Chairmen: J.J. Hayes, Jr., *US Nuclear Regulatory Commission*  
R.D. Porco, *Ellis & Watts*

Panel Members: J. Slawski, *Department of Energy*  
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## FOREWORD

The 24th DOE/NRC Nuclear Air Cleaning and Treatment Conference was held July 14 - 18, 1996 in Portland, Oregon. The Conference was sponsored by the International Society of Nuclear Air Treatment Technologies, the Harvard Air Cleaning Laboratory, and by the US Department of Energy and US Nuclear Regulatory Commission. International interest and participation remained high, with 30% of the papers being presented by scientists and engineers from nine foreign countries. A panel session was held to discuss international programs and research in nuclear air cleaning technology. Other major topics covered were: standards for manufacturing, operation and testing of air cleaning elements and systems; decontamination and decommissioning processes; waste management; instrumentation and measurement systems; gas adsorption; chemical operations; reactor accident scenarios; filters and filtration. Panel sessions were held to discuss the testing of air and gas cleaning systems and codes and standards for the construction and installation of filters and absorbers.

A highlight of the conference was a detailed review of DOE's operations at the Hanford Reservation, Richland, WA, where a ten-year multi-billion dollar decontamination and decommissioning project is underway. Some conference attendees toured the Hanford site after the Conference. The special emphasis on air cleaning for process gas treatment in the waste management area, featured at the 23rd Conference in July 1994, continued as a common theme throughout this conference. Air cleaning requirements for reactor decontamination and decommissioning has also come to the forefront.

I would like to express thanks to the representatives of the Conference's sponsors and financial supporters: Dr. Richard Lee, US Nuclear Regulatory Commission, Mr. James Slawski, US Department of Energy, and Mr. Richard Porco, Chairman of the International Society of Nuclear Air Treatment Technologies. Each of these individuals provided unstinting support and assistance during the planning and conduct of the Conference.

The Chairman would also like to extend his sincere thanks to all members of the Program Committee who worked diligently over the past couple of years to put together the program of the 24th Conference and who helped conduct it in an orderly manner. He is very grateful to each of them for their devotion to the Air Cleaning Conferences and for their willing assistance to the Chairman.

The thanks of all the attendees, as well as the Chairman, are due Mary Kovach for her kind management of each morning's hospitality gathering of family members.

The Chairman extends his special thanks to Suzanne Doyle Shaffner for her able handling of all the business affairs of the Conference and for her careful and timely assembly of the camera-ready master copy of the Proceedings.

Melvin W. First  
28 February, 1997



SESSION 1

**OPENING OF THE CONFERENCE**

Monday July 15, 1996  
Chairman: M.W. First

OPENING COMMENTS OF CHAIRMAN AND GREETINGS FROM  
SPONSORS

M. W. First, Conference Chairman

KEYNOTE ADDRESS: NUCLEAR AEROSOLS: UNFINISHED  
BUSINESS

Thomas Kress

Chairman, Advisory Committee on Reactor Safeguards

AIR CLEANING ISSUES WITH CONTAMINATED SITES

R.R. Bellamy

NEW CHALLENGES TO AIR/GAS CLEANING SYSTEMS

J.L. Kovach

APPLICATION OF INNOVATIVE POLICIES FOR CONTROLLING  
RADIONUCLIDE RELEASES: THE "OPEN-MARKET TRADING  
RULE"

D.W. Moeller

## 24th DOE/NRC NUCLEAR AIR CLEANING AND TREATMENT CONFERENCE

### OPENING OF THE CONFERENCE & GREETINGS FROM SPONSORS

**FIRST:** It is my special privilege to call the Conference to order, and to bid you all welcome on behalf of the program committee and the several sponsors of this conference. One of the conference sponsors is the Harvard Air Cleaning Laboratory. I am Melvin First, I bring you Harvard's greetings and a hearty welcome. The other sponsors will greet you shortly. I would like to extend a special greeting to the many friends who have joined us from other countries. I know I speak for all of the US attendees as well as myself when I say how much we appreciate your active participation in these conferences over the many years that they have been held. The delegates from other countries continue to be a major factor in these conferences. Were it not for the fact that two of US government agencies are financial sponsors, I would think of this Conference as being a world conference because truly it does represent the world community in the technical areas covered by the conference. So once again, we welcome you and hope that you find your trip useful and pleasurable.

It's obvious that these conferences require a lot of hard work on the part of the entire Program Committee. Their duties don't cease at the beginning of the conference, because they all have been given assignments as session chairmen, and you will interact with them throughout the Conference. The Conference Committee members are listed in the Conference Program. Let me identify by name: Wendell Anderson, consultant. Ronald Bellamy, Region One, Nuclear Regulatory Commission. Werner Bergman, Lawrence Livermore National Laboratory, California. Richard Dorman, formerly with the Porton Downs military establishment in England, and currently a consultant. Ken Duvall, Department of Energy. Tetsuo Fukasawa, Hitachi in Japan. Jack Hayes, Nuclear Regulatory Commission, Headquarters in Maryland. Robert Jubin, Oak Ridge National Laboratory. J Louis Kovach, NUCON International. Richard Lee, the Nuclear Regulatory Commission. Joseph Paul, Westinghouse Savannah River Company. Richard Porco, Ellis & Watts. Richard is the president of the International Society for Nuclear Air Treatment Technologies. Paul Sigli, consultant France. James Slawski, Department of Energy. Ray Weidler, Duke Power Company. Ray is the Chairman of the Committee on Nuclear Air and Gas Standards. Jeurgen Wilhelm, Germany, many years associated with KLK, and currently a consultant. And Roger Savadowski, Defense Nuclear Facilities Safety Board. One additional member of the program committee that I have not yet named is Humphrey Gilbert. Humphrey, because of physical disability, has been unable to be with us today. I'm sure this is the first Air Cleaning Conference he has missed since they started forty-five years ago. I know we all miss him as much as he misses not being here. We extend all our best wishes to him.

Now, for the other sponsors of the conference, I'm going to call on a representative from each of the organizations to send their own greetings and welcome to you. The first of these, from the US Department of Energy, is James Slawski, who is in DOE's Industrial Hygiene Office of Defense Programs. He is a certified industrial hygienist, with twenty-five years experience in occupational safety and health. He has been at the DOE for six years.

**SLAWSKI:** This is the first conference, that Humphrey Gilbert has missed, and the first conference I have attended. On behalf of DOE I welcome all of you. I look at this as an opportunity for all of us to figure out where we are and figure out what we have to do to try to do our jobs a little bit better and smarter in the future. We are working with CONAGT on standards for filters on the FC section in particular. We are trying to work our way to adopting for the Department that consensus standard. We are not sure we are there yet. We are working in that direction and we have discussions ongoing here at this Conference to help us go in that direction. Whatever we can do to get us to a state that satisfies DOE's needs for a consensus standard will be very beneficial. Again, welcome and thank you for attending.

## 24th DOE/NRC NUCLEAR AIR CLEANING AND TREATMENT CONFERENCE

**FIRST:** I will next call on Dr. Richard Lee representing the US Nuclear Regulatory Commission.

**LEE:** On behalf of the Nuclear Regulatory Commission, I welcome you to this Conference. We are very pleased that we have supported this Conference with the DOE and since its inception, and we hope we will do so in the future. Tomorrow Ronald Bellamy and I will give you a briefing on what is happening at the Commission with respect to domestic activities and international activities. I am from the Office of Research. Most of our research now focuses on the national arena, but I hope to give you a very brief report on what other programs we are tracking in the European and in the Pacific regions. I wish that you have a successful Conference and a pleasant stay at this city.

**FIRST:** The fourth sponsor is the International Society of Nuclear Air Treatment Technologies. To represent that organization we have Richard Porco, who is the president of ISNATT.

**PORCO:** Welcome you to the 24<sup>th</sup> Nuclear Air Cleaning and Treatment Conference on behalf of ISNATT. I also welcome you to the ISNATT Expo. I hope you will all take time to visit by the exhibits. They will be held in the foyer. I think you will find a lot of equipment on display there that will be topics of discussion at some of the technical sessions. I also want to thank all you who participated in the ISNATT short courses. Those interested in future short courses should stop by the booth for the ISNATT and ASME booths. I think it is very important to point out the work that ISNATT is doing to support the Nuclear Air Cleaning and Treatment Conferences. To in this endeavor I would encourage all to join ISNATT and get involved in promoting the Expo as well as the international exchange of technologies. This is the way to make this Conference a success and to make sure that we continue to have the type of support and the type of exchange that we have enjoyed during the course of the meetings.

**FIRST:** In addition to the many technical papers that are a hallmark of these Conferences, there are numerous highlights that I would like to call to your attention. Shortly, our keynote speaker will address a topic of special interest to specialists in nuclear air and gas cleaning technology. This will be followed by three very seminal papers concerning new directions for the nuclear industry, in general, and air and gas cleaning specialists in particular. Each will leave you with many new and important things to think about. I look forward to hearing the presentations. On Tuesday, we will have a working lunch with John Wagoner, Manager of the DOE's Richland Operations Office. He will talk about progress and challenges in cleaning up Hanford. Those intending to go on the Hanford tour starting Thursday afternoon will, I know, find this address a very special preparation for your visit. There will be an International Panel after the working lunch, and then our traditional Open-end Session. Those who have things you would like to present or questions you would like to ask the assembled group, please keep this session in mind. There will two panel sessions: one on testing of nuclear air cleaning systems that will include a newly-proposed AG1 code section on acceptance testing, plus a new standard tentatively referred to as N-511 on in-service testing. Both of these documents are nearing their final phase, and I am sure you will be interested in learning what they propose as well as having some input into the final document. The second panel session is concerned with the new AG1 code section on HEPA filters. This code section basically replaces the military specifications that we have been using for this purpose for many decades. Here also, I think you will want to hear about projected changes to the codes and how they will be brought about. I can promise you that these will be very interesting sessions.

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### KEYNOTE ADDRESS

Introduction of Thomas Kress, Keynote Speaker

**FIRST:** Dr. Kress has recently been appointed to the very important post of Chairman of the Nuclear Regulatory Commission's Advisory Committee for Reactor Safeguards. This committee, as many of you know, was created by a congressional statute at the very beginning of the government's nuclear program after World War II. It has continued, uninterrupted as a very important committee that assists the NRC with technical advice on all aspects of nuclear safety. One of the topics, of course, is air and gas cleaning technology. Dr. Kress has been involved in this technical area for many years. Before his appointment to the Advisory Committee for Reactor Safeguards he worked for thirty-five years at Oak Ridge National Laboratory in various posts concerned with areas of nuclear safety. He managed the NRC's research program at Oak Ridge in the area of source terms and nuclear aerosol behavior. His education included a number of different schools, but he received his doctorate in engineering sciences at the University of Tennessee. I've known Tom for many years, served on advisory panels with him, and it has been a sheer delight for me to have had him respond positively to the program committee's invitation to give this keynote address. The title of his talk is "Nuclear Aerosols: Unfinished Business".

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## NUCLEAR AEROSOLS: UNFINISHED BUSINESS

T. S. Kress

Talk presented to the 24th Nuclear Air Cleaning Conference \*

July 15, 1996

Portland, Oregon

I am delighted to be here to give the keynote address to this the 24th meeting of the Nuclear Air Cleaning Conference - a conference that I well respect. I have attended several of these in the past but I haven't been active recently. That is because the extent of my technical involvement in nuclear air cleaning over the past 5 years has been to argue with fellow ACRS members as to which is most important to reactor safety - thermal hydraulics or aerosol behavior. I am not sure who is winning the ongoing argument.

I think you can even correlate being asked to be a keynote speaker as being a pretty good sign that you may be near the end of your useful technical life. When asked if I would make this presentation, my first thought was why, couldn't the 1st, 2nd, 3rd, 4th, and 5th choices make it?

I understand the focus of this conference is on "nuclear air and waste treatment technology and its relationship to nuclear safety". If I interpret that in a broad sense to include aerosol behavior in general, I can say a few words about that.

I would like, first, to make the observation that over the years that I have dealt with source terms, severe accidents, and levels 1 and 2 PRAs, I have come to realize that assessing these important aspects of nuclear safety is largely an exercise in thermal hydraulics, chemistry, and aerosol physics. In the past, this series of conferences has made very substantial contributions to the field of aerosol physics and how to effectively clean aerosols and gases from air spaces and streams.

If you look at today's NRC's research effort on aerosol behavior, it is mostly limited to evaluating a few of the source magnitudes. NRC has proclaimed that they no longer need do research on the subsequent transport behavior of aerosols. Why have they reached this conclusion? They say because, in the overall assessment of risk of nuclear power plants, the uncertainties are very large and the contribution that is due to uncertainties in the aerosol transport behavior is very small compared to the other sources of uncertainty. If this is indeed true, then I take it as a tribute to the fine work that has been done in this area by you and others. But, will this remain the situation for much longer?

One of the very strong trends on the international nuclear scene for "new generation" nuclear power plants is that the containment must be designed to cope with severe accidents - meaning that they will not fail under even the lowest probability severe accident sequences.

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\* I am required by the by-laws of ACRS to announce that I do not represent the committee and that the views I express are my own and are not necessarily those of the committee.

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Along with this requirement for the containment to maintain its integrity under severe accident conditions, is a requirement that the release from the containment must be kept low enough that there will be no need for an emergency response.

These are, indeed, very stringent requirements. I just returned from a week-long meeting in Vienna for the IAEA in which the subject was...how should the source term be specified for such new generation plant requirements for use in containment and ESF design and for assessing compliance with the possible regulatory requirement of no evacuation.

One question we wrestled with a great deal in Vienna was...just how do you specify a fission-product/aerosol source term for a future plant of unknown design and give freedom (and even incentive) to the designer to choose such design parameters as reactor type, power, power density, fuel and cladding design, burnup, quantity of water available to the reactor cooling circuit, and strategies for coping with ex-vessel phenomena? If you have any thoughts or suggestions on this, I would like to hear about them before the follow-on meeting to be held in November which is supposed to come to grips with this issue.

Let me tell you now though that if these are to be new requirements, then the complete spectrum of aerosol considerations and their uncertainties jumps back to front and center. We may have to reconsider the need for additional research in this area.

Of course, nuclear aerosol research is still needed for decontamination, fuel reprocessing, waste treatment, and waste storage. If, also, it does re-emerge for nuclear reactor safety, then what are some of the areas that may need additional research or sharpening up?

Well - back in 19 ought..????, when I was actively developing and conducting research programs on nuclear aerosols, times were very good. *How good were they????* They were so good that my group had more research than they could actually handle. Therefore, I always made it a habit to keep in my left hand desk drawer a list of potential future aerosol research areas to follow-on with when we completed the ones that we were currently working on. In today's times of limited research money, I don't think this would be a successful strategy, but it worked well back then.

So, in preparation for this talk, I went back to my files to see if I could find my old list. Sure enough, it was still there. This is a list, mind you, that I made back in 1986 (before Chernobyl) which was essentially the time I quit being a researcher to become a Department Head -- a fate I would not wish on any of you.

[Slide number 1]

Ten years later, I do not really know the status of these, but I would bet that this would still be a pretty good list to start from. I meant to do as many of these as I could, but I didn't get the chance. That is why I have subtitled this talk "unfinished business." I no longer have a use for this list so you are welcome to it.

Before I leave this list, there is one more research area I nearly forgot. The British think more research is needed on the effects of smoke. They have concluded that smoke is an essential ingredient in making electronic and electrical equipment function properly. They reached this conclusion because of an astute observation that every time a piece of such equipment failed or malfunctioned it was because the internal smoke had escaped - they could see it leaving the piece of equipment. They conclude that better means to keep it from escaping are needed...an imminently reasonable conclusion don't you think.

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In parting then, I don't think I could do better than to quote from Mel First:

[Slide number 2]

“These conferences have been a force for advancement as well as a forum for refinement of current technology.”

“The conference will continue to be highly involved in the important task of maintaining and improving engineered safety features for existing power reactors and with meeting the air cleaning and treatment needs of advanced reactors.”

I can only add ...keep up the good work and I trust this Conference will be as highly successful as have been past ones.

# POTENTIAL NUCLEAR AEROSOL RESEARCH PROJECTS

## THE FOLLOWING WERE COPIED FROM A 1986 LIST

1. THEORETICAL VALIDATION OF THE GRAVITATIONAL  
SETTLING ASSUMPTION/MODEL
2. A BETTER MODEL FOR SHAPE FACTORS AS FUNCTIONS OF  
AEROSOL SIZE
3. DIRECT EXPERIMENTAL MEASUREMENT OF  $\eta$  AND  $\tau$  (AS  
FUNCTIONS OF AEROSOL SIZE AND TYPE)
4. EFFECTS OF HYDROGEN BURNING/DETONATION ON  
AEROSOL SIZE (DE-AGGLOMERATION AND EVAPORATION  
OF ABSORBED WATER)
5. CHEMICAL EFFECTS ON AEROSOLS (MOISTURE,  $H_2$   
BURNING, ATMOSPHERIC OXYGEN).
6. LIFT-OFF/RESUSPENSION
7. BETTER CODE TREATMENT OF MULTICOMPONENT  
AEROSOLS.
8. EXPERIMENTAL DETERMINATION OF THE NUCLEATION  
SIZES OF AEROSOLS . RELATE NUCLEATION SIZE TO  
MACROSCOPIC PROPERTIES.
9. AEROSOL SOURCES FROM STEAM EXPLOSIONS.
10. EFFECTS OF AEROSOLS ON RECOMBINERS.
11. BETTER IMPACTION DEPOSITION MODELING.
12. EXPERIMENTAL VALIDATION OF DIFFUSIOPHORESIS  
MODELS IN PRESENCE OF NON-CONDENSABLE.
13. BETTER MODELS FOR AEROSOL TRANSPORT THROUGH  
CRACKS IN CONCRETE CONTAINMENTS.
14. EFFECTS OF RADIATION-INDUCED CHARGES ON AEROSOL  
BEHAVIOR IN CONTAINMENTS.
15. EFFECTS OF AEROSOLS ON ELECTRONIC EQUIPMENT.

## **QUOTES FROM MEL FIRST**

***THESE CONFERENCES HAVE BEEN A FORCE FOR  
ADVANCEMENT AS WELL AS A FORUM FOR  
REFINEMENT OF CURRENT TECHNOLOGY."***

***THE CONFERENCE WILL CONTINUE TO BE HIGHLY  
INVOLVED IN THE IMPORTANT TASK OF  
MAINTAINING AND IMPROVING ENGINEERED SAFETY  
FEATURES FOR EXISTING POWER REACTORS AND  
WITH MEETING THE AIR CLEANING AND TREATMENT  
NEEDS OF ADVANCED REACTORS."***

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### DISCUSSION

**FIRST:** The talk is open for questions and comments. I would like to ask Tom to comment further on the long list of projects you wrote down approximately a decade ago. I gather that they have not yet been accomplished.

**KRESS:** I meant to do all of them, but I got out of the business about then, and that is the reason I listed them as unfinished business. At least they are unfinished for me.

**FIRST:** What do you think is the most important area that we should be concentrating on now, assuming that somebody will come up with adequate funds, which I realize is somewhat uncertain these days.

**KRESS:** That is a tough question, but I will try to give you a quick answer. I think that better, higher capacity HEPA-type filters that do not fail under loads that are relatively large, would go a long way toward solving many problems, I think that would be my choice.

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### INTRODUCTION

**FIRST:** As I mentioned earlier, we have three seminal papers that will occupy the rest of the morning, and I do call your attention to these papers because I think they are opening new ground. They are of extreme interest at present and will continue to be into the future. The first of these papers will be presented by Dr. Ronald Bellamy. Many of you know Ron, he's been a constant attendee and contributes at these Conferences since he left Ohio State University and joined the Nuclear Regulatory Commission. Because his doctoral thesis work was in activated carbon, he came to AEC headquarters at an opportune time with all the knowledge and assurance of a newly minted Ph.D. A nice thing about Ron is his consistency, he is still very positive and he has maintained his enthusiasm and elan through the years. He is my very valued colleague. He is presently Chief of the Decommissioning and Laboratory Branch in Region One of the Nuclear Regulatory Commission. He is on the ASME and ASTM committees on standards and on the Program Committee for this Conference. He's a visiting lecturer at Harvard University and lectures in the course that I am associated with, the In-place Filter Testing Workshop, as well as Dade Moeller's course on Nuclear Emergency Preparedness issues.

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### AIR CLEANING ISSUES WITH CONTAMINATED SITES

Dr. Ronald R. Bellamy  
US Nuclear Regulatory Commission  
King of Prussia, PA 19406

#### Abstract

The US Nuclear Regulatory Commission has developed a list of contaminated sites that warrant special USNRC attention because they pose unique or complex decommissioning issues. This list of radiologically contaminated sites is termed the Site Decommissioning Management Plan (SDMP), and was first issued in 1990. A site is placed on the SDMP list if it has;

1. Problems with the viability of the responsible organization (e.g., the licensee for the site is unable or unwilling to pay for the decommissioning;
2. Large amounts of soil contamination or unused settling ponds or burial grounds that may make the waste difficult to dispose of;
3. The long-term presence of contaminated, unused buildings;
4. A previously terminated license; or
5. Contaminated or potential contamination of the ground water from on-site wastes.

In deciding whether to add a site to the SDMP list, the NRC also considers the projected length of time for decommissioning and the willingness of the responsible organization to complete the decommissioning in a timely manner. Since the list was established, 9 sites have been removed from the list, and the current SDMP list contains 47 sites in 11 states. The USNRC annually publishes NUREG-1444, "Site Decommissioning Management Plan", which updates the status of each site.

This paper will discuss the philosophical goals of the SDMP, then will concentrate on the regulatory requirements associated with air cleaning issues at the SDMP sites during characterization and remediation. Both effluent and worker protection issues will be discussed. For effluents, the source terms at sites will be characterized, and measurement techniques will be presented. Off-site dose impacts will be included. For worker protection issues, air sampling analyses will be presented in order to show how the workers are adequately protected and their doses measured to satisfy regulatory criteria during decontamination operations.

#### Introduction

The cleanup of radiological contamination, both within the property of a licensee, and in the general environs as a result of licensee operation, is a major challenge facing the nuclear industry. In recognition of this focus of activity, the NRC formally acknowledged several contaminated sites to promote timely and safe cleanup of these sites and provide special NRC attention because they pose unique or complex decommissioning issues. This list is presently composed of 47 sites in 11 states. In addition, numerous other sites are undergoing or have completed decontamination efforts and have been decommissioned. Some of these are active licensees, while others are formerly-licensed sites from as long as 40 years ago. The methods used to review the decontamination activities, and the acceptance criteria, should be well-defined and understood so that achievable goals are acknowledged and used in the activities. The specified end-points for the cleanup

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activities used to release areas for unrestricted use should be readily available to the technical experts, and the public alike, open to public scrutiny, and, as generic as possible.

### The Site Decommissioning Management Program

NRC developed the Site Decommissioning Management Plan (SDMP) in 1990 to identify a list of contaminated sites that warrant special NRC attention because they pose unique or complex decommissioning issues. While none of these sites represent an immediate threat to the public health and safety, they have contamination that exceeds criteria for release for unrestricted use. All of these sites require some degree of remediation, and several involve regulatory issues that will need to be addressed by the NRC Commissioners. These problematic sites have buildings, former waste disposal areas, large piles of tailings, groundwater, and soil contaminated with low levels of uranium or thorium (source material) or other radionuclides. Consequently, they present varying degrees of radiological hazard, remediation complexity, and cost. Some of the sites are still under the control of active NRC licenses, whereas, licenses for other sites already may have been terminated or never may have been issued. At some sites, licensees are financially and technically capable of completing decommissioning in a reasonable timeframe, whereas, at other sites, the licensee or responsible party may be unable or unwilling to perform decommissioning. In addition, the sites are currently in various stages of decommissioning. At some sites, licensees have initiated decommissioning, whereas, at other sites, decommissioning has not yet been planned or initiated. Sites are placed on the SDMP if there are:

- (1) Problems with the viability of the responsible organization (e.g., the licensee for the site is unable or unwilling to pay for the decommissioning;
- (2) Large amounts of soil contamination or unused settling ponds or burial grounds that may make the water difficult to dispose of;
- (3) The long-term presence of contaminated, unused buildings;
- (4) A previously terminated license; or
- (5) Contamination or potential contamination of the groundwater from on-site wastes.

In deciding whether to add a site to the SDMP list, the NRC also considers the projected length of time for decommissioning and the willingness of the responsible organization to complete the decommissioning in a timely manner. Since the list was established, 9 sites have been removed from the list, and the current SDMP list contains 47 sites in 11 states. The USNRC annually publishes NUREG-1444, "Site Decommissioning Management Plan", which updates the status of each site. The list was established in 1990, and 9 sites have been removed after successful completion of cleanup to meet requirements, or transferred to another regulatory authority. There are eight major activities associated with any major decommissioning activity. Progress can be measured against these milestones.

- (1) A characterization of the site, which would identify the amount and location of radioactive material. A characterization plan is part of this activity, the performance of the characterization, and preparing the characterization report;
- (2) Regulatory review and approval of the site characterization plan and the site characterization report;
- (3) Development and submission of a decommissioning plan, outlining the steps to be taken to perform the decontamination activities;

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- (4) Regulatory review and approval of the decommissioning plan;
- (5) Performance of the decontamination and decommissioning activities outlined in the plan;
- (6) Performance of a final status survey to verify releasability of the site and submittal of a final status survey report;
- (7) Regulatory review of the termination survey report, and performance of a confirmatory survey;
- (8) Termination of the license.

### Radiological Criteria for Decommissioning

Generally, licensees decommission their facilities with the intent of terminating the license and using the facility for activities that do not involve licensed material. The ultimate goal of decommissioning is to reduce residual radioactivity to levels that are indistinguishable from background levels. These facilities must be decommissioned such that they do not contain residual radioactive material levels in excess of criteria for unrestricted use. The radiological criteria for unrestricted use are identified in the "Action Plan to Ensure Timely Remediation of Sites Listed in the Site Decommissioning Management Plan", 57 FR 13389, April 16, 1992. These criteria include the following:

- USNRC Policy and Guidance Directive FC 83-23, "Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Byproduct, Source and Special Nuclear Material Licenses", November 14, 1983;
- Regulatory Guide 1.86, "Termination of Operating Licenses for Nuclear Reactors", June 1974;
- Options 1 and 2 of the Branch Technical Position, "Disposal or Onsite Storage of Thorium and Uranium Wastes from Past Operations" 46 FR 52601, October 23, 1981;
- 40 CFR Part 141, Interim National Primary Drinking Water Regulations;
- EPA's "Radiation Dose Guidelines for Protection Against Transuranium Elements Present in the Environment as a Result of Unplanned Contamination".

These criteria are applied on a site-specific basis with emphasis on remediating residual radioactive material to levels that are as low as reasonably achievable. In addition, these criteria will be considered in establishing site-specific ALARA levels for SDMP sites in license amendments and orders. Further, implementation of residual contamination criteria is dependent on the establishment of acceptable dose or risk criteria for unrestricted use of nuclear facilities.

The Policy and Guidance Directive and the Regulatory Guide provide criteria in terms of fixed and removable contamination and acceptable radiation exposures associated with beta-and gamma-emitting surface contamination. The guidance also provide acceptable volumetric concentrations of uranium, thorium, americium and plutonium in soil. The Branch Technical Position, published in the Federal Register on October 23, 1981, 46 FR 52061, provides acceptable activity concentrations of uranium and thorium (with and without decay products) in soil under a variety of conditions.

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The Environmental Protection Agency's (EPA's) Interim National Primary Drinking Water Regulations, 40 CFR Part 141, July 9, 1976, 41 FR 38404, provides maximum contaminant limits for radionuclides in public drinking water, which can be extended to apply as acceptable activity concentration in groundwater and surface water. These documents provide guidelines for acceptable average and maximum surface contamination levels for a wide variety of radionuclides. Also provided are average and maximum radiation levels of 0.2 and 1.0 millirad per hour at 1 centimeter for beta and gamma-emitters. In addition, an acceptable external radiation exposure rate for soil contamination of 10 microroentgen above background per hour at one meter is specified.

### Regulatory Guide 1.86

When these acceptable surface contamination levels are combined with an exposure rate limit of 5  $\mu\text{R/hr}$  above background at 1 meter, this guide has been used in decommissioning and terminating licenses for a number of research reactors. The 5  $\mu\text{R/hr}$  criterion for indoor contamination corresponds to an annual whole body dose of about 10 millirem for an assumed indoor occupancy period of 2000 hours per year. The 5  $\mu\text{R/hr}$  criterion has been applied to  $^{60}\text{Co}$ ,  $^{137}\text{Cs}$ , and  $^{152}\text{Eu}$  that may exist in concrete, components, and structures at nuclear reactor research facilities, with an overall dose objective of 10 millirem/year.

The Branch Technical Position (BTP) on Disposal or Storage of Thorium and Uranium Wastes, 46 FR 52061 provides guidance on decommissioning and cleanup of fuel cycle and other facilities contaminated with relatively large volumes of waste with low activity concentrations of uranium and thorium. In combination with the disposal provisions in 10 CFR 20.302, the technical position provides four "options" for disposal of uranium and thorium wastes, which vary in activity concentration and corresponding potential radiological dose. Only the lower-activity concentration limits and disposal methods provided in Options 1 and 2 of the technical position can be applied as criteria for the release of a site for unrestricted use. Options 3 and 4 require deed restrictions, in effect releasing a site for restricted use.

Under Option 1 of the Branch Technical Position, licensees may dispose of wastes containing natural thorium, depleted or enriched uranium, and natural uranium without restrictions for burial method or post-termination land use. The activity concentrations for this option are consistent with the levels identified in Table I. The maximum activity concentration for natural uranium is based on EPA standards for cleanup and stabilization of uranium mill tailings for  $^{226}\text{Ra}$  (5 pCi/g) including its decay products (42 FR 2556-2563). The activity concentrations for natural thorium and depleted or enriched uranium are based on internal radiation dose guidelines recommended by the EPA for protection against transuranium elements present in the environment as a result of unplanned contamination (42 FR 60956-60959). As shown in Table 1, committed doses are expected to be on the order of one millirad per year to the lung or three millirad per year to the bone from inhalation and ingestion. The resulting concentrations would also limit external exposures to less than 10  $\mu\text{R/hr}$  above background.

Under Option 2 of the 1981 BTP, concentrations of natural thorium and depleted or enriched uranium are required to be buried under prescribed conditions without requiring land use restrictions after license termination. Disposals performed under Option 2 guidelines must be covered by four feet or more of clean soil. Acceptable activity concentrations for burial were calculated based on

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the criteria that (1) radiation doses to members of the public should not exceed Option 1 levels when the waste is buried in an approved manner under routine exposure conditions, and (2) radiation doses to an inadvertent intruder should not exceed 170 millirems to a critical organ or whole body.

When applying Option 2 of the technical position, the human intruder pathway is evaluated. In addition, consistent with the technical position, groundwater considerations are also evaluated, when necessary, because of site specific hydrogeologic features and groundwater use. Dose from the groundwater pathway should not exceed 3 mrad/yr to the bone (approximately 1.8 mrem/yr effective-dose-equivalent) consistent with the stated dose basis for the Option 1 concentration values. Dose from the human intruder pathway should not exceed 170 mrem/yr to the critical organ. For soluble uranium, the critical organ is the bone. For insoluble uranium, the critical organ is the lung. For thorium, both soluble and insoluble, the critical organ is the whole body.

The dose of 170 mrem/yr to the whole body, from Option 2 concentrations of thorium, via the human intruder pathway, may be unacceptably high. Further, this 170 mrem/yr whole body dose assumes 0.8 occupancy factor and a 0.5 shielding factor. If the occupancy and shielding factors are set to 1, the dose from thorium may be as high as 420 mrem/yr to the whole body. Therefore, for thorium concentrations above the Option 1 limit, the 10 CFR 20 limit of 100 mrem/yr total effective dose equivalent may be the appropriate unrestricted-use release limit. The intruder exposure pathway could possibly be ignored when the disposal method makes the chance of future human access very remote, such as via deep disposal, or disposal by mine backfill. Disposals under Option 2 that involve depleted or enriched uranium are evaluated for buildup of decay products for a period of 1000 years. The original dose assessments to determine the Option 2 limits for depleted and enriched uranium did not include decay products because the decay products are removed in processing the uranium. Significant ingrowth of the decay products requires more than 1000 years and has not been routinely considered in assessing the acceptability of the disposal under Option 2 even though potential doses may increase considerably with time (i.e., beyond 10,000 years).

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**TABLE I**

<u>Contamination</u>	<u>Criteria</u>	<u>Dose Basis</u>
Average, fixed U-nat, <sup>235</sup> U, <sup>238</sup> U,	5000 dpm/100 cm <sup>2</sup>	13 mrem/yr
Average, fixed <sup>226</sup> Ra, <sup>228</sup> Ra, transuranics, etc.	100 dpm/100 cm <sup>2</sup>	0.2 mrem/yr
Average, fixed Th-nat, <sup>232</sup> Th, Sr, etc.	1000 dpm/100 cm <sup>2</sup>	28 mrem/yr
Avg. and max. external beta-gamma dose	0.2-1 mrad/hr at 1 cm	20 mrem/yr
U-nat with decay products in soil	10 pCi/gm	2.4 mrem/yr
Depleted Uranium in soil	35 pCi/gm	1.8 mrem/yr
Th-nat with decay products in soil	10 pCi/gm	35 mrem/yr
Enriched Uranium in soil	30 pCi/gm	1 mrad/yr to lung 3 mrad/yr to bone
<sup>239</sup> Pu in soil	25 pCi/gm	15 mrem/yr
<sup>241</sup> Am in soil	30 pCi/gm	19 mrem/yr
External radiation	10 μR/hr at 1 meter above background	24 mrem/yr

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### Listing of Sites

The sites currently on the Site Decommissioning Management Plan include the following:

Advanced Medical Systems, Inc., Cleveland, OH  
Aluminum Company of America, Cleveland, OH  
Anne Arundel County/Curtis Bay, Anne Arundel County, MD  
Army, Department of, Aberdeen Proving Ground, Aberdeen, MD  
Army, Department of, Jefferson Proving Ground, Jefferson, IN  
Babcock & Wilcox, Apollo, PA  
Babcock & Wilcox, Parks Township, PA  
BP Chemicals America, Inc., Lima, OH  
Brooks & Perkins, Detroit, MI  
Brooks & Perkins, Livonia, MI  
Cabot Corporation, Boyerton, PA  
Cabot Corporation, Reading, PA  
Cabot Corporation, Revere, PA  
Chemetron Corporation, Bert Avenue, Cleveland, OH  
Chemetron Corporation, Harvard Avenue, Cleveland, OH  
Clevite, Cleveland, OH  
Dow Chemical Company, Bay City and Midland, MI  
Elkem Metals, Inc., Marietta, OH  
Englehard Corporation, Plainville, MA  
Fansteel, Inc., Muskogee, OK  
Hartley and Hartley (Kawkawlin) Landfill, Bay County, MI  
Heritage Minerals, Lakehurst, NJ  
Horizons, Inc., Cleveland, OH  
Kaiser Aluminum, Tulsa, OK  
Kerr-McGee, Cimarron, OK  
Kerr-McGee, Cushing, OK  
Lake City Army Ammunition Plant (formerly Remington Arms Co., Independence, MO)  
Minnesota Mining and Manufacturing Co., (3M), Pine County, MN  
Molycorp, Inc., Washington, PA  
Molycorp, Inc., York, PA  
Northeast Ohio Regional Sewer District/Southerly Plant, Cleveland, OH  
Nuclear Metals, Inc., Concord, MA  
Permagrain Products, Media, PA  
Pesses Company, METCOA Site, Pulaski, PA  
RMI Titanium Company, Ashtabula, OH  
RTI, Inc., (formerly Process Technology of North Jersey, Inc.), Rockaway, NJ  
Safety Light Corporation, Bloomsburg, PA  
Schott Glass Technologies, Duryea, PA  
Sequoyah Fuels Corporation, Gore, OK  
Shieldalloy Metallurgical Corporation, Cambridge, OH  
Shieldalloy Metallurgical Corporation, Newfield, NJ  
Texas Instruments, Inc., Attleboro, MA  
Watertown Arsenal/Mall, Watertown, MA

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Watertown GSA, Watertown, MA  
Westinghouse Electric Corporation, Waltz Mill, PA  
Whittaker Corporation, Greenville, PA  
Wyman-Gordon Company, North Grafton, MA

The nine sites that were formerly on the list, but have been removed are:

Allied Signal, Teterboro, NJ  
AMAX, Inc., Washington Bottom, WV  
Budd Co., Philadelphia, PA  
Chevron Corp, Pauling, NY  
Magnesium Electron, Flemmington, NJ  
Old Vic, Inc., Cleveland, OH  
United Nuclear Corp., Wood River Junction, RI  
Pratt & Whitney, Middletown, CT  
West Lake Landfill, Bridgeton, MD

### Formerly-Licensed Sites Identified As Potentially Contaminated

In 1976, the General Accounting Office (GAO) raised concerns about the decommissioning of sites formerly licensed by the Atomic Energy Commission's (AEC's) regulatory body, which is now the Nuclear Regulatory Commission (NRC). In its response, NRC agreed to reexamine the files of the terminated licenses. Between 1977 and 1982, Oak Ridge National Laboratory (ORNL) reviewed the docket files for all fuel cycle and materials licenses terminated before 1965 to verify that all sites had been properly decommissioned. This was done under an interagency agreement with the NRC. The files of 16,230 former licensees were reviewed and a total of 12 contaminated sites were identified. All of the 12 sites had been licensed pursuant to 10 CFR Part 40 and none represented a significant risk to public health and safety. NRC took action to have former licensees decontaminate seven of the sites. The Department of Energy (DOE) accepted responsibility for the other five sites under its Formerly Utilized Site Remedial Action Program (FUSRAP).

In 1989, GAO issued a report on NRC decommissioning procedures and criteria. This report raised additional concerns about the decommissioning of formerly-licensed sites. Before testimony presented to the House Subcommittee on Environment, Energy, and Natural Resources, a commitment was made to review the records of all sites terminated since 1965. ORNL was contracted again to review all docket files retired between 1965 and 1985. This second study required the creation of a computerized inventory of the docket files in addition to screening the files to determine whether all licensed sites had been properly decommissioned. If documentation were inadequate to verify that a formerly-licensed site had been properly decommissioned, the status of the site was to be verified by inspection. It was subsequently decided to review the files of all terminated licenses (Pre-1965 and Post-1985) using the same screening criteria and to document their status in one computer inventory. This would improve information retrieval and permit comparison of the review findings for all terminated license files.

The objective of the review was to evaluate the likelihood and possible magnitude of contamination at formerly licensed materials sites. In its review, ORNL used license files and related files (e.g., inspection and correspondence files) to obtain information relevant to the

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possibility of site contamination. The information was entered into a database and evaluated by an expert system that prompts the reviewer to enter additional data and judgements. For the sake of efficiency, the system first determined whether the license could be eliminated for administrative reasons, e.g., it was superseded by another license or it was transferred to an Agreement State. There is a provision to override this determination if the site had the potential for serious contamination based on materials possessed.

The system next assigned a score based on the nuclides and quantities the licensee was authorized to possess. This score considered the form of the material, inhalation and ingestion dose factors, and decrements for half-life. Some licenses were eliminated from consideration on the basis that they had small quantities of materials, only low-hazard materials, or materials that would have decayed to below levels of concern. The score was modified by information disposition, and by indications of possible contamination of equipment, structures, or the environment (releases, burials, incineration, operational incidents).

Using this system, ORNL has reviewed the files of over 31, 000 materials licenses. Scores from zero to as high as almost 500,000 were assigned. For 622 sites (or 2%), there was sufficient question about the documentation in the files to warrant further examination of the license. Scores greater than 300 were given first priority, then, scores less than 300 and then, sealed source files. Requests to the former licensee, current site owner or occupant, Agreement States, and NRC staff were made regarding concerns about the sites. Site visits have been required to resolve some concerns, including radiological surveys. If contamination above release limits is found, remedial actions are decided on, and responsible parties identified.

Approximately 10% of the 600 sites are being found to contain contamination above release limits for unrestricted use. Some of these sites have been cleaned up, others added to the SDMP (and in the case of Pratt-Whitney, since removed), and others are awaiting further action. This process is ongoing and is not expected to be complete until at least 1997.

### Timeliness of Actions

Throughout the United States, there are approximately 7,000 licensees authorized to use nuclear materials. Each specific license expires at the end of the day listed on the license, unless a renewal is requested. If a license expires, or is terminated, it is the licensee's responsibility to initiate any necessary decontamination and decommissioning efforts, at their expense, to return the property to such a condition that it can be released for unrestricted use. Financial responsibilities are discussed in the following section.

Decommissioning begins (license status is changed from active to decommissioning) if any of the following occur:

- (1) The license expires or is revoked;
- (2) The licensee decides to permanently cease operations with licensed material at the entire site, or in any separate building or outdoor area that contains residual radioactivity, such that the area is not releasable in accordance with NRC requirements;

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- (3) Twenty-four months have elapsed since principle activities have been conducted under the license; or
- (4) No principle activities have been conducted in a separate building, or outdoor area, for a period of 24 months and residual activity is present that would preclude release of the area in accordance with requirements.

Once any of the above occur, the licensee is required to notify NRC in writing, and begin decommissioning the facility, or within 12 months submit a decommissioning plan and begin decommissioning according to the plan once approved.

Regulations discussing these timeliness actions are contained in 10 CFR 30.36(d) (1-4), 40.42(d) (1-4), 70.38(d) (1-4) and 72.54(d) (1-4). The effective date of the rule was August 15, 1994, (59 FR 36026, July 15, 1994).

For licensees with unused facilities on August 15, 1994, the following submittals are required by August 15, 1996:

- (1) Within 12 months of submitting the required notification of decommissioning, they are to submit a decommissioning plan (if required) and begin decommissioning upon approval of the plan;
- (2) Unless otherwise approved, they are to complete decommissioning within 24 months of initiating decommissioning;
- (3) If notification was made prior to August 15, 1994, no further notification is required; and
- (4) Those licensees that made prior notification were required to submit a decommissioning plan, or request an alternative decommissioning schedule by August 15, 1995.

Extensions may be granted to these time periods in accordance with 10 CFR 30.36(e), 40.42(e), 70.38(e), and 72.54(s) (1). The extension must not be detrimental to the public health and safety and otherwise, in the public interest, considering:

- (1) Whether it is technically feasible to complete the decommissioning in the 24-month period;
- (2) Whether sufficient waste capacity is available to complete the decommissioning in the 24-month period;
- (3) Whether a significant volume reduction in waste requiring disposal and radiation exposures to workers will be achieved by allowing short-lived isotopes to decay, and
- (4) Other site-specific factors, such as the requirements of their regulatory agencies, lawsuits, groundwater issues, actions resulting in more environment harm than deferred cleanup, and other factors beyond the control of the licensee.

These actions are all designed to ensure that sites are decommissioned and released for unrestricted use in a timely manner, and that the responsible parties and the regulatory authorities ensure these actions occur.

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### Timeliness Rule for Former Radioactive Waste Burials

Prior to 1981, general licensees were allowed to bring radioactive waste on their property in accordance with 10 CFR 20.304 and 20.302. No regulatory approval was required for this action. The decommissioning timeliness rule discussed above applies to these sites, and current property owners need to assess these burials and possibly remediate them based on current regulatory release criteria for unrestricted use. However, this position was not clearly explained in 1989 with the promulgation of the Timeliness Rule, as mentioned in previous 10 CFR 20 regulations. Sites will need to be reviewed to ascertain existing information about the radionuclide content, concentration and total activity, the location and design of the burial, and applicable environmental characteristics important to waste isolation. Radionuclide concentrations and quantities below the threshold values of Table I do not warrant additional investigation, and these former burial areas are suitable for release without land use restrictions. Additional characterization may be needed to:

- (1) Assess the type, concentration, and total activity of radionuclides in the waste;
- (2) Determine environmental characteristics to estimate long-term fate and transport of radionuclides; and
- (3) Evaluate the potential for human intrusion into the waste and associated exposure characteristics.

The goal is to ensure that doses to members of the public will be a small fraction (e.g., 10-20 mrem/year) of the 100 mrem/year public dose limit in 10 CFR 20.1301. Stabilization or exhumation and disposal may be necessary if projected doses exceed a small fraction of the public dose limit.

Compliance with these decommissioning timeliness requirements may be difficult since universities and research institutions may not be aware of the requirements. There may be considerable cost to comply. The safety significance associated with the burial sites may not be high. It may not be possible to identify and notify the large number of property owners who own sites where former licensees may have conducted authorized burials. And finally, the Decommissioning Timeliness Rule only applies to present licensees. Non-licensed, responsible parties will be encouraged to meet the decommissioning schedules discussed in the timeliness Rule.

### Financial Assurance

In addition to identifying a responsible party for decontamination and decommissioning activities, and criteria for release for unrestricted use, an assurance of adequate financial resources is a key component in an overall decommissioning process. In recognition of this, regulations have been promulgated at 10 CFR 30.35, 40.36, and 70.25, with the purpose of assuring that decommissioning for licensed facilities will be accomplished in a safe and timely manner and that adequate licensee funds will be available for this purpose, such that, the financial burden and responsibility does not rest with the taxpayer.

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Financial assurance is based on the radioisotopes allowed to be possessed by the licensee, and the possession limits. Financial Assurance is not required for licenses involving radionuclides with half-lives less than 120 days. Possession limits for financial assurance requirements for materials licenses are based on Appendix B to 10 CFR Part 30. For a licensee that only possesses sealed sources, and in amounts greater than  $10^{10}$  times the quantities in Appendix B, financial assurance in the amount of \$75,000 is required. For licensees with materials in unsealed form and greater than  $10^3$  but less than  $10^4$  times the quantities in Appendix B, financial assurance in the amount of \$150,000 is required. For licensees with materials in unsealed form greater than  $10^4$  but less than  $10^5$  times the quantities in Appendix B, financial assurance in the amount of \$750,000 is required. If the quantity in unsealed form exceeds  $10^5$  times the Appendix B quantities, a decommissioning funding plan is required.

A decommissioning funding plan outlines the work required to decommission a facility, provides a site-specific cost estimate for the decommissioning, and states that funds necessary to complete the decommissioning have been obtained. In general, the cost estimate should provide for decommissioning the facility to allow unrestricted release. The estimate should assume that the work will be performed by an independent, third party contractor and not take credit for salvage value or reduced taxes. However, for certain sites where the licensee provides a viable alternative approach, or alternative basis for the cost estimate, the plan may be approved if the approach provides sufficient assurance of funding for decommissioning. Licensees may demonstrate financial assurance for decommissioning by one or more of the following mechanisms:

- (1) Prepayment - a deposit at the start of operation in a segregated account outside of the licensee's control. Prepayment mechanisms include trust funds, escrow accounts, certificates of deposits and government securities;
- (2) Surety, Insurance, or Parent Company Guarantee Method - assurance that the cost of decommissioning will be paid by another party should the licensee default on the responsibility to complete the decommissioning. In addition to insurance, surety methods may include payment surety bonds, letters of credit, lines of credit and parent company guarantees;
- (3) External Sinking Fund - a sinking fund account plus insurance or surety mechanism, such that the total of both at least equals the cost of decommissioning. A sinking fund is a segregated account outside of the licensee's control and any of the prepayment mechanisms may be used to hold the assets for the sinking fund account.

In addition, Federal, State or Local Government licensees may provide financial assurance for decommissioning with a statement of intent. A statement of intent is a statement from the appropriate government entity indicating that decommissioning funds will be obtained when necessary. Such statements need to state the estimated cost of decommissioning, as well as a demonstration that the party signing the statement has the authority to make such a statement on behalf of the government. In limited cases, a private licensee may rely on a government statement of intent if it is part of a binding contract between the government and the licensee.

The objective of NRC's financial assurance requirements are to ensure that a suitable mechanism for completing the decommissioning of licensed facilities is in place in the event that a licensee is unwilling or unable to complete the decommissioning.

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### Enhanced Participating Rulemaking or Radiological Criteria for Decommissioning

Commencing in May 1993, a significant effort has been expended to establish radiological criteria for decommissioning. After a series of seven public workshops to elicit informed discussions of the options and approaches for developing criteria, a proposed rule was published August 22, 1994 (FR 43200). The proposed criteria would apply to the decommissioning of all licensed facilities. The intent is to provide a clear and consistent regulatory basis for determining the extent to which lands and structures must be remediated before a site can be considered decommissioned. It is anticipated that having specific criteria in the regulations would result in more efficient and consistent actions related to the numerous and frequently complex site remediation and decommissioning activities anticipated in the future.

Decommissioning is presently allowed on a site-specific basis using the existing guidance as discussed above. Codifying the radiological criteria for decommissioning in the regulations should allow a more effective implementation of policies to protect public health and safety and the environment at decommissioned sites, by more efficient use of regulatory and license resources, consistent application for all types of contamination, and a predictable basis for decommissioning planning. In addition, delays in decommissioning could be eliminated since licensees could proceed with decommissioning without waiting for specific regulatory approval.

The overall conceptual basis for decommissioning, as proposed in this rulemaking, consists of an objective to reduce the residual radioactivity at the site so that it is indistinguishable from the background, a limit on the dose considered acceptable for release of a site with a stipulation that dose be as far below this limit as reasonably achievable (i.e., ALARA), provisions in regulatory guidance for administrative relief from performing sophisticated ALARA analyses for licensees who have little or no site contamination, provisions for restricted termination of a license when physical remediation activities cannot achieve the limit, and enhanced provisions for public participation. The limit for release of a site is 15 mrem/year total effective dose equivalent (TEDE) for residual radioactivity distinguishable from background. If doses from residual radioactivity are less than the TEDE, the license will be terminated and release for unrestricted use following the licensee's demonstration that the residual radioactivity at the site is ALARA.

The goal is to reduce residual radioactivity to levels that will allow unrestricted release of the site. However, in recognition that this may not always be feasible, licenses may be considered for termination where restrictions may be imposed on the use of the site to ensure that public doses are maintained below the 15 mrem/year TEDE limit, provided the licensee:

- (1) Can demonstrate that further reductions in residual radioactivity necessary to comply with the 15 mrem/year TEDE limit for unrestricted use are not technically achievable, would be prohibitively expensive, or would result in net public or environmental harm;
- (2) Has made adequate provisions for institutional controls to reduce annual TEDE from residual radioactivity distinguishable from background to the average member of the appropriate critical group to 15 mrem/year TEDE;
- (3) Has provided sufficient financial assurance to enable an independent third party to assume and carry out responsibilities for any necessary control and maintenance of the site; and

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- (4) Has reduced the residual radioactivity at the site so that the TEDE from residual radioactivity would not exceed 100 mrem/per year even if the restrictions applied in the termination were no longer effective in limiting the possible scenarios or pathways of exposure.

It is important for the public to not only be fully-informed of the decommissioning actions at a particular site but also to be able to effectively participate in site decommissioning decisions. The proposed rule will provide for public participation in the decommissioning process through three mechanisms in addition to the relevant requirements regarding hearing opportunities for a particular site. Upon the receipt of a decommissioning plan from the licensee or a proposal for restricted release of a site, the following actions will occur:

- (1) Notify and solicit comments from local and state governments in the vicinity of the site and Indian Nation or other indigenous people that have treaty or statutory rights that could be affected by the decommissioning;
- (2) Publish a notice in the Federal Register as well as in other media, such as local newspapers which are readily accessible to individual in the vicinity of the site; and
- (3) Solicit public comment on the proposed decommissioning action. These provisions are designed to provide affected individuals and organizations with both information about the proposed decommissioning and an opportunity to provide comments on the licensee's proposal. The Commission believes it is particularly important to provide notice in a forum that is accessible to local individuals. This forum may vary from site to site but would usually include providing notice to local media for publication.

With publication of the proposed rulemaking in August 1994, significant public comments were received. Comments argued for both higher and lower dose limits, more and less sophisticated ALARA analysis, and more and less guidance on surveys, surveying techniques and mathematical data analysis. Consideration of the comments and resolution continues.

### Pennsylvania Contaminated Site I

Schott Glass Technologies in Duryea, PA, is a site on the SDMP due to an onsite landfill containing relatively small, discrete volumes of thoriated glass chips and refractory material. Waste glass and materials from manufacturing of glass, including the thoriated glass, were placed in a landfill on the licensee's property from 1969 until 1980. Schott Glass proposes to keep the thoriated glass in the landfill, undisturbed. This will reduce exposure of radiation workers to radiation and lead, a hazardous material in the refractory and minimize air cleaning issues with disturbing a land area. The landfill contains 15,000 cubic feet of scrap, with 8000 lbs. of thoriated glass at a concentration of 17%. This translates into 1400 lbs of source material, or 30 cubic feet.

Since the property will remain under the control of Schott Glass, release for restricted use is appropriate. Schott Glass will cap the existing landfill with a multi-layered cap and erosion control plan consisting of a high density polyethylene (HDPE) textured synthetic liner, HDPE composite drainage net, granular drainage layer, and either a vegetative soil layer or asphalt layer.

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These added layers will eliminate any airborne contamination, reduce the external dose to levels indistinguishable from background, provide long-term erosion control, and reduce the likelihood of future excavation in the area of the landfill.

Nonetheless, an ALARA analysis was done. This analysis assumed that an individual would excavate the landfill, select a piece of thoriated glass over refractory or other scrap, fashion a 50 carat pendant by grinding, wear the pendant, and display the thoriated glass in a display jar at home. The resulting dose for this scenario is approximately 100 mrem/year.

### Pennsylvania Contaminated Site II

At the Babcock & Wilcox facility in Leechburg, PA, operations continue to decontaminate several buildings used by the reactor test staff. Procedures have been generated to assure appropriate air sampling. Air contaminant sampling is necessary in order to determine the extent of worker exposure, to determine the effectiveness of air contaminant controls, and to determine regulatory compliance.

Prior to performing air monitoring, a survey of the operation to be monitored should be made. This survey should include:

- (1) A review of specific operational activities;
- (2) A review of the materials used in the operation;
- (3) Identification of employee tasks associated with the operation; and
- (4) Review of the results of all previous monitoring for the operation.

In certain instances, it may be desirable to obtain and analyze grab samples by use of direct reading meters or instantaneous reading methods. The resulting information will be used to determine the duration of each sampling period and the number of samples required to obtain results that are representative of the normal work conditions for the operation. The sampling methodology should identify the sampling equipment, sample media, flow rate, and the total sample volume needed for proper sample collection. It is recommended that, prior to any sampling, the analytical laboratory be contacted in order to discuss any special requirements or limitations which may affect sampling methodology.

Prior to performing air sampling, all air sampling pumps must be charged and checked for proper operation prior to use. All air sampling pumps must be calibrated against a primary standard to the specific flow rate identified in the sampling methodology. As an alternate, the pumps may be calibrated against calibration equipment which is periodically checked against a primary standard.

If direct reading meters or instantaneous colorimetric detector tubes are used, follow the manufacturer's directions for equipment preparation and calibration.

Once sample pumps have been adequately charged and properly calibrated, proceed to the selected sample location and perform the following:

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- (1) Record employee identification and job description;
- (2) Place the sampling pump on the employee's belt and attach the sampling media to the employee's shirt collar (or similar position) so that it is within the employee's breathing zone (within a 6 to 9 inch radius of the nose). If measuring welders, place the media under the welder's helmet;
- (3) If sampling cassettes are used, ensure that they are in a vertical position with the inlet port of the cassette facing toward the employee's feet. Remove the cap from the inlet port of the cassette;
- (4) Turn on the sample pump and note the start time;
- (5) Instruct the employee to perform his duties in a normal fashion;
- (6) Observe employee activities and operation periodically, (at least every 2 hours) and record any significant observations.

It may also be advisable to record weather conditions and, if possible, obtain photographs of typical sample pump locations.

Procedures such as these have proven to be adequate for obtaining representative samples and assessing the hazard under which decontamination operations are performed.

### Massachusetts Contaminated Site

Nuclear Metals, Inc. has manufactured products from depleted uranium for various purposes since 1988. Located in Concord, MA, the major source of uranium contamination at the site was the discharge of neutralized pickling liquor containing copper and depleted uranium to an on-site holding basin between 1958 and 1985. Discharges to the holding basin ceased in 1985, and the basin has been covered with a synthetic cover to minimize evaporation, prevent additional water (rain and snow) from adding to the basin, and to eliminate the potential for any airborne concerns. A decommissioning plan has been prepared that includes removal of the basin sludge and shipment offsite in "superpoly" bags for disposal. Airborne sampling similar to that described above will be conducted during operation for worker's protection and environmental impact.

Two recent incidents have occurred that involved air cleaning issues. The first was a fire in a ventilation system, and the second was a broken buried pipe.

In February 1996, an unplanned/unexpected vent fire occurred within a torrit filter plenum housing and downstream prefilters assembly servicing a pulsed - combustion wastewater evaporation system. The thermocouple systems for the ventilation, installed to detect temperature inconsistencies, was reading low. After replacement of lead wires, troubleshooting, and startup testing, the system was approved for restart. Nonetheless, less than two hours after restart, a fire was observed coming out of the filter cartridges, and a maximum temperature of 750°F observed. Both water and carbon dioxide were used to extinguish the fire. The root cause of the fire was determined to be a thermocouple with reversed wires (polarity).

Damage was obvious. The cardboard framed pipefilters had been completely burned. The high temperature HEPA filters were substantially intact. Upon removal, they were physically dropped to the floor below, resulting in handling damage. Further analysis indicated three of the

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four HEPA filters were in good condition, with the fourth having suffered some heat damage, blinding the media rather than opening voids. The media had physically pulled away from one side of the frame, believed to be the result of dropping the filters on the floor.

A total of eight individuals were identified as potentially exposed; five were Emergency Response Team members involved in control and extinguishing of the vent fire, the remaining three acted in support positions, and were never very close to (or actively fighting) the fire itself. All personnel responding to the fire wore SCBA respiratory protective equipment, but were not monitored with any kind of breathing zone air sampler. Because the building was evacuated during response activities, and the HEPA exhaust filtration systems(s) were not compromised, there was no potential for outside/offsite exposures. Urine bioassay samples have been collected from all personnel identified as potentially exposed to any airborne activity, or involved in immediate response to the incident. No indication of uptake to any individual was noted. All potentially affected personnel were equipped with routine external dosimetry devices (film badges).

Air samples of four general types were collected and counted:

- (1) In-plant portable "hi-vol" samples (high flow rate, short duration 'grab' samples); taken during the incident, and preparatory to return to service;
- (2) In-plant stationary (fixed, continuous, low flow rate); routine workplace air monitoring samples;
- (3) Effluent (continuous, low volume); and three exhaust ventilation stacks servicing other areas;
- (4) Ambient/environmental (continuous, high volume); a total of eight samplers, two of which can be used as "backgrounds" for evaluation of local/closer stations.

Results of these analyses show no significant or unusual potential for exposure to any individuals (on or off-site) other than those eight persons already identified. Analyses (in-house counting using an automated gas-flow proportional counter) of samples from the eight environmental air stations yielded effective average ambient air alpha activity concentrations ranging from  $4.9 \times 10^{-15}$  to  $3.1 \times 10^{-15}$   $\mu\text{Ci/ml}$ ; this value is well within the analytical uncertainty of the measurement process, and the normal distribution of values observed in past datasets. It is apparent from these data that any potential exposure to the environment, public, or outside personnel arising from this incident is not significant with respect to routine facility operating emissions, and all applicable effluent regulatory statutes and standards.

During excavation to improve building drainage in May 1996, a wastewater transfer line was broken. This resulted in a leak of approximately 1800 gallons of water containing 380 grams of depleted uranium, a concentration of 20 picocuries/milliliter. The spill was contained onsite, and there were no offsite releases or effects. Contaminated soil was removed. The workers did not use respiratory protection equipment, but breathing zone air samples were employed. Workers with samplers included the maintenance staff who removed the soil, repaired the broken pipe, transferred the soil to bulk bags, provided shoring for the hole, and the backhoe operator. Results indicated minimal worker exposure; the highest DAC-hr (derived air concentration-hour) was less than 0.75.

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In addition, two hi-vol grab samples were taken. For ten-minute intervals, the count was equivalent to the minimum detectable activity (MDA) of  $4.5 \times 10^{-13}$  microcuries/milliliters. Similar results were obtained with 30-second counts and an MDA of  $2 \times 10^{-13}$   $\mu\text{Ci/ml}$ .

### Conclusion

A significant challenge for the nuclear community lies ahead in being able to successfully decontaminate and decommission contaminated structures and environment. Criteria must be clear, concise, fully-understood and achievable. A successful program for decommissioning has the following objectives:

- (1) Safety and Timeliness - Ensure timely and safe decommissioning of licensed and unlicensed sites that are contaminated with radioactive materials associated with the possession and use of source, special nuclear, and byproduct materials;
- (2) Documentation - Ensure that decommissioning decisions are thoroughly documented to develop a record that will withstand the test of time and avoid transferring a burden to future generations to redevelop information on the radiological status of formerly licensed sites;
- (3) Coordination - Coordinate decommissioning actions with regulatory agencies at the federal, state and local levels, with interested parties, and with members of the public to promote efficiency and finality for decommissioning actions;
- (4) Minimal Burden - Minimize the burden imposed on licensees and other responsible parties consistent with accomplishing the other objectives; and
- (5) Review Capabilities - Develop and maintain review capabilities, as required, to fulfill the objectives of the decommissioning program.

It is expected and anticipated to be able to release sites so that members of the public will have unrestricted access to areas where radioactive materials were once used.

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### DISCUSSION

**FIRST:** The acceptable numbers that you gave us with regard to residual contamination, would the NRC consider them to be de minimus exposures? I know the word de minimus gets a lot of peoples' hackles up, but still, you are proposing what I would interpret in that context. Would you comment on that?

**BELLAMY:** I am glad to. The Nuclear Regulatory Commission tried, about four or five years ago, to define a term which we called, and I have to say this very quietly, "below regulatory concern". That is not a term that we are allowed to use anymore. But to answer your question very specifically, the answer is, yes. This was our attempt to try to define a de minimus-type level, to define a below regulatory concern value without using it as a number.

**PORCO:** A couple of general questions on the fire, were the prefilters, the Torrit prefilters, cellulose or glass?

**BELLAMY:** They were glass.

**PORCO:** Were the HEPA filters commercial grade or were they in accordance with the accepted nuclear standard?

**PORCO:** Did anyone check on the type of binder that was used? It seems to me that they burned more vigorously than you would expect. Was this an issue?

**BELLAMY:** It was not an issue. You asked whether anybody checked and the answer is I don't know. I did not check, and I can't answer your question, I believe it may be in the Licensee Event Report that they submitted and I can get you and anybody else a copy if it is of interest.

**WEIDLER:** You talked about some small scale projects, are there any large-scale projects going on in Region 1 right now? And if so, do the same criteria apply to power plants.

**BELLAMY:** The answer is, yes. Region 1, in the northeast part of the country, seems to have more than its share of these activities. Of the forty-seven STMP sites that are presently on the list, twenty are in my region, and I have project management responsibility for eleven of them. Nine are managed out of headquarters, but it is still my responsibility to inspect them and make sure that the criteria are met. I believe you are referring to the decommissioning of nuclear power plants and I can assure you that the Shoreham facility did use the criteria. Shoreham has been officially decommissioned and is basically done. The activities at Yankee Rowe are still ongoing and the criteria we are trying to use for decommissioning tend to resist coming up with definitive criteria in the beginning. They would prefer to negotiate the process as it goes along. We have had a challenging time working with them and trying to agree on what would be the objective endpoints. The answer to your question is, yes, there are a number in Region 1.

**DAUBER:** Were the criteria for determining what would be the worst case determined by the facility owner, by NRC, or by whom?

**BELLAMY:** The criteria were generated by the Nuclear Regulatory Commission staff in Region 1. The responsible project manager and I, plus our headquarters staff (who give us the project and the program management guidelines) said, what is the worst-case scenario we can come up with that is somewhat realistic? I know that is a contradiction in terms, but that is what we headed for. So it was a Nuclear

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Regulatory Commission, an agency-generated scenario. I am not sure what area of the Aberdeen Proving Grounds you are from, but I should mention that Aberdeen is one of the sites on the decommissioning management plan that will be successfully removed from the list in the near future and we expect to renew their license after a public meeting that we will have to have down there. Please attend and be my supporter in the audience. So, congratulations to Aberdeen.

**ANON:** You talked about Shoreham as one of the utilities that was scheduled for decommissioning, did they meet your original time line? Second, are you aware of a user group, or any issues group, that has been established to effect the decommissioning of public utilities?

**BELLAMY:** The answer to your first question is, no. There was no success whatsoever in meeting the time lines for any of these activities by nuclear power stations. I am not aware of any utility user group. I know that there is an inter-agency task force that Ken Duvall is a member of, that is generating many decommissioning criteria, but I don't believe there are any utility activities in this area.

**FIRST:** Last Conference we went out to West Valley, do you have any comments on the clean-up of that facility?

**BELLAMY:** We are looking at West Valley as a fuel facility, it is in our fuel facility category. I would say we are not so much concerned about the clean-up of that facility as using it for the manufacture of the waste that will be generated from the clean-up of other facilities. I am not involved in West Valley day-to-day, but I understand that we are getting closer and closer to commercial operation at that facility, although we are not there yet.

**ENGELMANN:** Can you tell us something about the relative authority, the interrelationship of communications between EPA, NRC, and other federal agencies with regard to release criteria?

**BELLAMY:** As I indicated, there is an interagency task force that is looking on these activities as we speak. If you look at the preprint of my paper, you will note that there is a very long discussion on rule making. We have an enhanced participatory rule-making process which states that members of the public are welcome and expected to participate as we go along in the process, i.e., the term is "enhanced". The proposal is to take the numerical criteria that I have just gone over, and replace them with a criterion that simply says "fifteen millirem per year to any member of the public", period. The Environmental Protection Agency has separate criteria that are in the same ballpark but they are not exactly the same. There are some high level discussions going on at the cabinet level and at the Commission level to try to work out these differences with the Environmental Protection Agency. At the staff level, we work very closely with the Environmental Protection Agency and the Department of Energy on these sites. We will review any EPA documents that are generated. They take our comments very seriously, they welcome our comments, and we are working hand-in-glove with them at the staff level on a number of sites. The particular one that I can think of is the Metcoa-Pesses site near Pittsburgh, Pennsylvania.

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### INTRODUCTION

**FIRST:** Our next speaker is Dr. J Louis Kovach, President of NUCON International, Incorporated. Dr. Kovach is a chemical engineer who graduated from the Technical University in Hungary, his native country. This is Lou's seventeenth consecutive Air Cleaning Conference that he has attended. He tells me when he wants to remember how long he's been in the field of air and gas cleaning, he deducts seven from the current Air Cleaning Conference number, and multiplies by two, and that's how he knows how long he's been in the field. Those of you who have attended previous Conferences know that he has made a major contribution to the volumes of the Proceedings and we trust he will continue to do so. He has over a hundred papers in the field up to the present time. Currently he is on the High Level Waste Technical Advisory Panel for the Department of Energy. He is senior technical advisor of the Department of Energy's Hanford privatization initiative. And he is chairman of the Hanford Tank Waste Remediation Environmental Impact Statement preparation panel. He is a consultant for the US Department of Energy, US Environmental Protection Agency, and the US Nuclear Regulatory Commission. It seems like everybody wants a piece of Lou Kovach. We are delighted he is giving us one of the pieces this morning. The title of his paper is, "Challenges to Air and Gas Cleaning Systems".

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## NEW CHALLENGES TO AIR/GAS CLEANING SYSTEMS

J. Louis Kovach  
President  
NUCON International, Inc.  
Columbus OH

The construction of new nuclear power reactors in the U.S. has stopped now for over a decade. Thus, the currently generated conventional air cleaning system technical information is generally restricted to evaluation of operational problems with the existing systems. However, extensive nuclear waste management related needs have developed in the U.S. during this same period—mainly at DOE sites. The waste management and site remediation related air and gas cleaning needs are much broader in scope than the control of radioiodine and low concentration aerosols, and the systems in current design or in application also have different processing conditions.

The major difference is that many of the new air and gas cleaning needs are required to treat effluents continuously and under widely different processing conditions than those applied in the past for the nuclear power industry. Even the systems which are postulated for handling gases under potential upset conditions have different design envelopes than the conventional nuclear power plant (NPP) air cleaning or air handling units.

The new, greatly varied processing conditions of waste management activities make it difficult to use the standardized designs developed by ANSI and ASME for the NPPs, and most of the current design specifications and codes are not directly applicable for the new applications. The current conditions in the waste management and remediation activity are similar to the early days of the development of the NPP air cleaning systems in that their designs are highly individual and varied both by the specifiers, the designers and the manufacturers. The result is a greatly varied quality non-standard equipment specification and supply. At the same time, many of the application needs, but not all, are one of a kind systems, making the development and application of standard specifications and codes difficult and uneconomical.

There is a change needed in the design and manufacturing philosophy from the relatively large number of identical purpose units to the highly individualized special purpose design and manufacturing philosophy. For the new needs it is difficult to use the “cookbook” concept of such standards as ANSI/ASME N-509, ASME AG-1 or to follow the test requirements of ANSI/ASME N-510 or the currently developing Section TA of the ASME AG-1 code. This does not mean that the old NPP related standards are useless, but that their usefulness is only partial and inadequate to solve the waste management needs.

### Examples of New Waste Management Related Problems

#### Radon control from uranium wastes

Uranium processing solids containing silos need to be degassed prior to further processing by vitrification or during the initial steps of vitrification. While extensive information was developed for

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noble gas control (krypton and xenon isotopes) of the BWR off gas system or PWR gaseous radwaste system design and operation, there is very limited data available for the commensurate radon control design and operating conditions. The recent literature and data relating to home radon control or uranium mining purge control has not been extended to satisfy the design and operating requirements of the waste management type radon processing field.

### Effluent treatment from thermal processing of various radioactive wastes at greatly varying temperatures and gas compositions

Most waste management related activity is initially from dilute solutions which require concentration as a first step. As an example, evaporator effluents need to be treated under high humidity, corrosive or, in some cases, flammable gas presence conditions. Another process effluent is from drying radioisotope loaded spent liquid phase adsorbents which require both high efficiency solid particulate and vapor phase removal of hazardous constituents from humid and potentially corrosive streams.

### Off gas treatment for vitrification facilities which need product recycle, and in some cases, product recovery at very high concentration of volatiles and semivolatiles and particulates

The radioactive waste vitrification technology always includes the capture and treatment of volatile and semivolatile radioactive and other hazardous constituents. In some cases, the operating temperatures are high enough to vaporize large amounts of alkali metals and other waste constituents which need to be quenched, converted to filterable components and result in an off gas stream which can be above the lower flammability limits without additional dilution. There are special selective constituent removal needs for elements such as mercury, selenium, cadmium, ruthenium, etc.

### Filtration from potentially flammable gas streams

In several waste storage complexes, the original complexant organic material used to separate specific isotopes in the past is thermoradiolytically decomposing with a commensurate generation of hydrogen. This thermoradiolysis of organic compounds in the stored waste creates concerns of flammable or explosive environment generation even under normal storage temperature conditions. The various wastes have different gas retention capability and intrusive activity or transfer of the waste can release sufficient volumes of flammable gas mixtures which can result in structural damage in waste storage tanks if ignited.

### Filtration from highly corrosive gases

The waste processing technology generally includes dissolution steps involving concentrated acids or alkalis. The currently used glass fiber based filtration elements do not have sufficient corrosion resistance and the typical adsorbents used (e.g. carbon based) are unsafe in highly oxidizing environments. At the present time there is inadequate corrosion resistant filter or adsorbent material development and application data available to select material of construction or estimate filter/adsorbent life and performance information.

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### Filtration from gas streams which may have significant pressure challenges

As an example, at the Hanford site of the U.S. DOE, many of the potential consequences of off design conditions can result in unacceptable radioactivity release estimates, if the sudden pressure rise causes failure of the conventional HEPA filters. Currently, a large percentage of the "unsafe" conditions could be eliminated from the safety analysis if the pressure resistance of the HEPA filters can be increased to prevent pressure spike related failure. There is also inadequate information available on the aging of conventional HEPA filter components, particularly under high humidity conditions, for which deterioration is not measurable by conventional in-place aerosol testing.

### Back washable filter elements

The continuous processing of high particulate load streams does not permit the use of high efficiency filters which cannot be "regenerated" in place. The life of a conventional HEPA filter under many of the operating conditions is too short to permit economical and waste minimization satisfying requirements. While there is some development of metal filter media, currently there is very limited information on the efficiency, life, regenerability etc., of these media and often fibrous metal and sintered metal filters are considered as equals in performance.

### Continuously operating demister elements

While in the NPP application area, demisters only have a very limited expected operating life. In the continuous waste processing applications there is a requirement for droplet elimination as a continuous unit operation. Even in the NPP field, one of the least understood components is the "moisture eliminator" element. However, for waste processing application, the mist elimination component design and continuous operating technical data is not available.

### Adsorptive removal of varied constituents from air and gas streams

In the NPP applications, only radioiodine and noble gases are considered for gaseous phase treatment. The waste management area is much broader, and specific adsorbents need to be developed, optimized and applied for other elements or compounds under more adverse environmental conditions than that of the NPP field. Examples are mercury, ruthenium, iodine-129, etc.

### In-place testing highly contaminated systems

One of the major shortcomings of even the NPP related air and gas cleaning activity is the proof testing of highly contaminated components or systems. (It is generally assumed that the event for the amelioration of which the "safety" train is installed will never occur, thus testing under those conditions would not be needed. This misconception, as an example, created some interesting problems even after the TMI accident when highly contaminated air cleaning systems needed to be tested or serviced.) However, in waste processing gaseous or particulate treatment systems, the air and gas cleaning components can be highly contaminated by either alpha, beta or gamma radiating components. Many of these systems do not permit man entry into the air/gas treatment units on the contaminated side and, at times, not even on the "clean" side due to the radiation fields or other hazards present. Most of the

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current in-place testing steps as described in the existing test procedures cannot be performed on highly contaminated or, as an example, flammable gas containing systems.

### Maintainability under contaminated conditions

This is another area where even the NPP related currently available standards and codes fail to adequately address the design requirements. The consideration of replacement of most components of a contaminated air cleaning system are not included in the existing codes and standards. In the waste management field, the contamination of most air and gas processing systems, other than possibly the final building filtration units, is a forgone conclusion.

### Waste minimization challenges for consumable components

In most cases, the disposal cost of contaminated air and gas cleaning components is higher than their initial new cost. At the same time, the least specified (if at all) of the properties of the filters or adsorbents used is their operating life or disposal cost. This is also true in the NPP field, where, as an example, radioiodine adsorbent is purchased solely on initial efficiency cost without any regard for adsorbent life.

It is intended that by describing examples of these new challenges that the standard preparers, designers and manufacturers will be better informed of the special needs of these new air cleaning/gas processing applications.

The major challenge is that all parties involved in the specification, design and operation of these systems will have to be better trained in the broader filtration, and other contaminant removal basic principles and less dependent on the set design and operation practice of the NPP related applications. There will be no time available to develop detailed consensus specifications or codes for components and systems for the waste management field, but there is time to assure that all those involved with the program have available additional training opportunities to satisfy the qualification needs, i.e. the chemical, physical and engineering principles required to comprehend the air and gas purification specification, design, construction and operation expertise.

### Regulatory Concerns

The NPP related activity in the U.S. is regulated by the NRC, while the U.S. DOE sites are "self-regulated" with some oversight provided by the Defense Nuclear Facilities Safety Board (DNFSB). However, the impending privatization of some of the U.S. DOE activities postulates the integration of the NRC into the regulation of the waste management operations. The post-TMI new source term development in the U.S. has resulted in a lowered technical concern of air and gas cleaning activity by the NRC, while the administrative legalistic enforcement of Technical Specification or FSAR cited standards and codes has increased. Some of the "enforce the words," even if they are technically undefensible, has converted the regulation of the design, performance and testing of the NPP air cleaning systems into a "cargo cult" basis. This type of regulation will not suffice for the existing or the upcoming waste management area. There will be limited directly applicable standards and codes for the upcoming applications of air and gas cleaning systems and blind citing of standards and codes originally

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developed for other applications or of those which are outdated and, in many cases, withdrawn, that will not create a better or safer environment for the workers or the public. Both the DOE and the NRC has to establish a pool of competent technical personnel who clearly understand the technical basis for the specification, design control and operation of the existing, or to be developed, components and systems which are needed for the safe operation of waste management facilities.

The technical qualifications and the basic engineering expertise of all personnel involved in air and gas processing research, specification preparation, design, construction, operation and regulation for the waste management field needs to be far better than that which existed for the relatively narrow NPP type applications, which itself lately suffered from inadequate technical expertise. As John W. Crawford, one of the DNFSB members, explicitly pointed out in one of his recent reports "An Assessment Concerning Safety at Defense Nuclear Facilities, The DOE Technical Personnel Problem,"<sup>(1)</sup> the root cause of all currently identified safety and operational problems is lack of adequate technical expertise of design, operation and regulatory personnel. While the Crawford report concerned itself mainly with the DOE, its conclusions are valid for the entire U.S. nuclear industry whether public or private.

### Conclusions

The great variety of type and purpose of air and gas cleaning needs for radioactive waste management industry will require individual, special designs rather than many identical air/gas treatment systems. It would be very difficult to apply the existing codes and standards developed for the nuclear power plant environmental protection, as they exist, for this new application. The design, construction and safe operation of the new systems will be strongly dependent on the good understanding of the commensurate filtration, adsorption and absorption science and the special needs of engineering knowhow relating to both the nuclear and the chemical processes involved. The very large and expensive, but mostly one or two of a kind systems, are not amenable to long duration consensus standardization. The challenge of still meeting the required protection factors or separation efficiencies of the air and gas cleaning systems, often with greatly different components than the conventional systems, will be dependent on the technical understanding of all of the relevant criteria by a limited pool of personnel involved from the design of the process to the regulation of the quality and performance of these systems.

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<sup>(1)</sup>Crawford, Jr., J.W., "An assessment concerning safety at defense nuclear facilities, the DOE technical personnel problem," DNFSB/TECH-X, Vol. iii, March 1996.

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### DISCUSSION

**FIRST:** I appreciate your comments, warnings, and peering into the crystal ball. As you were talking about many of the technologies that you say we need, I was reminded of the fact that back in the 1950's and some part of the 60's, we were very much involved with the kinds of equipment that you cited. The particular application at that time was incineration. All of the problems that you enumerated, corrosion, heavy dust loadings, and so on, were all encountered in these situations. And you know we never solved the problems in 1960, therefore, we still have them with us today.

**BERGMAN:** A lot of comments you made ring true to many of the technical people who are familiar with the problems. For example, for the last three years, maybe even five, I have been going up and down the halls of the bureaucrats in the Department of Energy with a shopping list at least as long as yours with issues and problems, some of which are very severe. Almost invariably the response is, "we have not had a major accident". By an accident, they mean an entire city having to be evacuated, things of that nature. The philosophy is that if you don't have a major accident, you don't have to put money in. And it is a local issue. For example, it is like a stop sign, usually local communities do not install a stop sign or a street light until somebody is killed. After someone is killed they start to think, "we'd better do something about it". For example, in the HEPA filter area after the '69 Rocky Flats fire, there was a lot of money. The attitude right now from all of the bureaucrats I've encountered is that we are not going to spend any money on HEPA filters. In fact we're going to downsize. ES&H activities are slated for at least a thirty percent decrease. So, not only are we not keeping up, DOE in particular is going dramatically down. If there is no money, there are no opportunities to do any of the activities you suggest. I would appreciate your comments.

**KOVACH:** In some of these areas we are not doing anything either. So it is no wonder we do not have accidents. As long as we are only studying the problems rather than processing the wastes we are reasonably safe. Once we start waste processing, I am not sure we can do it without accidents.

**WEBER:** Dr. Bergman's comment and your response remind me of these issues every time I step on an airplane. I mean, the airplane hasn't fallen down, so why should we spend money maintaining it? That is a comment, not a question. As a comment, you mentioned a problem which was encountered with backwashing a metallic filter. I am totally unfamiliar with that particular installation. Over my involvement with backwash filters I've learned that for all manner of industries, including electric power generation, chemicals, liquids, gases, there are many, many parameters to bear in mind when installing a backwash-cleanable filter, including, but not limited to, the backwash-technique. This is because there are a myriad of backwash techniques. They include the cleaning fluid itself as you pointed out. There may be chemical interactions with the contaminant, and there are important waste disposal issues, i.e. you don't want to create more backwash waste than you started out with. I recommend that when someone is thinking of procuring such a system, that they make the vendor responsible to educate them and in those areas where they do not feel knowledgeable, that they seek out vendors who have the expertise to work with them to solve all the problems. Education can be acquired that way. So, seek out a vendor who is qualified, because if the vendor doesn't know the answer, you must question whether their system will work.

**KOVACH:** I agree that we all have the duty, not only the vendors, to learn at each step about the entire life cycle of the components that we are designing. When we deal with a back-washable filter, it is not enough just to say, "okay", we will just put water on it or spray a solution on it and it will be back-washed. Instead, we have to understand clearly the consequences of operating such a system.

INTRODUCTION

**FIRST:** Our next speaker is Dr. Dade Moeller, also a long-time attendee at the Air Cleaning Conferences, and for many years a member of the Program Committee. He has taken a very active role in the conduct of the Conferences, and has made major contributions with his technical papers. He is currently President of Dade Moeller and Associates, located at New Bern, North Carolina. He worked for the US Public Health Service as a commissioned officer from 1948 to 1966, with assignments that included Oak Ridge National Laboratory, Los Alamos National Laboratory, and the headquarters offices of the US Public Health Service in Washington, DC. From 1968 to 1983 he was Professor of Engineering and Environmental Health, and Chairman of the Department of Environmental Health Sciences at the Harvard School of Public Health. During those years, Dade and I worked very closely together, and it was a delightful experience for me. He is a first-class scientist and a wonderful person to work with. From 1983 to 1993 he became Associate Dean for Continuing Education at Harvard School of Public Health. It is interesting that Dade was a member of the Advisory Committee on Reactor Safeguards from 1973 to 1988, and for a number of those years was Chairman. I invited him to introduce our current chairman but he said their tenures did not overlap and he thought perhaps he didn't know quite enough about the speaker to undertake that assignment. Dade is a certified health physicist and a diplomate of the American Academy of Environmental Engineers. He has received the distinguished achievement award of the Health Physics Society, and a meritorious achievement award from the US Nuclear Regulatory Commission in 1988. He is a member of the National Academy of Engineering, dating from 1978. He is author of a textbook, now going into its second edition, entitled Environmental Health. Dade has many more honors, but I'm taking up too much of his time, so I will stop at this point. It is a delight to have you here, Dade. The topic of his talk is, "Application of Innovative Policies for Controlling Radionuclide Releases: The 'Open-market Trading Rule'". I think you will find this a very interesting concept.

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### APPLICATION OF INNOVATIVE POLICIES FOR CONTROLLING RADIONUCLIDE RELEASES: THE "OPEN-MARKET TRADING RULE"

Dade W. Moeller, Ph.D.  
President  
Dade Moeller & Associates, Inc.  
147 River Island Road  
New Bern, NC 28562

#### Abstract

In the past, most efforts for reducing airborne radionuclide releases and controlling radioactive wastes have been directed to the development of new and improved technologies. Little attention has been paid to the possible application to these problems of new, innovative policies. Yet, experience in other fields shows that such applications could be beneficial. A prime example is the "open-market trading rule," now being widely used in the U.S. for the control of a range of environmental problems. Through this rule, nuclear facility operators would be permitted to control airborne emissions in a more cost-effective manner, and those responsible for decommissioning and decontaminating nuclear facilities no longer in operation could do so at far lower costs while generating significantly smaller volumes of radioactive wastes. Application of such a policy would also significantly reduce the demands on existing, and the need for research to develop new, improved, control technologies.

#### I. Introduction

Most efforts for reducing airborne radionuclide releases from operating nuclear facilities have been directed to the development and application of new and improved technologies. This is also true in the case of the decommissioning and decontamination of commercial nuclear power plants and the cleanup of nuclear installations under the control of the U.S. Department of Energy (DOE), as well as in the management and disposal of the associated radioactive wastes. Little attention has been paid to the possible application of new, innovative policies. Yet, experience in other fields of environmental protection shows that the application of such policies might be beneficial. The purpose of this paper is to review one such policy that may prove useful, namely, the "open-market trading rule."

#### II. The "Open-Market Trading Rule"

Through the "open-market trading rule," the U.S. Environmental Protection Agency (EPA) permits an industry that is having a problem with excessive releases of a given toxic chemical either: (a) to spend whatever is required to reduce the releases; or (b) to "make room" for the releases either by purchasing and shutting down other industries discharging the same toxic

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chemical within the same geographic area, or by assisting other dischargers of the same pollutant in reducing the quantities of their releases.

One of the major benefits of this approach, sometimes called "emissions trading," is that it enables industrial and governmental organizations to control pollutants in the most cost-effective manner.<sup>(1)</sup> That is to say, if one company can control their releases of a given toxic agent at a lower cost than another, it is wiser for the second company to assist the first in its cleanup efforts than to spend more money in trying to reduce its own releases.

Initially, the "open-market trading rule" was applied solely to the control of a single toxic chemical within a single environmental medium. Under the Clean Air Act, for example, U.S. industries are permitted to optimize releases to the atmosphere based on mitigative technologies, thereby "trading" exposure rights.<sup>(2)</sup> In effect, this Act permits industries to buy and sell pollution rights and encourages one industry to assist another in reducing its airborne releases, if this can be accomplished at lesser costs. The same type of optimization is permitted under the Clean Water Act to control discharges to lakes and rivers. With the increasing success of this approach, however, its applications have been extended to broader arenas. For example, through an emission allowance program, the rule is being used to control airborne emissions that cause acid rain, thus providing opportunities for additional low-cost reductions of sulfur dioxide emissions. In fact, an allowance market for such emissions has been established by the Chicago Board of Trade.<sup>(3)</sup> The rule is also being applied to trade-offs in which industrial and community organizations have been given permission to create artificial wetlands to replace those that have been (or will be) destroyed by industrial and commercial development.

But the broadening of the applications of this rule has not stopped here. In recent months, still wider applications have been explored and implemented. EPA, for example, is now exploring trade-offs among different pollutants within the same medium (for example, trade-offs between releases of oxides of sulfur and oxides of nitrogen to the atmosphere), as well as trade-offs among several media, so called "cross-media" trading whereby releases of one or more pollutants to the atmosphere can be balanced against releases of other pollutants to the water environment.<sup>(4)</sup>

To exploit the benefits of this rule, EPA is proposing that it be applied on a generic basis and they are encouraging State and local agencies to create new, innovative programs for its application.<sup>(5)</sup> In fact, the EPA Assistant Administrator for Air and Radiation has stated that "EPA's experience with these trading programs, and with our own successful acid rain program, (has) led us to conclude that properly structured programs can reduce emissions earlier and cheaper than would otherwise be

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possible."<sup>(6)</sup> Dan W. Reicher, J.D., Chief of Staff, U.S. DOE, has also expressed interest and support for the concept. Concurrently, application of the "open-market trading rule" has received widespread endorsement from various independent "watch-dog" agencies, such as the U.S. General Accounting Office.<sup>(7,8)</sup> In addition, the concept has been endorsed by a variety of other groups,<sup>(9,10)</sup> and it is being applied internationally as part of the worldwide efforts to reduce airborne emissions that could lead to global warming. One of the major benefits of this concept is that it requires that an integrated or systems approach be applied to the control of environmental releases of various pollutants.

### III. Applications of the Concept to Nuclear Facilities

Although the applications cited above have proven extremely successful, it appears that the "open-market trading rule" would have even greater benefits in the control of airborne releases from operating nuclear facilities, in the cleanup of contaminated nuclear facilities, and in the control of associated wastes. These benefits, which are unique due to the origin of the radiation sources affecting typical population groups, include those of a technical and economic nature as well as public education and goodwill. Perhaps surpassing all of these benefits, however, is the fact that applications of the "open-market trading rule" to the control of environmental radiation exposures may prove to be exactly the vehicle needed to expedite the cleanup of decommissioned commercial nuclear power plants and various DOE facilities. It may also enable State and local regulatory groups and nuclear facility operators to ensure that financial resources for the control of radiation exposures are being directed to those sources that contribute the highest dose and can be controlled at least cost.

As an example, consider the operation of an existing nuclear facility or the cleanup of a facility that is no longer in operation. As in most such cases, the goal will be to assure that offsite population groups will not be exposed to radiation doses in excess of the applicable limits. The basic steps required in applying the rule to such a situation, and the benefits that would be accrued, are outlined below. As will be noted, in certain cases, application of the concept requires changing the ways in which exposures from such sources have been viewed in the past.

#### Basic Steps

1. As an initial step, there would be a need to assess the full range of radiation sources that affect nearby population groups. Such sources include natural background radiation, medical and dental uses, and consumer products, as well as contributions from the nuclear facility.

The benefits of this exercise would be several. First of all, it would require all concerned parties, both within

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and outside the facility, to apply an holistic approach to the assessment and evaluation of the various radiation sources affecting nearby members of the public and stakeholders. Other benefits would be gained in terms of public education since it would reveal to nearby groups the major sources of their exposures. In essentially all cases, the nuclear facility would prove to be a minor contributor.

2. The next step would be to rank the various sources according to their relative contributions to the doses to offsite population groups. Once this had been done, the dose rates from each source would be compared to the relevant mandatory limits, where such limits exist. This would lead to the identification of those sources to which controls must be applied and the quantification of the degree of reduction that is necessary. It is only after these basic reductions in dose rates have been achieved that the "open-market trading rule" would be applied.

For facilities being decommissioned and/or decontaminated, such an assessment would need to include the decision on whether the site on which the facility is located is to be released for unrestricted or restricted use -- with appropriate consideration of the degree to which this affects the amount by which the associated dose rates must be reduced. As a minimum, restoration efforts would probably need to be applied to the nuclear facility to reduce the accompanying dose rates to neighboring population groups to the long-term standard dose rate limit of 1 mSv (100 mrem) per year, as recommended by the International Commission on Radiological Protection and the National Council on Radiation Protection and Measurements,<sup>(11)</sup> and as required by the regulations of the U.S. Nuclear Regulatory Commission.<sup>(12)</sup> Under terms of the "open-market trading rule," additional cleanup of the facility would be required only if it were more cost-effective as compared to other sources affecting local population groups.

3. Subsequent to this step, each individual contributor (from both onsite and offsite sources) to the radiation dose rates to offsite population groups would need to be evaluated in terms of its feasibility for control, including a review of the applicable control technologies, associated costs, and potential societal impacts. On the basis of this evaluation, each source would then be ranked in terms of its priority for reduction and/or control.

Following this approach, public health and regulatory agencies, as well as members of the public, would soon learn that, in many cases, it would be far more effective and less expensive to reduce exposures to offsite groups from indoor radon or medical sources, than to continue to

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pursue additional controls on airborne releases from operating facilities or to proceed with additional cleanup of a nuclear facility that is no longer operating. Studies have shown, for example, that reductions in exposures to indoor radon (and its decay products) can be accomplished at relatively low cost.(13,14) Other steps that could be taken include the installation of a more modern (reduced dose) mammography x-ray unit or an improved fluoroscopy screen in the local hospital, as well as encouraging wider scale application of newer techniques, such as endoscopy and colonoscopy, in place of x-ray fluoroscopy, as a primary means for conducting gastrointestinal examinations. Additional steps that might be considered include developing better controls for handling the excreta from medical patients to whom radiopharmaceuticals have been administered.

4. Once doses due to releases from the nuclear facility had been reduced to the basic mandatory standard, attention would be directed to the control of other sources for the required additional dose reductions, for example, down to perhaps 0.1 to 0.25 mSv (10 to 25 mrem) per year. As explained above, this would be accomplished by reducing those sources that can be reduced most effectively and at least cost.

Based on this information, a definitive plan of action for remediating the dose rates to the offsite population living in the neighborhood of the given facility would be proposed, taking into account the input of the facility operators, regulatory authorities, the local populace, and related stakeholders.

### IV. Benefits of the "Open-Market Trading Rule"

There is a multitude of benefits that would be generated as a result of the application of the "open-market trading rule" to the cleanup of nuclear facilities.

#### Benefits

1. First and foremost, this rule would require the use of an integrated or systems approach in assessing and controlling radionuclide releases and associated radiation exposures. One of the immediate outcomes would be to provide significant latitude to State and local regulatory officials, as well as facility operators, in selecting which sources should be addressed to accomplish the required dose rate reductions.
  - a. Having been provided this latitude, such officials and facility operators could direct their attention to sources, such as natural radiation background and medical radiation applications, which currently contribute over 95% of the total dose to the average member of the U.S. public.(15)

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- b. This would also permit regulatory officials and facility operators to direct their attention to those sources that can be most effectively controlled at least cost.
2. Another benefit would be significant reductions in the associated costs of nuclear facility operation and/or cleanup and the volumes of radioactive wastes being generated.
    - a. Because of the reduced controls and cleanup required, there would be ancillary reductions in the demands on associated technologies.
    - b. There would be similar reductions in the expenditures required for research on the development of new, improved technologies.
  3. This approach would serve as an outstanding tool for educating the public on the relative importance of various radiation sources. In this regard:
    - a. The procedures involved would offer unusual opportunities for involving and gaining the approval of offsite populations and stakeholders for programs proposed for the operation and cleanup of nuclear facilities.
    - b. This approach would enable nuclear facility operators to demonstrate on a one-on-one basis their interest and concern for controlling dose rates to local population groups. In many cases, application of this approach would enable facility operators to reduce the dose rates to neighboring populations to levels less than they were prior to the original construction and operation of the facilities. This becomes possible, as noted above, because of the relatively high dose rates currently coming from medical and natural background sources, such as indoor radon, and the fact that many of these sources can be readily controlled.
  4. Application of this rule would enable nuclear facility operators to begin now to reduce the dose rates to offsite population groups, not having to wait until all the environmental and associated administrative and regulatory requirements had been met.
  5. It would provide a cushion in case the engineered barriers installed to control environmental releases did not perform as designed, or unanticipated failures occurred in various natural and engineered control systems. In such cases, facility operators could immediately apply additional controls to other radiation sources while awaiting corrections to be made in the controls being applied to the nuclear facility.

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6. Application of this policy would enable State and local regulators to apply a risk-based approach to the cleanup of nuclear facilities. This has long been a major goal of the EPA, the U.S. Congress, and many State and local regulators.
7. A program such as this would provide a stimulus to the efforts of the EPA and various State and local environmental and public health groups to encourage the monitoring and control of exposures to members of the public from indoor radon. It would also provide a stimulus for increased assessment and evaluation of the radiation doses associated with medical procedures.
8. In the case of U.S. Federal nuclear facilities, such a program would provide a new and challenging mission for the DOE National Laboratories. These Laboratories represent a rich resource of scientists and engineers whose expertise would be extremely beneficial in evaluating, analyzing, and applying the concepts associated with such a program. Participation in such activities would bring them into the mainstream of DOE's environmental restoration program.
9. This approach would provide an initial step in the ultimate development of a system for making similar tradeoffs among the various human and environmental impacts of toxic chemicals and radiation sources. Here, again, the DOE National Laboratories could play a major role.

### V. Commentary

As noted above, application of the "open-market trading rule" would offer a range of benefits to State and local officials and industrial organizations in their efforts to improve the control of airborne releases and the cleanup of nuclear facilities as well as to apply a risk-based approach to associated decision-making.

In addition, it appears that application of such a rule would be entirely consistent with directives issued by the President. Under Executive Order 12866, all Federal agencies, including DOE, are required, in setting regulatory priorities, to "consider, to the extent reasonable, the degree and nature of the risks posed by various substances or activities within its jurisdiction," and to "design their regulations in the most cost-effective manner to achieve the regulatory objectives.<sup>(16)</sup> In doing so, each agency shall consider incentives for innovation, consistency, predictability, the costs of enforcement and compliance (to the government, regulated entities, and the public), flexibility, distributive impacts, and equity," and "each agency shall identify and assess alternative forms of regulation and shall, to the extent feasible, specify performance objectives, rather than specifying the behavior or manner of compliance that regulated entities must adopt."

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What is needed is the conduct of several pilot studies to demonstrate the feasibility of the concept through its application to one or more nuclear facilities. In terms of the commercial nuclear utilities, such studies might be directed to several of the plants for which decommissioning operations are underway or contemplated. In terms of DOE, such studies might be directed to the control of radionuclide releases from one or more operating facilities or to the cleanup of sites such as Hanford, Idaho Falls, and West Valley. Although application of this approach might not prove viable for the control of facilities in which the principal radionuclide contaminants (for example,  $^{239}\text{Pu}$ ) are extremely long-lived, it would be directly applicable to the control of doses from facilities in which shorter-lived radionuclides, such as  $^3\text{H}$ ,  $^{60}\text{Co}$ ,  $^{90}\text{Sr}$ , and  $^{137}\text{Cs}$ , play dominant roles. For many facilities, this is the case.

Once these studies have been completed, the resulting reports and analyses could be submitted to the National Academy of Sciences/National Research Council for review and evaluation. Assuming that such a review would result in their endorsement, Federal, State and local regulatory agencies and plant operators would be armed with a powerful tool for the more effective control of radiation doses to offsite population groups. They would also be provided with a vehicle that would enable them to move ahead with the cleanup of the vast array of Federal nuclear facilities now awaiting action. Proving success in the radiation arena could well lead to more widespread applications of the concept. Such applications might ultimately include trade offs in exposures derived from combinations of radioactive materials and toxic chemicals.

Application of the "open-market trading rule" to the control of doses to offsite populations from nuclear facilities would represent professional environmental and public health practices at their best. This approach would also serve as a superb tool for educating the U.S. public in gaining a better understanding of the relative significance of various radiation sources in their everyday lives.

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### DISCUSSION

**FIRST:** I was wondering about the aspect of not requiring reductions by nuclear facilities as an offset. How do you reconcile that with the ALARA principle?

**MOELLER:** I have no problem whatsoever reconciling it, because I am practicing ALARA at the highest level. This is more ALARA than any nuclear facility ever thought of, because I am looking at all sources. I am saving money, that's ALARA.

**FIRST:** But the reality is that the regulation applies only to nuclear facilities.

**MOELLER:** Correct. And that is where we obviously need to make some changes. But I think we would have very little difficulty making these changes because of the support of the concept by the congress, by all of the federal agencies, and so forth. I don't mean to be flippant, but I really think that once people understand it, we will have no problems. Obviously it is going to take education of the public, the technical community, and our politicians.

**FIRST:** Do you think it is possible to educate the public? Look what has happened over the past fifty years with regard to trying to educate the public, not only with nuclear power, but also sanitary landfills, incinerators, and Olestra, the latest on the hit list. What gives you hope?

**MOELLER:** What gives me hope is the following example. At a public meeting around the XYZ Nuclear Facility, I would say all of you are taxpayers. For fifty dollars per person, (or five hundred or whatever the number is), I can reduce your dose fifty millirems a year. Would you rather have me do that by controlling something in your personal environment, radon, medical x-rays, consumer products that you use or would you rather control the same amount of dose within this nuclear facility at a cost of a million dollars per person. I think if that approach is used often enough, we will prevail, I am an optimist. I know it is going to be difficult, but if there is ever to be any hope of educating the public about the risk associated with various sources of ionizing radiation, this policy may provide a vehicle. And at the moment it seems to me to be one of our best vehicles.

**DAUBER:** Do you think we will have to have a congressional or a bureaucratic implementation of this principle to make it work, or can simply education do the job?

**MOELLER:** I believe we already have much of what we need. As I mentioned, the Chief of Staff of DOE is for it, the top people in EPA are for it. In fact they've spoken out, and have written on it. Congress is for it. I am not a lawyer or even a legislative authority, but I can see no obstacles to it if we can get the right people to get going. What is needed, immediately, is to conduct a pilot study at Hanford, at Idaho Falls, West Valley, at Oak Ridge. We need a few pilot studies. Once they have been completed the results should be submitted to the National Research Council for an independent review.

SESSION 2

**WASTE MANAGEMENT**

Monday July 15, 1996

Co-Chairmen: R.R. Bellamy  
J.G. Wilhelm

**RADIOACTIVE WASTE TANK VENTILATION SYSTEM  
INCORPORATING TRITIUM CONTROL**  
P.D. Rice

**DEVELOPMENT OF A COMPUTER CODE TO PREDICT  
A VENTILATION REQUIREMENT FOR AN  
UNDERGROUND RADIOACTIVE WASTE STORAGE  
TANK**  
Y.J. Lee and E.L. Dalpiaz

**TESTING CLEANABLE/REUSABLE HEPA PREFILTERS  
FOR MIXED WASTE INCINERATOR AIR POLLUTION  
CONTROL SYSTEMS**  
D. B. Burns, A. Wong, B.W. Walker, and J.D. Paul

**DEVELOPMENT OF AN AIR CLEANING SYSTEM FOR  
DISSOLVING HIGH EXPLOSIVES FROM NUCLEAR  
WAR HEADS**  
W. Bergman, K. Wilson, K. Stagges, D. Beason, S. Doughty,  
R. Arganbright, D. Wapman, and G. Nelson

**A THICK HOMOGENEOUS VEGETATED COVER  
DESIGN PROVES COST- AND SCHEDULE-EFFECTIVE  
FOR THE RECLAMATION OF URANIUM MILL SITES  
NEAR SPOKANE, WASHINGTON**  
J. Blacklaw, G. Robertson, D. Stoffel, J. Ahmad, E. Fordham,  
S. Pachernegg, L. Wainhouse, and J. Riley

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### RADIOACTIVE WASTE TANK VENTILATION SYSTEM INCORPORATING TRITIUM CONTROL

Paul D. Rice, P.E.  
ICF Kaiser Hanford Company  
Richland, Washington 99352

#### Abstract

This paper describes the development of a ventilation system for radioactive waste tanks at the U.S. Department of Energy's (DOE) Hanford Site in Richland, Washington. The unique design of the system is aimed at cost-effective control of tritiated water vapor.

The system includes recirculation ventilation and cooling for each tank in the facility and a central exhaust air clean-up train that includes a low-temperature vapor condenser and high-efficiency mist eliminator (HEME). A one-seventh scale pilot plant was built and tested to verify predicted performance of the low-temperature tritium removal system. Tests were conducted to determine the effectiveness of the removal of condensible vapor and soluble and insoluble aerosols and to estimate the operating life of the mist eliminator. Definitive design of the ventilation system relied heavily on the test data.

The unique design features of the ventilation system will result in far less release of tritium to the atmosphere than from conventional high-volume dilution systems and will greatly reduce operating costs. NESHAPs and TAPs NOC applications have been approved, and field construction is nearly complete. Start-up is scheduled for late 1996.

#### Introduction

Safe storage of radioactive waste resulting from reprocessing nuclear reactor spent fuel can be a special challenge when large amounts of tritium are present. High tritium concentrations have been a concern at the Aging Waste Tank Farm (AWTF) at the Hanford Site in Richland, Washington. The AWTF is a complex of four 3800-m<sup>3</sup> (1,000,000-gallon) underground double-shell tanks (DST) identified as 241-AY-101 and -102, and 241-AZ -101 and -102. Although the aging waste volume is small compared to the total waste in the 177 underground tanks at Hanford, its activity level is high. The AWTF tanks have the potential to operate at significantly higher temperatures and can generate large quantities of tritiated water vapor at the waste surface as a natural consequence of heat and mass transfer to the ventilation flow through the tank head space. The ventilation system design for heat removal alone presents no great challenge. The fact that tritium is present changes the entire direction of the design.

#### Background

In 1986 a conceptual design was begun by Kaiser Engineers Hanford (KEH; renamed ICF Kaiser Hanford Company in 1994) to upgrade the AWTF facility (then operated by Rockwell Hanford Operations) to current codes and standards, to achieve compliance with new environmental release criteria, and to handle unusually high heat from future fuel reprocessing campaigns.

The design criteria imposed on the project greatly restricted allowable radionuclide concentrations in the ventilation system exhaust stack and also identified deficiencies in the existing system. In particular, the HEPA filters had lifetimes that varied from two days to two years, depending on waste processing operations.

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The initial conceptual design of the new system included two stages of HEPA filters to control (primarily) strontium, cesium, and plutonium particulate, and a refrigerated wet scrubber to control tritium, ruthenium, and other condensible vapors and to protect the HEPA filters from various soluble compounds such as ammonium salts.

The search for an effective wet scrubber that was practical to maintain in a radioactive mixed waste environment led to a rather novel device, patterned after a submerged gravel scrubber (SGS). The SGS had been developed by Westinghouse Hanford Company (WHC) as a passive venting system for nuclear reactor containment during accident conditions. The device designed by KEH incorporated ceramic balls, rather than gravel, and added a cooling system and a high-efficiency pad-type mist eliminator. See Figure 1.

Two stages of cooling with a total capacity of 4.4 MW (15 million Btu/h) were incorporated in the ventilation system design. The first stage incorporated shell-and-tube heat exchangers with evaporative cooling towers to take efficient advantage of the high-temperature process-ventilation air stream. The second stage of cooling was accomplished with a refrigerated heat exchanger in connection with the scrubber spray system.

Kaiser Engineers recommended that funds be allocated for construction and testing of a prototype scrubber to verify the calculated performance of the proposed system. The services of Pacific Northwest Laboratories (PNL) at Hanford were requested to construct and test the prototype.

By chance, PNL had recently completed a series of tests of a scale SGS in combination with a high-efficiency mist eliminator (HEME) as part of a development program for a waste vitrification melter off-gas ventilation system. PNL's tests revealed that operation of the SGS resulted in a large mist carryover fraction, which drove the use of the HEME in the design. Since the HEME also collected submicron particulate, PNL recommended incorporation of the HEME into KEH's scrubber system to extend the life of the HEPA filters. PNL also suggested that a shell-and-tube heat exchanger be substituted for the SGS and still accomplish the desired end results, using off-the-shelf equipment. The goal was to remove a high percentage of condensible vapors and to enhance HEPA filter protection by removing a wide range of soluble and insoluble particulate.

The "new" scrubber design proposed for testing is shown in Figure 2. It was agreed that a pilot plant based on this configuration should be built and tested. Appropriate program and test plans were prepared by PNL, while KEH procured the needed refrigeration equipment for the pilot plant. The completed pilot plant was ready for testing in 1988.

### Off-Gas Characterization

In support of the PNL test program, the Hanford operations contractor, WHC, performed characterization tests of the AWTF off gas. These tests (Powell 1989) determined particle size, mass concentration, and chemical composition of the off-gas aerosol. The sample data was intended for PNL's use in selecting test aerosols for the pilot plant experiments.

The sample port in the AWTF existing ventilation system was located to approximate the conditions expected just upstream of the proposed scrubber system. The point selected was downstream of existing raw-water-cooled condensers, similar to a location between the two stages of cooling proposed in the new system. An off-gas temperature of approximately 38°C (100°F) was typical at this point.

Test results showed that the temperature of the saturated off gas leaving the condensers affected mass and beta emission concentration (principally Cs 137) in the gas stream. As the vapor outlet temperature of the condensers increased, the mass concentration in the off gas increased. Mass concentration varied from 0.9 to 64.8  $\mu\text{g}/\text{m}^3$ , averaging 16.5  $\mu\text{g}/\text{m}^3$ . Beta concentration increased with increasing condenser outlet temperature, varying between 507 and 2935 pCi/m<sup>3</sup>. Gamma concentration in the off gas varied between 408 and 1294 pCi/m<sup>3</sup> Cs137, but had no apparent correlation to condenser off-gas temperature.

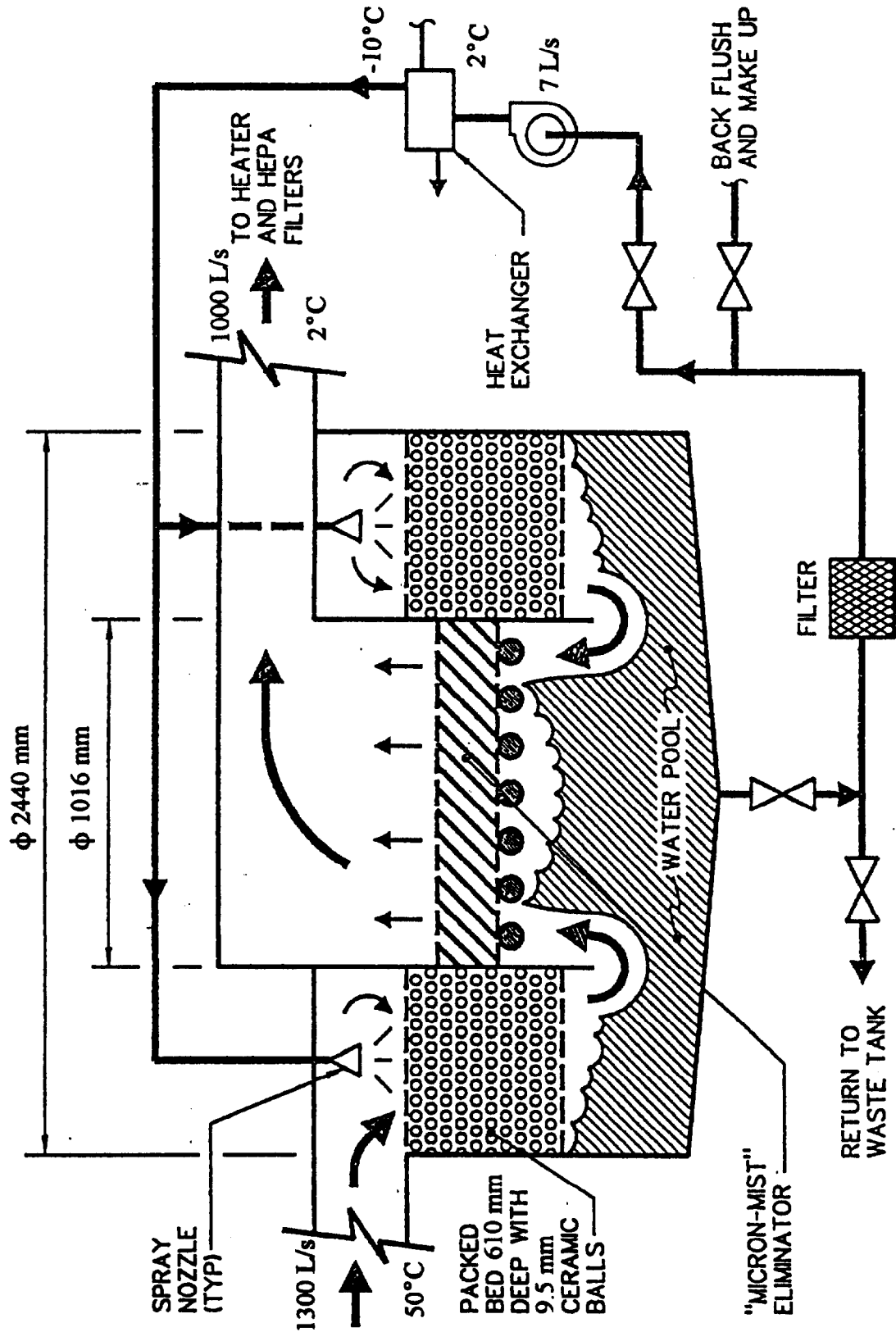


Figure 1 Scrubber/deentrainer/filter.

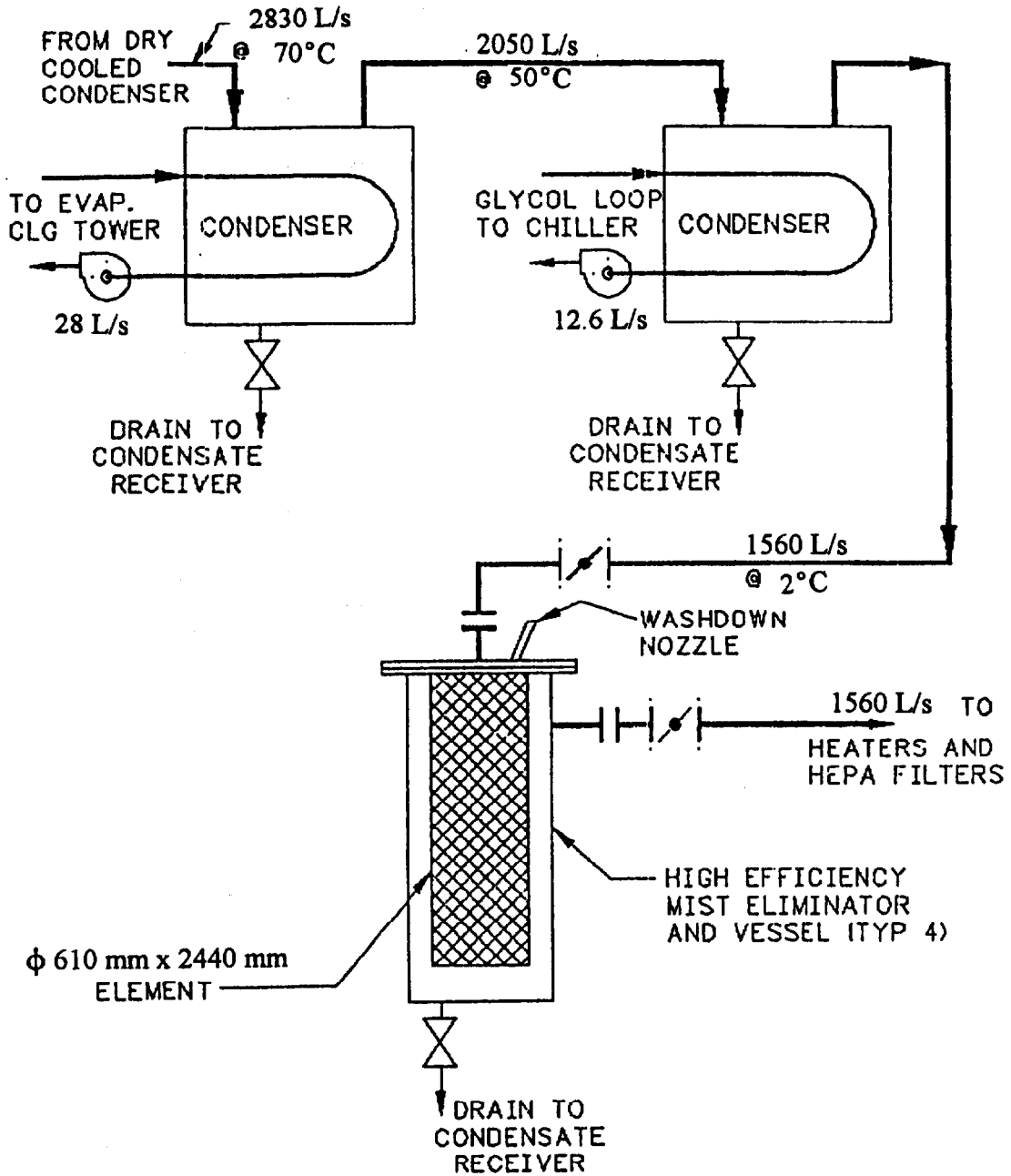


Figure 2 Primary vent scrubber.

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The off-gas stream was found to have two separate mass size distributions (bimodal). Both mass and beta activity readings confirmed that the bimodal size distribution existed. Most of the mass loading and beta/gamma activity was concentrated in the smaller aerodynamic diameter size range of 0.4 to 0.05  $\mu\text{m}$ . The average mass mean aerodynamic diameter (MMAD) of the particulate in the gas stream was 0.073  $\mu\text{m}$ . The beta mean aerodynamic diameter (BMAD) of particulate containing beta activity was 0.084  $\mu\text{m}$ . The established mean of the larger diameter mass and beta distribution was about 2  $\mu\text{m}$ . Statistical analysis indicated that the mean particle size was a function of the temperature of the off gas and location of the sample point in the duct. The larger particulate size distribution was found in the high velocity center of the off-gas duct at higher off-gas temperatures.

### Experimental Apparatus

A pilot-scale scrubber for a DST ventilation system, shown in Figure 3, was fabricated, installed, and tested at PNL (Brouns and Peterson 1989). Table 1 contains the key for the symbols used in Figure 3. Ambient air is pulled into the inlet through a HEPA filter by an off-gas blower. Aerosols are injected into the line to simulate test conditions. Steam can be injected into the aerosol-containing air stream through a metered injection port to adjust the absolute humidity. The stream then passes through a heat exchanger that is used to adjust the relative humidity and temperature. The simulated off gas then passes through the primary components of the pilot-scale system--the refrigerated condenser and the HEME--and then out through the off-gas blower. Temperature, pressure, and flow rate sensors are mounted throughout the test system to monitor, adjust, and record operating parameters. The system was designed to allow for simulation of a variety of conditions expected in a full-scale ventilation system. The individual components in the pilot-scale ventilation system are described in the following sections.

#### Aerosol Generation

Aerosols were produced by Virtis® SG-40 aerosol generators. This apparatus uses a Laskin-type nozzle that shears a liquid solution with sparged air to create a liquid aerosol. Air at 140 kPa (20 psi) was provided to generate the aerosols. Soluble aerosols were produced from a NaCl or  $\text{NH}_4\text{NO}_3$  solution. Insoluble aerosols were produced from a suspension of  $\text{TiO}_2$  in water. Mixed soluble-insoluble tests were conducted by means of two aerosol generators, one for soluble  $\text{NH}_4\text{NO}_3$  and the other for insoluble  $\text{TiO}_2$ . Each generator was adjusted separately to obtain the desired aerosol production rate. Aerosol sizes in the 0.05- to 25- $\mu\text{m}$  size range were measured.

#### Process Gas Line Heater or Cooler

The incoming process gas stream could be heated above or cooled below the ambient temperature with the heater or cooler. The stainless steel shell and tube heat exchanger used either 200 kPa (30-psig) steam or process water. The process gas temperatures that were used in testing ranged from 16° to 66°C (60° to 150°F).

#### High-Efficiency Mist Eliminator

The HEME unit, shown in Figure 4, is a mist eliminator designed to eliminate submicron particles from the process gas stream. The process gas enters the top and center of the HEME and then passes through a cylindrical filter (Flexifiber® type BD-PFF) consisting of approximately 80 mm of 8- to 10- $\mu\text{m}$ -diameter glass fibers. The filter captures aerosol particles by impaction and by Brownian diffusion. A water-spray full-cone nozzle positioned above the filter sprays directly at the filter and can be used to wash the filter free of captured particles. Wash solution and mist removed from the off-gas stream are collected and metered via a dip leg connected to the bottom of the HEME. This collection rate is monitored and is necessary for material balance calculations.

#### Process Gas Chiller

The process gas chiller consists of an air/glycol condenser coupled to a glycol/refrigerant heat removal system. The air/glycol condenser is a four-pass shell-and-tube heat exchanger, with the process gas passing through the shell side of the exchanger and the water-glycol mixture passing through the tube side. A refrigerant evaporator cools the 50 wt% water-glycol mixture, which is maintained at -1°C (30°F) to +2°C (35°F) in a storage tank. A three-way splitter valve (V8) is adjusted to maintain the temperature of the process gas stream leaving the condenser. The three-way valve is manipulated by a pneumatic actuator tied to a set-point temperature controller.

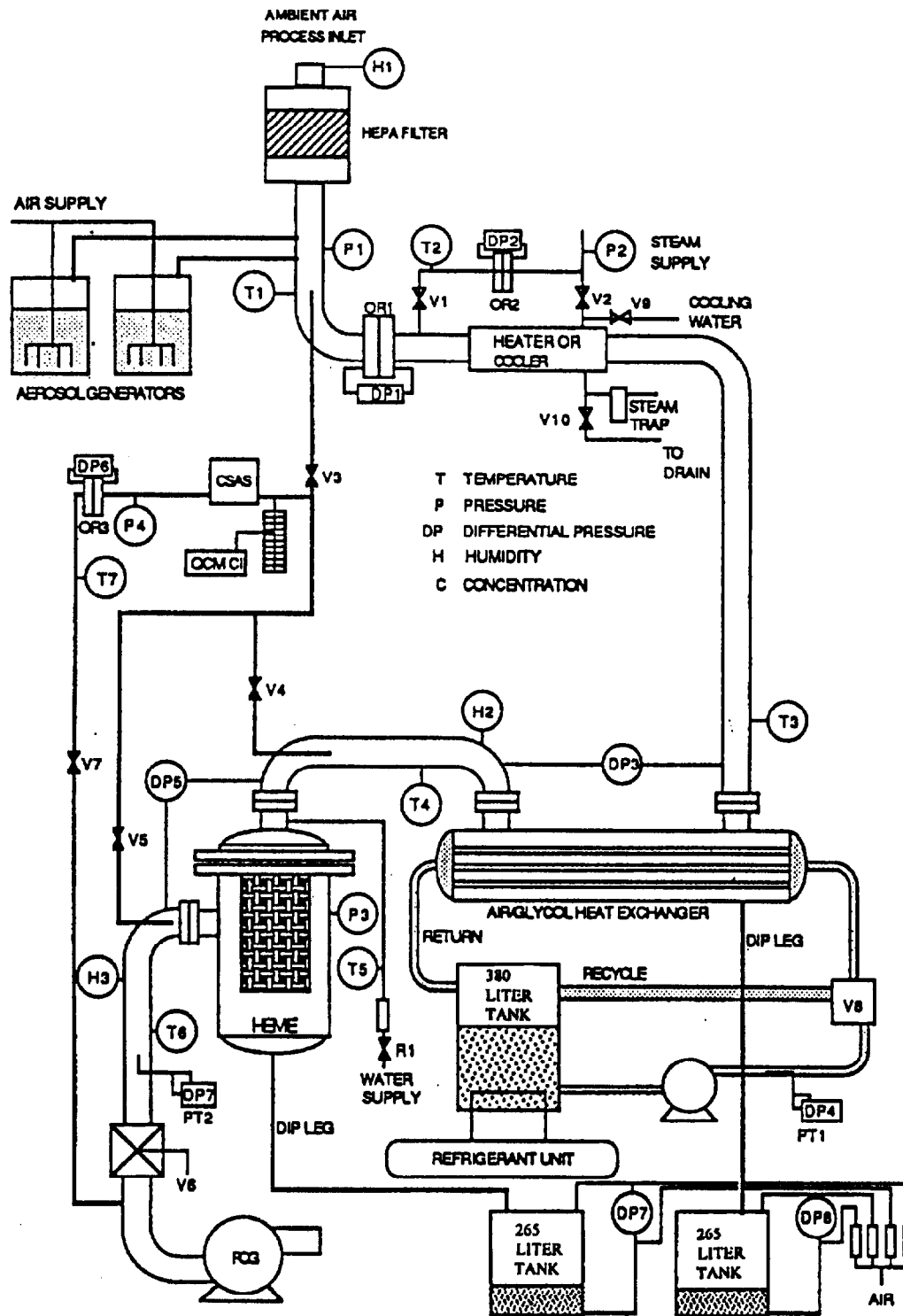


Figure 3 Schematic of the pilot-scale scrubber (from Brouns and Peterson 1989).

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Table 1 Equipment descriptions.

ID Number	Description
CSAS	Classical scattering aerosol spectrometer
QCM CI	Quartz crystal microbalance cascade impactor
TI-T7	Type K thermocouples - temperature
H1	Hygrometer - ambient air dewpoint
P1	Barometer - ambient pressure
P2	Pressure gauge - steam pressure
P3	Differential pressure transducer - HEME operating pressure
P4	Differential pressure transducer - CSAS operating pressure
OR1	Orifice plate (102 mm) - inlet flow rate
OR2	Orifice plate (13 mm) - injection steam flow rate
OR3	Orifice plate (25 mm) - CSAS flow rate
PT1	Pitot tube - water/glycol coolant flow rate
PT2	Pitot tube - HEME outlet flow rate
DP1	Differential pressure transducer - OR1
DP2	Differential pressure transducer - OR2
DP3	Differential pressure transducer - heat exchanger pressure drop
DP4	Differential pressure transducer - PT1
DP5	Differential pressure transducer - HEME pressure drop
DP6	Differential pressure transducer - OR3
DP7	Differential pressure transducer - HEME condensate level
DP8	Differential pressure transducer - HX condensate level
V1	Regulating valve - steam injection control
V2	Regulating valve - steam heater control
V3	Ball valve - inlet aerosol sample manifold
V4	Ball valve - HEME inlet aerosol sample manifold
V5	Ball valve - HEME outlet aerosol sample manifold
V6	Control valve (102 mm) - system air flow control
V7	Regulating valve - CSAS sample flow control
V8	Diverter control valve - process gas temperature control
V9	Regulating valve - water cooler control
V10	Diverter valve - cooling water drain
R1	Flowmeter and control valve - HEME water spray
POG	Primary off-gas system blower

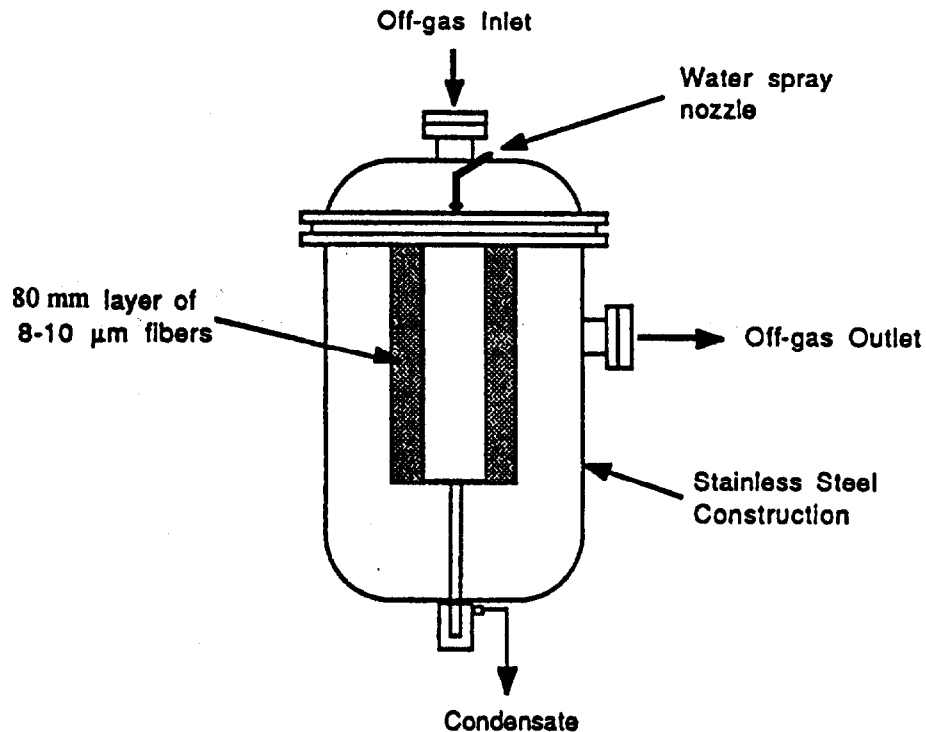


Figure 4 Schematic of the high-efficiency mist eliminator.

With this system, it is possible to cool 70 L/s (150 acfm) of saturated air at 38°C (100°F) to 2°C (35°F), saturated. Condensate from the condenser was collected and monitored by means of a dip leg arrangement similar to that described above for the HEME.

#### Condensate Collection System

The water collection system consists of two steel tanks to contain condensate from the condenser and HEME. Dip legs from the condenser and HEME terminate several inches above the bottom of each tank. Instrument air is purged through tubing to the top and bottom of each tank. Rotameters are used to set and adjust the purged air flow rate. Differential pressure transducers are connected between the top and bottom air lines to measure the liquid head in each tank.

#### Classical Scattering Aerosol Spectrometer/Sampling Manifold

The classical scattering aerosol spectrometer (CSAS) system uses light-scattering theory to measure aerosol particle diameters. A classical He-Ne laser tube is used to create a light beam that is passed through windows mounted on the side of the sample tube. The process gas is drawn through the sample tube, and any entrained aerosols will scatter the light beam. The energy of the pulse of scattered light is proportional to the size of the aerosol that scattered the light; thus, the CSAS can count the number of aerosols passing through the beam and determine the aerosol "optical" or equivalent geometric size distribution. The instrument was calibrated for aerosols in the 0.32 to 0.755- $\mu\text{m}$  size range; therefore, aerosols below 0.32  $\mu\text{m}$  or above 0.755  $\mu\text{m}$  were not measured by the CSAS. The sampling manifold allowed for samples to be drawn from three locations in the system. By appropriate valve switching, samples were taken and analyzed from the inlet to the system, from the entrance to the HEME, and from the exit from the HEME. In general, results of aerosol sampling are expected to be quite accurate for particles smaller than 3  $\mu\text{m}$  and inaccurate for larger particles. Aerosol data from each sample

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port were used to determine the efficiency and the DF for the heat exchanger, the HEME, and the overall system. It was necessary to maintain the temperature of the gas flowing through the sampling chamber above saturation in order to avoid condensation on the optics of the CSAS. Data were not collected when sample lines were at a temperature lower than that of the process gas.

### Quartz Crystal Microbalance Cascade Impactor

In addition to the CSAS, a quartz microbalance cascade impactor (QCM CI) was used to measure aerosol particle size distribution and concentration. While the CSAS measures a particle number distribution, the QCM CI measures a mass concentration distribution. Use of the QCM CI in series with the CSAS allowed comparison between the two methods and obtained data that could be compared directly to field data.

The QCM CI pulls process gas from the CSAS sampling manifold through an isokinetic sampling probe into the sensing stack, which comprises 10 impactor stages. Particles of sufficient size and mass strike a piezoelectric crystal microbalance (PCM) present on each stage of the impactor. Smaller particles escape impaction on the first stages but are captured later as the velocity of the process gas is increased through smaller orifices. The sensing stack segregates particles into ten 50%-efficiency cut-off sizes ( $D_{p50}$ ) between aerodynamic diameters of 25 and 0.05  $\mu\text{m}$ . With an assumed particle density of 2 g/mL, the  $D_{p50}$ s are shown in Table 2. The impacted particles on each stage result in a change in frequency of the quartz crystal that is proportional to the mass of particles collected. Because the QCM CI measures particle size distribution over a wider size range than the CSAS, it is better suited to broadly distributed aerosols. The CSAS is more precise in a narrower distribution but inaccurate for broadly distributed aerosols.

Table 2 QCM CI 50% cut-off sizes.

Stage	$D_{p50}, \mu\text{m}$
1	25.00
2	12.50
3	6.40
4	3.20
5	1.60
6	0.80
7	0.40
8	0.20
9	0.10
10	0.05

### Data Acquisition System

The data acquisition system consists of a Hewlett-Packard 9000/200 computer system interfaced to a Fluke 2240B data logger, a Validyne SPM 380 digital scanning panel meter, and the CSAS. All temperature measurements were provided by Type K thermocouples interfaced to the Fluke logger. Flow rates were measured by means of orifice plates and pitot tubes with all pressure drops, and all operating pressure measurements were determined with Validyne pressure transducers interfaced to the Validyne panel meter. Temperatures, pressure drops, flow rates, and aerosol size and count in each of the 15 channels of the CSAS were collected by the HP 9000/200 computer

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system and stored on its hard disc. QCM CI measurements were printed on thermal paper, referenced in the laboratory record book, and stored for later analysis.

### Experimental Test Results

#### Condensible Vapor Removal

The pilot-scale ventilation system effectively removed 100% of the water that theoretically could be condensed with a saturated stream at the HEME outlet conditions. Condensed water not collected by the condenser was removed by the HEME. When the flow rate was at the high test level (70 L/s or 150 scfm) and the absolute humidity was high, condensate was collected by the condenser. At the low humidity, the condensate was carried to the HEME before collection. At the low test flow rate of 38 L/s (80 scfm), condensate was collected by the condenser at all absolute humidities. The condenser was operated with a coolant temperature of 2° to 3°C (35° to 37°F). Lower temperatures resulted in ice formation and a subsequent decrease in the heat transfer coefficient.

#### Soluble Aerosol Removal

Removal of sodium chloride (NaCl) and ammonium nitrate (NH<sub>4</sub>NO<sub>3</sub>) soluble aerosols occurred in both the condenser and the HEME. At high absolute humidity (0.07 to 0.08 kg H<sub>2</sub>O/kg air), condenser DFs ranged from 3 to 16 with a feed concentration of 30 to 51 μg/m<sup>3</sup>. Condenser DFs generally increased with the off-gas flow rate. At a lower absolute humidity, condenser DFs ranged from 1 to 2, and decontamination was primarily controlled by the HEME. System DFs for soluble NH<sub>4</sub>NO<sub>3</sub> aerosols based on total mass concentrations were between 5.8 and 37 with an average of 19. System DFs averaged 18 for NH<sub>4</sub>NO<sub>3</sub> aerosols in the 0.05- to 0.1- μm size range and 7.1 for aerosols in the 1.6- to 3.2- μm size range at an inlet concentration of 120 μg/m<sup>3</sup>.

#### Insoluble Aerosol Removal

Removal of insoluble titanium dioxide (TiO<sub>2</sub>) aerosols was controlled primarily by the HEME and appeared to be affected by the aerosol concentration. HEME DFs for insoluble aerosols averaged 5.9 at an inlet concentration of 68 μg/m<sup>3</sup>. At a higher inlet concentration of 188 μg/m<sup>3</sup>, the average HEME DF increased to 25. An average system DF of 13 was obtained during tests with a system inlet concentration of 153 μg/m<sup>3</sup> and a HEME inlet concentration of 68 μg/m<sup>3</sup>. System DFs averaged 22 for TiO<sub>2</sub> aerosols in the 0.05- to 0.1- μm size range and 12 for aerosols in the 1.6- to 3.2-μm size range at an inlet concentration of 153 μg/m<sup>3</sup>.

#### HEME Life Expectancy

HEME life expectancy tests with soluble, insoluble, and mixed soluble-insoluble aerosols resulted in an increase in pressure drop of less than 15% over the 30-day test periods. The results of the mixed soluble-insoluble aerosol test indicated that increase in the pressure drop through the HEME of less than 8% was achieved with a system inlet concentration of 537 μg/m<sup>3</sup>. Based on these results, an estimated average full-scale aerosol concentration of 16.5 μg/m<sup>3</sup>, and similar operating conditions (i.e., HEME face velocity of 122 mm/s to 244 mm/s [0.4 to 0.8 ft/sec], and >80% RH), we conclude that the HEME will operate for more than 900 days ((537/16.5)(30 days)) without an appreciable (>15%) increase in the pressure drop. Water spray was effective at washing soluble aerosols from the HEME filter and partially effective at washing insoluble aerosols. Intermittent washing of the HEME filter with a water spray would be beneficial in removing collected aerosol and regenerating the filter, especially during periods of low absolute humidity. A spray flow rate of 10 L/(h·m<sup>2</sup>) (0.25 gph/ft<sup>2</sup>) filter surface was effective during testing.

The detailed report of the pilot-plant experiment was published by PNL in December 1989, in time for use by KEH in definitive design of the AWTF ventilation system.

### Recirculation Ventilation Concept

Definitive design of the new AWTF ventilation system (Project W-030) was approved to start in 1989. However, changes in the project scope had occurred since the original conceptual design, creating growth in the project cost

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estimate. The scope changes were related to changes in the Hanford mission, closure of the PUREX spent fuel reprocessing facility, interfaces with other projects, and previously hidden problems in the existing AWTF ventilation system.

A Value Engineering team was assigned to investigate methods of cutting costs. One major outcome of the investigation was the recommendation by KEH that a detailed study of a recirculation ventilation and cooling concept be performed. An engineering report (KEH 1992) comparing three alternative recirculation schemes was completed in 1992. All three schemes resulted in cost savings, mainly from the reduction in size of facilities required to house smaller equipment in a recirculation ventilation system. The report recommended a tank farm ventilation system that incorporated a small central ventilation exhaust system with individual air recirculation loops to cool each tank.

The proposed central ventilation exhaust system was sized for a 190- to 480-L/s (400- to 1000-scfm) flow rate and allowed a minimum ventilation flow of 50 L/s (100 scfm) for each of four tanks for gas dilution and pressure control. The additional 280 L/s (600 scfm) capacity provided operational flexibility for existing airlift circulator (waste mixing) operation or additional inleakage if desired. Each tank ventilation system recirculated and cooled an airflow of 240 L/s (500 scfm).

A major environmental benefit will be realized by using recirculation for cooling in lieu of the once-through system. The total discharge to the environment will be reduced from about 1400 L/s (3000 scfm) to 190 to 480 L/s (400 to 1000 scfm). Recirculation not only reduces the total discharge, but also reduces material collected in the air clean-up train which reduces operational and maintenance costs.

A side benefit of the reduced size exhaust system was to effectively change the pilot plant scale factor from 1/20 to 1/7 scale, thus boosting credibility of the test data.

The project cost for the recirculation ventilation concept was estimated at \$24.6 million. The project cost for the facility incorporating a once-through system was estimated at \$30 million. This considerable cost savings, as well as the environmental advantages, drove the definitive design to incorporate the recirculation ventilation concept.

### Environmental Impact

Process flow diagrams were developed by using the pilot plant test results to predict environmental discharge for four different operating scenarios. These operating scenarios resulted from different assumptions about heat generated in the waste tanks and variations in waste composition and from operation with failed cooling systems.

During normal operation (current waste composition, no mechanical waste agitation, and operating cooling systems), the annual radioactive release was calculated to be 18 Ci, of which tritium is more than 99%. By comparison, calculated tritium release from the existing system under the same operating scenario amounts to 840 Ci/yr. This gross reduction in tritium release achieved with the new system depends heavily on reliable operation of the cooling system. It should be noted that failure of the cooling system, or for that matter, continued operation of the existing system, will result in a dose to the public that is less than 1% of the exposure permitted by DOE guidelines.

The TAP and NESHAP applications were approved in 1994, and permission to construct the project was granted by the Washington Department of Health, the Washington Department of Ecology, and the U.S. Environmental Protection Agency.

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### Conclusion

A unique ventilation system has been developed and constructed at the AWTF at DOE's Hanford Site. The new system includes recirculation ventilation and cooling for each tank in the facility, followed by a central exhaust air clean-up train that includes a low-temperature vapor condenser and an HEME.

The system is capable of reducing the atmospheric release of tritium to only 2% of the existing system capability. The condenser and HEME will reduce loading of the final HEPA filters in the air clean-up train by a factor of 20 for soluble aerosols, and by a factor of 13 for insoluble aerosols. The operating life of the remotely replaceable HEME cartridge is predicted to be approximately three years.

The new ventilation system, along with the support facilities, is scheduled to begin full-time operation in late 1996.

### References

Brouns, T. M., and M. E. Peterson, 1989, "Performance Evaluation of the Pilot-Scale, Double-Shell Tank Ventilation System Using Simulated Aerosol Streams," PNL-7188, Pacific Northwest Laboratory, Richland, Washington.

KEH 1992, "Tank Farm Recirculation and Ventilation," W030ER, Kaiser Engineers Hanford Company, Richland, Washington.

Powell, W. J., 1989, "Aging Waste Off-Gas Sampling Status Report," Internal memo 13314-89-032, Westinghouse Hanford Company, Richland, Washington.

DISCUSSION

**BELLAMY:** The comment I would like to make is that it took me a little while to understand exactly what you meant by HEME. I think, as an industry, we are falling into a very poor habit of using acronyms for everything. Some of the things that we discussed last week at our ASME standards committee meeting were HEMA's versus HEPA's, high efficiency metal filters versus high efficiency particulate filters, and what do these terms really mean. I think you were understood, but it took me a couple of minutes to realize exactly what you were talking about. You will notice that in the summary that we prepare for this Conference for publication in Nuclear Safety there is a very detailed list of acronyms in the beginning. I would just caution all of us to pay attention to explaining acronyms.

**WILHELM:** At one of the earlier Air Cleaning Conferences, we published results identified as a HEME, a metallic filter with a layer of glass fibers; in this case around twenty microns thick. The real decontamination factor measured was around 3,000 for all the aerosols together.

**RICE:** I might have forgotten to mention the decontamination factors that we achieved. I should have mentioned that the system of the condenser and the HEME together gave us a decontamination factor of about thirteen for insoluble particles, and about twenty for soluble particles. We really did a pretty good job of relieving the load on the HEPA filters.

**CONKLIN:** I am with the Washington State Department of Health, and I regulate radioactive air emissions from Hanford. Since you are already below 0.1 millirem per year to the maximally exposed individual, what was the reason to put in this system? I am not sure I caught how efficient it is for tritium. The third question is, do you consider this system cost-effective?

**RICE:** Yes, it was definitely cost-effective compared to other methods that might be used to reduce tritium. Of course, we are taking advantage of the fact that tritium is basically tritiated water vapor, so we are really just handling water vapor. The concentration off-site is, in fact, quite low and you asked, why did we bother to do this in the first place? I tried to point out that we engaged in this upgrading project for several reasons: one was that we were anticipating adding extra heat to the tanks by operating mixer pumps in order to keep the waste mixed. Other methods of mixing, such as the air lift circulators that are now in those tanks have given us problems. The mixer pump demonstration program will greatly impact the heat load in the tanks. That is a reason for the upgrades, plus the fact that spent fuel intended to be processed in the PUREX plant still remains in storage, and there would be a whole new load of hot fuel that we would have to handle. As it turned out, that fuel probably never will be reprocessed because the PUREX plant has been shut down. However, we do have a cooling system in the tanks that is able to handle extra heat loads. The cooling system also had to meet new codes and standards, plus the Derived Concentration Guides, at the point of release. So you see, our criteria were telling us that it did not matter what the off-site projected dose was; design-wise, we had a problem at the point of release and had to face up to it. It was kind of unrealistic in a way because the off-site impact is so terribly small. Nevertheless, it is just one of many release points at Hanford and you always do the best you can. We felt that using the refrigeration system would be very cost-effective, which it turned out to be. So, we did our job.

**CONKLIN:** What was the efficiency for tritium?

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**RICE:** The existing system, under more or less standard operating conditions, releases to the atmosphere 840 curies per year. That is more than 99% of the total radioactivity released from the entire tank farm. The new system, i.e., the recirculation and refrigeration system together, will release 18 curies, a 50:1 reduction.

**WEBER:** This apparently is the same HEME which was used in the Zone -1 melter offgas test. As you mentioned, it was also used upstream of a HEPA-grade filter, in fact a metallic filter. If you have not already done so you may be interested in speaking with Greg Whyatt at Battelle who did this study, and who documented the performance of the HEME and the downstream HEPA life in that study.

**RICE:** Yes, I know Greg Whyatt. The work for this project started back in '89. It's been a long time, and there were three different scientists at Battelle that worked on this project.

**WEBER:** Apparently there is a completed report by Greg and his co-authors which has now been awaiting DOE approval for issue for something like two years.

**RICE:** Maybe that is a different report. One of my references is a report that was done by Brouns and Peterson. They were the last two individuals that worked on the development of the HEME for this particular project. The HEME that was in the laboratory was, in fact, used for a melter off-gas experiment.

**WEBER:** That would put it back to Greg.

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### DEVELOPMENT OF A COMPUTER CODE TO PREDICT A VENTILATION REQUIREMENT FOR AN UNDERGROUND RADIOACTIVE WASTE STORAGE TANK

Young J. Lee  
1800 Harrison Street  
Oakland, California 94623

Edwin L. Dalpiaz  
ICF Kaiser Hanford Company  
P O Box 888, MSIN G3-17  
Richland, Washington 99352

#### Abstract

Computer code, WTVFE (Waste Tank Ventilation Flow Evaluation), has been developed to evaluate the ventilation requirement for an underground storage tank for radioactive waste. Heat generated by the radioactive waste and mixing pumps in the tank is removed mainly through the ventilation system. The heat removal process by the ventilation system includes the evaporation of water from the waste and the heat transfer by natural convection from the waste surface. Also, a portion of the heat will be removed through the soil and the air circulating through the gap between the primary and secondary tanks. The heat loss caused by evaporation is modeled based on recent evaporation test results by the Westinghouse Hanford Company using a simulated small scale waste tank. Other heat transfer phenomena are evaluated based on well established conduction and convection heat transfer relationships.

#### I. Introduction

The ventilation system has been used as the main method of removing heat from the underground tank that stores heat-generating radioactive waste materials on the Hanford Site. The ventilation system can remove a large amount of heat from the waste tank by introducing cold and dry air into the tank vapor space and removing hot and humid air. The ventilation air removes a major portion of the heat from the tank by carrying away water vapor evaporated from the waste surface. Also, the heat is removed from the waste surface to the ventilation air by the natural convection in the vapor space. In addition to the ventilation air, a small portion of the heat will be removed by air circulating between the primary and secondary tanks (annulus flow). The tank will lose heat through the soil if the temperature of the tank is higher than the temperature of the surrounding soil. An evaluation of the required ventilation flow to remove the heat from the waste tank is an important design parameter for the design of a new tank.

Waters<sup>(1)</sup> developed a simple code to predict the ventilation

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requirement based on the evaporation rate equation developed by Boelter et al<sup>(2)</sup>. In this code, other heat transfer phenomena such as the natural convection have not been evaluated properly. Recently, Crea<sup>(3)</sup> at Westinghouse Hanford Company has performed an experiment measuring the evaporation rate from a 12-ft (3.66-m) diameter simulated waste tank to improve the Boelter equation. Based on these experimental results, computer code WTVFE has been developed to predict the ventilation flow conditions for a waste tank containing heat-generating elements. Also, other heat transfer phenomena have been properly treated in this new code.

### II. Description of Analysis Methods

This section discusses the analysis methods used in code WTVFE for various heat removal modes such as evaporation, natural convection, conduction through the soil, and heat removal by the annulus flow. The analysis methods are based on steady-state conditions with well mixed waste.

#### 1. Evaluation of Evaporation Rate from the Waste

Since water has a large latent heat, a small amount of water evaporation from the waste into the ventilation system will remove a significant amount of the heat from the tank. The water vapor pressure in the ventilation outlet depends on the equilibrium between the amount of water vapor transferred from the waste surface to the bulk air space above the waste and the amount of vapor taken away by the ventilation system. In this evaluation, it is assumed that the bulk air inside the tank is well-mixed and that the outlet condition of the ventilation air is the same as that of the bulk air inside of the tank. Boelter et al<sup>(2)</sup> have developed the following equation to predict the amount of the water vapor transferred from the pure water surface to the bulk air based on the experimental data.

$$W = 0.00129A(P_i - P_b)^{1.22} \quad (1)$$

where:

- W -- amount of water vapor transferred (lb/hr)
- A -- surface area (ft<sup>2</sup>)
- P<sub>i</sub> -- waste surface water vapor pressure (mm Hg)
- P<sub>b</sub> -- bulk phase water vapor pressure (mm Hg)

The validity of applying the Boelter equation to a large tank has been questioned, since Boelter et al developed the empirical equation based on experimental data using a small pan. To confirm the Boelter equation for a large tank like the radioactive storage tanks at Hanford, an experiment was performed by Westinghouse Hanford Company<sup>(3)</sup> to measure the evaporation rate from a 12-ft (3.66-m) diameter tank. The comparison between the experimental results and the predictions by the Boelter equation shows that the predictions by the Boelter equation are an average of 2.9% lower than the experimental data. In the code,

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Boelter's equation has been used for the calculation of the evaporation rate with this adjustment. Table 1 summarizes the comparisons between the experimental data and the predictions by the original and improved Boelter's equation.

Table 1 Comparison between Westinghouse Experimental Data and Predictions for Water Loss.

Test Run No	Experimental Data (lb/hr*ft <sup>2</sup> )	Prediction Boelter (lb/hr*ft <sup>2</sup> )	Error (%)	Prediction Modified (lb/hr*ft <sup>2</sup> )	Error (%)
1	1.2	1.19	-0.8	1.23	2.5
2	14.75	15.13	2.6	15.5	5.1
3	29.03	25.38	-12.6	25.9	-10.8
4	12.73	12.47	-2.0	12.79	0.5
5	23.98	22.86	-4.7	23.35	-2.6
7	30.25	27.16	-10.2	27.69	-8.5
6	9.78	8.92	-8.8	9.14	-6.5
8	23.96	21.9	-8.6	22.39	-6.6
11	25.79	22.06	-14.5	22.54	-12.6
12	3.52	2.98	-15.3	3.05	-13.4
10-10R	8.71	8.5	-2.4	8.71	0.0
17	2.58	2.74	6.2	2.81	8.9
20	12.66	13.39	5.8	13.68	8.1
5R	23.43	23.8	1.6	24.3	3.7
6R	8.48	9.02	6.4	9.25	9.1
9	14.57	16.0	9.8	16.37	12.4
21	4.92	4.55	-7.5	4.67	-5.1
13	0.71	0.69	-2.8	0.72	1.4
22	1.53	1.44	-5.9	1.49	-2.6

The inlet flow rate of the ventilation air required to remove the water vapor transferred from the waste surface shown in equation (1) is equal to:

$$V_a = \left( \frac{760}{60\rho(760-P_n)} \right) \left( \frac{1.6W}{\frac{P_b}{(760-P_b)} - \frac{P_n}{(760-P_n)}} \right) \quad (2)$$

where:

- $V_a$  -- inlet ventilation air flow rate (SCFM)
- $P_n$  -- inlet air water vapor pressure (mm Hg)
- $\rho$  -- air density (lb/ft<sup>3</sup>)

Since the waste contains chemicals, the vapor pressure is lower than pure water. The code has an arrangement to input the factor representing the vapor pressure suppression due to chemicals in the waste.

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### 2. Evaluation of Ventilation Exit Air Temperature

The ventilation air removes heat from the waste by increasing the air temperature while the air is passing through the tank. To evaluate this method of heat removal, the temperature of the ventilation exit air has to be evaluated accurately. As stated previously, the exit conditions of the ventilation air is assumed to be the same as that of the bulk air inside of the tank. The temperature of the ventilation exit air is dependent on the heat transfer rate from the waste surface to the bulk air space above the waste and the ventilation air flow rate. The heat is transferred to the bulk air from the waste surface by the natural convection caused by the density difference between the bulk phase and the interface at the waste. This density difference is caused by the temperature and water vapor pressure differences.

The relationships between the Nusselt number (Nu) and the Rayleigh number (Ra) have been established for laminar and turbulent natural convection<sup>(4)</sup>. The heat transfer coefficient from the waste surface to the bulk phase can be calculated from these relationships. The Nu and Ra numbers are defined as

$$Nu = \frac{h}{Lk} \quad (3)$$

where:

- h -- heat transfer coefficient (Btu/hr\*F\*ft<sup>2</sup>)
- k -- conductivity (Btu/hr\*F\*ft)
- L -- characteristic length (ft)

$$Ra = \frac{g\Delta\rho L^3 \rho_f C_{p_f}}{\mu_f k_f} \quad (4)$$

where:

- g -- acceleration of gravity (ft/hr<sup>2</sup>)
- $\Delta\rho$  -- density gradient  $(=\rho_b - \rho_i) / \rho_i$
- C<sub>p</sub> -- specific heat (Btu/lb\*F)
- $\mu$  -- viscosity (lb/ft\*hr)
- subscript i -- interface
- b -- bulk phase
- f -- film

The relationship between the Nu and Ra number for the laminar natural convection ( $Ra < 10^8$ ) is

$$Nu = 0.56 Ra^{1/4} \quad (5)$$

and the relationship for the turbulent natural convection ( $Ra > 10^8$ ) is

$$Nu = 0.13 Ra^{1/3} \quad (6)$$

The exit temperature of the ventilation air can be evaluated from

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the energy balance equation using the heat transfer coefficient obtained by either equation (5) or (6).

$$60V_a \rho C_{p_a} (T_b - T_n) + Cl = 1.5hA(T_i - T_b) + (C_{p_s}W + C_{p_a}W_{1c})(T_i - T_b) \quad (7)$$

where:

T -- temperature (F)  
 Cl -- heat loss through soil (Btu/hr)  
 W<sub>1c</sub> -- air flow rate through air lift circulation (lb/hr)  
 subscript n -- inlet  
           a -- air  
           s -- water vapor

The heat transfer surface, A in equation (7), is increased by 50% to account for the side wall of the tank above the waste. This surface increase minimizes the exit temperature differences between predicted values and experimental data.

Also, the code prediction for the exit temperature of ventilation air has been compared to the Westinghouse experimental data<sup>(3)</sup>. The results show that the predicted values are an average 1.2% lower than experimental ones. This difference has been factored into the code. In this comparison, a few experimental data have been disregarded since its values are so obviously erroneous. Table 2 summarizes the

Table 2. Comparison between Westinghouse Experimental Data and Predictions for Exit Air Temperature

Test Run No	Experimental Data (F)	Prediction Theory (F)	Error (%)	Prediction Modified (F)	Error (%)
1	98.8	96.0	-2.8	96.8	-2.0
2	170.1	166.8	-1.9	167.5	-1.5
3	154.4	149.0	-3.5	149.8	-3.0
4	171.7	168.4	-1.9	169.0	-1.6
5	167.2	168.8	1.0	170.4	1.9
7	163.6	159.3	-2.6	160.9	-1.7
6*	167.3	180.6	-	182.3	-
8*	172.2	182.4	-	184.2	-
11	172.2	168.6	-2.1	170.3	-1.1
12	126.2	123.0	-2.5	124.1	-1.7
10-10R	155.3	154.7	-0.4	156.1	0.5
17	141.1	143.5	1.7	144.8	2.6
20	154.2	147.8	-4.2	149.2	-3.2
5R	170.9	169.5	-0.8	171.2	0.2
6R	174.3	182.2	4.5	183.9	5.5
9*	155.3	172.6	-	174.3	-
21	140.1	138.9	-0.9	140.1	0.0
13	95.6	91.8	-4.0	92.6	-3.1
22	127.4	129.0	1.3	130.1	2.1

\* These runs are not used for the comparison.

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comparisons between the experimental data and the predictions by the original and improved code calculations. If the exit water vapor pressure calculated in the previous section is higher than the saturation vapor pressure at the exit air temperature calculated in this section, the code will evaluate the exit air temperature where the exit vapor pressure matches with the saturation pressure. In this calculation, it is assumed that the heat that increases the exit air temperature to the saturation temperature comes from the condensation of the water vapor.

### 3. Evaluation of Heat Loss through the Soil

Since the waste tanks on the Hanford Site are underground, heat loss from the tanks to the soil will occur when the waste temperature is higher than that of the surrounding soil. Because the surrounding soil has a large heat capacity and the amount of heat generated by the waste in the tank is relatively small, it will take a long time to reach a steady state during the operation. In the code, it is assumed that there is a water table with a constant temperature of 55°F (12.8°C) below 200-ft (60.96-m) from the tank bottom and the surrounding soil has reached the steady state temperature as suggested in the thermal analyses of the MWWTF (Multi-Function Waste Tank Facility) design<sup>(5)</sup>. Also, there is a steady state heat loss through the soil covering the top of the tank to the outside air.

A simplified model developed for a disc heat source stored in the infinite medium<sup>(6)</sup> was used as the basis for the calculation of heat loss from the tank through the soil to the water table. The tank is assumed to be a disk, since the tank height is small compared with the distance from the tank to the water table and the upper portion of tank will lose heat to the outside air. Furthermore, the pads installed under the tank bottom, such as the concrete and insulating pads with annulus air distribution channels, are ignored since the conduction resistance through 200-ft (60.96-m) of soil is dominant compared with the resistance through these pads.

$$Q_{cb} = \left( \frac{4.45D}{1 - \frac{D}{1-5.67z}} \right) k_z (T_t - T_w) \quad (8)$$

where:

$Q_{cb}$  -- heat loss to water table (Btu/hr)  
 $D$  -- tank diameter (ft)  
 $z$  -- distance from tank bottom to water table (ft)  
subscript  $t$  -- tank  
           $w$  -- water table  
           $z$  -- soil

The conductivity of the soil is estimated to be 0.35 Btu/F\*hr\*ft (0.606 W/m\*K) in the code<sup>(5)</sup>.

The heat loss from the top of the tank to the outside air was evaluated assuming that the top surface of the tank is a flat circle and the heat transfer path in the soil is limited to the cylindrical

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area above the tank. This is an acceptable approach since the depth from the ground surface to the tank is not generally deep. Also, a factor is assigned to adjust possible error due to this simplification as shown in the following equation.

$$Q_{ct} = F\pi D^2 \frac{1}{h_a + \frac{d_s}{k_s} + \frac{d_c}{k_c}} \quad (9)$$

where:

$Q_{ct}$  -- heat loss to outside air (Btu/lb)  
 $F$  -- factor to adjust the error  
 $d$  -- Thickness (ft)  
 subscript c -- concrete

The heat transfer coefficient from the ground to the air is assigned to be 0.5 Btu/F\*hr\*ft<sup>2</sup> (2.837 W/m<sup>2</sup>\*K) and the conductivity of the concrete to be 0.6 Btu/F\*hr\*ft (1.038 W/m\*K) in the code.

If the tank top surface is not flat, it is recommended to use the average depth based on the area. The factor assigned to accommodate any possible error was determined to be 1.12 comparing the code predictions with the calculation results using a sophisticated finite element code<sup>(7)</sup> for the design of the MWWF tank<sup>(5)</sup>. The comparisons between the finite element code calculations and the predictions with and without a factor by equation (9) are summarized in Table 3. Since the factor in equation (9) was determined based on the comparison to the analysis data for only the MWWF design, a large amount of error is possible in applying this factor to other configurations. However, an error in the conduction loss calculation will not significantly affect the evaluation of the ventilation flow rate in most cases since the conduction loss through the soil is very small compared with the other losses.

Table 3. Comparison between Finite Element Calculations and Predictions for Heat Loss through Soil

Waste Temperature (F)	Out side Air Temperature (F)	Finite Element Prediction (Btu/hr)	The Code Prediction (Btu/hr)	Error (%)
187	77	33000	31166	-5.6
118	77	12000	13539	12.8
109	77	10000	10963	9.6
104	77	9000	9757	8.4
98	77	7000	8136	16.2
93	53	12000	10267	-14.4
88	53	9000	8771	-2.5
69	53	4000	3928	-1.8
64	53	3000	2577	-14.1

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### 4. Evaluation of Heat Loss to Annulus Air Flow

Most of the waste tanks designed to store radioactive nuclear waste have a secondary containment. Air is circulated through the gap between the primary tank and the secondary tank in to detect any radioactive waste leak from the primary tank. This circulating air is called the annulus air flow and removes heat from the tank. The overall heat transfer coefficient from the waste to the annulus air flow consists of the resistance in the waste side, tank wall, and air side heat transfer coefficients. An arbitrarily high heat transfer coefficient of 10 Btu/F\*hr\*ft<sup>2</sup> (56.74 W/m<sup>2</sup>\*K) has been assigned for the waste side since the waste is assumed to be well mixed.

For the air side, the heat transfer coefficient<sup>(8)</sup> based on natural convection was used when the air flow was not turbulent (Reynolds number is less than 10<sup>4</sup>).

$$h_a = 0.19 (\Delta T)^{1/3} \quad (10)$$

where:

$\Delta T$  -- Temperature difference (F)

Since the temperature difference is not uniform (large at the bottom of the tank and small at the top of the tank), the logarithmic mean temperature difference is used for the calculation. When the air flow is turbulent, the heat transfer coefficient is evaluated based on forced convection<sup>(9)</sup>.

$$h_a = 0.023 Re^{0.8} Pr^{0.4} k_a / G_p \quad (11)$$

where:

Re -- Reynolds number  
Pr -- Prandtl number  
Gp -- gap distance (ft)

In this equation, properties of the air are evaluated at 100°F (37.8°C).

For the overall heat transfer calculation, it is assumed that air is uniformly distributed throughout the annulus and that 30% of the tank bottom area is in contact with the annulus air. When the annulus air temperature is higher than waste temperature, it is assumed in the code that there is no heat transfer between the annulus air and the waste.

### 5. Consideration on Air Lift Circulation Air

Some of the radioactive waste storage tanks on the Hanford Site have an air lift circulation system to mix the waste during storage. In the air lift circulation system, air is introduced into the waste and passes through it as bubbles. Since air from the air lift circulation system is introduced into the waste, it is assumed in the code that the air temperature leaving the waste is the same as the

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waste temperature and that the water vapor pressure in the air is the same as the saturation vapor pressure for the waste at the surface. When air from the air lift circulation system mixes with the ventilation air, proper material and energy balance equations are solved to account for the high air temperature and vapor pressure from the air lift circulation system.

### III. Description of Computer Code

This section presents a brief description of computer code WTVFE. The code is written in Q-Basic language and a detailed description on how to use the code is in the user's manual section of reference 10.

The code requires the ventilation air inlet conditions, the annulus flow rate, tank geometry and the vapor suppression factor for the waste as input data. Also, it requires the waste temperature and the heat generation rate as input data. First, the code calculates the heat removal rate by the conduction through the soil and annulus air flow. Then, it calculates the amount of water to be vaporized in order to remove the rest of the heat, assuming that heat removal due to the ventilation air temperature rise is negligible. The required vaporization rate is converted to the required ventilation flow rate using equation (2). Based on the required ventilation flow rate and the outlet temperature to be calculated later, heat removal by the ventilation air temperature rise will be calculated and the required ventilation flow rate recalculated. This iteration continues until the previous value of the ventilation flow rate matches the recalculated value within 0.5% of error.

After the iteration of the ventilation flow rate, the iteration of the ventilation air exit temperature will be performed. First, the temperature of the exit air is assumed to be 20°F (11°C) lower than the waste temperature. Using this assumed exit temperature, the Ra number and heat transfer coefficient are calculated. Then, the temperature of the exit air is calculated using equation (7). If the difference between the calculated temperature and the assumed temperature of the exit air is larger than 0.05°F (0.03°C), the exit temperature will be reassigned based on the previously assumed and calculated values. This iteration continues until the difference becomes less than 0.05°F (0.03°C).

After the exit air temperature is converged properly, the code will return to the iteration of ventilation air flow rate again with the newly calculated exit air temperature. Iteration of the ventilation air flow rate and exit air temperature will be repeated until the differences between the previous values and the recalculated values of both variables are within the desired limits.

### IV. Conclusions

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Computer code, WTVFE, has been developed successfully to predict the requirement of the ventilation air flow rate for an underground storage tank for heat-generating radioactive materials.

### Acknowledgment

This work was performed under the auspices of the U.S. Department of Energy by ICF Kaiser Hanford Company under contract number DE-AC06-87RL-10900.

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### DISCUSSION

**BERGMAN:** We heard this morning from Louis Kovach about potential accidents in some of the tank farms, e.g., explosions, filter burstings, things like that. Can you tell us something from your experience that you have actually observed; cracks, things of that nature?

**DALPIAZ:** No, I don't have any actual experiences I could use to answer your question.

**PORCO:** I will address this to speakers from Hanford. Based on your experience with tank farm ventilation, what do you see as the biggest need for product development? I guess the best way to phrase it is, is there a lack in the industry for a product that would serve your needs or assist you in treatment? Is everything that you need available in the market today?

**RICE:** The thing that comes to my mind right away as the biggest concern at Hanford, is flammable gas issues. Control of particulates is really not a problem and has never been a problem as far as I know. Sometimes the filters have a rough life and they may need rapid change-out, but they have never really been a big deal. But now the flammable gas issue is the real problem. What we are faced with are tanks that generate flammable gases in the waste that can build a pressure under the crust and then suddenly overturn the contents and make a large release to the environment. There have been occasions of this occurring. There is one tank in particular that has equipment in it, a mixer pump, to prevent gas build up by keeping the contents agitated. This prevents episodic releases of gas, by allowing continuous average releases. In the paper I presented we discussed a cleanable mist eliminator that is taking out particles. We may find out that it loads up quickly or that there is some problem with washing it. That is why we studied the prototype. We hope, based on the prototype test, that it will turn out to be okay.

**BERGMAN:** I forgot the exact details, but Russia had some tanks out by the Urals that had minor mishaps. And I think they had, as a consequence, several hundred miles of uninhabitable area. I am sure this is well known to your people. I was not quite satisfied with your response to my earlier question as we have an inconsistency between what Louis Kovach said this morning and what you are saying. And I would like to find out who is telling the truth.

**BELLAMY:** I think Dr. Kovach was indicating a little different opinion this morning. You are welcome to comment further if you want. I don't think it's a question of who is telling the truth and I do not think we should go further with that thought. The way I interpreted Mr. Porco's question was that, as a representative of the industry, if there is some piece of equipment that would help to control radioactive releases from the Hanford facility, please speak up and maybe we can take care of it. The answer I heard was that, there really is nothing that would basically solve all our problems.

**RICE:** I think there is really a lot to the idea that the codes and standards that we are forced to use in the processing industry are related to the nuclear power plant industry. They really do not line up very well with the real problems that we are trying to solve. We have been getting by, but if there were a set of codes and standards designed for processing and reprocessing, maybe some new equipment would come out to meet those codes. But right now, we have only N-509 and we build HEPA filter systems to that standard.

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### TESTING CLEANABLE/REUSABLE HEPA PREFILTERS FOR MIXED WASTE INCINERATOR AIR POLLUTION CONTROL SYSTEMS

D. B. Burns, A. Wong, B. W. Walker, and J. D. Paul  
Westinghouse Savannah River Company  
Savannah River Technology Center  
Aiken, SC 29808

#### **Abstract**

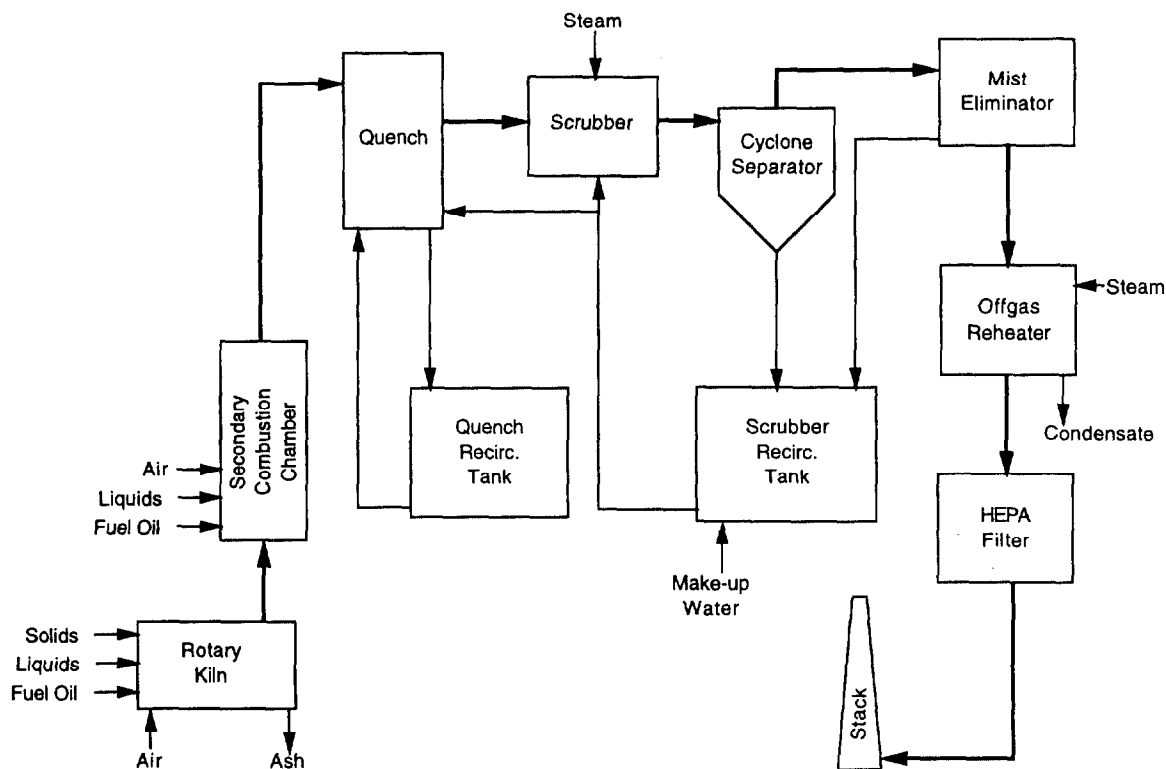
The Consolidated Incineration Facility (CIF) at the US Department of Energy (DOE) Savannah River Site is currently undergoing preoperational testing. The CIF is designed to treat solid and liquid RCRA hazardous and mixed wastes generated by site operations and clean-up activities. The technologies selected for use in the CIF air pollution control system (APCS) were based on reviews of existing commercial and DOE incinerators, on-site air pollution control experience, and recommendations from contracted consultants. This approach resulted in a unique facility design utilizing experience gained from other operating hazardous/radioactive incinerators. In order to study the CIF APCS prior to operation, a 1/10 scale pilot facility, known as the Offgas Components Test Facility (OCTF) was constructed by the Savannah River Technology Center and has been in operation since late 1994. Its current mission is to demonstrate the design integrity of the CIF APCS and optimize equipment/instrument performance of the full scale production facility. Operation of this on-site pilot facility has provided long-term performance data of integrated systems and critical facility components. This effort has reduced facility start-up problems and helped to insure compliance with all facility performance requirements. In today's environment of increased public participation and awareness, technical support programs of this type assist in assuring all stakeholders the CIF can properly treat combustible hazardous, mixed, and low-level radioactive wastes.

Due to the nature of the wastes to be incinerated at the CIF, High Efficiency Particulate Air (HEPA) filters are used to remove hazardous and radioactive particulates from the exhaust gas stream before being released into the atmosphere. The HEPA filter change-out frequency has been a potential issue and was the first technical issue to be studied at the OCTF. Tests were conducted to evaluate the performance of HEPA filters under different operating conditions. These tests included evaluating the impact on HEPA life of scrubber operating parameters and the type of HEPA prefilter used. This pilot-scale testing demonstrated satisfactory HEPA filter life when using cleanable metal prefilters and high flows of steam and water in the offgas scrubber.

#### **I. Introduction**

The Consolidated Incineration Facility (CIF), located at the Savannah River Site, is currently undergoing preoperational testing to treat solid and liquid RCRA hazardous and mixed wastes generated by site operations and clean-up activities. In this facility, waste thermal treatment is performed in a 13 million Btu rotary kiln incinerator and 5 million Btu secondary combustion chamber. The facility air pollution control system (APCS) consists of a recirculating liquid quench and steam-atomized scrubber for offgas cooling and cleaning, a cyclone separator and mist eliminator for liquid/gas separation, and final HEPA filtration prior to atmospheric discharge through the facility stack. A process flow diagram for the CIF is shown in Figure 1.

**Figure 1**  
CIF Process Flow Diagram



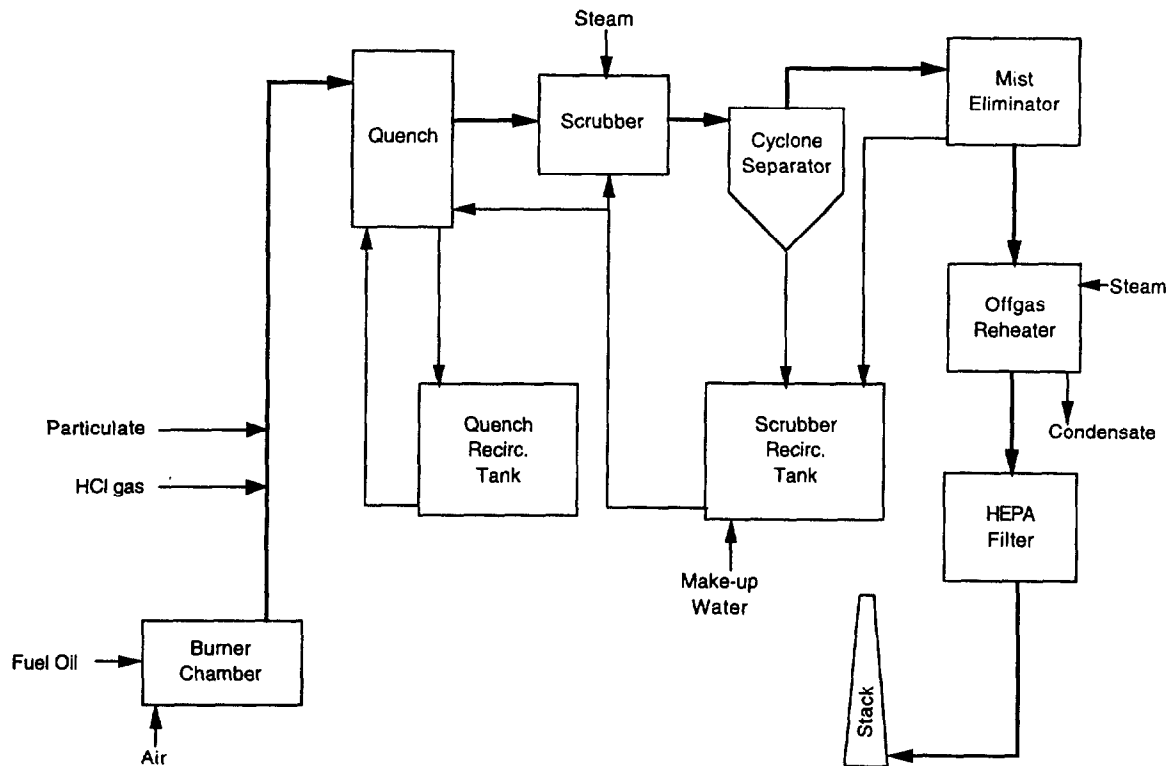
The technologies selected for use in the CIF were based on reviews of existing commercial and DOE incinerators, on-site air pollution control experience, and recommendations from contracted consultants. This approach resulted in a unique facility design utilizing experience gained from other operating hazardous/radioactive incinerators. The Savannah River Technology Center (SRTC) designed, installed, and operated a 1/10 scale pilot facility, known as the Offgas Components Test Facility (OCTF), to demonstrate the design integrity of the CIF APCS and optimize the equipment/instrument performance in the full scale waste treatment facility. Operation of this on-site pilot facility has provided long-term performance data of integrated systems and critical facility components. This effort has reduced facility start-up problems and helped to insure compliance with all facility performance requirements.

## II. OCTF Design and Capabilities

The OCTF is a pilot-scale air pollution control system, currently configured to test the design of the CIF APCS. A schematic of the OCTF is shown in Figure 2. Hot offgas is produced in a three million Btu burner chamber. Particulate and HCl gas are metered into the gas stream to simulate particulate carry-over and acid gas produced during incineration of typical hazardous wastes. The offgas is cooled in a co-current recirculating water quench before entering a high efficiency steam-atomized scrubber. The scrubber removes particulates and neutralizes acid gases. The scrubbed offgas enters a cyclone separator where liquid and solid particulates are removed from the gas stream. After exiting the cyclone, the offgas enters a mist eliminator to remove any residual liquid droplets. A reheater upstream of the HEPA filters prevents

condensation in the filter housing. The filtered offgas is discharged to the atmosphere through the facility stack.

**Figure 2**  
OCTF Process Flow Diagram



The OCTF is designed to evaluate operational parameters of air pollution control system designs. The OCTF utilizes a modular design which allows replacement/addition of existing unit operations with other technologies that could be tested in the future. The current configuration of the OCTF is a 1/10 scale mock-up of the CIF APCS. Individual equipment components and instruments currently installed were designed and fabricated by the same vendors selected for the CIF. The performance of all CIF APCS components were evaluated as a function of system operating parameters at the OCTF. In addition to obtaining valuable performance data, the OCTF is a useful tool for training operators and maintenance personnel.

### III. OCTF Filter Testing

The first test series at the OCTF investigated process parameters that impact system HEPA filter and prefilter life. The APCS must be operated in such a manner to provide acceptable HEPA filter and prefilter life (> 30 days). Short filter life significantly increases facility operating costs associated with procuring, replacing (or cleaning), and disposing system filters. The filter housings used both at the CIF and the OCTF contain 24" x 24" x 11.5" disposable fiber HEPA filters. Upstream of the HEPA filters are 24" x 24" x 6" prefilters. The primary objective of these tests was to determine the APCS operating parameters that are required to meet the goal of 30-day HEPA filter and prefilter life.

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### Test Plan

This test consisted of six runs. The test facility was operated in a mode that simulated the average design operating conditions of the CIF. The gas temperature exiting the burner chamber was held at approximately 1026°C. The gas flow through the HEPA housing was maintained at approximately 2100 ACFM (700 ACFM/HEPA filter). The offgas temperature passing through the HEPA housing was maintained above 115°C to prevent water condensation. The concentration of salt (NaCl) in the quench recirculating stream was held constant during each run. Salt concentrations in the scrubber solution were maintained below 0.1 wt% due to inflow of makeup water. The operating parameters that were investigated in this test included:

- Type of HEPA prefilter
- Mass ratio of scrubber steam to offgas ( $\alpha$ )
- Mass ratio of scrubber water to offgas ( $\beta$ )
- Salt concentration in the quench liquid

Two types of HEPA prefilters were tested. The first was a Flanders paper prefilter (model # T-00K-C-04-00-NL-12-00-E0281, 60-65% @ 1000 cfm). The second prefilter was an Otto York 304 stainless steel prefilter sized to remove 99% of all particles greater than 5  $\mu$ m in diameter. The Flanders prefilter is a disposable filter, while the Otto York prefilter was cleaned with water after each test and reused.

The test matrix for this program is shown in Table 1.

**Table 1 Test Matrix**

Run #	Steam/Offgas ( $\alpha$ )	Water/Offgas ( $\beta$ )	Quench Salt (wt %)	Prefilter Type
1	0.22	0.5	10	Paper
2	0.22	0.5	5	Paper
3	0.43	1.0	10	304 SS
6	0.26	1.0	10	304 SS
7	0.26	1.0	10	Paper
8	0.26	0.5	10	304 SS

### Discussion

The results of all HEPA life test runs are summarized in Table 2. New (or cleaned) prefilters and HEPA filters were installed in the test facility prior to beginning each run. The scrubber operating conditions were maintained at the settings given in the Table 2. Each run ended after sufficient filter pressure drop vs. time data was collected. The actual prefilter and HEPA filter pressure drop observations at the conclusion of each run is listed in Table 2.

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**Table 2 HEPA LIFE TESTS RESULTS SUMMARY**

	Run #					
	1	2	3	6	7	8
Steam Alpha	0.22	0.22	0.43	0.26	0.26	0.26
Water Beta	0.5##	0.5	1.0	1.0	1.0	0.5
Prefilter Type	Paper	Paper	304 SS	304 SS	Paper	304 SS
Quench Salt Concentration	10 wt%	5 wt%	10 wt%	10 wt%	10 wt%	10 wt%
Observed Prefilter dP	3.50" after 40 hrs	2.20" after 110 hrs	1.20" after 415 hrs	1.15" after 375 hrs	3.25" after 215 hrs	0.85" after 475 hrs
Observed HEPA dP	0.40" after 40 hrs	0.35" after 110 hrs	0.85" after 415 hrs	3.00" after 375 hrs	0.40" after 215 hrs	2.80" after 475 hrs
Projected Prefilter Life*	2 days	10 days	42 days	30 days	10 days	68 days
Projected HEPA Life**	#	#	37 days	18 days	#	27 days

\* Projected Prefilter Life estimates are derived by extrapolating a third order polynomial function fit to observed data. For paper prefilters, the maximum dP permitted is 4". For cleanable metal prefilters, the maximum dP is 10"

\*\* Projected HEPA life estimates are derived by extrapolating a third order polynomial function fit to observed data. The maximum dP for HEPA filters is 4".

# Insufficient data to fit a valid a third order polynomial model.

## Partial plugging of scrubber water nozzles during this run is expected to have contributed to poor scrubber performance.

A mathematical model was fitted to the prefilter and HEPA filter pressure drop (dP) vs. time data. The model that consistently showed the best data fit (in particular for the data sets showing a filter at the maximum useful dP) was a third order polynomial relating the dependent variable (dP) to the independent variable (time). Using this model, filter life expectancies were extrapolated for runs ending prior to reaching the maximum allowable dP. For the disposable Flanders prefilters and HEPA filters, this value was assumed to be 4" water. If filter dP was allowed to exceed this value, filter breakthrough was often observed. For the cleanable metal prefilters, the maximum dP was assumed to be 10" water. These filter life predictions are included in the last two lines of Table 2.

Acceptable filter performance was obtained only when using the cleanable metal prefilters. The maximum observed disposable prefilter life was 10 days under all conditions tested. Under similar conditions, prefilter life was extended approximately 3X when using the metal prefilters. It should be noted that use of the disposable paper prefilters always resulted in plugging and changing of the prefilter before any significant dP increase occurred on the HEPA filter. This explains the inability to predict HEPA life for these runs (1, 2, 7). Insufficient data was available for the HEPA dP profile because the prefilter would plug too rapidly. Yet, use of the metal cleanable prefilter often resulted in plugging of the HEPA filter before the dP limit for the prefilter was obtained. Thus, the data tends to indicate the cleanable prefilter allows a greater fraction of particulate through to the HEPA filter. Yet, this more even distribution of particulate between the prefilter and HEPA filter permits a significantly longer time interval between filter (either prefilter or HEPA filter) changeout or cleaning.

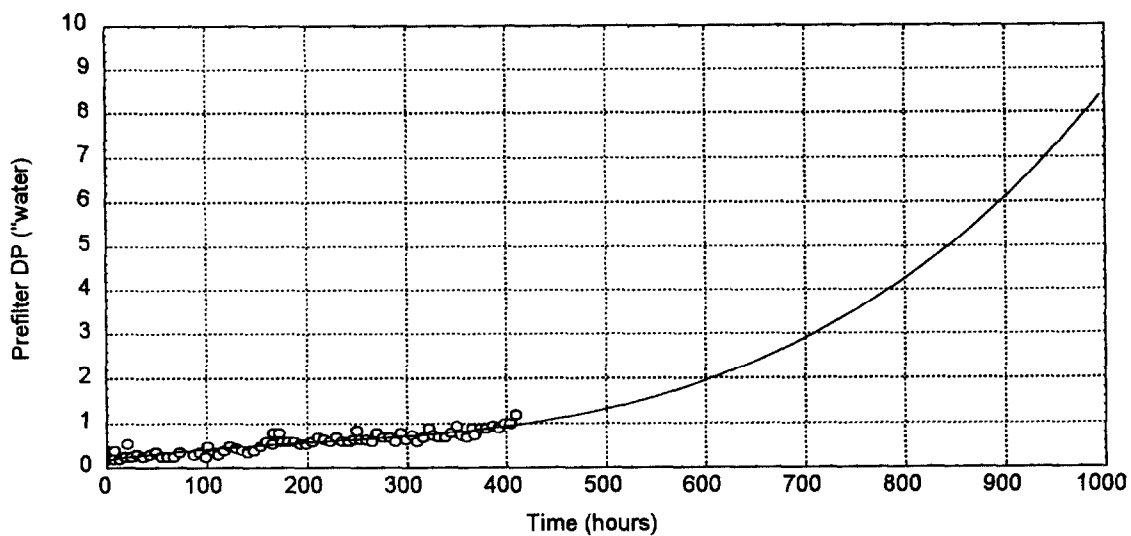
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The runs which utilized cleanable HEPA filters were #3, 6, and 8. During these runs, the steam/offgas flow ratio was varied between 0.43 and 0.26. Also, the scrubber water/offgas flow ratio was varied between 1.0 and 0.5. The theoretical best conditions are at higher steam and water flowrates (Run 3). Figures 3 and 4 contain the graphs of prefilter (Fig 3) and HEPA filter (Fig 4) dP vs. time. Also on the plots are the projected performance curves predicted by the third order polynomial model. For this run, it can be seen that the actual data does not cover a significant fraction of the model, particularly where the slope begins increasing. It is likely that the model being used for these conditions is a "worst case" projection. Thus, there is a relatively high probability that actual filter life would be at least what is predicted for this case (and possibly greater).

**Figure 3 Run 3 Prefilter Performance**

$$\text{Model: } V6=K+A*V1+B*V1**2+C*V1**3$$

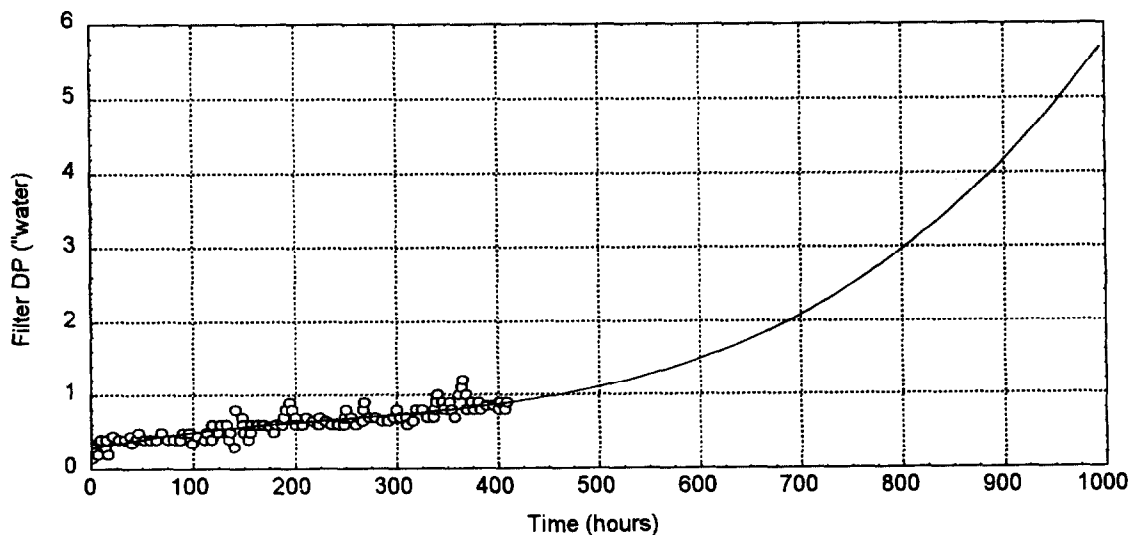
$$y=(0.1817287)+(0.003141479)*x+(-8.596414e-006)*x**2+(1.379748e-008)*x**3$$



**Figure 4 Run 3 HEPA Filter Performance**

$$\text{Model: } V7=K+A*V1+B*V1**2+C*V1**3$$

$$y=(0.2844875)+(0.002788966)*x+(-7.295733e-006)*x**2+(9.993183e-009)*x**3$$



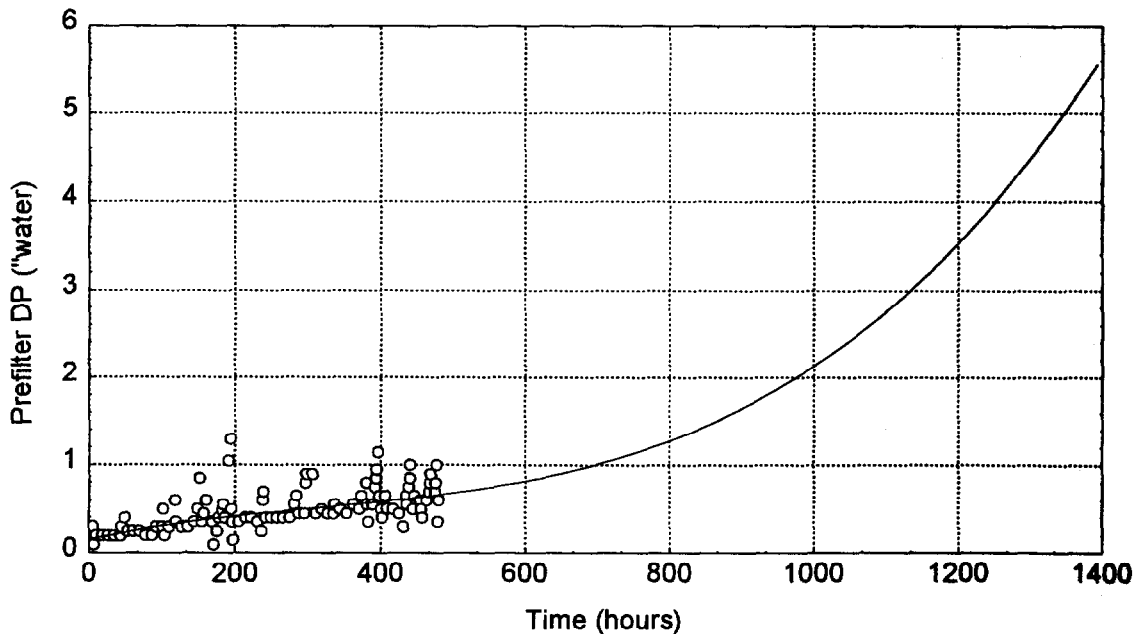
The second best performance was observed in Run 8, when the steam and water flows were both low. This is due to the fact that proper scrubber performance requires the ratio between the scrubber water flow to scrubber steam flow equal two (# water / # steam = 2). If the ratio is too high, the majority of the steam is used to atomize the water and there is insufficient steam for turbulence and pulling offgas through the scrubber. While a low ratio results in insufficient water to properly scrub the offgas. This explains the relatively poor performance in Run 6 (water / steam ratio = 3.8).

Figures 5 and 6 contain the graphs of prefilter (Fig 5) and HEPA filter (Fig 6) dP vs. time for the second best run, Run 8. For this run, it can be seen that the actual data covers enough of the model (especially for the HEPA filter), to consider the projected HEPA filter life a likely estimate. Thus, it is probable that the projected HEPA life of 27 days is an accurate estimate, not a "worst-case" estimate as in Run 3

Figure 5 Run 8 Prefilter Performance

Model:  $V13=K+A*V1+B*V1**2+C*V1**3$

$y=(0.1525723)+(0.001824109)*x+(-3.208998e-006)*x**2+(3.36416e-009)*x**3$



The particulate size distribution data obtained during these tests indicated that increasing the flow of steam to the scrubber decreased the fraction of large particulates (> 10 μm). This can be seen by comparing the size distribution plot for runs 6 and 3 (Figures 7 and 8). The only difference between these runs is the mass flow of steam. The steam flow was low (0.26 alpha) in Run 6 (Fig 7), and high (0.43 alpha) in Run 3 (Fig 8). This change in the particulate size distribution resulted in increased filter life at the higher steam flow (and a water/steam ratio closer to 2).

Figure 6 Run 8 HEPA Filter Performance

Model:  $V12=K+A*V1+B*V1^{**2}+C*V1^{**3}$

$y=(0.5212461)+(0.0009766396)*x+(9.477834e-006)*x^{**2}+(-4.058634e-009)*x^{**3}$

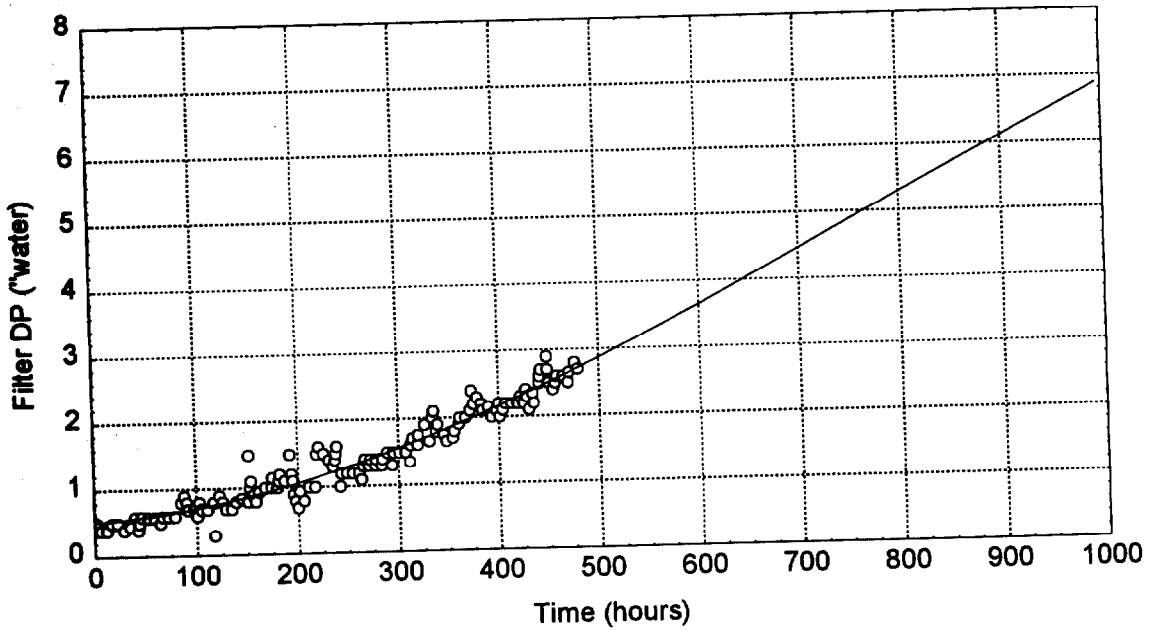


Figure 7 Run 6 Offgas Particulate Size Distribution

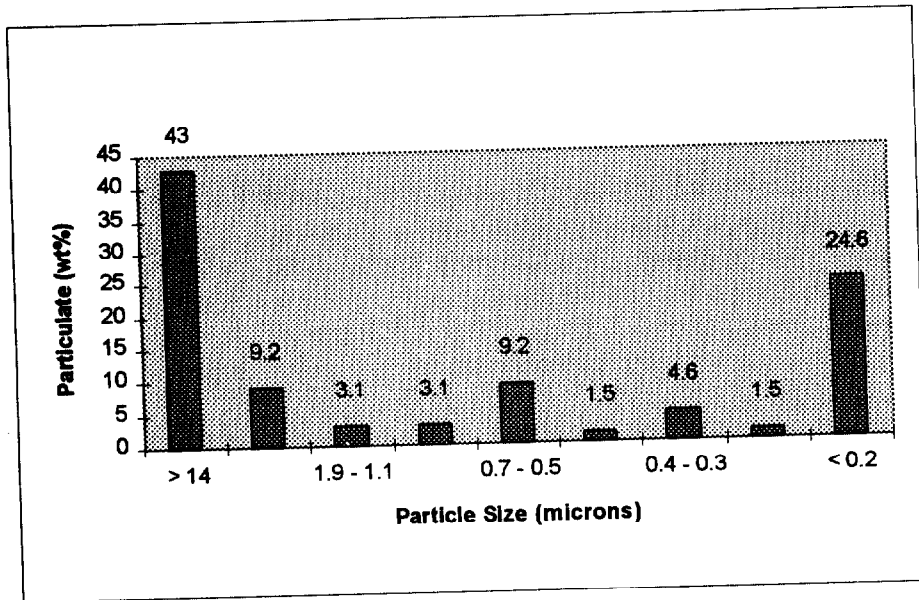
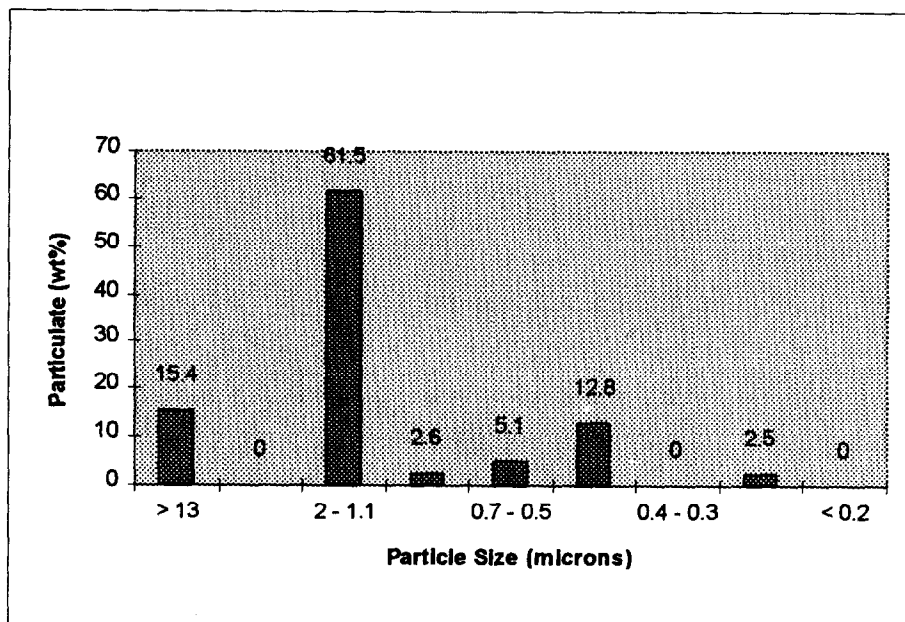


Figure 8 Run 3 Offgas Particulate Size Distribution



**Conclusions**

The primary conclusion of this test program is that satisfactory prefilter and HEPA filter life is obtainable with the existing CIF APCS. Test results indicate that the life of HEPA prefilters/filters can exceed the operational goal of thirty days under the following conditions: steam ratio,  $\alpha = 0.43$ , scrubber water ratio,  $\beta = 1$ , and using 304 SS cleanable prefilters.

**IV. Summary**

The Consolidated Incineration Facility (CIF) at the US Department of Energy (DOE) Savannah River Site has a unique facility design utilizing experience gained from other operating hazardous/radioactive incinerators. In order to study the CIF APCS prior to operation, a 1/10 scale pilot facility, known as the Off-gas Components Test Facility (OCTF) was constructed by the Savannah River Technology Center and has been in operation since late 1994. This test facility demonstrated the design integrity of the APCS and is currently being used to optimize the equipment/instrument performance of the full scale production facility. Operation of this on-site pilot facility has provided long-term performance data of integrated systems and critical facility components. This effort has reduced facility start-up problems and helped to insure compliance with all facility performance requirements.

Tests were conducted to evaluate the performance of the HEPA filters under different operating conditions. These tests included evaluating the impact on HEPA life of scrubber operating parameters and the type of HEPA prefilter used. This pilot-scale testing demonstrated satisfactory HEPA filter life when using cleanable metal prefilters and high flows of steam and water in the offgas scrubber.

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### DISCUSSION

**BELLAMY:** I have two questions I would like to ask. The first is on the slide that showed useful life versus number of runs. For the three runs that were done for the cleanable filters, two of the runs did not get to your acceptable thirty day life. I assume that each run was under different operating conditions?

**BURNS:** Correct.

**BELLAMY:** So run three, that was over thirty days, basically defined for you your future operating conditions, rather than the average of those three to be over thirty days?

**BURNS:** Each run was for a separate operating condition.

**BELLAMY:** The second question I have is concerned with service life and useful life. For a cleanable pre-filter, how many washable cycles are possible? If I buy one filter am I done forever? If I wash it every thirty days, do I have to replace it every year, two years, three years?

**BURNS:** That is something we haven't an update on. We are still using the original filter in the test facility. We have at least twenty-five cycles on it. Typically, we just load it up until we have to shut down; usually the HEPA filter is plugged and has to be replaced. The most resistance we have ever gotten on the prefilter has been about 3 in. w.g. When it starts clean, it is less than an inch.

**BELLAMY:** Not being intimately familiar with manufacturers' names and products, the final conclusion on your final slide used the term Otto-York prefilter. What is the significance of an Otto-York prefilter versus anybody else's prefilter?

**BURNS:** That just happens to be the one we tested. We consulted our site experts and they had some experience with that particular type of filter, so that was what was recommended. I have no doubt that a similar filter, manufactured by another company, would most likely behave the same.

**PORCO:** The question I have is, did you check the initial resistance after you cleaned your moisture separator? Did you do a pressure drop test on your moisture separator after you cleaned it?

**BURNS:** Yes.

**PORCO:** How close did it get to the original pressure drop?

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**BURNS:** The same.

**PORCO:** That answers the question about being reusable. As long as you keep coming down to the initial resistance it means you are getting most of the particles off.

**BURNS:** The particles we have are salt and iron oxide. When we analyze it we typically see a lot of iron chloride, stuff that washes out fairly easily. It is not sticky or anything like that. It tends to return to the silver clean appearance every time after we have washed it.

**PIERCE:** You noted on your slide that the glass prefilter you used was rated at 60 - 65% ASHRAE efficiency. What was the ASHRAE efficiency rating of the stainless prefilter?

**BURNS:** It is a mist eliminator, it has no ASHRAE efficiency rating because it is not really an air filter. The closest figure I have is what the manufacturer says, 95 % removal for water droplets greater than five microns.

**PIERCE:** The suggestion I am making is that you might not be looking at apples-to-apples if they do not have the same efficiency.

**BURNS:** It is a totally different item, it is a mist eliminator. It is not an air filter and it is not sold as an air filter.

**WEBER:** This was an extremely interesting paper. It is not critical to your presentation, but would you say that there was anything done to the knit-mesh of glass and stainless steel to create a fixed pore size?

**BURNS:** For that filter, to my knowledge, they do not advertise any kind of fixed pore size, it is just a spun fiber. This is really just a totally new application. The gases we are dealing with here contain a lot of water vapor. It is a totally different application than a typical HVAC HEPA filter application. In this case, we found that this particular unit happened to help us out quite a bit.

**PORCO:** If you want to find the ASHRAE efficiencies for moisture separators, there is a Mine Safety Appliances Co. report, MSAR-71-45 where you will find efficiencies for a moisture separator. Also in Air Cleaning Conference Proceedings, 14th Conf. p. 694.

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**FLEMING:** Did you say that you were adding HCL to the airstream at some point?

**BURNS:** Yes, we burn PVC waste, so there is an acid gas. That is the source of the sodium chloride.

**FLEMING:** That is what I was going to ask, is the sodium coming from a neutralization of the HCL?

**BURNS:** Exactly.

**FLEMING:** Do you put it in after the quench or before the quench?

**BURNS:** It is before. Here is how the system works: from burning PVC or chlorinated waste, HCL or chlorine gas comes out of the incinerator. The scrubber takes it out and the pH in the scrubber solution quickly goes very low, so you have to neutralize it with a caustic. That creates the sodium chloride. The sodium chloride is usually what gets entrained into a fine salt mist that plugs the HEPA filters. Therefore, the concentration of sodium chloride you allow to build up in your loops is a very critical parameter.

**FLEMING:** What I am really getting to is, what effect does the corrosion have on the filters themselves? Up to this point, have you noticed any corrosive effects, any eating away of the filter as you rinse it off, anything like that?

**BURNS:** We have seen some. We have not seen any corrosion on that particular unit, but we have seen some signs of corrosion in our HEPA filter housings. Corrosion would be what is going to limit the life of the prefilter. I am surprised we have not seen any corrosion yet.

**FLEMING:** I am too.

**BURNS:** It stays pretty dry in there, so that is probably what limits corrosion.

**FRANKLIN:** From looking at your data, I concluded that you are really using the Otto-York pad as a mist eliminator. The pressure drop does not seem to be rising very much, and I assume all the particles are going through into your HEPA filter. Are you really collecting anything on the pad?

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**BURNS:** Absolutely, yes. The unit is a very dark red when pulled out. The ideal situation for us would be to get a more efficient mist eliminator that would allow more loading. We are not loading the prefilter up as much as we would like to, because our HEPA filter is plugging. To even further optimize the system, we would like to find a more efficient mist eliminator to increase HEPA life.

**FRANKLIN:** Have you measured the amount of particles on the prefilter?

**BURNS:** Yes, we did weights before and after. The most we have seen is about three pounds.

**DYMENT:** I am a little puzzled as to why you decided to use a mist eliminator as a dry filter. Would it not have performed better as a mist eliminator by using it earlier in the system, before you had heated the solution?

**BURNS:** We have a mist eliminator earlier in the system. We have a mist eliminator already in the process line.

**DYMENT:** Is it perhaps not a very good mist eliminator?

**BURNS:** I would not argue with that.

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### DEVELOPMENT OF AN AIR CLEANING SYSTEM FOR DISSOLVING HIGH EXPLOSIVES FROM NUCLEAR WARHEADS\*

by

W. Bergman, K. Wilson, K. Staggs, and D. Wapman  
Lawrence Livermore National Laboratory  
Livermore, CA 94550

#### Abstract

The Department of Energy (DOE) has a major effort underway in dismantling nuclear weapons. In support of this effort we have been developing a workstation for removing the high explosive (HE) from nuclear warheads using hot sprays of dimethyl sulfoxide (DMSO) solvent to dissolve the HE. An important component of the workstation is the air cleaning system that is used to contain DMSO aerosols and vapor and radioactive aerosols.

The air cleaning system consists of a condenser to liquefy the hot DMSO vapor, a demister pad to remove most of the DMSO aerosols, a high efficiency particulate air (HEPA) filter to remove the remaining aerosols, an activated carbon filter to remove the DMSO vapor, and a final HEPA filter to meet the redundancy requirement for HEPA filters in radioactive applications. The demister pad is a 4" thick mat of glass and steel fibers and was selected after conducting screening tests on promising candidates. We also conducted screening tests on various activated carbons and found that all had a similar performance. The carbon breakthrough curves were fitted to a modified Wheeler's equation and gave excellent predictions for the effect of different flow rates. After all of the components were assembled, we ran a series of performance tests on the components and system to determine the particle capture efficiency as a function of size for dioctyl sebacate (DOS) and DMSO aerosols using laser particle counters and filter samples. The pad had an efficiency greater than 99% for 0.1  $\mu\text{m}$  DMSO particles. Test results on the prototype carbon filter showed only 70% efficiency, instead of the 99.9% in small scale laboratory tests. Thus further work will be required to develop the prototype carbon filter.

#### I. Introduction

This study is a continuation of the development previously described of an air cleaning system in support of the DOE nuclear weapons dismantlement program in which hot DMSO sprays are used to dissolve the HE from nuclear warheads.<sup>(1)</sup> The DMSO spray generates a high concentration of aerosols containing dissolved HE that must be contained and filtered by HEPA filters in the exhaust line to prevent HE or potential radioactive contamination from being released to the

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atmosphere. In our previous study, the exhaust from the dissolution workstation was exhausted directly into wooden frame HEPA filters.<sup>(1)</sup> These HEPA filters showed rapid plugging from the DMSO aerosols and developed leak paths through chemical attack by the DMSO. The exhaust system was criticized by reviewers of the previous paper for not using a demister to remove the bulk of the DMSO mist prior to reaching the HEPA filter. This paper presents the results of our recent efforts to develop a more robust exhaust filtration system for the HE dissolution workstations.

### II. Air Cleaning System for the HE Dissolution Workstation

The major components of the air cleaning system for the HE Dissolution Workstation are shown in the schematic in Figure 1. The air cleaning system consists of a condenser to chill and condense the hot DMSO vapor, a demister pad to remove most of the DMSO aerosols, a high efficiency particulate air (HEPA) filter to remove the remaining aerosols, an activated carbon filter to remove the DMSO vapor, and a final HEPA filter to meet the redundancy requirement for HEPA filters in radioactive applications. An inlet valve connected to the workstation is used to vent the workstation chamber with HEPA filtered air.

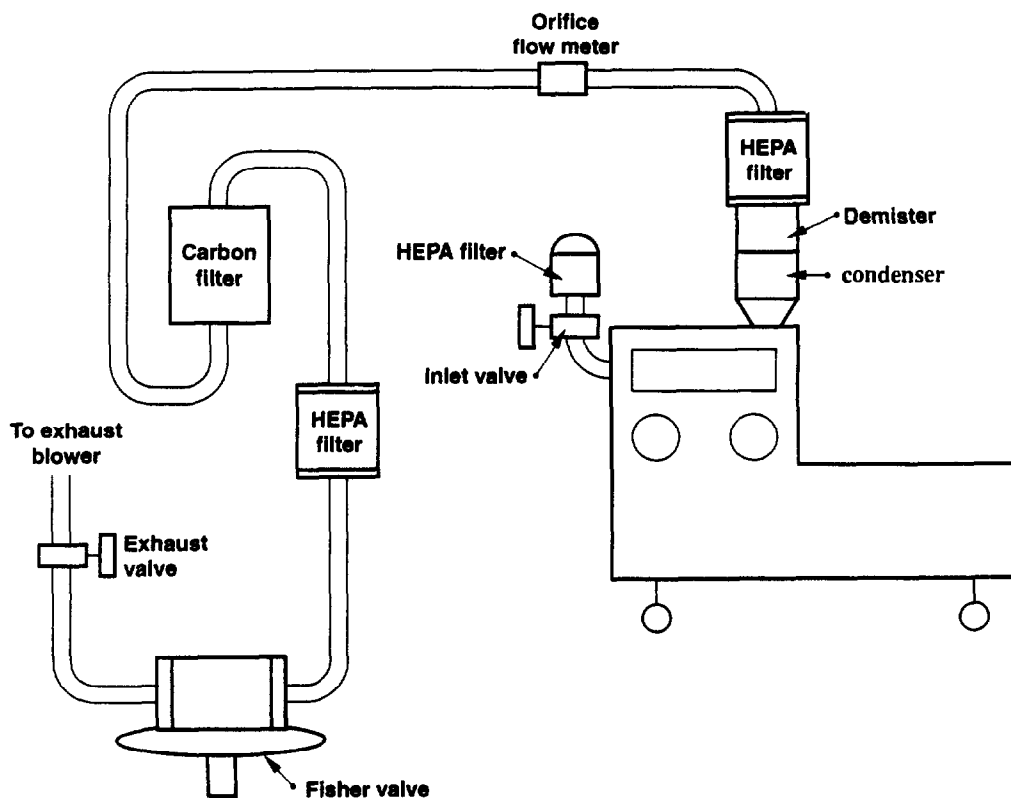


Figure 1 Schematic of exhaust system on the HE dissolution workstation.

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One of the most important safety features of the exhaust system is the Fisher regulator valve. The Fisher valve controls the amount of vacuum applied to the workstation by opening or closing the valve as the workstation vacuum drops below or increases beyond a preset vacuum (usually 1 inch of water) respectively. A vacuum control line (not shown in Figure 1) from the workstation to the diaphragm of the Fisher valve controls the opening of the valve. Maintaining a negative pressure within the workstation insures that the contaminants do not leak out into the workplace. When the inlet valve to the workstation is closed, the building exhaust blower pulls an increasing vacuum on the workstation until the Fisher valve is nearly closed. The Fisher valve is still cracked slightly open to draw a small flow through the workstation due to unintentional leaks in the workstation and components of the exhaust system. Generally this flow is about 1 cfm. The leak flow should be minimized to avoid drawing an excessive amount of DMSO aerosol and vapor through the exhaust system.

In addition to controlling the workstation vacuum during normal operations, the Fisher valve also provides a rapid exhaust flow under accident conditions when the workstation barrier is breached. The most likely scenario for a breached barrier is the loss of a glove. Under this condition, the workstation vacuum drops to nearly 0 vacuum (atmospheric pressure), and the Fisher valve opens fully. This pulls the maximum air flow from the workstation into the exhaust. The exhaust system was designed with minimal restriction to this flow.

A photograph of the front side of the HE Dissolution Workstation is shown in Figure 2. The heated DMSO reservoir and the pump for the DMSO spray are located in the lower, covered portion of the workstation. Hot water is used to heat the DMSO liquid to 150-155 °F by means of a heat exchanger also located in the lower part of the workstation. The dissolution is performed in the 18 ft<sup>3</sup> chamber having glove ports and a viewing window. An access door on the right side of glove ports is used to install and remove the HE assembly. The exhaust condenser, demister and first HEPA filter are mounted directly on the roof of the workstation. Condensate from the condenser and the demister can freely drip back into the workstation. The carbon filter, second HEPA filter, Fisher valve, and exhaust valve are mounted on the rack to the left of the workstation.

Figure 3 shows the side view of the workstation as well as the exhaust rack on the right. The cover plate to the side access door is clearly visible. The access door is opened and closed by using a turn screw to slide the access door along tracks. The exhaust train consisting of a condenser, demister, and first HEPA filter are seen directly over the access door. The remainder of the exhaust system is mounted in the rack on the right. Note that the rack has a duplicate set of components to accommodate a second workstation. A detailed view of the exhaust rack is shown in the photograph in Figure 4. This figure also shows the inlet valve and HEPA filter leading to the workstation.

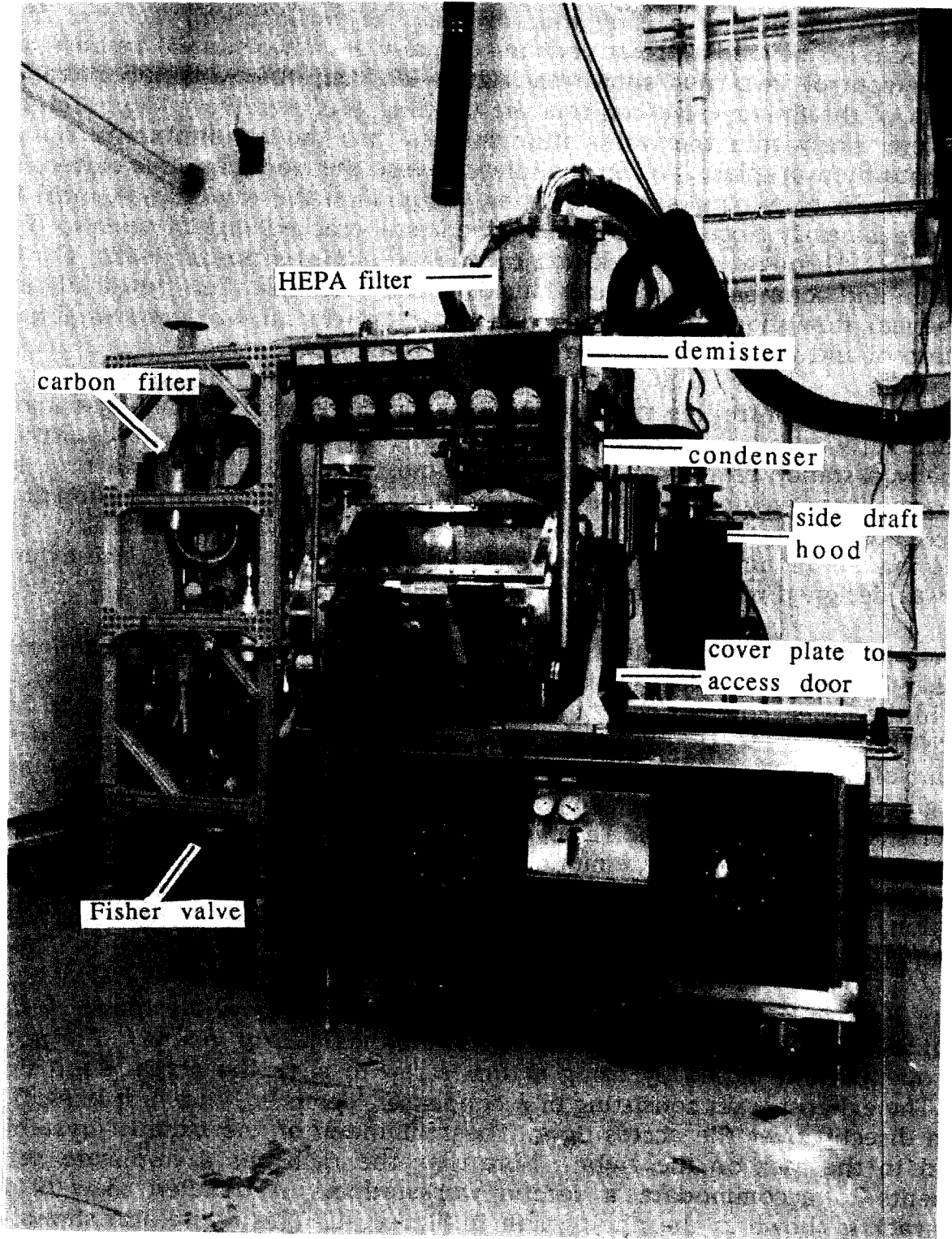


Figure 2. Photograph of the front side of the HE Dissolution Workstation with the exhaust rack on the left side.

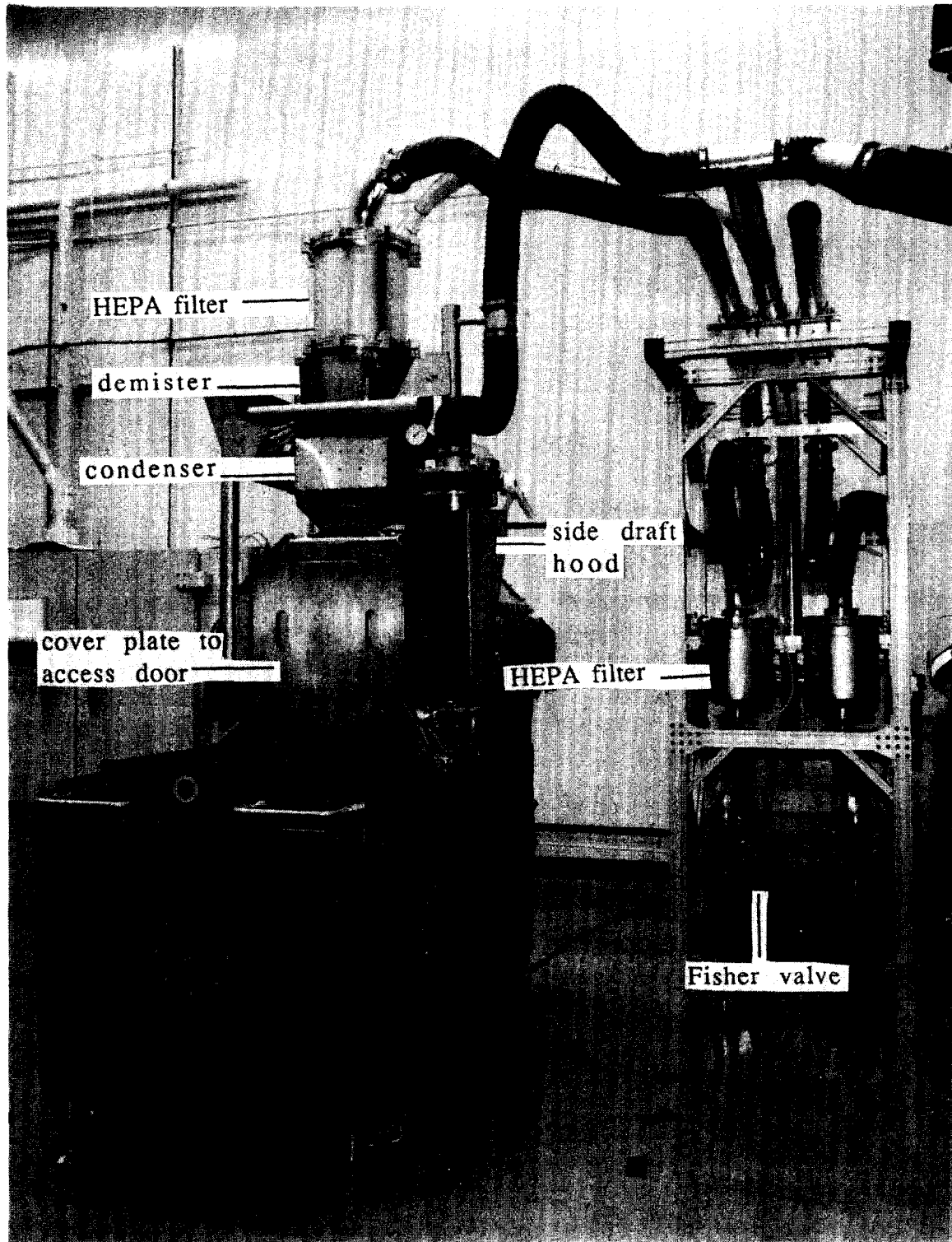


Figure 3. Photograph of the side view of the HE Dissolution Workstation with the exhaust rack shown on the right side. Note that the exhaust rack contains a duplicate set of components for a second workstation.

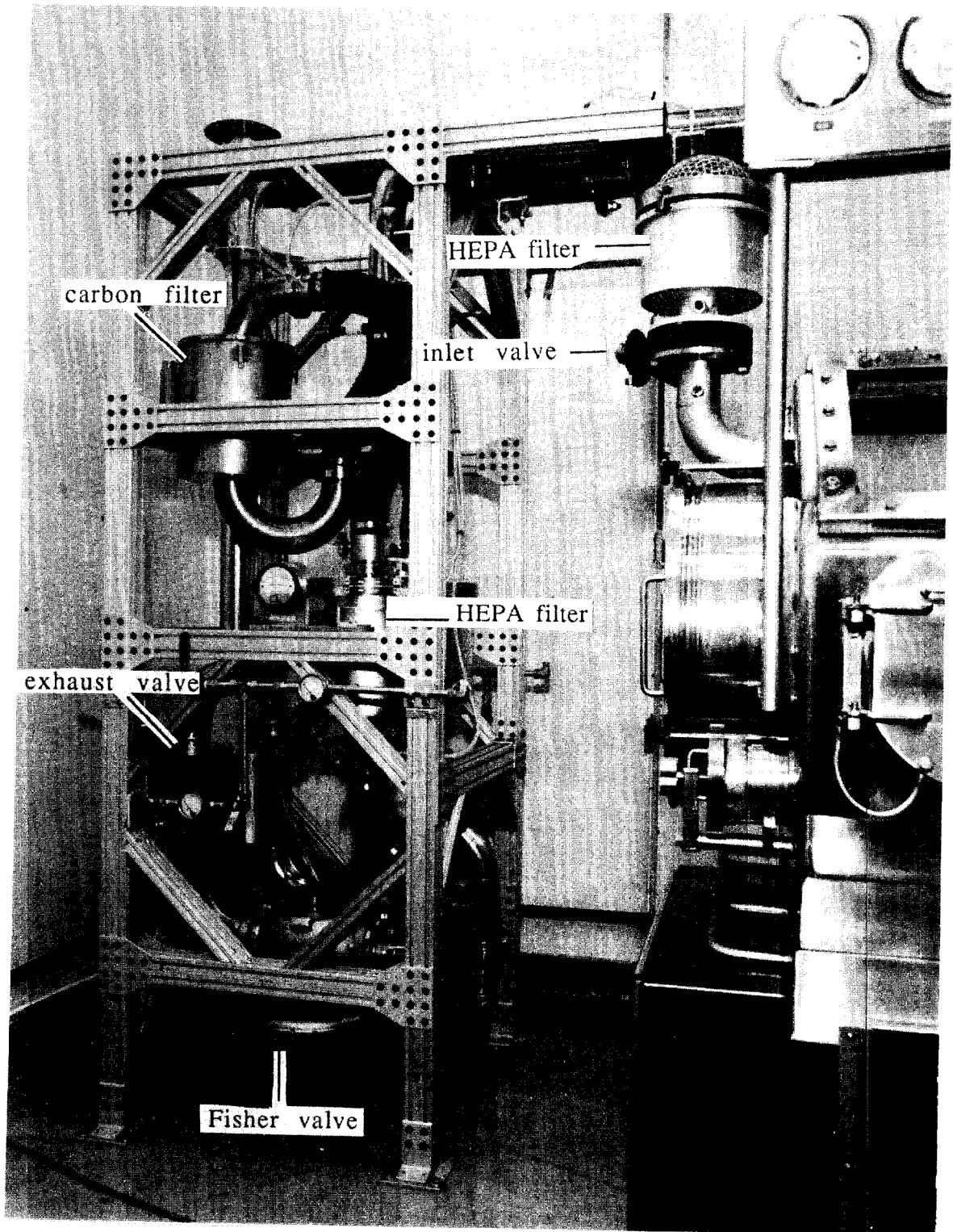


Figure 4. Photograph of the exhaust rack showing the carbon filter, HEPA filter, Fisher valve and exhaust valve. The HEPA filter and inlet valve to the workstation are also seen in this photograph.

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From the point of view of the air cleaning system, the HE dissolution operation can be divided into two phases, a dissolution phase and a venting phase. After the HE assembly is mounted on a fixture and placed inside the workstation, the inlet valve is closed and the hot DMSO spray turned on. In this dissolution phase the workstation is filled with DMSO aerosols and vapor. The only flow through the workstation into the exhaust is due to leaks. When operators need to make adjustments or other operations inside the workstation, the spray is first turned off and the inlet valve opened. This pulls HEPA filtered air through the workstation and sweeps out DMSO aerosols and vapor. The workstation is vented, and personnel are electrically bonded to the workstation prior to entry through the glove ports to prevent the unlikely occurrence of a spark from human electrostatic discharge. This phase of the dissolution operation is the vent phase. The operating parameters during the two phases and during an actual operation are shown in Table 1. We also tabulated some of the measurements made during a preliminary test to demonstrate the actual operation. The exhaust flow and temperatures in the air cleaning system are expected to differ slightly during the venting phase in production operations because the exhaust blowers are stronger than that used in our tests.

Table 1. Operating parameters in the HE Dissolution Workstation (WS).

Parameter	Steady State Simulation		Actual Operation*
	Dissolution	Venting	
Exhaust flow	1 cfm	20 cfm	1-20 cfm
DMSO liquid reservoir temp.	150+/-3 °F	150+/-3 °F	145-155 °F
WS interior air temp.	127+/-5 °F	127+/-5 °F	---
WS exterior surface temp.	107+/-3 °F	107+/-3 °F	---
Condenser inlet temp.	65+/-5 °F	105+/-5 °F	58-107 °F
Condenser exit temp.	44+/- 2 °F	52+/-3 °F	50-56 °F
Demister inlet temp.	44+/- 2 °F	52+/-3 °F	50-56 °F
Demister exit temp.	65+/-3 °F	55+/-3 °F	53-67 °F
HEPA 1 exit temp.	72+/- 2 °F	60+/-3 °F	---

\*Note that not all of the temperature measurements were taken during the actual operation. The missing data falls between the 1 and 20 cfm steady state data.

The most significant improvement over the previous exhaust system was the addition of a condenser and demister at the exhaust port.<sup>(1)</sup> The condenser consists of tightly packed stainless steel tubes in which Fluorinert, FC-77, chilled to 40 °F, flows at 3 gallons/min. We used Fluorinert as the heat exchange medium instead of water because of incompatibility issues with water in case the condenser develops a leak. The 130 °F exhaust, which contains DMSO/HE aerosols and saturated DMSO vapor, is cooled to 50-56 °F under typical conditions. The condenser performance was selected to condense as much of the DMSO vapor as

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possible without causing the DMSO to freeze. Although pure DMSO freezes at 65.4 °F, we did not observe any evidence of freezing, presumably due to the freezing point lowering by the dissolved HE. By condensing out the DMSO vapor into the liquid state, most of the DMSO is removed by the condenser tubes or by the demister. Locating the condenser and demister directly above the workstation allows condensate to drop back into the workstation.

We evaluated how quickly the workstation is vented after the DMSO spray is turned off and the inlet valve opened to establish a time limit before the side access door can be opened to prevent DMSO aerosols from contaminating the workplace. Figure 5 shows the concentration of DMSO aerosols measured in the exhaust of the workstation before the condenser while the inlet vent is open and a constant 20 cfm of air passes through the workstation. Separate measurements were made with the waist and the polar spray manifolds operating normally except for the inlet valve being open. These spray manifolds are two of several different types that are used in the dissolution operation. Figure 5 shows that when the spray is turned off, the aerosol concentration decreases very quickly. After 1 minute, the concentration decreased by about 70%, and after 3 minutes, by 99%. These aerosols have an average diameter of 0.1  $\mu\text{m}$  and behave like gas. Figure 6 shows the same data on a logarithmic scale. The aerosol venting will be much faster in the production operations since the venting flow will be about 30 cfm instead of 20 cfm in our tests.

The release of DMSO vapor from films of hot DMSO on the interior workstation walls, the spray manifold fixture, and the cleaned assembly is expected to be the primary source of DMSO release into the workplace. Allowing the workstation to vent until most of the liquid film is drained and the temperature reduced before the side door is opened will mitigate the release of DMSO vapor. No tests were conducted to establish these time limits. A side draft hood shown in Figures 2 and 3 is intended to mitigate the vapor release when the cleaned assembly is removed from the workstation chamber.

Since we have demonstrated in our previous study that the DMSO sprays are flammable, we set a 1 minute waiting period before workers can work inside the workstation using the butyl rubber gloves after turning off the spray. This time limit was based on computations to establish how quickly the spray droplets would settle out in the workstation. The typical size of the droplets ranged from 107 to 120  $\mu\text{m}$ , based on data from the spray nozzle manufacturer, Bete Fog Nozzle Company (Greenfield, MA). Willeke and Baron showed that the fraction of particles,  $N$ , remaining after time,  $t$ , is given by <sup>(2)</sup>

$$N = \exp(-V_g t / H) \quad (1)$$

$$V_g = 0.003 \rho_p d_p^2 \quad (2)$$

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- where
- $N$  = fraction of particles of diameter  $d_p$  remaining
  - $V_g$  = settling velocity, cm/s
  - $t$  = time, s
  - $H$  = height at the start of settling, cm
  - $\rho_p$  = particle density, g/cc
  - $d_p$  = particle diameter,  $\mu\text{m}$

We used Equations 1 and 2 to compute the settling times for different size DMSO droplets and plotted the results in Figure 7. To be conservative, we assumed that all the droplets were located at the ceiling of the workstation chamber, 3 feet. We see that the spray droplets greater than  $50 \mu\text{m}$  will be gone in less than one minute. Since we have shown in a separate study that it is only possible to ignite the DMSO spray droplets and not the small aerosols, waiting for one minute after the spray is turned off will eliminate any potential fire hazard from human electrostatic discharge.<sup>(3)</sup>

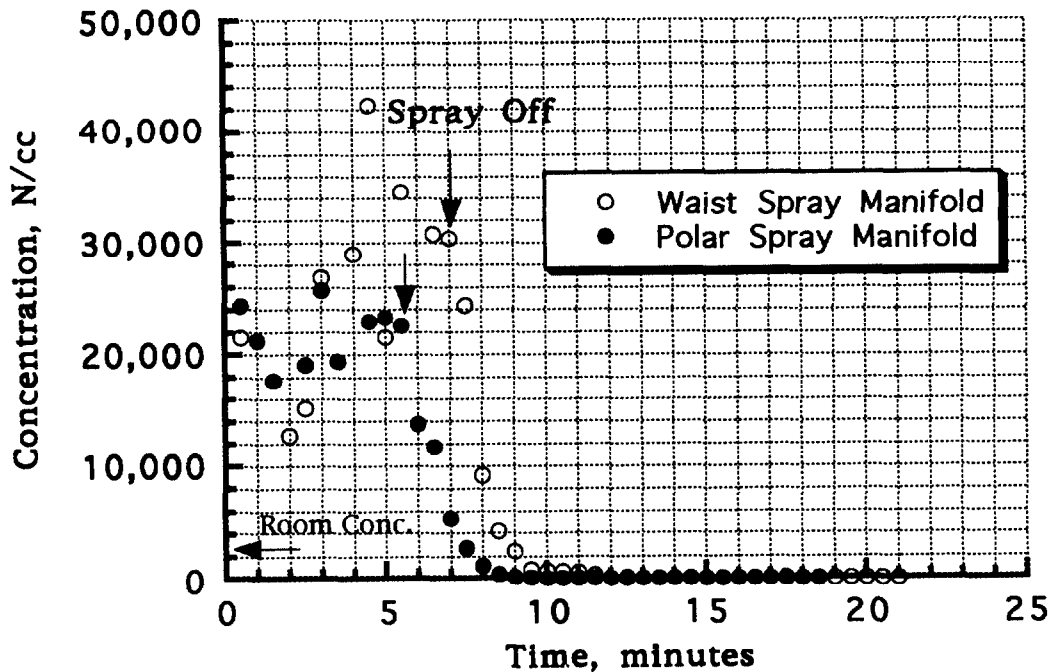


Figure 5. Concentration decay measurements using the polar and waist spray manifolds.

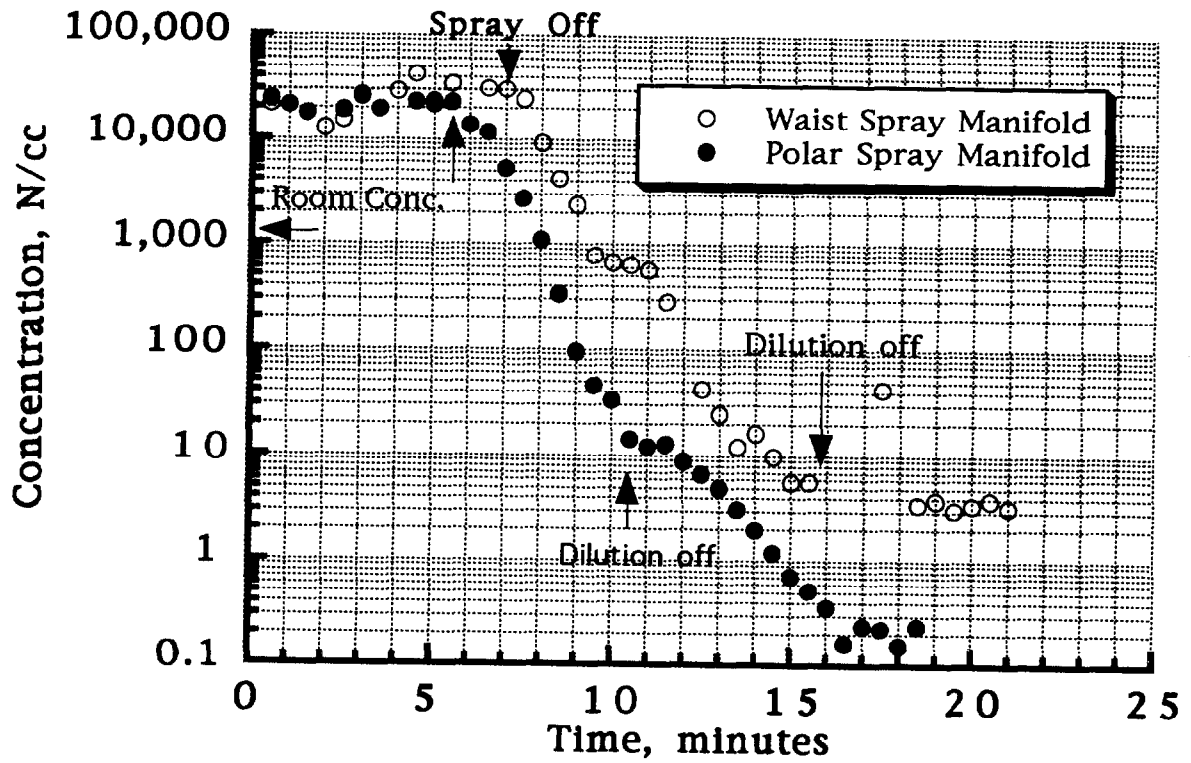


Figure 6. Concentration decay measurements using the polar and waist spray manifolds

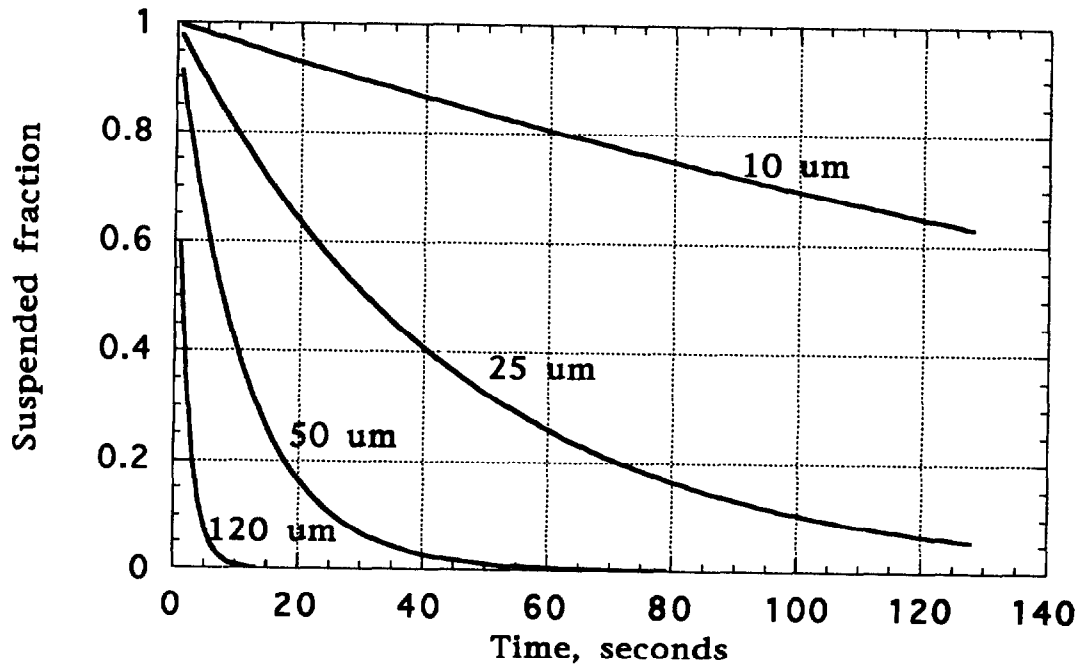


Figure 7. Sedimentation losses as a function of time for different size DMSO droplets.

III. Demister Evaluation

We conducted a series of screening tests to select the most promising demister for use in the air cleaning system. The candidate demisters were chosen based on the performance data provided by the different manufacturers. Most of the standard demisters used in nuclear exhaust systems were not available in smaller sizes and were therefore not evaluated. The most promising demisters were purchased from Amisco (Alvin, TX 77511) and from Coastal Technologies, Inc. (Hampton, SC 29924) and are designated Am and CT respectively. Each of the test samples were 12" x 12" x 4". A description of the different demisters is given in Table 2.

Table 2. Description of selected demisters evaluated in our study.

Demister	Bulk density, lb/cu. ft	Composition	Fiber volume fraction	Fiber Dia. inches
Am GLEC	15	90% 304 ss fiber 10% glass fiber by weight	0.027 ss 0.010 glass 0.037 total	0.011 ss 0.00045 glass
Am 1112	12	304 ss fiber	0.024	0.011
Am 1105	5	304 ss fiber	0.010	0.011
Am 0607	7	304 ss fiber	0.014	0.006
CT 1111	10.8	316 ss fiber	0.022	0.011
CT 911	9	316 ss fiber	0.019	0.011
CT 806	8	316 ss fiber	0.016	0.006

Our screening tests consisted of mounting each demister in a frame and measuring the penetration of DOS aerosols through the demister at 1 and 20 cfm flow rate. Since the demister has a 1 ft<sup>2</sup> cross-sectional area, the flow velocity through the filter is either 1 or 20 ft/min.. DOS aerosols were generated using the Laskin nozzle generator from the Virtis Co. (Gardiner, NY). We used the Aerodynamic Particle Sizer from TSI (Minneapolis, MN) to measure the DOS particles before and after the demister. The ratio of the downstream to the upstream concentration at each particle size gave the demister penetration at that size. Tables 3 and 4 show the test results for the demister penetration measurements at 1 and 20 cfm respectively.

Table 3. DOS penetration measurements on candidate demisters at 1 cfm.

Demister	DP, in. H <sub>2</sub> O	DOS Penetration at Indicated Diameter			
		0.5 μm	1.0 μm	2.0 μm	3.0 μm
Am GLEC	0.004	0.33	0.34	0.12	0.05
Am 1112	<0.001	0.95	0.86	0.67	0.38
Am 1105	<0.001	0.91	0.83	0.70	0.45
Am 0607	<0.001	1.00	1.00	0.80	0.60
CT 1111	<0.001	0.88	0.83	0.65	0.48
CT 911	<0.001	0.90	0.85	0.72	0.56
CT 806	<0.001	1.00	0.95	0.88	0.70

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Table 4. DOS penetration measurements on candidate demisters at 20 cfm.

Demister	DP, in. H <sub>2</sub> O	DOS Penetration at Indicated Diameter			
		0.5 μm	1.0 μm	2.0 μm	3.0 μm
Am GLEC	0.165	0.80	0.65	0.38	0.15
Am 1112	<0.001	0.86	0.85	0.80	0.68
Am 1105	<0.001	1.00	0.98	1.00	0.83
Am 0607	<0.001	0.92	0.92	0.92	0.90
CT 1111	0.002	0.90	0.90	0.90	0.80
CT 911	0.003	0.98	0.94	0.95	0.90
CT 806	0.002	0.95	0.95	0.83	0.60

Based on these screening tests, the best demister for our application was the Amistco GLEC demister. Note that this demister also had significantly higher pressure drop than the other demisters because of the glass fiber blend. We did not evaluate the ease of liquid drainage as part of our screening test because we were primarily concerned with high removal efficiency. In effect, we viewed the demister as a disposable prefilter.

Figure 8 shows a photograph of the GLEC demister pad selected for our study. The demister pad consists of multiple layers of glass fiber cloth with steel fibers interwoven to provide rigidity and some space between the layers. The high collection efficiency and pressure drop for the GLEC demister is due to the small diameter glass fibers (12 μm) that make up the yarn in the cloth layers.

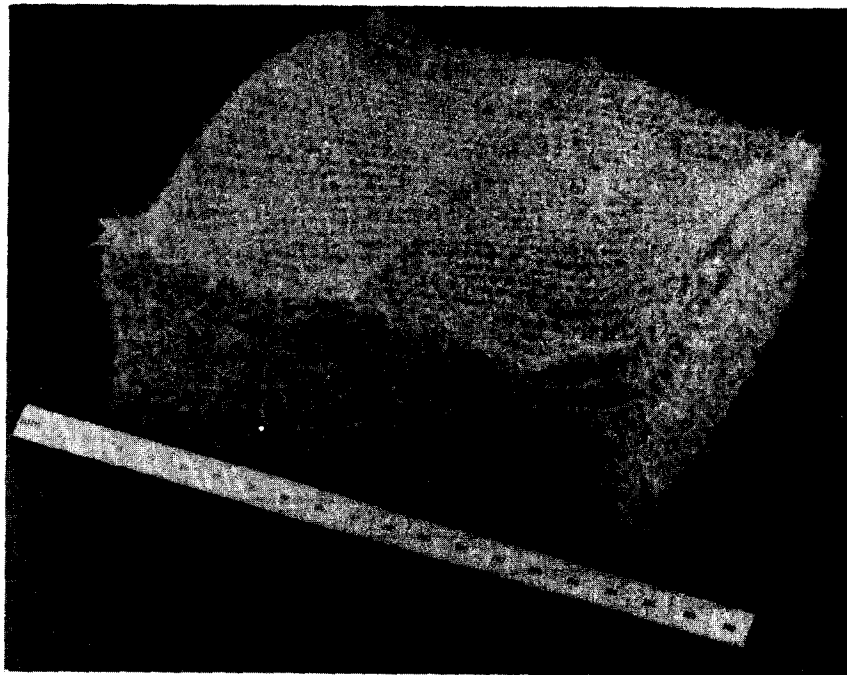


Figure 8. Photograph of the Amistco GLEC glass/steel fiber demister next to 410 mm ruler.

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We then evaluated the performance of the GLEC demister using DOS aerosols at room temperature and DMSO aerosols under actual operating conditions in the HE dissolution workstation. The DOS aerosols were generated using a Laskin nozzle generator and were injected into the workstation. We determined the penetration of DOS aerosols through the demister from the ratio of the downstream to the upstream concentration measurements. We used a LASAIR laser particle counter from Particle Measuring Systems (Boulder, CO) to measure the aerosols.

Figures 9 and 10 show the results of our DOS penetration measurements on two different GLEC demisters at 1 and 20 cfm. Note that the maximum DOS penetration at 1 cfm and 20 cfm occur at about 1.4  $\mu\text{m}$  and 0.5  $\mu\text{m}$  diameter respectively. The aerosol penetration at 20 cfm is also much higher than at 1 cfm. These observations are consistent with filtration theory and demonstrate that diffusional deposition is the primary mechanism responsible for capturing the submicron particles.

We obtained separate measurements with the demister at 70 °F and at 40 °F to determine what effect the temperature would have on the demister performance. The data collected at 40 °F are shown as dark points, whereas the data collected at 70 °F are shown as open points. From Figures 9 and 10, we see that at 20 cfm, the tests at 40 °F showed a higher penetration at the smaller particle sizes than the corresponding tests at 70 °F. This is consistent with the diffusional capture mechanism whereby particles have lower Brownian motion at lower temperatures and consequently are not captured as well as at the higher temperatures. The temperature effect on the aerosol penetration is less noticeable at 1 cfm than at 20 cfm because Brownian capture is already dominant at the low flow rate, and increasing the temperature would not make a large change.

The higher penetration at the 1 cfm flow in Figure 10 compared to the 1 cfm flow in Figure 9 is most likely due to greater leak paths through the demister. It is well established that filters having leaks have much higher penetrations at low flow rates than filters without leaks because of the preferential flow through leaks. The preferential flow through leak paths does not occur at higher flow rates as shown by the same penetration in Figures 9 and 10.

We also measured the penetration of DMSO aerosols through the demister at 1 and 20 cfm under steady state conditions with constant DMSO spraying. Although the DMSO spray normally would be turned off before the inlet valve is opened, we conducted the tests to see if there were any differences in performance between the DMSO and the DOS tests. We also measured the DMSO concentration before the condenser to characterize the challenge DMSO aerosols. Figure 11 shows the results of the DMSO concentration measurements at 1 cfm. An important finding in this figure is that the DMSO challenge aerosols have an average diameter of 0.1  $\mu\text{m}$ . These are extremely small aerosols and generally require high efficiency filters to remove them. Figure 11 also shows the condenser is removing about 50% of the aerosols. This is not surprising considering the thermal gradient that is driving the DMSO aerosols to the cold condensing tubes. A portion of this removal efficiency also may be an artifact of the aerosol measurement. The DMSO

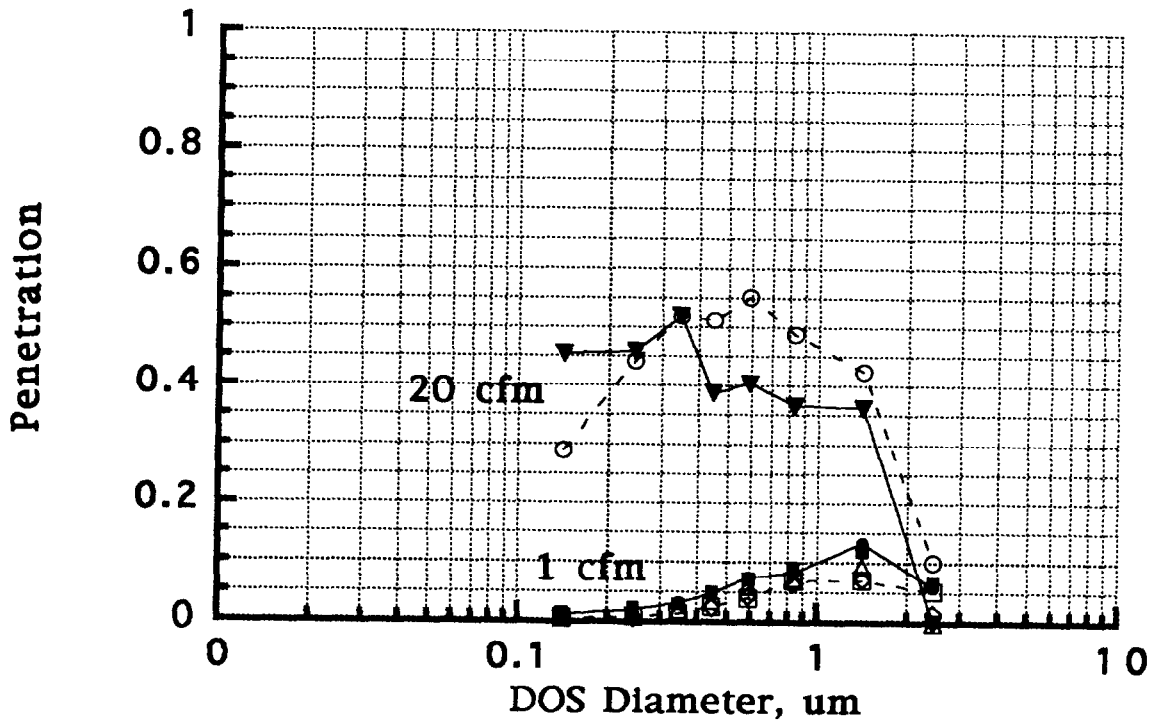


Figure 9. Penetration of DOS aerosols through a demister at 1 and 20 cfm exhaust flow. The open data points were taken at 70 °F. The solid data points were taken at 40 °F.

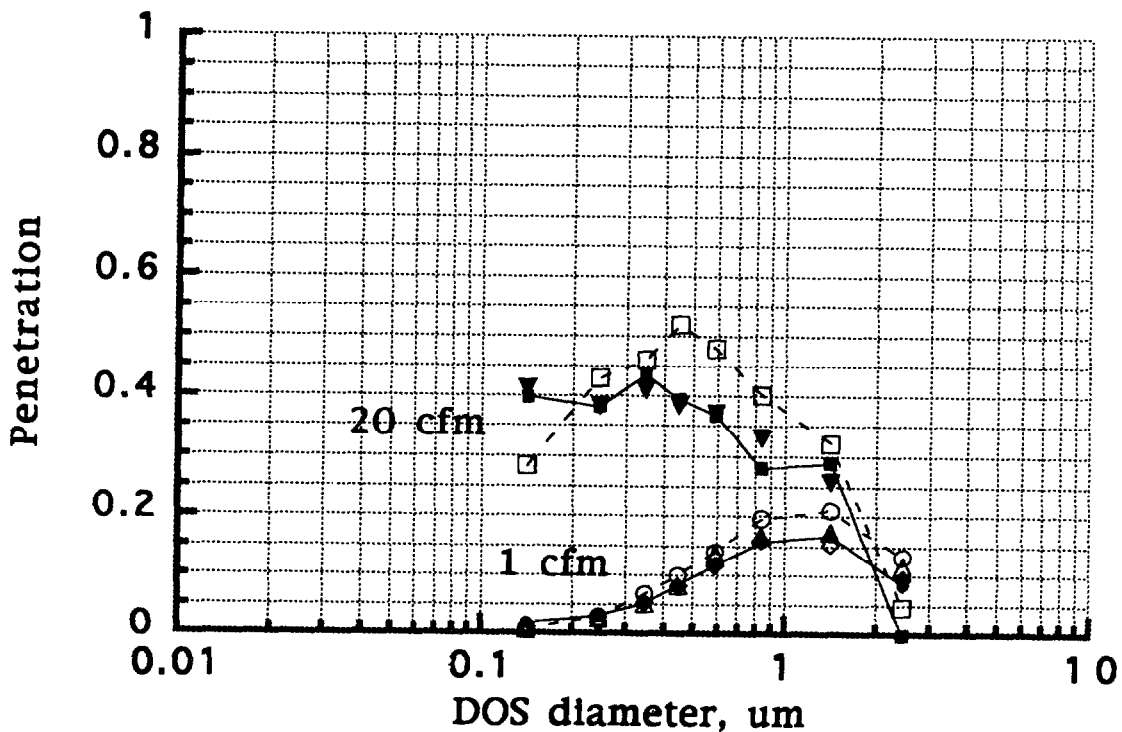


Figure 10. Penetration of DOS aerosols through another demister at 1 and 20 cfm exhaust flow. Open data points were taken at 70 F. Closed data points were taken at 40 F.

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aerosol concentration may have decreased due to evaporation in the diluter prior to the laser counter as the temperature increased from 44 °F at the condenser exit port to 70 °F at the diluter.

However, an unexpected finding in the 1 cfm test is that the aerosol penetration increases with increasing particle diameter until 65% of the particles at 0.3  $\mu\text{m}$  penetrate the demister as shown in Figure 12. We did not have data beyond 0.3  $\mu\text{m}$  because we did not have measurable counts with the 100:1 dilution prior to the laser counter. The DMSO penetration in Figure 12 is in sharp contrast to the DOS penetration in Figures 9 and 10, where the demisters have very low penetration in this size range. We have carefully reviewed the data in Figures 11 and 12 and verified that the results are not due to coincidence counting, a common measurement error. The unexpected results are also not due to Brownian motion effects as previously discussed with the DOS tests. In addition, we were able to repeat the results several times.

We believe that the high penetration with DMSO aerosols is an artifact resulting from a decrease in the pre-demister aerosol concentration due to evaporation as the 44 °F sample is heated to 70 °F in the sampling lines and diluter. The aerosol sample after the demister is only heated from 65 °F to 70 °F in the sampling lines and diluter and therefore would not suffer much evaporation. The disproportionate sample heating before and after the demister is the most probable cause of the unusually high demister penetration in Figure 12.

Anomalies were also found in the DMSO aerosol measurements at 20 cfm. Figure 13 shows the DMSO aerosol concentration measurements taken at 20 cfm before the condenser, before the demister, and after the demister. We see that the concentration of DMSO aerosols has increased significantly after passing through the condenser. This is opposite to what was seen in Figure 11 at 1 cfm. The only explanation is that the saturated DMSO vapor condensed into particles at a faster rate than the DMSO particles were deposited on the cooling tubes. Note in Table 1 that the temperature across the heat exchanger drops 53 °F at 20 cfm and only 21 °F at 1 cfm. The greater temperature drop coupled with the rapid transport through the condenser are the likely reasons for the increase in particle concentration across the condenser. Sampling artifacts due to heating and cooling of the aerosols and the subsequent evaporation and condensation are probably also reflected in Figure 13. Accounting for these effects would increase the difference in aerosol concentration before and after the condenser.

However, the most striking anomaly in the DMSO measurements at 20 cfm is the rapid increase in aerosol penetration with decreasing particle size as shown in Figure 14. Based on the DOS measurements shown in Figures 9 and 10, the aerosol penetration in Figure 14 should decrease with decreasing particle size, not increase. Filtration theory also supports the contention that the Brownian motion will increase with decreasing particle size and therefore result in decreased penetration. We were able to repeat the anomalous results and also verified that the laser counter was not in error due to coincidence counting. As previously

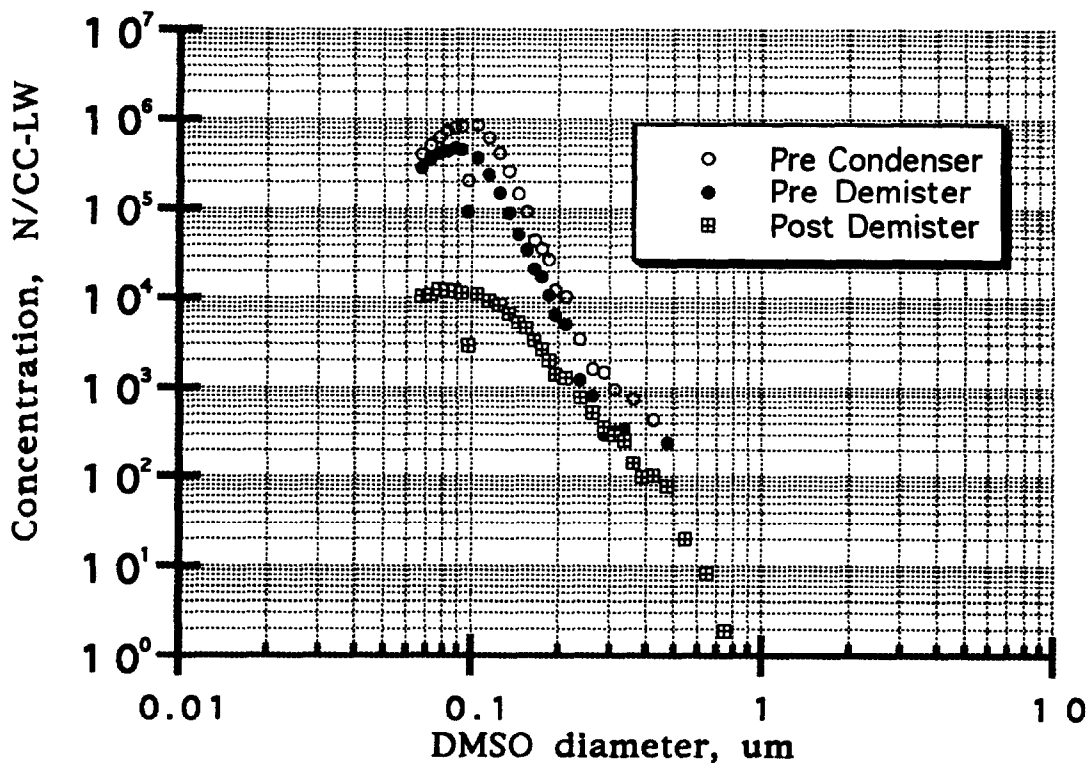


Figure 11. DMSO concentration before the condenser and before and after the demister at 1 cfm exhaust flow.

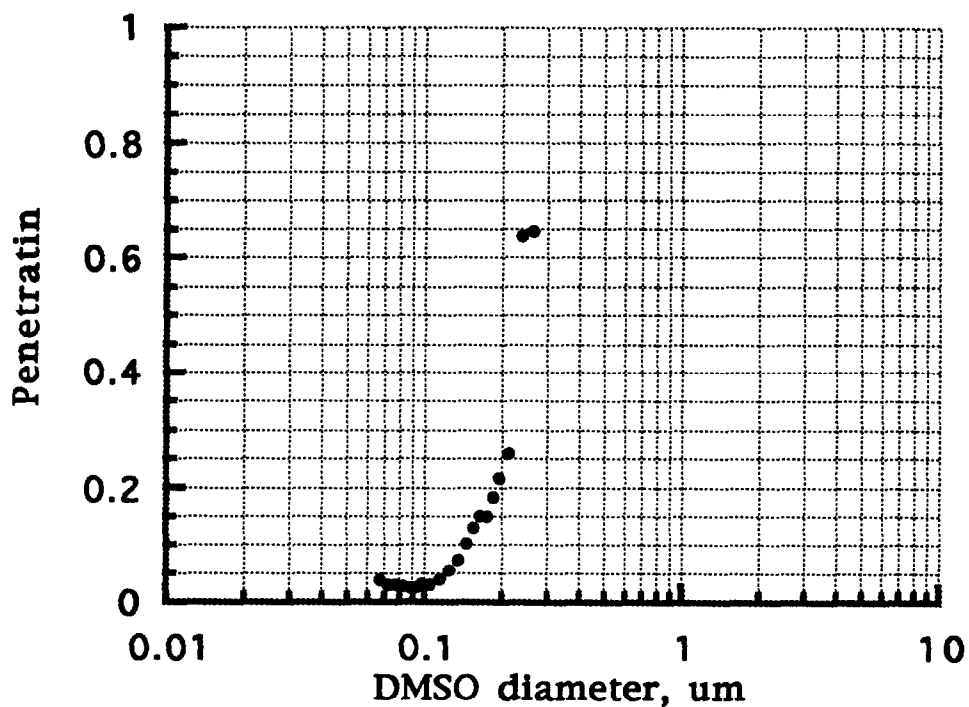


Figure 12. Penetration of DMSO aerosol through the demister at 1 cfm exhaust flow.

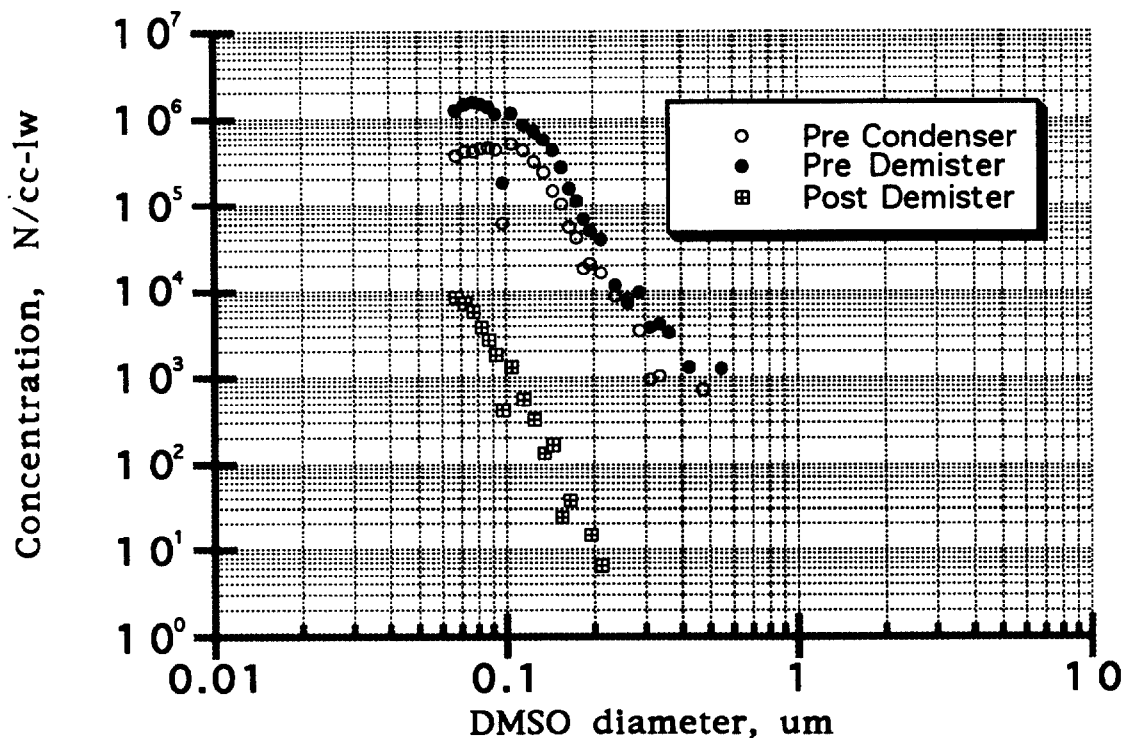


Figure 13. Concentration of DMSO aerosol before the condenser and before and after the demister at 20 cfm exhaust flow.

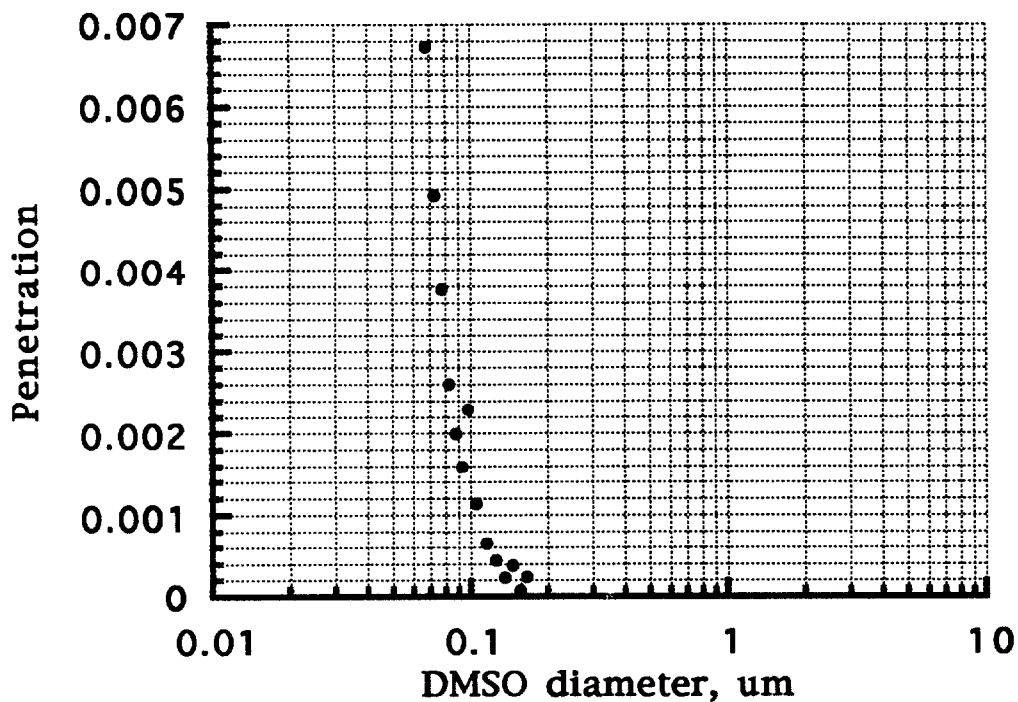


Figure 14. Penetration of DMSO aerosol through the demister at 20 cfm exhaust flow.

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discussed with the 1 cfm data, we believe that the observed penetration curve in Figure 14 is an artifact resulting from changes in concentration due to condensation/evaporation due to temperature changes.

Another observation when comparing the DMSO aerosol penetration in Figure 14 with the DOS aerosol penetration in Figures 9 and 10 is that the demister removes about 100 times more DMSO than DOS. This large difference can only be explained in terms of other processes that are occurring in the demister than classical particle filtration. We can only speculate that DMSO condensation plays a major role in these observations.

In addition to the aerosol measurements with the LASAIR and HSLAS laser counters, we also measured the aerosol concentration using filter samples. Most of our filter measurements were made using MSA HEPA filter cartridges typically used in respirators. In some cases, we also used flat filter media samples. A major problem in all of these measurements was the hygroscopic nature of the DMSO. In our initial filter measurements, we observed a weight loss despite the accumulation of significant DMSO mass. We attributed this loss to the removal of adsorbed water on the filter when filtering DMSO aerosols and vapor. To mitigate this weight loss problem, we preconditioned all filter samples by taking baseline filter samples prior to the actual sample. Another problem with the filter samples was the rapid increase in weight after the filter was removed from the filter holder. To mitigate this problem, we measured the filter weight at periodic intervals (typically 60 seconds) and extrapolated to the time the filter was removed. In some cases, we obtained negative mass measurements as seen in Tables 5 and 7 despite our precautions. For the mass measurements before and after the condenser, the DMSO liquid would condense and accumulate in the filter holder and in the upstream sample line. This weight was measured separately.

Table 5. Concentration measurements of liquid DMSO in the exhaust of the Workstation at 1 cfm.

Location	test	Concentration, g/m <sup>3</sup>		
		Total	Aerosol	Condensate
pre-condenser	1	12.78	2.07	10.71
	2	9.16	2.45	6.71
pre-demister	1	2.64	0.54*	2.10
	2	----	0.12,0.11,0.067	----
post-demister	1	----	0.005*, 0.012*	----
	2	----	-0.011,-0.007	----

\* Test conducted on a new demister. All other tests conducted on a used demister.

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Using the procedures described, we measured the DMSO mass concentration before the condenser, before the demister and after the demister when the workstation was operated at 1 and 20 cfm under the conditions shown in Table 1. The test results for the 1 and 20 cfm measurements are shown in Tables 5 and 7 respectively. By taking the ratio of the mass measurements before and after the condenser and before and after the demister, we were able to determine the DMSO removal efficiency for the condenser and the demister. The mass removal efficiencies for the 1 and 20 cfm operations are shown in Tables 6 and 8 respectively. We did not compute efficiency values for negative values of the mass concentration.

Table 6. Removal efficiency for liquid DMSO in the exhaust of the Workstation at 1 cfm.

Component	test	Efficiency, %		
		Total	Aerosol	Condensate
condenser	1	79	74	80
	2	----	95,96,97	----
demister	1	----	99, 98	----
	2	----	----	----

Table 7. Concentration measurements of liquid DMSO in the exhaust of the Workstation at 20 cfm.

Location	test	Concentration, g/m <sup>3</sup>		
		Total	Aerosol	Condensate
pre-condenser	1	11.77	1.81	9.96
	2	----	----	----
pre-demister	1	5.72	1.09	4.63
	2	----	3.62*	----
post-demister	1	----	-0.013	----
	2	----	0.0053*	----

\* Test conducted on flat filter sample and may include condensate.

Table 8. Removal efficiency for liquid DMSO in the exhaust of the Workstation at 20 cfm.

Component	test	Efficiency, %		
		Total	Aerosol	Condensate
condenser	1	51	40	54
	2	----	----	----
demister	1	----	----	----
	2	----	99.9	----

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Our measurements based on laser counts and filter weights show the demister has an efficiency greater than 99% for removing 0.1  $\mu\text{m}$  DMSO aerosols. This data is shown in Figures 12 and 14 for the laser counts and in Tables 6 and 8 for the filter weight measurements. The demister also has a relatively high pressure drop due to the higher fiber volume fraction and small diameter glass fibers.

However, we have not demonstrated the ability of the GLEC demister to drain the DMSO liquid. Data collected on the weight gain of the demisters used in our efficiency studies and demonstration tests showed the demister could collect about 1 kg of DMSO when the pressure drop reached our limit of one inch of water at 20 cfm. The weight gains and corresponding pressure drops for 4 GLEC demisters were 1.57 kg at 0.8 inches, 1.17 kg at 1.1 inches, 0.92 kg at 1.1 inches, and 0.55 kg at 0.7 inches. We could not determine the number of dissolution operations per demister because separate tests were not conducted. However, we estimate each demister can be used for about three dissolutions before changing the demister. No further studies were conducted because we decided to replace the demister after each dissolution operation to avoid the possibility of HE accumulation in the demister. Thus, the demister in our air cleaning system is used as a disposable prefilter.

### III. Carbon Filter

We developed a carbon filter to remove the DMSO vapor from the Workstation exhaust because commercially available units were either designed for much larger ventilation systems or had excessive pressure drops. The typical ventilation filter had a 2' x 2' cross sectional area and was designed for flow rates of 1,000 cfm or greater. Smaller annular cartridge filters were developed for military vehicle applications but had pressure drops that greatly exceeded the requirement of less than one inch of water at 50 cfm. In addition to the lack of suitable carbon filter units, there also was no information on the performance of carbon filters for removing DMSO vapors. Thus, we had to establish the basic adsorption characteristics in addition to the design parameters to develop the DMSO carbon filter. The initial step was to demonstrate that activated carbon was effective in removing DMSO vapors.

We conducted a survey test of eight different activated carbons to establish that activated carbon is effective in removing DMSO vapors and to identify the best carbon. The test carbons were packed into empty respirator cartridges having a total carbon volume of 112 cc, a diameter of 7.9 cm and a bed depth of 2.3 cm. The cartridges were filled with carbon poured through a tube having multiple screens and a 2 foot free fall to insure tight packing. Each of the cartridges were weighed before and after the test to establish the weight of the carbon and the weight gain due to adsorbed DMSO vapor. The test consisted of passing 29.4 l/min air containing 500 ppm ( $1.59 \times 10^{-3}$  g/l) of DMSO vapor with less than 10% relative humidity at 25 °C through each cartridge. This flow rate corresponded to a flow velocity of 6 m/min since the area was 49 cm<sup>2</sup> (4.9 l/m). The efficiency of DMSO removal was determined by measuring the concentration of DMSO vapor

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before and after the cartridge using a Miran infrared analyzer (Foxborough Inc.). Since each of the tests were conducted until the carbon was saturated and had 0% efficiency, the increase in carbon weight represented the dynamic adsorption capacity of the carbon for DMSO.

Figure 15 shows the DMSO removal efficiency for each of the eight carbon canisters as a function of exposure time. All of the carbons have similar DMSO adsorption properties. However, sample G215 from PICA USA Inc. (Columbus, OH) had a slightly better performance than the other samples and was therefore selected for the carbon filter in our project. The carbon weight, adsorbed DMSO weight, and the pressure drop for each of the canisters is shown in Table 9.

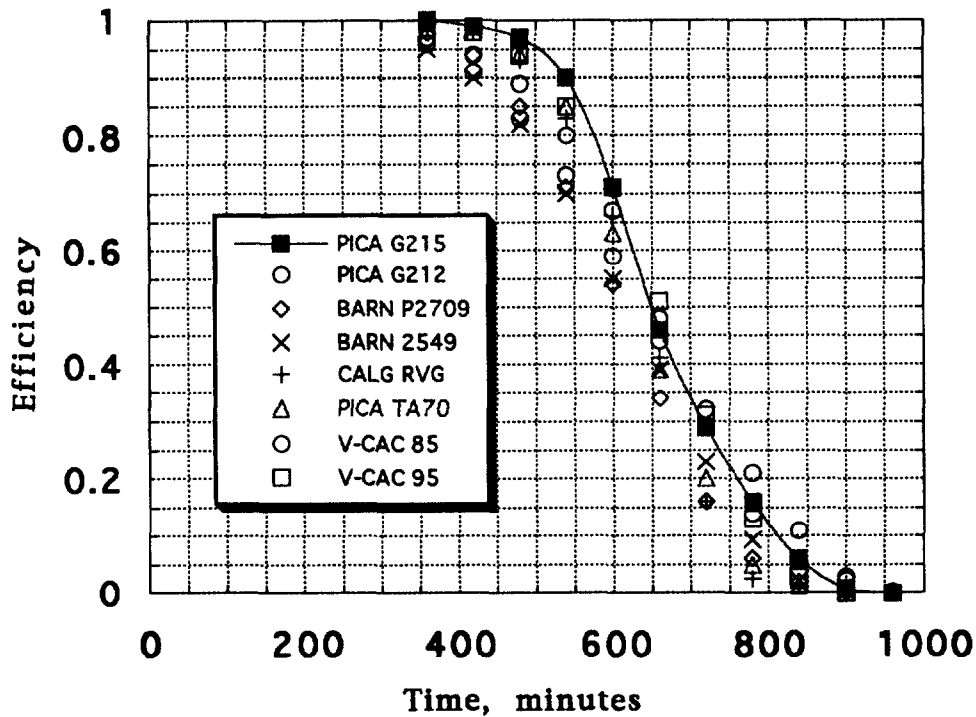


Figure 15 . Survey of carbon capacities plotted as efficiency versus exposure time at 6m/min flow velocity.

Table 9. Experimental measurements of carbon cartridge samples in screening tests at 6 m/min.

Sample	Carbon Weight, g	DMSO Adsorbed, g	Pressure Drop, in. H <sub>2</sub> O
PICA G215	45.9	31.6	0.31
PICA G212	42.6	31.3	0.21
BARN P2709	55.2	29.7	0.27
BARN 2549	47.7	30.4	0.20
CALG RVG	51.7	30.9	9.31
PICA TA70	51.1	30.6	0.30
V-CAC 85	44.3	31.9	0.29
V-CAC 95	45.8	32.5	0.31

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We then conducted additional tests on new cartridges of PICA G215 at 14.7 and 43.9 l/min flow rates, which correspond to flow velocities of 3 and 12 m/min. These tests were needed to establish the adsorption parameters for the design of the carbon filter. Figure 16 shows the results of the three carbon canisters of PICA G215 tested at 3, 6 and 12 m/min flow velocity. We see that the faster flows results in shorter saturation times. The experimental measurements of the PICA G215 carbon samples are shown in Table 10.

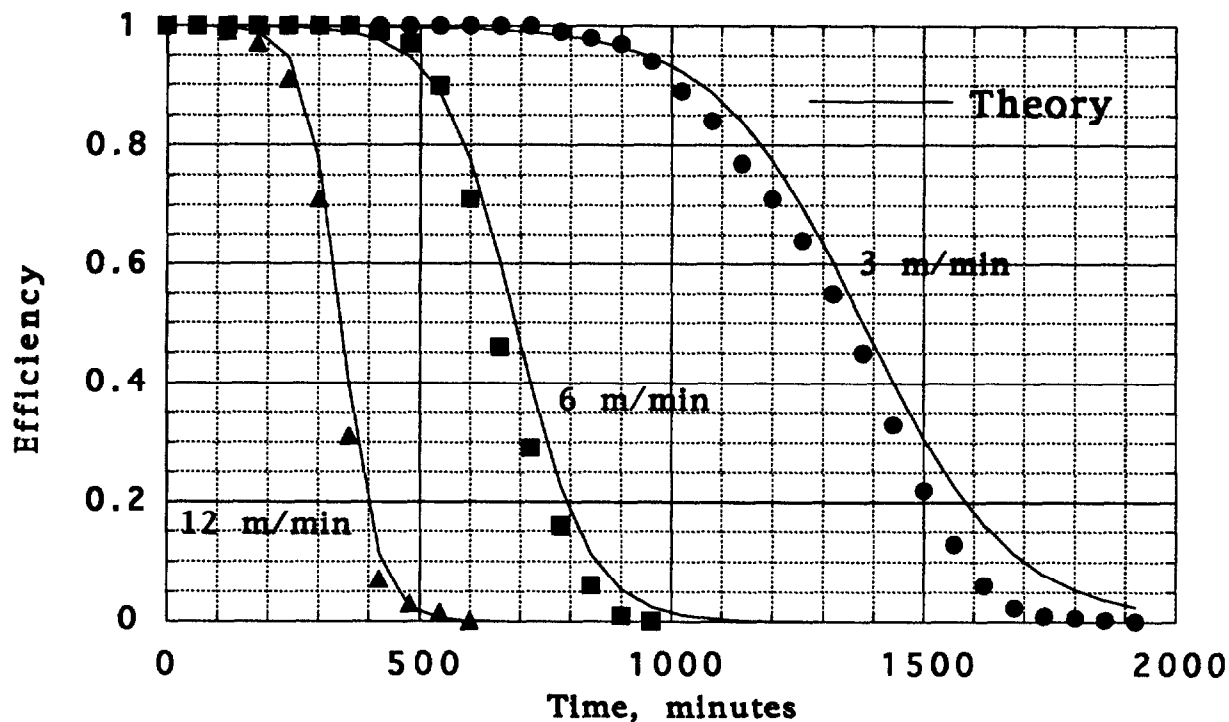


Figure 16. Efficiency of PICA G215 canisters at 3, 6 and 12 m/min flow velocity. Points are experimental data; solid lines represent theory.

Table 10. Experimental measurements of PICA G215 carbon samples in tests at 3, 6 and 12 m/min.

Velocity V m/min	Flow rate, l/min	Pressure drop in. H <sub>2</sub> O	Carbon Wt W <sub>c</sub> , g	DMSO Wt W <sub>a</sub> , g	Saturated Capacity W <sub>s</sub> =W <sub>a</sub> /W <sub>c</sub>	Carbon bulk density, ρ <sub>c</sub> g/l
3	14.7	0.13	44.0	32.8	0.745	393
6	29.4	0.31	45.9	31.6	0.688	410
12	58.8	0.57	43.9	32.5	0.740	392

In order to design an activated carbon filter for removing DMSO vapor, it was first necessary to determine the adsorption capacity of the selected carbon for DMSO,  $W_s$ , and the coefficient,  $K_v$ , for the rate of adsorption. Once these two parameters are determined, theoretical equations can be used to determine the key design parameters for the gas filter. The dynamic adsorption capacity,  $W_s$ ,

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was experimentally determined and is shown in Table 10. The kinetic coefficient,  $K_v$ , characterizing the rate of adsorption is derived from matching experimental data with a theoretical model. We used the modified Wheeler equation, shown in Equation 3 to derive the kinetic coefficient.<sup>(4)</sup>

$$t = \frac{W_s W_c}{C A V} + \frac{W_s \rho_c}{C K_v} \ln \left[ \frac{(1 - E)}{E} \right] \quad (3)$$

where

- A = cartridge area, 4.9 l/m (49 cm<sup>2</sup>)
- C = DMSO concentration, 1.59 x 10<sup>-3</sup> g/l (500 ppm)
- E = DMSO removal efficiency
- $K_v$  = kinetic adsorption coefficient, min.<sup>-1</sup>
- $\rho_c$  = carbon bulk density, g/l
- t = time, minutes
- V = flow velocity, m/min.
- $W_c$  = carbon weight in cartridge, g
- $W_a$  = DMSO weight adsorbed, g
- $W_s$  = DMSO saturated capacity =  $W_a/W_c$ , dimensionless

Values of  $K_v$  were determined by substituting the parameter values from Table 10 into Equation 3 and fitting each of the three equations to the corresponding efficiency curves in Figure 16. The least squares fits produced  $K_v$  values of 1369, 2750 and 4801 min<sup>-1</sup> at 3, 6 and 12 m/min flow velocities respectively. To establish the velocity dependence of  $K_v$ , we plotted the values of  $K_v$  versus the flow velocity in Figure 17.

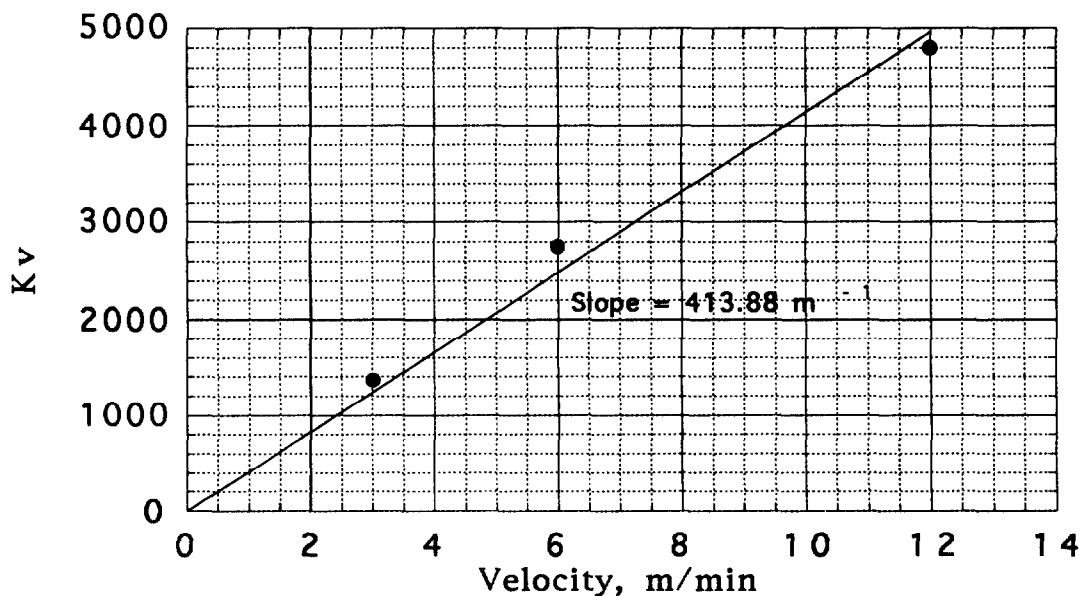


Figure 17 Determination of  $K_v$  dependence on velocity.

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From Figure 17, we have

$$K_v = k_v V = 413.88 \text{ V min.}^{-1} \quad (R=0.99035) \quad (4)$$

where the slope,  $k_v$ , equals  $413.88 \text{ m}^{-1}$ . Substituting this expression into Equation 3 yields,

$$t = W_s W_c / (C A V) + W_s \rho_c / (C k_v V) \ln [(1 - E) / E] \quad (5)$$

All of the constants in Equation 5 can be lumped together into constants  $c_1$  and  $c_2$  to yield.

$$t = c_1 / V + (c_2 / V) \ln [(1 - E) / E] \quad (6)$$

Replacing the constants in Equation 6 with the values in Table 10 yields  $c_1 = 4207.4, 4053$  and  $4169.7$  and  $c_2 = 444.6, 427.7$  and  $439.7$  for  $V = 3, 6$  and  $12$  m/min respectively. Averaging these constant values yields

$$t = 4143.4 / V + (437.3 / V) \ln [(1 - E) / E] \quad (7)$$

Equation 7 was used to generate the theoretical curves in Figure 16.

The increasing deviation in Figure 16 between the experimental data and theory at slower velocities is most likely due to the assumption of irreversible adsorption. In practice, the adsorbed DMSO will not be adsorbed irreversibly and will be released, which is more pronounced at longer times and at higher carbon saturation values.

We used Equation 5 and the parameter values determined in the cartridge studies to design the carbon filter for use in the HE Dissolution Workstation. A major constraint on the filter design is the thickness of the carbon bed. Although we used a bed depth of 2.3 cm (0.91 inch) in our screening tests, existing standards on carbon filters require a minimum of 2 inches.<sup>(5,6)</sup> This minimum bed depth was established to avoid channeling effects in the ventilation filters. However, since the pressure drop across the filter is directly proportional to the bed depth, it is desirable to minimize the bed depth. Thus, the optimum bed depth that satisfies the current standards and minimizes the pressure drop is 2 inches. To include the effect of carbon bed depth in Equation 5, we made the following two substitutions:

$$Q = A V \quad (8)$$

$$\rho_c = W_c / A T \quad (9)$$

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where,  $Q$  = flow rate, l/min.  
 $T$  = carbon bed thickness, m

Substituting Equations 8 and 9 into Equation 5 and rearranging yields,

$$t = W_s W_c / (C Q) [ 1 + (1 / k_v T) \ln [(1 - E) / E] ] \quad (10)$$

Equation 10 can be used to establish how much carbon,  $W_c$ , should be used for a given set of operating conditions and for a desired filter life,  $t$ .

The primary operating conditions are exhaust flow rate,  $Q$ , and concentration of DMSO,  $C$ . The exhaust flow to be used in Equation 10 is primarily the leak flow in the Workstation during the dissolution operation. We have estimated the leak at 1 cfm based on previous measurements. The only critical leaks are those that allow air into the Workstation during the spraying operation. Leaks occurring in the exhaust system do not increase the DMSO loading on the carbon although they obviously increase the exhaust flow. The increased flow during the venting cycle can be ignored because the box is purged in less than three minutes as shown in Figures 5 and 6.

The DMSO concentration is determined by the air temperature to which the exhaust is cooled. We can assume the DMSO concentration equals the saturated concentration at the demister temperature because the demister removes nearly all of the suspended aerosols, thereby leaving only the saturated vapor to reach the carbon filter. In our application, the typical air temperature within the demister is less than 65 °F, which corresponds to a concentration of 1.6 g/m<sup>3</sup>.<sup>(7)</sup>

In our design, we wanted the carbon filter to have a useful life of at least one month of continuous operation. The number of operating minutes in a typical month is 5,160 minutes, assuming 4 hours of dissolution per day and 21.5 days per month. We also assumed the life of the carbon filter was over when the efficiency decreased below 95%.

Substituting these and the other parameter values into Equation 10 yields

$$5,160 \text{ min.} = \{ (0.724) W_c / [(1.6 \times 10^{-3} \text{ g/l})(28.3 \text{ l/min})] \} \times \\ \{ 1 + [1 / (413.9 \text{ m}^{-1})(0.0508 \text{ m})] \ln [(1 - 0.95) / (0.95)] \}$$

Solving this equation yields  $W_c = 375 \text{ g}$ . Since the average bulk density of the carbon from Table is 398g/l, the minimum volume of carbon for one month operation is 0.95 l or 58 in.<sup>3</sup>. Dividing this volume by the required 2 inches for the bed thickness yields an area of 29 in.<sup>2</sup>. How this area will be configured into a filter is now a matter of construction considerations. We have selected the cylindrical cartridge design because it is easy to fabricate and to service.

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The cylindrical cartridge filter that we designed is shown in Figure 18, where the cartridge is shown mounted inside a cylindrical housing. The exhaust flows from the bottom port into the interior of the carbon filter, passes through the 2 inch bed and exits around the exterior of the cartridge and finally through the top port. The carbon bed is a 2 inch thick concentric cylinder contained between concentric cylinders made of perforated metal screens that are 12 inches long and have 10 and 6 inch diameters. The net carbon volume of this filter is 9.82 l, which is much larger than the minimum 0.95 l required for one month operation. If the operating assumptions for the HE Dissolution Workstation are correct, then the carbon filter will last for 10.4 months of daily operation before it must be recharged with fresh carbon. Even if the Workstation developed leaks up to 2 cfm, the carbon filter will last for 5.2 months of daily operation.

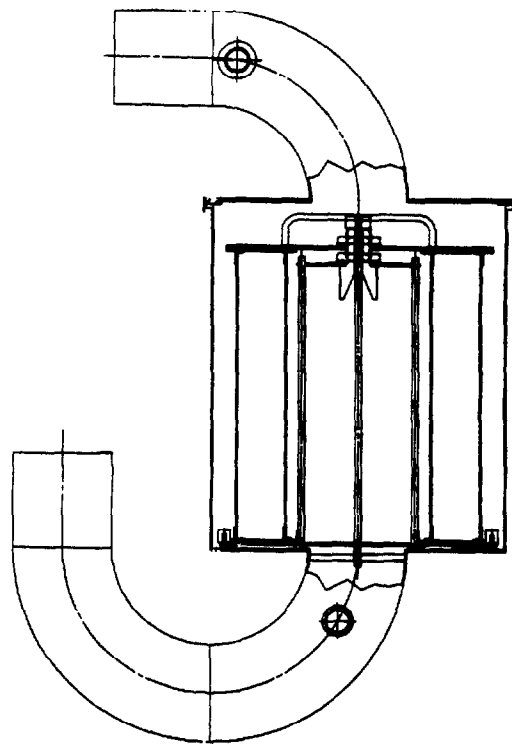


Figure 18. Schematic of cylindrical carbon filter cartridge mounted in a housing.

To prevent the remote possibility of DMSO condensing and collecting inside the carbon filter, we directed the exhaust through a U-tube section before entering the carbon filter. Any DMSO condensate would collect at the low point of the U-tube and can be drained through a plug. It is possible to form DMSO condensate in the lines if the ambient laboratory temperature is lower than the exit temperature of the demister. This can happen if the room heater or if the exhaust condenser do not work properly.

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We have not yet completed developing and testing the carbon filter, but will do so in the near future. A preliminary test during a practice dissolution operation showed the carbon filter was only about 70% efficient. Since the predicted efficiency should be in excess of 99%, additional development is required before the carbon filter is acceptable for use in the HE Dissolution Workstation. One of the leading possibilities for the poor performance is the carbon loading procedure that we used. We filled the annular space with carbon by pouring the carbon granules directly from a container and then shaking the filter unit to insure tight packing. Although we designed a fixture to fill the annular space using gravitational settling, the unit was not available at the time of this report. We plan to complete the loading fixture and correct the low removal efficiency. We also plan to conduct accelerated loading tests on the filter in a similar fashion as seen in Figure 16 for the small test cartridges.

### IV. Conclusions

We have developed an air cleaning system for workstations that will be used to remove HE from nuclear warheads using hot sprays of DMSO. The air cleaning system consists of a condenser to cool and condense the hot DMSO vapor, a demister pad to remove most of the DMSO aerosols, a HEPA filter to remove the remaining aerosols, an activated carbon filter to remove the DMSO vapor, and a final HEPA filter to meet the redundancy requirement for HEPA filters in radioactive applications. The demister pad is a 4" thick mat of glass and steel fibers and has an efficiency greater than 99% for 0.1  $\mu\text{m}$  DMSO particles. However, the demister pad is disposed after each dissolution operation to prevent the accumulation of HE. Test results on the prototype carbon filter showed only 70% efficiency instead of the 99.9% in small scale laboratory tests. Thus further work will be required to develop the prototype carbon filter.

### V. Acknowledgment

We gratefully acknowledge the help of Messrs. Donald Beason, Scott Doughty, and Ron Arganbright in performing tests on the HE Dissolution Workstation and of Mr. Jeff Oh for designing the exhaust system components. We also thank Mr. Gary Nelson of Miller-Nelson Inc. (Monterey, CA) for performing the carbon canister tests.

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DISCUSSION

**BELLAMY:** It is interesting to hear about the destruction effort that is underway. There are people worried about nuclear war heads, but it is now more in decontamination and decommissioning activities than in their use.

**FLEMING:** I was going to suggest that when conducting the filling procedure for the cartridge that perhaps you could take a lesson from the people who fill carbon filters, Fred Leckie will tell you that you need to "triculate" the carbon in to get it to pack efficiently. Perhaps you should talk to a few of the manufacturers to get a good method, because I think that will improve your efficiency dramatically.

**BERGMAN:** Thank you for your suggestion.

**RICKETTS:** I was wondering how you actually measured the DMSO concentration up and downstream of your carbon filter?

**BERGMAN:** We measured DMSO as a relative measurement, based on a Moran analyzer, it was not an absolute measurement. We calibrated the instrument in the laboratory with a known concentration, by injecting it with a syringe, and called that the 100% upstream concentration. Then, for zero percent, we used air filtered through a carbon bed. Although we could do this fairly nicely in the laboratory when we went into the field we did not have the luxury of all these things, and whatever the instrument read at the time, we used. So, it was a relative measurement. We had an upstream zero, and that was the extent of our calibration.

**RICKETTS:** I understand DMSO is very hygroscopic. Do you have to worry about the concentration of the water vapor in the air stream coming into the system?

**BERGMAN:** Yes, DMSO is extremely hygroscopic, to the point where we had tremendous experimental problems with things like measuring filter weights. We would load a lot of particles on to a filter, but the filter would lose weight because of losing the previously absorbed water. We had to effectively precondition the filter, i.e., dry it, by passing DMSO vapor through it. It is a tremendously effective water scrubber. For most applications we would have to use an inlet filter to remove water vapor, otherwise we would have a real horrendous problem. Fortunately, the place where these operations will be conducted is in Pantex, which typically has 10% RH, so they do not foresee it as a problem. If there is a problem, you immediately start seeing a lot of high explosives on the bottom of all your trays, not the most optimum condition. When that becomes apparent, you do not proceed very far under those conditions.

**A THICK HOMOGENEOUS VEGETATED COVER  
DESIGN PROVES COST- AND SCHEDULE-EFFECTIVE  
FOR THE RECLAMATION OF URANIUM MILL SITES  
NEAR SPOKANE, WASHINGTON**

**John Blacklaw, Gary Robertson, Dorothy Stoffel,  
Jamil Ahmad, Earl Fordham, Sheila Pachernegg,  
Leo Wainhouse, and John Riley**

**Division of Radiation Protection  
Washington State Department of Health  
Thurston Airdustrial Center, Building 5  
Olympia, Washington 98504-47827**

Abstract

The Washington State Department of Health (WDOH) has licensed two medium sized uranium mills with tailings impoundments covering 28 and 40 hectares (70 and 100 acres), respectively. The uranium mill licensees have submitted closure and reclamation plans to the state, and site-specific conditions have determined the closure design features.

Conventional uranium mill cover designs usually incorporate an overall cap of one to three meters, which includes a low-permeability clay barrier layer. A technical evaluation of several uranium mill facilities that used this design was published in the fall of 1994 and reported that unexpected vegetation root damage had occurred in the low-permeability clay (or bentonite amended) barrier layers. The technical report suggested that the low-permeability design feature at some sites could be compromised within a very short time and the regulatory goal of 1,000 years performance might not be achieved. In October 1994, WDOH sponsored a technical forum meeting to consider design alternatives to address these reliability concerns. Representatives from the federal government, nuclear industry, licensees, engineering firms, and state regulatory agencies attended the workshop.

Risk factors considered in the evaluation of the uranium mill reclamation plans include: (1) radon gas emanation through the cover (the air pathway), and (2) migration of hazardous and/or radioactive constituents (the groundwater pathway). Additional design considerations include site structural stability, longevity of 1,000 years, and no active (ongoing) maintenance.

Both closure plan designs originally presented to the department incorporated conventional low-permeability clay or bentonite amended cover layer designs. The department determined that the low-permeability layers at the Washington sites would be prone to failure due to biointrusion and freeze-thaw at these sites. A thick homogeneous vegetated cover design was then evaluated. Consequently, both closure plan designs were revised. All outstanding design and construction regulatory requirements were addressed prior to final approval by the state. The revised plan meets regulatory requirements, allows for construction efficiency (cost and schedule), and meets QA/QC goals.

### I. Introduction

The Waste Management Section of the Division of Radiation Protection in the state's Department of Health manages the Uranium Mill program through rules and regulations. These rules are the result of professional rule development based on legislative authority and evaluation of risk. The NRC<sup>(1)</sup> and EPA<sup>(2)</sup> each produced environmental impact statements as the basis for their uranium mill regulations. The state of Washington, as an NRC Agreement State, enforces the federal regulations under state legislative mandate<sup>(3)</sup> and agency rule.<sup>(4)</sup> The resulting rule language is presented in the form of performance-based, non-prescriptive "Criteria." The NRC has developed several guidance documents, with the most applicable being a Staff Technical Position for Design of Erosion Protection Covers for Uranium Mill Tailings Sites.<sup>(5)</sup> This paper describes the state's involvement in the evolution of the thick homogeneous vegetated cover design.

### II. Conventional Cover Design

When the state's uranium mill licensees decided to terminate their radioactive materials licenses and begin closure and reclamation of their sites, the department required that final closure plans be submitted for approval. This review was a technical evaluation to ensure compliance with regulatory criteria. WDOH regulations allow licensees to propose any cover designs that can demonstrate compliance with performance-based requirements in the regulatory "Criteria". In 1994, both uranium mill licensees submitted closure plans<sup>(6)</sup> & <sup>(7)</sup> to the department for review and approval.

During the same period of time, a technical report<sup>(8)</sup> was published by the Uranium Mill Tailings Remedial Action (UMTRA) Project. The report described how biointrusion on rock-covered

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disposal cells had impacted the stability of covers at completed U.S. Department of Energy (DOE) sites. The study suggested that "continued plant growth on the rock-covered cells will alter the characteristics of the cover system. As roots advance through the cover, they introduce organic matter into the cover, and upon their death leave conduits through which liquids and gasses may pass readily. These roots and associated processes will eventually transform the radon barrier into a biological soil, which could degrade the performance of the engineered layer relative to its intended function." In response to this report and staff concerns, the Waste Management Section sponsored a technical meeting<sup>(9)</sup> to discuss and identify potential impacts to the low-permeability barriers from biointrusion, freeze-thaw, no active maintenance, and other factors.

### III. Long-Term Reliability Concerns

One of the major concern with uranium mill cover designs is that they should be stable for 1,000 years. Studies show that conventional cover designs may not meet this longevity requirement. Since department regulations do not allow the inclusion of active maintenance into closure plans, cover designs must be evaluated to account for this. The following paragraphs describe typical problems faced by uranium mill sites, which conventional cover designs may not be adequate to meet:

#### III.1 Background

Uranium production in this nation supports the uranium fuel cycle for the nuclear power industry, and the nation's nuclear weapons program. Uranium mill tailings are the byproduct (waste stream) resulting from the production of uranium oxide from uranium ores. Tailings are produced as a result of chemical separations and typically produce an acidic liquid slurry waste stream. The high volume liquid waste is pumped to large impoundments where pH balance is accomplished and solids precipitate and settle out. Larger particles settle near the discharge, with fine particles settling further away. This results in a concentrating effect in the distribution of fine particles, sometimes called "slimes." These slimes are difficult to stabilize because they do not readily de-water and lack structural strength.

The radioactive constituents of potential environmental concern include radium-226 and radon-222 gas produced by radioactive decay. Radon gas has a half-life of 3.8 days and

diffuses from the tailings through the cover to the atmosphere. Uranium mill covers are designed to slow the rate of radon gas diffusion/emanation to acceptable regulatory standards. Many of the radioactive and hazardous constituents present in the tailings may affect the groundwater. Their mobility and potential impacts are dependent on many factors. For example, the site-specific geology and hydrogeology can strongly influence how well the uranium mill tailings are isolated. Design features of the impoundment include the liner (or lack thereof), methods used to control pH during waste disposal, ore and process variables, and cover design. Environmental site features of major importance include weather, upstream watershed characteristics, soil characteristics, earthquake potential, and natural vegetation succession.

Since radium-226 has a half life of 1620 years, the regulatory requirement for the isolation of uranium mill tailings is "1,000 years to the extent reasonably achievable, and, in any case, for at least two hundred years." From a regulatory point of view, it is impractical to expect that active, ongoing maintenance could be assured by administrative and institutional controls for more than 100 years. Therefore, the regulatory requirement states that "final disposition of tailings or wastes at milling sites should be such that ongoing active maintenance is not necessary to preserve isolation."

### III.2 UMTRA Project Experience

Burt and Cox reported on experiences at UMTRA Project sites in a technical report published in 1994<sup>(B)</sup>. The six sites discussed included five in relatively dry locations, some at higher elevations, and one in much wetter Pennsylvania. In each case, site-specific environmental and design features affected the impact and rate of sand and vegetation intrusion. The contaminated materials at these disposal cells were covered by a three-part system consisting of a radon barrier, a bedding layer, and a rock erosion layer. The radon barrier consists of a highly compacted soil/clay layer designed to limit radon emanation and water infiltration. The bedding layer is designed to support the rock erosion layer, prevent the rock from penetrating the radon barrier, and reduce or prevent the erosion of the radon barrier. The rock cover is designed to prevent water and wind erosion from affecting the stability of the disposal cell. In the relatively short time-span of one to three years after construction completion, the characteristics of vegetation coverage had exceeded design expectations. Deep-rooted species had invaded cover areas and had

begun to grow into the radon barrier. Maintenance of the sites now includes cutting of vegetation and use of herbicides. Report recommendations include design modifications for new sites to either increase cover rock thickness to prevent vegetation, or increase thickness of cover to minimize detrimental effects of deep-rooted vegetation.

Conventional cover designs are typically based on a design infiltration rate of  $2.5 \times 10^{-7}$  cm/sec ( $1.0 \times 10^{-7}$  in/sec), and there are concerns that vegetation or animal intrusion could increase the infiltration rate.

### III.3 Biointrusion

In 1994, the department began its technical review of the submitted closure plans, with both plans incorporating relatively thin (about two meters) cover designs with low-permeability clay or bentonite amended soil layers. The amended layers were 0.5 to 1.0 meter (1.5 to 3 feet) thick and were placed below native soil and a top soil cover. A rock mulch and synthetic layer were included in one of the designs. After extensive study, the department determined that biointrusion could cause failure of the low-permeability clay barrier. Factors which influenced this determination included the inability of clay-type soils to self-heal following root intrusion, and the ability of burrowing animals to move through supportive soils to depths of two meters, thus creating holes (voids) or channels which then could fill with less permeable materials. The net effect of such biointrusion is possible failure of the low-permeability clay barriers during the 1,000 year period at these sites.

### III.4 Freeze-Thaw

For many sites at higher elevations or in northern latitudes, the soil column will freeze to an appreciable depth during periods of prolonged cold weather. This is true for each of Washington's sites, which are located in the northeastern section of the state. Soil columns in these areas are known to freeze to a depth of one meter or more. When considering a design that must retain performance for such a long time period, even rare occurrences that affect performance must be considered. It has been demonstrated that highly compacted clay barriers lose their low-permeability performance after repeated cycles of freeze-thaw conditions. Therefore, any clay barrier designed in a soil horizon susceptible to freeze-thaw action will not likely retain its long-term low-permeability performance.

### III.5 Maintenance

Any design that must last 1,000 years must not be based on administrative/institutional controls to assure performance. Man's historical record does not justify such an allowance, even in the best of assumptions of political and economic stability. If maintenance is required over short time periods, then such a design cannot be considered, unless there is no other practical approach. When the department considered this factor, it became obvious that plant and animal intrusion would occur at Washington's sites because there is sufficient moisture and the soil and weather conditions are favorable for plant and animal life. The department had to assume that biointrusion would occur; not only that, but biointrusion could potentially be very beneficial to the cover design. Therefore, the cover must be designed to either prevent biointrusion, or to incorporate it; either way, ongoing active maintenance would not be required.

### IV. Thick Homogeneous Vegetated Cover Design

The concept of a thick homogeneous vegetated cover design is certainly not new and novel in the sense that it has been considered in the past. Such a design is simple and is not considered high-technology. It is simply a brute force method that uses a larger mass of material (greater thickness) to provide isolation of tailings. The larger mass is more stable, considering structural impacts from the environment (erosion, earthquakes, root penetration, etc.). The larger mass is also less sensitive to construction methods and techniques, material properties for available borrow soils, and requires less exported materials (bentonite, clay, rock, synthetics, etc.).

#### IV.1 Vegetation

The thick cover design must account for vegetation and animal intrusion. Since the presence of vegetation is almost guaranteed, one should consider its effects on the design. A thick cover that contains homogeneous, free-flowing material will be self-healing and the presence of plant root successional effects will not provide preferential pathways, since a low-permeability barrier layer is not present. Performance will not be degraded by the presence of plants and plant roots. If the cover is thick enough, a very large portion of root mass will be found in the upper portion, and root effects will be diminished. A cover depth of four to five meters is considered sufficient to mitigate biointrusion impacts.

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There is a very significant benefit from vegetation in that plants transpire large volumes of water from the ground into the air in the process of producing plant mass. The ratio of water volume transpired to plant mass produced is species-dependent, and ranges from 100 to 1,000. Evapotranspiration is greater during higher temperature summer conditions and generally exceeds natural rainfall precipitation, on average. Since most precipitation occurs during winter and most evapotranspiration occurs during summer, the soil column (cover) must be thick enough to contain the water without allowing deep percolation during the winter and spring, and release it in the summer and fall through evapotranspiration. If the cover is thick enough, the seasonal cycles will not impact deeper than the upper layer of the cover, and the tailings will remain well protected. In fact, if vegetation is deep rooted enough to access available moisture, essentially all of the year's accumulated precipitation will be removed by the end of the dry season. This process achieves the same general result as a low-permeability clay layer design.

### IV.2 Radon Gas Emanation

Radon gas emanation is a process of vapor diffusion through the soil and release to the atmosphere at the surface, where it could be inhaled. The radon gas inhaled could decay and produce a negative health effect to the exposed person. In practice, a relatively thin (about one meter) low-permeability clay barrier layer incorporated into a conventional design (total cover thickness of about two meters) has almost the same theoretical radon emanation rate as a thick (about four meters) homogeneous uncompacted soil cover. With conservative assumptions of soil characteristics, soil moisture, and soil compaction, it becomes quite unlikely that any external variable can cause the thick soil cover design to exceed the design limit. This is not the case with thin barriers placed near the surface. For instance, gas diffusion is highly dependent upon soil moisture content. A thick cover design is much more likely to maintain generally average soil moisture properties during the course of seasons and years than will a thin clay layer.

### IV.3 Infiltration of Radioactive or Hazardous Constituents

Infiltration of moisture through the cover, and subsequent percolation through tailings and the underlying vadose zone to the groundwater, will determine the groundwater impact. This impact is generally in the form of a concentration (e.g., ppm) or a rate of contaminant flux, (e.g., gm/yr). For radioactivity, the usual

units are pCi/l for concentration and pCi/yr for flux rate, and each radionuclide is considered individually because of the inherent difference in potential health effects. Reducing infiltration rates to zero theoretically eliminates the groundwater impact, since a potential waste stream that does not flow is not evident (impacting) to a potential recipient. Low-permeability barrier layers that are likely to fail their design permeability rates will likely produce greater infiltration rates on average over the design life of 1,000 years, than thick homogeneous vegetated cover designs that are optimized for vegetative production and high rates of evapotranspiration. Specific site conditions are important to this general statement and must be fully evaluated to achieve the benefit expressed.

#### IV.4 Structural Stability

The structural stability design parameters for uranium mills provide guidance to assess performance over the long term. This includes resistance to the detrimental effects of wind and water erosion, earthquakes, post-construction settlement, rock durability limitations, and others. The design analysis that justifies the design compliance with structural requirements includes long-term wind and water erosion and deposition estimates, and flooding from a probable maximum precipitation (PMP) event and its resulting probable maximum flood (PMF). In all cases, the thickness of the cover enhances compliance and long-term reliability performance. The effects of settlement can produce changes in slope that could affect erosion or deposition. Closure plans reviewed by the department used very shallow slopes (less than 2%) and did not require rock mulch on the surface to attain erosional stability. This enhances the natural vegetative production needed by other performance parameters. It was determined that even if settlement occurred and changed the slope, it would not be significant to erosional performance; vegetation would eliminate any ponding of water that might result, so there would be no increase in infiltration. The detrimental settlement effects of compacted clay barriers (infiltration breaks) are absent in thick homogeneous cover designs. Therefore, an uncompacted cover design would not be compromised by settlement. The department also found that the thick homogeneous cover is easy to build and readily meets design specifications.

#### IV.5 Longevity

The thick homogeneous cover was determined to be the most suitable for assuring compliance with the 1,000 year design

criteria at Washington State sites.

#### IV.6 Administrative Requirements

The regulations impose several administrative requirements that take effect after construction is completed, and after the radioactive materials license is terminated. By regulation, the following requirements are imposed: (1) surety is provided, based on a 1% real rate of return, to perpetually fund a surveillance program; (2) the state or federal government will own the land and/or provide responsibility for long-term performance; and (3) the facility will be annually surveyed.

### V. Conclusions

The performance-based regulations relative to the development of closure and reclamation plans at Washington's two uranium mill sites have allowed for a potential improvement in their closure designs. There is now another method of isolating waste using a thick cover approach that has potential long-term reliability benefits, when compared with the low-permeability, relatively thin barrier designs. It is likely that these benefits can also be achieved at other sites with similar environmental characteristics. In the following sections are examples of department experience at the two uranium mill sites, both of which are located in northeastern Washington:

#### V.1 Cost Impacts

The closure design for one of the mills was approved conceptually, on condition that detailed construction designs and specifications be submitted for review when the site is ready for final closure. It is estimated that by using the thick cover design instead of the conventional design, approximately \$1 million will be saved on closure costs.

Closure of the other uranium mill is being performed in phases and contains a Tailings Reclamation Plan that includes the design basis and construction of the tailings cover and surrounding diversion channel. The mill building and process equipment were disposed of previously. Contaminated site soils were cleaned up in a separate plan that is essentially complete. Construction is well underway and is expected to be essentially complete by autumn 1996. The cover will be installed, the diversion channel cut, rock erosion protection placed, and exposed disturbed ground re-vegetated (seeded). Again, it is estimated that by using the thick

cover design instead of the conventional design, approximately \$1 million will be saved on closure costs.

### V.2 Schedule Impacts

Schedule impacts at one uranium mill facility have not been identified, as the design is approved only conceptually and details of construction scheduling have not been developed. Nevertheless, it will certainly be a positive schedule benefit when bentonite imported from Wyoming and mixed and placed to tight specifications is replaced by native borrow material from the site or from other local sources.

It is readily apparent that the closure project at the other uranium mill facility would be greatly impacted by the schedule implications of a conventional cover design. The normal weather conditions in northeast Washington would make it quite difficult to produce a highly compacted clay barrier in any case. The normal requirement to monitor for settlement of the cover would, in itself, cause an additional year of construction. The design, as approved is approximately 25% complete at this time and is expected to be greater than 95% complete this fall. When time is money, this schedule benefit will surely result in additional unaccounted cost savings.

### V.3 Quality Assurance

Although not mandated, it is important for a regulatory agency to be cost or schedule conscious; it is a public service to be considerate of such things, so long as the environment and the public are adequately protected by compliance with regulatory requirements. Quality assurance can therefore provide the check that all regulatory requirements have been, or will be, met. Compliance has been assured by considerable technical review by a multi-disciplinary review team of engineers, hydrogeologists, health physicists, licensing specialists, and others. The licensees, their engineering and technical consultants and their contractors have been most cooperative. Quality control will be provided by department field inspection.

### V.4 Long-Term Reliability

One of the best ways to achieve long-term reliability is to develop something that is in harmony with its environment and also resistant to the erosional and depositional forces that may come to bear. Such stability must be assured for both the relentless

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forces of everyday environmental impacts and for the intensity of the unusual event (floods, earthquakes, droughts, and others).

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8. Burt, Charles J., and Cox, Steven W., "An Assessment of Plant Biointrusion on Six UMTRA Project Disposal Cells," UMTRA Project, Albuquerque, NM, 1994.
9. Technical Meeting, Sponsored by Waste Management Section, Division of Radiation Protection, Washington Department of Health, "Conceptual Cover Designs," September 29, 1994, Spokane, WA.

**DISCUSSION**

**BELLAMY:** Do you know any basis for the thousand-year criterion that you mentioned, because I don't?

**BLACKLAW:** The first basis is that it is in the regulations as a criterion, and is specifically noted there. I believe it comes from the development of regulations by NRC, which also came from a generic environmental impact statement where risks were evaluated. I am sure that it comes from the half-life of radium-226, 1600 years.

**CHAIRMAN'S CONCLUSION**

**BELLAMY:** It is clear that decontamination and decommissioning in the waste management area is an up and coming concern and that we are going to have to tackle it in the years to come. Additional discussion of Hanford will be presented tomorrow at the working luncheon. I encourage everybody to have further thoughts on the topic.

SESSION 3

**INSTRUMENTATION AND MEASUREMENT**

Monday July 15, 1996  
Co-Chairmen: W.L. Anderson  
R. Zavadoski

PRACTICAL EXPERIENCE APPLIED TO THE DESIGN OF  
INJECTION AND SAMPLE MANIFOLDS TO PERFORM IN-PLACE  
SURVEILLANCE TESTS ACCORDING TO ANSI/ASME N-510  
E.M. Banks, W.O. Wikoff, and L.L. Shaffer

UNIT VENT AIRFLOW MEASUREMENTS USING A TRACER  
GAS TECHNIQUE  
D.G. Adams, P.L. Lagus, and K.M. Fleming

DEVELOPMENT OF REAL TIME DETECTOR FOR  
FLUORESCENT PARTICLES  
C. Prevost, J. Vendel, and A. Seigneur

ACCURACY IMPROVEMENT IN LEAK DETECTION OF  
CHARCOAL ADSORBERS BY HALIDE PULSE INTEGRATION  
METHOD  
B.J. Kovach and E.M. Banks

TESTING THE SAMPLING EFFICIENCY OF A NUCLEAR  
POWER STATION STACK MONITOR  
L.H. Ström

THE INFLUENCE OF SALT AEROSOL ON ALPHA RADIATION  
DETECTION BY WIPP CONTINUOUS AIR MONITORS  
W.T. Bartlett and B.A. Walker

## 24th DOE/NRC NUCLEAR AIR CLEANING AND TREATMENT CONFERENCE

### PRACTICAL EXPERIENCE APPLIED TO THE DESIGN OF INJECTION AND SAMPLE MANIFOLDS TO PERFORM IN-PLACE SURVEILLANCE TESTS ACCORDING TO ANSI/ASME N-510

Eric M. Banks, Walter O. Wikoff, Larry L. Shaffer  
NUCON International, Inc.  
Columbus, Ohio

#### Abstract

At the current level of maturity and experience in the nuclear industry, regarding testing of air treatment systems, it is now possible to design and qualify injection and sample manifolds for most applications. While the qualification of sample manifolds is still in its infancy, injection manifolds have reached a mature stage that helps to eliminate the "hit or miss" type of design.

During the design phase, manifolds can be adjusted to compensate for poor airflow distribution, laminar flow conditions, and to take advantage of any system attributes. Experience has shown that knowing the system attributes before the design phase begins is an essential element to a successful manifold design. The use of a spreadsheet type program commonly found on most personal computers can afford a greater flexibility and a reduction in time spent in the design phase.

The experience gained from several generations of manifold design has culminated in a set of general design guidelines. Use of these guidelines, along with a good understanding of the type of testing (theoretical and practical), can result in a good manifold design requiring little or no field modification. The requirements for manifolds came about because of the use of multiple banks of components and unconventional housing inlet configurations. Multiple banks of adsorbers and pre and post HEPA's required that each bank be tested to insure that each one does not exceed a specific allowable leakage criterion.

#### Introduction

The often critical application of nuclear air treatment systems (NATS) installed at various nuclear, chemical, and biological facilities has necessitated the testing of the individual components to ensure their leak tightness. As the various facilities have grown and matured over the years, so have the NATS. The design of NATS has gone from simple single bank, sheet metal, and silicone sealed units to multiple bank, stainless or coated steel, all welded construction. Since the industry needs to ensure with a high degree of confidence that the individual banks of components inside the NATS will perform as required, refined injection and sampling techniques had to be developed. The use of injection and sample manifolds has been introduced to meet this need.

While this paper will introduce some basic design guidelines for manifolds, it can in no way envelop all of the variables associated with system, component, and application design and installation. The major emphasis will be placed on injection manifolds required on post installation NATS. Although the major emphasis is on injection manifolds, most of these guidelines can be applied to the design of sample manifolds as well.

### Discussion

One of the most important steps in the design of an injection manifold is deciding where to place the manifold in the NATS. The primary placement of the manifold is determined by the function of the manifold and the component layout of the filter bank. The best location takes advantage of system or component attributes that create increased velocity and flow turbulence in the housing (for example, at the outlet air slots of type II adsorber trays or at the inlet or outlet slots of a type III deep bed adsorber bank). Other locations could be at the air flow traverse station or just upstream of the system inlet plenum. All these options must be examined and the best location chosen before the design phase.

These steps are given in order of importance for determining the best location of the injection manifold:

- Function of the injection manifold.
  - Is it an injection or sample manifold only or is to be used as a combination injection / sample manifold?
- Airflow velocity.
  - What are the maximum and minimum velocities expected at the manifold location?
- Airflow distribution.
  - What is the velocity profile of the airstream at the manifold location?
- Ease of installation and use.
  - Is the manifold to be temporary or permanent?
  - Is the manifold to be installed in the ductwork or inside the NATS housing?
  - From what material should the manifold be constructed?

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During the design process it is important to understand how the system and its components work. For example:

- The air velocity through a NATS housing is usually less than 200 feet per minute (fpm) which is considered to be in the laminar flow region. By being laminar, very little mixing will occur inside the housing.
- The air velocity at the face of a 24 x 24 x 11.5 inch standard size 1000 cfm HEPA filter is approximately 300 fpm.
- The air velocity at the face of the outlet air slot for a standard type II adsorber tray is approximately 1300 fpm.
- The airflow velocity at the inlet and outlet air slots of a type III adsorber bed is generally lower than that exiting a type II tray, and higher than at the face of a standard size HEPA.
- On most Type III adsorber beds the outermost air slots are, by design, operating at an assumed 50% of the airflow of the inner air slots due to the bed geometry.

Another factor that will affect the manifold design is the airflow distribution (velocity profile) at the proposed manifold location. When designing an injection manifold for use downstream of the upstream HEPA bank, an airflow distribution test must be performed. If the airflow distribution meets the acceptance criteria of no one reading exceeding  $\pm 20\%$  of the average velocity, then no special design adjustments are required. However, if this  $\pm 20\%$  is exceeded then design adjustments of the manifold may be required.

Generally in most NATS there are other factors that enhance challenge agent mixing (e.g., distance) to eliminate a concern over a  $\leq 20\%$  difference in airflow distribution. If the manifold is to be located where the airflow distribution exceeds  $\pm 20\%$ , then the manifold should be designed proportionately. The need for proportionate design usually occurs when the manifold is to be installed in ductwork where short distance mixing is required.

A typical manifold consists of a header and risers (See Figure 1). Each riser has a series of holes through which the challenge agent is introduced to, or withdrawn from, the air stream. See Figure 2 for more details.

Figure 1 Simplified layout of an injection/sample manifold.

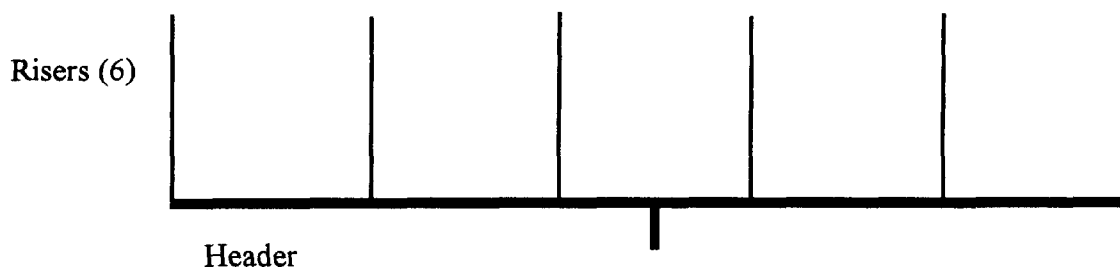
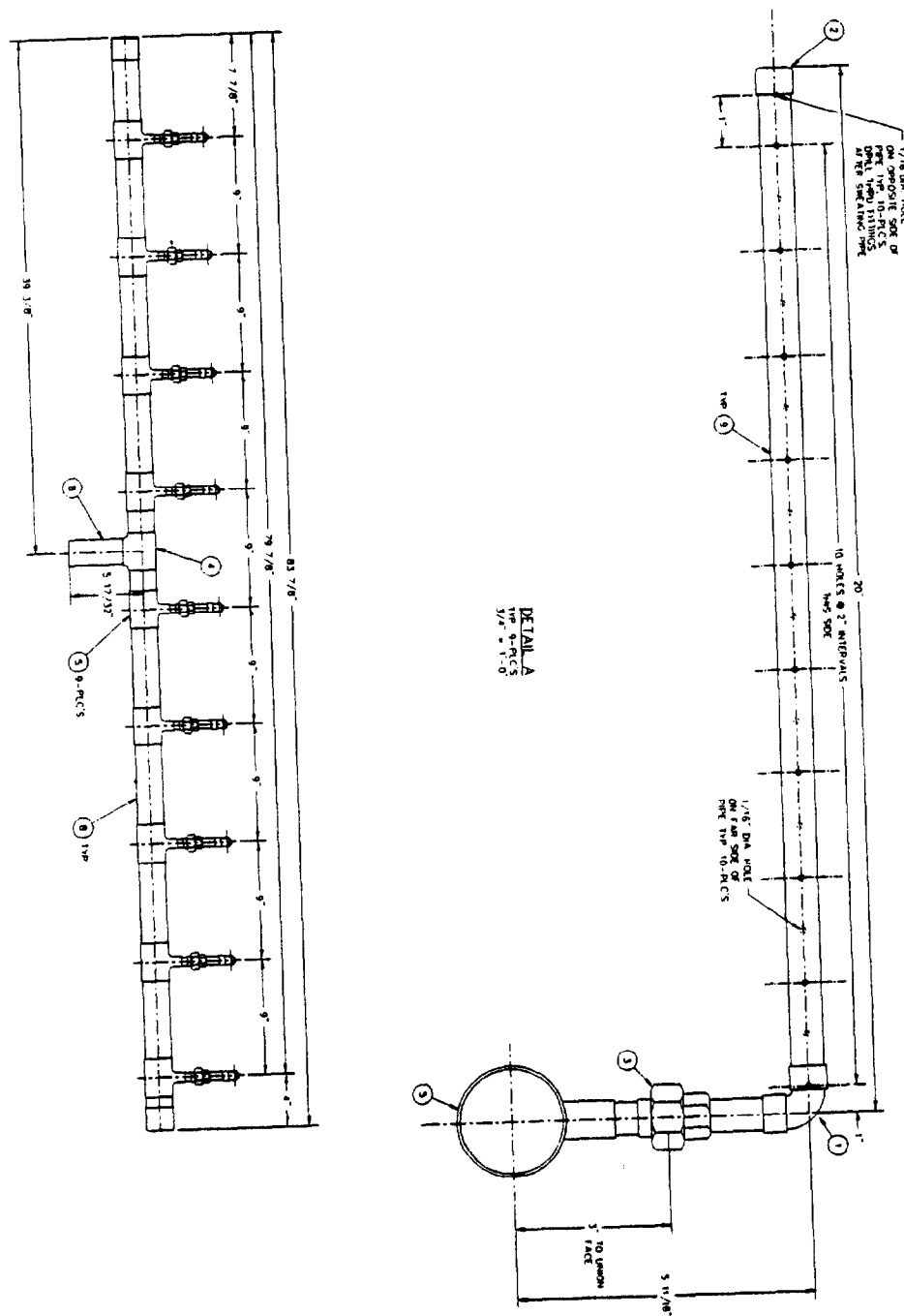


Figure 2  
 Typical combination manifold (injection & sample) designed to be installed in the air channels of a type II adsorber bank.



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Once the location of the manifold is identified, the next step is determining the location of each riser. The risers should be placed to take advantage of system or component designs that increase velocity. For example, risers placed directly in the air channel of a type II or type III adsorber bed will take advantage of the increased velocity associated with those air channels.

If the manifold is to be placed in rectangular ductwork supplying the NATS, then divide one axis of the ductwork into equal areas using the same methodology for determining the traverse points for a rectangular duct airflow traverse. Each manifold riser should be positioned in the center of these equal areas. The distance between these equal areas should generally not exceed six inches. Depending on the velocity of the airflow, duct layout and the distance to the bank being tested, the distance between these equal areas could exceed or be less than six inches. This methodology can also be applied to a round duct.

Another possible location is at the downstream face of the prefilter bank or upstream HEPA bank. The latter would be necessary if the NATS contained a downstream HEPA bank that was required to be tested. While this location is usually less desirable due to the low exit airflow velocity of these components, designing a suitable manifold is possible. Two items to keep in mind are; first, if the filters do not load evenly (dirt loading) this will affect the performance of the manifold and second, when the filter bank is replaced it should be a full replacement rather than a partial replacement. The location of the risers is determined using the same method as for ductwork. The risers need to be positioned to cover only the face of each filter. No holes should be drilled in an area of no airflow (i.e., between filters).

An ideal location for a manifold in a NATS housing will take advantage of the high airflow velocities associated with type II or Type III adsorber banks. The risers for these manifolds need to be located at each air channel. The best position for each riser is just inside each air channel (approximately 50% should be inside the air channel) to take full advantage of the higher velocities.

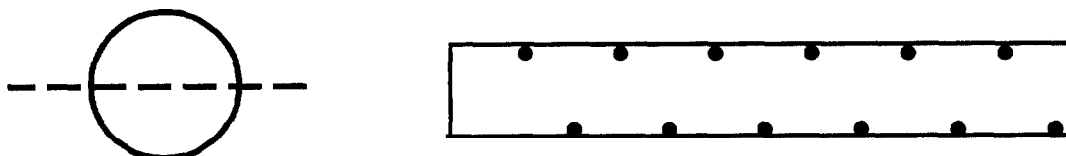
### Design Method

After the location of the manifold and positioning of the risers has been established, the next step is designing the manifold. The basic steps in designing a manifold require determining:

- 1) Riser hole layouts (spacing and angular position with respect to airflow).
- 2) Quantity of holes per riser.
- 3) Diameter and area of the riser holes.
- 4) Riser pipe diameter and area.
- 5) Header pipe diameter and area.

The hole layout on each riser should cover the effective airflow area. From applied experience a hole spacing of approximately two inches apart per side and staggered on each side is desirable. Hole location should be 180° degrees apart and perpendicular to the direction of airflow.

Figure 3 Typical hole layout of a riser.



The riser pipe diameter depends on the quantity of holes per riser and the sum of their areas. Depending on the positioning of the individual risers and the adjacent components (if any), the riser diameter can also be used to increase the velocity and turbulent flow of the air stream. Experience has shown that the decrease in air channel area will add approximately 0.5 to 1.0 inches of pressure drop across the bank. This does not apply when the risers are to be positioned in the ductwork or on the downstream side of a prefilter or HEPA bank.

Two rules apply to the sizing of riser holes:

- The cross-sectional area of the riser should be greater than or equal to ( $\pm 10\%$ ) the sum of the areas of the holes per riser.
- The cross-sectional area of the header should be greater than or equal to ( $\pm 10\%$ ) the sum of the areas of the holes in all the risers.

When designing a manifold to be placed where the airflow distribution (velocity profile) exceeds  $\pm 20\%$  of the average and short distance mixing is required, the hole sizing on the risers must be proportional to the airflow. The use of any spreadsheet program with plotting capabilities is very useful when performing the following steps:

- 1) Perform an airflow distribution test by measuring the airflow velocities at equal areas for each riser region position.
- 2) Calculate the velocity total for all readings.
- 3) Calculate the % of average for each velocity reading.
- 4) Determine the % of total velocity for each riser region.
- 5) Determine the total riser area.

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- 6) Calculate the required total hole area for each riser region.
- 7) Determine the quantity of holes corresponding to each riser region from the location of the velocity readings and the desired hole layout.
- 8) Determine the hole diameter for each riser region.

The sizing of the holes, riser, and header may allow several variations from which to decide. From these options, several items should be evaluated:

- Difficulty in drilling the holes.
  - Very small holes are difficult and time consuming to drill.
- Ease of use if it is only installed temporarily for testing.
- Complexity of assembling temporary manifolds.

Once the design is finished, the material from which to construct the manifold needs to be chosen. Things to consider when deciding on construction materials are:

- Composition of the airstream (e.g., acid or alkaline gases, particulate types and concentration, moisture, etc.).
- Temperature of the air stream.
- Velocity of the air stream at the manifold location.
- Decontamination requirements, especially if it is a temporary manifold.

While PVC, stainless steel, and mild steel have all been used in the past, copper tends to be the best overall choice. It is easy to work with, relatively light, and cost effective. After the manifold has been constructed it is important that all burrs be ground smooth and provisions made to clean the internals of the manifold. This is especially important when the manifold is to be used as a combination injection and sample manifold.

Once the manifold has been constructed, it still must be qualified by performing an air-aerosol mixing test. If the design guidelines have been properly followed then this test should be uneventful. However, if the design guidelines were not followed or some unforeseen problems occur, then field modifications of the manifold may be required. This field modification may range from minor changes, such as hole plugging or enlarging holes, to major redesign work.

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The following is an illustration of a 30,000 CFM NATS. Although it contained only a single HEPA and adsorber, bank an injection manifold was required. The only available injection point was located at the pitot traverse location. This location was approximately four feet from the inlet to the housing (See Figure 4). First, a velocity traverse was performed and this profile was graphically plotted out (See Charts 1 & 2). After analyzing the velocity profile and determining the riser hole layout a spreadsheet was designed to simplify the process of calculating the required velocity percentages and hole areas (See Table 1). The manifold was designed using this information and a successful air-aerosol mixing test was performed with no field modifications required of the manifold (See Figure 5).

Figure 4 Physical layout of the 30,000 CFM NATS.

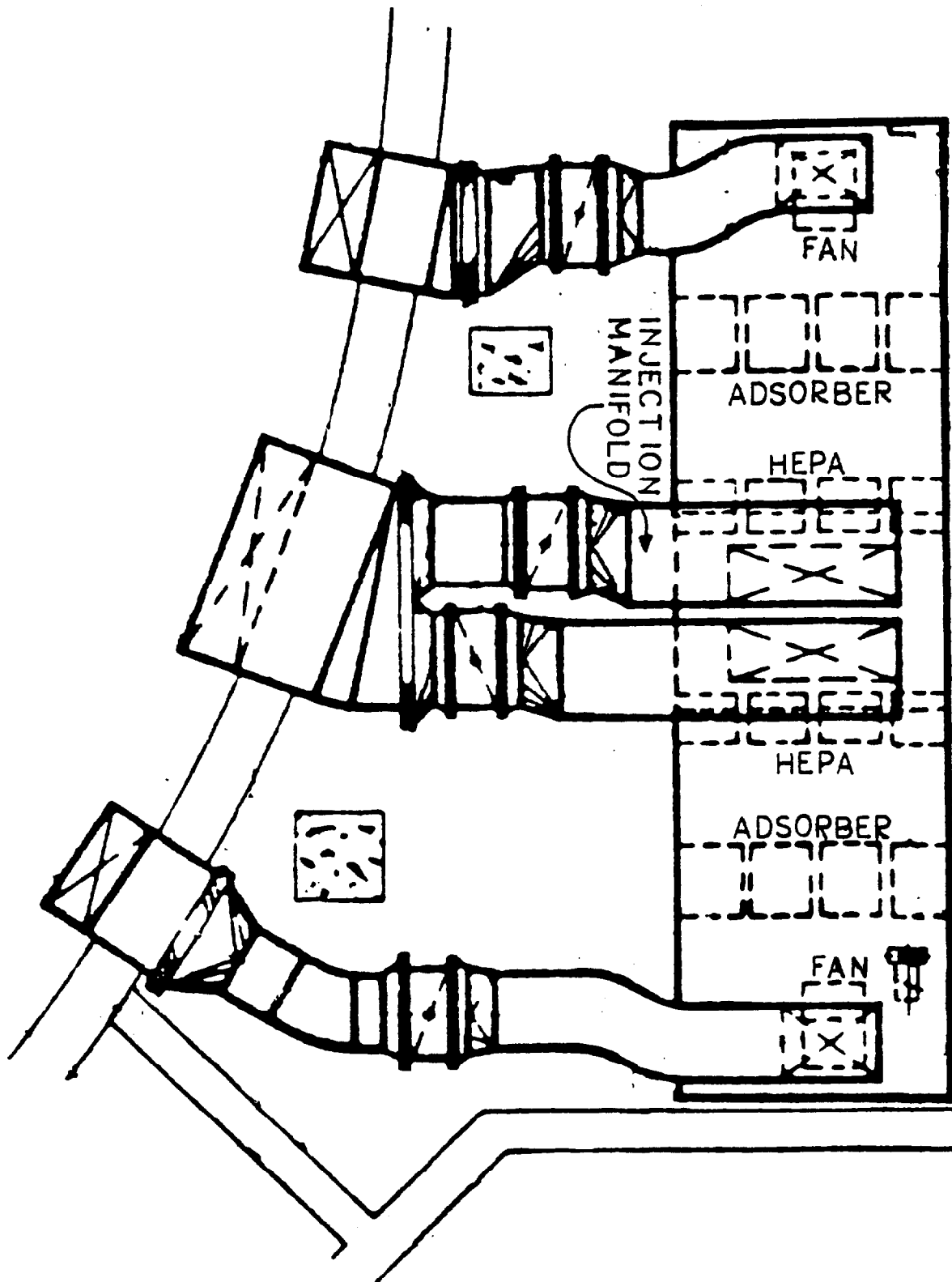


Chart 1 Bar graph plot of the individual velocity points inside the duct.

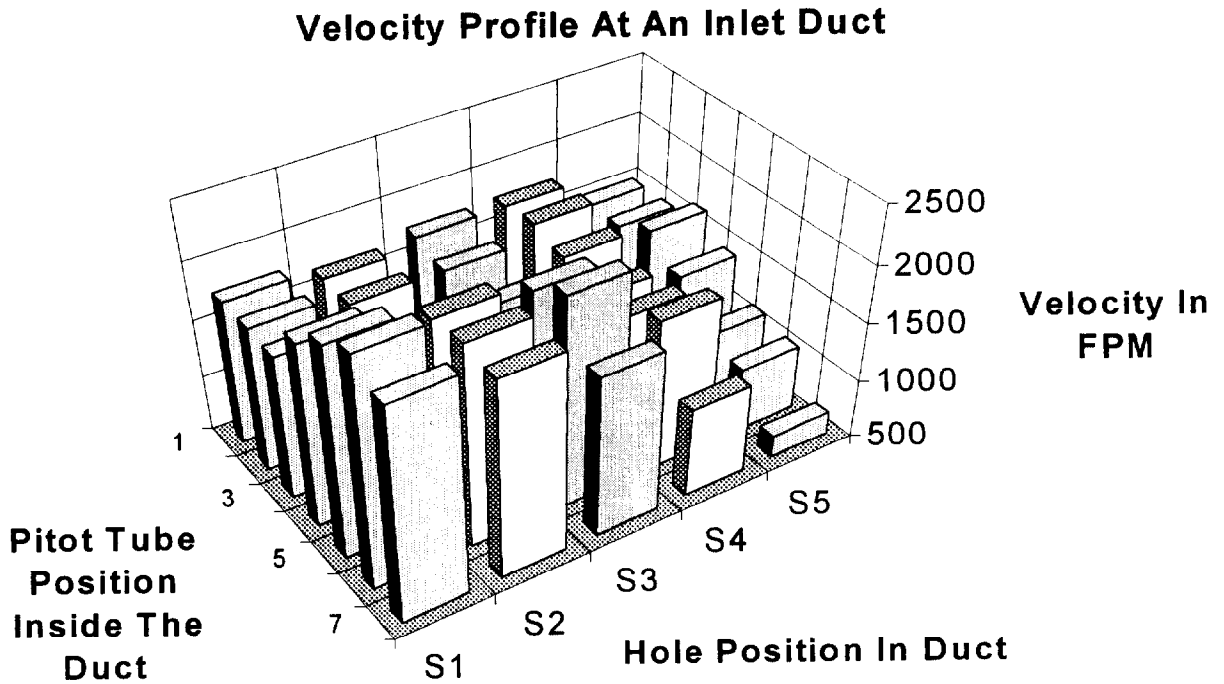
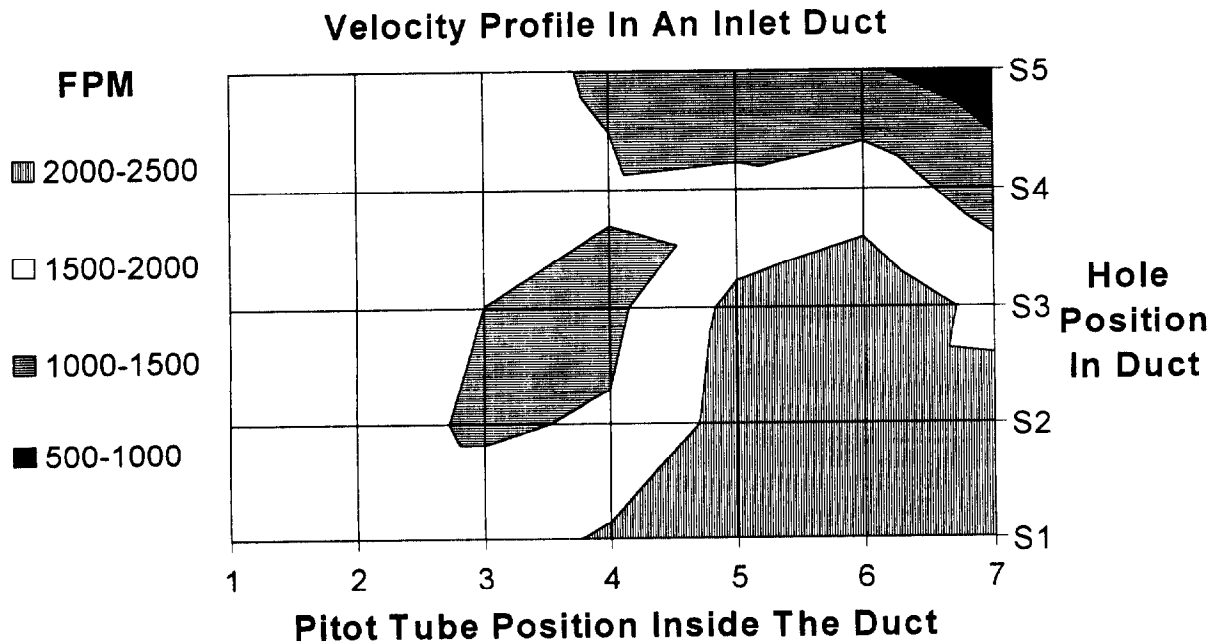


Chart 2 Surface plot of the velocity profile inside the duct.



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Table 1 Worksheet used to plot velocity graphs and calculate hole size.

	<b>DATA VELOCITY</b>						<b>TOTAL BY TUBE</b>	<b>% BY TUBE</b>	
	1499	1499	1651	1444	1133	1060	694	8980	15%
	1746	1791	1699	1551	1602	1791	1266	11446	19%
	1746	1651	1499	1387	2119	2301	1879	12582	21%
	1651	1651	1444	1551	2194	2230	2194	12915	21%
	1746	1746	1746	2081	2301	2469	2335	14424	24%
<b>TOTAL</b>	8388	8338	8039	8014	9349	9851	8368	60347	100%

### PERCENT OF AVERAGE FLOW

87%	87%	96%	84%	66%	61%	40%
101%	104%	99%	90%	93%	104%	73%
101%	96%	87%	80%	123%	133%	109%
96%	96%	84%	90%	127%	129%	127%
101%	101%	101%	121%	133%	143%	135%

### PERCENT OF FLOW BY RISER

16.7%	16.7%	18.4%	16.1%	12.6%	11.8%	7.7%	100%
15.3%	15.6%	14.8%	13.6%	14.0%	15.6%	11.1%	100%
13.9%	13.1%	11.9%	11.0%	16.8%	18.3%	14.9%	100%
12.8%	12.8%	11.2%	12.0%	17.0%	17.3%	17.0%	100%
12.1%	12.1%	12.1%	14.4%	16.0%	17.1%	16.2%	100%

### AREAS OF OPENINGS BY REGION

							<b>TOTAL</b>	<b>AREA OF HOLES</b>
0.050	0.050	0.055	0.048	0.038	0.035	0.023	0.298	0.30
0.058	0.059	0.056	0.051	0.053	0.059	0.042	0.379	0.38
0.058	0.055	0.050	0.046	0.070	0.076	0.062	0.417	0.42
0.055	0.055	0.048	0.051	0.073	0.074	0.073	0.428	0.43
0.058	0.058	0.058	0.069	0.076	0.082	0.077	0.478	0.48

### HOLE SIZE BY REGION

<b>QTY</b>	6	6	5	6	5	6	6
	0.103	0.103	0.118	0.101	0.098	0.086	0.070
	0.111	0.112	0.120	0.104	0.116	0.112	0.094
	0.111	0.108	0.112	0.099	0.134	0.127	0.115
	0.108	0.108	0.110	0.104	0.136	0.125	0.124
	0.111	0.111	0.121	0.121	0.139	0.132	0.128



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While this paper does not address manifolds dedicated to sampling only, the general design guidelines for an injection manifold may be applied to the design of sample manifolds. When a manifold is to be used as both an injection and sample manifold, the design guidelines that apply to the injection manifold take precedence.

### Summary

The need to test multiple banks of components in a single NATS required that a method be developed to introduce a test agent uniformly for each bank in the NATS. For a single bank of components, this requirement for uniform distribution of the test agent is still required. To meet the acceptance requirements of the various testing documents and Regulatory Guides, a qualified method of test agent distribution had to be developed. Injection and sample manifolds have made it possible to test entire NATS without having to disturb a single bank of components or by placing test personnel inside the NATS to perform a multi-point sample or shroud test method.

The authors would like to thank Mr. Robert R. Sommer II and Mr. Jonathan E. Otermat for their editorial reviews and technical contributions in the writing of this paper.

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2. ANSI/ASME N-510, "Testing of Nuclear Air Treatment Systems."
3. ASME, CONAGT, AG-1, "Code On Nuclear Air and Gas Treatment."
4. USNRC, Regulatory Guide 1.52, "Design, Testing and Maintenance Criteria for Atmosphere Cleanup System Air Filtration and Adsorption Unit of Light-Water-Cooled Nuclear Power Plants."
5. USNRC, Regulatory Guide 1.140, "Design, Testing and Maintenance Criteria for Normal Ventilation Exhaust System air Filtration and Adsorption Units of Light-Water-Cooled Nuclear Power Plants."

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### DISCUSSION

**SCRIPSICK:** Has size dependent particle loss been considered when testing HEPA filter systems? Photometry can introduce you to uncertainties. Are you evaluating injection sample manifolds for size-dependent effects? I do not think that has been addressed in this work. For the kinds of testing being conducted the type generator being used, and the amount of aerosol generated, there should be no such effects. I do not think there is a problem in that regard because they are using  $0.3 \mu\text{m}$  particles according to the procedure in N510. When using a light scattering photometer the response is strongly dependent on particle size. Therefore, if you introduce a size bias either to your sampling technique or your injection device, the size distribution upstream will be different from the size distribution downstream. Alternatively, if you have losses in the sampling system that are not balanced, you will not have the same losses as a function of size upstream as you do downstream. The error propagates into your photometer measurement, and ultimately will affect the error in your test results.

**GRAVES:** I am not sure I follow you, but we can always make the case that our sampling lines will affect the results. I do not believe the aerosol was degenerated. We were using NUCON equipment, we were not using laser light for particle light scattering. I don't think that is a problem with this technique.

**KOVACH, B:** I know you are talking about large particles becoming lost in different places. This means that you are going to smaller and smaller particles when you use a manifold. Let me tell you that the aerosol generator being used has no particles above  $2 \mu\text{m}$ . There is a baffle plate that collects the larger particles. Therefore the manifold is contributing little to change the particle size. Using the particle size spectrometer we have at NUCON, we could not see much difference. Therefore size change if any, has been neglected. If we used a laser spectrometer we might find size differences, but they would not make much change in the results.

**ENGELMANN:** As a quality control-quality assurance matter, did you, by any chance, sample without any intervening filtration? Did you look at the release characteristics to see if your sampler showed the same thing as is present in the air stream?

**GRAVES:** After installation you have to qualify manifolds. You do this with an aerosol mixing test; in this particular case, at 30,000 CFM maximum flow rate as shown on the view graphs. You must make the usual scan to see if you have good aerosol mixing. Between the injection point and the measurement point all you have is duct length so there is no filtration involved.

**ENGELMANN:** The reason for looking at particle size might be to see to what extent the particle size distribution may become biased between the release point and the sampling point in the interpretation of the results. They should show the same sizes.

**GRAVES:** I would expect them to be the same sizes.

**ENGELMANN:** What about concentration?

**GRAVES:** You inject aerosol upstream through a manifold to solve a maldistribution problem. You are using a device that generates an aerosol of the appropriate particle size distribution. You use one that is know to do that. You are simply directing it in such a way as to cover the cross section of the airstream and to get the required distribution. You are solving a problem with a single point injection into the manifold.

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and to get the required distribution. You are solving a problem with a single point injection into the manifold.

**ENGELMANN:** I wonder if you determined the need for an injection manifold based on a mixing test, or just on the geometry of the housing?

**GRAVES:** In this particular case a single injection point without a manifold was deemed to be unsuitable because mixing was not very good. A manifold was needed to solve that problem.

**HOLTORP:** Did you perform some air-aerosol mixing uniformity tests before installing the manifold? What was the improvement you saw on the mixing test results?

**GRAVES:** This was used as an example because of the quality of the solution. In this particular case, there was no good place designated for this particular system, it just didn't work. After installation it went from failure to easy pass. We are very happy with this particular installation.

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## UNIT VENT AIRFLOW MEASUREMENTS USING A TRACER GAS TECHNIQUE

Dennis G. Adams  
Union Electric Company  
Callaway Nuclear Plant  
Fulton, MO

P.L. Lagus, Ph.D., CIH  
Lagus Applied Technology, Inc.  
San Diego, CA

K.M. Fleming  
NCS Corporation  
Columbus, OH

### ABSTRACT

An alternative method for assessing flowrates that does not depend on point measurements of air flow velocity is the constant tracer injection technique. In this method one injects a tracer gas at a constant rate into a duct and measures the resulting concentration downstream of the injection point. A simple equation derived from the conservation of mass allows calculation of the flowrate at the point of injection.

Flowrate data obtained using both a pitot tube and a flow measuring station were compared with tracer gas flowrate measurements in the unit vent duct at the Callaway Nuclear Station during late 1995 and early 1996. These data are presented and discussed with an eye toward obtaining precise flowrate data for release rate calculations. The advantages and disadvantages of the technique are also described.

In those test situations for which many flowrate combinations are required, or in large area ducts, a tracer flowrate determination requires fewer man-hours than does a conventional traverse-based technique and does not require knowledge of the duct area.

### I. INTRODUCTION

Air balance and ventilation performance testing requires precise flowrate measurement. Conventionally, flowrates are calculated from duct area and air velocity data. Velocity data are usually obtained by performing a multi-point traverse at the duct using a pitot tube or hot wire anemometer. In order to minimize non quantifiable errors in the velocity measurement certain conditions must be satisfied:

- (1) The flow streamlines are parallel to the axis of the duct.
- (2) No significant flow change occurs upstream for 8 to 10 diameters and downstream for 2 to 4 diameters from the flow measurement point.

Often in the field, these conditions cannot be satisfied and significant non-quantifiable errors may exist in the measurement. For example, due to access conditions or ductwork design, velocity measurements may have to be performed near a duct transition, elbow or damper. In these cases, the flow profile is perturbed and the previously stated conditions for precise measurement cannot be achieved.

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Other field situations exist which resist precise measurement by conventional techniques, e.g. the measurement of air flowrates in plant chiller equipment where duct runs are minimal and velocity traverse based measurements are severely compromised.

### II. TECHNICAL BACKGROUND

For most ventilation type measurements, duct flow is completely turbulent resulting in differences in flow velocities measured across the diameter of a duct even in the absence of flow perturbing elements such as the above mentioned transitions, elbows or dampers. ANSI/ASHRAE Standard 111<sup>(1)</sup> requires that for any flow traverse measurement to be valid more than 75% of the traverse readings must be greater than 10% of the maximum velocity pressure. Yet sometimes a flow rate is required from a point where this condition is NOT satisfied. Any flow rate calculated from a traverse under these conditions is in error by an unknown amount. This standard also requires a minimum of 25 measurement points even in moderately sized ducts.<sup>(2)</sup> For rectangular ducts larger than 4.5 feet on any side a maximum measurement spacing of eight inches is recommended. This can require that a very large number of data points be obtained. Hence to perform a traverse measurement correctly can require a substantial investment of time to obtain the necessary individual data points in addition to requiring that the flow be well behaved.

For at least twenty years it has been known that an alternative method to measure duct flowrates exists. It entails the use of a tracer gas dilution method. This method is a *volumetric* as opposed to a point measurement. To undertake such a measurement, a tracer gas is continuously metered into a flowing duct at a known rate. After allowing for mixing, air samples are collected at a point downstream and the concentration of tracer gas is measured. The rate of flow is readily calculated from the ratio of the tracer injection flowrate to the diluted concentration--in symbols:

$$Q = S / C$$

where  $Q$  = volumetric flowrate

$S$  = tracer injection flow rate

$C$  = duct tracer concentration

Note that for this equation to be valid the tracer must be *well mixed* within the duct. Since mixing is enhanced by the existence of flow direction changes within a duct, unsatisfied conditions (1) and (2) above which serve to complicate a traverse-type flow measurement actually enhance a tracer dilution flow measurement.

The tracer dilution technique has been used in the mine engineering, industrial hygiene, and energy conservation communities, but has been largely ignored in the ventilation engineering community.<sup>(3,4,5)</sup> This is unfortunate since many difficult flow characterization problems can be easily accommodated using the technique.

The tracer gas of choice for tracer dilution flowrate testing is sulfur hexafluoride, SF<sub>6</sub>. This gas is inert, non-toxic, non-reactive, and is easily measured by means of electron capture gas chromatography to concentrations approaching one part per trillion (10<sup>-12</sup>) although this sensitivity level is only required for the largest of flows. The gas is monitored on-site using specially designed monitors that have been optimized for the detection of SF<sub>6</sub> used as a tracer gas. These monitors are not affected by the presence of

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other gases in the plant background such as freons and halogenated solvents. In addition since SF<sub>6</sub> possesses a zero ozone depletion factor it will not harm the ozone layer.

Tracer gas is injected into a duct using a mass flow controller or calibrated orifice. If the duct is large or the sampling point is fairly close to the injection point without adequate flow disturbances to promote mixing, tracer gas may be injected using a distributed manifold inserted into the duct. Tracer gas samples are drawn from the duct using a recirculating pump to take samples for analysis using a gas chromatograph.

### III. SYSTEM DESCRIPTION

#### Ventilation System Lineups

A combination of charcoal filtration units and fans discharge to the unit vent based upon the operational requirements of the plant. The components with their design flow rates for each applicable system are given in Table 1. Which fan or filtration unit is running depends on the ventilation system lineup required by the plant.

Table 1 Unit vent exhaust plenum

<u>Fan/Filtration Unit</u>	<u>Design Flow</u>
Condenser Air Removal Filtration Unit (GE)	1000 cfm
Main Steam Enclosure Fan Exhaust (GF)	16500 cfm
Aux/Fuel Building Emergency Exhaust Filtration Unit-Train A(GG)	9000 cfm
Aux/Fuel Building Emergency Exhaust Filtration Unit-Train B(GG)	9000 cfm
Auxiliary Building Access Control Exhaust Filtration Unit(GK)	6000 cfm
Auxiliary/Fuel Building Normal Exhaust Filtration Unit(GL)	32000 cfm (Fast)
	13000 cfm (Slow)
Containment Mini-Purge Exhaust Filtration Unit(GT)	4000 cfm

There are five major ventilation system lineups that occur during normal plant operations. Each is given in Table 2 with the fan status as shown. These lineups are designated for testing purposes as Normal, Normal/Mini-Purge, FBIS (Fuel Building Ventilation Isolation Signal)/Mini-Purge, FBIS/CRVIS (Control Room Ventilation Isolation Signal)/Mini-Purge and FBIS/CRVIS. Each lineup is fully explained below.

Table 2 Ventilation lineups/fan status

(X) indicates running

<b>VENTILATION LINEUP</b>	<b>GE</b>	<b>GK</b>	<b>GF</b>	<b>GL (SLOW)</b>	<b>GL (FAST)</b>	<b>GG</b>	<b>GT</b>
<b>NORMAL</b>	X	X	X		X		
<b>NORMAL/MINI PURGE</b>	X	X	X		X		X
<b>FBIS/MINI PURGE</b>	X	X	X	X		X	X
<b>FBIS/CRVIS/ MINI PURGE</b>	X		X	X		X	X
<b>FBIS/CRVIS</b>	X		X	X		X	

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**Normal Ventilation Lineup**-The normal ventilation lineup is a combination of charcoal filtration units GL(Fast), GE,GK and the GF exhaust fan. This ventilation lineup exhausts the Auxiliary Building, the Fuel Building, Access Control Area and the Condenser Air Removal System. The design air flow rates are listed in Table 1. The fans normally exhausting to the unit vent during this ventilation lineup are shown by the shaded portions in Figure 1.

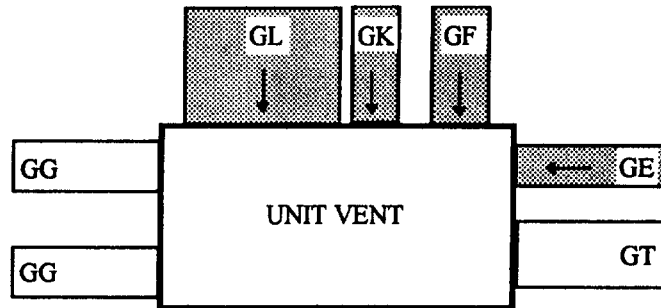


Figure 1 Normal ventilation lineup

**Normal/Mini-Purge Ventilation Lineup**-The Normal/Mini-Purge Ventilation Lineup is a combination of charcoal filtration units GL(Fast), GE,GK, GT and the GF exhaust fan. The Containment Mini-Purge Charcoal Filtration Unit, GT, controls the containment atmosphere during normal plant operations. The design air flow rates are listed in Table 1. The fans normally exhausting to the unit vent during this ventilation lineup are shown by the shaded portions in Figure 2.

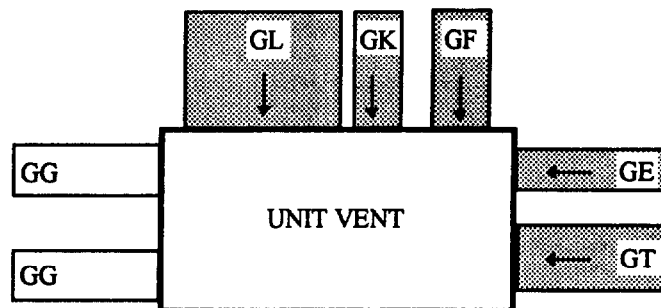


Figure 2 Normal/Mini-Purge ventilation lineup

**FBIS/Mini-Purge Ventilation Lineup**-The FBIS/Mini-Purge Ventilation Lineup is a combination of charcoal filtration units GL(Slow), GE,GK, GT, GG and the GF exhaust fan. This ventilation lineup supports special fuel handling operations for the Fuel Building. The design air flow rates are listed in Table 1. The fans normally exhausting to the unit vent during this ventilation lineup are shown by the shaded portions in Figure 3.

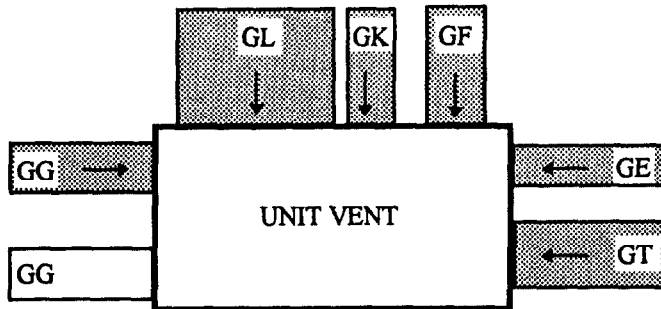


Figure 3 FBIS/Mini-Purge ventilation lineup

**FBIS/CRVIS/Mini-Purge Ventilation Lineup-**The FBIS/CRVIS/Mini-Purge Ventilation Lineup is a combination of charcoal filtration units GL(Slow), GE, GT, GG and the GF exhaust fan. The ventilation lineup supports special control room and fuel building ventilation requirements. The design air flow rates are listed in Table 1. The fans normally exhausting to the unit vent during this ventilation lineup are shown by the shaded portions in the Figure 4.

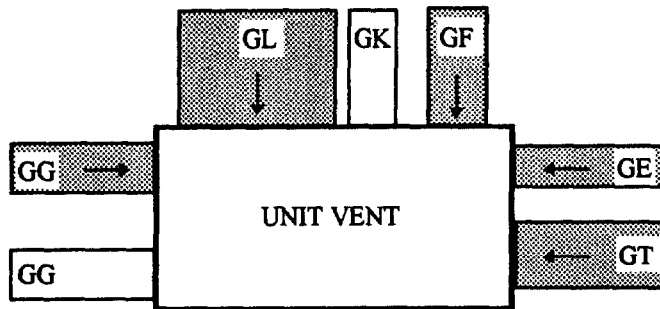


Figure 4 FBIS/CRVIS/Mini-Purge ventilation lineup

**FBIS/CRVIS Ventilation Lineup-**The FBIS/CRVIS Ventilation Lineup is a combination of charcoal filtration units GL(Slow), GE, GG and the GF exhaust fan. The ventilation lineup supports special control room and fuel building ventilation requirements. The design air flow rates are listed in Table 1. The fans normally exhausting to the unit vent during this ventilation lineup are shown by the shaded portions in Figure 5.

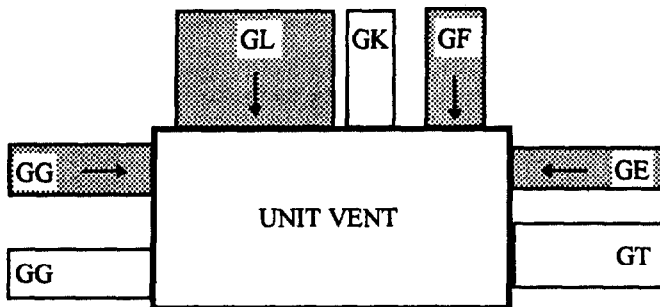


Figure 5 FBIS/CRVIS ventilation lineup

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## Unit Vent Configuration

The unit vent exhaust plenum exits the Auxiliary Building through the roof as shown by Figure 6 only to make two short coupled 90 degree turns before continuing along the Reactor Building containment structure.

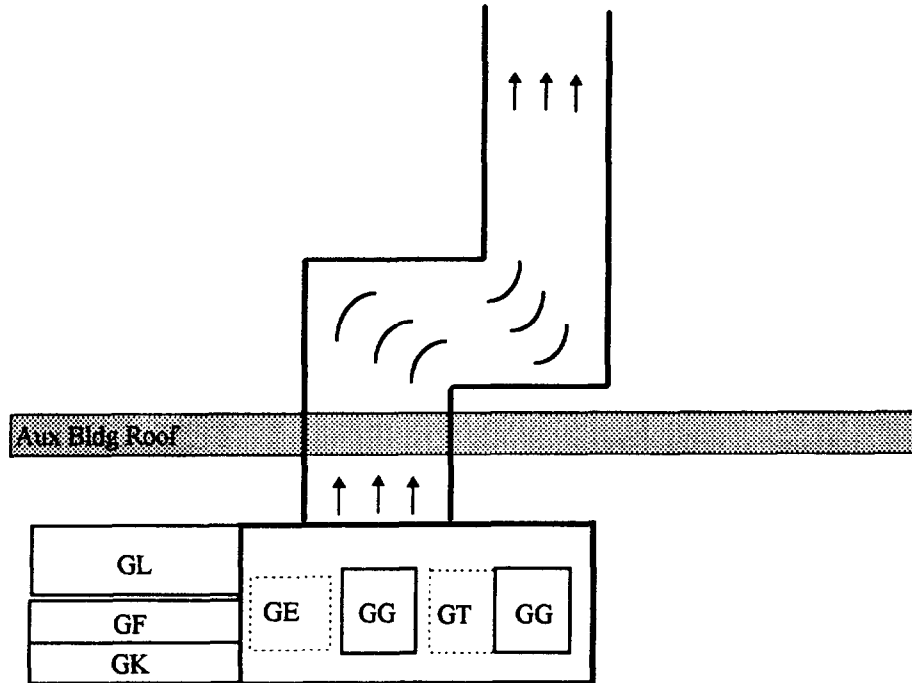


Figure 6 Unit vent exhaust plenum

Figure 7 below shows the physical location of the unit along the Reactor Building containment structure.

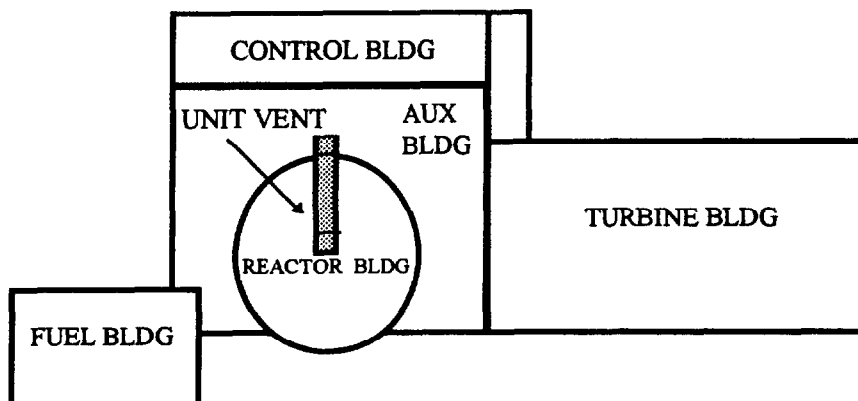


Figure 7 Unit vent location

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Figure 8 below shows a side view of the unit vent ducting along the containment structure.

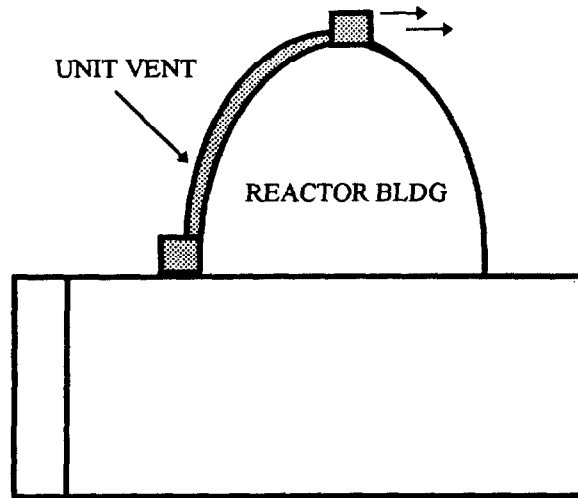


Figure 8 Unit vent physical layout

### IV. HISTORICAL SYSTEM PERFORMANCE

The function of the flow measurement station is to provide a 0-5 VDC signal to the Wide Range Gas Monitor (WRGM) RM-80 microprocessor which in turn displays this flow value (cfm) on the RM-11 control panel. The 0-5 VDC output signal is used by the WRGM to maintain isokinetic flow control, isokinetic nozzle selection and perform effluent calculations. The RM-80 microprocessor data base file determines which set of sampling nozzles, *normal or accident*, to use based upon the flow signal developed by the flow measuring station. If the flow signal is above the isokinetic range (46,930 cfm), the *normal* nozzles will be on-line and conversely for the *accident* nozzles should the flowrate become non-isokinetic. An alarm will sound on the RM-11 panel should this condition exist. Nearly all normal operation flow lineups result in isokinetic flow conditions in the unit vent. Should the unit vent flow measuring equipment become inoperable, installation of conservative substituted flows will be initiated. Precise flow measurement to preclude premature switching of the sampling nozzles or the initiation of manual sampling due to inoperable sampling nozzles has proven to be labor intensive and a *work-around* for the unit operators.

#### October 1994 Testing

Corrective action measures were initiated as early as October 1994 to ensure the unit vent instrumentation components were properly calibrated. Each specific ventilation lineup imparts a different air flow signal for the instrumentation to acquire and condition. Not only did it take several days to affect a complete calibration but the instrumentation exhibited evidence of drift over a period of time.

A pitot tube traverse of the unit vent ducting was performed just upstream of the installed air flow measuring station for each ventilation lineup previously discussed in this paper. This required the erection of a thirty foot scaffolding adjacent to the unit vent ducting. In conjunction with the pitot tube traverse data, RM-11 readings were obtained for comparison. The results of this testing are documented in Table 3. Based upon the data obtained, a single correction factor was applied to the RM-11 readings using linear regression analysis to achieve an RM-11 flow more in line with the pitot tube traverse. This method proved to be precise on only certain areas of the curve.

Table 3 Unit vent measurements without Tracer-Oct 94

VENTILATION LINEUP	PITOT cfm	RM-11 cfm	Difference cfm
NORMAL	50194	63616	13422
NORMAL/MINI PURGE	50394	69014	18620
FBIS/MINI PURGE	44556	55545	10989
FBIS/CRVIS	36813	41639	4826

As can be seen from Table 3, a large difference existed between the RM-11 reading and the pitot tube traverse results for most lineups. Since the unit vent instrumentation was calibrated just prior to the test, the difference between the RM-11 and the pitot tube traverse results was due to the inability to precisely measure the effective duct area or achieve optimum pitot tube orientation in the duct. Figure 9 shows the basic internal construction of the ducting in the area of the flow measuring station. One inch diameter cross-members extend diagonally across the duct every two feet. Additionally, a two inch internal angle iron web is added for strength every two feet as well. The cross-members and the internal web serve to decrease the effective flow area of the duct by approximately 16% as well as set up turbulence throughout the flowstream. These turbulence coupled with an unknown flow area imposes non quantifiable errors for calculating the air flow rate in the duct.

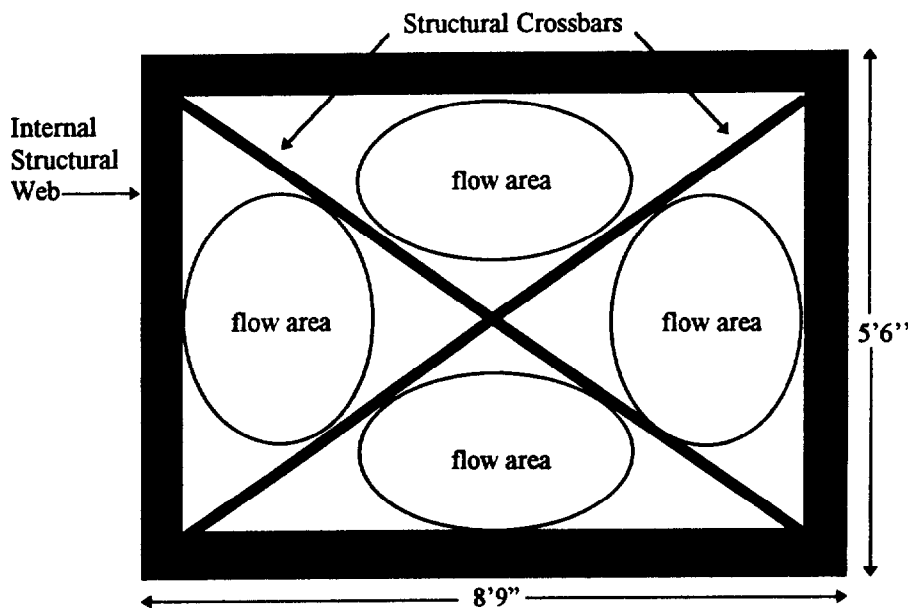


Figure 9 Internal duct construction

### V. TRACER GAS TECHNIQUE

#### Tracer Gas Test Setup

Figure 10 shows the equipment setup to perform the tracer gas test. A 150 ft<sup>3</sup> cylinder of 0.1 % SF<sub>6</sub> injection gas was connected to a flow control valve. The mass flow controller served to finely control the flow of SF<sub>6</sub> injection gas to the injection tube manifold. The injection point for the gas was selected upstream of a fan inlet approximately 50 feet from the unit vent plenum and a total of 90 feet from the sampling point. The injection gas was introduced at three different points across the traverse of the duct with insignificant changes in the results. This established the fact that the gas was sufficiently mixed prior to pulling a sample. The downstream sample was obtained by inserting a sample tube at specific locations in the flowstream and using a pump to retrieve the sample. A list of specific equipment and test precautions is provided in the appendix attached to this paper.

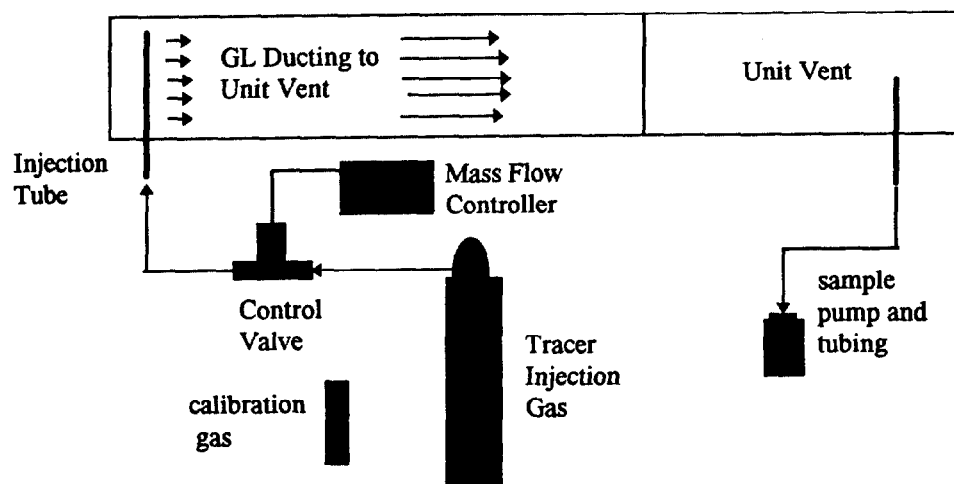


Figure 10 Tracer gas injection setup

#### Preliminary tracer gas testing-October 1995

Tracer gas technology was tested as to the applicability to Callaway Nuclear for potential incorporation not only in unit vent flow measurement but in the routine checks of all systems and components capacities. The technology had been used for other applications within the nuclear industry to check the migration of noble gases. <sup>(6)</sup> Basic test verification was conducted to demonstrate the desired results could be achieved on the unit vent.

By October 1995, procedures were in place and equipment had been obtained to perform a trial test of the Tracer Gas Technique in the Normal Ventilation Lineup. A total of 15 samples were taken in the unit vent as shown on Figure 11. There are seventeen access plugs available for testing. Plug #4, #9 and #14 were selected since they were evenly spaced across the duct area and were representative of the total flow within the unit vent. Five samples were taken in each plug location and the samples were labeled accordingly. The results of the test are given in Table 4.

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Table 4 Preliminary single test-October 1995

VENTILATION LINEUP	PITOT cfm	TRACER cfm	Difference cfm (pitot - tracer)	RM-11 cfm	Difference cfm (RM 11-tracer)
NORMAL	51037	50812	225	54960	4148

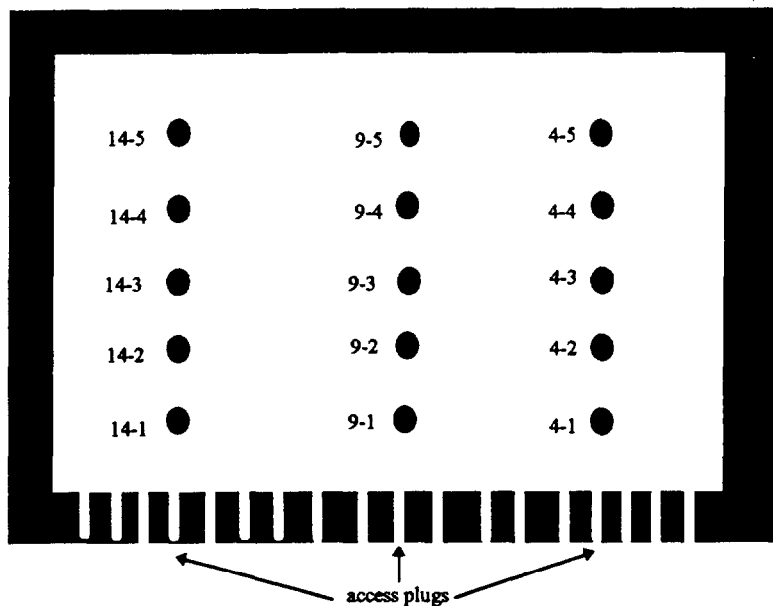


Figure 11 Unit vent sample locations-top view

**Tracer gas test-January 1996**

January 1996 marked to first unit vent test to be performed at Callaway Nuclear with the Tracer Gas Technique. Ventilation systems were placed in standard lineups that would occur during normal plant operation. A pitot tube traverse was performed on the unit vent ducting just upstream of the flow measuring station at 170 points. The ducting area was estimated based upon the outside diameter of the duct minus the area of the internal web and the cross-members. There would still be non quantifiable errors due to the estimation of area as well as effects from turbulence set up by the design. Nevertheless, attempts were made to meticulously measure the velocity pressures in the duct without encountering the effects of any cross-member. Table 5 below shows the results of this test for the standard ventilation lineups.

Based on the data shown in Table 5, it was apparent that the RM-11 instrumentation was out of calibration. Additionally, the observed difference between the pitot traverse and the tracer gas measurement under these same conditions also indicated a greater difference than projected. The test was rescheduled and the instrumentation was to be calibrated just prior to the next test.

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Table 5 Tracer gas test-January 1996

VENTILATION LINEUP	PITOT cfm	TRACER cfm	Difference cfm (pitot-tracer)	RM-11 cfm	Difference cfm (RM-11-tracer)
<b>NORMAL</b>	55881	52027	3854	78200	26173
<b>NORMAL/MINI PURGE</b>	55254	58674	3420	79600	20926
<b>FBIS/MINI PURGE</b>	51480	52614	1134	71800	19186
<b>FBIS/CRVIS/MINI PURGE</b>	48752	43151	5598	66700	23549
<b>FBIS/CRVIS</b>	45186	47247	2061	63000	15753

### Tracer gas test- February 1996

The unit vent instrumentation was calibrated and verified to be operating correctly. The same ventilation lineups used in January 1996 were repeated. Table 6 shows fairly good alignment between the pitot traverse and the tracer measurement for most ventilation lineups. Where differences were greater, this would be attributed to the error in determining the effective flow area. Some disparity existed between the RM-11 and the tracer gas test but to a lesser degree after calibration. This can be attributed to several factors in addition to the calibration of instrumentation. The use of a recorder with much better resolution than that used in any previous test improved the precision of this testing. Another impact was the experience level of the individuals performing the testing and refining the test methodology.

Table 6 Tracer gas test-February 1996

VENTILATION LINEUP	PITOT cfm	TRACER cfm	Difference cfm (pitot-tracer)	RM-11 cfm	Difference cfm (RM 11-tracer)
<b>NORMAL</b>	56984	49187	7797	52400	3213
<b>NORMAL/MINI PURGE</b>	56588	53245	3343	56000	2755
<b>FBIS/MINI PURGE</b>	53547	44409	9138	49600	5191
<b>FBIS/CRVIS/MINI PURGE</b>	46167	44187	1980	45400	1213
<b>FBIS/CRVIS</b>	45978	42748	3230	42600	148

### Test preparation

Several preliminary items were required prior to the actual performance of the test such as determining the injection rate for the SF<sub>6</sub> gas. This is calculated based upon the estimated flow rate of the system based upon the design flow for the ventilation lineup described given in Table 1 and 2 above. Injection rate is a function of the volumetric flowrate of the system and concentration of tracer gas as discussed in Section II, Technical Background, of this paper. The selection of the concentration value is based upon testing experience to render acceptable results when using a mixture of 0.1% or 0.01% SF<sub>6</sub> in nitrogen or air as the tracer gas. Other parameters such as airstream temperature and barometric pressure are required for conversion assistance.

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The equipment was configured as described in Figure 10. Sample retrieval was obtained using heavy duty syringes and needles. Each syringe was clearly marked prior to the test so as not to delay sampling. The syringe with needle attached was exercised prior to sampling to ensure no clogging of the tip occurred.

### Tracer gas injection and sampling

Radio communications were established between the injection gas operator and the sampling station at the unit vent. The injection gas was introduced into the airstream and the sampling station was notified. Injection rate was monitored every 30 seconds. A delay of 1-2 minutes was required prior to taking the first sample to ensure the injection gas mixing had time to stabilize. A sample was taken every 30 seconds until all samples for a given access hole were taken. The sampling tube was moved from access hole #4 to #9 and finally to #14 until all samples were obtained. The samples were transported to the counting station taking care not to depress the syringe prematurely.

### Sample analysis

Before any sample was analyzed, the atmospheric level of SF<sub>6</sub> (if any) in the vicinity of the gas chromatograph was determined. In addition, two calibration gas standards were read to provide the standard response level for calculating the gas concentration in each sample. Each sample was successively injected into the gas chromatograph after the proper stripchart response was achieved.

### Data reduction

The response of each sample is determined by measuring the peak height of each sample. From this value and the standard response level of the calibration gas samples, the concentration of the downstream sample can be determined. From this concentration level and a known tracer gas injection rate, the flowrate of the airstream can be precisely determined.

## VI. CONCLUSIONS

By performing flow tests using the tracer dilution method, *volumetric* flowrate data can be easily obtained in the worst duct configurations. Errors introduced by probe orientation, manometer orientation, state of the thermoanemometer batteries, marginal duct velocities, physical configuration, operator fatigue, vents, grilles, and the condition of the flow are eliminated. Another benefit is that expensive flow probes do not have to be inserted into potentially contaminated ducts. The only equipment that actually goes into the airstream is cheap, disposable tubing. Other benefits include minimizing the number of penetrations that must be made in a duct thereby reducing the amount of inleakage or outleakage induced by these holes as well as creating less structural weakening. Flow measurements by the tracer dilution method are more rapid than those by conventional techniques thereby decreasing the time required in high radiation areas in keeping with ALARA considerations of the Health Physics staff.

Since the flow data are not dependent on operator skill and the other physical problems associated with the flow measurement process, more reliable, precise and defensible test data can be generated. These flow rate data can be directly compared to one another to assess the effect of various operational configurations. In-place flow measurement instruments can be directly and wholly calibrated with real volumetric flows using real time data. This provides Health Physics personnel with reliable flowrates to calculate precise radioactive release data. The technique can also provide operations personnel with precise air flow monitoring information, and systems engineering personnel with flow balancing data that are more reliable than those obtained by conventional techniques.

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### Appendix A. Equipment list and test precautions

#### Equipment list

- Electron capture gas chromatograph with SF<sub>6</sub> oven installed
- Mass flow meter
- Mass flow meter, extension transducer
- 30 ft<sup>3</sup> cylinder SF<sub>6</sub>, 1 ppb calibration gas with regulator
- 30 ft<sup>3</sup> cylinder SF<sub>6</sub>, 10 ppb calibration gas with regulator
- 150 ft<sup>3</sup> cylinder .1% SF<sub>6</sub> injection gas with regulator
- 150 ft<sup>3</sup> cylinder .01% SF<sub>6</sub> injection gas with regulator
- Sample pump with tubing and septa
- Tracer gas injection manifold and tubing
- Tracer gas sample retrieval tube and tubing
- Needles-(23 X 1")
- Syringes-(12-20 cc)
- Spare septum
- External recorder

#### Test precautions

- An electron capture gas chromatograph was used to measure the samples obtained. This same instrument was used to perform bypass leakage test on charcoal filter beds however, the oven column was replaced with one compatible with SF<sub>6</sub> gas. Approximately 24 hours is required for the unit to properly warm-up.
- Cross contamination of the SF<sub>6</sub> gas within hoses and regulators is a constant prevention requirement.
- Background samples of the surrounding atmosphere where the samples are being analyzed is required for pre and post test validation.
- Calibration gas samples are analyzed prior to sample counting.
- Septum on the Calibration Gas tank and sample pump should be periodically changed out.
- New syringes should be used for each sample series/location to preclude any cross contamination.
- A high resolution printer with an integrator is best for a more precise reading.
- Care should be taken to use needles on the syringes that do not clog when the septum is penetrated.
- This test is currently limited to areas where the exhaust from the airstream does not communicate with the compartment where injection is taking place.
- If air flow is < 5,000 cfm, the .01% injection gas should be used.
- Samples should be pulled from the downstream at least every 30 seconds during the injection phase.
- Purging of calibration gas through the regulator prior to taking a calibration sample is essential.
- Samples should not be injected into the gas chromatograph more frequently than 3 minutes apart.
- If replacement of the sample oven is performed on site, ensure the oven snaps fully in place to prevent contamination of the system.
- The holes in the injection tube should point into the direction of flow.
- Only polyethylene or nylon tubing is recommended for use with SF<sub>6</sub>.
- All SF<sub>6</sub> containing cylinders and tubing should be stored in a separate cabinet, to prevent cross contamination.

**DISCUSSION**

**RICKETTS:** I am wondering if you addressed the compatibility of your choice for a test gas with the proper operation of iodine adsorption filters?

**ADAMS:** I am not sure I am qualified to answer that. Seeing that the trace gas was inert and non-toxic and that the same tracer gas has been used in other industries, we felt comfortable in doing likewise. Especially because it was not ozone depleting. In fact, I made some calls to some of the charcoal vendors prior to doing the test, and it was their determination that it did not affect the carbon or the HEPA filter tests. The other thing we did to make sure it would have less effect on the filters, was to inject it downstream of the charcoal filtration units. The real answer to your question, I think, is that we injected downstream of the adsorber units and upstream of a fan to get proper mixing.

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DEVELOPMENT OF REAL TIME DETECTOR FOR FLUORESCENT PARTICLES  
C. PREVOST\*, A. SEIGNEUR\*\*, J. VENDEL\*

\*Institut de Protection et de Sûreté Nucléaire  
Département de Prévention et d'Etude des Accidents - DPEA/SERAC  
CEA/Saclay, Bâtiment 383 - 91191 GIF-SUR-YVETTE Cedex, France  
\*\*LETI (Direction des Techniques Avancées)  
Département d'Electronique et d'Instrumentation  
CEA/Saclay, Bâtiment 528 - 91191 GIF-SUR-YVETTE Cedex, France

**ABSTRACT**

Aerosols tagged by a fluorescent dye are a worthwhile tool within the framework of ventilation and filtration studies. The detection in real time of a specific particulate tracer allows characterization of ventilation behaviour such as air change rate, the determination of a good or bad mixing zone and transfer coefficient, or the determination of the decontamination factor for High Efficiency Particulate Air (HEPA) filters.

Generally, these tests require specific aerosols in order to get rid of the atmospheric aerosol background.

Until now the principle of fluorescent aerosol concentration measuring has only allowed an integral response with a time lag by means of sampling on filters and a fluorimetric analysis after specific conditioning of these filters.

To make it possible to detect a specific tracer in real time, a new monitor has been developed to count these particles on the following basis :

- ⇒ fluorescent particles pass through a sampling nozzle to a specially designed measurement chamber ; ducting flow rate is used to contain the test aerosol in the sample flow rate at the nozzle outlet ;
- ⇒ interception of this stream with a laser beam allows aerosol detection and characterization, particle by particle ;
- ⇒ optical signals are produced by fluorescence emission of glycerol particles tagged with fluorescein sodium when they are excited by a laser beam emitting on a suitable wavelength (ionized argon laser) ; these signals are transmitted to a photodetector by a patented optical arrangement.

The paper presents the detection concept and the experimental device. The main results achieved in this study show the feasibility of such a technique providing aerosol tracer detection in real time.

## **I. INTRODUCTION**

Aerosols artificially tagged with a fluorescent substance are a powerful tool for the specific follow-up of a polluting agent in an atmosphere naturally free from such particles. Most tests carried out within the framework of research into air contamination, confinement or else purification act on these aerosols both in some industrial fields and in specialist laboratories.

The detection of such particles can thus help in understanding the various complex phenomena produced inside premises and thus enable them to be controlled. In fact, the combination of ventilation and pollutant is a major concern when designing ventilation plant and making it comply with the relevant standards.

Therefore, the follow-up in real time of the transfer of contamination from a harmless polluting agent injected instead of a source of contamination enables the location of detection markers to be optimized and the rate of homogenization of the pollutant in the premises determined. Optimization of the rate of renewal is then conceivable when making a "map" of the concentration of the pollutant inside the premises. This reveals the presence of a "dead zone", the site of pollutant accumulation, and thus enables it to be eliminated.

This particle tracing technique can also be used in designwork concerning in particular dynamic confinement, the validation of aeraulic design calculation codes, the modelling of flows of air loaded with particles or even the qualification of the filtering equipment.

The principle of measuring such specific aerosols previously only allowed for integral measurement of their concentration with a time lag through taking samples on filters, and then preparing the samples for analysis by fluorimetry.

As has previously been explained, the need for following up the concentration of a tracer in the air in real time has led us to show the feasibility of a new technique for detecting fluorescent aerosols.

In this paper, we explain the principle of detection which we apply, the experimental device made, and the main results achieved during our research.

## **II. PRINCIPLE OF MEASUREMENT**

The main objective of our research lies in designing a technique for characterizing and counting aerosols, based on detection of their fluorescence, in real time [4].

When a fluorescent fluid aerosol intercepts a beam of monochromatic light of a wavelength included within its spectrum of absorption, it sends back a light of a higher wavelength due to the fluorescence.

With constant lighting, its intensity is in proportion to the amount of fluorescent substance contained in the particle.

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It's a question of collecting this fluorescent light using a suitable optical system on a photosensitive detector in order to quantify the fluorophore content [5].

$$Q_f = k \cdot P_L \cdot \lambda_a \cdot \Phi \cdot \varepsilon \cdot N_f \cdot t$$

where  $Q_f$  = amount of fluorescence (number of photons)  
 $k$  = proportionality factor  
 $P_L$  = power of the laser beam (Watt)  
 $\lambda_a$  = absorption wavelength (nm)  
 $\Phi$  = quantum yield of fluorescence  
 $\varepsilon$  = molar absorption coefficient (L/mol.cm)  
 $t$  = time during particle remains in the light beam (s)

An aerodynamic focusing device aligns the particles behind each other. Fine focusing of the excitation light enables lighting as a particle moves.

Using a laser source of light facilitates concentration of the excitation power of the beam on a narrow spot of light.

The volume of measurement can be estimated at about  $3 \cdot 10^{-6} \text{ cm}^3$  ; the maximum concentration which can be detected with a rate of coincidence below 5% must not exceed  $10^4$  particles/cm<sup>3</sup>.

### III. MEASUREMENT CELL AND ASSOCIATED OPTICS

The measurement cell essentially comprises :

→ a sampling system (Figure 1) in brass with a low surface finish index for the inner surface, ending in a small diameter nozzle ( $d_{bp} = 0.6 \text{ mm}$ ) which allows the aerosols to be routed into the measurement chamber within a centered jet.

A ducting air system improves the aerodynamic centering of the output jet in the same time as it prevents any droplets being deposited on the walls of the collector optics.

→ a measurement chamber (Figure 2), the special geometry of which enables the maximum fluorescent light emitted to be collected. The fluorescence collection performance is in the region of 15 %. This collector optics is covered by a patent [1]. Its rear face, centered on the jet, is metallized which allows the light emitted to the rear to be returned to the place of emission where it's added to the flow emitted forward.

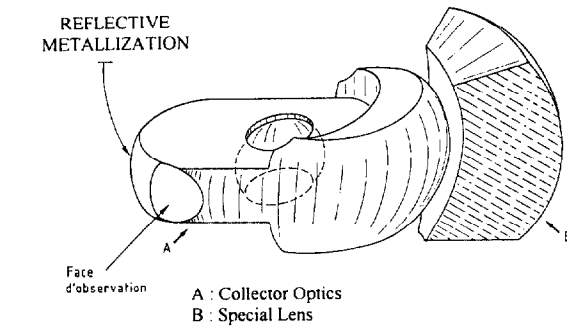
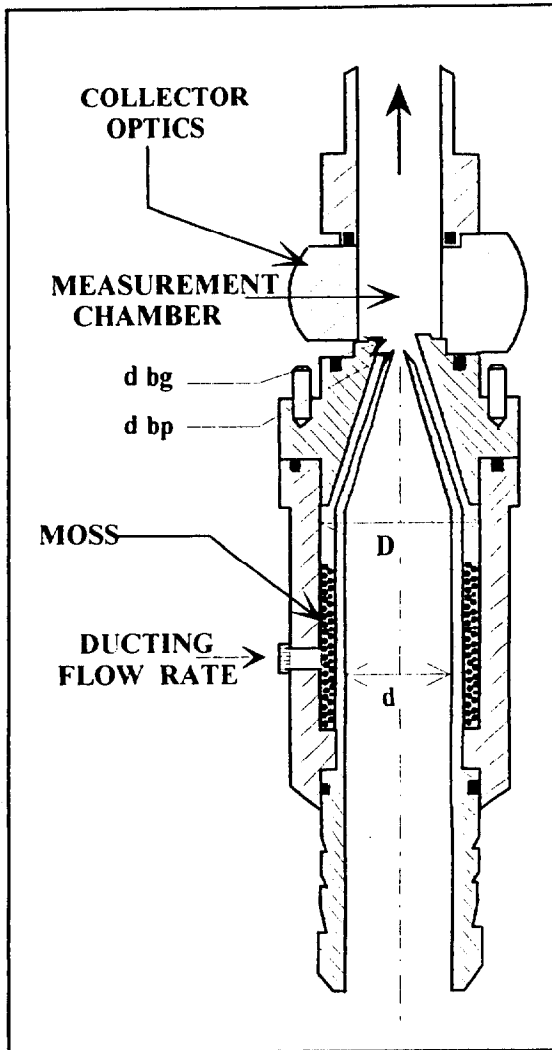


Figure 2 : Measurement chamber

Lens B catches the flow of light and sends it all back to the rest of the optic arrangement.

Figure 1 : Sampling system

Specification of the nozzle :  $D = 10.6 \text{ mm}$   
 $d = 6.0 \text{ mm}$   
 $d_{bp} = 0.6 \text{ mm}$   
 $d_{bg} = 2.6 \text{ mm}$

#### IV. CHOICE OF FLUOROPHORE

The fluorophore selected for carrying out our tests is soda fluorescein ( $C_{20}H_{10}O_5Na_2$ ) ; it is an excellent product to use in tracing work, essentially because it's non toxic in the usual concentrations and also because it is soluble in water and in glycerol, often used when producing calibrated droplets. Further, it's used in a standardized measurement method (NF Standard X 44.011) for the test of HEPA filters efficiency. This tracer has very good fluorescence properties in solution in glycerol (quantum performance evaluated at 92% under the best conditions) and can easily be detected by any fluorimetric technique.

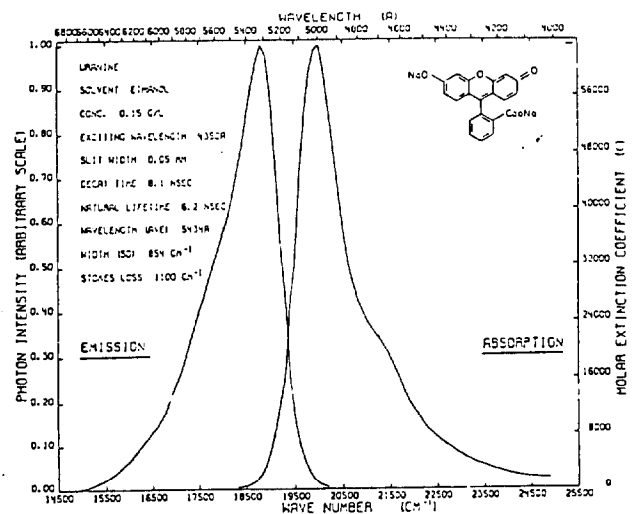
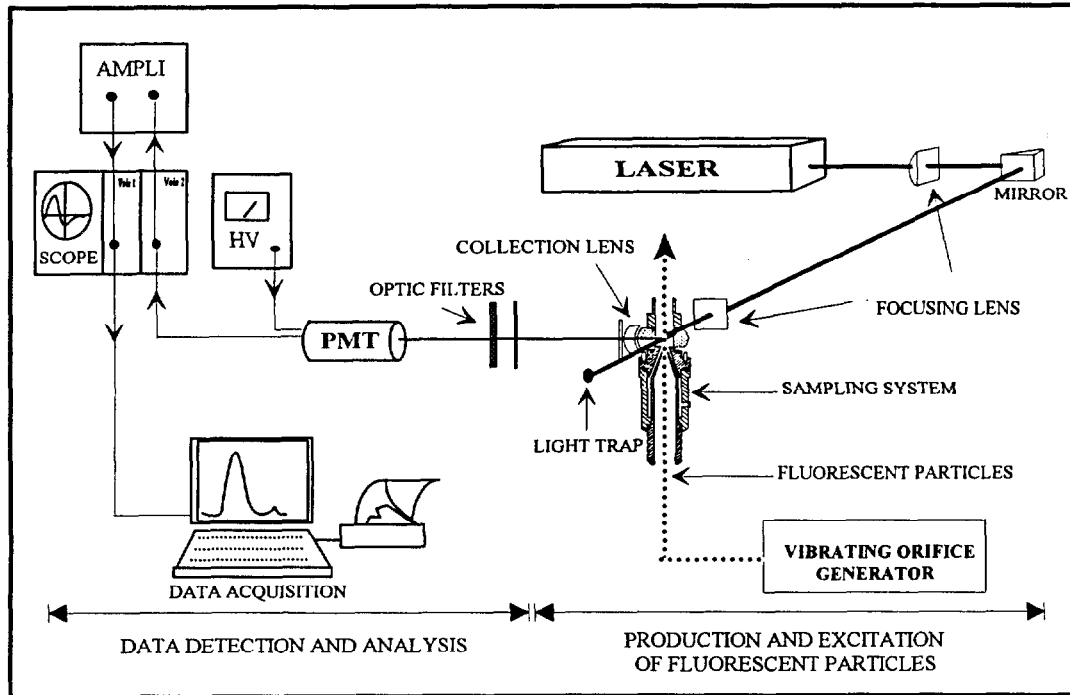


Figure 3 : Spectrum of soda fluorescein absorption and emission [3].

**V. SETUP OF THE EXPERIMENT**

Two main sections can illustrate the principle of operation of our arrangement (Figure 4) :



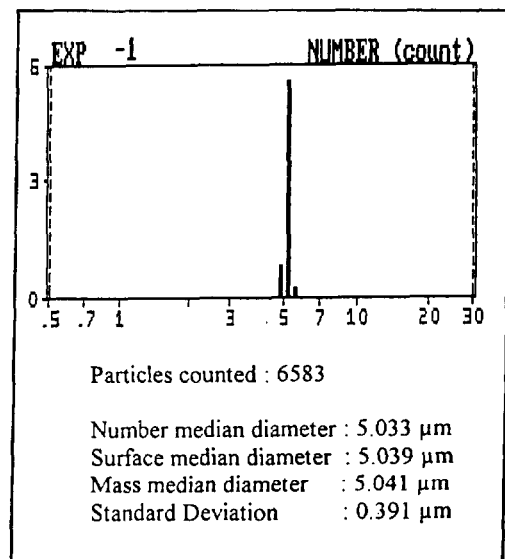
**Figure 4** : Overall view of the experimental device

**V.1. Production of droplets**

A vibrating orifice generator (TSI Inc., Model 3050) provides for producing monodispersed droplets of glycerol tagged with soda fluorescein at concentrations of 1 and 10 g/L.

The range of diameters of aerosols produced extends from 1 to 10  $\mu\text{m}$  (aerodynamic diameter), i.e. quantities of fluorophore contained per particle between  $3 \cdot 10^{-16}$  and  $3 \cdot 10^{-12}$  g/particle inclusive i.e.  $6 \cdot 10^5$  to  $6 \cdot 10^9$  molecules/particle.

It has been possible to check the particle size features of the test aerosols by means of an APS (Aerodynamic Particle Sizer, Model 3310, TSI Inc.). The spectrum illustrated in Figure 5 is found when producing droplets with a diameter of 5  $\mu\text{m}$ .



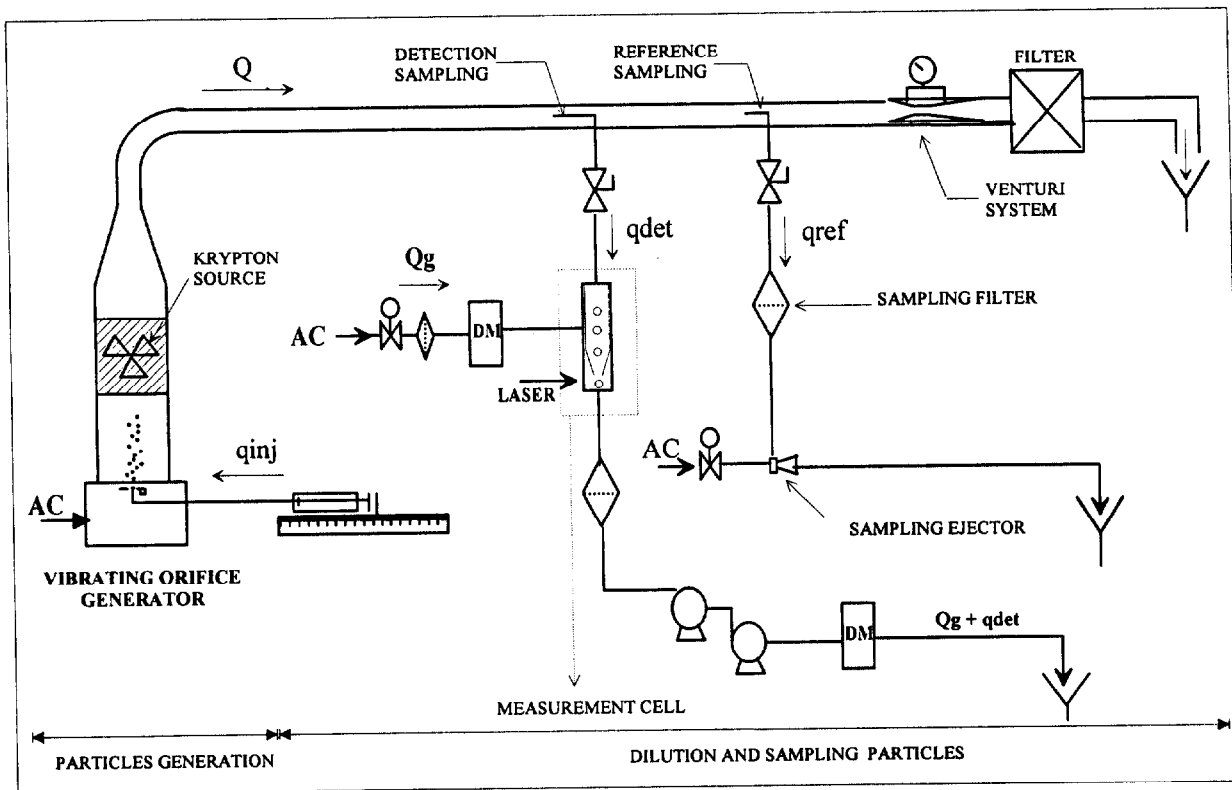
**Figure 5** : Results from APS System

**V.2. Dilution and sampling**

The reference sample is delivered by an ejector with the flow rate controlled by a calibrated sonic orifice (SAPELEM) at the required rate (5 L/min.).

The total sample (sum of ducting and sampling flow rates) is delivered by two vane pumps mounted in series (RIETSCHLE).

The ducting deliveries and total sampling are checked by calibrated mass flowmeters (BROOKS, Models 5851) in the range of outputs used ; the difference corresponds to the delivery of particles taken.



**Figure 6 : Aeraulic diagram for the counter qualification**

**KEYS:**

- $Q$  = dilution output of aerosols in the main line ( $m^3/h$ )
- $Q_g$  = delivery of ducting air in the measuring cell (L/min)
- $q_{det}$  = sample flow rate in the detection cell (L/min)
- $q_{ref}$  = sample flow rate on the reference filter (L/min)
- $q_{inj}$  = injection delivery of fluorescent solution into the generator (mL/min)
- DM = mass flowmeter
- AC = compressed air

**VI. DETECTION OF AEROSOLS**

**VI.1. Laser source**

The intention to make a device for measuring high sensitivity has led us to adopt a laser as the source of very bright light, monochromatic, easy to focus and, moreover, stable.

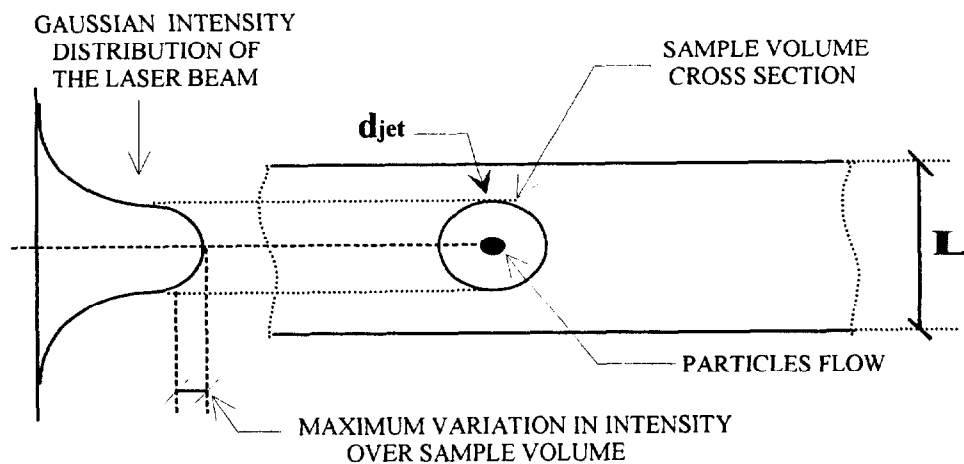
So we use an ionized argon laser (SPECTRA PHYSICS, Series 2000) which emits on wavelength 488 nm in accordance with the absorption wavelength of fluorescein sodium. The power is intentionally limited from 10 to 300 mW. It supplies a beam on TEM<sub>00</sub> mode, i.e. its profile of intensity is Gaussian.

**VI.2. Focusing the beam**

Figure 7 shows the distribution of the intensity of the laser beam at the level of the particles loaded air jet.

The focusing device is large in front of the diameter of the sample stream ; the intensity of the particle excitation is thus uniform, even for particle positions which fluctuate slightly in the lighted area.

The combination of special lenses enables the beam to take on the appearance of a sheet of light at the level of the flow of particles, the focusing thickness of which is fine so as only to illuminate a single particle going through (see Principle of Measurement).



**Figure 7 :** Distribution of the laser intensity at the level of the jet as it leaves the nozzle.

**VI.3. Chromatic filtering on the fluorescence light analysis channel**

The association in series of an interference filter (CORION, LL500) and a colored filter (OG515) discriminates well between the wavelengths transmitted in comparison with the excitation light ; only fluorescence signals coming from the particles reach the detector.

Therefore, we clear the parasite light reflected mainly by the walls of the cell and the diffusion light also produced by the particles.

**VI.4. Detection and collection of data**

A photomultiplier (HAMAMATSU, Type R928) collects the fluorescence photons and converts them, depending on the performance of the photocathode and its gain, into electric current ; the signal leaving this detector can be observed directly on one of the two channels of an oscilloscope before it is transmitted to the amplifier (SCHLUMBERGER, Type 7129) where it is formed and amplified.

The outlet from the amplifier is connected to the second channel of the oscilloscope mounted in parallel with the data collection line.

The data collection line consists of a computer (PC 386) completed with an interface card, type Accuspec NaI (CANBERRA) ; the coding is done on 2048 channels.

We thus have a high performance pulse analyzer which reconstitutes the spectrum of quantities of fluorescent photons detected ; it delivers histograms worked out by adding up the number of events filed according to their amplitude.

This arrangement allows us to follow in real time the detection of fluorescence signals emitted by the particles, simultaneously on the dial of the oscilloscope and on the computer. It is then easy correctly to adjust the focusing of the laser beam on the jet of particles by adjusting the micrometric settings of the cell (XY movement). The interaction between the laser beam and the particle flow is thus optimized by finding the maximum amplitude signal which offers the best resolution.

**VII. MAIN RESULTS**

**VII.1. Estimating the rate of retention in the measurement cell**

One of the main stages in the qualification of our device is to validate that laser detection is representative in relation to a reference sampling made in parallel. To do this, we have estimated the rate of retention "T" of the droplets right inside the device.

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Three series of ten tests with simultaneous sampling reference and downstream of the laser detection device (Figure 6) carried out for each particle diameter between 1 and 10  $\mu\text{m}$  inclusive, enable us to draw a retention curve characteristic of the device (Figure 8) after conventional fluorimetric analysis of the sampling filters.

The bars associated with the results correspond to uncertainty over the results, given with 95% probability.

$$T = \frac{C_{\text{ref}} - C_{\text{det}}}{C_{\text{ref}}}$$

where  $C_{\text{ref}}$  = reference concentration (g/L)  
 $C_{\text{det}}$  = concentration (sampling) measured downstream of the device (g/L)

The characteristic spectrum found during the detection of fluorescent particles is illustrated by few results recorded when detecting particles of different diameters (Figure 9).

The scale of the abscissa is in direct proportion to the amount of fluorescein measured per particle counted off, i.e. to the volume of the particle for a constant fluorescein concentration in the solvent (glycerol).

As far as the scale of the ordinates is concerned, it totals the number of particles detected per unit of time.

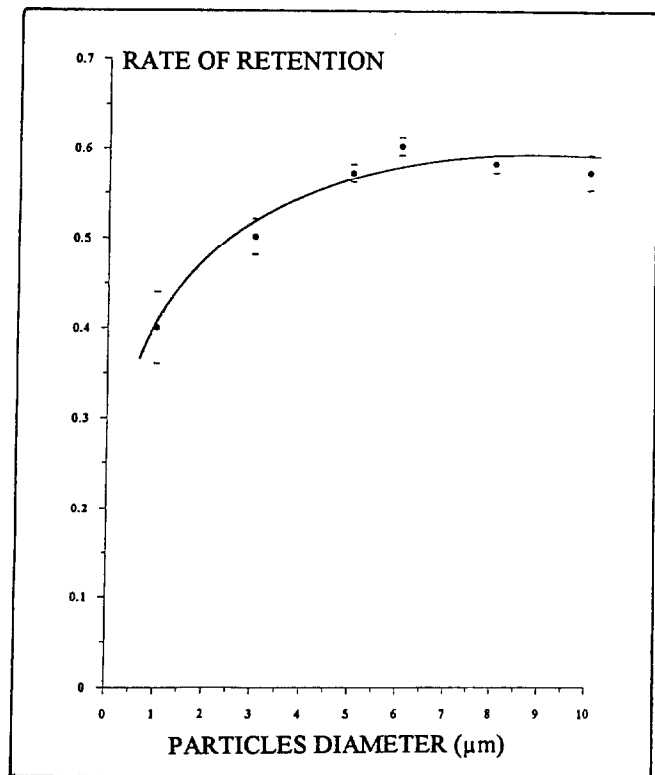
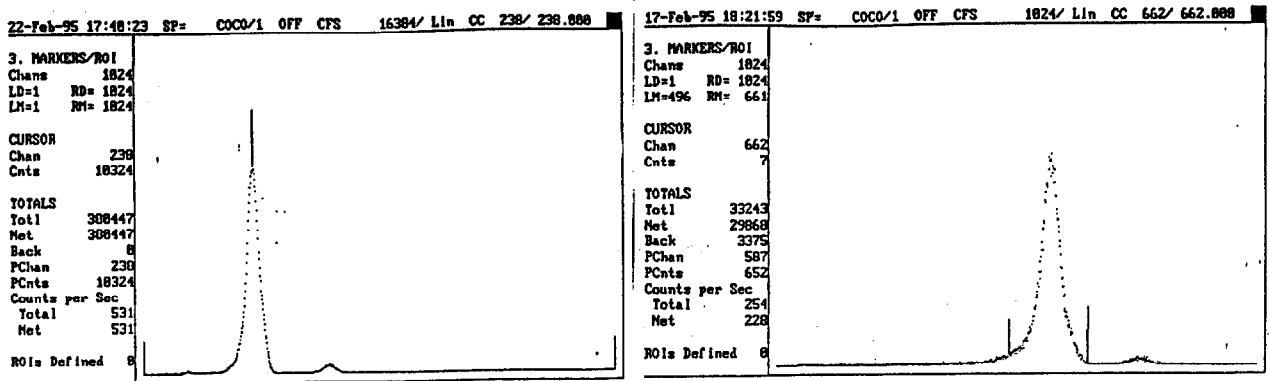


Figure 8 : Rate of retention versus particle diameter.

**VII.2. Analysis of the signal given**

Under good test conditions, i.e. optimum focusing of the laser beam on the jet of particles and a population of monodispersed droplets, the histogram found takes on a gaussian pace centered on the average value of the intensity of fluorescence measured.

Integration under the peak allows for determining the total number of particles detected during the analysis time.



dae = 5 μm

dae = 10 μm

**Figure 9** : Examples of spectra recorded

**VII.3. Effect of different parameters**

Several parameters can change the rate of the spectra recorded for a given diameter of particle with a fixed fluorophore concentration ; they are mainly :

- power of the laser beam (therefore of the excitation lighting) ;
- high voltage applied at the photomultiplier (PMT) ;
- time during particle remains in the laser beam ;
  
- alignment of the excitation beam on the jet of particles ;
- centering of the flow of particles (action of the ducting air flow rate).

The first three parameters quoted act essentially on the limit of detection of the device ; as for the other two, they can entail the spectrum being wrongly interpreted when they are incorrect.

Figures 10 and 11 show that the figures for the power provided by the laser and for the high voltage applied at the PMT must be optimized to maintain the linearity of the detection signal with the fluorescence of standard particles.

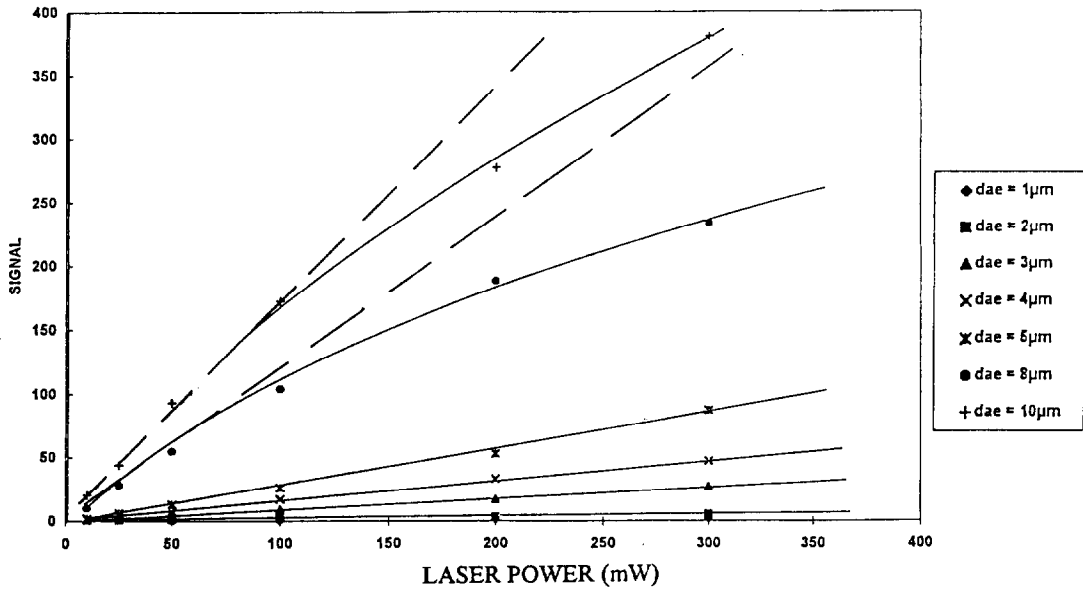


Figure 10 : Effect of the laser power on the fluorescence signal.

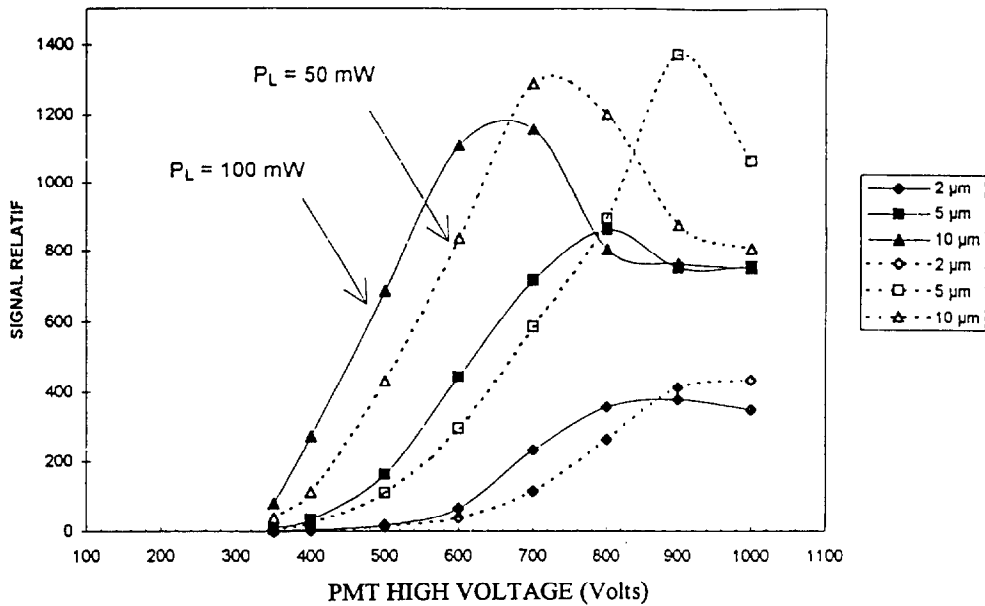


Figure 11 : Effect of the High Voltage of the PMT on the fluorescence signal

#### VII.4. Calibration test

A calibration curve can be drawn from the time one is working with all different optimized and fixed parameters.

The fluorescence signals emitted depend on the weight of fluorophore contained per particle, this is shown in Figure 12.

However, beyond certain conditions concerning laser power, high voltage of the PMT, size of droplets or else the fluorescein concentration, we encounter problems both with the limit of detection and with electronic saturation of the system.

In fact, when any of these various parameters increase, the linearity of the signal is only maintained in a certain field.

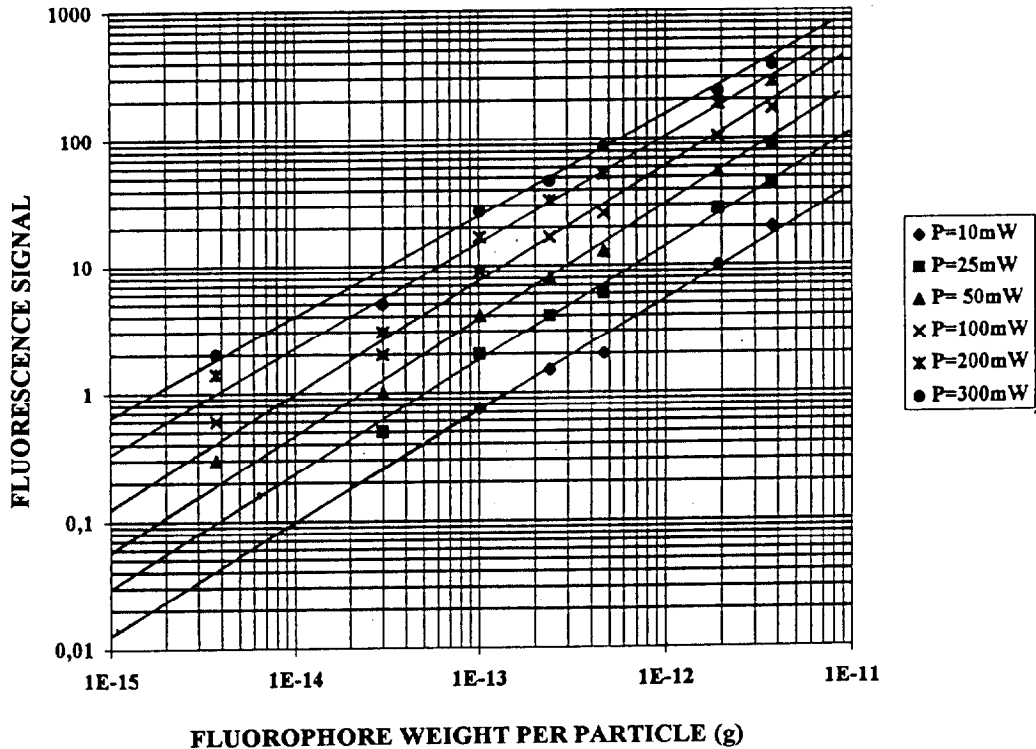


Figure 12 : Fluorescence signal versus weight of fluorophore contained per particle.

### VII.5. Threshold of detection

The detection threshold of the device depends on the noise disturbing the signal for a fixed high voltage and laser power.

Thus, the detection threshold characteristic of our device is expressed as the lowest amount of fluorophore which can be detected. It's about  $6 \cdot 10^6$  molecules per particle ( $10^{-15}$  g of soda fluorescein) detected at a laser power of 50 mW .

This limit value of detection can also be expressed in terms of the minimum particle diameter which can be measured, variable in accordance with the fluorophore concentration used.

### VII.6. Comparison of results with conventional fluorimetry

Various tests have enabled us to compare the two different systems by estimating the mean deviation between the results achieved by laser detection with those achieved with conventional fluorimetry when measuring an identical particulate concentration, for different droplet diameters.

We find results which are quite closed between the two techniques since the difference is below 10% in all instances in which the spectra obtained can be used (separation of the fluorescence signal with that corresponding to the electronic or optic noise).

The parity diagram (Figure 13) illustrates that the laser detection is a reliable method of particles counting versus the conventional fluorimetry method.

The analysis times using the laser counting method are reduced and depend only on the particulate concentration present, for a constant delivery : it is desirable to wait for detection for a minimum of  $10^4$  events in total in order to reach satisfactory counting statistics (2 % accuracy) which, depending on the concentration measured, can involve counting times of less than one minute.

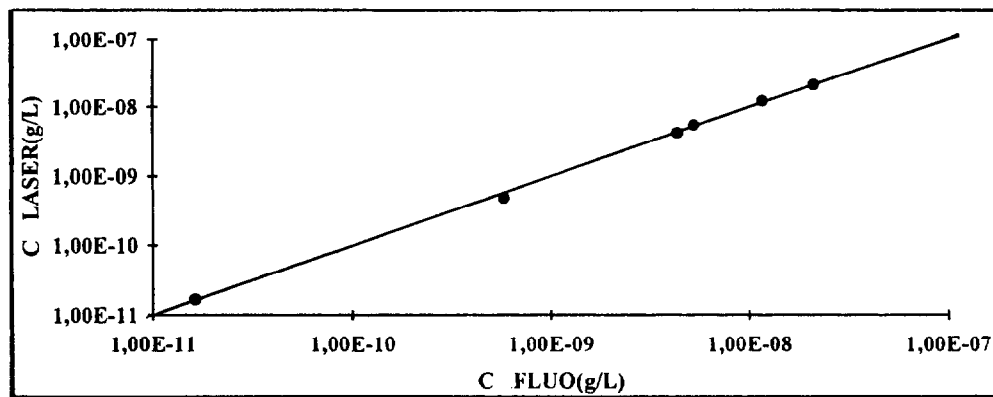


Figure 13 : Parity diagram

where  $C_{LASER}$  = results from laser detection (g/L)  
 $C_{FLUO}$  = results from conventional fluorimetry (g/L)

Our device allows great selectivity of detection since it only counts fluorescent particles. Spectra which have nil counting rates are found when samples are taken direct in the ambient air.

## VIII. CONCLUSIONS AND PROSPECTS

Using a suitable laser source associated with high yield collection optics contributes to making a high performance fluorescent aerosol detection device for follow-up in real time and continuously of a test particulate concentration injected into a room or test rig.

Through the data collected the technique allows direct access to particle counting rates while controlling the particle size of the aerosols produced.

Estimating the total weight of fluorophore detected is facilitated for monodispersed particle analysis as soon as the content of each of them is known.

The limitations of this technique are directly connected with the noise level (optics and electronics) produced by the device as well as by the physical and chemical properties of the fluorophore used.

Manufacturing in the course of time a portable unit for taking measurements on site, calls for a technology which is compact and light and that essentially limits the size of the laser source used. In spite of the fact that there are ionized argon lasers on the market producing powers in the region of 20 to 100 mW, it would be wise to consider new excitable dyes in the red to permit the use of laser diodes which are very small and inexpensive. However, the dyes used must be quite harmless to human beings, which considerably limits the choice. In spite of our various researchs, only one dye is appropriate, the allophycocyanin that is a very costly product.

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## 24th DOE/NRC NUCLEAR AIR CLEANING AND TREATMENT CONFERENCE

### ACCURACY IMPROVEMENT IN LEAK DETECTION OF CHARCOAL ADSORBERS BY HALIDE PULSE INTEGRATION METHOD.

Bela J. Kovach, Eric M. Banks  
NUCON International, Inc.  
Columbus, Ohio

#### Abstract

Due to the phaseout of the supply of R-11, which is used as a charcoal adsorber leak-testing agent, several new substitutes have been suggested and tested. <sup>(2)</sup> Pulse testing using agents with higher boiling points produced longer response times (due to prolonged evaporation and dispersion times). This longer evaporation time alters the pulse shape and lowers the peak concentration. Since the dispersion and evaporation time under different ambient condition are unpredictable, the peak concentration becomes unpredictable as well. One way to eliminate this unpredictability is to determine the area under the curve (of concentration versus time) after test-agent injection rather than the peak concentration (height). This value should be independent of the injection time and evaporation rate as long as the volume of the test agent injected remains constant.

Thus, tests were performed with a constant volume injection of test agent but with different injection times and evaporation rates. The area under the curve of concentration versus time was then compared with the peak concentration for each injection.

#### Introduction

Testing with a pulse of challenge agent has an advantage over testing with continuous injection, as described by several authors. <sup>(1,3,4)</sup> During pulse mode leak testing, the leak is calculated from the ratio of the pulse height detected simultaneously on the downstream and upstream side of the adsorber bed. This calculation is correct as long as the referenced two detectors have identical characteristics and they are working in their linear range. Several institutions have pushed the permissible leak threshold level from  $10^{-2}$  % to  $10^{-4}$  %. This is a new challenge for the detectors, since there is no sensor with linear characteristics over 6-7 orders of magnitude. Therefore, such tests are performed by comparison of a calculated upstream concentration with the detected highest peak concentration detected downstream of the adsorber. The comparison of a calculated concentration value on the upstream side of the adsorber to a detected peak height on the downstream side can be a significant source of error, varying with ambient conditions.

However, if the area under the curve of concentration versus time is used rather than the peak concentration (with constant volume injection of test agent), then this source of error can be reduced. Tests were performed to confirm this hypothesis.

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### Test and Equipment Description

A test was performed on a full size air cleaning unit at the NUCON® facilities to check the validity of the concept. The purpose was to show that no matter what the geometric shape of the pulse, the integrated value would provide an accurate measurement of the quantity of challenge agent.

The challenge agent was injected at the inlet of a 6,000 scfm. air cleaning unit in which the air flow is provided by a downstream fan. A long length of duct (approximately 30 ft) and three stages of filtration (mist eliminator, pre-filter and HEPA filter) provided enough time for complete evaporation and dispersion. A syringe was used to dispense 0.1 cc of 1-Bromobutane liquid onto a hot plate. Injection time varied from 2 seconds to 155 seconds.

A NUCON® F-1000 BBD detector was used to measure the concentration continuously. This instrument has a threshold sensitivity of 1 VPPB and the response is linear over the range of 1 - 450 VPPB. A single point sample was taken and pulled through the instrument by the internally mounted pump. A YOKOGAWA analog recorder recorded the concentration curves and a Hewlett-Packard integrator was used to analyze the output signal from the detector. The points on PPB curve represent the maximum concentrations recorded while the points on the integral curve are proportional to the mass of injected 1-Bromobutane.

### Results and Interpretation

The test results shown on Figure 1 proved that if a constant volume of 1-Bromobutane is injected in the air stream, an open diode continuous halide detector will detect a constant integral value with less than  $\pm 10\%$  error although the injection and dispersion time is varied between 2 second and 155 seconds. With pulses shorter than 2 second, larger error is expected, since the open diode response time is in the 1 second range.

### Conclusion

1. When using a single downstream continuous Halide detector with calculated upstream injection, the integral value under the detected curve should be used for leak calculation rather than the highest peak concentration.
2. If the mass (or volume) of injected halide is proportional to the air flow rate, a single downstream continuous detector using pulse integration will display the leakage as ratio of masses, even if the pulse height and shape are varied by the injection time. Using this method, the detector can be calibrated to display the leak rate, for fast, easy and accurate operation.

### Acknowledgment

The authors wish to thank Miss Luanne Armstrong as well as Mr. Gyorgy Kovacs, Mr. Joseph C. Enneking and W. Peter Freeman for technical support during the experiments and interpretation of the results.

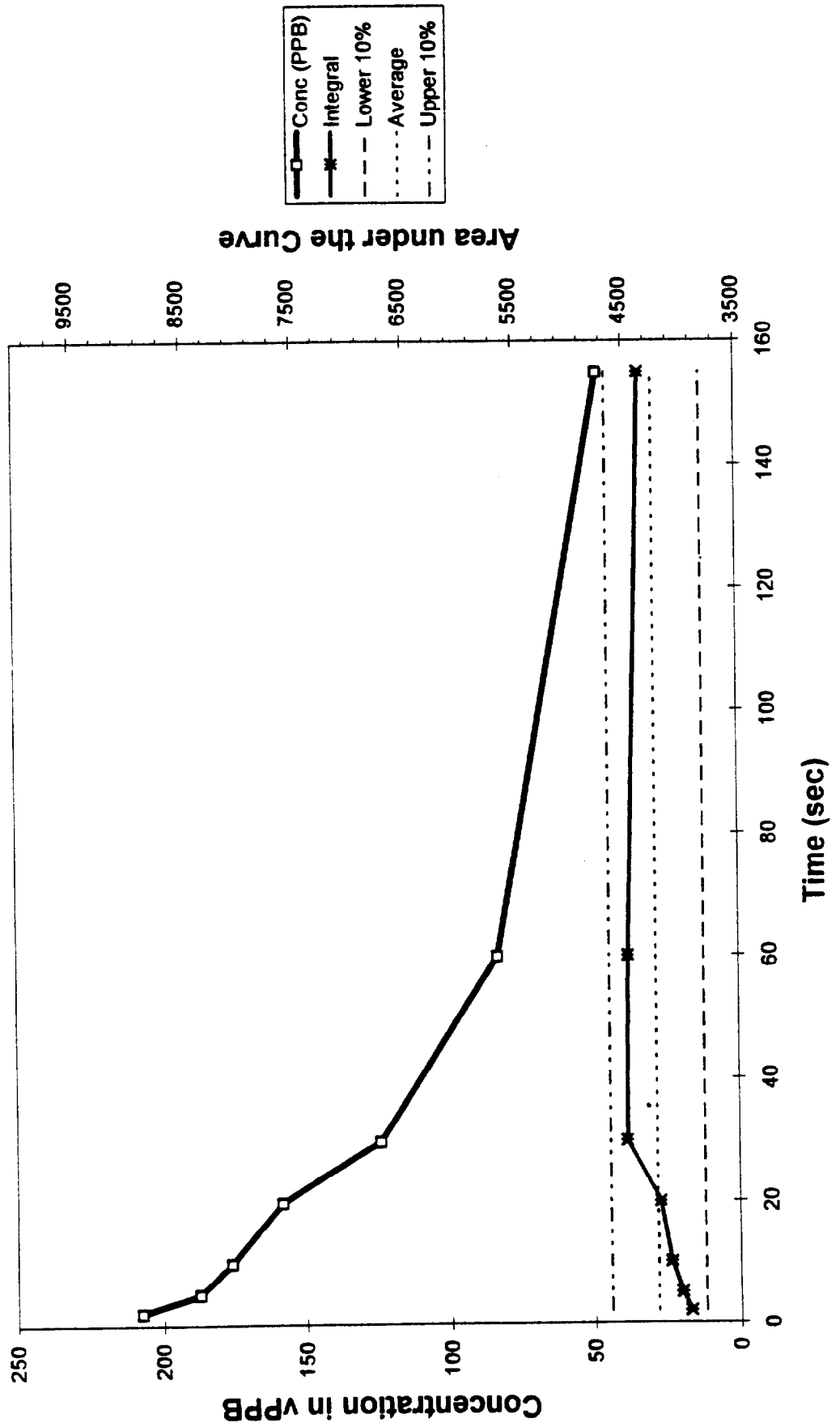
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# Constant Volume vs Time & Integral of Injection



**DISCUSSION**

**ANON:** Is this replacement for R-11 a problem?

**B. KOVACH:** This is a R-11 replacement solution rather than a problem.

TESTING THE SAMPLING EFFICIENCY OF A NUCLEAR POWER STATION STACK MONITOR\*

Lars H Ström  
Instrumentinvest  
S-611 63 Nyköping, Sweden

Abstract

The test method comprises the injection of known amounts of monodisperse particles in the stack air stream, at a suitable point upstream of the sampling installation. To find a suitable injection point, the gas flow was mapped by means of a tracer gas, released in various points in the stack base. The resulting concentration distributions at the stack sampler level were observed by means of an array of gas detectors. An injection point that produced symmetrical distribution over the stack area, and low concentrations at the stack walls was selected for the particle tests.

Monodisperse particles of 6, 10, and 19  $\mu\text{m}$  aerodynamic diameter, tagged with dysprosium, were dispersed in the selected injection point. Particle concentration at the sampler level was measured. The losses to the stack walls were found to be less than 10 %. The particle concentrations at the four sampler inlets were calculated from the observed gas distribution. The amount calculated to be aspirated into the sampler piping was compared with the quantity collected by the sampling train ordinary filter, to obtain the sampling line transmission efficiency.

Introduction

Installations for the monitoring of ventilation stack releases of radioactive gases and particles should be tested periodically. This report describes experiments with a relatively simple method to investigate the relation between particles passing in the stack and particles collected on a monitoring filter. The stack sampler employed for the experiments was of the normal Swedish design, consisting of four isokinetic probes connected to a 100 mm diameter transport pipe, and filters and radiation detectors, sampling from the transport pipe. Figure 1 shows the stack and the room below the stack where the ventilation air flows come together, the stack base chamber. At the stack sampler level, four isokinetic probes sample the stack air, and a 100 mm pipe conducts the combined air flows (64 l/s) to the monitor room. Assuming equal flows in the probes, the inlet concentration is

$$C_{in} = \left( \sum_{i=1}^4 C_i \right) / 4$$

The mean concentration of particles in the stack over the time can be expressed as

$$C_{mean} = M / Q t$$

where M is the quantity of particles passing the stack in the time interval t. Q is the air flow in the stack, 164  $\text{m}^3/\text{s}$ . If the particle concentration varies over the stack area,  $C_{in}$  and  $C_{mean}$  will generally differ by a factor  $f$

$$C_{in} = f C_{mean}$$

$f$  is called the "form factor" to indicate that it depends on the shape of the concentration profile and the disposition of the sampler probes.

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In the monitor room several secondary samples are drawn isokinetically from the transport pipe into filters and other monitoring devices (0.5 - 0.7 l/s each). Particle concentration in the air reaching the filters is generally lower than in the stack air, due to losses in the pipes etc. This is expressed by the transmission efficiency  $\eta$

$$C_{out} = \eta C_{in}$$

The purpose of the work reported here was to test a method to determine the sampling efficiency, which includes the form factor as well as the transmission efficiency. By means of these factors the stack release is calculated as

$$M = C_{mean} Q t = \frac{C_{in}}{f} Q t = \frac{C_{out}}{\eta f} Q t$$

Due to the strong dependence on particle size the investigation could also be called determination of upper size limit of the sampling installation.

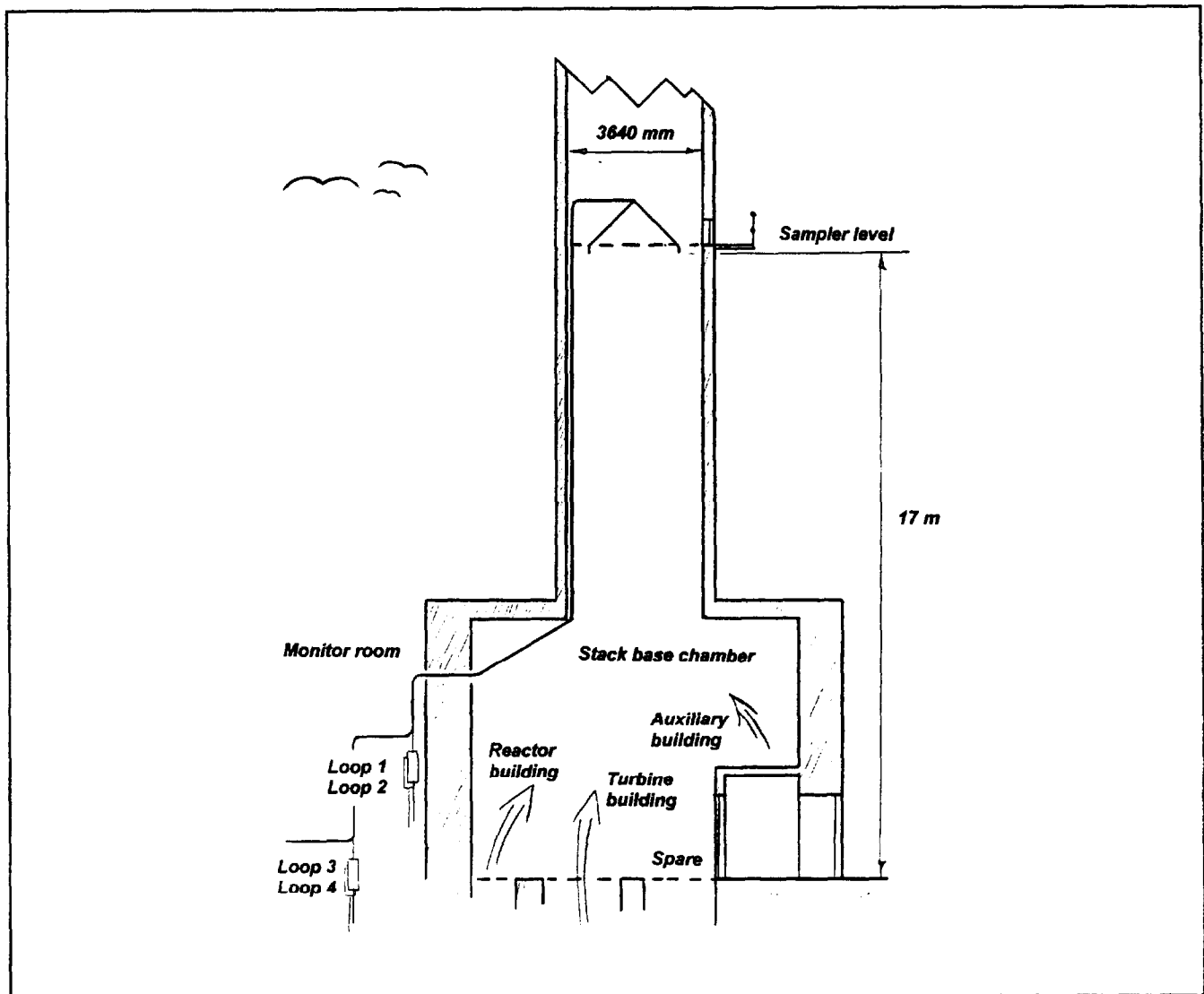


Figure 1. The stack base chamber, the stack, and the installation for air sampling.