First Morning Session

AIR CLEANING SYSTEMS

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VILES: Dr. Moeller's welcome and Mr. Belter's excellent presentation not only brought us up-to-date on the history of air cleaning in the USAEC but also provided much valuable information on this subject and set the stage, so to speak, for our meeting today. The first paper is a review and projection of air cleaning systems which will be presented by your chairman of this session. Following that presentation, I will introduce C. E. Linderoth, Battelle-Northwest, who will tell us about "CSE: Testing Full Scale Systems" which is very apropos to what I will discuss and a subject in which we have much interest. Part of this paper is to be presented by Mr. Linderoth and the remainder by Mr. J. D. McCormack, also of Battelle-Northwest.

AIR CLEANING SYSTEMS: REVIEW AND PROJECTION

by

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ABSTRACT

Filter-charcoal air cleaning systems and their application, testing, and suggested further development are described for cleanup of containment atmospheres following fission product release from reactor water coolant failures. Decontamination of containment air by condensation processes, sprays, gas phase reactions, foams and diffusion boards are discussed briefly and their use noted as supportive operations to effect more rapid cleanup. Comparisons of air cleaning problems and design are made between water and sodium cooled reactors accidents.

INTRODUCTION

The philosophy on air cleaning systems as engineered safeguards was summarized by the Advisory Committee on Reactor Safeguards in December, 1964, (1) and repeated by Keilholtz (2) in 1966. Briefly, this summary states that the function of an air cleaning system as an engineering safeguard is to remove and to retain fission products from an accidental release, including fuel melt down, and that for cleaning or decontamination purposes, the released fission products may be divided into four groups: (1) noble gases (krypton, xenon); (2) halogens (bromine, iodine); (3) volatile solids (tellurium, selenium, cesium, ruthenium); and (4) non-volatile solids (strontium, yttrium and barium). The summary also states that usually, radioactive noble gases can be treated only by containment or by controlled release from elevated locations such as tall stacks and that consideration must be given to meteorological dispersion and dilution as influenced by the surrounding environment. Although noble gas removal is under investigation, the few devices currently in use are based on cryogenic distillation or solid adsorption with cryogenic enrichment and are limited to small capacity (∿ 200 cfm) air cleaning systems. Noble gas removal will not be included in this presentation.

The work reported upon herein was performed under terms of contract AT (30-1) 841 between Harvard University and the U. S. Atomic Energy Commission.

With this latter qualification, it may be stated that air cleaning systems are required to remove and retain all fission product particles and radioactive halogens and their compounds. The following is a review of various air cleaning systems which have been selected for this task, including comments and suggestions concerning their application and improvement in performance.

FILTER - CHARCOAL SYSTEMS

Marked advances in filter technology in the past fifteen odd years has resulted in a high, if not universal, acceptance of the HEPA or absolute type filter as the most efficient particle collector for air cleaning systems. Improvements in activated charcoal, particularly with impregnants, has led to its wide use as an adsorbent for iodine and its compounds (methyl iodide and hydrogen iodide) which are considered to be the most hazardous gaseous fission products. Other halogens such as bromine would be expected to exhibit collection efficiencies by charcoal similar to the corresponding iodine compounds. An arrangement comprised of HEPA filters and charcoal and employing an air mover and a gas conveying unit (ventilation system) constitute what may be termed an accepted if not the most accepted basic air cleaning system.

Performance of high efficiency filters and activated charcoal are adversely affected by moisture (water droplets) and, in the case of charcoal, also but less seriously, by saturated water vapor. Their application in air cleaning systems for water cooled reactors, requires removal of water by the use of moisture eliminators.

It should be noted that since halogens adsorb on particles and are not irreversibly bound to the particles, the filter must be placed before the charcoal bed to assure collection of any de-sorbed halogen.

Further improvements in this accepted air cleaning system have included: (1) pre or roughing filter to extend the life of the high efficiency filter; (2) water repellants on the filter media to prevent filter wetting; (3) iodine impregnants on the activated charcoal to provide additional removal of radioiodine and its compounds by isotopic exchange; and (4) silver plated copper screens or filters before the charcoal to remove elemental iodine and thus extend the operational life of the charcoal and minimize its temperature increase due to fission decay heat. In a few cases silver plated copper filters have also been located downstream of the charcoal to remove elemental iodine that would be released if charcoal ignition occurred.

Applications of Filter - Charcoal Systems

Air cleaning systems for removal of fission products must be sized to collect not only the amounts of fission products anticipated but also all other airborne contamination that the cleaner would collect from a fuel melt-down. This would include fume particles from the cladding, the fuel and possibly the reactor vessel and associated piping and also non-radioactive gases and vapors such as ^{127}I.

The cleaning devices in the system must also be sized to accommodate the design air flows to the final or end condition of the cleanup process.

Internal Air Cleaning. Location of the air cleaning system within the containment vessel provides cleanup under recirculation conditions and is used in many water cooled reactors. Capacities of these systems are in the tens of thousands cfm. These systems include moisture eliminators, absolute type filters with or without pre-filters, activated charcoal with or without impregnants and in some cases, cooling devices. Containment water sprays are usually used where cooling is not provided by the air cleaning system.

Since the air cleaning system is within the containment, internal and external pressures and temperatures of the system are essentially the same and equal to containment conditions. However, during rapid changes in pressure occurring in the initial phases of a coolant rupture accident, marked internal and external pressure differences could exist momentarily on the air cleaning system. Internal systems must be constructed to withstand these pressure differentials.

Improved dehumidification could be obtained in these systems if the cooling device were located first rather than last on the air cleaning train. This would provide increased condensation of water, particle size growth, and cooling of the air entering the air cleaning system. Since the air cleaning unit is subject to the higher temperature of the containment atmosphere, air passing through the cleanup train would experience a gradual temperature rise with a lowering in its relative humidity and improved halogen removal efficiency by the charcoal. In addition, the higher heat capacity of the wet air passing over the cooling coils would provide more efficient cooling.

External Air Cleaning. Cleanup systems located external to the containment vessel are usually employed to vent the secondary containment of boiling and pressurized water reactors utilizing pressure-suppression primary containments. Under these conditions humidities significantly below 100% are involved and efficient air cleaning is obtained permitting release of the cleaned secondary containment air. External air cleaning systems for secondary containments are low (hundreds of cfm) in contrast to internal recirculation cleanup in single pressurized containment vessels and are utilized to maintain slight negative pressure (0.25 inches of water) on the secondary containment. These systems only provide cleaning of the air that leaks from the primary to the secondary containment and do not effect significant cleaning of the highly contaminated primary containment atmosphere.

Direct release of cleaned primary containment air presents an excellent means of relieving containment pressure and would be highly desirable. External systems for air cleaning primary or high pressure containments for water cooled reactors which would permit direct release to the atmosphere are possible if particle and halogen removal efficiency is high enough to result in permissible release concentrations. In order to obtain the high removal efficiencies needed, complete moisture (water droplets) removal and significant humidity reductions would be required. These goals could be obtained by various means.

The first step required in the application of an external air cleaning system for pressurized containment vessels is a means for reducing the variable pressures of the containment air entering the system while maintaining design flow rates. This may be accomplished by a number of differently sized orifices in parallel, each operated at pre-set pressures. The smallest orifice, which allows air flow at the highest containment pressures, would remain open at all times. However, a damper in the main feed line upstream of the orifices would prevent air flow until containment cleanup was required. The remaining orifices would remain closed until upstream or containment pressures dropped to pre-set values which would result in different orifices opening in turn to re-establish system air flow as the containment pressure decreased. Pressure differentials across the orifice would be close to that between atmospheric and the containment since the air cleaning system would be operated at pressures essentially atmospheric.

Moisture eliminators employed upstream of the orifice would remove existing water droplets in the gas stream and permit greater water condensation on ultra fine particles and other condensation nuclei downstream of the orifice if significant cooling occurs by any Joule-Thompson effect at the orifices.

With the system essentially at atmospheric pressure, further means for cooling and water condensation would be provided. This may be accomplished by refrigeration, coolant coils or air condensers. After adequate air temperatures are obtained the newly formed water droplets would be removed by a second water droplet eliminator. Final treatment of the air stream would involve dehumidification employing (1) heating units; (2) additional cooling followed by reheating; (3) adsorbents (silica gel, molecular sieves, activated alumina) or (4) dehydrating chemicals (zinc chloride, calcium chloride). If dry warm air were available it also could be fed into the system to effect adequate dehumidification.

The lower air temperatures entering the cleaning train would decrease the temperature gradients (cooling) through the train thus minimizing the increase in relative humidity of the gas in its passage through the cleanup devices. Application of pressure reduction, cooling, moisture elimination and dehumidification to result in air relative humidities 90% or less at the inlet of the charcoal adsorbers appear to be feasible and practical. Under these conditions, removal efficiencies of fission products should be adequate (hopefully $\geq$ 99.9%) to permit gradual release of the containment air following an accidental coolant failure.

Testing Air Cleaning Systems

It is important to establish and maintain the integrity of air cleaning systems. This indicates the need for testing such systems or their prototype under the conditions contemplated for a nuclear accident. It also dictates the need for a surveillance type of program such as in-place testing of individual components or even the complete system.

Pre-Use (Development) Test. Small scale tests are usually involved in research and development studies to determine removal efficiency, flow capacity, and contaminant holding capacity of individual components. Complete systems tests on a small scale are useful to determine any affects filter train components will have on each other. Final small scale testing of components individually or as a complete air cleaning system should involve the condition of temperature, pressure and wet saturated atmospheres under which the units are to function. Such tests were at one time proposed for the Loft study (Smith 3) but re-direction of the Loft program resulted in an unlimited postponement of this work. As a result of small scale tests, the capability and operating life of the cleanup train can be resolved for the conditions contemplated for accidental fission products release.

Large scale tests, particularly on full scale prototypes or the actual components for an air cleaning system, reveal any mounting leaks or air channeling in the assembled components. Large scale tests are difficult to perform under simulated accident conditions because of the volume of contaminated air needed. Perhaps the most difficult large scale test is that designed to determine holding capacity of the fission products involved under accident conditions. It appears that capacity studies would be limited to small scale studies for such conditions.

In-Place Tests. It is necessary to perform in-place tests periodically to demonstrate that an air cleaning system and its components will continue to function as designed. Usually these tests are made only for particle and iodine removal efficiencies with very little if any tests made for collection capacity.

Present day efficiency in-place tests are still in need for improvement. The accepted DOP (dioctyl phthalate) test for filter efficiency involves a liquid aerosol which favors high efficiency because of good adherence to filter fibers. Many of the fission product aerosols are solids which further support the argument that solid aerosols should be adopted for filter testing.

Iodine in-place tests are accomplished by using ^{127}I with determinations made by activation analysis or else by using ^{131}I as a tracer with analysis by radiological counting methods (Adams 4). The former method was slow and required special equipment while the latter demanded special precaution because of the hazardous nature of ^{131}I. A third method involving chemical analysis of ^{127}I (Viles 5) encountered analytical difficulties but have now been corrected and the method should be available in the near future.

Iodine in-place tests using ^{131}I may lead to erroneous results for iodine impregnated adsorbents. Since isotopic exchange would be involved in ^{131}I removal, the rate of exchange would be less when amounts of ^{131}I greater than that used in the in-place test were present which would be the situation with a major nuclear accident.

Sampling immediately up and downstream of the iodine removal device is necessary so that its efficiency is not influenced by iodine removal by adsorption on upstream filters. Iodine sampling must involve low line losses to the collecting device or else the iodine must be accounted for in some manner.

It has been suggested that methyl iodide be used for iodine efficiency tests since it is always present and its removal is more difficult than elemental iodine. Analysis by gas chromatography would be rapid (∿ 5 minutes) and accurate, and would be less subjected to background contamination. Its high vapor pressure would permit a compact and simplified feed system. Since it is not adsorbed to any degree on surfaces, in marked contrast to iodine, it can be injected in the vapor form well upstream of the cleanup train thus assuring uniform mixing and accurate synthesis of upstream concentrations. In contrast iodine injected into the system also upstream of the filter to provide adequate mixing, is highly adsorbed by moisture eliminators, duct work and filter fibers.

In-place testing of adsorbent beds for iodine removal at high humidities are not made as a rule. Yet, if inefficiency is to occur it will first manifest itself under these conditions. This type of test is justified but apparently its impracticability has been responsible for its omission in most cases.

In-place studies of available removal capacity of aerosols by filters can be accomplished by recorded pressure drops across the units. However, capacity in-place tests for iodine adsorbents are not so easily performed. The present technique involves removal and laboratory studies of one of a group of representative test cartridges to determine the amount of iodine the system is capable of removing before reduction to a pre-determined iodine removal efficiency.

OTHER AIR CLEANING SYSTEMS

Although this conference is primarily concerned with the filter-charcoal air cleaning system, other systems are used or available for water cooled reactors. These will be discussed briefly.

Condensation. During the cooling phase of a containment following a water coolant failure, the natural process of water condensation on nuclei including soluble and wettable aerosols result in particle and droplet growth and removal by settling from the atmosphere. Soluble gases also experience a significant rate of removal by solution in the condensate.

Sprays. In many water cooled power reactors, water sprays are available to cool containment atmospheres following coolant failure. Reactive chemicals may be added to these sprays, to provide increased removal of fission product gases, particularly iodine and methyl iodide. For example, spray solutions containing sodium thiosulfate provided 50% iodine removal from a contained atmosphere in less than one minute (Parsly 6).

Gas Phase Reactants. Selected volatile reactants may be added to the containment atmosphere to produce gas phase reactions with iodine and methyl iodide. If the product formed is water soluble it will be scrubbed out of the atmosphere by the water condensation process mentioned above. Examples of gas phase reactions are hydrazines which react with iodine to form soluble hydrazinium iodide aerosols and tributyl phosphine which combines with methyl iodide to produce soluble tributyl methyl phosphonium iodide particles (Viles 7).

Foams. Encapsulation of fission-product air contaminants by water foams containing reactants has been proposed as a means of air cleaning (Silverman 8). Foams have the advantages of providing large reactive surfaces with long reaction times and offer small distances which gases and particles have to travel to reach reactive or wettable surfaces. Recent studies (Viles 7) have demonstrated that reactants in the foam are displaced from the foam bubble film by the surfactants present thus canceling the benefits supposedly offered by large reactive surface areas. However, application of foams using gas phase reactants provides increased removal rates for particles formed because of small diffusional and settling distances. Obviously foams cannot be used in the presence of water sprays.

Diffusion Board. The diffusion board is an application of a pressure-release containment with the containment wall made of porous reactive materials which remove particles and iodine and its compounds. Diffusion board containment is not adaptable to water cooled reactors at the present time because means for preventing plugging of the material by water condensate have not been found (Reist 9). However, the diffusion board containment concept, might find application for air or gas cooled reactors since large quantities of condensable water vapor are not present.

CONTAINMENT DECONTAMINATION BY AIR CLEANING SYSTEMS

The rate of decontamination of a containment atmosphere by an air cleaning system is related to the removal efficiency of the system and its air handling capacity with respect to the containment volume. If it is assumed that an internal containment air cleaning system is 100% efficient and that instantaneous mixing is always present in the containment atmosphere, the decrease in the initial concentration with time can be determined from the equation

$$C = C_o e^{-t/A}$$

where C is the fission product concentration at time t, C_o, the initial concentration and A the time for one containment volume air change. Concentrations in terms of fraction of the initial concentration and fission product removal efficiencies for various containment volume air changes are presented in Table 1.

The time required to effect efficient fission product removal by an assumed 100% efficient internal recirculating air cleaning systems is demonstrated by selecting a pressurized water reactor for analysis. Connecticut Yankee has a containment volume of 2.23×10^6 cubic feet and four 50,000 cfm cleanup systems, three of which have been assigned as operable following a loss of coolant accident (10). With the three air cleaning systems operating, 15 minutes would be required for one air change. If it is assumed that no losses of fission products from the containment atmosphere occur other than by the air cleaning system, it would take 15 minutes to remove 63.2% of a given fission product, 45 minutes for 95% removal and 105 minutes for 99.9% removal (decontamination factor = 10^3). Actual times for these removals, would vary for different fission products depending upon removal effected by water condensation and sprays and also by the removal efficiency of the air cleaning system.

It has been proposed that iodine released into the containment space must be reduced to 10^{-3} of its maximum concentration in 1/2 hour to assure safety should containment fail (Morrison 11). It would appear from the above analysis that internal air cleaning systems may not be sufficient to meet this requirement. This suggests that internal recirculated air cleaning filter-charcoal ventilation systems should have very high capacities and be very efficient for the conditions presented by a major accident. Of equal importance, they should be supported by other air cleaning methods such as reactive sprays and gas phase reactants.

Table 1

Fission Product Air Concentrations vs. Containment Vol. Clean Air Changes

Containment Vol. Air Changes	(C/C_o) 100%	Fission Product Removal Eff. %
0	100	0
1	36.8	63.2
2	13.5	86.5
3	5.0	95.0
4	1.8	98.2
5	0.67	99.33
6	0.25	99.75
7	0.091	99.909

AIR CLEANING FOR FAST (SODIUM COOLED) REACTORS

Because of increasing development of fast (breeder) reactors employing liquid sodium as a coolant, mention should be made of the air cleaning problem this reactor presents with a coolant failure. Sodium coolant loss could result in fuel melt down and fission product release comparable with that of a water cooled reactor although sodium would act as an excellent scavenger for iodine. The anticipated large amounts of sodium fume as well as airborne fission products require efficient removal. Design of a high capacity (up to 1.5 lbs of sodium per square foot of filter surface) - high efficiency filters for all particulates including sodium has been developed (Viles 12) and are being improved upon. One desirable feature of an accident with this type of reactor is the complete absence of water which should result in excellent removal efficiencies of iodine and methyl (alkyl) iodides by activated charcoal. In addition to the advantages presented for high air cleaning efficiencies for sodium cooled reactor accidents, sodium coolant losses should not produce the high containment pressures characteristic of water cooled reactors.

CONCLUSIONS

Although much has been accomplished in the development, testing, and application of air cleaning systems for removal of fission products originating from nuclear reactor accidents, many areas of these activities still require further studies for needed improvement.

Better efficiencies and removal capacities of the filter-charcoal air cleaning system is desirable if not necessary. In this connection, more efficient moisture eliminators and, particularly, means for dehumidification would be most desirable. Devices for removal of iodine which are not subject to ignition by decay heat and which would preceed the charcoal adsorbers would reduce or eliminate charcoal ignition problems and also extend the holding capacity of the air cleaning system. In connection with the latter, application of pre-filters to extend the life of the accepted HEPA filter and also increase the overall particle removal efficiency should be investigated further and if possible standardized or receive some sort of acceptance.

Development of highly efficient filter-charcoal air cleaning systems which will be applicable to direct release of containment air to the atmosphere is also desirable since cleanup could start with the onset of a major accident and containment pressures would be reduced accordingly.

Full scale testing of air cleaning systems, including individual components, under simulated accident conditions has been needed for some time. Filter in-place tests should be performed with solid as well as DOP aerosols to be more representative of fission product particles. More adaptable and simplified iodine in-place tests are much in demand.

Although it was not discussed, aging or shelf life of components in stand-by (emergency use) air cleaning systems should be investigated further and better methods found for determining and minimizing detrimental storage affects.

Finally, it makes a great deal of sense to utilize multiple air cleaning systems to effect rapid cleanup of the containment atmosphere. Present indications would suggest simultaneous application of filter-charcoal systems (internal and if possible external), reactive sprays and gas phase reactants for rapid cleanup of released fission products.

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FACILITIES AND PROCEDURES FOR TESTING LARGE SCALE AIR CLEANING SYSTEMS CONTAINMENT SYSTEMS EXPERIMENT

by

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Abstract

The primary facilities of the Containment Systems Experiment are described in brief and pertinent physical data provided. The equipment designed for the internal air cleaning system is described in some detail. A series of six experiments is discussed which has the objective of determining the effect of a recirculating filter system on the behavior of fission products in containment under post accident conditions.

Part I - Presented by Mr. Linderoth

Many of you are familiar with Containment Systems Experiment. However, I have not seen most of you at Hanford and I am sure that a little introduction to our facilities will be of value.

The Containment System Experiment, Figure 1, is located at Hanford in a deactivated separations plant. Therefore, the whole facility is contained in a building which excludes outside temperature fluctuations due to weather, or seasonal changes -- winter and summer -- night and day as a factor in our experiments.

The main facility, of course, is the containment vessel. It consists of three parts, the containment vessel, the dry well and the wet wells.

The containment vessel is approximately 66 feet tall, 25 feet in diameter and is designed for 75 psi working pressure. The volume of the space, not including the dry well and wet wells, amounts to 24,000 cubic feet. The dry well is 11 feet in diameter and 25 feet tall and is designed for 150 psi working

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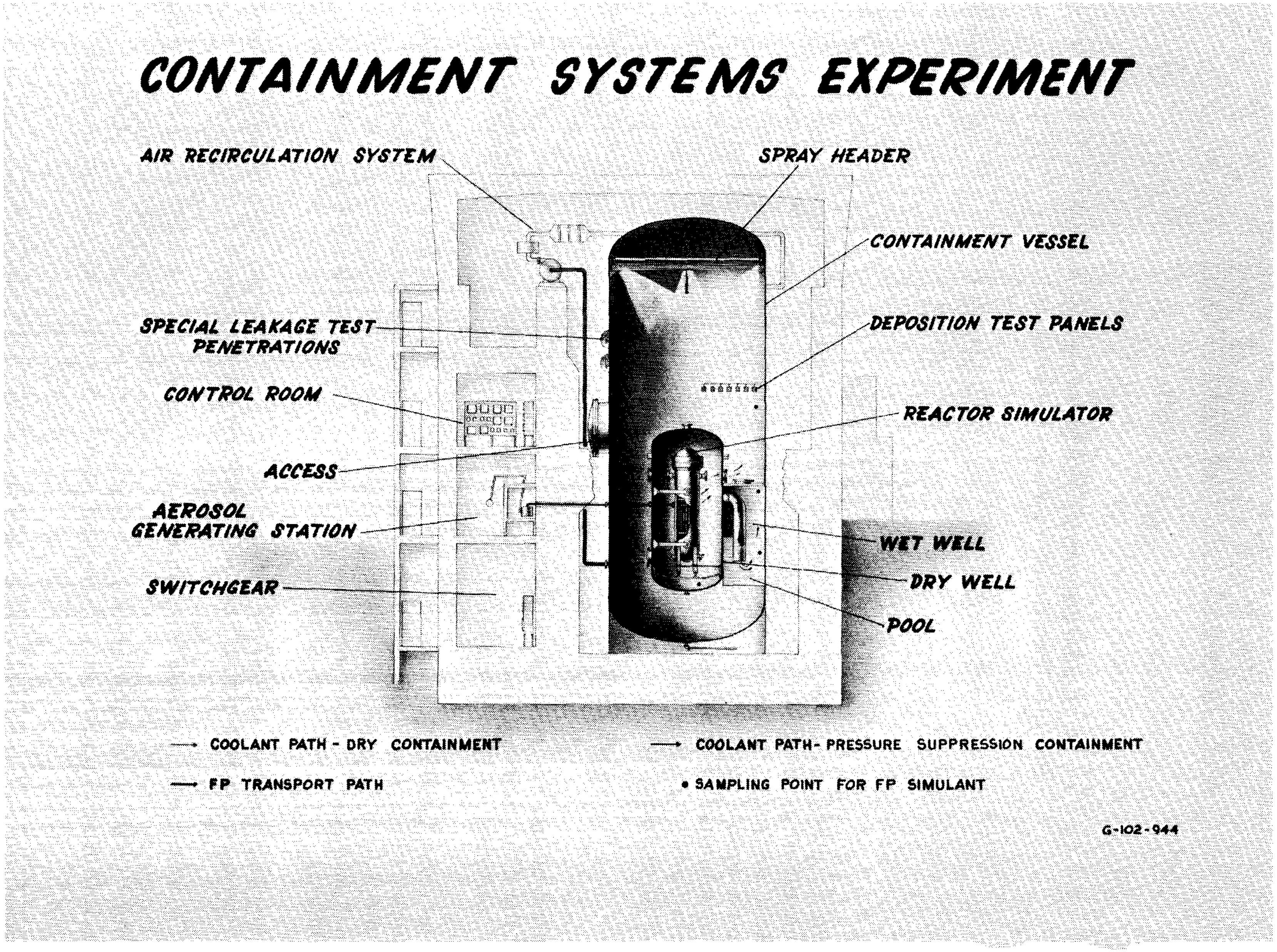
CONTAINMENT SYSTEMS EXPERIMENT
AIR RECIRCULATION SYSTEM
SPRAY HEADER
CONTAINMENT VESSEL
SPECIAL LEAKAGE TEST PENETRATIONS
DEPOSITION TEST PANELS
CONTROL ROOM
REACTOR SIMULATOR
ACCESS
AEROSOL GENERATING STATION
WET WELL
DRY WELL
SWITCHGEAR
POOL
→ COOLANT PATH - DRY CONTAINMENT
→ COOLANT PATH- PRESSURE SUPPRESSION CONTAINMENT
→ FP TRANSPORT PATH
• SAMPLING POINT FOR FP SIMULANT
G-102-944

Figure 1

TABLE I

PHYSICAL DATA - CONTAINMENT SYSTEMS

Containment Vessel	
Height	66' 8"
Diameter	25'
Max Oper Press	75 psig
Max Oper Temp	320 °F
Mtl of Const	SA 212B
Dry Well	
Height	25'
Diameter	11'
Max Oper Press	150 psig
Max Oper Temp	330 °F
Mtl of Const	SA 212B
Wet Wells	
Height	16'
Depth	7'
Max Oper Press	25 psig
Max Oper Temp	200 °F
Volumes	Cubic Feet
Containment Vessel	23, 682
Dry Well	2, 270
Wet Wells	4, 134
	30, 086

pressure. The contained volume is about 2,000 cubic feet. The wet wells are approximately 20 feet tall and 7 feet deep and contains about 4,000 cubic feet. The total contained volume totals about 30,000 cubic feet. Table I presents more exact physical data of the facilities.

The vessel shown in Figure 1 inside the dry well is the reactor simulator vessel which is not installed at the present time; however it will be installed in the future for studies on the pressure suppresum concept.

The wet wells occupy two-thirds of the space between the dry well and the containment vessel. The final one-third is used for the pipe chase and personnel access to the lower levels.

Some of the other features of the system shown in the figure are the 8 foot equipment access door, the 3 foot personnel access door and a ventilation loop. This ventilation loop is permanently in place--and it should not be confused with the planned filtration system that I will discuss in a few minutes. Its purpose is for pretreating the air prior to an experiment and for post-treating after an experiment and prior to personnel entering the vessel.

In addition, the adjoining galleries house the switch gear, the laboratories, a control room, offices and various other essentials.

To date, we have conducted about nine experiments; four in the dry well and five in the containment vessel. The experiments generally are conducted along the following pattern.

Prior to the experiment, air is recirculated through the ventilation loop in order to precondition the air to a condensation nucleii count of less than 500.

The atmosphere in the containment vessel is adjusted to the desired conditions either by injecting air, steam, or both, until a desired temperature and pressure is reached. The steam flow is then adjusted to hold constant conditions. The aerosol is then generated in the laboratory--and it is jetted into the dry well inside the containment vessel.

Once the aerosol injection is completed the sampling of the atmosphere and liquid is started. Samples are taken in decreasing frequencies for about 24 hours. In other words, we may take a sample 10 minutes after injection, another one in twenty minutes, and then go maybe 20 or 30 minutes between samples and finally hours apart. The little squares shown on the figure indicate where the gas samplers are located. We also take frequent samples out of the water pools that form in the containment vessel and dry well. We also have troughs on the inside walls of the containment vessel with which we can take samples of the condensate that forms and runs down the walls.

After about 24 hours, the vessel is cooled to permit entry into the vessel to recover the Maypack samples and various deposition coupon samples. So far we have conducted with the vessel uninsulated several national transport runs, no engineering safeguards such as sprays or filtration systems employed. We have done experiments also with the uninsulated vessel and using a spray system safeguard. Recently, we installed one-inch of insulation on the vessel and have since conducted another natural experiment.

Figure 2 provides some perspective of the size of the vessel, although only the upper half of the containment vessel is visible.

The advantages of our system are two.

One, it is large enough to perform significant engineering studies, yet it is not so large that we can't think about testing the parameters of interest to some degree. Obviously, we cannot make exhaustive studies of all the parameters but we can bracket them. Secondly, it is flexible. By adding or removing equipment we can conduct studies on the various concepts of containment and safeguards conceived.

As I have stated, we have conducted basically two types of tests. In future tests we intend to expand the studies by including air cleaning systems.

Figure 3 shows our conception of the filter system installation inside the containment vessel.

Basically, we have two thoughts in mind. One, we want to provide experimental flexibility and, secondly, we want a scale that will compare reasonably with those used in nuclear power stations.

I don't think you'll find anything unique in this installation. Our initial installation will be of the recirculating type and it will be constructed out of stainless steel. The diameter of the suction and discharge pipes is 14-inches. The diameter of the modules containing the various components will be 36-inches. The 36 diameter permits the use of commercially size filters up to a maximum size of 24-inch square.

We plan on having a heat exchanger, a demister, a roughing filter, an absolute filter, and a series of charcoal filters and of course a fan.

From each module condensate samples will be taken. The condensates will be routed outside the containment vessel through stainless steel tubing to individual tanks where the volumes will be recorded and aliquot taken for analysis. Between each component will be a tap for obtaining the pressures and also a battery of tubes for obtaining air samples.

Figure 4 is an artist's conception of how the assembled modules will look. For visual aid purposes the assembly is turned 45 degrees. The air passes through a heat exchanger with two banks of stainless steel finned tubes, up through a york mesh type teflon demister on through particle filters and finally through charcoal filters.

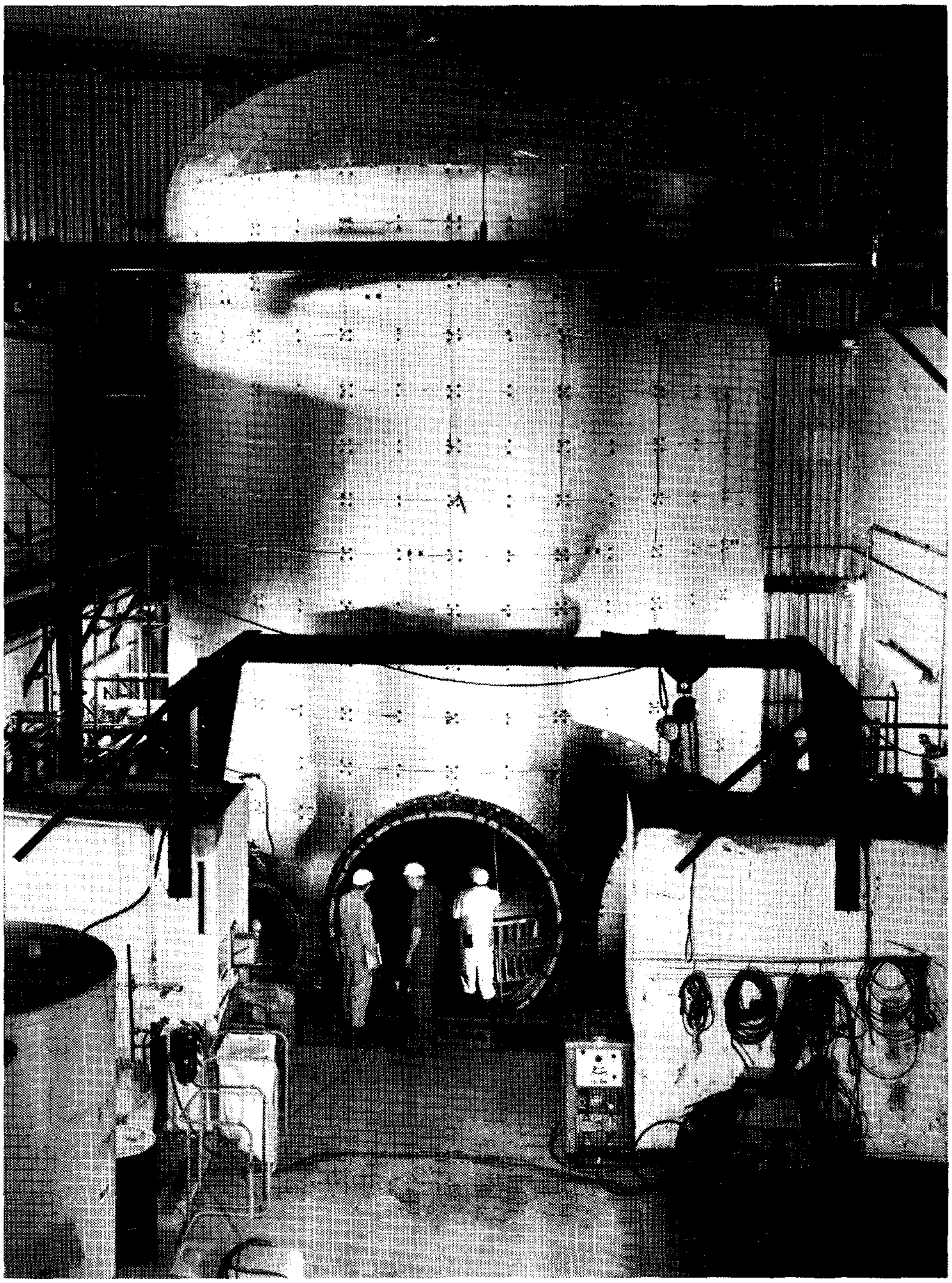

Figure 2 Upper half of containment vessel

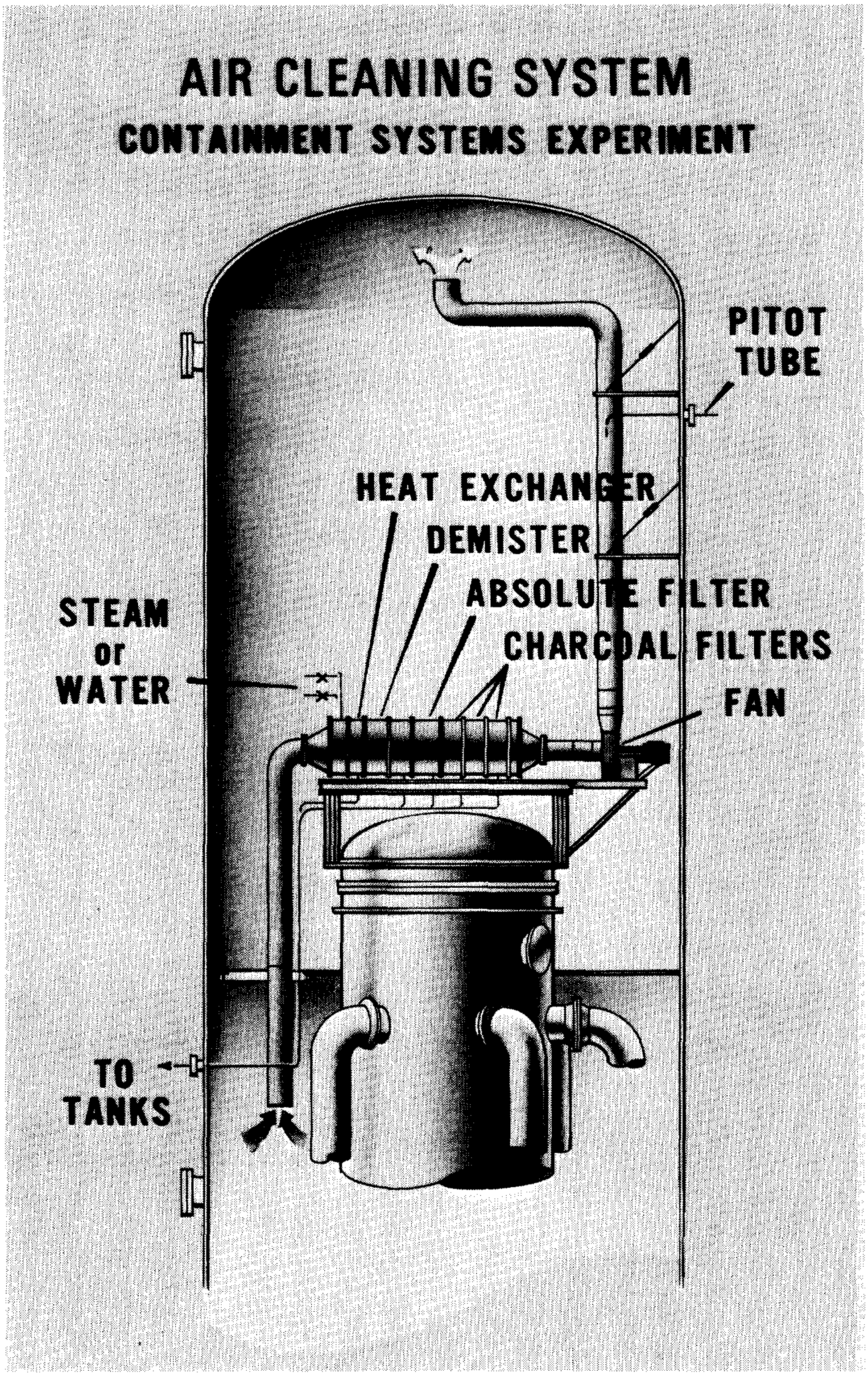
AIR CLEANING SYSTEM
CONTAINMENT SYSTEMS EXPERIMENT
PITOT TUBE
HEAT EXCHANGER
DEMISTER
ABSOLUTE FILTER
CHARCOAL FILTERS
FAN
STEAM or WATER
TO TANKS

Figure 3

TABLE II

PHYSICAL DATA - INTERNAL AIR CLEANING SYSTEM

Material of Construction	Stainless Steel
Atmosphere	Steam-Air Mixture 250°F
Air Flow	1050 CFM
Design Pressure	10 psi (internal)
Diameters	
Suction Pipe	14 inches
Discharge Pipe	14 inches
Component Modules	36 inches
Heat Exchanger	
Type	Finned Tube
No of Rows Deep	Eight
Est Δ P	.25" H_2O at 1000 CFM
Water Flow	15 gallon/minute
Face Area	4 sq ft
Demister	
Packing	Mesh Type
Depth	6 inches
Face Area	1.76 sq ft
Filters	
Type	Standard commercially available absolute filter and charcoal adsorbers. Maximum face area of four square feet.

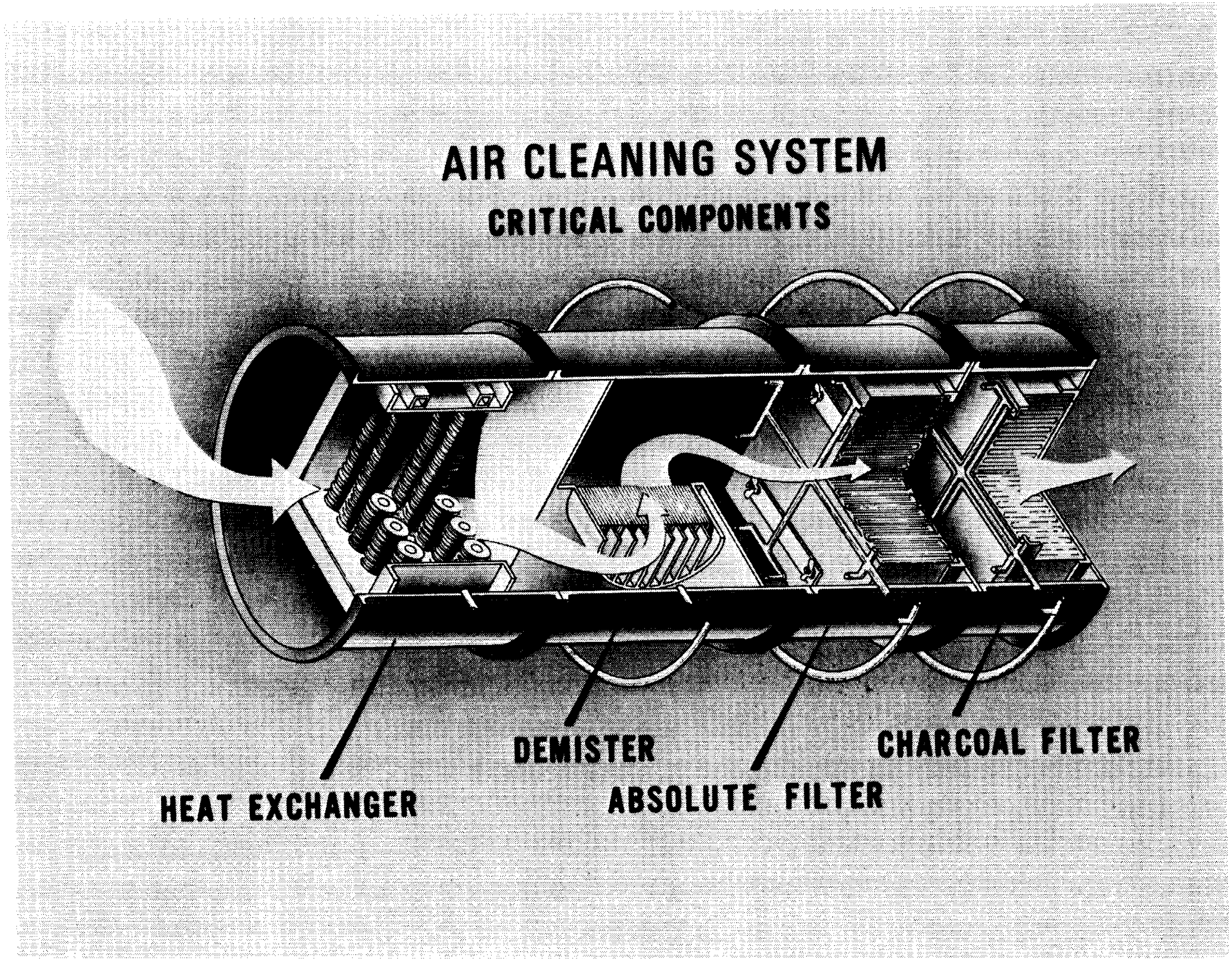
AIR CLEANING SYSTEM
CRITICAL COMPONENTS
HEAT EXCHANGER
DEMISTER
ABSOLUTE FILTER
CHARCOAL FILTER

Figure 4

The rings shown external to the components are a schematic of the sampling system that we plan to use.

The flow rate for this filter train will be a maximum of 1,000 cubic feet per minute. With a total volume in the containment vessel of 30,000 cubic feet, this flow rate will give a turnover of once every 30 minutes.

There's one other point on flexibility. These modules are designed for an internal pressure of 10 psig and if we desire, they can be relocated outside the vessel across any two major penetrations of the containment vessel and we can thus provide a loop located outside the containment vessel. Or, if we desire to make a single pass test, we can simply repipe the discharge line from the stack out through a large penetration of the containment vessel and thus make it a once-through system.

So, basically, what we are trying to provide is flexibility where we can go with reasonable simplicity from a multiple pass to a single pass to an external unit. As the introductory speaker stated, there are many things to consider when planning an engineering scale test of this size.

Figure 5 shows one of the items that I am sure people are curious and concerned about is the aerosol sampling system. The last figure shows our idea. One of these assemblies will be installed after each of the components. Each assembly will have 12 samplers, each of which can be operated independently of the others. Thus all samples can be taken simultaneously throughout the whole filter train and the efficiencies of the various components can be evaluated as a function of time and concentration.

The technician, who is in the laboratory selects the sample he wishes to take and sets a selector switch for each sample assembly. At the specified time, he throws a master switch and one valve in each assembly will open simultaneously. The air will be drawn through the stainless steel tube, through the opened valve, through the Maypack samples on to a vacuum header to the laboratory, where there are condensers and cold traps to remove any of the aerosol that may have penetrated the sampler.

In summary then, I do believe we have a concept, in fact a design, of a flexible system that can help to answer many of the questions concerning air validation systems. We have not attempted in this design to look into the shock question that was mentioned during the introduction, but at a later date when this equipment has served its purpose it could be a very useful tool to answer some of the questions.

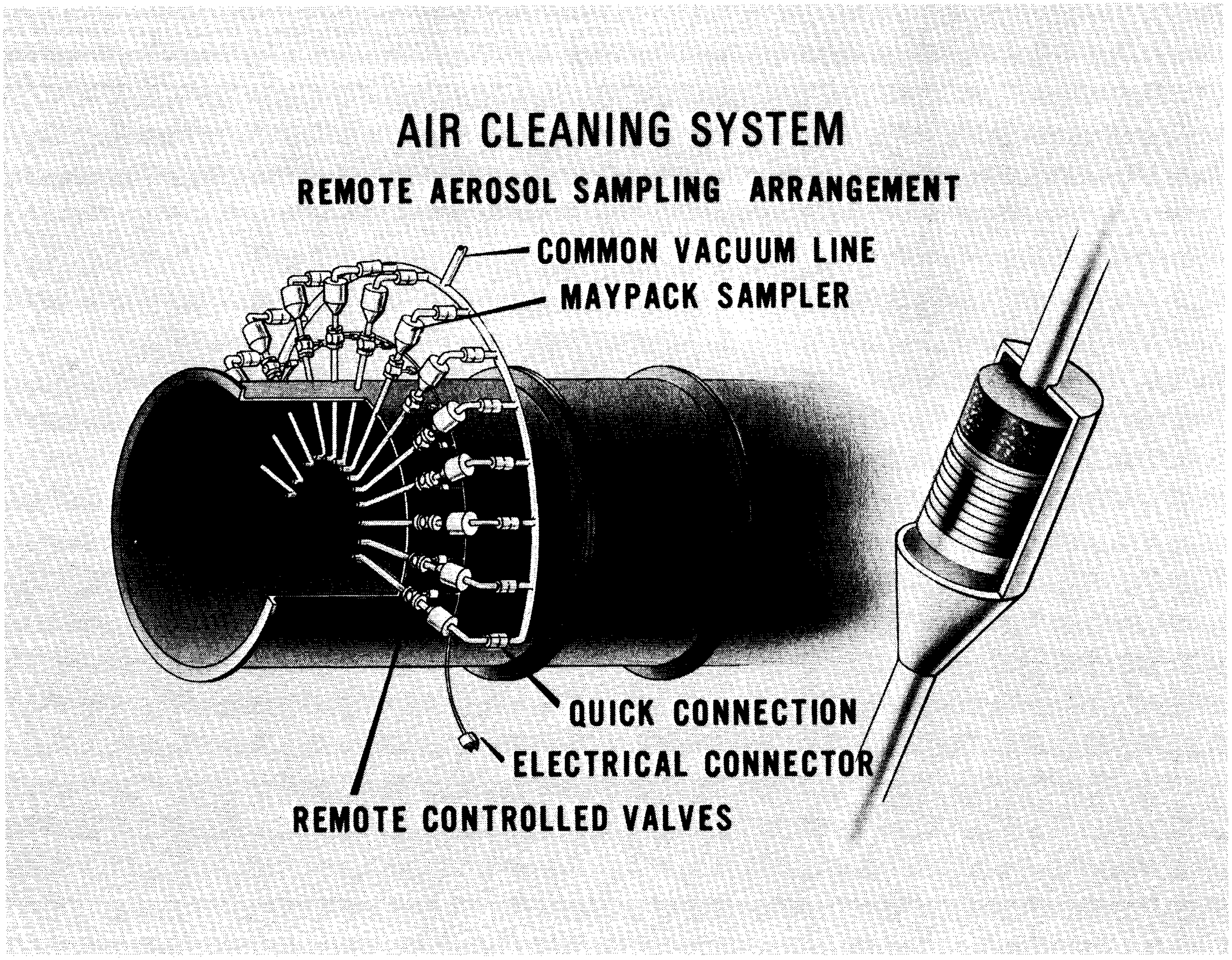
AIR CLEANING SYSTEM
REMOTE AEROSOL SAMPLING ARRANGEMENT
COMMON VACUUM LINE
MAYPACK SAMPLER
QUICK CONNECTION
ELECTRICAL CONNECTOR
REMOTE CONTROLLED VALVES

Figure 5

Part II - Presented by Mr. McCormack

It's self-evident that air cleaning systems are designed to remove and retain fission products from containment atmosphere. However, there have been few if any large scale tests to demonstrate that they do in fact accomplish this effectively from a realistic post-accident environment.

The major efforts to date as witnessed by this air cleaning conference and earlier ones have been on defining the individual component performance of the air cleaning train.

So, then, if I could have the first slide, Table III. We think that one of the principal objectives of the CSE air cleaning test could be to demonstrate the effects of the air cleaning loop on the containment atmosphere.

We feel that this is the most important thing that the CSE could accomplish with air cleaning tests.

The CSE is well suited to do this for several reasons: We think the scale is large enough to be significant. We can use commercial type and size of components. We can have realistic flows both through these components and through the containment vessel itself. We can establish in the containment vessel realistic post-accident environments, as far as temperature and pressure and aerosol concentrations are concerned. The vessel has good geometry characteristics; that is, there are interconnecting rooms which are typical of many reactor containment situations and which do complicate things. The facility is completely instrumented and we have, as Cliff mentioned, sampling points for measuring fission products throughout the vessel. We have complete temperature monitoring equipment within the vessel. We can keep track of the material balance with time by sampling liquid streams and so on.

And, further, we have a characterized system. We've made natural process tests and will make more natural process tests which demonstrate the behavior of the system in the absence of the engineered safeguards. In order to properly evaluate the impact of the engineered safeguards, you must know what would happen without them.

While that is the main objective, we are certainly trying to do other things with the air cleaning system. We would examine the air cleaning system performance as function of time. We would take samples between each cleaning component, as Cliff mentioned, so we would know the individual efficiencies. We would look for such things as impregnant loss, for activity in condensate streams, and for distribution of the activity in the charcoal beds. That's why we have several beds. We would propose two half-inch beds and one one-inch bed and would look at the distribution without having to dissect the individual beds. The third thing we might think of doing is to look at the response of the loop to the post-accident environment.

TABLE III

TEST OBJECTIVES

Air Cleaning Systems

(1) Containment Atmosphere Response

(2) Air Cleaning System Performance

(3) System Mechanical Response

TABLE IV

GAS CONCENTRATION TIME DEPENDENCE*

(Internal or External Recirculation Systems)

$$\frac{C}{C_o} = e^{-\left(\frac{FE}{V} + \frac{kA}{V}\right) t}$$

Where C = concentration in gas

C_o = concentration at time = 0

F = system flow rate

E = efficiency

V = vessel volume

k = mass transfer coefficient for natural processes

A = surface area in vessel

t = time

*Assuming gas phase is always well mixed.

Now, CSE really isn't an environmental testing station, but we certainly would make what observations we can on motor and fan reliability, on such things as gasket disturbance by the temperature and on the effect of the atmosphere on the filters.

Table V shows some of the variables we can think about if we did have a loop installed. The component arrangement is certainly up to question, do we have condensers, for instance, and reheaters? This is another question. Do we use the demisters? What about the flow rate to the containment vessel? This is certainly a variable to be considered. Containment atmosphere; is there any relation to the humid air and elevated temperatures and filter loop behavior? This is certainly important. Fission product form and concentration could be a variable to study. Specific loop location, internal or external, as Cliff mentioned, could be studied. Intake and exhaust locations again are open to question. Do the circulation patterns enforced on a containment vessel reinforce the natural convection patterns or are they opposed to it? What is the flow of pattern in relation to these other chambers and rooms that I mentioned? And, another variable could be component age.

Obviously, at CSE we cannot examine all of these variables in the proposed number of tests and we will arbitrarily perhaps, but necessarily, try to fix some of these variables.

Component age--most reactor cleaning systems aren't used until they're needed. Therefore, they're unexposed to atmospheric dust and protected from organic vapors and so on. Therefore, we propose to use new components for each CSE test. We will fix the intake/exhaust locations. System location, we will assume has been located internally although it doesn't necessarily matter for the purpose of our discussion today. Fission product type and concentrations, we propose to fix for a series of tests. We have developed somewhat of a standard mixture that we use to run our natural process tests.

Containment atmosphere, we would like to vary. Flow rate, we would like to vary. Component arrangement is variable.

You might combine these remaining variables into a series of tests and Table VII shows the aerosol release, the system's component arrangement, the recirculation rate as containment vessel volumes per hour, and the approximate test atmosphere.

The first test is a base case, humid air, with a short aerosol release. We would use all the components, first the condenser, than the demister, filter and charcoal beds. The second test then would be to look at the atmosphere as a variable. We would propose to use the same test arrangement except that the vessel would be pressurized with steam and air to 250 degrees F. The third test would determine the effectiveness of the air cleaning loop deleting the condenser.

TABLE V

TEST VARIABLES

Air Cleaning Systems

(1) Component Arrangement

(2) Flow Rate

(3) Containment Atmosphere

(4) Fission Product Type and Concentration

(5) System Location; Internal or External

(6) Intake and Exhaust Locations

(7) Component Age

Table VI

TYPICAL INITIAL AEROSOL CONCENTRATIONS

Containment Systems Experiment

Elemental I_2	95 mg/m^3
Particle Assoc. I_2	$\sim$ 4 mg/m^3
Methyl Iodide	1 mg/m^3
Cs_2O; CsOH	10 mg/m^3
UO_2 - Zr-2	$\sim$10 mg/m^3

TABLE VII

PROPOSED CSE AIR CLEANING TESTS

Test	Aerosol Release	System Components	Recirc. Vol/Hr	Contain. Atmos	Purpose
1	Puff	Full	2	Air, 80°F	Atmos.
2	Puff	Full	2	S-A,250°F	Atmos.
3	Puff	No condenser	2	S-A,250°F	Condenser
4	Puff	Full	4	S-A,250°F	Recirc. rate
5	Continuous	Full	2	S-A,250°F	Source term
6	Puff	Full	2	S-A,180°F	Atmos.

TABLE VIII

SUMMARY

CSE Air Cleaning Systems Tests

Full Sized Components

Characterized Containment System

Selected, Controlled Environment

Measure Containment Response

Measure System Performance

The recirculation rate is certainly an important variable. To change this is somewhat difficult experimentally. You could provide parallel loops but it's expensive and time consuming to make the change. It's hard to change the volume in the containment vessel, so we propose by using properly sized fans to increase the flow rates through the existing air cleaning system.

We recognize that this will probably reduce the individual component efficiency in the train, but on the other hand, the overall cleaning effectiveness is related to the product of the flow and efficiency. We think we will gain more than we will lose.

The source term of the aerosol is another variable that has been mentioned previously and we would propose to make one test using a long term generation of the aerosol. The air filter system would be running during this entire time. Additional tests at other conditions could be made if needed.

Figure 6 is a schematic of the CSE vessel showing the arrangement for a typical natural process run. This is a typical layout and as you can see, the aerosol is injected in the main room by the steam jet compressor. The other features to notice are the interconnecting rooms as mentioned earlier.

The squares represent the places where we can locate the Maypack clusters and take atmospheric samples. We have a window where we can view and places where we can take samples for immediate analysis.

Figure 7 shows the actual interior of the vessel with the clusters hanging in place. There are 12 Maypacks in each cluster and we can have up to 15 clusters throughout the vessel. You can see the flexible vacuum hoses, electrical cables, and suspending cables that hold these Maypacks. The CSE Maypack arrangement uses particulate filters for solid aerosols, followed by silvered screens, charcoal paper and charcoal beds.

Our analysis is generally by gamma counting of cesium and iodine and alpha counting of UO_2.

Table VI shows a typical aerosol mixture.

We, in general, have been making runs based on the MCA and inject about 100 mg. of iodine per cubic meter of containment volume. We generate the aerosol from separate furnaces. We vaporize elemental iodine, we vaporize cesium oxide, and we vaporize UO_2 + cladding fumes, blend them together and put them into the vessel. After delivery a typical mixture might be about 95 per cent elemental I_2, 4 or 5 per cent of the iodine commonly will be found on particles.

We add one per cent of methyl iodide. The cesium concentration is about 10 mg. per cubic meter. It can be released as the oxide, however we think and will rapidly convert to the hydroxide in the steam atmosphere. The UO_2 is about there at 10 mg. per cubic meter concentrations.

SCHEMATIC OF CONTAINMENT VESSEL ARRANGEMENT USED IN CSE RUNS A-1 AND A-2

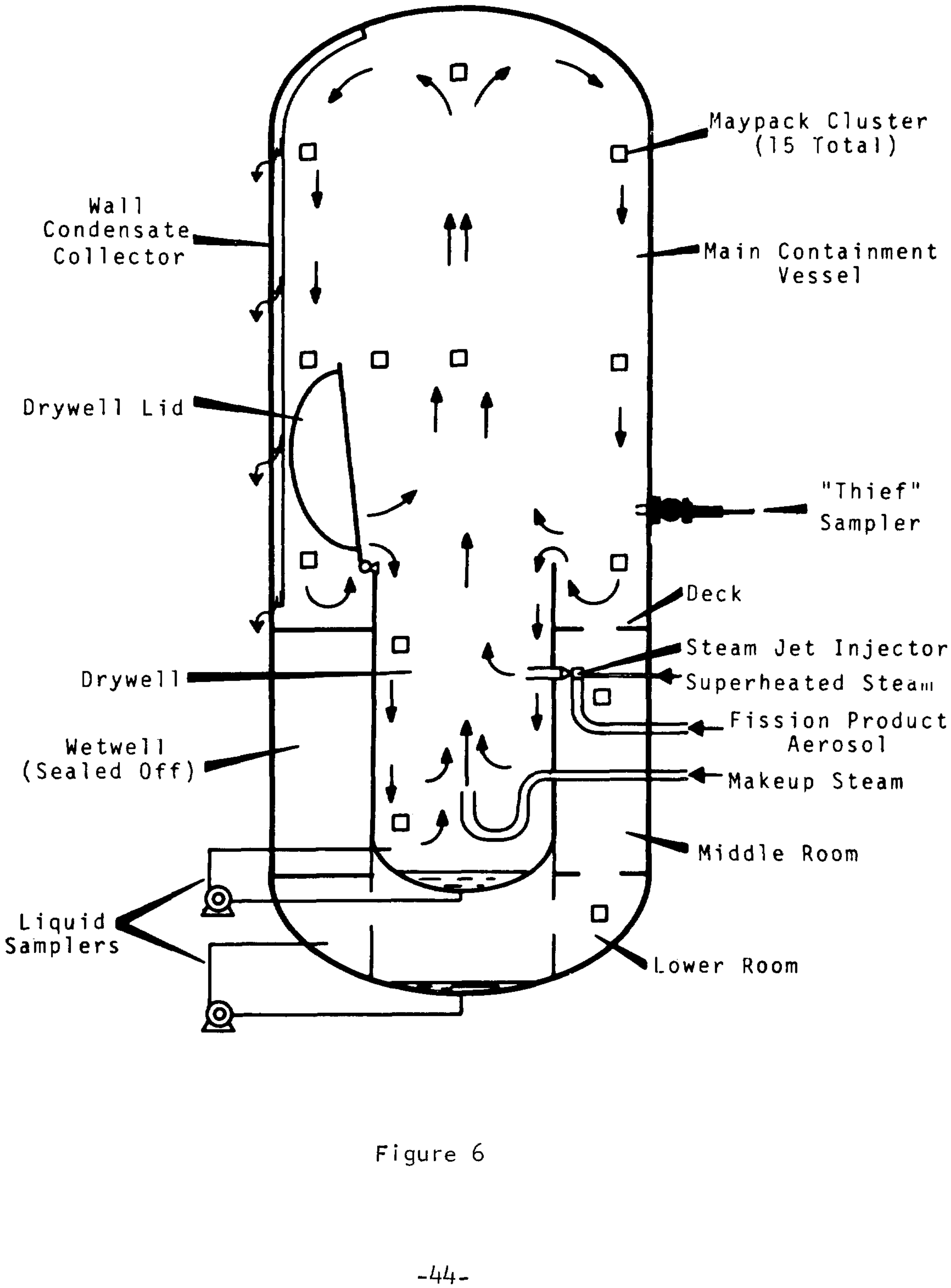

Figure 6

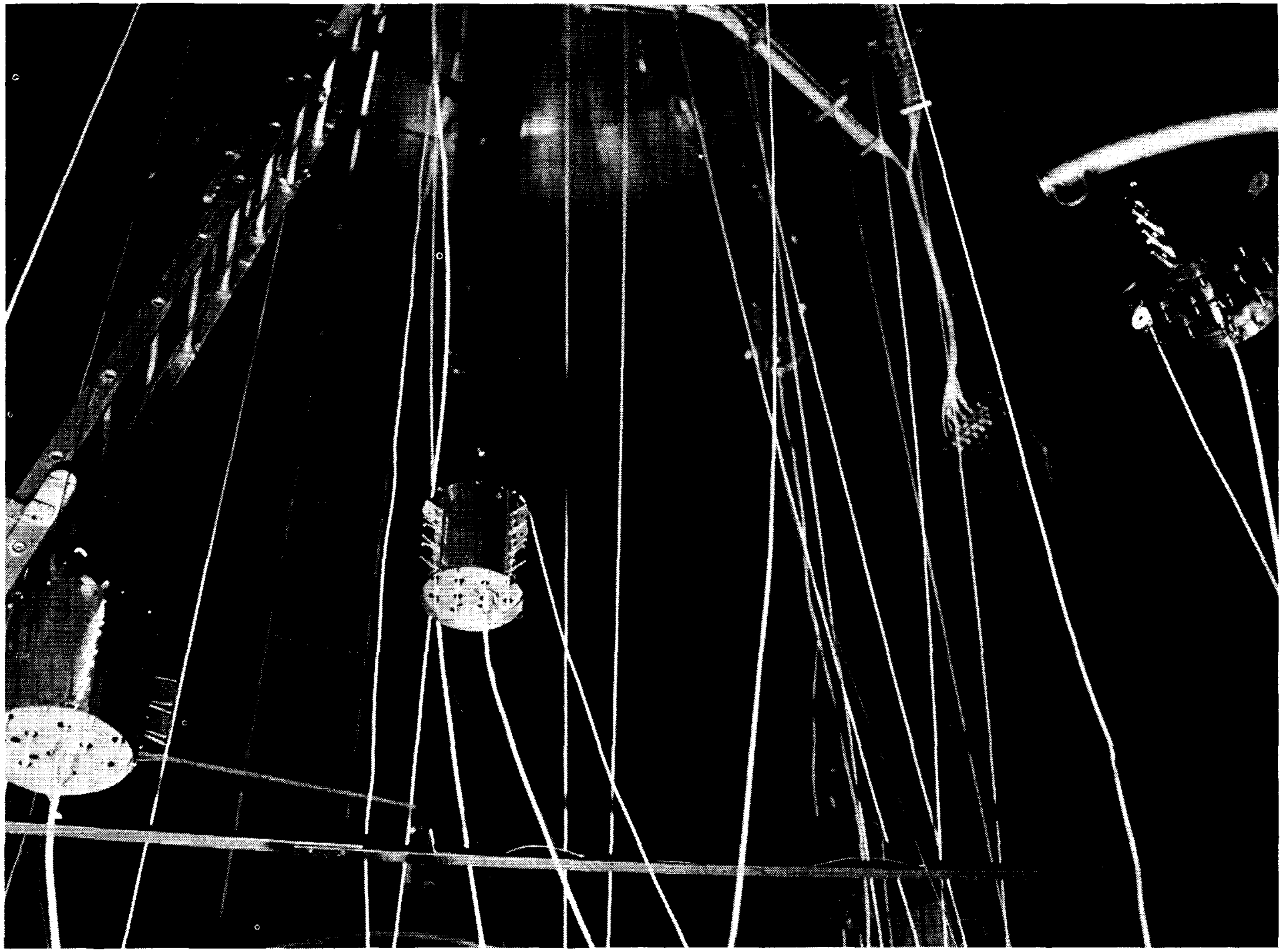

Figure 7 Interior of vessel with clusters hanging in place

A typical run would consist of the installing sampling equipment, installing a filter train, DOP testing the filter train, leak testing the vessel, pressurizing the vessel with steam and air for the conditions required, releasing the aerosol, allowing a few minutes to mix and then sampling the atmosphere so that we know the initial conditions. The filter train flow would then be started, and additional atmospherics and loop samples taken. A typical run lasts 24 hours. The steam feed is held constant.

What forces are at work inside the vessel during this time? We can make simple guesses--could I have the next slide?

Table IV shows about the simplest guess you can make on the behavior of the gas concentration in the vessel as related to the flow rate and the efficiency of the loop.

Helping deplete the airborne concentration this will be also the natural processes which are also at work. You can look at this (K) as a mass transport coefficient of iodine into the condensate film on the vessel wall and this makes the point that we need to know what the natural processes are in order to evaluate the effectiveness of the filter, because what we measure is the atmospheric concentration for a period of time.

For instance, in a recent run at 250°F in the CSE the natural convection caused a mass transport of elemental I_2 such that the concentration was reduced to about one-half in 14 minutes.

By the same token, our air cleaning loop operating at 1,000 cfm would be expected, in a well mixed model like this, to have approximately a 20 minute half time. These processes would combine to give an overall system half time for a test, with the loop running, of 8 minutes. Obviously, it would be improper to credit that 8 minute half time entirely to the air cleaning system.

The data in Figure 8 shows airborne concentrations for iodine in a typical test. This is the logarithem of vapor concentration, iodine in this case, for a run at 180°F from the Maypack data. We see an exponential decrease for an hour or so, and then there's a gradual tapering off as deviations from this very simple model become in Table IV important.

Another thing this curve shows is that in fact the vessel is well mixed. You can see from the data points, which are at some nine locations in the vessel, that the spread is satisfactorily small and this justifies use of a simple, well mixed model.

Figure 9 shows one of the reasons for the deviations. In this figure airborne cesium particulate material is shown. The aerosol, you will recall, is released into the main room and the primary steam condensation is in the main room and consequently the material mixes rapidly there. The material diffuses from the main room into the middle and into the lower room. You can see the build up of cesium concentration at these locations with increasing time.

IODINE GAS PHASE CONCENTRATION VERSUS TIME IN THE MAIN VAPOR SPACE -- RUN A-2

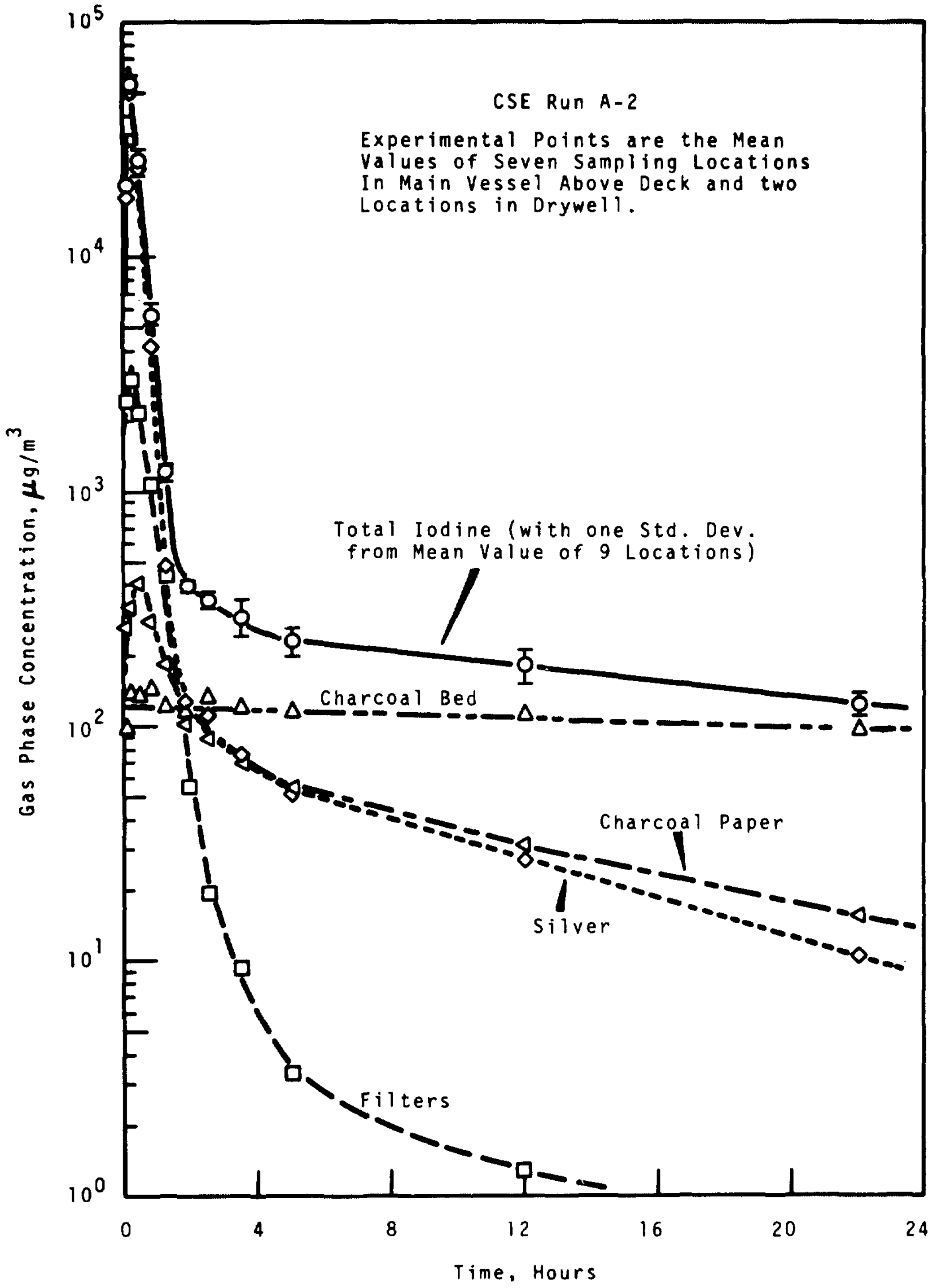

Figure 8

CESIUM GAS PHASE CONCENTRATION VS TIME IN INTERCONNECTED VESSEL COMPARTMENTS -- RUN A-2

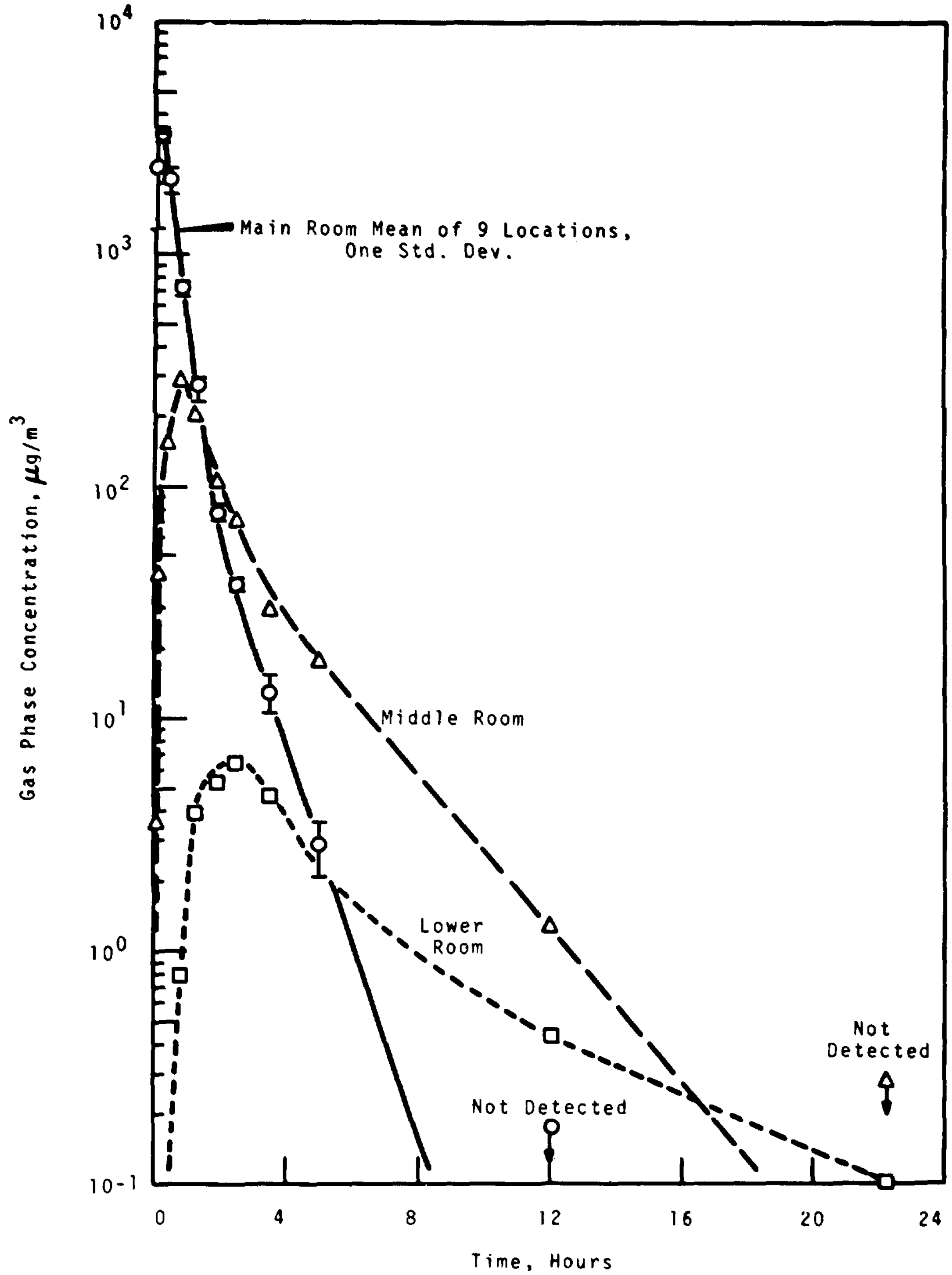

Figure 9

Later, these concentrations are higher than in the main room because of higher steam condensation in the main room and these other compartments are now acting as sources as material diffuses into the main vessel. Hence, the puff release model no longer applies. These are illustrations of some of the deviations you can get from this very simple behavior.

Well, then, to summarize look at Table VIII. We think that air cleaning tests in the CSE might have some of these features. We think that being able to use full size components is a desirable feature and that the flow rate through the vessel can be realistically sized.

We do have a characterizing containment system, the natural processes are being evaluated, and we think this is very important.

Our vessel is fully instrumented and we feel this is important to understand the performance of the air cleaning system. We can effectively control the environment. We would attempt to gain information on containment response as the primary thing of interest. We would also look at the system performance during the tests.

DISCUSSION

THOMAS: I'd like to make a comment on Mr. Viles' remark regarding in-place testing where you think the solid aerosol would be a better selection than a liquid aerosol. Actually I suppose it would be closer to real conditions than a liquid aerosol but I think, as a practical matter, it doesn't make any difference.

First, we've done some work at our laboratory which shows no difference in penetration between liquid and solid aerosols. We used latex for the solid aerosol and DOP for the liquid aerosol. It really doesn't make any difference which aerosol you use for in-place testing.

Penetration in in-place tests is usually due to defects, bad gaskets, etc., which act as pinholes. Obviously if you have a one or two millimeter hole it's not going to make any difference whether you use a liquid or solid aerosol, or what the particle size is (within limits), since the hole is hundreds of times as large as the particle. I think it might very well boil down to a matter of economics and convenience what aerosol is used for in-place testing.

Incidentally, at our laboratory we did make a test using condensation nuclei and DOP and on the same filter system and we got little or no difference in filter system penetration.

VILES: The reason why I discussed the question of liquid and solid aerosols for testing was to raise a discussion on this subject. Mr. Adams, if he's still here, might support me on this. In some of the studies made at Oak Ridge with HEPA filters, efficiencies obtained were considerably lower than 99.97 and yet these were supposed to be good filters and probably they were. Whether they were tested on DOP or not I don't know.

It's simply a question of in-place testing where the filters themselves didn't measure up to standard on the basis of using a uranium aerosol.

Would you want to discuss this Mr. Adams?

ADAMS: We feel that the in-place DOP test method is actually a system test for locating holes or bypass in filter systems. The point we wish to make is that one should not assume the 99.97 percent efficiency value for DOP aerosol when rating a filter system against other aerosols. We find that uranium oxide aerosols do penetrate filter media somewhat more readily than 0.3 micron DOP droplets - the penetration being greater under wet conditions.

VILES: I think I was wrong in placing this subject in the in-place test rather than a R and D category. I just want to bring out that just because it is 99.97 per cent efficiency on DOP, it may not be for another aerosol and that you'd better check your aerosol if you want to know more accurately what the efficiency is.

FIRST: I didn't get a chance to examine your test results in detail as they flashed on the screen rapidly, but I wondered about the equation in which the transport coefficient "K" appears to be a constant. It seems to me that "K" should be concentration dependent because conditions are changing in the vessel including particle size. Therefore, the relative importance of natural plate out in the vessel versus clean up half time for the filtration system as a whole may change quite radically as time goes on. I would be happy to have your comment on that point, but first I would like to make another comment which you may wish to answer at the same time.

It concerns the matter of the number of vessel changes per hour through the clean up system. It seems to me that two volume changes per hour is a very small number. Even four would be a slow ventilation rate and I have the impression that if one really wanted to clean things up in a hurry, much larger volumes would be required. I would like very much to see the system built in such a way that more than four air volume changes per hour could be utilized in one or more experiments.

McCORMACK: We welcome your comments on volumes. We picked two perhaps arbitrarily but we are willing to listen.

In regards to the "K" being constant, the constant and the half life given were for elemental iodine. We have found it to be a constant during the first hour or so. We feel the mass transport is caused by the convection velocities in the vessel, and can be predicted. Less is known about the behavior of the particles. We don't have a simple equation to describe particle deposition.

VILES: I might make mention that the average conventional reactor design air changes on air clean up systems is roughly four air changes an hour.

I'd like to direct a question to Mr. McCormack, please.

You have mentioned that you had a concentration of 95 milligrams of iodine per cubic meter of air which corresponds, according to my calculation, to 9.5 parts per million. This seems quite high, at least in comparison to what's anticipated for a maximum credible accident with conventional containment.

McCORMACK: We decided our aerosol release earlier based on CSE scaling factors and this was about what we came up with as a peak following a MCA. We have tended to use that quantity in our tests although if we decide to change we can.

VILES: Is that what you predict might be the case in an actual event?

McCORMACK: If you look at our data back there this is about what we come up with.

VILES: This is interesting. It's sometimes difficult to get enough information to make a calculation and usually when I do it comes to about a tenth of a part of a million for iodine. Of course, you run into the situation where you have one or two ppm, but I hadn't realized that it could be as high as 9 ppm.

NITTI: I'd like to clarify that point. Our calculations agree with Jerry McCormack's. Assuming that 25 per cent of the iodine in the fuel becomes airborne, for large power reactors the airborne iodine concentration during a PWR loss of coolant accident is expected to be between 10 and 100 milligrams per cubic meter depending on the amount of fuel burnup. I think Mr. Viles may have overlooked some of the other iodine isotopes, like 127 and 129.

VILES: That is right, I did overlook these. Very good.

ROBERTS: Is this test applicable to a pressure-supression system?

McCORMACK: Well, some of the results will be, yes and if we really understand the loop behavior and if we know that's going back into the vessel, we could make appropriate allowances for that; obviously, it's not a once-through system and it doesn't duplicate that as well.

ROBERTS: Could you modify the test to be "once through" and thereby yield information applicable to pressure suppression systems?

LINDEROTH: Yes and I mentioned this rather hurriedly.

This is just a matter of repiping the discharge stack to a large penetration on the containment vessel so it will exhaust externally. Some other changes would be necessary.

First of all we would have to put in a flow control system so that during the initial part of the test the air flow will be induced by the pressure differential between the containment vessel and the external atmosphere. Secondly, once the differential is nil we would then open another port in the containment vessel and turn on the fan to move clean air into the containment vessel to mix with the contaminated air. The mixture would flow through the filter system and out to the atmosphere so it would be a once-through system.

ROBERTS: Could you put the gases through the pressure-suppression wet well?

LINDEROTH: It could be done.

BURCHSTED: In the function of the test was there any effort to determine the system's response? Is there any plan to do any rapid pressure rise test and, if so, to what pressures and at what rate of rise?

LINDEROTH: This particular system is not specifically designed to study effect of shock waves which I interpret you are referring to. But we do believe it may have some use in future tests when we do install the simulator--if you recall, my first slide showed the simulator--this vessel is rated at 600° and 2500 psi and has a volume of 150 cubic feet. We are capable of rupturing discs up to 6 or 8 inches diameter located in one of its nozzles which would release pressurized high temperature water in a matter of a couple of seconds. This I am sure would subject the filter system to a shock. I would prefer studies on shock effects be delayed until we exhaust all the other parameters of interest first!

BURCHSTED: No, the point is not so much shock as the effect of a rapid pressure transient.

The pressure in the containment space may, according to some estimates, increase to as much as 40 to 50 psig in some power reactors in 1 to 10 seconds. Since the filter housing is a small contained volume within the larger volume of the containment space, the pressure rise in the housing will probably lag behind that in the containment space -- my question is, how will the duct and filter housing react to this resultant differential in pressure?

The other point I'd like to make is, how far could these tests be carried so far as system response is concerned, because I feel that the pattern of system deterioration is unknown and it's very important to find out how far it deteriorates in a given period of time as well as to know what its performance is.

McCORMACK: We prefer not to get into the environmental test business but we will make what observations we can with the normal run of two to three days at temperature.

We dislike extending this time for several reasons. We like to move into the vessel soon after a run to get our samples out, so as not to disturb the analytical aspects of the test.

ISBIN: Is the last statement of your paper Mr. Viles meant to say that power reactors should include both the spray system and the filter bed system?

VILES: Yes, and something else if we can put it in!

The concept is this, Morrison at Battelle--I don't know whether Dave is here today or not, but I think some of his co-workers are--raised the question about the possibility of failed containment, and this always has to be recognized, and based on his computer calculations and considering all the facts that were available, he concludes that the optimum time of failed containment would be roughly one-half hour after coolant rupture. He's sort of pleading that we shouldn't forget this and endeavor to do everything we can to effect a good clean up within this one-half hour period in case containment does fail.

Now, in order to do this with a conventional filter charcoal system, we would have to have very high capacity systems for a couple of million cubic feet containment and this might be impractical, but we probably could do it with a conventional internal recirculation system, supporting it with reactor sprays and possibly gas phase reactions or something else that may be developed in the meantime.

I see no objection to the multiple use of clean up arrangements providing they don't interfere with each other.