Session 4

AIR CLEANING SYSTEM DESIGN

MONDAY: October 20, 1980
CHAIRMAN: R.R. Bellamy
Nuclear Regulatory Commission

OPENING REMARKS OF SESSION CHAIRMAN:

Welcome to Session 4 of the 16th Air Cleaning Conference, entitled "Air Cleaning System Design." In this session, we will get away from the specialized approach all too prevalent in air cleaning today, and not concentrate simply on filters, or fans, or blowers, or whatever. In this session we will present six papers that will tie entire systems together, present methods of analyses for these systems, and also the results of such analyses on entire ventilation systems. We will also discuss data obtained from pre-operational testing of a pressurized water reactor, and become educated about some specialized reactors from Canada and also the Breeder Project.

It is interesting to note the foreign influence in this session, and their high regard for the quite necessary overall system review. One-half of our speakers will be from outside the United States.

SAFETY EVALUATION OF LARGE VENTILATION NETWORKS

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Abstract

For large ventilation networks, it is necessary to make a safety evaluation of their responses to perturbations such as blower failure, unexpected transfers , local pressurization....

This evaluation is not easy to perform because of the many interrelationships between the different parts of the networks, interrelationships coming from the circulations of workers and materials between cells and rooms and from the usefulness of air transfers through zones of different classifications. This evaluation is all the more necessary since new imperatives in energy savings push for minimizing the air flows, which tends to render the network more sensitive to perturbations.

A program to evaluate safety has been developed by the Service de Protection Technique in cooperation with operators and designers of big nuclear facilities and the first applications presented here show the weak points of the installation studied from the safety view point.

I. Introduction

When analysing the safety of large ventilation networks, one must know the response of these networks to diverse perturbations from inside or outside the facility. But, responses of ventilation systems are often difficult to evaluate when interrelationships between different parts of the network are numerous. This situation is risky from the safety view point :

- during the conceptual phase, because one cannot precisely choose the basic ventilation parameters (flow rates, number of air changes, leakage levels, number of fans in operation and on standby...) as to minimize the consequences of the main perturbations.

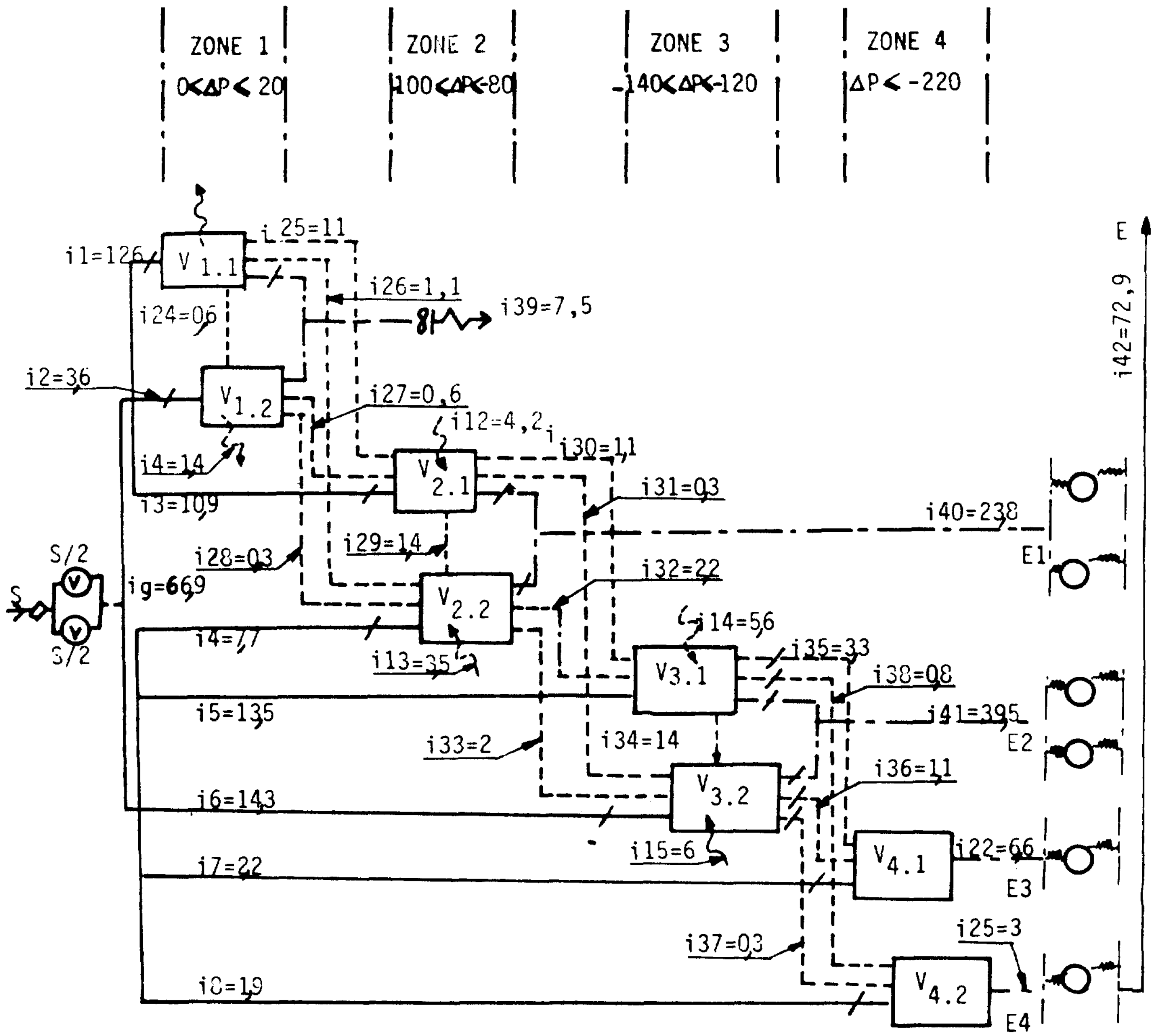
- during the operating phase, because a tool for quick evaluation of the network behaviour in any circumstance would help to guide at best the ventilation system.

A program has then been decided by the Institut de Protection et Sûreté Nucléaire in cooperation with operators and designers of big nuclear facilities where high level products are manipulated.

The objective of this paper is to describe the drive to set up this tool of assistance for design and management of ventilation networks and to present the first results obtained.

II. Description of the network studied

The ventilation network studied first is the one in figure 1.



i:Flow-rate in m^3/s E:air exhaust S:air intake

V_{kl}:Volume of one or several rooms

FIGURE 1
TYPE OF FACILITY STUDIED

In this figure, V_{ij} represents one or several rooms. The structure of the facility is classical : classification of rooms in controlled areas of different pressure, only one inflow with regulation of flow rates by dampers, numerous transfers between rooms, specialized outflows by area, leaks towards outside for positive pressure rooms and towards inside for negative ones.

The flow of ventilation air and the laws directing it can be simply represented by the electrical analogy in figure 2.

In this figure, rooms are represented by pressure knots.

The system of equations governing the ventilation network has the following structure :

Resistant branches

$|\Delta p|\ ri^2$ and $\Delta p = Ri$

where r is a resistance of damper type, R is a resistance of HEPA filter type, p is the pressure and i the flow in the branch.

Branches with fans

one fan

$\Delta p = a - b\ (i - c)^2$

which is a parabolic approximation of the fan curve.

n fans in parallel

$\Delta p = a - b\ (j - c)^2$

$I = n\ i$

P fans in operation among n

$\Delta p = a - b\ (j - c)^2$

$J = p\ j$

The fan laws can also be introduced numerically.

Balance of flows

For each knot, Σ i (input) = Σ i (output)

III. Utilization of ASTEC Code

In order to easily handle such a system, a computer code was necessary. The electrical analogy which has been mentioned above has driven us towards ASTEC code.

ASTEC is a software product distributed by the Compagnie Internationale de Services en Informatique (CISI). Aimed at treating electrical or electronic circuits, this code can also simulate systems governed by differential or algebraïc equations in continuous, transition or alternative states.

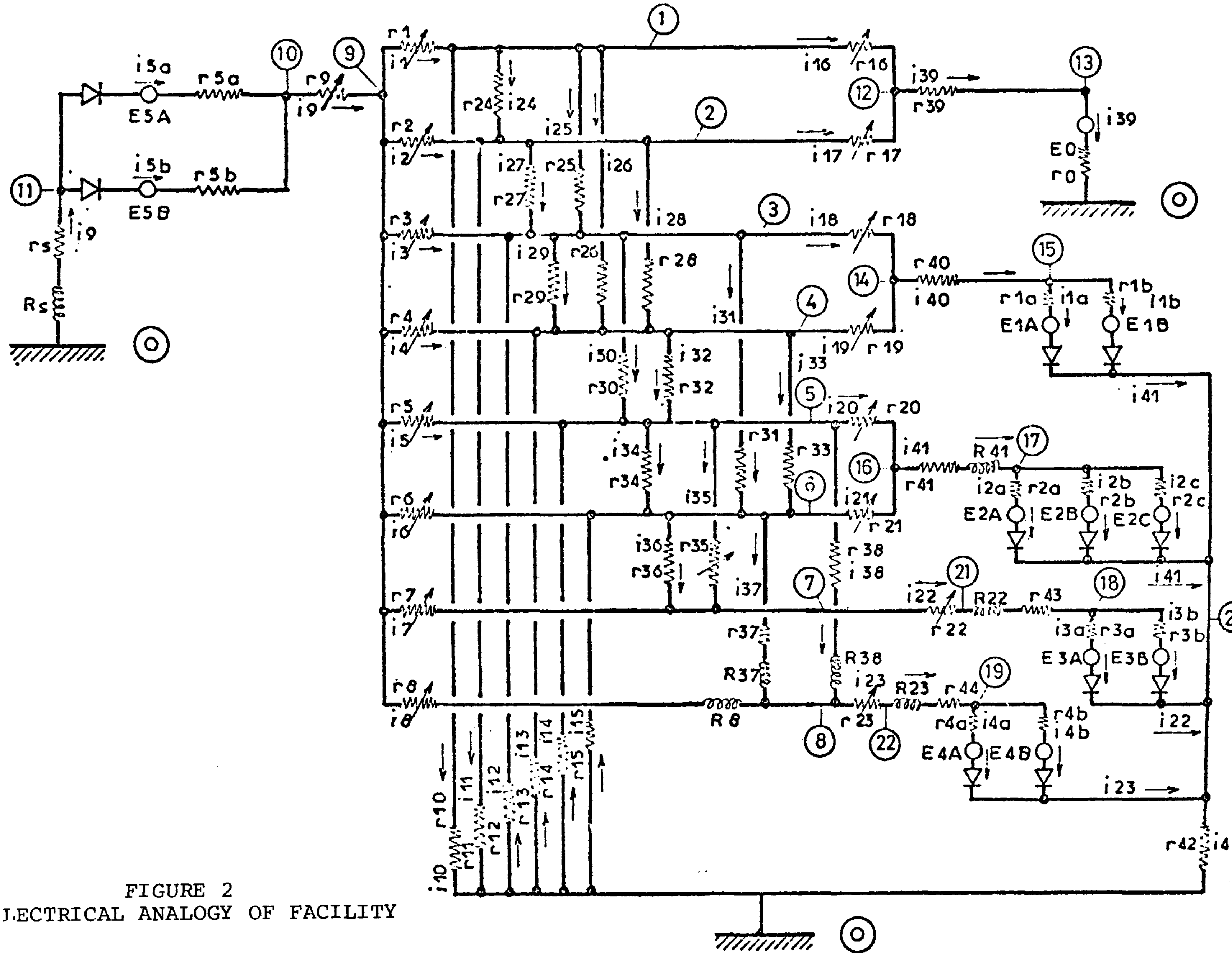


FIGURE 2
ELECTRICAL ANALOGY OF FACILITY

The performances obtained, as for core requirements or calculational time allow currently ASTEC to be utilized by the leading French companies for solving electronic problems and also thermal (Spacelab), biologic, hydraulic problems...

In our case, the equations of resistance for filters, and the equations of equality of input and output flows at each knot are equations of an electrical type, already written in the code.

We had only to add equations of resistances for dampers and equations for fans so that ASTEC could be adapted to our problem.

IV. Results

We have first calculated by hand a normal operating state of the network described above. This calculation has given the resistant characteristics of the circuit and has allowed the determination of the fans to be utilized. Knowing the r, R and the fan characteristics, we have then validated our utilization of ASTEC code in making it recalculate outflow rates and pressures of the circuit.

Considering the agreement of results, we could then study on computer other states resulting from the following disturbances:

Disturbances on the fans

The failure of one or several extract fans in areas one to four has been studied. The same has been done for one or two inlet fans.

Disturbances in the network

Pressures : We have evaluated :

- the influence of a variation of dampers on inflows.
- the states corresponding to equalization of pressures between different rooms of the same area or of different areas.
- the influence of a variation of outside pressure.

Flow rates : We have studied :

- the influence of different leakage flow rates.
- the obturation of some inlet and extract branches.
- the isolation of a room, for example, in case of fire.

Results

Among the numerous disturbances studied, we have selected some of them which show the application of our code for nuclear safety of ventilation networks.

These results are presented in tables I (pressures) and II (flow rates).

Table I. Pressures for reference and disturbances cases

Pressure knot Number	Reference Pa	Failure of extract E_3 Pa	Failure of extract E_4 Pa	Pressure equalization in area 3 Pa	Obturation of branch 6 Pa
1	+ 20	+ 25	+ 22	+ 20	+ 33
2	+ 10	+ 14	+ 12	+ 10	+ 19
3	- 80	- 51	- 68	- 81	- 92
4	- 101	- 59	- 83	- 102	- 152
5	- 122	- 61	- 95	- 131	- 187
6	- 142	- 88	- 118	- 131	- 393
7	- 222	- 46	- 197	- 224	- 366
8	- 394	- 346	+ 72	- 396	- 459
9	+1008	+1033	+1025	+1008	+1317
10	+1208	+1229	+1222	+1208	+1478
11	- 997	- 987	- 990	- 994	- 866
12	- 100	- 97	- 98	- 100	- 91
13	- 250	- 248	- 249	- 250	- 244
14	- 800	- 781	- 791	- 800	- 815
15	-1200	-1191	-1197	-1201	-1209
16	- 999	- 964	- 984	- 997	-1106
17	-2001	-1987	-1995	-2000	-2044
18	-2001	- 46	-1995	-2001	-2031
19	-2825	-2814	+ 64	-2826	-2842
20	+ 10	+ 8	+ 9	+ 10	+ 9
21	-1001	- 46	- 986	-1003	-1089
22	-1070	-1035	+ 72	-1072	-1118

Table II. Flow rates for reference and disturbance cases

Branch Number	Reference outflows m^3/s	Failure of extract E_3 m^3/s	Failure of extract E_4 m^3/s	Pressure equalization in area 3 m^3/s	Obturation of branch 6 m^3/s
1	12.7	12.8	12.7	12.7	14.4
2	3.6	3.7	3.6	3.6	4.1
3	10.9	10.9	11.0	11.0	12.5
4	7.7	7.7	7.7	7.7	8.9
5	13.6	13.3	13.5	13.6	15.6
6	14.4	14.2	14.3	14.3	0

7	2.2	2.1	2.2	2.2	2.6
8	1.4	1.4	1.1	1.4	1.7
9	66.5	66.0	66.2	66.5	59.8
10	4.2	4.7	4.4	4.2	5.4
11	1.4	1.6	1.5	1.4	1.9
12	4.2	3.4	3.9	4.2	4.5
13	3.5	2.7	3.2	3.5	4.3
14	5.7	4.0	5.0	5.8	7.0
15	6.0	4.7	5.5	5.8	10.0
16	5.6	5.6	5.6	5.4	5.7
17	1.9	1.9	1.9	1.9	1.9
18	14.0	14.1	14.0	14.0	14.0
19	9.8	10.0	9.9	9.8	9.5
20	16.9	17.1	17.0	16.8	17.3
21	22.6	22.8	22.7	22.7	20.6
22	6.6	0	6.6	6.6	6.4
23	2.9	3.0	0	2.9	2.9
24	0.6	0.6	0.6	0.6	0.7
25	1.1	1.0	1.0	1.1	1.2
26	1.1	0.9	1.0	1.1	1.4
27	0.6	0.5	0.6	0.6	0.7
28	0.3	0.2	0.3	0.3	0.4
29	1.4	0.9	1.2	1.4	2.4
30	1.1	0.5	0.9	1.2	1.7
31	0.3	0.2	0.3	0.3	0.7
32	2.3	0.7	1.7	2.6	2.9
33	2.0	1.7	1.9	1.7	4.9
34	1.4	1.6	1.5	2.3	4.5
35	3.3	- 1.3	3.3	3.2	4.4
36	1.1	- 0.8	1.1	1.2	- 0.6
37	0.4	0.4	- 0.3	0.4	0.1
38	1.0	1.1	- 0.8	1.1	1.1
39	7.5	7.5	7.5	7.5	7.6
40	23.8	24.1	23.9	23.8	23.6
41	39.5	40.0	39.7	39.5	37.9
42	72.8	67.0	70.3	72.8	70.7

General comments

- For most of the disturbances, we noticed that the hierarchy of pressures is disturbed only locally and rarely, which is satisfying from the safety view point.

- The reequilibrations of flow rates mainly come from leakages ; which constitute a kind of "lung" for the ventilatior network; a more detailed study of leakages will allow a determination of ratios of volume to level of sealing for rooms.

- Registered flow rate variations will need more detailed studies when security flow rates are necessary.

Particular comments related to tables I and II

- Failure of extract E_3: The reversal of pressure P_6 and P_7 produces a rather strong reversal of the air flow between $V_{4.1}$ and $V_{3.1}$ (i_{35}) and a weaker reversal between $V_{4.1}$ and $V_{3.2}$ (i_{36}). The leakage flow rates i_{12} to i_{15} (rooms from areas 2 and 3) are diminished, so as the transfer flow rates from area 2 to 3 (i_{30} and i_{32}).

Failure of extract E_4 : The same type of reaction as above is registered, but the modifications of flow rates are weaker. The main disturbance consists of a reversal of air flow between $V_{4.2}$ and $V_{3.1}$ (i_{38}) and between $V_{4.2}$ and $V_{3.2}$ (i_{37}).

Pressure equalization in area 3 : The hierarchy of pressures (apart from equipressure in area 3) is maintained. One interesting phenomena is the formation of a regulation loop between $V_{2.2}$, $V_{3.1}$ and $V_{3.2}$ (decrease of i_{33} is compensated by increase of i_{32} and i_{34}).

Obturation of branch 6 : Pressures P_6 and P_7 are reversed, which produces a reversal of air flow between $V_{3.2}$ and $V_{4.1}$. Leakages are strongly increased, such as the inlet flow rates and transfer flow rate between $V_{3.1}$ and $V_{3.2}$.

V. Actual program of utilization and prospects for development of the code

These first results allow, first, an appreciation of the actual possibilities of the code and, second, an anticipation of more ambitions development.

Actual utilization of the code

Indirect assistance in design : In the first application described in this paper, the code has been utilized for a type of assistance in the design that we call "indirect" : from a study of several disturbances, we can deduce rules concerning the main parameters of a ventilation network, the structure of which is almost determined. Action is indirect because the code does not calculate the optimal steady state, but it can verify that the states which are presented to it are stable from a safety view point.

Assistance to management : For existing facilities, utilization of the code for assistance to management is perfectly suitable. The state of ventilation of the facility is entered with the most in situ measured data (flow rates, pressures...) and we can for example :

- Simulate any disturbance in order to deduce a strategy of management in case of an incident, accident or intervention.

- Detect more quickly the origin of a modification of permanent ventilation parameters.

- Optimize the set-up an automatic pressure control system.

Prospects for development

The following development prospects are foreseen :

Design optimization : Knowledge of the behaviour of the ventilation system gained by the above disturbance studies will progressively allow a thorough optimization of the design of ventilation facilities by making optimal structures from the safety view point

Ventilation control : In some exceptionnal situations (important accident, disturbance from unknown origin, delicate intervention...), one must react as rapidly as possible to limit the consequences.

Manual action must then be assisted or replaced by an automatic action. The automatic control systems actually under development (particularly decentralized hierarchised command) allow real time control of ventilation in such cases.

The code will serve as a basic tool for data storage (structures, strategies) and for computer control programs.

EXPERIMENTAL DATA REQUIRED FOR THE DESIGN AND ANALYSIS OF EMERGENCY FILTERED AIR DISCHARGE SYSTEMS

by J.D. Jefford and R.J. Fluke

Abstract

The radiological consequences of an accident in a CANDU nuclear generating station are mitigated by special safety systems which include an Emergency Filtered Air Discharge (EFAD) system. EFAD systems are designed to provide a controlled leakage path following an accident. They remove radioiodine and particulates from the air discharge required, to inhibit uncontrolled emissions by maintaining containment sub-atmospheric in the long term. The design and analysis of an EFAD system requires an accurate data base comprised of the numerous parameters involved in the simulation of fission product behaviour within containment.

This paper emphasizes the data requirements of EFAD system design with regard to those parameters which preliminary sensitivity analyses have shown to most effect environmental releases. These include the source term radioisotopes; their chemical behaviour and distribution within containment; the repressurization time during the vacuum hold-up period (a feature of CANDU multi-unit containment systems); and parameters effecting the long term releases through the EFAD system. The net radioiodine trapping efficiency of charcoal filters in the long term is dependent on the adsorption efficiency and desorption of the deep charcoal bed. These are a function of many parameters such as impregnate, aging, humidity, temperature, radiation, recirculation, etc.. Although the effect of these parameters on charcoal filters has been individually investigated, generally at ideal or extreme values, there is little applicable data to determine their combined effect under expected post accident operating conditions. As a consequence, designers tend to overdesign by using unduely conservative parameters. This invariably leads to unnecessary cost penalties both in terms of capital cost and maintenance.

A summary comparison is presented to illustrate the information gap between the experimental data from the literature and the data required for optimal design and analysis of the EFAD systems.

Introduction

Safety System designers in conjunction with analysts are required to ensure that the radiological consequences of an accident will not exceed the regulatory dose limits. All pathways and interactions must be accounted for to determine the adequacy of the safety systems in protecting the public under all postulated accident conditions. Since not all of the physical and chemical processes which serve to mitigate the consequences of an accident are well understood, conservative assumptions and parameter sensitivity analysis are used to ensure the public will not receive an excessive dose of radiation.

To provide an understanding of the CANDU negative pressure containment system and the emergency filtered air discharge system, a brief review of these systems is given.

Some of the experimental data desired may be specific to the CANDU negative pressure containment system. However, many of them should be applicable to all charcoal filtration systems.

CANDU Negative Pressure Containment System

In the CANDU multi-unit stations, such as Darlington NGS, all four reactor vaults are interconnected via the fuelling duct to the pressure relief duct as shown in Figure 1. In the event of an overpressurization in the pressure relief duct, the self actuating pressure relief valves open relieving the pressure into the vacuum building which is illustrated in Figure 2. Following the brief over pressure pulse, which initiates containment box-up, the vacuum building has sufficient reserve to compensate for instrument air and inleakage and can maintain an unimpaired containment subatmospheric for approximately nine days (see Figure 3).

Emergency Filtered Air Discharge System

When the vacuum is expended, the EFAD system then provides a controlled filtered exhaust which effectively maintains containment subatmospheric for a period of several months. The Darlington system is shown in Figure 4. Air is drawn from containment and if desired a portion of the flow can be recirculated. The EFAD system components have been described previously[1] and are shown schematically for convenience in Figure 5.

Summary Comparison of Experimental Data Desired vs Experimental Data in the Literature for Optimal Design and Analysis of EFAD Systems

a) Long Term Iodine Removal Efficiency for Charcoal Filters

Following an accident, the EFAD system is intended to operate continuously for several months after the vacuum reserve has been depleted. Consequently, the primary concern is with the iodine removal efficiency of the charcoal filters under conditions of continuous loading. Presently, the majority of experimental data available deals with loading iodine on the charcoal filters for one or two hours then measuring the desorption rate over the next four hours. A parameter sensitivity analysis was performed and some of the results are shown in Figure 6. However, it is difficult to determine whether recirculation is desirable based on the range of efficiency and desorption data given in Figure 6. The facility for recirculation has been provided pending experimental data to verify its desirability.

b) Iodine Concentration

With the large containment volume (2 x 10^5 m^3) and the negative pressure hold-up time (9 days) provided by the pre-established vacuum, the atmospheric iodine concentrations seen by the charcoal filters are initially expected to be less than 0.5 $\mu g/m^3$. The present standards for radioiodine testing of nuclear grade gas - phase adsorbents require iodine test concentrations which are orders of magnitude higher (e.g., RDT 16-1T[2] specifies I_2 concentration of 17.5 mg/m^3). The applicability of this higher concentration data to the lower concentrations is uncertain.

c) Relative Humidity

From previous experimental data it has been determined that high humidities are detrimental to the iodine removal efficiency of charcoal filters. Consequently standards such as ANSI N510[3] require emergency filtration systems to have moisture separators and heaters to reduce the relative humidities seen by the filters to below 70% RH. By requiring the charcoal filters to be tested at 95% RH, the standards and experimenters appear to be overly conservative.

d) Aging

Emergency filtered air discharge systems, since they are a safety related system, are not operated (except for testing) until required after an accident occurs. The majority of aging data is determined with a continuous air flow. Since EFAD systems are subject to static aging, it is very difficult for designers to determine the optimum depth of bed and stand-by storage conditions to achieve the best trade-off between initial bed depth and frequency of replacement.

e) Radiation

The relatively few experiments which have been published on the desorptive effects of radiation, have used extremely high fields and unfortunately also 95% RH (eg. Evans[4] at 10^5 Gy/h (10^7 R/h)). Predictions indicate that the fields due to the radio-active iodines adsorbed will be in the order of 10^2 Gy/h (10^4 R/h).

f) Holistic Effects

Although the difficulty in performing long term experiments with combined parameters to simulate operating conditions is appreciated, it seems reasonable to perform experimental tests on the charcoal under the set of conditions predicted by accident analysis (i.e., initial aging, temperature, humidity, radiation fields, appropriate concentration of chemical forms of iodine, inclusion of noble gases and hydrogen in the air flow, etc.).

Conclusions and Recommendations

From a safety system designer's and analyst's point of view, in order to optimize emergency filtered air discharge systems and to improve the accuracy of accident analysis, less conservatism should be used for individual parameters during testing and more effort should be given to trying to reproduce the combined parameter conditions that would be expected under post accident operating conditions.

References

1. R.J. Fluke and J.D. Jefford, "Post Accident Filtered Air Discharge," Proceedings of CNA Nineteenth Annual International Conference, Toronto, June, 1979.

2. RDT Standard M16-1T "Gas - Phase Adsorbents for Trapping Radioactive Iodine and Iodine Compounds," U.S. Department of Energy, December, 1977.

3. American National Standard ANSI N510, "Testing of Nuclear Air Cleaning Systems," American Society of Mechanical Engineers, 1975.

4. A.G. Evans, "Effect of Intense Gamma Radiation on Radioiodine Retention by Activated Carbon," Proceedings of the 12th AEC Air Cleaning Conference, Oak Ridge, Tennessee, August, 1972 (Conference 720823), pp. 401-415.

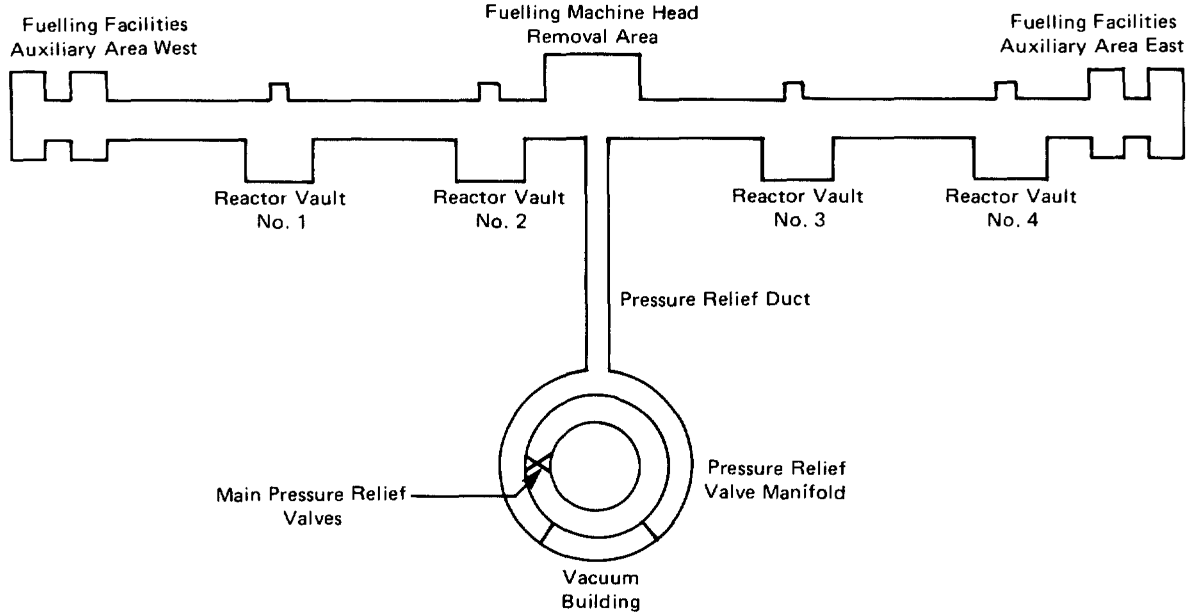


FIGURE 1
Containment Envelope

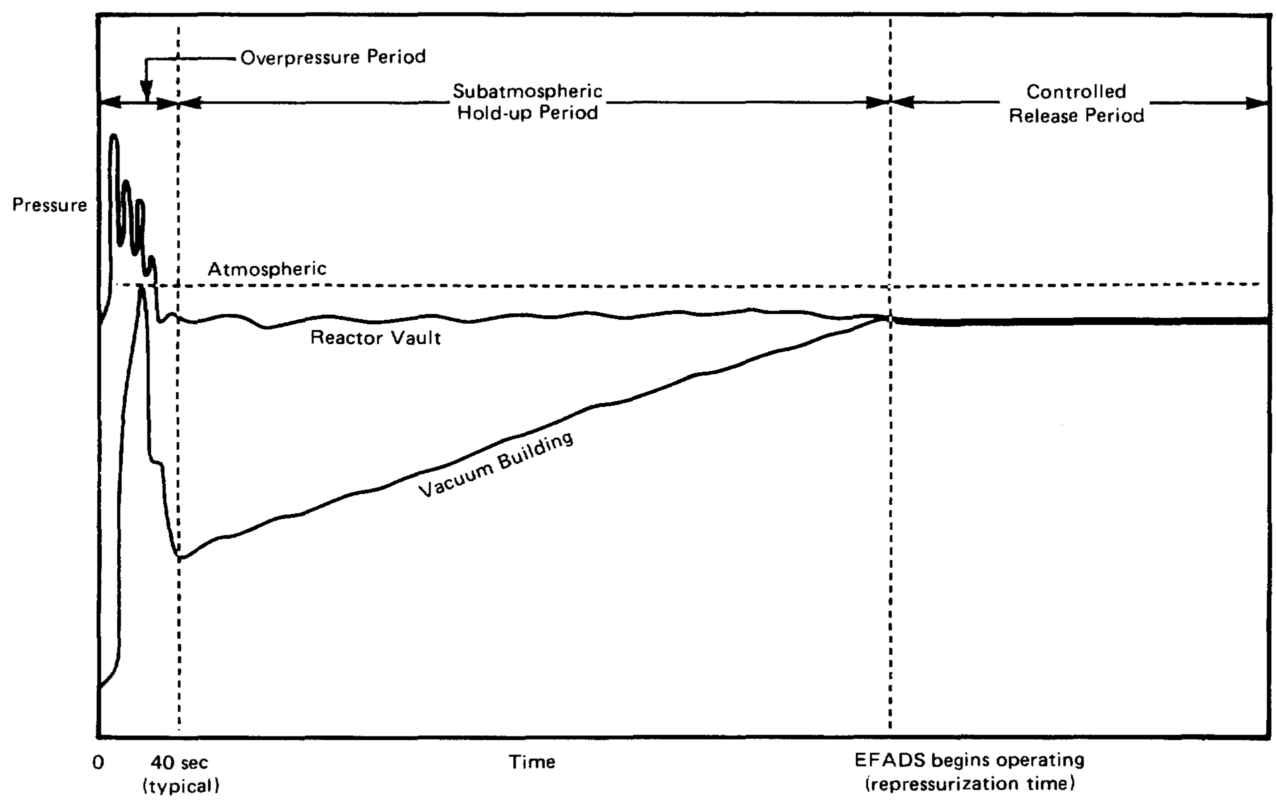


FIGURE 3
Long term containment atmosphere pressure following LOCA

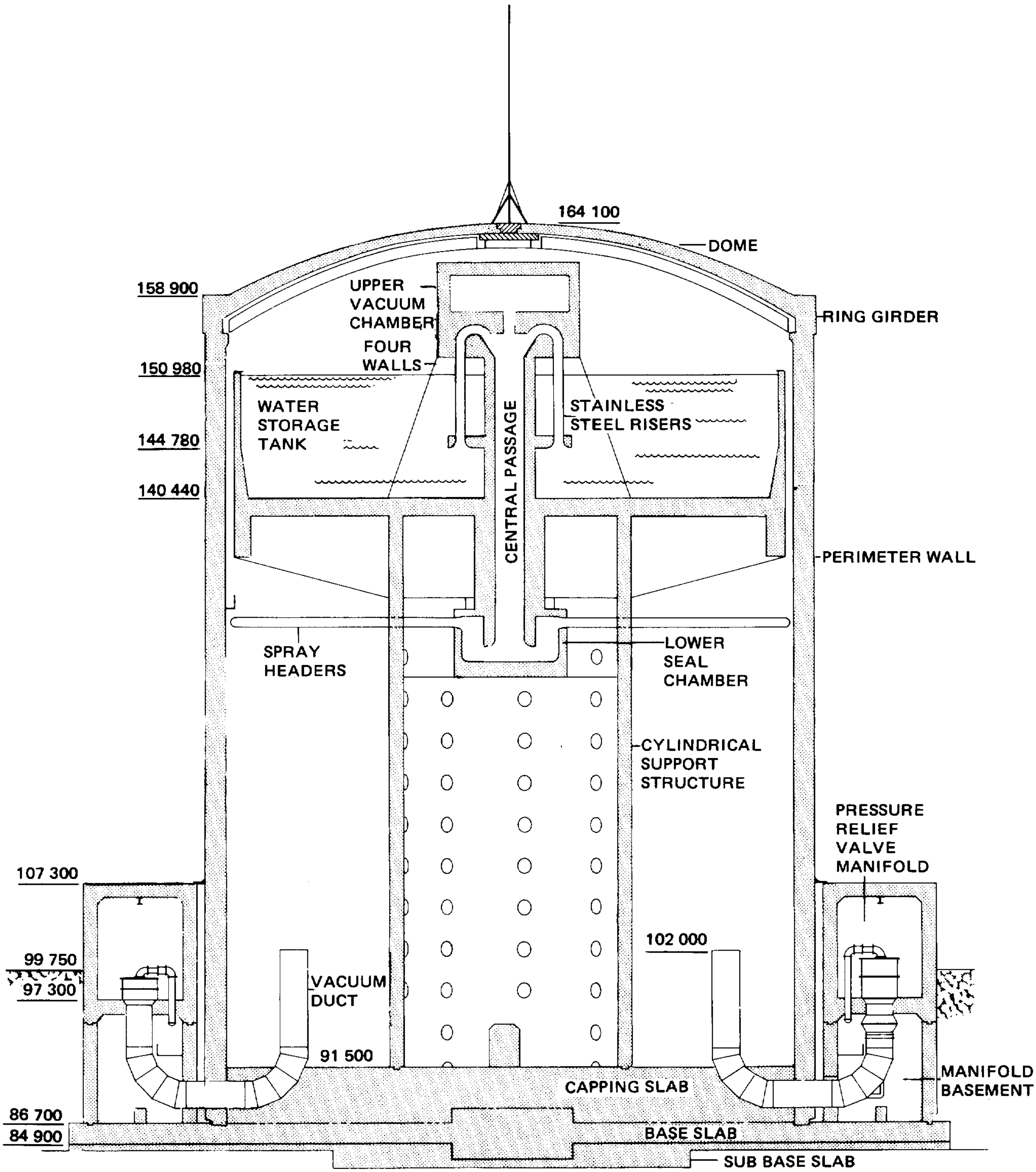


FIGURE 2
Vacuum Building Cross Section

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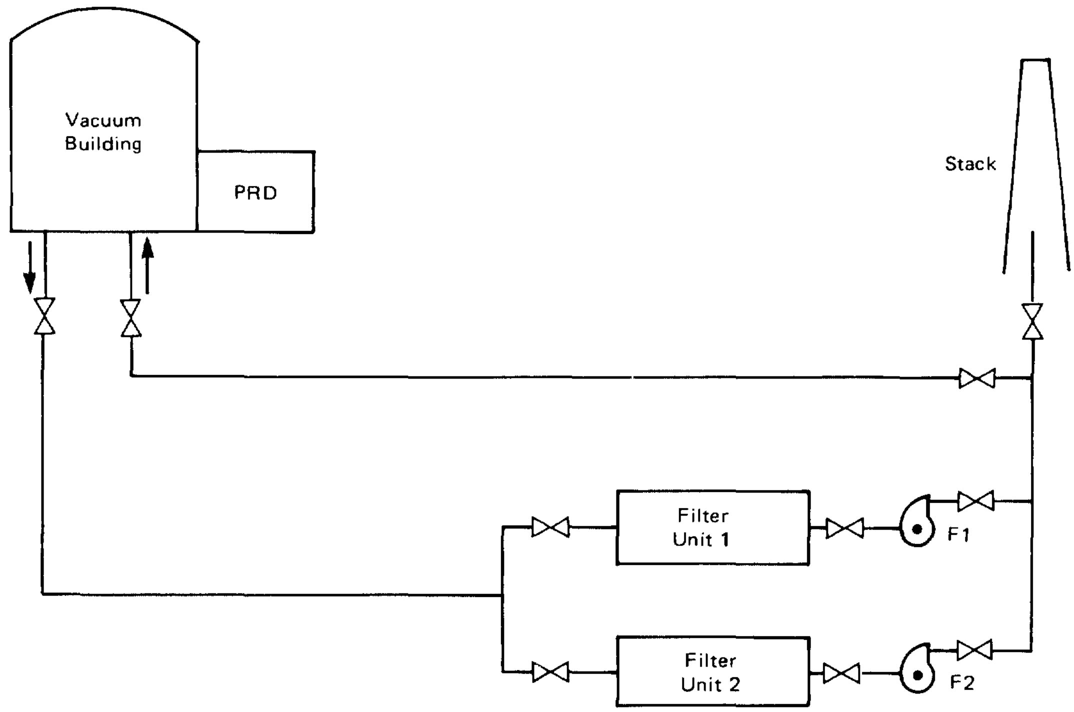

FIGURE 4
EFAD System Arrangement

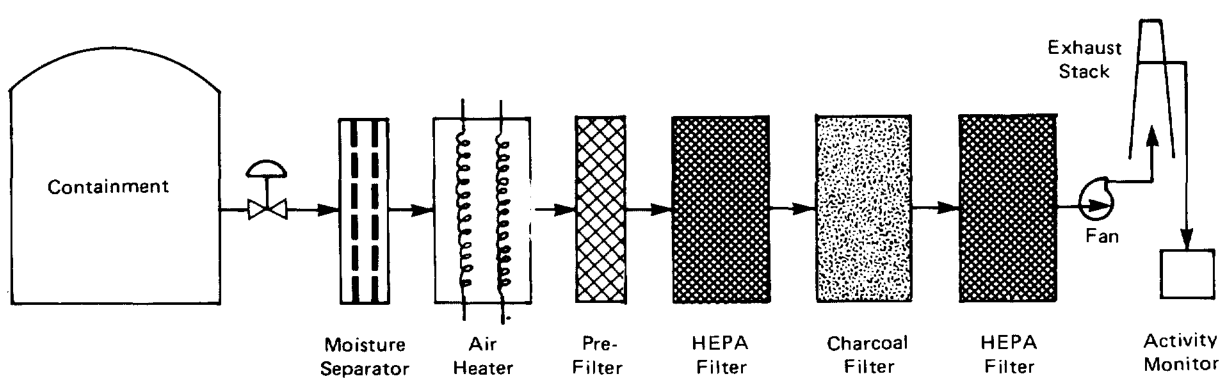

FIGURE 5
EFAD System Components

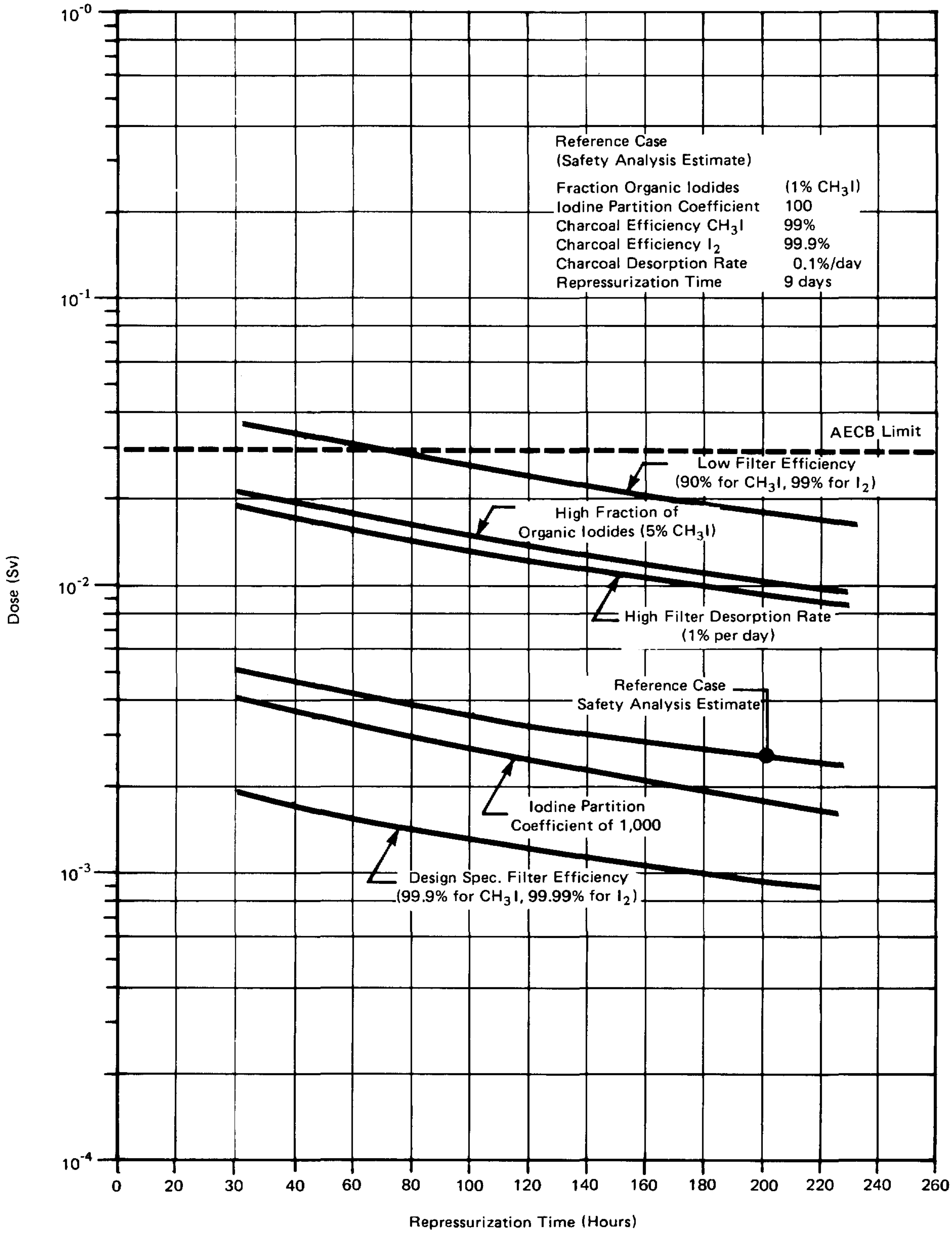

FIGURE 6
Long Term Integrated Dose To Critical Individual at the Boundary Fence:
Sensitivity of Thyroid Dose (Sv) To
Parameter Variations on Iodine Behaviour
(Large Break with Unimpaired Containment)

DYNAMIC ANALYSIS OF THE CRBRP CLEAN-UP SYSTEM

(Three Stage Aqueous Scrubber)

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Abstract

The CRBRP containment clean-up system design required the determination of the thermal-hydraulic performance of the system during its projected operating cycle. The reduced scale component tests at HEDL provided valuable information about the generic performance of the components, however due to the limitations of the test facility the exact simulation of the actual CRBRP conditions was not feasible. A computer program was developed to permit dynamic system analysis of the full size air cleaning system. The dynamic system analysis considered the mass and energy balances across each component. In addition to the major filtration system components, the system modeling included the supporting fluid system components such as pumps, tanks and heat exchangers. Variable gas flow, temperature, chemical concentrations, and other system parameters were also modeled. Fission product heat, chemical reaction heat and heat of solution were considered. The analysis results provided sodium hydroxide solution concentrations and temperatures, gas temperatures and other variables at the various components within the air cleaning system for each calculated time interval. The accuracy of the computer modeling was verified by comparing the calculated results with HEDL test data. The comparison indicated a better than $\pm 10\%$ agreement with the test data. The analysis results provided the basis for the selection of the system components.

I. Introduction

The CRBRP design includes features to mitigate the consequences of a hypothetical core disruptive accident (HCDA). One of those features is the Containment Cleanup system.

Based on the evaluation of various LMFBR air cleaning concepts by HEDL (Reference 1), the CRBRP project selected a three stage aqueous scrubber system for the containment cleanup. The three stage system consists of a quench tank, venturi scrubber and high efficiency fibrous scrubber in series arrangement. To demonstrate the performance of the selected components, HEDL performed reduced scale demonstrations based on the development specification of the CRBRP project and sponsorship of the U.S. Department of Energy. The demonstration tests exposed the scaled down scrubber system to conditions similar to those expected during the CRBRP containment venting. Use of the experimental results for CRBRP dynamic analysis is summarized in this paper. The dynamic analysis evaluates the transient thermal performance of the full scale containment cleanup system. It was used to size some components of this system.

II. Definition of the Containment Clean-up System

Design Requirements

The CRBRP containment clean-up system is designed to remove 99% of all vented solids and liquids and 97% of all vented vapors. The system will have maximum capability for 26,400 ACFM flow rate, 30 PSIA pressure and 1100^{o}F temperature. The system is functional up to 5600 lb/hr. aerosol mass flow rate and capable to treat and store 3×10^5 lbs. aerosol entering the system. Table I provides the detailed system design requirements for the CRBRP containment clean-up system.

Table I System design requirements for CRBRP.

Principal constituents of aerosol:

$NaOH$ and Na_2O (Proportions between 0-100%)

Na_2CO_3 (Proportion 0-8%)

Aerosol particle properties:

Mass mean radius (microns)	$5 < r_{50} < 10$
Aerodynamic equivalent radius (microns)	$2.3 < AER < 4.7$
Density (g/cc)	$2.1 < \rho < 2.5$
Mass geometric standard deviation	$3.0 < \sigma < 3.5$

Fission products power level:

Time, Hours	Power, MW
0	0
24	3.1×10^{-5}
48	0.16
96	0.16
240	0.11
720	0.05

System Design Description

The containment clean-up system flow diagram is shown in Figure 1. The major filtration components of the system include the quench tank, venturi scrubber and the high efficiency fibrous scrubber. The auxiliary components are the solution tank, solution heat exchangers, and the circulating pump. Cooling water and make-up water are provided from the emergency cooling tower.

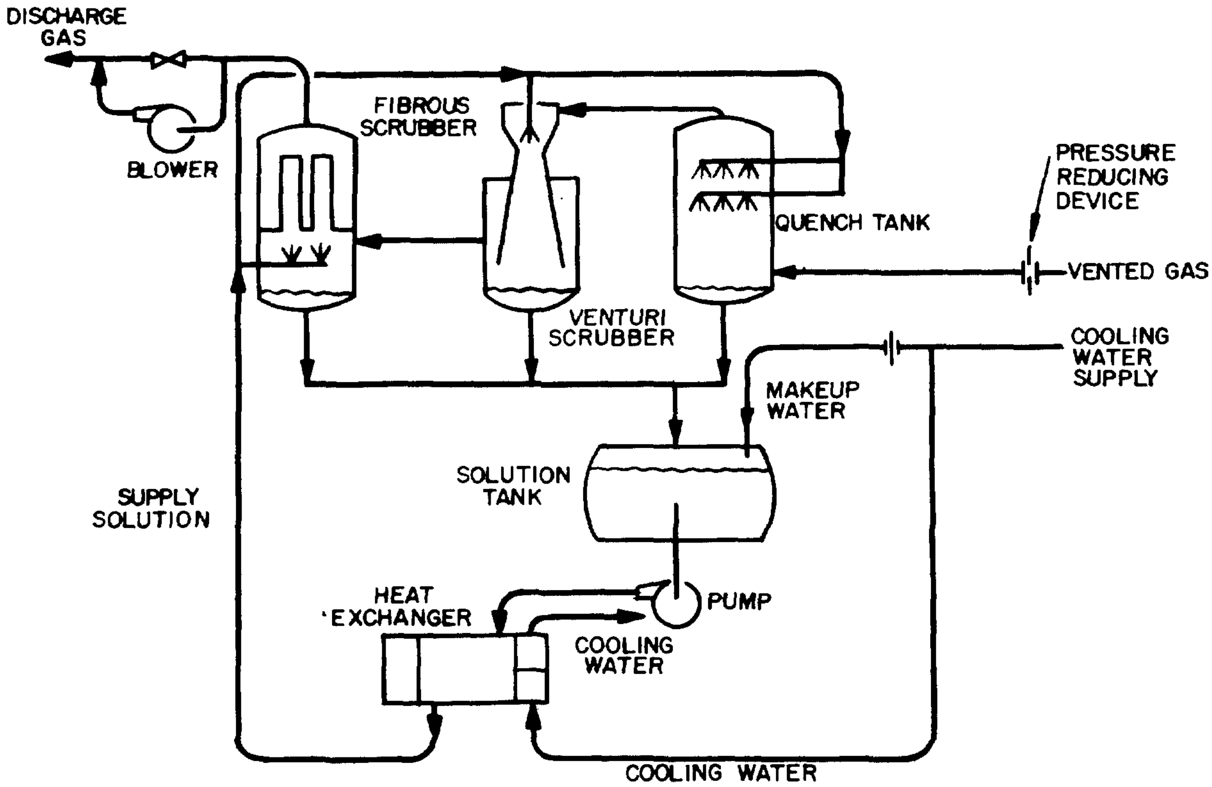

FIGURE I

CLEANUP SYSTEM FLOW DIAGRAM

The vented gases and aerosols are scrubbed and cooled in the quench tank. The configuration of the quench tank is shown in Figure 2. The design of the tank includes provisions to cool the vent gas from 1100°F to approximately 160°F with a peak vent gas flow rate of 26,400 ACFM.

The jet venturi scrubber provides prefiltering capabilities to reduce the aerosol concentration to prevent plugging of the high efficiency fibrous filter elements. The vented gas and aerosol is further cooled in this component due to the high water/gas ratio in the scrubber.

The high efficiency fibrous scrubber contains cylindrical polypropylene fiber elements housed in a steel tank. Spray nozzles provide mist to wash the fibers. The configuration of the high efficiency fibrous scrubber is shown in Figure 2.

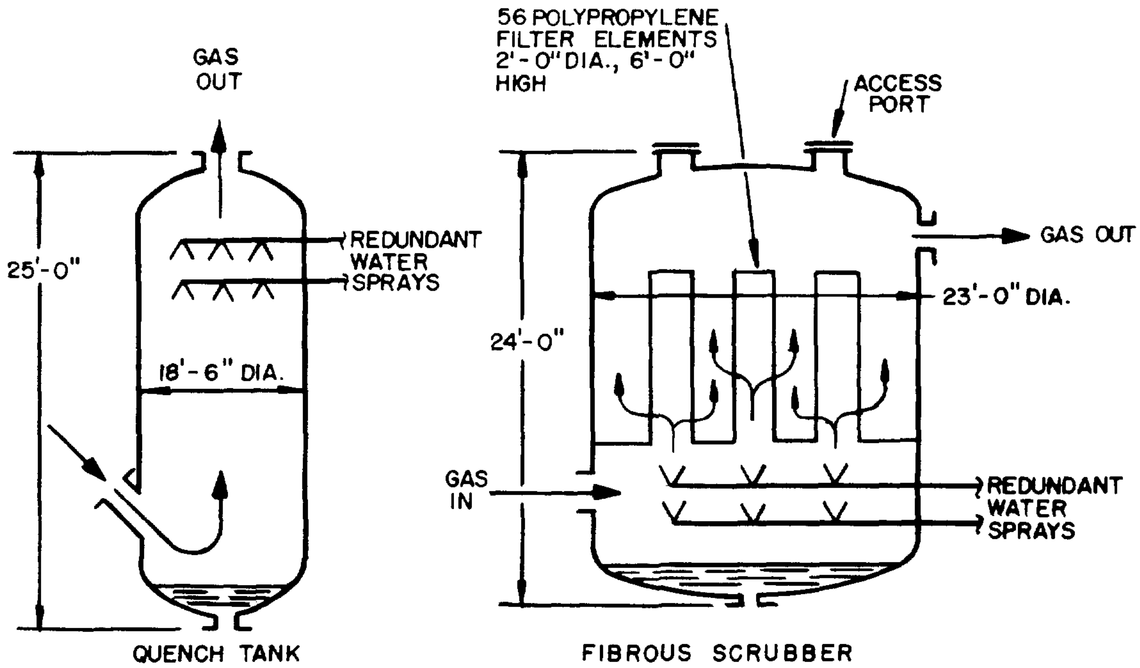

FIGURE 2

QUENCH TANK AND FIBROUS SCRUBBER CONFIGURATION FOR CRBRP

During the blowdown phase of the process, the containment pressure provides the motive force for the effluent flow. Following this period, one of the two redundant blowers maintains the required vent flow from the containment.

The solution circulated to the various components is cooled by cooling water from the emergency cooling tower.

III. HEDL Test and Comparison with CRBRP System Parameters

The detailed description of the HEDL test components, their arrangement, testing procedure and results of the first two tests is contained in Reference 2. The comparison of the test conditions and the expected CRBRP conditions is shown in Table II. CRBRP scrubber/filter components were selected so that their key parameters match with those of components used for the HEDL tests (See Table II). The flow diagram of the HEDL test setup is shown in Figure 3.

Table II Comparison of test conditions and key component specifications.

	CRBRP	HEDL Test AC1	HEDL Test AC2
Inlet gas temp., ^oF	670-1100	298-515	207-726
Inlet gas flow rate, SCFM	0-22781	0-1009	0-1014
Containment aerosol composition, % by wt.	NaOH and Na_2O (0 to 100%), Na_2CO_3 (0-8%)	70% Na_2O_2, 30% NaOH	NaOH, 0.7 H_2O
Average particle size, µm	7.7	3.6	4.2
NaOH concentration in solution, % by wt.	0-23.7%	0-8%	0-8%
Minimum Quench tank gas residence time, sec.	5.7	6.5	6.5
Maximum Quench tank gas velocity, FPM	200	150	150
Quench tank gas flow rate to solution flow rate ratio, SCFM/GPM	0-46	0-∞	0-∞
Venturi scrubber gas flow rate to solution flow rate ratio, SCFM/GPM	0-30	0-∞	0-40
Fibrous scrubber gas flow rate to solution flow rate ratio, SCFM/GPM	0-5700	0-12,000	0-∞
Fibrous scrubber max. face velocity, FPM	18.1	15.9	15.9

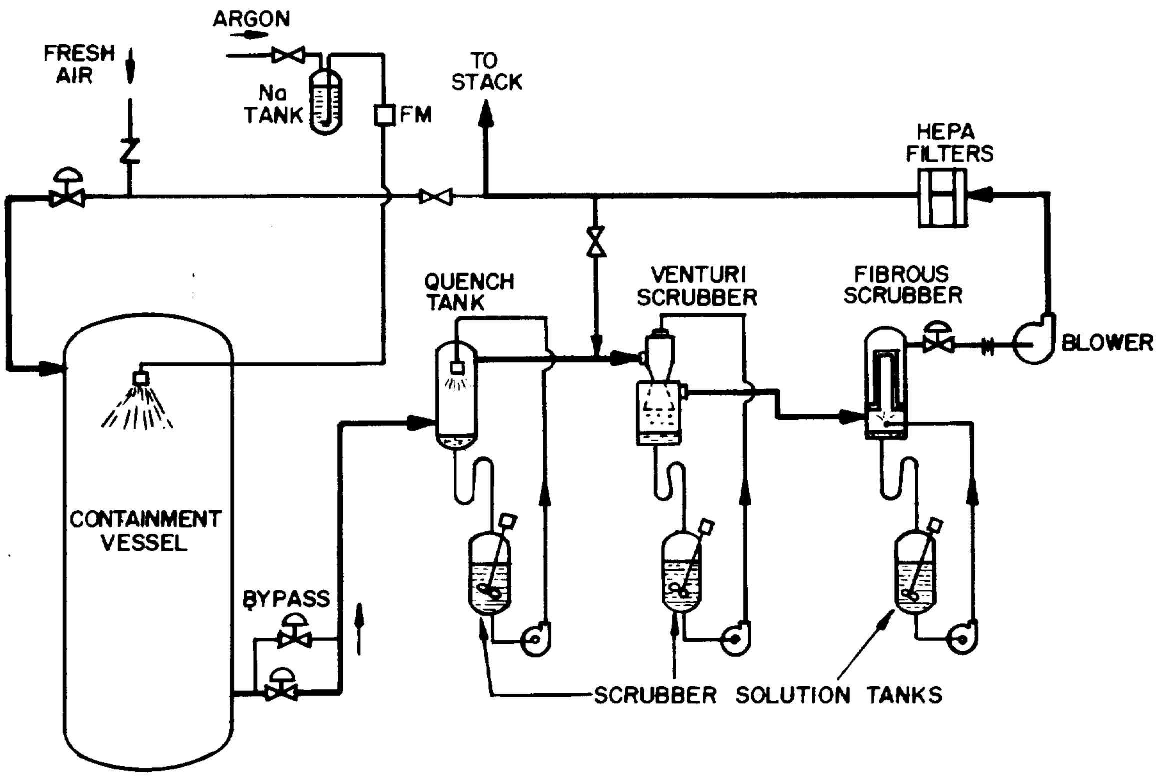

FIGURE 3

FLOW DIAGRAM OF THE HEDL TEST SETUP

In HEDL test setup each scrubber/filter uses a separate closed loop solution circuit while CRBRP has a common cooled solution supply to each scrubber/filter. Reference (2) established that combined system filtration efficiency is little affected by variations in gas flow rate, liquid concentration, aerosol concentration and aerosol particle size. Reference (2) reported the following individual component filtration efficiencies:

Quench scrubber efficiency	=	79.4%
Venturi scrubber efficiency	=	90.6%
Fibrous scrubber efficiency	=	98.8%

Some unpublished HEDL results pertaining to fluid flow rates and temperatures across the quench tank and venturi scrubber indicate a relationship which is shown in Figures 4 and 5. It should be noted that no test data was available for solution temperature leaving the venturi scrubber. These relationships have been assumed to hold good for the entire range of values of parameters for CRBRP. The following equations express these relationships:

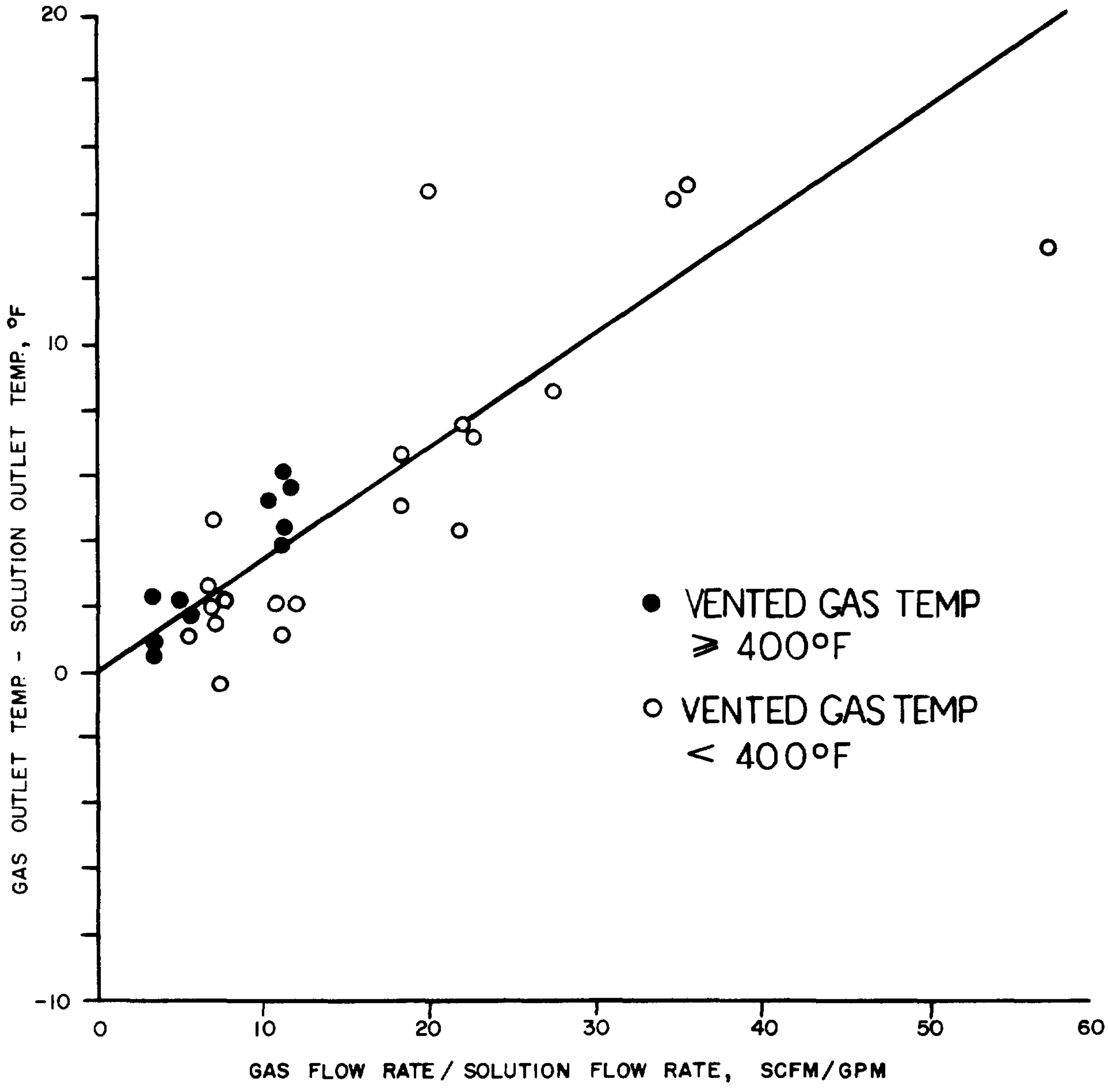

FIGURE 5

RELATIONSHIP FOR QUENCH TANK DATA FROM HEDL TEST RUN ACI

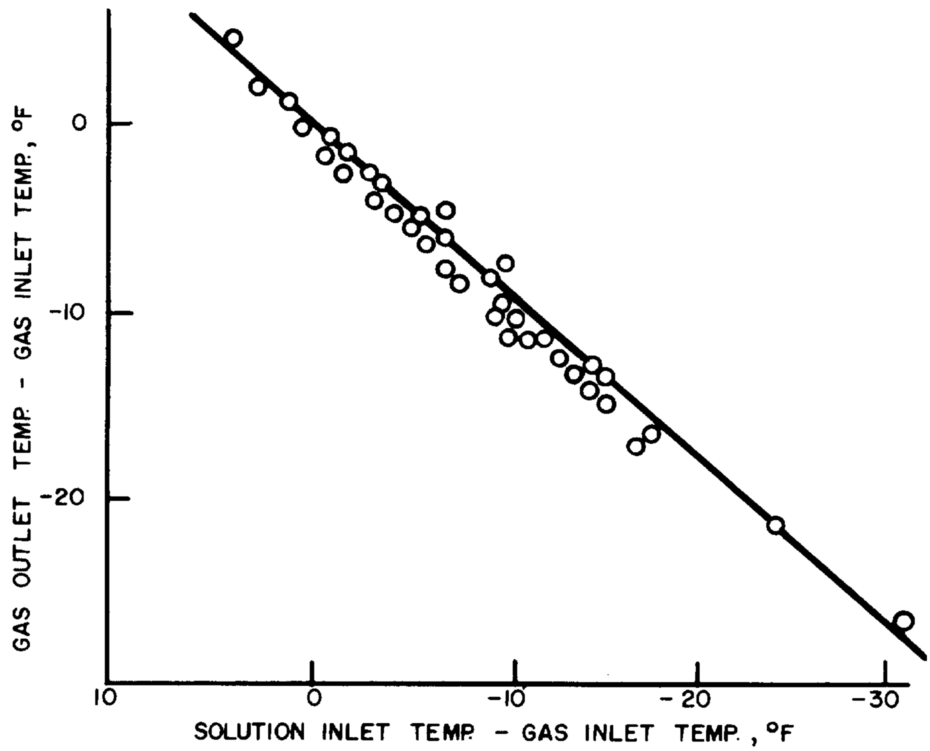

FIGURE 4

RELATIONSHIP FOR VENTURI SCRUBBER DATA FROM HEDL TEST RUN AC I

Quench Tank

(Air outlet temperature - Solution outlet temperature)
= 0.333 (Flow of air in SCFM/Solution flow rate in GPM) - (1)

Venturi Scrubber

Air outlet temperature = Solution inlet temperature - (2)

IV. Dynamic Thermal Analysis

The HEDL tests (Reference 2) established component filtration efficiencies which can be used for CRBRP with confidence. CRBRP has also to establish the thermal performance of the filtration system under time variant reactor containment conditions predetermined from accident analyses. This is to ensure that the fibrous scrubber would not be subjected to temperatures greater than 170°F. HEDL tests have indicated breakdown of polypropylene fibres when subjecting dry fibrous scrubber to temperatures greater than 200°F for a short time. It is presumed that the conditon of fibres is affected by solution constituents and nuclear radiation.

The vented gas stream is expected to vary in conditions as shown in Figures 6 and 7. The filtration system is expected to start at 36 hours after the accident (24 hour delay in venting is required by Federal regulations).

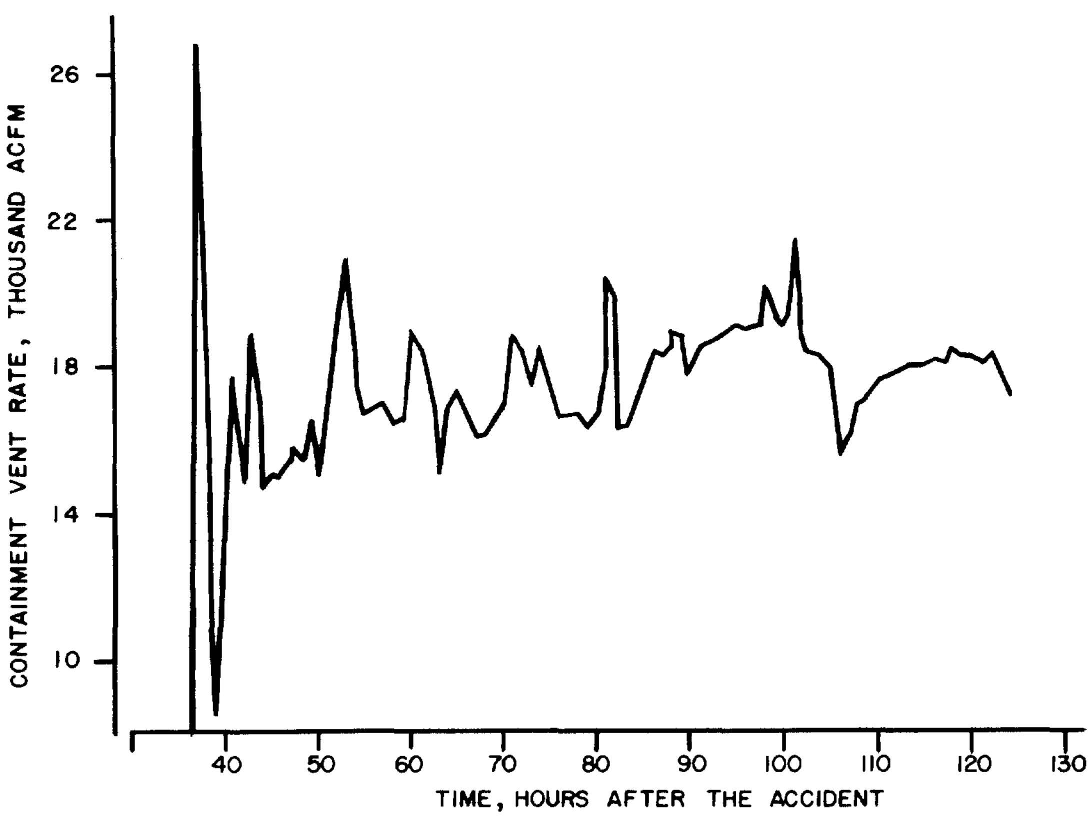

FIGURE 6

CONTAINMENT VENT RATE

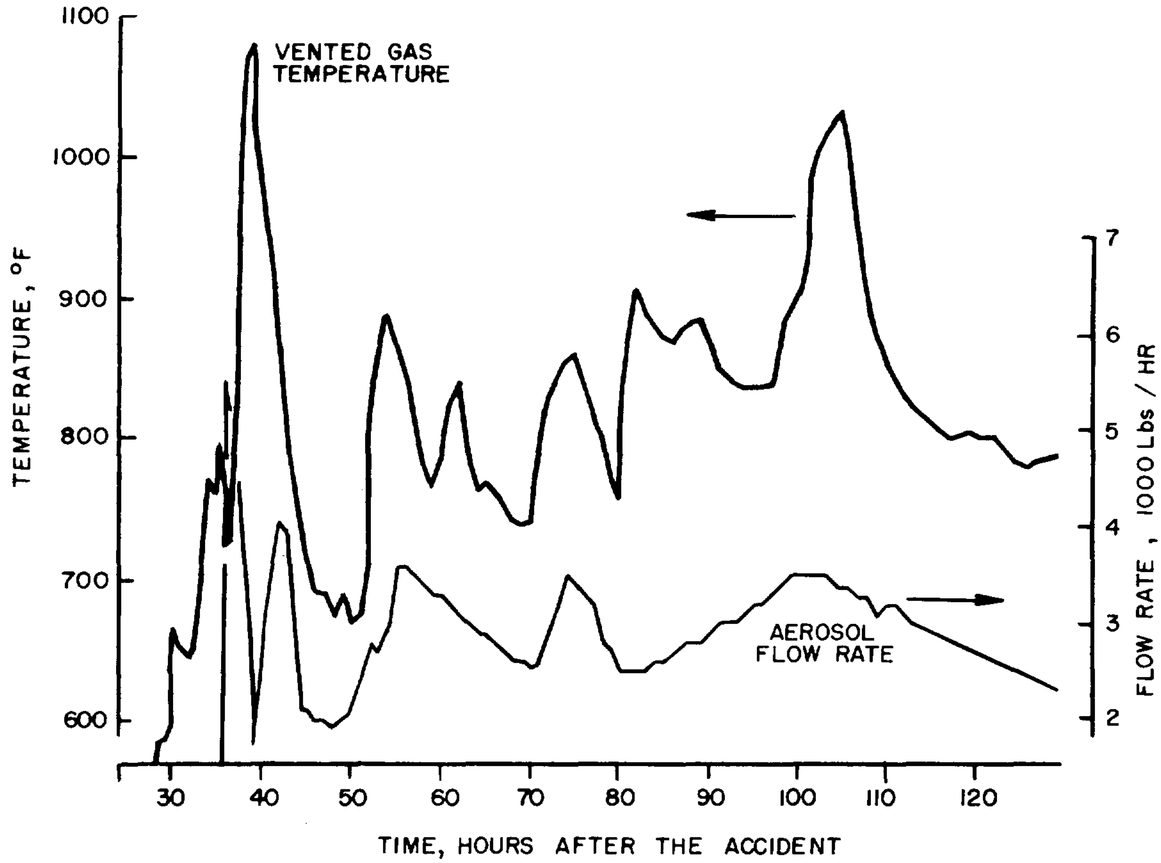

FIGURE 7

VENTED GAS TEMPERATURE AND AEROSOL FLOW RATE

The CRBRP input parameters for dynamic thermal analysis are shown in Table III. The dynamic thermal analysis is used to determine the quantity of water required to be stored in the solution tank, size of the heat exchanger and cooling water flow rate so that the temperature of fibrous scrubber does not exceed 170°F.

Table III Input parameters for dynamic analysis

Quench tank solution flow rate, gpm	500
Quench tank particle removal efficiency, %	67
Venturi scrubber solution flow rate, gpm	1000
Venturi scrubber particle removal efficiency, %	80
Fibrous scrubber solution flow rate, gpm	4
Fibrous scrubber particle removal efficiency, %	98.8
Initial temperature of water stored in the solution tank, ^oF	60
Cooling water/make-up water temperature, ^oF	91
Make-up water flow rate, gpm	5

<u>Assumptions and their Justification</u>

Several assumptions were made in the dynamic analysis. The major assumptions are listed below along with their justification:

1. Vented gas contains only Na_2O (i.e. no NaOH or Na_2CO_3)

   Justification: This is a conservative assumption since conversion of Na_2O to NaOH releases 1050 Btu/lb. of Na_2O. The total flow rate of all aerosols in lb/hr (Figure 7) is predetermined from accident analyses in the containment. Hence by assuming that the entire quantity of aerosol consists of Na_2O only, larger quantity of heat is released in the scrubber/filtration system.

2. Equations (1) and (2) which are based on quasi-steady state test data are valid for transient state.

   Justification: Equation (1) establishes that effect of change in ratio of gas flow rate in scfm to solution flow rate in gpm from 20 to 30 results in the difference between air outlet temperature and solution outlet temperature of less than 4^oF. Hence Equation (1) represents a fairly insensitive relationship. In addition, this analysis aims at maximum inaccuracy in the temperature of gas leaving the filtration system of $\pm 15^oF$.

   The difference between the gas leaving temperature, solution inlet and outlet temperatures in the venturi scrubber are expected to be within 5^oF of each other. Hence for the reasons explained above use of Equation (2) is justified.

3. Quench tank and venturi scrubber aerosol removal efficiencies are 67% and 80% (Reference (2) reported these two efficiencies to be 79.4% and 90.6% respectively for test AC1 and 65.6% and 88.4% for test AC2).

Justification: Use of lower efficiencies for quench tank and fibrous scrubber results in higher discharged gas temperatures. Hence this assumption is conservative.

4. Equations (1) and (2) are valid for temperatures upto 1100°F and NaOH concentrations upto 23.7%. Also, these equations are valid when the vented gas contains only Na_2O.

   Justification: For lack of any other test data in the higher temperature and concentration region and also with Na_2O aerosols, Equations (1) and (2) were assumed valid. The validity of this will have to be verified by tests.

5. All Na_2O reacts with water to form NaOH in the quench tank.

   Justification: This assumption is based on HEDL observations during the tests conducted by HEDL.

6. Moisture in gas stream leaving quench tank and venturi scrubber is in equilibrium with NaOH solution leaving the quench tank and venturi scrubber respectively, at the leaving gas temperature.

   Justification: Because of the very thorough contact between the gas and solution in the quench tank and venturi scrubber one would expect an equilibrium between

   a) leaving gas and leaving solution surface film (at gas temperature) for venturi scrubber,

   b) leaving gas and incoming solution surface film (at gas temperature) for quench tank. Leaving solution has higher concentration of NaOH and thus has lower vapor pressure than incoming solution. Assuming equilibrium between leaving gas and leaving solution surface film results in higher gas temperatures.

7. There is no water evaporation in fibrous scrubber. Heat of solution is transferred to gas stream only in the fibrous scrubber.

   Justification: This is a conservative assumption from the viewpoint of leaving gas temperature. The water flow rate to the fibrous scrubber is only 4 gpm, hence it does not affect the temperature of solution in solution tank.

8. The temperature of cooling water to the heat exchanger is 91°F.

   Justification: This assumption is conservative since this is the maximum temperature of water from the cooling tower. This temperature in reality could occur for approximately one hour on the day when wet bulb temperature is the highest ever.

9. There is no heat transfer from, and, aerosol removal in the vent pipe between the containment and the scrubber system.

Justification: This is a conservative assumption. Reference (2) reported an average sodium aerosol removal efficiency of 17.1% and 41.6% for the vent pipe in tests AC1 and AC2 respectively.

10. Initial water temperature in the solution tank = 60°F.

Justification: The tank is located underground in an enclosed space. The walls and floor of this space are in touch with soil at approximately 55°F.

Method of Analysis

Dynamic analysis of the CRBRP containment clean-up system was by means of digital computer simulation using the sequential finite time segment method. It was utilized to predict system performance and conditions under various system operating conditions. The method involved the division of the entire operation period into numerous equal time segments. During each time segment, the operation is assumed to be a steady state operation.

An overview of the filtration system is first presented to understand the overall constraints imposed, the variables involved and method of solution (Figure 8).

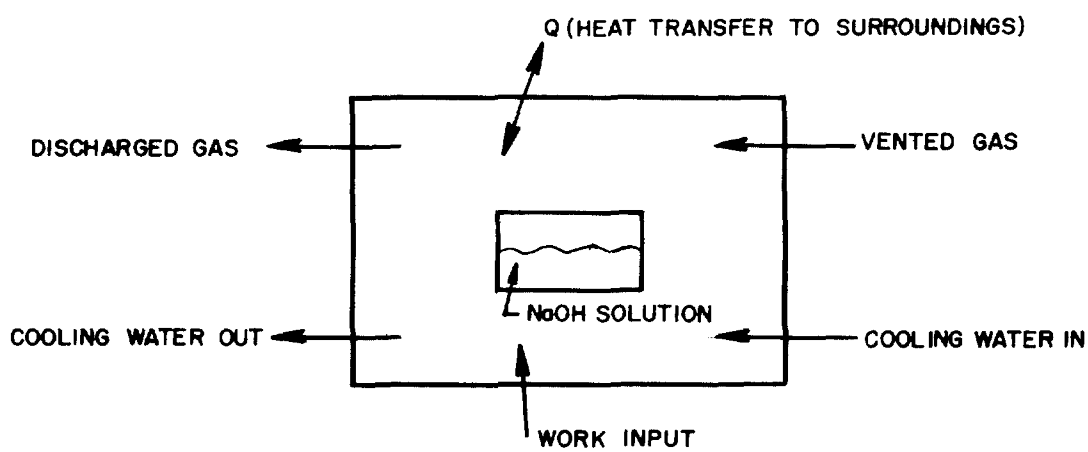

FIGURE 8

OVERVIEW OF FILTRATION SYSTEM

Energy Balance:

Increase in enthalpy of cooling water stream in time δt
= Enthalpy of vented gas in time δt − Enthalpy of discharged gas in time δt

+ Heat of reaction and solution in time δt
+ Decay heat from fission products in time δt
- Increase in energy stored in solution in time $\delta t \pm Q$ in time δt
    + Work Input in time δt

Time dependent vented gas flow rate, composition, pressure and temperature are predetermined from the analysis of the accident within the containment and hence are known. Knowing the composition of the vented gas and overall filtration efficiency, heat of reaction and solution and decay heat from fission products can be estimated.

The temperature of the cooling water from cooling tower is assumed $91^{\circ}F$. Thus, the unknown parameters are: mass of solution, heat removed in the heat exchanger and moisture content of the discharged gas. The dynamic analysis assumed mass of solution and various sizes of heat exchangers and evaluated moisture content of discharge gas from vapor pressure equilibrium considerations.

Component Analysis

The operation of each component was represented by three types of equations: mass balances, energy balances and equipment characteristics. Mass balances are used for gas, water and sodium oxide.

These equations are developed here for quench tank. The parameters involved are defined in Figure 9.

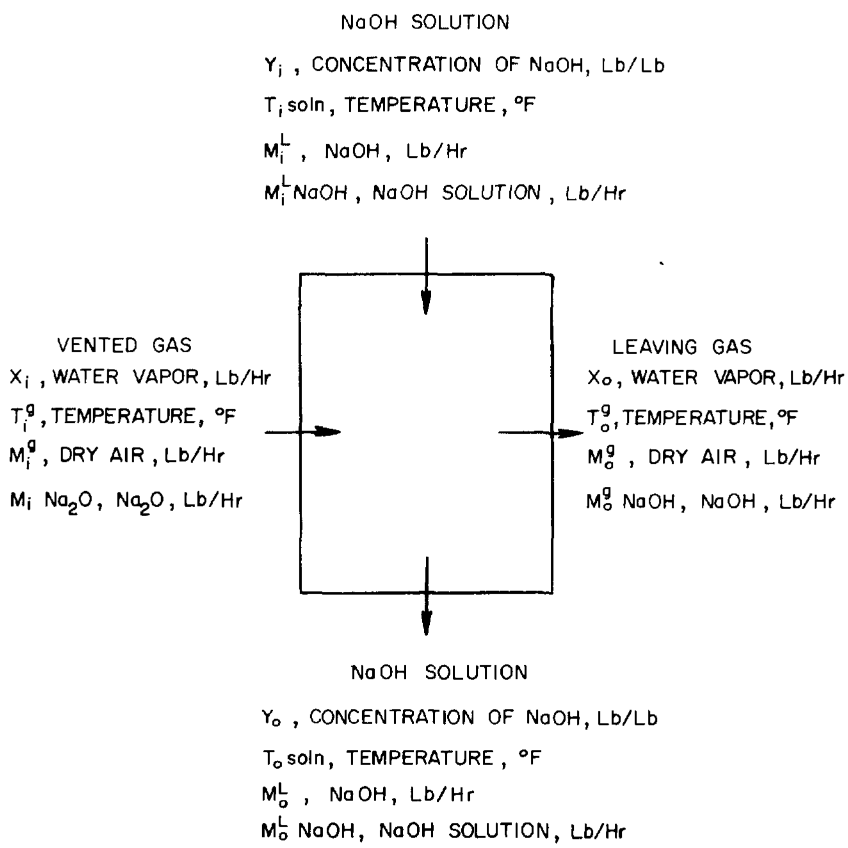

FIGURE 9

QUENCH TANK STREAMS' PARAMETERS

Mass Balance

$$\sum_{i,o} M_j = 0$$

where j refers to chemical constituent, and "i" and "o" to inlet and outlet respectively.

For dry air: $M_i^g = M_o^g$

For Na_2O/NaOH:

$$M_i Na_2O \times \eta \times \frac{80}{62} = M_O^L - M_i^L = M$$

Where η = Filtration efficiency

Energy Balance is based on a fixed reference temperature:

$$\sum_o M_j h_j \,\delta t = \sum_i M_j \, h_j \delta t + \text{Heat of reaction in time interval}$$

δt due to conversion of all solid

Na_2O to solid NaOH + Heat of solution

in time interval δt due to

(M x δt) lbs. of solid NaOH going

into solution.

It is assumed that moisture in leaving gas stream is in equilibrium with leaving NaOH solution at the gas leaving temperature. If an exit gas temperature is assumed, the mass balances establish the masses of all individual components in the leaving liquid and gas streams. The leaving solution temperature is calculated from Equation (1). Lastly, the assumed gas temperature is verified against the energy balance. If energy equation does not balance, the entire process is repeated for the given time period assuming another exit gas temperature.

Venturi Scrubber

The basis of calculating the venturi scrubber performance is same as for the quench tank. There is only one distinction - the incoming gas stream is assumed to contain solid NaOH.

Fibrous Scrubber

It is assumed that the gas entering the fibrous scrubber contains solid NaOH. It is also assumed that heat of solution is transferred to gas stream only.

Pump

Volumetric flow rate of liquid through a piping system at high Reynold's number is given by:

$$\text{Flow} = \text{Constant (Head of liquid pumped)}^{0.5}$$

At constant speed, the head of liquid developed by a centrifugal pump is determined only by the flow rate of liquid.

Hence, the system and pump flow versus head relationships are unaffected by fluid density, viscosity, etc. In other words, the NaOH solution flow rate in the system is unaffected by changes in temperature of solution as well as by changes in concentration of the solution.

Heat Exchanger

The heat transfer coefficient 'h' for NaOH solution flowing through tubes must take into account the changes in properties of the solution due to changes in its temperature and concentration. This was accounted by correction factors applied to the heat transfer coefficient h^o under predetermined fixed conditions:

$$h = h^o \left(\frac{k}{k^o}\right)^{0.65} \left(\frac{\mu}{\mu^o}\right)^{-0.45} \left(\frac{C_p}{C_p^{\,o}}\right)^{0.35} \left(\frac{\rho}{\rho^o}\right)^{0.8}$$

where k, μ, C_p and ρ are conductivity, viscosity, specific heat at constant pressure and density respectively.

The above equation is derived from the basic equation for heat transfer coefficient for flow through a tube.

Solution Tank

All fission products are assumed to be in the solution tank. The energy balance for the solution tank takes into account all the decay heat.

Programming and Results

A computer program in BASIC language was written based on the sequential finite time segment method. All steady-state operational mathematical equations were transferred into program statements. The program was verified against test results for test runs AC1 and AC4 from HEDL. The comparison indicated a better than 10% agreement with the limited test data which is applicable to system analyzed here. Comparison with HEDL test data is shown in Figure 10. Time interval of one tenth of an hour was considered adequate and used in the analysis.

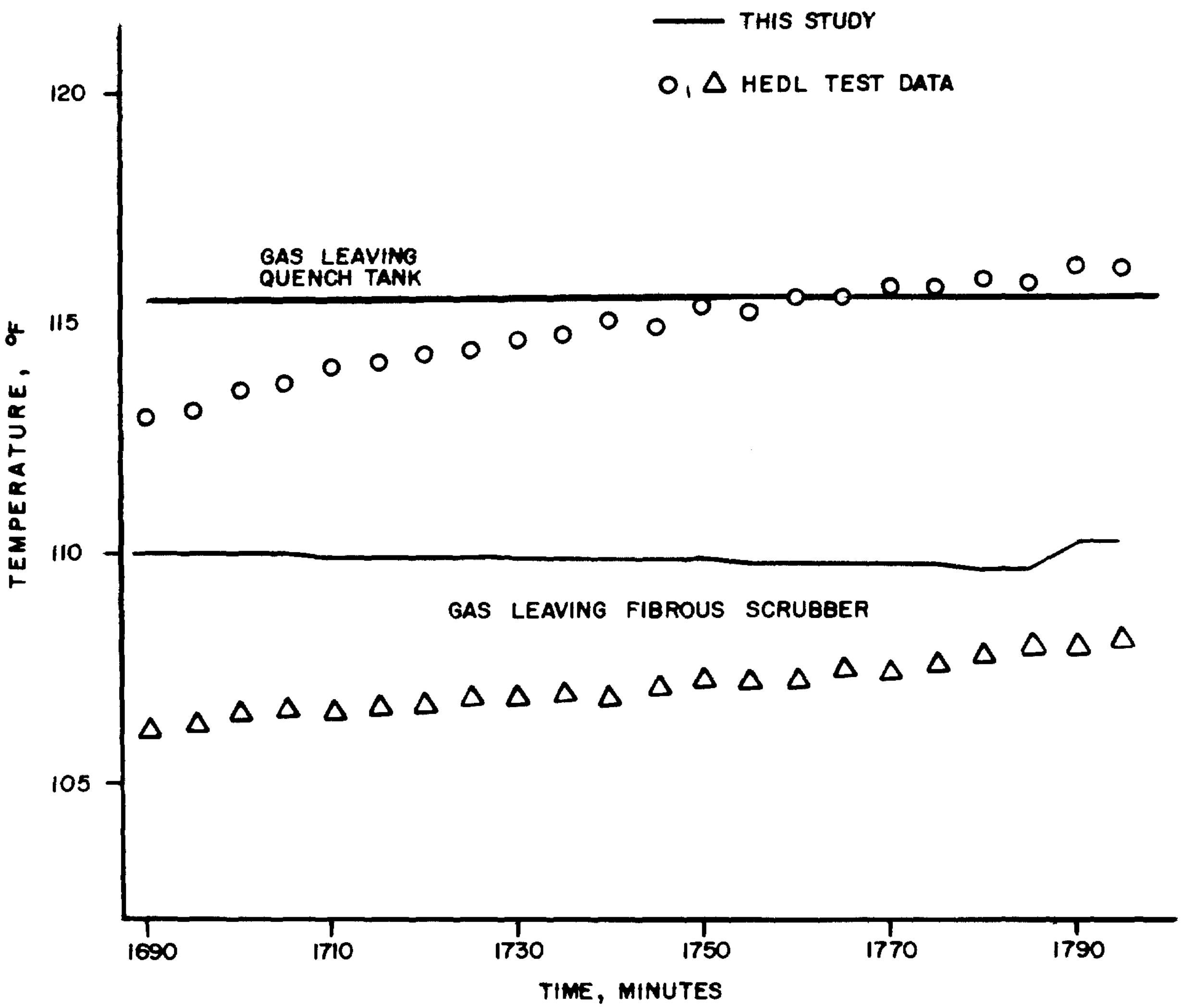

FIGURE 10

COMPARISON OF RESULTS WITH HEDL TEST RUN AC1

The following parameters were established by this analysis:

Volume of water stored in solution tank = 130,000 gallons

Flow rate of cooling water = 1000 gpm

Heat exchanger heat transfer rate = 0.3×10^6 Btu/hr/$^{\circ}$F

The maximum gas temperature in the fibrous scrubber is $146 \pm 15^{\circ}$F. The analysis showed that the discharged gas temperature will rise to approximately 175°F if the heat exchanger is eliminated. In this case, the cooling is provided only by evaporation of water.

Concentrations of NaOH and $NaCO_3$ in the solution at the end of the operation are below their respective solubility limits.

Figure 11 shows the variation in discharged gas temperature in relation to temperature of the vented gas.

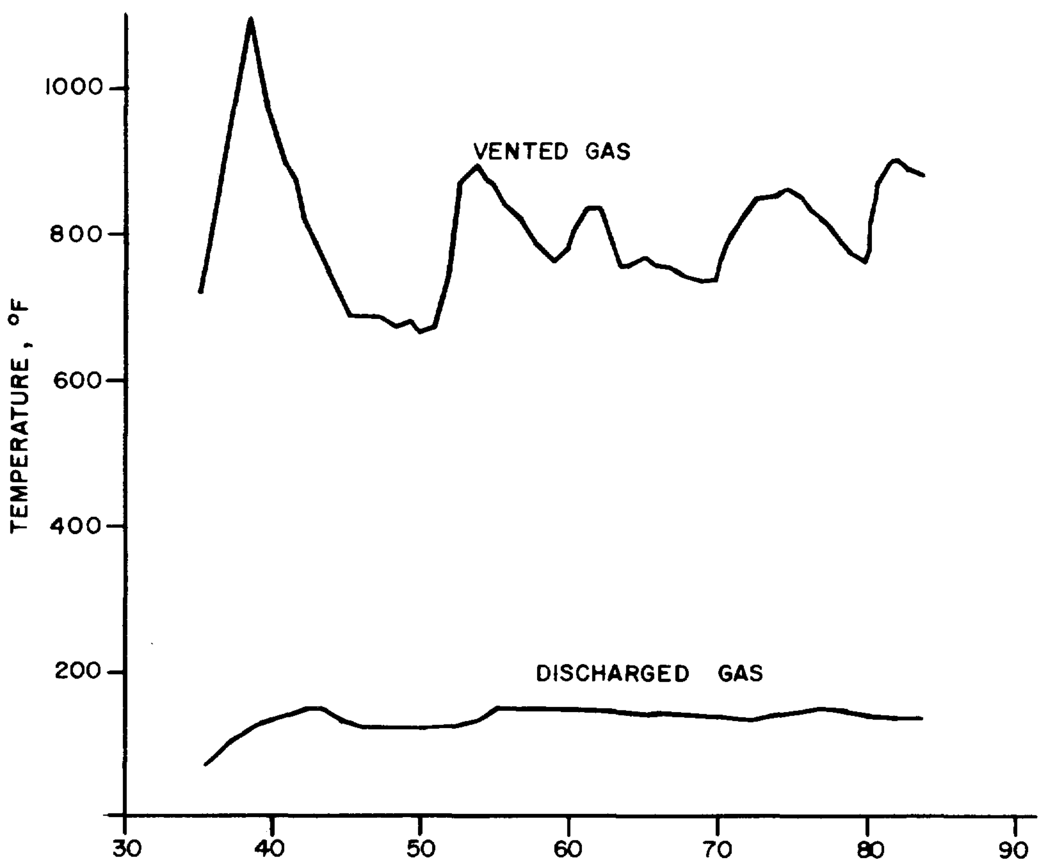

FIGURE 11

CALCULATED DISCHARGED GAS TEMPERATURE

V. Conclusions

Computer simulation of the process helped to establish the quantity of water required to be stored in the solution tank, size of the heat exchanger and flow rate of cooling water to ensure that the fibrous scrubber will not be subjected to temperatures greater than $170^{o}F$, and that the system will perform satisfactorily at higher concentrations of NaOH in the solution.

The program is a very convenient tool to analyze the effect of change in system parameters or component sizes. Additional benefits are in investigation of the effects of certain equipment malfunction and/or the effectiveness of any remedial action. The thermal performance of the filtration system needs to be verified by tests at vent gas temperatures upto $1100^{o}F$, solution concentrations upto 23.7% NaOH, and with high content of Na_2O aerosols in the vented gas.

VI. References

(1) McCormack, J.D. et al, "An Evaluation of Alternative Air Cleaning Systems for Emergency Use in LMFBR Plants", Proceedings of the 14th ERDA Air Cleaning Conference, 1976

(2) R.K. Hilliard et al, "Containment Air Cleaning for LMFBR's" ANS International Meeting on Fast Reactor Technology, Seattle, Washington, August 1979.

DISCUSSION

SGALAMBRO: I would like to know if you have considered the recirculation of gas in the containment vessel. If, for example, the temperatures that you calculated will be higher, is it still possible to have recirculation in the containment vessel?

BIJLANI: Containment venting is essential to relieve pressure in the containment vessel and also for reducing hydrogen buildup in the containment. Recirculation of gas back to the containment is thus non-productive.

A CONSISTENT APPROACH TO AIR-CLEANING SYSTEM DUCT DESIGN

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Abstract

Nuclear power plant air-cleaning system effectiveness is dependent on the capability of a duct system to safely convey contaminated gas to a filtration unit and subsequently to a point of discharge. The radiation protection engineer and the duct system design engineer must be familiar with design objectives, criteria, standards and regulatory requirements.

This paper presents a logical and consistent design approach for selecting sheet metal ductwork construction to meet applicable criteria. The differences in design engineers' duct construction specifications are acknowledged. Typical duct construction details and suggestions for their effective use are presented. Improvements in duct design sections of ANSI/ASME N509-80 are highlighted.[1]

A detailed leakage analysis of a control room HVAC system is undertaken to illustrate the effects of conceptual design variations on duct construction requirements. Shortcomings of previously published analyses and interpretations of a current standard are included.

I. Introduction

In the early 1970's it became apparent that nuclear power plant air-cleaning systems designed and built in accordance with conventional sheet metal standards would not meet the needs of the utility industry. Lightweight ducts were prone to high leakage and were structurally inadequate for accident service conditions. Typical deficiencies of the early designs were documented in WASH-1234.[2]

Regulatory Guide 1.52[3] and ANSI/ASME N509-76[4], issued in the mid 70's, contained many prescriptions for curing these design deficiencies. The utility industry will soon be operating the first air-cleaning systems designed to meet these prescriptions.

Further improvements in air-cleaning system designs will follow the imminent issue of ANSI/ASME N509-80[1] and the future issue of the ASME Nuclear Air and Gas Treatment Code.

For consistency and comparability with the reference documents, such as ANSI/ASME Standards, regulatory guides, and industry duct construction standards, only English units have been used throughout this paper.

II. Duct System Design Objectives

During normal plant operations, nuclear power station ventilation systems supply fresh air to occupied plant spaces to dilute potential contaminant concentrations to some fraction of the maximum permissible concentration (MPC) allowed by 10 CFR 20.[5] Any ventilation exhaust flow paths that contain cleanup filters to limit offsite contaminant releases are classified as air-cleaning systems. Contaminant releases to the environment through these systems must meet as low as reasonably achievable (ALARA) criteria as defined in Appendix I to 10 CFR 50.[6] The function of air-cleaning systems during postulated accidents is to limit airborne radioactive concentrations to occupied plant areas such as the control room, the technical support center, etc., to comply with 10 CFR 50, Appendix A, General Design Criterion 19.[7] Engineered Safety Feature (ESF) accident air-cleaning systems are provided in plant effluent paths to limit offsite radiation doses to a fraction of 10 CFR 100 limits.[8]

Design objectives for an air-cleaning system can be stated simply as follows:

a. Capture the airborne contaminant as close to the release source as possible.

b. Convey the contaminant to a cleanup filter train, where applicable, while minimizing loss of contaminant during conveying.

c. Remove applicable contaminants from the airstream in the filter train.

d. Convey the cleaned airstream to an outdoor release point designed to achieve dispersion.

Such an air-cleaning system uses concrete duct shafts, sheet metal ductwork, and standard steel pipe to convey the airborne contaminants from one point to another within the plant. This paper focuses on the design of sheet metal ductwork; however, the design principles described here apply to any construction.

III. Duct System Design Criteria

Volume flow rates for air-cleaning systems are determined by the design engineer based on one or more of the following criteria:

a. Volume flow required to maintain a space pressure differential (positive or negative) with respect to outdoor ambient or an adjacent space. The flow rate is normally dictated by assessing potential leak paths in the room or building perimeter.

b. Volume flow required to remove a quantity of heat from a room or building.

c. Volume flow required to dilute airborne contaminants.

d. Volume flow required to maintain a minimum control velocity across a room access opening (e.g., a door) to preclude the spread of contamination.

Once the airflow quantities are determined, the engineer proceeds with the design of the ductwork utilizing the following criteria:

a. The cross-sectional area of the duct is determined based on velocity required to keep contaminated dust particles suspended (normally 2000 - 3000 fpm).[9] Where gas holdup time is important for instrumentation actuation, additional duct length is also specified.

b. The maximum allowable leakage for duct design and testing is determined according to the guidelines of ANSI/ASME N-509, which prescribes the following criteria for determining the design value:

   1. Air-cleaning effectiveness requirements,

   2. Health physics requirements,

   3. Duct and housing quality requirements.

c. The ductwork and the hanging subsystem are designed for the appropriate design-basis transient and steady-state static and dynamic loads depending on duct location, safety classification, system applications, etc. Loading factors include the following:

   1. Seismic Excitation

   2. Hydrodynamic Forces (principally boiling water reactors)

   3. Environmental Condition Transients (thermal expansion, etc.)

   4. Pressure Transients (internal and external)

   5. Steam and Water Jet Impingement Forces (resulting from high energy line breaks)

   6. Static Duct Weight including insulation and one person's weight at duct midspan between two adjacent hangers

   7. Corrosion Allowances where abrasive dusts are conveyed.

IV. Implementation

The ductwork design criteria as determined by the procedure of Section III are carefully analyzed and converted into duct construction design requirements, as follows:

a. Ductwork Materials Types (Sheets, Angles, Bolts, Gaskets, etc.)
b. Sheet Thickness
c. Stiffening Member Type, Size, and Spacing
d. Transverse Joint Type and Size
e. Longitudinal Seam Type
f. Fitting Details
g. Welding
h. Penetrations and Seal Details
i. Hangers and Auxiliary Steel Supports
j. Axial and Transverse Restraints
k. Expansion Joints

Although the ANSI/ASME N509 guidelines present the design engineer with three methods for assessing the duct system maximum allowable leakage, there is no one generally accepted method of analyzing the duct system structural requirements, especially for ESF (seismic) duct systems. The ASME Committee on Nuclear Air & Gas Treatment (CONAGT) is presently formulating consensus duct design procedures.

V. Duct Design Methods

As one might expect, the methods of structural analysis for duct design differ from design engineer to design engineer. Some engineers base their analysis of ducts and hangers on a "rigid" type design methodology. This approach is based on a frequency concept and effectively decouples the duct from the hanging systems. Another design approach is to utilize a "flexible" type design using finite-element modeling techniques to analyze the system deflection and stress levels. At least one design engineer[10] uses a "partially rigid" design based on frequency and hanger load carrying capacity. Finally, some design engineers have also performed qualification testing of duct and support systems to confirm analytical design approaches.

With the different analytical testing and combined approaches for duct design available in the industry, it is not uncommon to see the same size ductwork designed by different engineers in the same type of system, subjected to the same loads but constructed quite differently. An engineer selecting a duct design method to satisfy the requirements of the duct design criteria is therefore confronted with a myriad of possible construction combinations.

Table I shows how the construction of ductwork 36 inches x 36 inches varies for seismic and non-seismic applications for three different nuclear power plants presently under construction. While the construction of non-seismic ductwork is similar for all three plants, the seismic duct construction differs significantly. Plant A employs a rigid design approach by using 12-gauge sheet metal, while Plant C employs a partially rigid design approach using 20-gauge sheet metal.

The cost of a duct system varies directly with the system weight and amount of required welding. We feel that Plant C construction offers the client the most economical design, since it is lightweight and minimizes welding.

Variations in duct construction methods are traditional in the sheet metal industry. For non-ESF, non-seismic duct systems, SMACNA(11) duct construction standards contain dozens of combinations of sheet metal gauge, stiffener design (shape, size and spacing), transverse joint design (type and size), longitudinal seam type and internal bracing for given duct pressure ranges. An HVAC contractor selects the duct construction which is most economical for him to build and install. However, for ESF (seismic) duct systems, there are presently no industry standards detailing acceptable duct design and construction methods.

VI. Suggested Duct Construction Methods

The design engineer must achieve allowable leakage, but must also consider duct structural requirements when specifying duct construction. The allowable leakage for a given duct system may dictate the type of construction. For example, Figure 1 shows the type of longitudinal seams available for use. Where low leakage is required (leakage Class I - ESF), use of fully welded seams should be considered. Galvanized sheet metal is difficult to weld when thinner than 18 gauge (0.0516 inch), thus this limitation can dictate minimum sheet metal thickness.

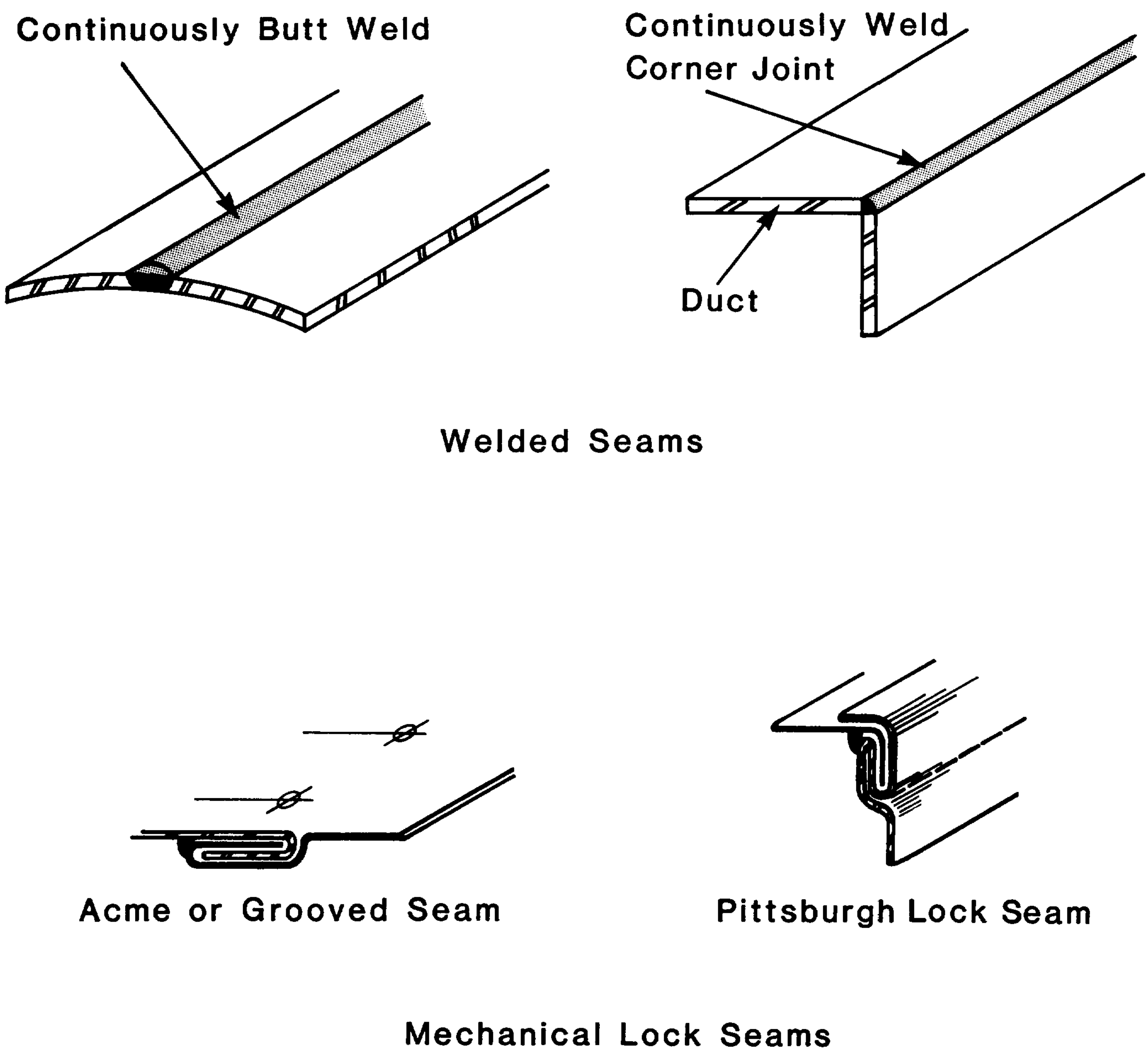
Examples of typical transverse joints are shown in Figure 2. Experience has shown that if good construction techniques are followed, the companion angle joint can be used on most systems.

The unwelded ductwork transverse joint is a significant potential leak path unless properly designed and installed. Specifications may permit a knockover of the duct sheet over the angle as shown in Figure 3. This knockover must be flattened and not allowed to ripple in order to provide a flat mating surface. Also of particular importance in reducing leakage at companion angle flanged joints is the sealing of the duct corners as shown in Figure 3. For duct sheet thickness greater than 16 gauge, the knockover should not be used and the duct sheet should be welded to the mating angle as shown in Figure 2b.

The companion angle flange joint must be gasketed to prevent leakage. Normally, on rectangular ducts, the gasket joint occurs at the corners. If it is not carefully mitered or lapped, unacceptable leakage will result. The Contractor may elect to use a wide punched gasket which encompasses the bolt holes.

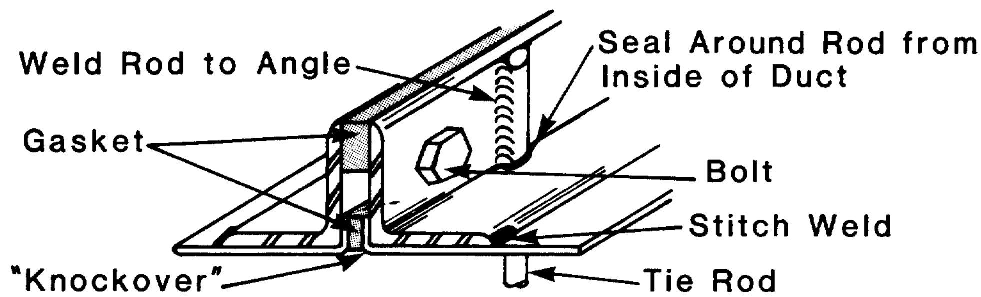
Table I. Examples of duct construction for 36" x 36" medium pressure ductwork.

	PLANT A		PLANT B		PLANT C		INDUSTRY STANDARD		
	Non-Seismic	Seismic	Non-Seismic	Seismic	Non-Seismic	Seismic	Non-Seismic		Seismic
1. Duct Gauge.....	20	12	18	16	20	20	20	18	No stds. Available
2. Transverse Joint									
a. Type...	Comp. Angle	Comp. Angle	Comp. Angle	Comp. Angle	Comp. Angle	Comp. Angle	Comp. Angle	Comp. Angle	
b. Size (in.)..	1½x1½x1/8	1½x1½x1/8	1½x1½x1/8	2½x2x¼	1½x1½x1/8	1½x1½x1/8	1¼x1¼x1/8	1¼x1¼x1/8	
c. Spacing (in.)..	40	60	60	120	36	36	48	60	
3. Intermed. Stiffener.									
a. Size (in.)..	None	None	1½x1½x¼	2½x2x¼	None	None	None	None	
b. Spacing (in.)..	-	-	60	49	-	-			
4. Type of Long. Seam......	Mechanical Lock	Welded	Mechanical Lock	Welded	Mechanical Lock	Mechanical Lock	Mechanical Lock	Mechanical Lock	

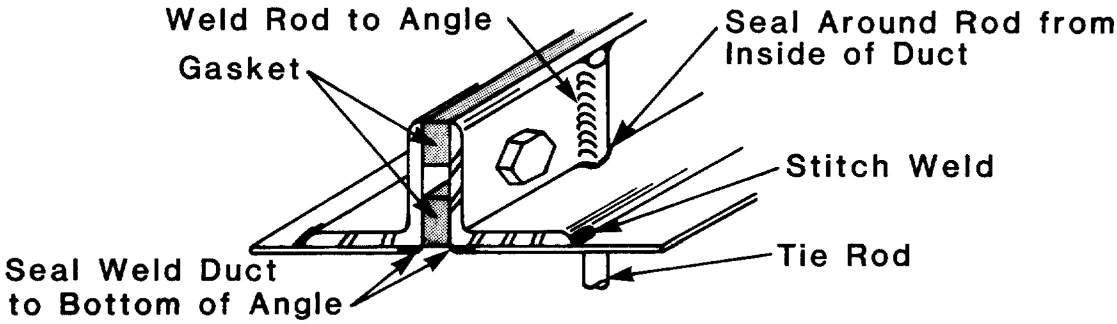


TYPES OF LONGITUDINAL SEAM CONSTRUCTION

FIGURE 1

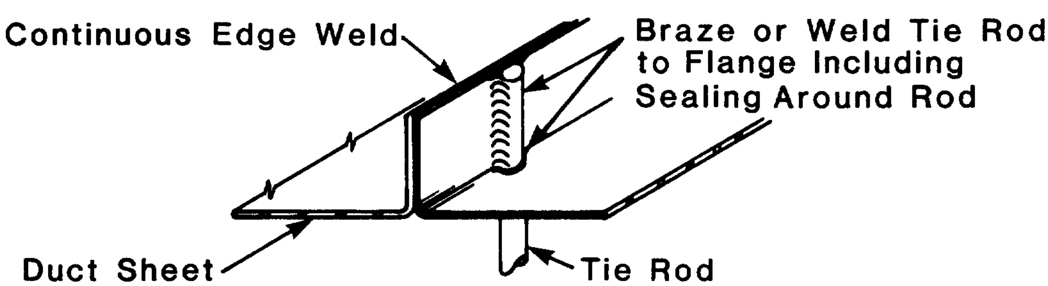


a)Companion Angle with "Knockover"



b)Companion Angle Seal Welded

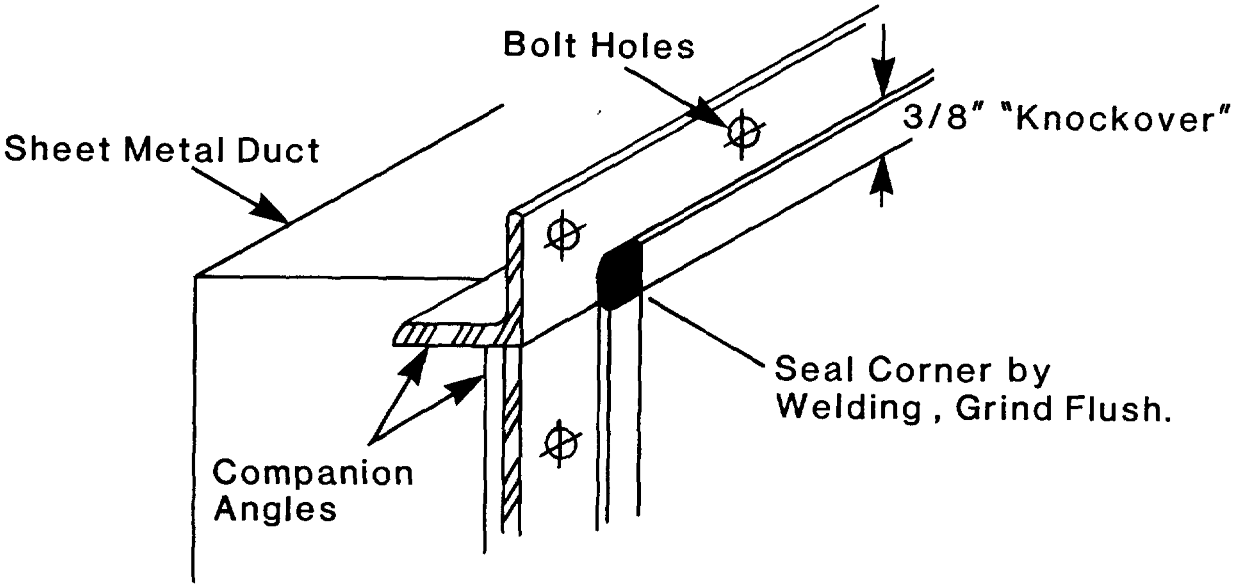
Bolted Companion Angle Flanged Joint



Welded Flange Joint

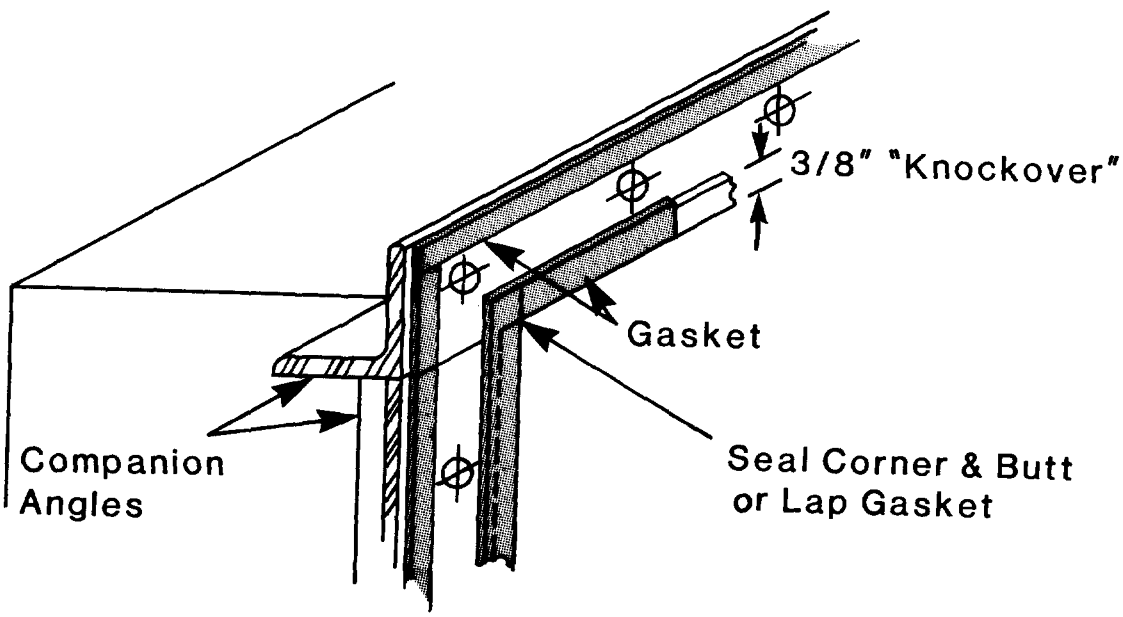
TYPES OF TRANSVERSE JOINT CONSTRUCTION

FIGURE 2



SEALING OF COMPANION ANGLE JOINT CORNER

FIGURE 3



GASKET DETAIL FOR COMPANION ANGLE JOINT

FIGURE 4

This works well. Beware of gasket details which show gaskets only on the outside perimeter of bolt center line, since air will leak from the duct through bolt holes. Thinner parallel gaskets have been used on both sides of the bolt center line with success as shown in Figure 4.

The spacing of flange bolts and bolt torquing requirements must also be specified to assure control of joint leakage. A bolt in each corner of the duct will provide better alignment and squaring of the duct sections and reduce corner leakage. Excessive tightening of the bolts can lead to bolt over-stress and may increase the leakage, since only the ends of the angle legs are pulled together and the distance at the base of the angle widens. Bolt tightening procedures should also include uniform torquing of alternate opposite side flange bolts. NRC inspectors are asking for torquing criteria and calibrated torque wrenches used to perform this work. "Huck" type bolts are being used on one of our projects. These bolts do not require torquing but cannot be adjusted after installation.

Construction of duct-mounted components, such as dampers, flow measuring devices, radiation probes, flexible connections, etc., must also be reviewed by the designer for leakage characteristics. This is discussed in greater detail in Section IX.

VII. Significant Changes in ANSI/ASME N509-80 Pertaining to Duct Design

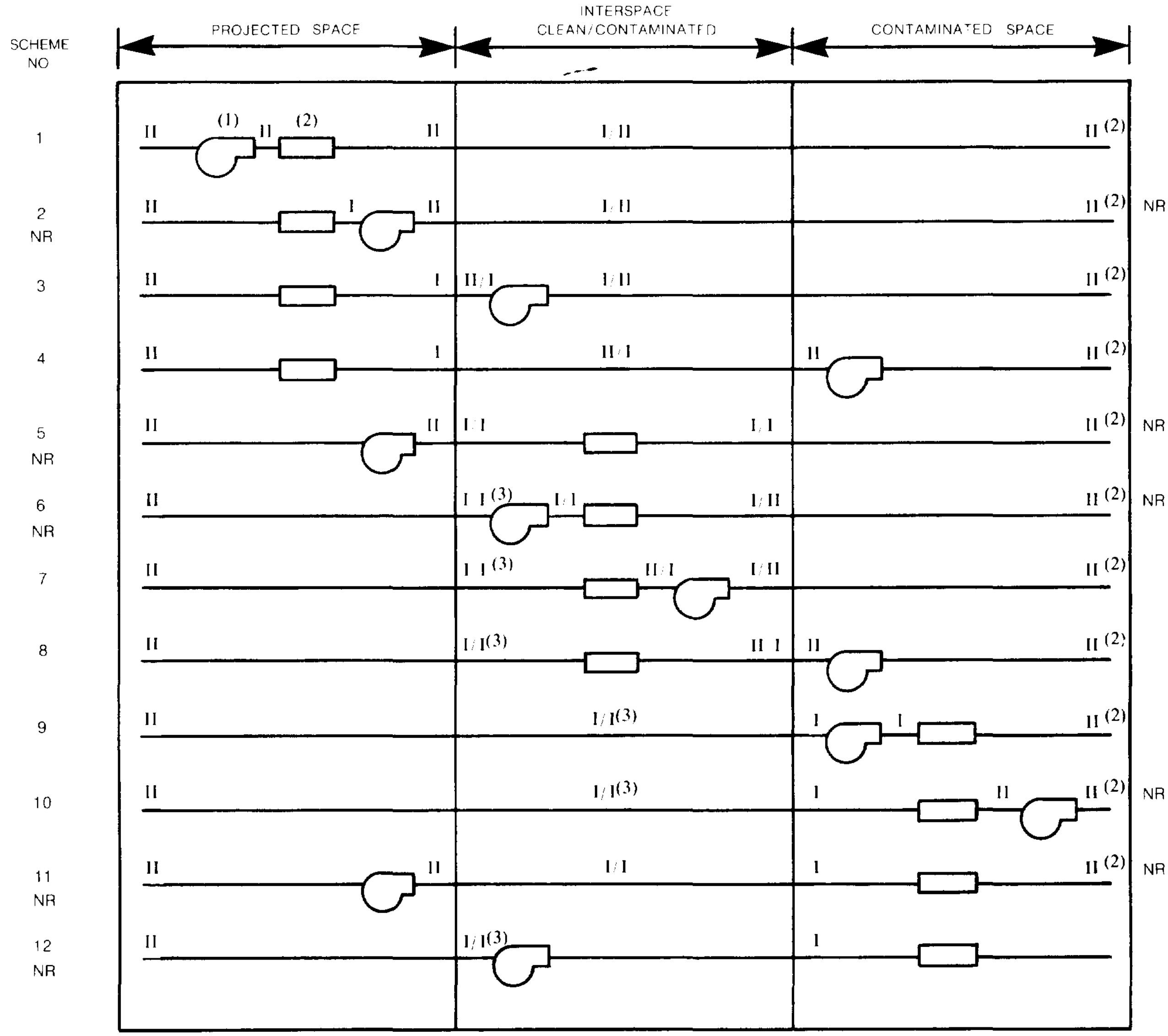
ASME recently completed a 2-year revision of ANSI/ASME N509—76. These revisions will appear in the 1980 issue and will affect duct design in several areas, as detailed in the following.

Leakage

The original ANSI/ASME N509-76 properly recognized the importance of duct leakage on the overall air-cleaning system effectiveness. Excessive duct inleakage on the suction side of the filters can result in system imbalances, flow deficiencies at terminal points and inability to maintain design pressure differentials, control velocities across openings, etc. Excessive duct outleakages of airborne contaminants can result in higher radiation doses to operating personnel, low flow at plant discharges, inability to maintain building or space pressure differentials, etc.

Revisions to the standard took into account the need of design engineers for additional guidance in determining the maximum allowable duct leak rate criteria for various air-cleaning system configurations.

Figures 5, 6, and 7 show the 30 system configuration diagrams which are now included in ANSI/ASME N509. Certain of the configurations are noted as "Not Recommended" where it was determined after much discussion in CONAGT meetings that the location of the fan or filter train would increase unnecessarily the risk of spreading contaminant. Based on the configurations shown, the air-cleaning system ducts and housings are now categorized into Class I and Class II for both ESF and non-ESF.



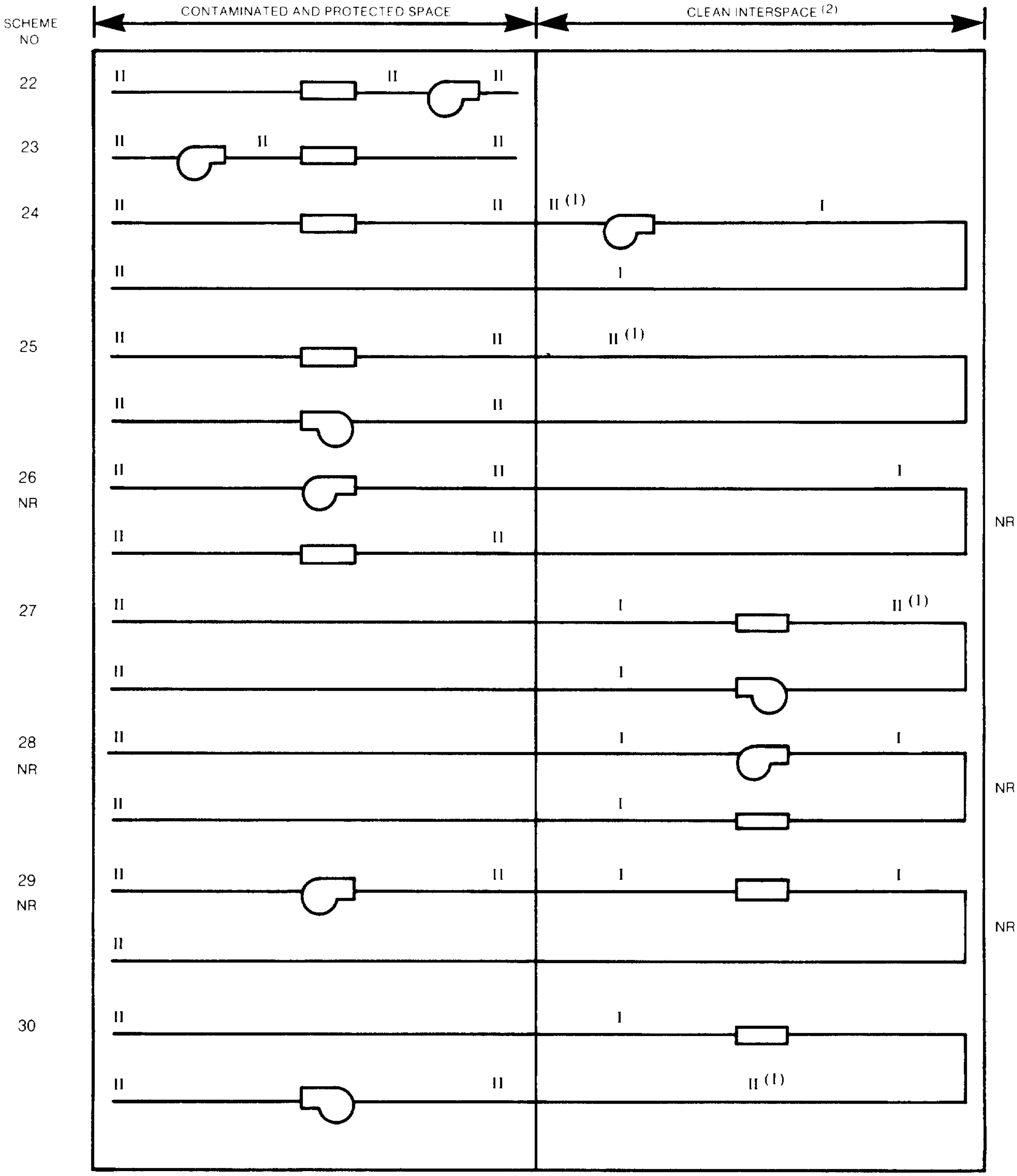
NOTES:
(1) Symbols - Air Cleaning Unit Fan
NR - Not Recommended

(2) All ducts under positive pressure which discharge into the plant stack for high level release credit shall be leakage Class I.

(3) Noted duct sections which pass through a Clean Interspace and which are under negative pressure for all modes of operation may be leakage Class II

SINGLE PASS AIR-CLEANING SYSTEM CONFIGURATIONS (B-2 OF ANSI N509-80)

FIGURE 5



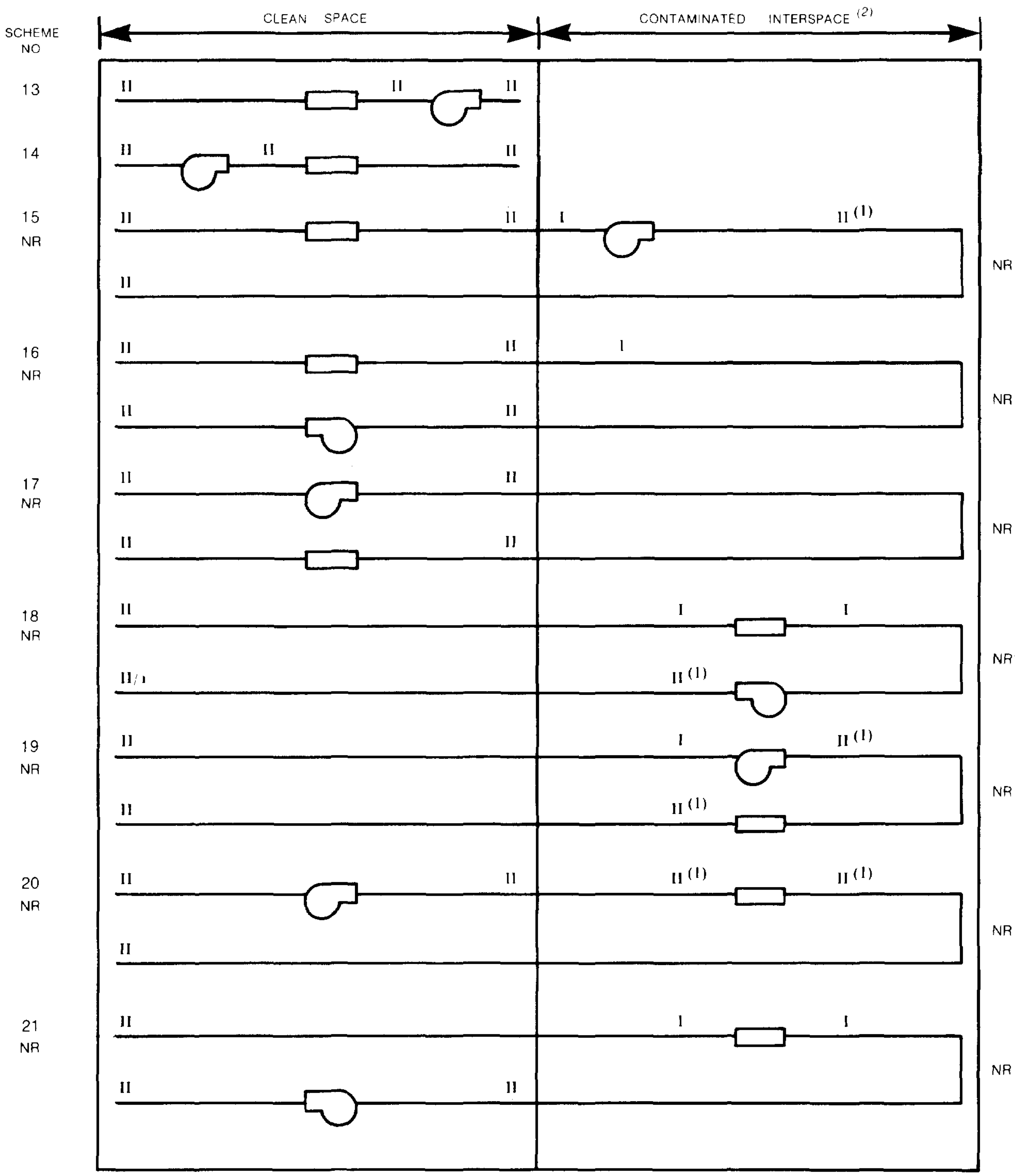
NOTES:

(1) Leakage Class I shall be used if ductwork is under negative pressure with respect to interspace during normal or transient system operation

(2) Contamination level of fluid within ductwork >> contamination level of interspace

RECIRCULATING AIR-CLEANING SYSTEM CONFIGURATIONS (B-3 OF ANSI N-50980)

FIGURE 6



NOTES

(1) Leakage Class I shall be used if ductwork is under negative pressure with respect to interspace during normal or transient system operation

(2) Contamination level of fluid within ductwork << contamination level of interspace

RECIRCULATING AIR-CLEANING SYSTEM CONFIGURATIONS (B-4 OF ANSI N509-80)

FIGURE 7

Table II shows that maximum leakage rates based on air-cleaning effectiveness requirements were reclassified and relaxed.

Table III shows that the maximum leakage rates based on duct quality requirements were reclassified and relaxed for non-ESF applications.

Construction

The previous version of the standard permitted only all-welded construction on ESF ducts. ANSI/ASME N509-80 permits the use of bolted and gasketed flanged transverse joints (Figure 2) and mechanical lock type longitudinal seams (Figure 1) on ESF ducts.

Stress

The maximum allowable stress criterion has been revised from 0.7 of the elastic limit to the following:

a. 0.6 of yield stress for loads during normal plant operation.

b. 0.9 of yield stress for design basis loads during Safe Shutdown Earthquake and Design-Basis Tornado.

These criteria are based on AISC allowable stress values.

Plate or Sheet Resonant Frequency

The plate or sheet resonant frequency criterion was reviewed and deleted from the standard.

VIII. Typical Air-Cleaning System Analysis

The number of air-cleaning systems varies with the type of nuclear power plant and radiological requirements. Figures 8A and 8B show ESF and non-ESF Air-Cleaning Systems frequently found on PWR nuclear power plants. Regulatory Guides 1.52 and 1.140 require these systems to be designed and constructed in accordance with ANSI/ASME N509. As such, an understanding of the allowable leakage for each system is required in order to determine the acceptable duct construction. The complexity of this leakage analysis will depend upon the complexity of the duct system and the health physics requirements.

Appendix A presents a detailed analysis of a typical control room HVAC system using the objectives, design criteria and ANSI/ASME N509 revisions affecting duct design. The intent of this analysis is to demonstrate the methodology, and not to present "cook-book" equations for analysis. Each different system configuration must be analyzed using its unique equations based on the methodology presented.

Results of the Analysis

The results of this analysis show that the air-cleaning effectiveness requirement is the governing design requirement for

Table II. Requirements for maximum allowable leakage for air-cleaning effectiveness as specified by ANSI/ASME N509 for 1976 and 1980.

ANSI/ASME N509-1976

4.12.1 Air-Cleaning Effectiveness Requirements

1. Ducts-percent of rated flow at internal design pressure.

ESF System Ducts Discharging to Environment	0.1%
ESF Control Room Systems	0.1%
Other ESF Systems	0.5%
Non-ESF Systems	1.0%

2. Housings-0.02% of rated flow at rated design pressure.

ANSI/ASME N509-1980

4.12.1 Air-Cleaning Effectiveness Requirements

Table 4.3 Maximum allowable leakage for air-cleaning effectiveness (percent of rated flow)

Leakage Class	ESF		Non-ESF	
	Duct[(1)]	Housing	Duct[(1)]	Housing
I	0.10	0.10	0.50	0.10[(2)]
II	1.00	0.20[(1)]	5.00	1.00[(2)]

NOTES:

1) Air ducts under positive pressure which discharge into the plant stack for high level release credit shall be Leakage Class I.

2) Assumes housing surface area is 20 percent of duct surface area. Duct and housing leakages may be adjusted for actual housing and duct surface area ratios, but the total percent leakage shall not exceed the sum of the listed percent leakages for duct and housing.

Table III. Requirements for maximum allowable leakage for duct and housing quality as specified by ANSI/ASME N509 for 1976 and 1980.

ANSI/ASME N509-1976

4.12.3 Duct and Housing Quality Requirements

Table 4-1 Maximum unit leakage rates according to construction types

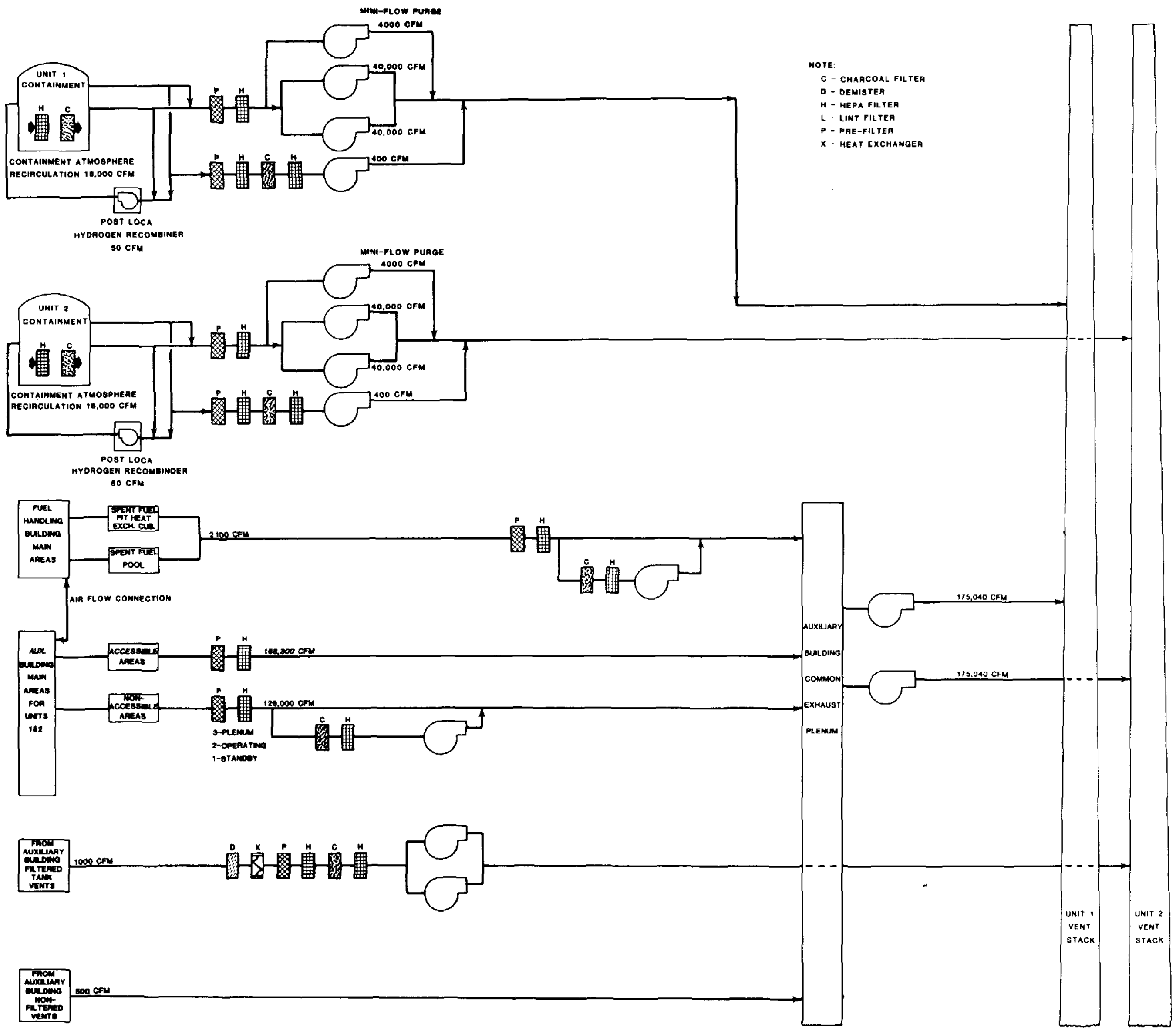
Construction	Allowable Unit Leakage Adjusted to 10 in. wg. cfm/ft
Welded	0.005
Nonwelded	0.100

ANSI/ASME N509-1980

4.12.3 Duct and Housing Quality Requirements

Table 4-4 Maximum unit leakage rates (scfm/sq ft of duct or housing surface at 10 in. wg.)

Leakage Class	ESF	Non-ESF
I	0.005	0.010
II	0.100	0.200

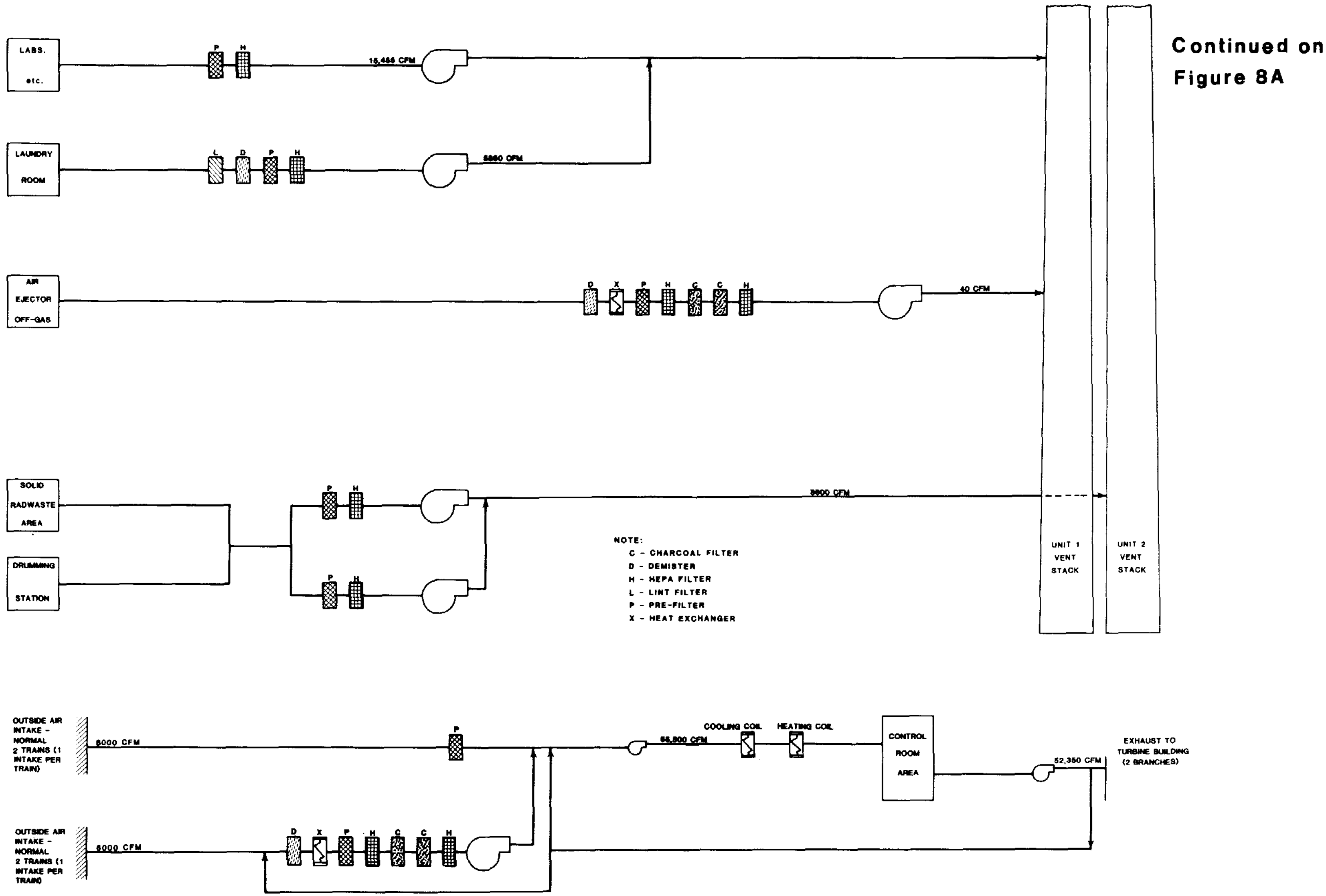


Continued on Figure 8B

TYPICAL PWR NUCLEAR POWER PLANT AIR-CLEANING SYSTEMS

FIGURE 8A

Continued on Figure 8A



TYPICAL PWR NUCLEAR POWER PLANT AIR-CLEANING SYSTEMS

FIGURE 8B

the air-cleaning duct system leakage analysis. However, the unfiltered leakage of the duct system associated with the air-conditioning portion of the system has a significant impact on the control room iodine protection factor (IPF). Table IV shows that for this example the air-conditioning duct leakage, when evaluated using the same leakage criteria as for the air-cleaning duct system, results in a reduction in the control room IPF by a factor of 5. The duct construction, system flow rates, and/or the location of air-conditioning equipment must be revised to attain an acceptable iodine protection factor.

The analysis also illustrates that basing duct leakage on duct and housing quality requirements is very conservative. Where a duct system is designed and constructed to meet the health physics and air-cleaning effectiveness requirements and type testing or actual testing confirm this level of performance, then the quality of the construction is proven. Duct and housing quality is an effect of the duct construction selected to meet health physics and/or air-cleaning effectiveness requirements. It is interesting to note that the Canadian Standards Association draft version of ANSI/ASME N509-80 for air-cleaning systems for normal operation has deleted the duct and housing quality requirements.(12) The CONAGT committee should review the need for this requirement in future reviews of N509.

The Appendix A analysis also shows that many factors have an impact on the extent of analysis, analysis equations, and system design, including the location of fans relative to air-cleaning units, interface with non-air-cleaning duct systems, and location of equipment in contaminated or protected spaces.

Systems Which May Not Require Analysis

It is important to note that a detailed duct leakage analysis may not be required to determine the duct construction of all air-cleaning system ducts. For example, non-ESF ductwork which is under a negative pressure during all modes of operation is not a health physics concern. It is thus classified as Leakage Class II per ANSI/ASME N509, which allows a maximum leakage of 5% of rated flow for air-cleaning effectiveness. Ductwork constructed to SMACNA standards can meet this leakage level.

Air-cleaning effectiveness is based on percent of rated flow, and duct leakage (cfm) varies as a function of duct surface area (ft^2), thus the system flow rate and total duct surface area must be known to determine whether leakage is within the limits of standard construction. Experience has shown that for companion flange joint and mechanical lock seam construction, a leak rate of 0.05 cfm/ft^2 is achievable.

An example of this is an auxiliary building ventilation/air-cleaning system with a capacity of 350,000 cfm and an exhaust duct-surface area of 60,000 ft^2. Based on the criterion of 5% of rated flow, total leakage is 17,500 cfm and unit leakage is 0.29 cfm/ft^2. In fact, at 0.05 cfm/ft^2, this duct system can meet a leakage requirement of 1% of rated flow.

Table IV. Effect of duct leakage on control room IPF.[1]

	Air-Cleaning System		Air-Conditioning System		
Case	Quantity of Filtered Inleakage cfm	Quantity of Outleakage cfm	Quantity of Unfiltered Inleakage cfm	Quantity of Outleakage cfm	IPF
I	0	0	0	0	248.5
II	11.0[2]	16.4[2]	0	0	247.14
III	11.0[2]	16.4[2]	56.25[2]	71.3[2]	44.52
IV	11.0[2]	16.4[2]	18[3]	71.3[2]	100

NOTES:

1) Refer to Appendix A for system flow rates and IPF equations.

2) Based on maximum allowable leakage for air-cleaning effectiveness.

3) Maximum leakage required to achieve acceptable IPF of 100.

Duct leakage analysis should not be required for ESF or non-ESF recirculating systems which are located totally within the space served. Duct leakage is not a concern for either air-cleaning effectiveness or for health physics and should therefore, not require analysis. An example of this is recirculating air-cleaning units inside containment. A knowledge of the unit leak rate for various types of duct construction will significantly decrease the extent of analysis required in most cases. Continued testing of systems presently being placed in operation will add greatly to our knowledge in this area.

IX. Potential Problem Areas

Much has been stated so far about the importance of duct leakage and how it is affected by duct design and construction. Equally important to the overall system leak rate are the design and construction of equipment casings and duct-mounted accessories.

Duct-Mounted Accessories

ANSI/ASME N509 presents design guidance for many air-cleaning system components but it is not all inclusive. Very little design guidance or quantitative leakage data exists for the following commonly used duct-mounted accessories:

a. Duct access doors.

b. Flexible connections (between fans and ducts).

c. Duct-mounted coils.

d. Dampers (through-jamb leakage).

e. Humidifiers.

f. Instrument penetrations.

The industry standard construction details for this type of equipment may adequately limit leakage to the rates normally found acceptable for commercial heating, ventilating, or air-conditioning systems, but these leak rates may not be acceptable for ESF Leakage Class I and II requirements. Without proper attention to the construction of these accessories, the allowable leakage "budget" for a system may be exceeded by the accessories alone.

Engineers should specify factory leakage testing on production samples of these accessories where appropriate (dampers, flexible connections, and coils) to ascertain leaktightness prior to installation. For equipment which cannot be factory tested (duct access doors, humidifiers, instrument penetrations), the engineer should work with the manufacturers to develop installation details aimed at achieving minimum leakage.

Equipment Casings

Equipment casings, whether factory fabricated or built-up on site, can be considered as extensions of the duct system. For detailing those casings which house equipment other than filters (such as cooling coils, fans), either current SMACNA casing details are followed or manufacturer's standard housings are used. The latter are usually inadequate where tight leakage requirements are important. As illustrated in the analysis in Appendix A, the leakage of the air-conditioning system can significantly affect the air-cleaning effectiveness/health physics requirements.

Therefore, the engineer should specify leak testing on these casings wherever leakage is of importance. The engineer should also provide supplementary sealing details to the contractor and review the contractor's shop drawings prior to fabrication.

X. Conclusions

Air-cleaning system design does not end with the filter train design and sizing. The duct system plays an important role in achieving an effective air-cleaning system. Duct leakage is particularly important to the design and construction of an effective duct system. ANSI/ASME N509 presents guidelines to be used to analyze system leakage, however, several additional items need to be considered:

a. For habitability systems, a detailed leakage analysis of associated air-conditioning duct systems is also required.

b. Equations used for health physics review must be uniquely derived for each variation of system design.

c. Duct system quality should meet air-cleaning effectiveness and health physics requirements.

d. A review of system configuration will indicate where detailed leakage analysis is required.

e. Equipment location plays a very important part in duct leakage and construction requirements and therefore, should be reviewed early during plant design.

f. More attention must be given to controlling leakage of duct-mounted accessories and of equipment casings.

APPENDIX A

Analysis of Control Air-Cleaning Duct Systems

In accordance with 10 CFR 50, Appendix A, General Design Criterion 19, the control room must be protected to ensure that personnel exposure is less than 5 rem whole body (or its equivalent to any part of the body) for the duration of an accident. A number of methods of achieving this protection are cited by Murphy and Campe.(13)

The emergency air-cleaning system chosen for this example, consists of a filtered pressurized/recirculation type as shown in Figure 9.

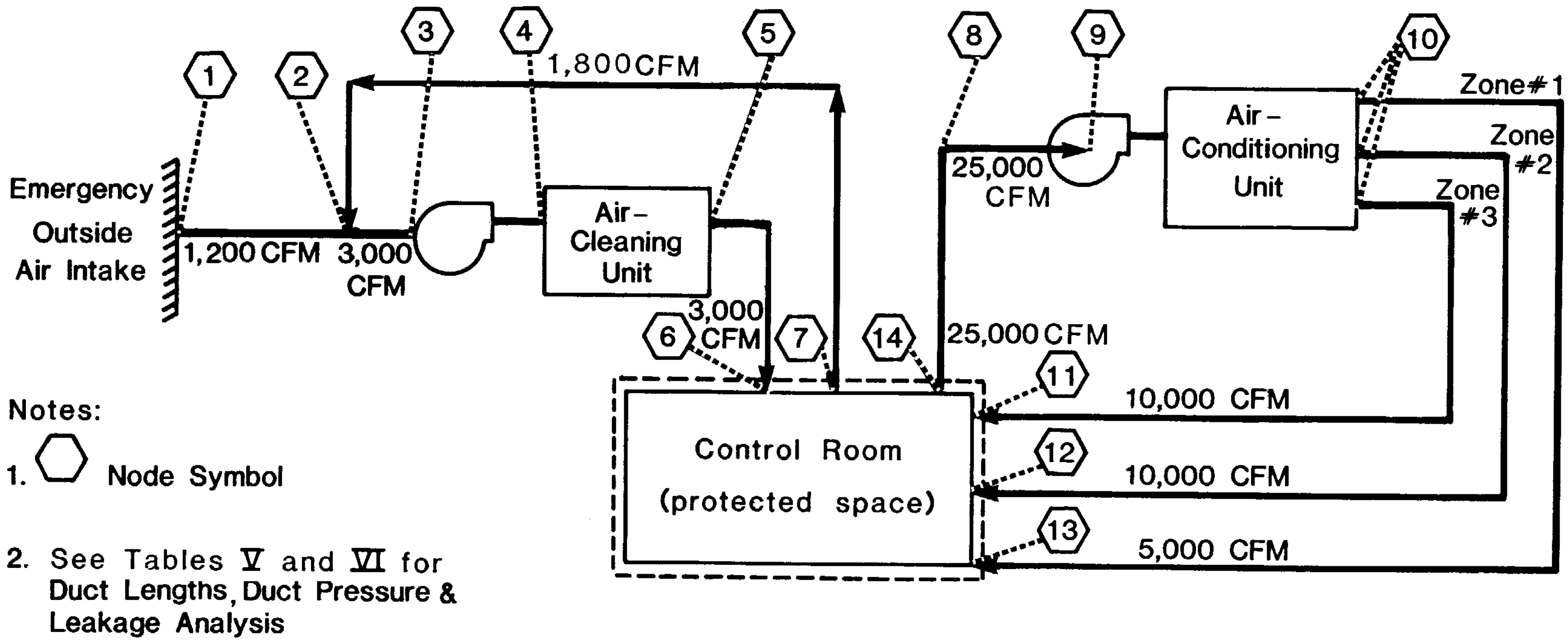
The determination of the air-cleaning system flow rate usually involves an iterative process because it is based on 1) the amount of airflow required to maintain a positive pressure differential (approximately 0.125 in. H_2O) across the control boundary, including leakage through the duct system, and 2) the amount of filtered recirculation air required to achieve the required iodine protection factor (IPF).

The air required to pressurize the control room is first calculated and an assumed quantity for duct leakage added to it. After duct and housing leakage calculations have been performed for the system configuration and layout, the original assumption is revised accordingly.

The filtered recirculation air quantity is determined by calculating the ratio of recirculated air to outside air required to meet a conservative IPF. The conservative IPF is determined by calculating the minimum acceptable IPF required to meet General Design Criterion 19 limits and multiplying this by a safety factor which will allow for a decrease in IPF due to duct leakage. The recirculation air quantity is then rechecked and revised as necessary when evaluating the iodine protection factor reduction due to duct leakage.

After the outside air and recirculated air quantities are initially determined and the equipment located, the ductwork can be sized and routed. The pressure in the duct relative to the surrounding area must also be determined for the purpose of duct leakage calculations.

For this example, an air-cleaning system of 3000 cfm flow capacity has been selected based on 1200 cfm required for pressurization and a ratio of recirculation airflow to outside flow of 1.5. This ratio has been selected in order to obtain an initial conservative IPF of 248. For this hypothetical case a minimum acceptable IPF of 100 will be assumed. In addition to the air-cleaning system, the control room also requires a recirculating type air-conditioning system with an assumed capacity of 25,000 cfm (approximately 100 tons of cooling capacity).



CONTROL ROOM SYSTEM FLOW DIAGRAM

FIGURE 9

Figure 9 shows the relative location of equipment and ductwork. Table V gives the values used for duct size, length and pressure.

Once the arrangement of equipment and ductwork is known, the system must be analyzed to determine the maximum allowable duct leakage for air-cleaning effectiveness, health physics, and duct/housing quality in accordance with ANSI/ASME N509-80 as outlined in the following:

Air-Cleaning Effectiveness

The procedure for evaluating the air-cleaning effectiveness of the system is:

a. Determine the leakage class for each section of ductwork in accordance with Figures 5, 6, and 7 (ANSI/ASME N509-80, Figures B-2, B-3, B-4).

b. Determine the maximum allowable leakage for each leakage class per Table II (ANSI/ASME N509-80, Table 4-3).

c. Determine the total duct surface area for each leakage class.

d. Determine the total housing surface area for each leakage class.

e. Adjust the leakage values for the actual duct/housing surface area ratio.

f. Apportion the total leakage to each duct section by surface area according to the following:

$$L_s = \frac{a}{A} \times \frac{P \times Q}{100} \tag{1}$$

L_s = Allowable leakage in duct section (cfm)

P = Allowable percent leakage

Q = System rated flow (cfm)

a = Surface area of duct section (ft^2)

A = Surface area of the total system ductwork (ft^2)

The allowable unit leakage is L_s/a, cfm/ft^2

The leakage class for each duct section is shown in Table V. In order to determine the appropriate leakage class, the designer must identify if the duct is under positive or negative pressure and determine if the concentration of airborne contamination is less than or greater than the space where the equipment is located or through which the ducts are routed.

For habitability systems, the leakage class is determined by keeping the leakage at a minimum (Leakage Class I) for negative pressure ducts which pass through a contaminated interspace and for positive pressure ducts which pass through a clean interspace.

Table V. Control room air-cleaning system leakage analysis.

Nodes From-To	Duct Size	Duct Length (ft)	Duct Surface Area (ft^2)	Duct Pressure (in. W.G.)	Leakage Class	Air-Cleaning Effectiveness Maximum Allowable: Leakage (%)	Unit Leak Rate(2) cfm/ft^2	Total Leakage cfm	Duct and Housing Quality cfm/ft^2(4)
1-2	10"Ø	50	131	-1.0	II	1.2[3]	0.047	-6.2	0.03
2-3	16"Ø	20	84	-2.0	II	1.2[3]	0.047	-3.9	0.04
3-4	22x12	5	28	+10.0	I	0.1	0.004	+0.11	0.005
4-5	3'-0"x7'-0" (See Note 1)	40	842	+10.0	I	0.1	0.0036	+3.00	0.005
5-6	22x12	50	283	+2.0	II	1.2[3]	0.047	+13.3	0.04
7-2	12"Ø	75	236	-1.0	I	0.1	0.004	-0.9	0.0016

Total Air-Cleaning Class I Duct ft^2 = 264
Class II Duct ft^2 = 498
Total = 762

Class I Housing ft^2 = 842
Class II Housing ft^2 = 0

Total Inleakage = 11
Total Outleakage = 16.4

NOTES:

1) Housing Dimensions
2) Leak Rate = $Ls/a = \frac{PxQ}{Ax100}$
3) Adjusted for Actual Housing/Duct Surface Area Ratio
4) Adjusted for Actual Duct Pressure
5) Negative sign indicates inleakage; positive sign indicates outleakage.

Figures B-3 through B-4 of ANSI/ASME N509-80 give typical examples for various types of system configurations.

For this particular example, the possible system configurations and leakage classes are shown in Figure 10. It is important to note the effect of location of the fan and filter unit or air-conditioning unit. For the air-cleaning unit, Scheme 6 has been selected because it minimizes the amount of infiltration of radioactive air into the air-cleaning duct system after the filter unit.

For the air-cleaning system, the maximum allowable unit leak rate (cfm/ft^2) and the total leakage (cfm) are shown in Table V. It is important to note a few things about the method of determining the leakage.

a. For Leakage Class II, since no housing area exists, the percent leakage allocated to housings per ANSI/ASME N509 Table 4-3 is included in the allowable percent leakage for Class II ducts.

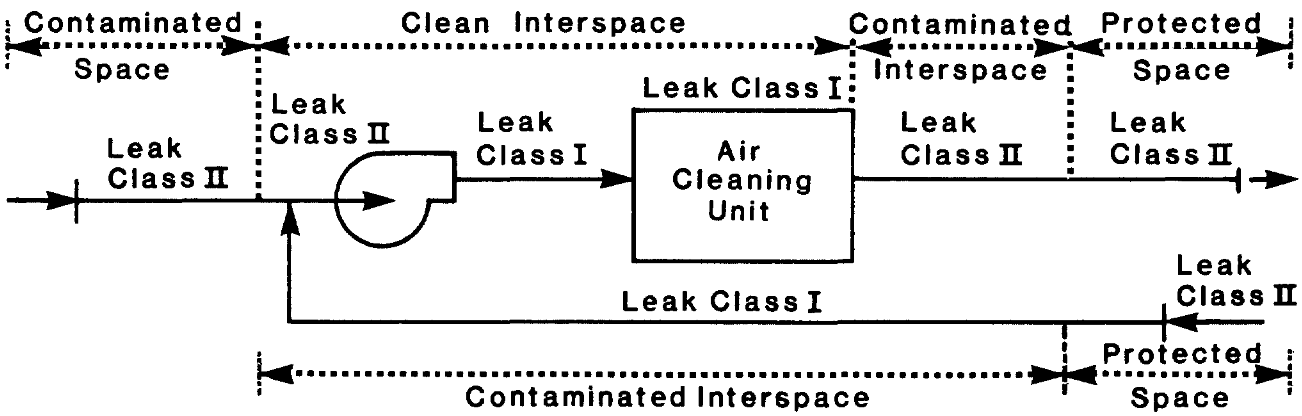
b. The allowable unit leak rate for each duct section is determined by dividing each duct section area by the total duct area for Class I and Class II (762 ft^2). Note that the housing area is not included.

The total allowable leakage in this example amounts to 11 cfm inleakage and 16.4 cfm outleakage. Note that for test purposes, the unit leak rate (cfm/ft^2) will be used as the acceptance criterion since the ductwork is usually tested in sections.

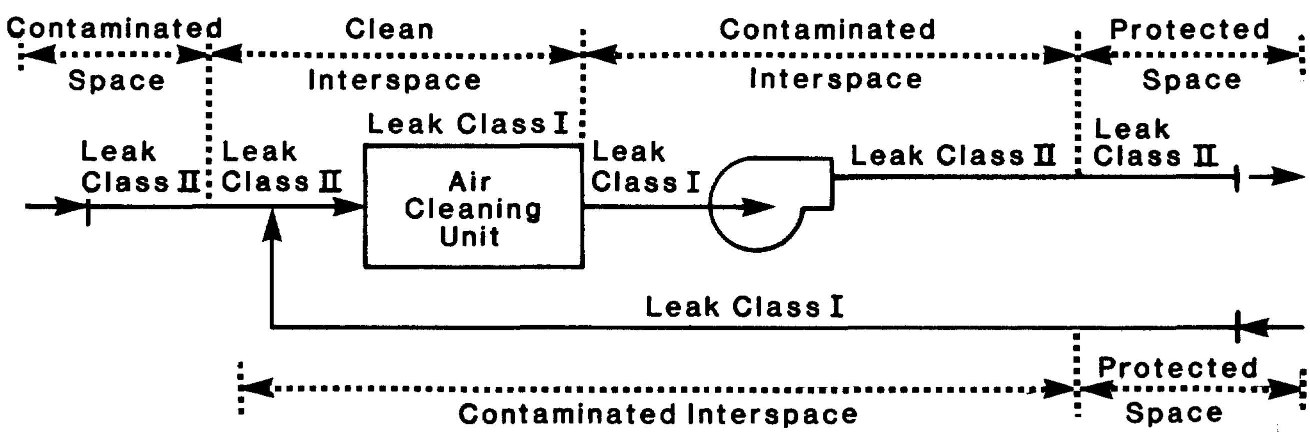
It is also important to note that if the system were located closer to the protected space, the duct surface area would be decreased (shorter duct length), and the allowable unit leakage rate thus higher. For example, assume the total duct area to be only 350 ft^2. The allowable unit leak rate would be approximately 0.008 cfm/ft^2 for Leakage Class I and 0.094 cfm/ft^2 for Leakage Class II. This could have significant impact on the type of duct construction selected to meet the leakage requirements.

Another factor which could decrease the unit leak rate is combining the recirculated air for the air-cleaning system with the recirculated air for the air-conditioning system (Nodes 7-2 and 14-8). This is usually done if the air-cleaning unit and the air-conditioning unit are located close to one another. Using one duct to transport the air from the protected space will decrease the amount of ductwork. However, if this approach is taken, the total surface area increases. In this example, the area would increase by 750 ft^2 or about two times the original area, resulting in unit leak rates one-half of the present value (0.002 cfm/ft^2 for Class I and 0.024 cfm/ft^2 Class II). The duct designer has the option of different types of duct construction depending on how these duct systems are designed.

These factors must be considered in the early stages of plant conceptual design to minimize more costly all-welded duct construction.



Scheme No. 6 of ANSI/ASME N509-80



Scheme No. 7 of ANSI/ASME N509-80

DETERMINATION OF LEAKAGE CLASSES

FIGURE 10

Health Physics

The maximum allowable duct leakage that will satisfy the health physics requirements is determined for this example by evaluating the reduction in the iodine protection factor (IPF). The iodine protection factor is used to express the reduction in radioiodine concentration within the control room as a result of filtration and recirculation. IPF is defined as follows:

$$IPF = \frac{\text{Dose without Protection}}{\text{Dose with Protection}}$$

For this example, the IPF is determined using the following equation from Figure 4a of Reference 12.

$$IPF = \frac{F_1 + \eta F_2 + F_3}{(1-\eta)\ F_1 + F_3} \tag{2}$$

F_1 = filtered outside air (1200 cfm)

F_2 = filtered recirculated air (1800 cfm)

F_3 = unfiltered inleakage air

η = filtration efficiency/100

Assuming an unfiltered inleakage (through the control room boundary) of zero and a filter efficiency of 99% gives:

$$IPF = \frac{1200 + (.99)\ (1800) + 0}{(1-.99)\ 1200 + 0} = 248.5 \tag{3}$$

For this particular example, a minimum IPF of 100 is required in order to meet the dose requirements of General Design Criterion 19.

In this case, as long as there is no duct leakage, the minimum required IPF is exceeded. However, the IPF is reduced when the duct inleakage and outleakage are accounted for. This must therefore be evaluated to determine if the reduced IPF is still acceptable.

Previous papers on this subject (References 13, 14, 15), have discussed the methodology used to evaluate the IPF for various cases, but these papers, however, neglected the impact of duct system leakage on the IPF. This leakage can have an effect on the iodine protection factor and must therefore be evaluated to determine any impact on control room dose.

The equation (see Appendix B for the derivation) for the reduced iodine protection factor (IPF_R) of this specific system is:

$$IPF_R = \frac{\left[F_1 + L_1 - L_2 + \eta F_2 + F_3 + \left(\frac{F_2}{F_1 + F_2 + L_1}\right)(L_2)\ (1-\eta)\right]}{\left\{\left[F_1 + L_1 - \left(\frac{F_1 + L_1}{F_1 + F_2 + L_1}\right) L_2\right](1 - \eta) + F_3\right\}} \qquad (4)$$

where: L_1 = filtered inleakage, cfm
($L_{1-2} + L_{2-3} + L_{7-2}$)

L_2 = outleakage, cfm
($L_{3-4} + L_{4-5} + L_{5-6}$)

Based on the values for leakage for air-cleaning effectiveness listed in Table V and on assumptions of F_1 = 1200 cfm, F_2 = 1800 cfm and F_3 = 0 and filter efficiency η = .99, then:

$$IPF_R = \frac{1200 + 11 - 16.4 + .99(1800) + 0 + (.60)\ (16.4)\ (1-.99)}{1200 + 11 - (.40)\ (16.4) \quad 1 - .99 \quad + 0} \qquad (5)$$

$$= \frac{2976.70}{12.04} = 247.14$$

It is apparent that the leakage in this example does not significantly lower the IPF and that the allowable leakage for air-cleaning effectiveness is still the governing case. However, the impact of duct leakage for the recirculating air-conditioning system has not been accounted for. In this example, the air-conditioning unit is located in a contaminated interspace. Since there is no filtration of this air, any duct inleakage will be unfiltered. The magnitude of this duct leakage must thus be evaluated and the reduced iodine protection factor (IPF_R^1) calculated. (See Appendix B for derivation of equation.)

$$IPF_R^1 = \frac{\left[F_1 + L_1 - L_2 + \eta F_2 + F_3 + \left(\frac{F_2}{F_1+F_2+L_1}\right)(L_2)\ (1-\eta) + L_3 - (L_4)\left(1 - \frac{F_4}{F_4 + L_3}\right)\right]}{\left\{\left[F_1 + L_1 - \left(\frac{F_1 + L_1}{F_1+F_2+L_1}\right) L_2\right](1-\eta) + F_3 + L_3 - \left(\frac{L_3}{F_4 + L_3}\right)(L_4)\right\}} \qquad (6)$$

where: F_4 = recirculation airflow rate, cfm

L_3 = unfiltered inleakage (cfm) in the air-conditioning system

($L_{14-8} + L_{8-9}$)

L_4 = air-conditioning system outleakage

($L_{9-10} + L_{10-11} + L_{10-12} + L_{10-13}$)

For the first iteration, assume that the duct leakage at design duct pressure is equal to 0.05 cfm/ft^2 (approximately the value of Class II unit leak rate for air-cleaning effectiveness). Based on the duct sizes, lengths, and areas shown in Table VI, the duct inleakage is 56.25 cfm, and the duct and housing outleakage is 71.3 cfm. Factoring this leakage into the evaluation of the IPF gives:

$$IPF_R^1 = \frac{2976.70 + 56.09}{12.04 + 56.09} = \frac{3032.79}{68.13} = 44.52$$

The IPF is thus very sensitive to this leakage. Based on the minimum acceptable IPF of 100, this is unacceptable. The allowable duct leakage must be less in order to meet the minimum IPF. With L_4 = 71.3 cfm and IPF equal to the minimum, L_3 can be determined based on the following:

$$100 = \frac{2986.34 + L_3 - 71.3\left(1 - \overbrace{\left(\frac{25,000}{25,000 + L_3}\right)}^{\sim 1}\right)}{12.04 + L_3 - \underbrace{\left(\frac{L_3}{25,000 + L_3}\right)}_{\sim 0} 71.3}$$

$L_3 \simeq$ 18.0 cfm. Thus, the unit duct leakage must be:

$$\frac{18.0}{56.25}\ (.05\ \text{cfm/ft}^2) = 0.016\ \text{cfm/ft}^2$$

The foregoing analysis of the air-conditioning system assumed that the air-conditioning unit and associated ductwork were within a contaminated space or interspace. If the unit and <u>all</u> ductwork were located within a protected space (part of the habitability envelope), then the duct and housing leakage would not have to be evaluated. The location of the unit within the protected space may dictate other design considerations of which the designer should be aware. For example, with the air-conditioning unit inside the protected space, a direct expansion refrigerant cooling system should not be used due to the potential for a tube failure and the resulting chemical release inside the protected space. These potential design problems must be reviewed and resolved if the system is to be located within the protected space.

Another alternative to decreasing air-conditioning system duct leakage to achieve the minimum acceptable IPF is to increase the quantity of filtered recirculated air. In this example, the filtered recirculation air quantity would have to be increased from 1800 cfm to more than 6000 cfm to offset the decrease in IPF caused by the air-conditioning system leakage. This increase of course will increase the size of the filter unit from 3000 cfm to more than 7000 cfm as well as increase the sizes of the air-cleaning system recirculation and discharge ductwork. The cost of these increases must be evaluated against the cost of making the air-conditioning system duct more leaktight. In this case, ducts constructed to meet a unit leak rate of 0.015 cfm/ft^2 would be more economical.

Table VI. Control room air-conditioning system leakage analysis.[1]

Nodes	Duct Size	Duct Length	Duct Area	Design Pressure (in. w.g.)	Leakage at 0.05 cfm/ft^2
14-8	60"x30"	50	750	-2.0	-37.5
8-9	60"x30"	25	375	-3.0	-18.75
9-10	6'-0"x 8'-0"H (See Note 1)	10	376	+5.0	+18.8
10-11	40"x20"	40	400	+4.0	+20.0
10-12	40"x20"	40	400	+4.0	+20.0
10-13	26"x12"	40	250	+4.0	+12.7

Total Inleakage = 56.25

Total Outleakage = 71.3

NOTE:

1) Housing Dimensions

The results of the analysis for this example indicate that the unit leak rate for air-cleaning effectiveness, shown in Table V, will apply for all air-cleaning ductwork, and that the air-conditioning recirculation ductwork must be designed for 0.016 cfm/ft^2 for all negative pressure ducts, and 0.05 cfm/ft^2(*) for all positive pressure ducts and housings. These values will then determine the type of duct and housing construction required to meet the duct leakage requirements.

Duct and Housing Quality

The duct and housing unit leak rates which indicate a "minimum level of acceptable workmanship" given in Table 4-4 of ANSI/ASME N509-80 are as follows:

Class I	0.005 cfm/ft^2
Class II	0.100 cfm/ft^2

These rates are based on a duct pressure of 10 in. H_2O. The leak rate assigned each section of duct must be adjusted for the design pressure in the duct. Table V shows the adjusted unit leak rate.

It is to be noted that in some cases, the unit leak rate required for duct and housing quality is lower than that required for air-cleaning effectiveness.

The values for allowable leakage for duct and housing quality contained in ANSI/ASME N509 were originally determined in order to provide an upper bound on allowable leakage, especially for short duct runs, which result in high allowable leak rates when evaluated based on air-cleaning effectiveness and health physics. However, if a duct is constructed to meet the air-cleaning effectiveness and demonstrates this by testing, then that alone should indicate that the duct and housing quality are acceptable. It is interesting to note that the Canadian Standards Association draft version of ANSI/ASME N509-80 for air-cleaning systems for normal operation has deleted the duct and housing quality requirements.(12) The CONAGT committee should review the need for this requirement in future reviews of N509.

The analysis for structural requirements which will not be covered here, must of course be factored into the selection of duct and housing construction.

(*)This assumes that the air-conditioning unit housing leakage is also 0.05 cfm/ft^2 or 18.8 cfm for this case. Depending on the type of construction, this may or may not be accurate. If housing leakage is already known, it should be factored into the analysis. These housings are traditionally not that leaktight, thus, the housing construction may have to be modified to reduce the housing leakage.

It must be re-emphasized that the intent of this analysis is to demonstrate the methodology and not to present "cook-book" equations for analysis. Each system configuration must be analyzed based on the methods presented here. Location of fans relative to air-cleaning units, interface with non-air-cleaning duct systems, and location of the equipment in protected spaces all will have an impact on the extent of the analysis and the equations involved.

APPENDIX B

Derivation of Reduced Iodine Protection Factor Due to Duct Leakage Effects

The equation for the reduction in the iodine protection factor (IPF) is derived using the methodology of Murphy and Campe[13], given on page 495, where the IPF is evaluated by considering an equilibrium balance between the iodine sources and losses within the control room boundary. Figure 11 shows the diagram of the control room system with the flow and leakage paths identified.

The reduced iodine protection factor (IPF_R) will first be derived based only on the air-cleaning system. The effect of duct leakage in the recirculating air-conditioning system will then be addressed.

With the airflow balance shown in Figure 11 the balance of activity can be expressed:

$$\frac{dA}{dt} = \left\{ A_oF_1 + AF_2 + A_oL_1 - \left[A_o\left(\frac{F_1 + L_1}{F_1+F_2+L_1}\right) + A\left(\frac{F_2}{F_1+F_2+L_1}\right)\right] (L_2) \right\} (1-\eta) \qquad (1)$$

$$+ A_oF_3 - AF_2 - AF_3 - AF_1 - A(L_1 - L_2)$$

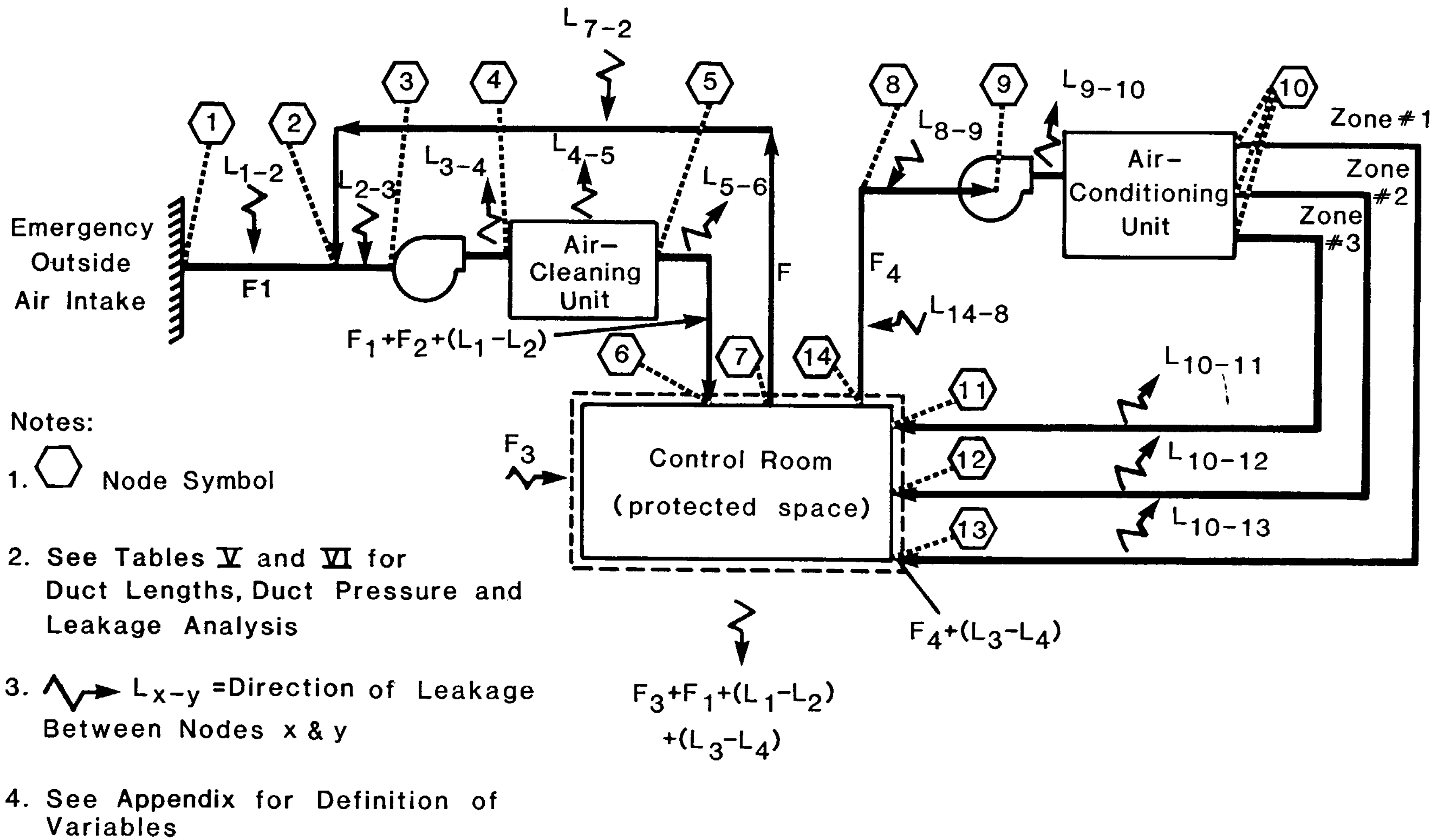
For equilibrium conditions $\frac{dA}{dt} = 0$, therefore:

$$A_o \left[(F_1 + L_1 - \left(\frac{F_1 + L_1}{F_1+F_2+L_1}\right) L_2) (1-\eta) + F_3 \right] = \qquad (2)$$

$$A \left[F_2 + F_3 + F_1 + (L_1 - L_2) + \left(\frac{F_2}{F_1+F_2+L_1}\right) (L_2) (1-\eta) - F_2 (1-\eta) \right]$$

if $IPF_R = \frac{A_o}{A}$, then

$$IPF_R = \frac{\left[F_1 + F_2 + F_3 + (L_1 - L_2) + \left(\frac{F_2}{F_1+F_2+L_1}\right) (L_2) (1-\eta) - F_2 (1-\eta) \right]}{\left[(F_1 + L_1 - \left(\frac{F_1 + L_1}{F_1 + F_2 + L_1}\right) L_2) (1-\eta) + F_3 \right]} \qquad (3)$$



LEAKAGE AND FLOW PATHS FOR CONTROL ROOM SYSTEM

FIGURE 11

This reduces to:

$$IPF_R = \frac{F_1 + \eta F_2 + F_3 + (L_1 - L_2) + \left(\frac{F_2}{F_1+F_2+L_1}\right)(L_2)\ (1-\eta)}{\left[F_1 + L_1 - \left(\frac{F_1 + L_1}{F_1+F_2+L_1}\right) L_2\right](1-\eta) + F_3} \tag{4}$$

The effect of the duct leakage of the air-conditioning system can be evaluated in the same fashion as above. In this case $\frac{dA}{dt}$ =

$$\text{Equation (1)} + AF_4 + A_oL_3 - A\ (L_3 - L_4) - AF_4$$

$$- \left(A\left(\frac{F_4}{F_4 + L_3}\right) + A_o\left(\frac{L_3}{F_4 + L_3}\right)\right)(L_4) \tag{5}$$

Setting $\frac{dA}{dt} = 0$ gives:

$$A_o\left[(F_1 + L_1 - \left(\frac{F_1 + L_1}{F_1+F_2+L_1}\right) L_2)\ (1-\eta) + F_3 + L_3 - \left(\frac{L_3}{F_4 + L_3}\right) L_4\right] = \tag{6}$$

$$A\left[F_1 + \eta F_2 + F_3 + (L_1 - L_2) + \left(\frac{F_2}{F_1+F_2+L_1}\right)(L_2)\ (1-\eta) + \left(\frac{F_4}{F_4 + L_3}\right) L_4 + (L_3 - L_4)\right]$$

with $\frac{A_o}{A} = IPF_R^1$

$$IPF_R^1 = \frac{\left[F_1 + L_1 - L_2 + \eta F_2 + F_3 + \left(\frac{F_2}{F_1+F_2+L_1}\right)(L_2)\ (1-\eta) + L_3 - (L_4)\left(1 - \frac{F_4}{F_4 + L_3}\right)\right]}{\left\{\left[F_1 + L_1 - \left(\frac{F_1 + L_1}{F_1+F_2+L_1}\right) L_2\right](1-\eta) + F_3 + L_3 - \left(\frac{L_3}{F_4 + L_3}\right)(L_4)\right\}} \tag{7}$$

$A_o\left(\frac{F_1 + L_1}{F_1+F_2+L_1}\right) + A\left(\frac{F_2}{F_1+F_2+L_1}\right)$ represents the resultant specific activity for the mixed gas stream

The aforementioned equations represent the reduced iodine protection factor for the example shown in Figure 11. If the fan and air-cleaning unit positions are reversed, the equation must be revised to reflect the effect of the unfiltered leakage. In short, the equation must be derived for each particular configuration.

DEFINITION OF VARIABLES

A_o = Specific Activity Outside Control Room

A = Specific Activity Inside Control Room

F_1 = Rate of Filtered Outside Air

F_2 = Rate of Filtered Recirculated Air

F_3 = Rate of Unfiltered Outside Air

F_4 = Rate of Unfiltered Recirculated Air

L_1 = Filtered Inleakage from Leak Paths $\left(L_{1-2} + L_{2-3} + L_{7-2}\right)$

L_2 = Outleakage from Leak Paths $\left(L_{3-4} + L_{4-5} + L_{5-6}\right)$

L_3 = Unfiltered Inleakage from Leak Paths $\left(L_{14-8} + L_{8-9}\right)$

L_4 = Outleakage from Leak Paths $\left(L_{9-10} + L_{10-11} + L_{10-12} + L_{10-13}\right)$

η = Filter Efficiency/100

Acknowledgements

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DISCUSSION

BELLAMY: I would like to state that the 1980 edition of ANSI N509 has been published and is now available through ASME.

THE EFFECTS OF SECONDARY CONTAINMENT AIR CLEANUP SYSTEM LEAKAGE ON THE ACCIDENT OFFSITE DOSE AS DETERMINED DURING PREOP TESTS OF THE SEQUOYAH NUCLEAR PLANT

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ABSTRACT

The Sequoyah Nuclear Plant has two secondary containments. One is the annular region between the primary containment and the shield building surrounding the primary containment. The second secondary containment is that part of the auxiliary building called the auxiliary building secondary containment enclosure which is potentially subject to direct airborne radioactivity. Two air cleanup systems are provided to serve these areas. The emergency gas treatment system (EGTS) serves the annulus between the primary containment and the shield building, and the auxiliary building gas treatment system (ABGTS) serves the area inside of the auxiliary building secondary containment enclosure.

The major function served by these air cleanup systems is that of controlling and processing airborne contamination released in these areas during any accident up to a design basis accident. This is accomplished by (1) creating a negative pressure in the areas served to ensure that no unprocessed air is released to the atmosphere, (2) providing filtration units to process all air exhausted from the secondary containment spaces, and (3) providing a low-leakage enclosure to limit exhaust flows.

Releases from these spaces significantly affect the offsite dose and thus must be closely controlled. Factors that contribute to the offsite dose include not only the release rate from the secondary containment spaces but also other factors which are not readily apparent. Among these factors, preoperational tests at Sequoyah Nuclear Plant identified air cleanup unit bypass leakage and duct and damper leakage as having major impact on the offsite dose.

Offsite dose effects due to secondary containment release rates, bypass leakage, and duct and damper leakages are presented and parameter variations are considered. For the EGTS, a recirculation system, the most important parameter is the total inleakage of the system which causes an increase in both whole body (gamma) and thyroid (iodine) doses. For the ABGTS, a once-through system, the most important parameter is the inleakage which bypasses the filters resulting in an increase in the thyroid dose only. Actual preoperational test data are utilized. Problems encountered during the "preop" test are summarized. Solutions incorporated to bring the EGTS and ABGTS air cleanup systems within the test acceptance criteria required to meet offsite dose limitations are discussed and the resultant calculated offsite dose is presented.

BACKGROUND

Description of Secondary Containment Areas

There are two secondary containments at the Sequoyah Nuclear Plant. One of these is the annulus region between the primary containment and the shield building surrounding the primary containment. The second secondary containment is that part of the auxiliary building which is subject to direct airborne radioactivity.

The annulus, shown schematically in figure 1, surrounds and encloses the steel primary containment vessel. Its outer boundary is formed by the shield building. The shield building is a reinforced concrete structure of circular cross section. Its vertical centerline is coincident with that of the primary containment vessel. The volume of the annulus between the shield building and the primary containment is approximately 10,600 cubic meters (375,000 cubic feet).

The auxiliary building is a conventional reinforced concrete structure located between the reactor building and the control building as shown in figure 2. Its basic function is to house support and safety equipment for the primary steam system. Portions of the auxiliary building bounding areas potentially are subject to direct airborne contamination in the postaccident condition so these areas provide a secondary containment function. That part of the building is known as the auxiliary building secondary containment enclosure (ABSCE). The volume of the ABSCE is approximately 99000 cubic meters (3,500,000 cubic feet).

Description of Air Cleanup Systems

Two air cleanup systems are provided to serve the secondary containment areas. The emergency gas treatment system (EGTS) serves the annulus and the auxiliary building gas treatment system (ABGTS) serves the ABSCE.

Design bases for the EGTS are:

1. To keep the air pressure within the annulus below atmospheric at all times in which containment integrity is required.

2. To reduce the concentration of radioactive nuclides in annulus air released to the environs during an accident to levels sufficiently low to keep the site boundary dose rate below the 10CFR100 guideline.

Design bases for the ABGTS are:

1. To establish and maintain an air pressure below atmospheric within the ABSCE during accidents.

2. To reduce the concentration of radionuclides in air released from the ABSCE to levels sufficiently low to keep the site boundary dose rate below the 10CFR100 guideline.

3. To minimize the spreading of airborne radioactivity within the auxiliary building following a fuel handling accident.

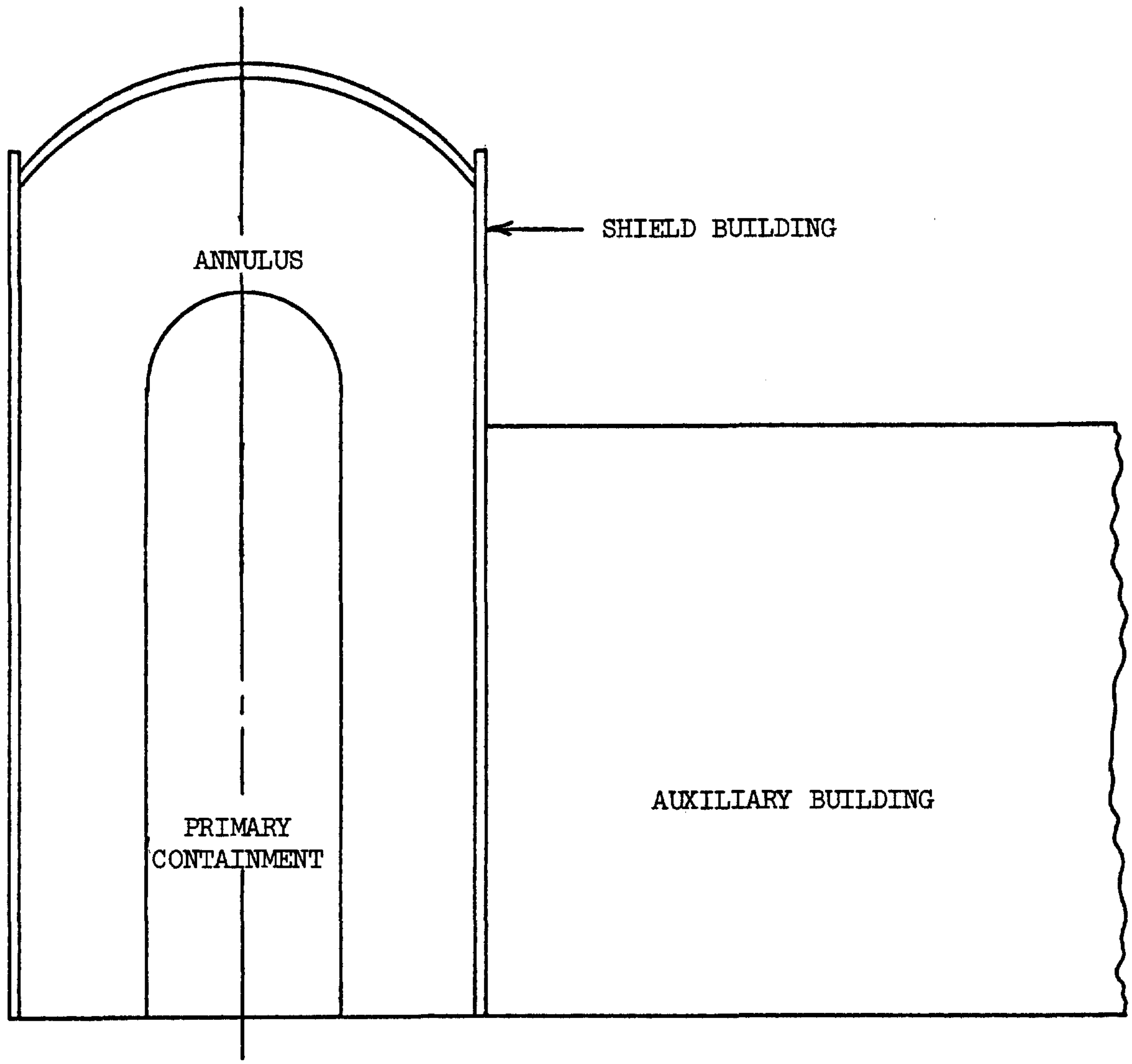

SHIELD BUILDING
ANNULUS
AUXILIARY BUILDING
PRIMARY
CONTAINMENT

FIGURE 1

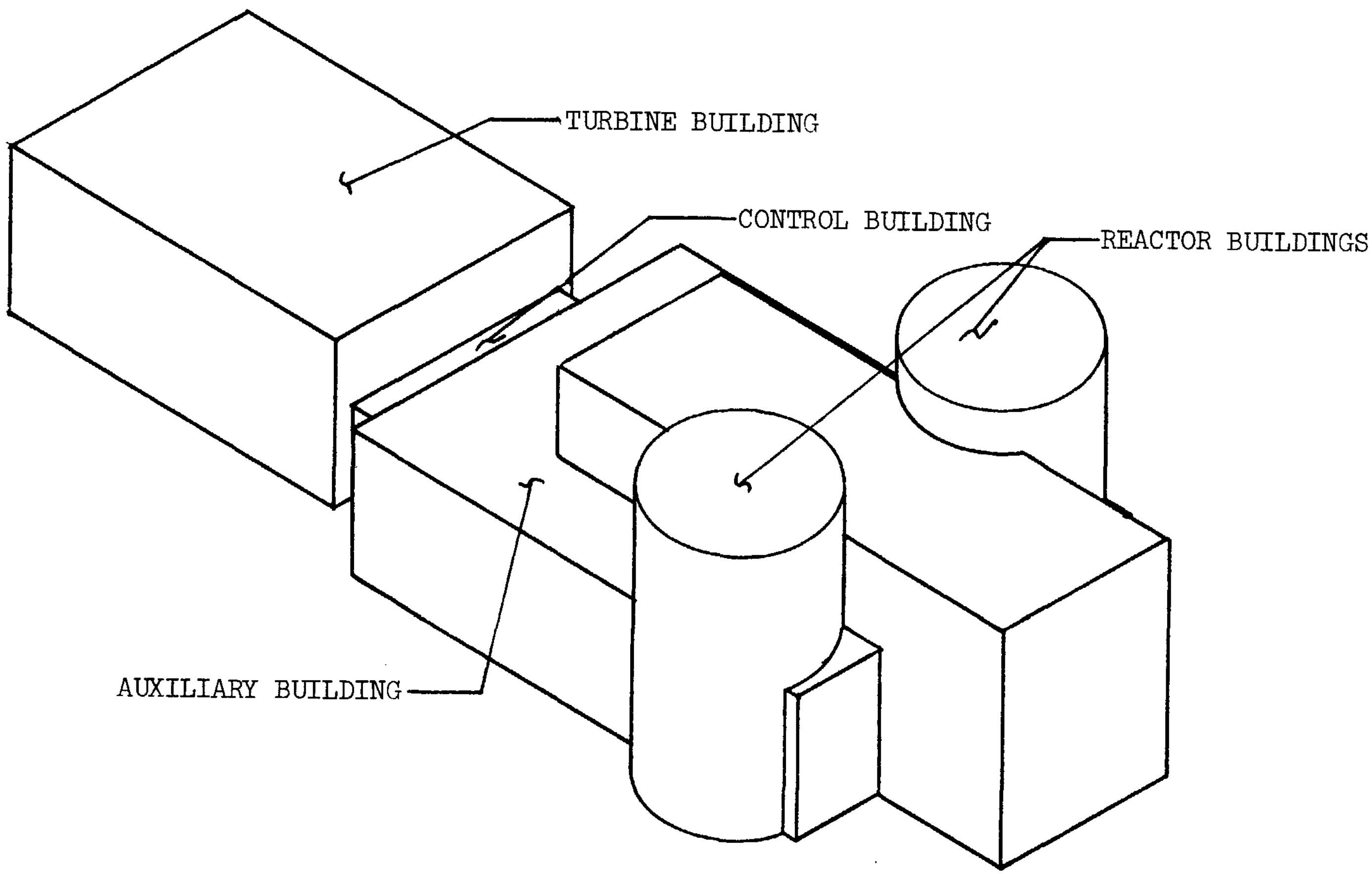

TURBINE BUILDING
CONTROL BUILDING
REACTOR BUILDINGS
AUXILIARY BUILDING

FIGURE 2

The EGTS, shown in figure 3, is a redundant, air cleanup system having the capability to serve either of the two reactor units at the Sequoyah plant. For startup of the unit 1 reactor, the system interface with the unit 2 portion of the plant was blocked. Therefore, for purposes of this presentation, system operation will primarily be discussed in the context of unit 1 only.

During normal operations, the EGTS interfaces with the normal annulus vacuum control system. That system maintains annulus pressure at a level sufficiently below atmospheric to ensure that during the initial phases of a design basis LOCA, coincident with a postulated loss of normal power, annulus pressure will remain below atmospheric, thus precluding release of airborne contaminants from primary containment, directly to the environs. Upon receipt of an accident signal, the normal system is shutdown, isolated from the EGTS, and EGTS operation is initiated.

The system functions in the postaccident mode by drawing air from the annulus, processing it through a cleanup unit, releasing a portion of the air to the environs and recirculating the balance of the flow to the annulus. The fraction of the total flow released to the environs is determined based on a differential pressure controller which maintains annulus pressure at a nominal 12.7 mm (1/2 inch) H_2O below atmospheric pressure. Filtration components provided in the air cleanup unit include prefilters, HEPA filters, and two banks of adsorber trays.

System capacity is a nominal 113 cubic meters per minute (4000 cubic feet per minute). The steady-state flow exhausted to the environs is equivalent to the annulus infiltration rate at the design negative pressure. Maximum allowable flow rate released to the environs was determined during system design based on 10CFR100 guidelines for the site boundary dose rate. Under that constraint, the maximum flow to the environs was chosen to be 2.83 cubic meters per minute (100 cubic feet per minute). Thus, total design leak rate through annulus penetrations was limited to this flow rate. The remainder of the total EGTS flow is released near the floor of the annulus and allowed to rise past the primary containment penetrations, mixing with any airborne contamination which may be leaking from primary containment and then rise to the air intake near the shield building dome.

More than 200 penetrations pass through the shield building wall. These accommodate piping, cable trays, and electrical conduit which serve equipment in the primary containment or the annulus. Each penetration is provided with a seal to limit leakage into the annulus. Piping penetrations are equipped with flexible membrane type seals; electrical conduit and cable tray penetrations utilize an RTV type silicon sealant. Seals were designed such that total inleakage to the annulus will not exceed the 2.83 cubic meters per minute (100 cubic feet per minute) limit at a negative 12.7 mm (1/2-inch) H_2O annulus pressure.

The auxiliary building gas treatment system, shown schematically in figure 4, also is a redundant system shared by the two reactor units at Sequoyah. As in the case of the EGTS, the system interface with unit 2 was defined and isolated to facilitate startup of unit 1. The system draws air from the auxiliary building safety-related pump rooms, the fuel handling area, and the waste packaging area through ducting normally used for ventilation of the areas.

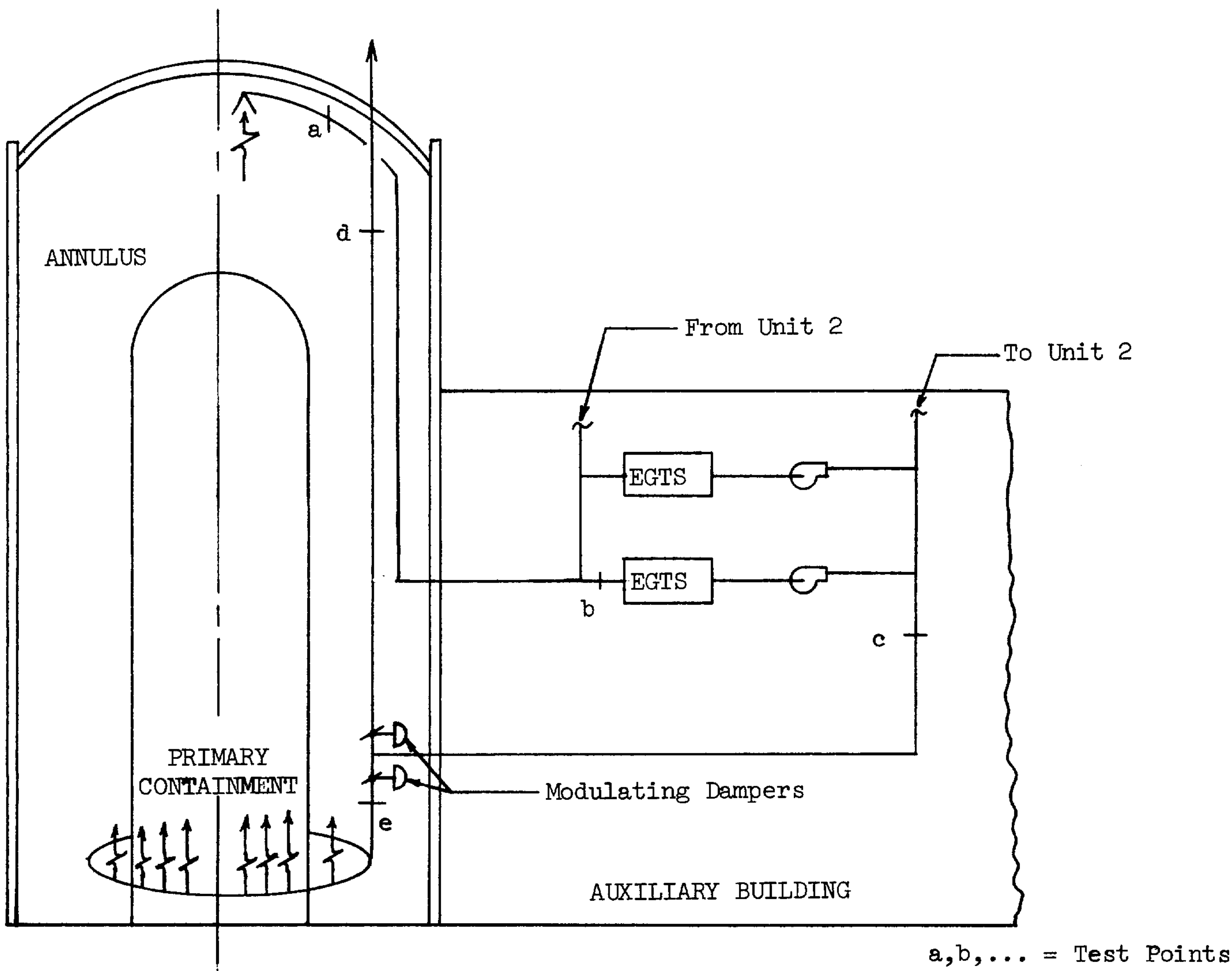
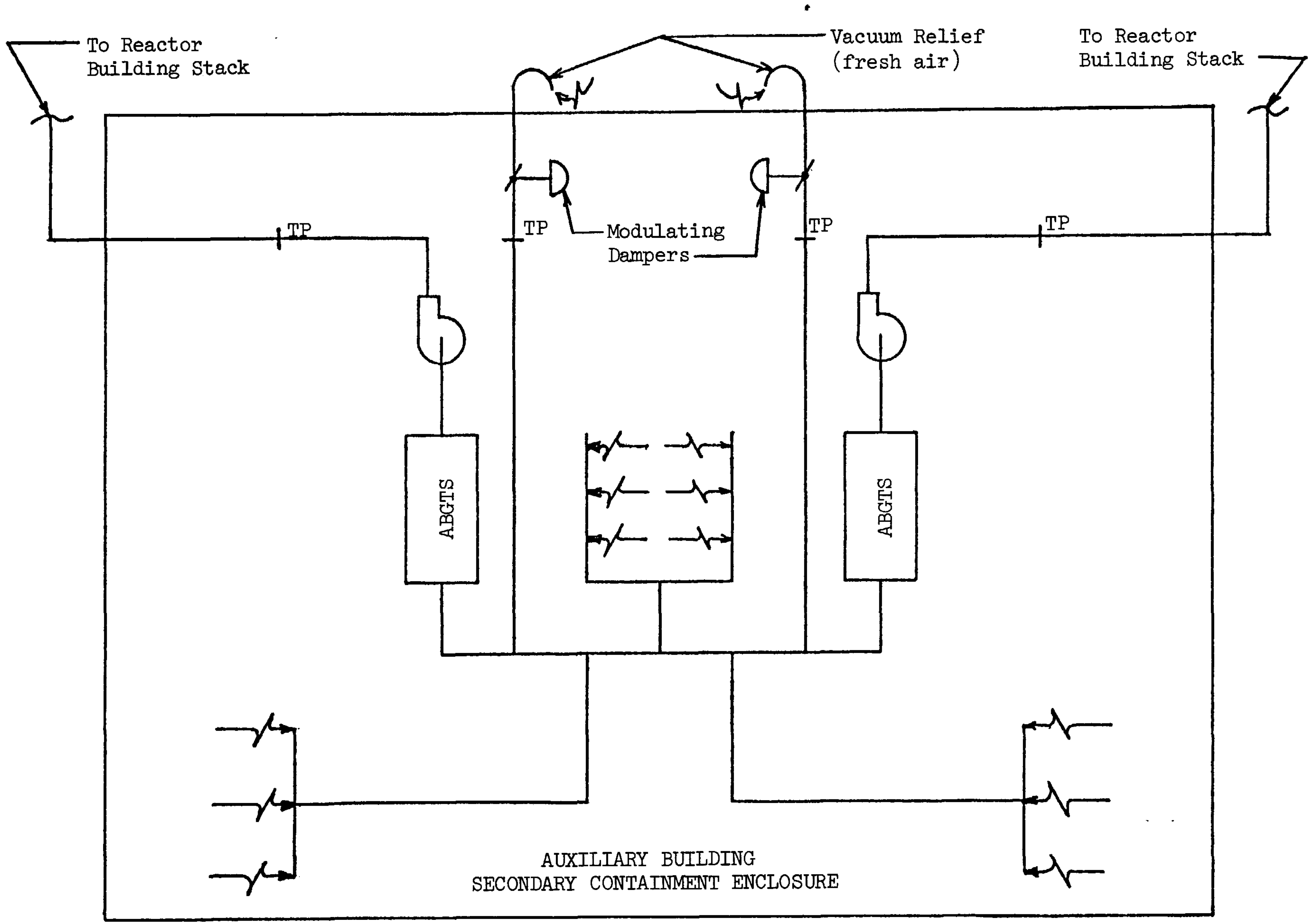

a
d
ANNULUS
From Unit 2
To Unit 2
EGTS
EGTS
b
c
PRIMARY CONTAINMENT
Modulating Dampers
e
AUXILIARY BUILDING
a,b,... = Test Points

FIGURE 3



TP= Test Point

FIGURE 4

The air is processed by one of two air cleanup units containing prefilters, HEPA filters and adsorbers, then exhausts to the environs through the reactor unit vent.

System rated capacity is 255 cubic meters per minute (9000 cubic feet per per minute). Total flow is essentially constant, with modulating flow controllers mixing air from inside the ABSCE with vacuum relief air taken from outside. The controllers are set to maintain flow at the level required to maintain a pressure in the ABSCE of 6.35 mm (1/4-inch) H_2O below atmospheric pressure. The ABSCE boundary is designed to limit inleakage to about 170 cubic meters per minute (6000 cubic feet per minute) when ABSCE pressure is 6.35 mm (1/4-inch) H_2O below atmospheric.

Piping and electrical penetrations of the ABSCE boundary utilize seals similar to those used to seal shield building penetrations. In addition, doors in the boundary are provided with weatherstripping and thresholds. Ventilation ducts which penetrate the boundary are provided with redundant isolation dampers that close automatically upon ABGTS startup.

Preoperational Test Program

The preoperational test programs for the EGTS and the ABGTS were designed to verify that the systems are capable of meeting their design bases. As such, the programs included verification of the negative pressure levels maintained in the secondary containment areas (annulus and ABSCE); determination of infiltration rates for the annulus, and ABSCE; verification of system flows; and measurement of air cleanup unit leak rates.

EGTS Preop Test

With the annulus in the isolated state, i.e., penetrations sealed, purge line isolation valves closed, and doors shut, the EGTS was aligned to draw from the annulus. After verifying that the pressure controllers maintained the required 12.7 mm (1/2-inch) H_2O pressure, flow rates were measured at the following locations:

(a) intake in the annulus

(b) entrance to air cleanup unit

(c) downstream of the EGTS fan

(d) at the reactor building exhaust vent

(e) in the recirculation line to the annulus

These test points are shown schematically in figure 3. The test points were selected such that the flows measured would indicate:

(a) total system flow

(b) increase in system flow between exit from the annulus and the entrance to the air cleanup unit

(c) decrease in system flow between the fan discharge and the reentrance to the annulus

(d) flow exhausted to the environs

(e) flow recirculated to the annulus

ABGTS Preop Test

The preop test for the ABGTS was similar in scope to that of the EGTS. The ABSCE was isolated; penetrations were sealed; doors were closed; isolation dampers were closed. It was verified that the pressure controllers maintained the desired negative 6.35 mm (1/4 inch) H_2O in the ABSCE. Vacuum relief flow rate was measured and subtracted from total system flow to determine ABSCE infiltration rate. These test points are indicated in figure 4.

Air Cleanup Unit Leak Rate Test

Tests conducted on the EGTS and ABGTS air cleanup units included housing leak rate tests. Tests were conducted using the methodology of ANSI N510. Housing leak rate acceptance criteria were determined based on the estimated effect that the bypass leakage has on the offsite dose. The parameter study conducted to determine this effort is discussed later in this document.

Preop Test Problems and Solutions

Several problem areas were encountered during the preop tests of the ABGTS and the EGTS which initially prevented demonstration that the system could meet the design bases. The greater part of the problems encountered were a result of the fact that the early stages of design and construction at Sequoyah did not recognize the evolving need for more stringent quality control and assurances which were subsequently identified in the issuance of Regulatory Guide 1.52 and ANSI N509. After the needed quality was incorporated, the test objectives were met.

In general, problem areas related to system leakage can be divided into three categories:

(a) those problems resulting in leakage across the secondary containment boundary

(b) those problems resulting in damper leakage into or out of the system

(c) those problems resulting in bypass leakage

Problems Resulting in Leakage Across Secondary Containment Boundary

Leakage into the secondary containment areas impacts air cleanup system operations because the system must be capable of maintaining a certain negative pressure without exceeding permissible flows. In the case of the ABGTS and EGTS, the systems must maintain a pressure of 6.35 mm (1/4 inch) and 12.7 mm (1/2 inch) below atmospheric pressure, respectively. The flow which can be utilized to maintain the annulus pressure is equal to the inleakage rate of 2.83 cubic meters per minute (100 cubic feet per minute), as noted above. The flow which can be utilized to maintain ABSCE pressure is 170 cubic meters per minute (6000 cubic feet per minute). Thus, infiltration to these spaces must be limited to those values at the design negative pressures.

This limitation was very difficult to accomplish due to the large number of piping, electrical, and other types of penetrations which breach the secondary containment boundaries. Initial efforts to conduct the preop tests revealed various leakage paths which contributed to the overall infiltration to the secondary containment areas and initially resulted in infiltration rates significantly higher than the design values. In fact, the systems were at first unable to maintain the required pressures. It became apparent that, in order to resolve these problems, great attention to detail and quality would be needed in sealing potential leakage paths. Examples of the more significant leakage paths are discussed below.

All penetrations of both the annulus and ABSCE were by design supposed to be sealed to limit infiltration. However, some problems were encountered with penetrations which had inadvertently been left open. In some cases, this was due to oversight; in others it was a result of construction in progress. In still other cases, penetrations had been sealed; but due to the extremely low allowable leakages, the seals were not tight enough. This type of problem was resolved by repeated inspections of the secondary containment boundaries and sealing or resealing of open or leaking penetrations.

Doorways which penetrate the secondary containment boundary were also found to be a major source of leakage. In some cases, it was found that during the course of construction the doors had been sprung such that gaps of up to 12.7 mm (1/2 inch) existed between the door and the frame with the door closed. In addition, the door gaskets or thresholds had been damaged during the construction period. The gaskets or thresholds were replaced or repaired as necessary, and the doors were returned to their original shapes so they could be closed and latched properly.

Ducting which penetrates the secondary containment areas (other than those ducts associated with the EGTS or ABGTS) is provided with redundant series dampers. These dampers are designed to close automatically during accident conditions. It was found that the blade seals on several of the dampers had been damaged during construction. In addition, it was found that some of the dampers did not close completely, in some cases leaving a 6.35 mm (1/4-inch) gap between the blades. To resolve these problems, the blade seals were replaced or refurbished and operator linkages were adjusted to ensure complete, positive closure.

Problems Resulting in Leakage Into or Out of the System

A second major problem area was found to be leakage into or out of the air cleanup system duct network which resulted in an overall decrease in flow to or from the areas being served. This problem occurred primarily with the EGTS since it is partially located outside the annulus. The ABGTS was not significantly affected by this problem since it is almost entirely within the area being served, the ABSCE.

In particular, the problem encountered with the EGTS was due at least partially to: (1) its complex duct layout; (2) the interfaces between it and the normal annulus vacuum control system; and (3) the interfaces between the unit 1 and the unit 2 side of the plant. A detailed flow diagram for the EGTS is shown in figure 5.

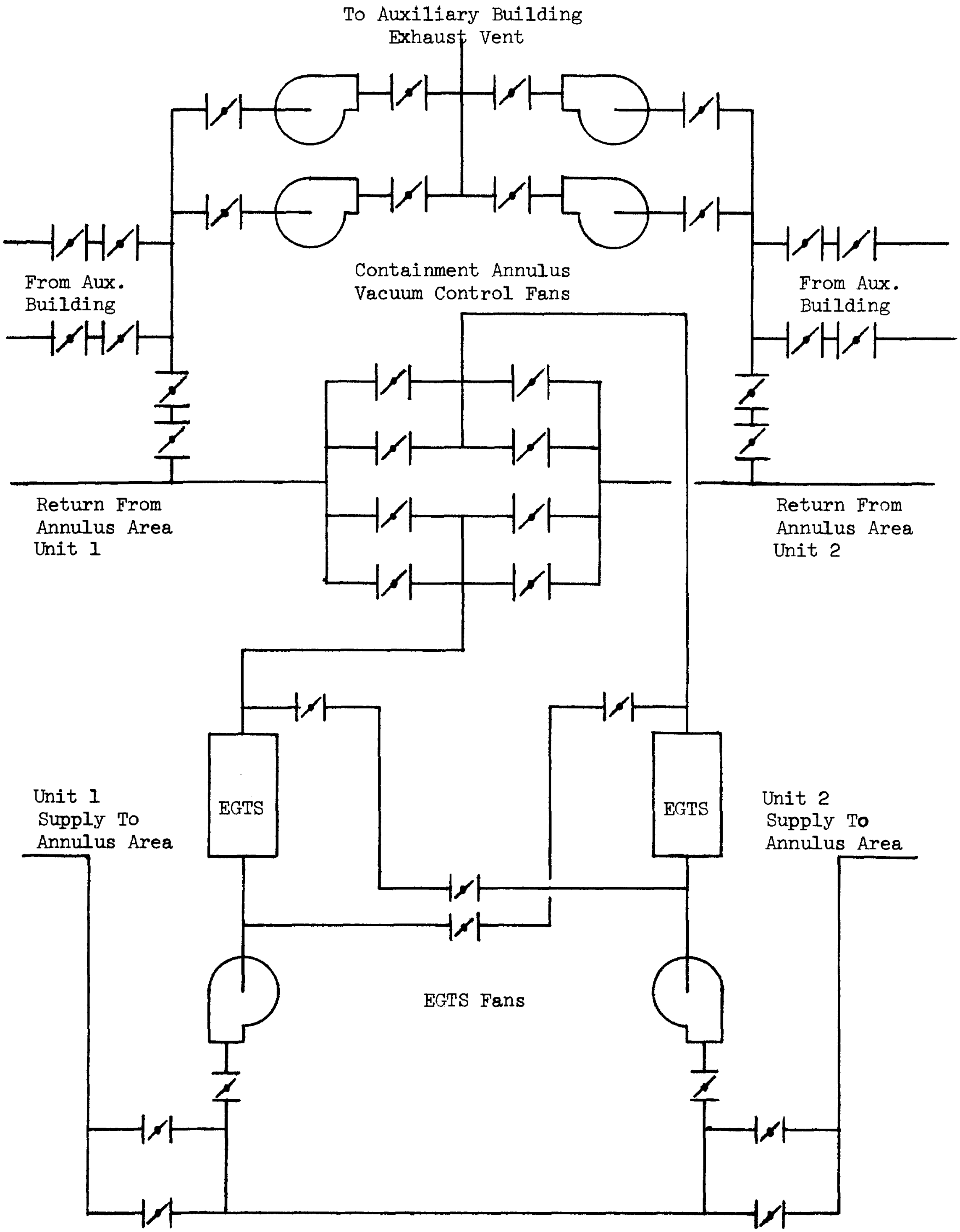


FIGURE 5
EMERGENCY GAS TREATMENT SYSTEM

During the initial phases of preop testing of the EGTS, it was determined that duct and damper leakage was significant. Air flow being drawn from the annulus was measured and compared to the flow at the entrance to the air cleanup units. There was a difference of several cubic meters per minute (hundreds of cubic feet per minute).

The system was inspected and obvious leakage paths were noted. One of the most obvious paths was around the shafts of dampers. In some cases, 50.8 by 50.8 mm (2 by 2 inch) holes had been left in the duct where the damper shaft penetrated it. These openings were closed using a neoprene-type gasket material and metal backing plates.

Access openings in the duct constituted another source of leakage. Some of those were not adequately gasketed, and the door on others needed adjustments to pull the access covers tightly against the gaskets.

Further inspections and tests revealed that as had been true elsewhere, some of the damper blade seals were either damaged or missing. These were replaced or refurbished as necessary. In general, all dampers lacked blade end seals; this condition was left as is, due to the difficulty in designing acceptable seals. Also, as had been found for other dampers, some operator linkages required adjustment to properly close the isolation dampers.

Some of the dampers were of the type which is inserted into the ductwork rather than having flanged connections. In this type of installation, leakages occurred between the damper frame and the duct wall. Gaps between the frames and the duct walls were sealed.

EGTS ducting is primarily welded duct outside of the annulus; however, leakages did occur at the gasketed joints. This was principally due to improper forming of the gasket corners in the rectangular duct sections. Gasketed joints were reworked as necessary to correct this problem. To reduce overall system leakage, the interfaces between the EGTS and the unit 2 reactor building annulus were blocked and sealed. These flow paths would normally be closed by isolation dampers during emergency operation of the system (assuming the accident occurs on the unit 1 side).

The flexible connection between the fan and the duct system was another major source of leakage. Leakage occurred through worn places in the fabric and also at the connection of the flexible material to the duct system. The flexible material was replaced and the connection was redone, using an RTV sealant to "butter" the flexible material at the flex-to-duct interface.

Problems Resulting in Bypass Leakage

A third major leakage category identified was that leakage associated with the air cleanup unit housing leakage, i.e., bypass leakage. It was considered essential to minimize this leakage since it bypasses the filtering components and is exhausted without being processed.

The EGTS and ABGTS air cleanup units were designed and purchased before issuance of Regulatory Guide 1.52 and ANSI N509/N510. Therefore, housing leakage criteria in accordance with those documents were not specified in the procurement specifications. In fact, the air cleanup unit housings had not been leak tested prior to the preop test program. It was recognized that the housing leakage could represent a significant contribution to the overall doses. Therefore, housing leakage was measured as part of the preop test data.

Early in the preoperational test program, an NRC inspection had identified the fact that the ABGTS and EGTS air cleanup units were not "all-welded" units and thus did not comply with the latest revisions of Regulatory Guide 1.52 and ANSI N509. As a result, the gasketed joints in the housings were backed by a welded cover plate to provide a leaktight joint.

Both EGTS and ABGTS were designed such that the system fans are downstream of the air cleanup unit, thus creating additional potential for bypass leakage between the air cleanup unit housing and the fan suction. During testing for the housing leak rate, the test boundary was extended beyond the air cleanup unit housing to include the fan suction and the ducting between the housing and the fan.

The duct between the housings and the fans was the standard lock-joint construction. This section of duct was replaced with an all-welded section. In addition, the duct connection at the fan section was neither properly gasketed nor tightly joined to the fan. The gasket was replaced and the duct flange tightly cinched to the fan. As noted previously, the flexible connections between the duct sections and the fans had become worn during the construction period and thus had to be replaced. When they were replaced, the joint between the flexible connection and the fan suction connection was buttered with RTV sealant before tightening the clamp.

Since the fans were located downstream and outside of the air cleanup units, the fan shaft created an additional bypass leakage path. No special seals had been specified for this shaft during the design phase; thus air was being drawn through the hole in the fan housing where the shaft penetrated it. A special seal was designed for this penetration; a neoprene material was friction fitted around the shaft, and a metal backing plate was added to hold the seal in place.

Some leakage paths were created as a result of post-procurement design changes in the systems. The housings had not originally been supplied with fire protection sprays; however, they were subsequently added in the field. In the case of the ABGTS, an access opening was added to permit entry to the housing downstream of the adsorber bank for inspection of the spray nozzles. This opening had been added by construction forces without the knowledge of the design groups. No special precautions had been taken to ensure a leaktight seal. In fact, the access opening was the standard opening and cover installed in normal ventilation systems. Minimizing the leakage was considered to take precedence over personnel access to the fire protection spray nozzles. Thus, the access opening was welded shut.

In the course of construction, the air cleanup unit housing doors had been sprung slightly and the gaskets had lost some of their resiliency. Thus, it was necessary to replace the gaskets and return the doors to their original shapes before an adequate seal could be established at the doors.

Due to construction oversight, some housing penetrations had been installed without the proper gaskets inserted. The lighting penetrations and fire protection sprays are examples of this. These penetrations were reworked to ensure a proper seal.

Presentation and Discussion of Resulting Doses

Part 100 of Title 10 in the Code of Federal Regulations (10CFR100) sets acceptable site criteria, including limits on doses of radiation in the event of an accident. The regulations specify that a person located at any point on the exclusion area boundary for two hours immediately following the onset of a postulated accident shall not receive a total radiation dose to the whole body in excess of 25 rem or a total radiation dose in excess of 300 rem to the thyroid from iodine exposure.

Concurrent with the preop test program, the calculational model utilized to determine the dose presented in the FSAR was reviewed in an effort to verify its conservatism with respect to the flows and leakages actually measured in the field. A parameter study was carried out to estimate the effect of various leakage sources and rates upon the previously calculated doses.

Model for FSAR Analysis

Radiation doses from fission product releases were calculated using the conservative assumptions of Regulatory Guide 1.4 for a design basis loss-of-coolant accident. The radioactive effluents from the Sequoyah plant were calculated and presented in the Final Safety Analysis Report (FSAR) based on a model shown schematically in figure 6.

The containment was assumed to leak radioactive fission products into the annulus and auxiliary building through penetrations and seals. Most of the leakage (75 percent) was assumed to be released into the annulus with the remainder being released in the auxiliary building. The EGTS, a constant flow recirculating system, was modeled as taking suction from the annulus and exhausting only enough air to maintain a less than atmospheric pressure in the annulus. The activity released through the EGTS was dependent upon the EGTS
exhausting only enough air to maintain a less-than-atmospheric pressure in the
of 2.83 cubic meters per minute (100 cubic feet per minute) at the design negative pressure.

The ABGTS was modeled as taking suction from the auxiliary building and exhausting it via the reactor building vent. The ABGTS, an essentially constant flow system, was assumed to draw air from the auxiliary building at a rate equal to the design inleakage rate, 170 cubic meters per minute (6000 cubic feet per minute), at the design negative pressure. The balance of the ABGTS flow was assumed to be fresh air.

Model for Parameter Variation Study

Duct and damper leakages into the systems were not considered in the FSAR analysis. However, during the preoperational test program, it was found that these sources could not be neglected and may, in fact, significantly affect the calculated doses. Duct and damper leakage into the system increases the rate at which air must be exhausted. If the leakge into the EGTS is downstream of

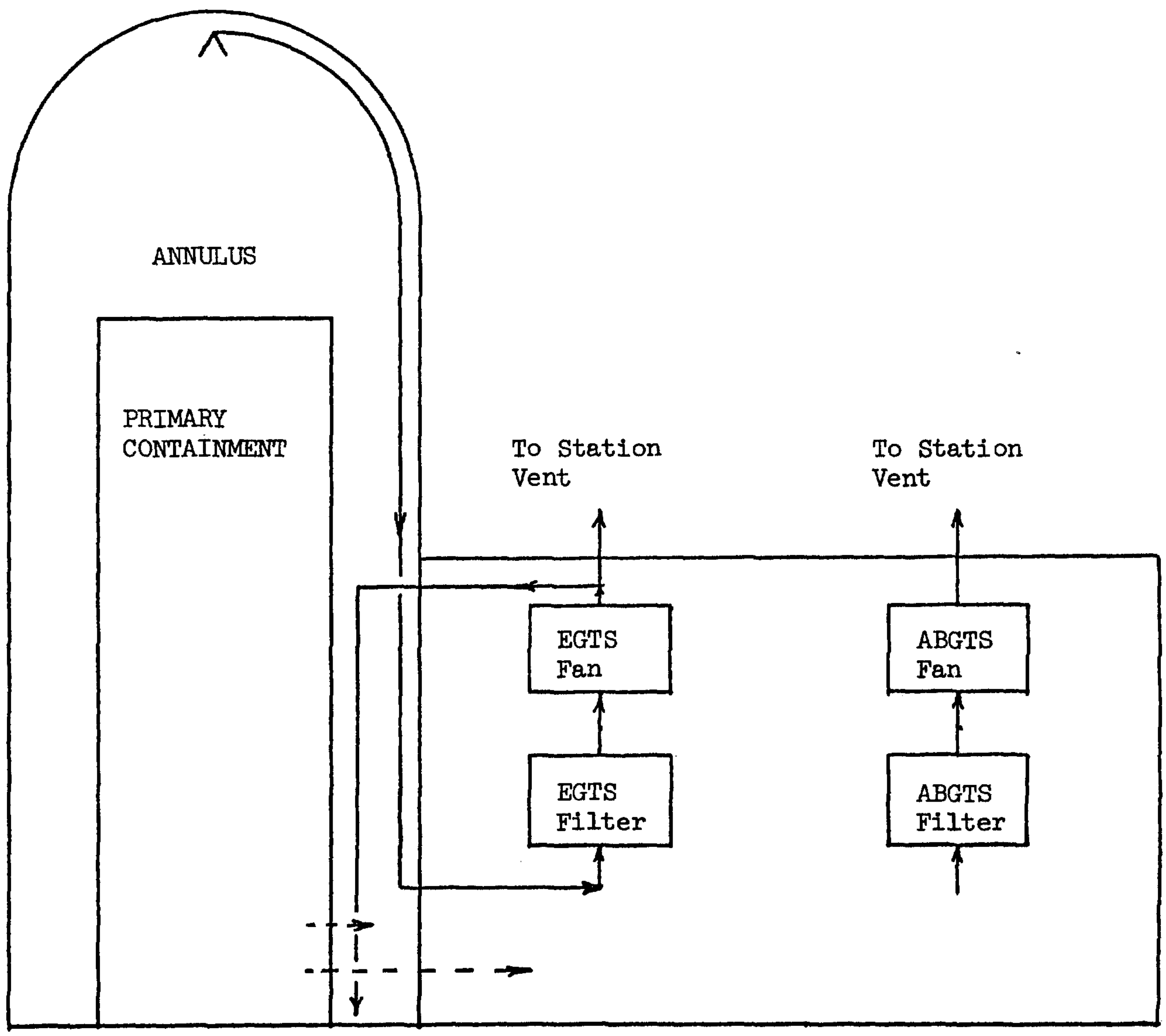

ANNULUS
PRIMARY
CONTAINMENT
To Station
Vent
To Station
Vent
EGTS
Fan
EGTS
Filter
ABGTS
Fan
ABGTS
Filter

FIGURE 6

the filters, part of the air is exhausted without being filtered. Similarly, leakage into the ABGTS downstream of the filters will be exhausted without being filtered.

Flow paths examined in this analysis are shown schematically in figure 7. These included the sources assumed in the FSAR analysis plus leakage into the EGTS upstream and downstream (bypass leakage) of the filters and leakage out of the EGTS into the auxiliary building downstream of the fan, also leakage into the ABGTS downstream of the filters (bypass leakage).

Effect of Parameter Variation on Doses

The results of the parameter variation study are shown in Table I. Figure 8 graphically shows the two-hour exclusion area boundary (EAB) thyroid dose as a function of EGTS leakage. The most significant leakage path in the EGTS for the thyroid dose is the bypass leakage; however, even inleakage upstream of the filter increases the dose. The reason there is not a greater difference in the effects of the EGTS leakages upstream and downstream of the filter is because a major portion of the dose is due to releases through the ABGTS. For example, 2.83 cubic meters per minute (100 cubic feet per minute) of bypass inleakage will produce about a 4-rem increase in the thyroid dose while 2.83 cubic meters per minute (100 cubic foot per minute) inleakage upstream of the filters will produce about a 3.5-rem increase in the thyroid dose. The effect of EGTS leakage on the whole body dose is shown in figure 9. Since the whole body dose is primarily a result of releasing noble gas fission products, which are not removed by the filters, the increase in whole body dose is a function of total exhaust and therefore total inleakage regardless of where it occurs. Leakage out of the EGTS into the auxiliary building reduces the doses because it reduces the fraction of the flow which must be exhausted. Of course, it will decrease the ABGTS vacuum relief flow and increase the amount of activity in the auxiliary building, but there it has a chance to decay before it is exhausted through the ABGTS filters.

The effect of system leakage in the ABGTS is shown in figure 10. Since the ABGTS is not a recirculating system, inleakage upstream of the filters has no effect on the dose, only the leakage which bypasses the filters will increase the dose. Also, since the ABGTS is a constant flow system, it exhausts the same amount regardless of system leakage; therefore, the whole body dose is not affected. If there is 2.83 cubic meters per minute (100 cubic foot per minute) leakage bypassing the ABGTS filters, the two-hour EAB thyroid dose increased by about 10 rem.

Measured Leakages and Resultant Dose

As indicated previously, the ABGTS is a once-through system and only leakage which bypasses the filters affects the offsite dose. First attempts to measure this leakage yielded leak rates well above 2.83 cubic meters per minute (100 cubic feet per minute). However, after sealing the major leakage paths as discussed above, the bypass leak rate was reduced to about 0.57 cubic meters per minute (20 cubic feet per minute).

Not only bypass leakage but also duct and damper leakage both upstream and downstream of the EGTS air cleanup unit affect the offsite dose. Bypass leak rate initially measured at about 100 cubic feet per minute was ultimately reduced to about 0.57 cubic meters per minute (20 cubic feet per minute). Duct

TABLE I

	EGTS Flow Rate (ft^3/min)	EGTS Inleakage Before Filter (ft^3/min)	EGTS Inleakage After Filter (ft^3/min)	EGTS Outleakage After Fan (ft^3/min)	ABGTS Inleakage After Filter (ft^3/min)	2-Hour EAB Doses Gamma (Rem)	2-Hour EAB Doses Beta (Rem)	2-Hour EAB Doses Thyroid (Rem)	30-Day LPZ Doses Gamma (Rem)	30-Day LPZ Doses Beta (Rem)	30-Day LPZ Doses Thyroid (Rem)
1	4000	0	0	0	0	8.02	4.29	179.3	1.34	1.14	29.8
2	4000	500	500	0	0	14.0	7.64	222.2	2.31	1.78	41.0
3	4000	0	1000	0	0	14.0	7.65	231.0	2.31	1.78	43.8
4	4000	1000	0	0	0	14.0	7.65	213.5	2.30	1.78	38.2
5	4000	250	250	0	0	11.4	6.20	198.9	1.94	1.57	34.4
6	4000	0	500	0	0	11.4	6.20	201.5	1.94	1.57	35.2
7	4000	500	0	0	0	11.4	6.20	196.4	1.94	1.56	33.6
8	4000	400	50	150	50	10.7	5.83	194.5	1.84	1.51	33.2
9	4000	400	50	150	100	10.76	5.83	199.4	1.85	1.51	34.8
10	4000	400	50	150	200	10.8	5.84	209.1	1.85	1.51	27.8

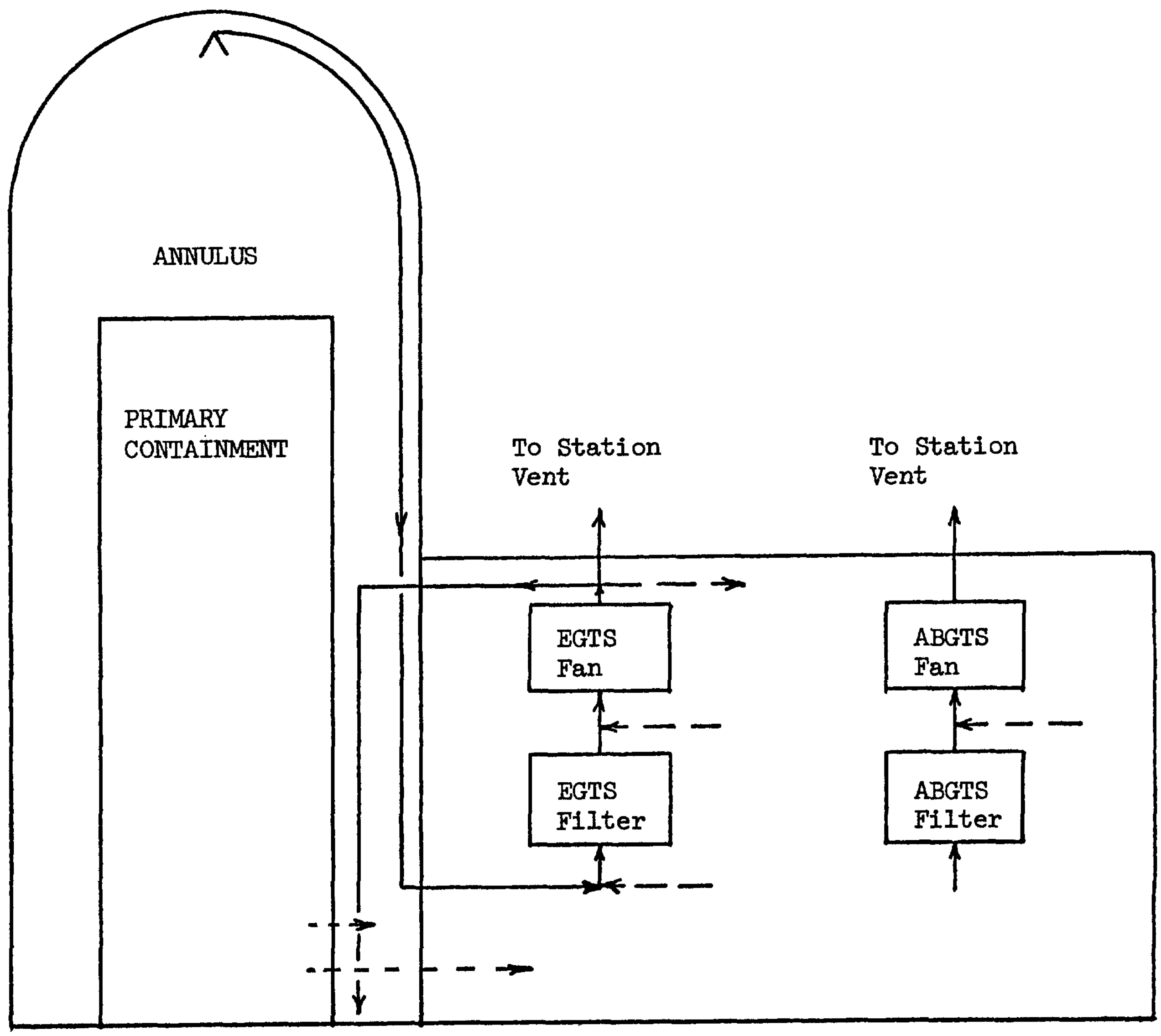

ANNULUS
PRIMARY
CONTAINMENT
To Station
Vent
To Station
Vent
EGTS
Fan
EGTS
Filter
ABGTS
Fan
ABGTS
Filter

FIGURE 7

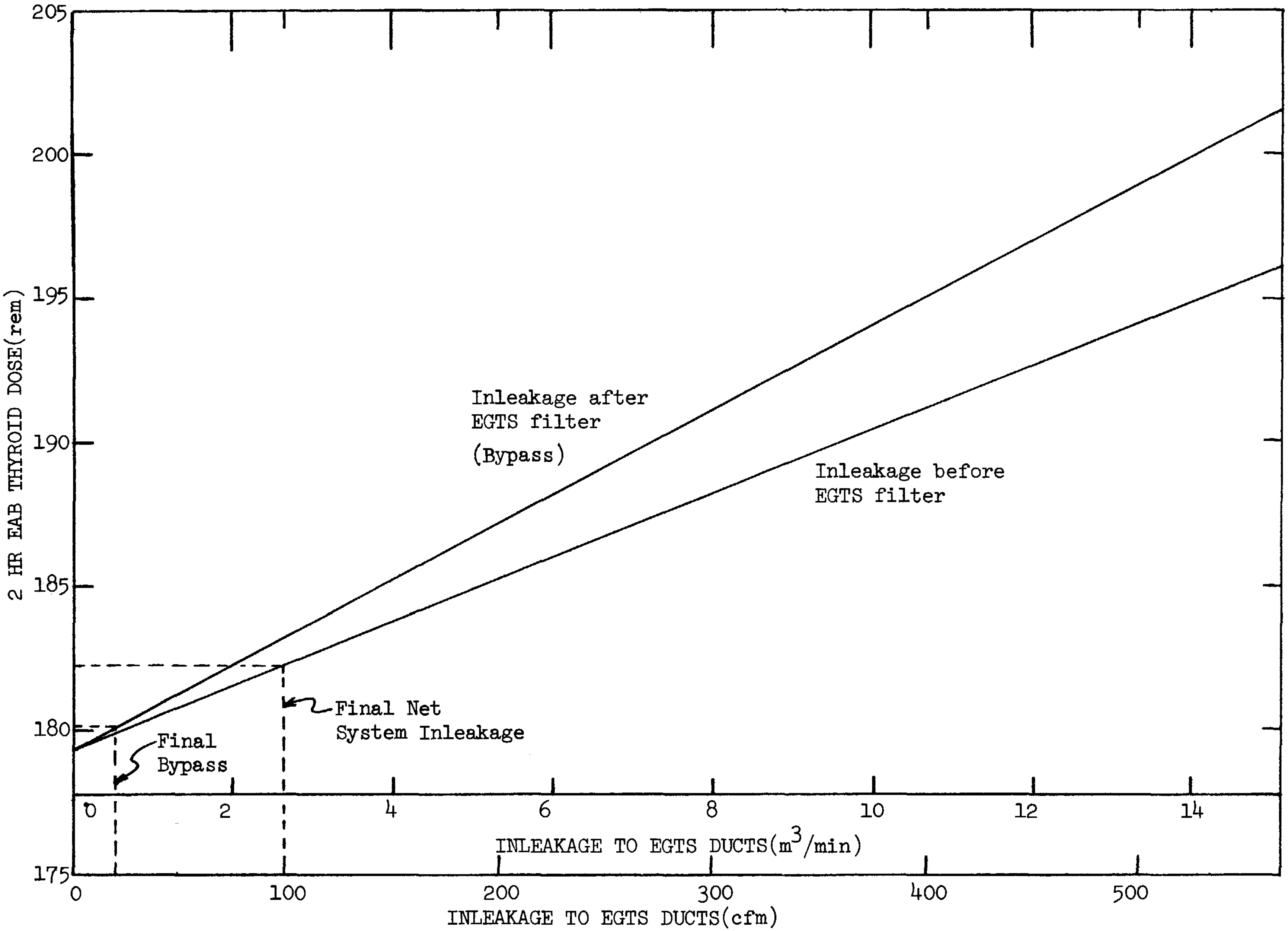

205
200
195
190
185
180
175
2 HR EAB THYROID DOSE(rem)
Inleakage after
EGTS filter
(Bypass)
Inleakage before
EGTS filter
Final Net
System Inleakage
Final
Bypass
0
2
4
6
8
10
12
14
INLEAKAGE TO EGTS DUCTS(m^3/min)
0
100
200
300
400
500
INLEAKAGE TO EGTS DUCTS(cfm)

FIGURE 8

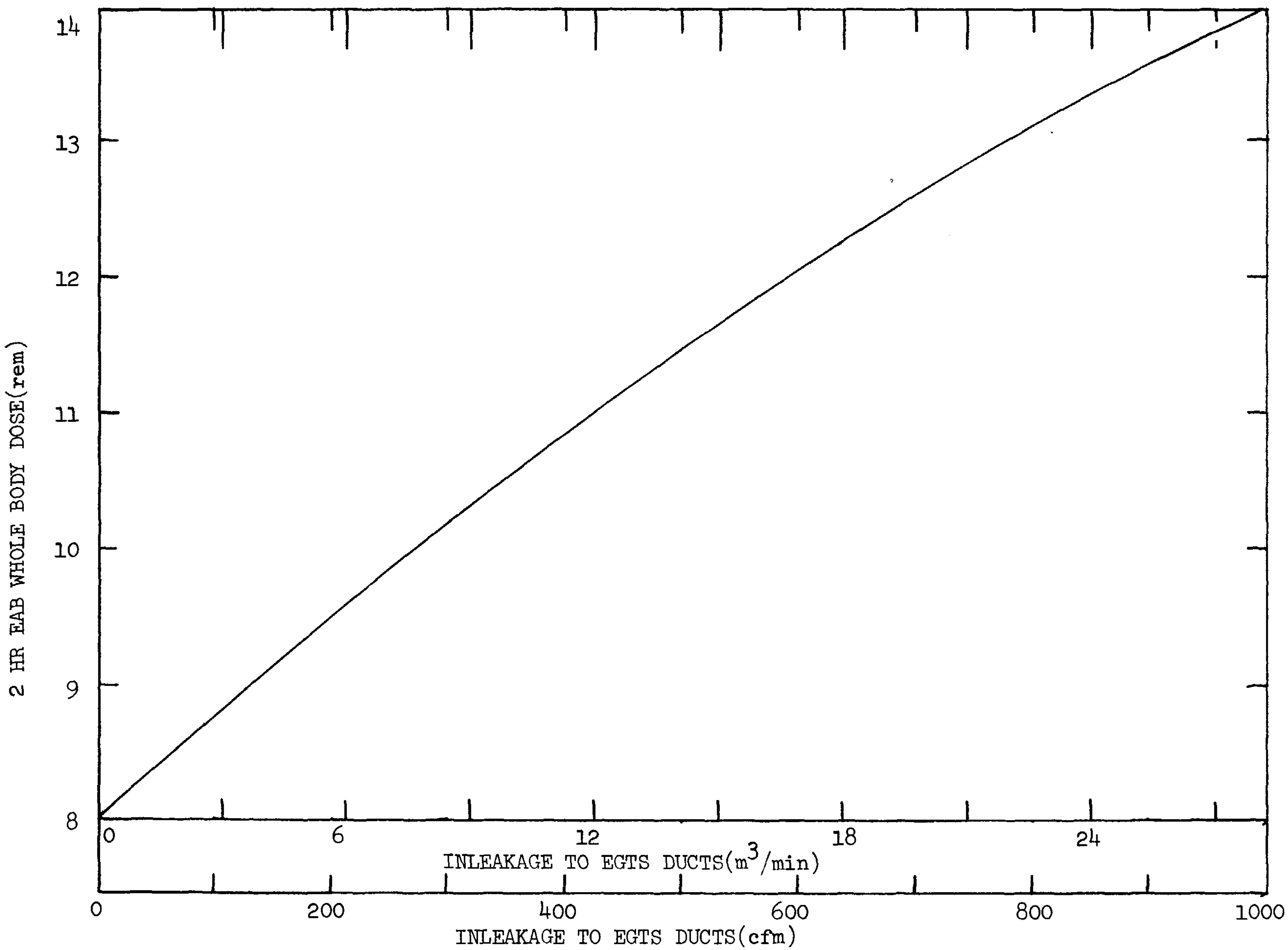

2 HR EAB WHOLE BODY DOSE(rem)
8
9
10
11
12
13
14
0
6
12
18
24
INLEAKAGE TO EGTS DUCTS(m^3/min)
0
200
400
600
800
1000
INLEAKAGE TO EGTS DUCTS(cfm)

FIGURE 9

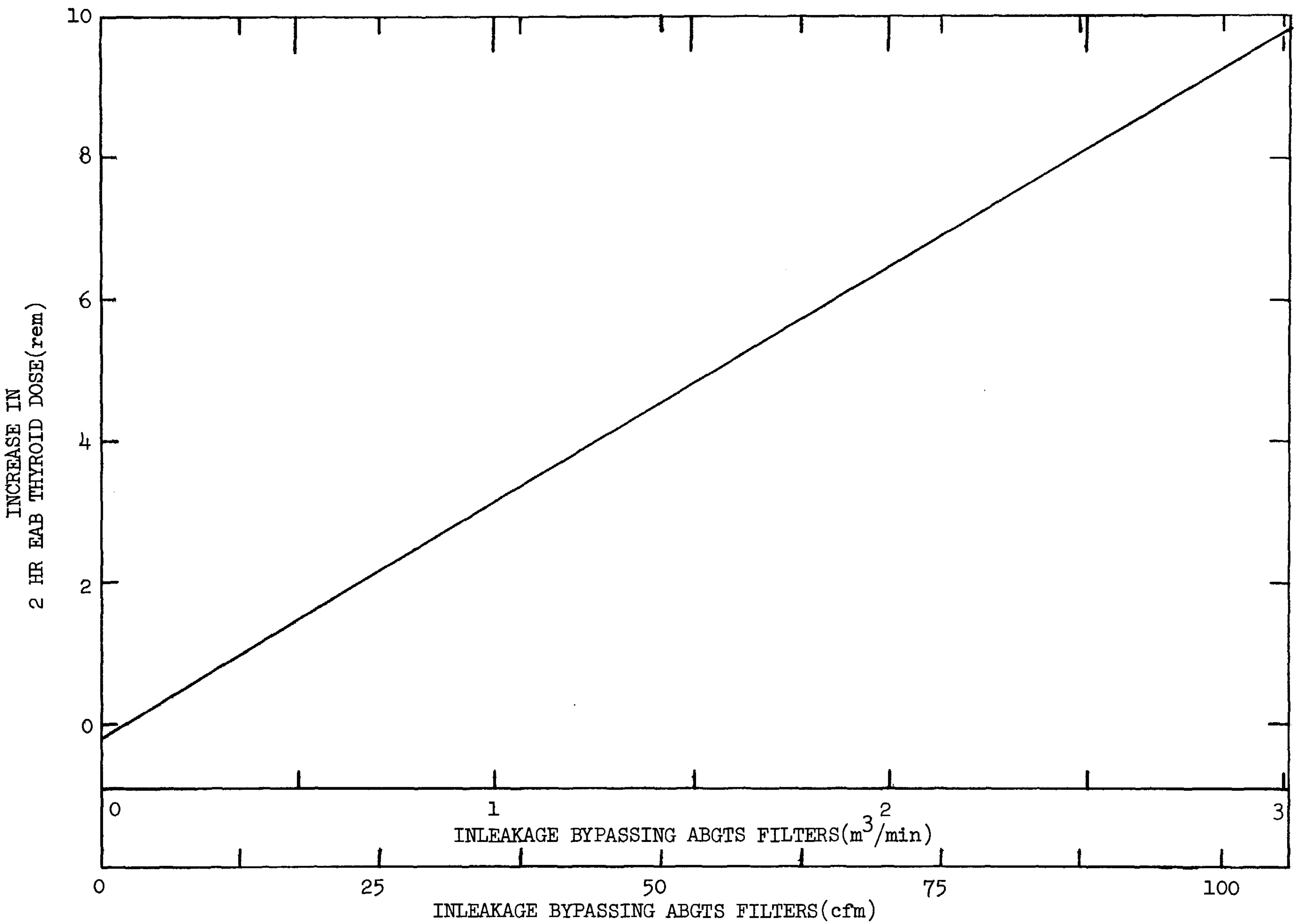

INCREASE IN
2 HR EAB THYROID DOSE(rem)
0
2
4
6
8
10
0
1
2
3
INLEAKAGE BYPASSING ABGTS FILTERS(m^3/min)
0
25
50
75
100
INLEAKAGE BYPASSING ABGTS FILTERS(cfm)

FIGURE 10

and damper leakage upstream of the air cleanup unit was determined by measuring EGTS intake flow in the annulus and comparing that to the flow measured at the inlet to the air cleanup unit. Initial measurements indicated that 11.32 to 14.15 cubic meters per minute (400 to 500 cubic feet per minute) were leaking into the system. However, this leakage was reduced to about 7.65 cubic meters per minute (270 cubic feet per minute) after accomplishing the steps described above. First measurements of the outleakage downstream of the fan indicated an exfiltration rate of 5.66 to 8.49 cubic meters per minute (200-300 cubic feet per minute). This leakage, determined by comparing the flow at the fan to that at the entrance to the annulus was finally reduced to about 5 cubic meters per minute (170 cubic feet per minute). These flows and leakages are shown schematically in figure 11.

To estimate the offsite dose resulting from the measured EGTS bypass leakages, the increase in the dose was taken from the upper curve on figure 8. This was approximately 1.0 rem. To estimate the effect of EGTS duct and damper leakage, the increase in the dose was taken from the lower curve of figure 8 at the net measured leakage; i.e., that which leaks in upstream of the filters minus that which leaks out downstream of the fan. This increased the dose about 3.0 rem. Adding these contributions to the previously calculated dose, as presented in the FSAR, results in a 183-rem thyroid dose. This point was then taken as the initial point to construct a curve parallel to that shown in figure 10. This is indicated in figure 12. Using that curve, the effect of ABGTS housing leakage can be estimated. At the measured leakage of 0.57 cubic meters per minute (20 cubic feet per minute), an increase of about 2.0 rem occurs in the dose as indicated in figure 12. Thus, the total two-hour EAB thyroid dose resulting from the design release flows of the EGTS and ABGTS plus the measured duct and damper leakages and the housing leakages is 179 + 1.0 + 3.0 + 2.0 = 185 rem total.

In addition to the activity released and the resulting doses discussed above, there is a potential for leakage from the ECCS pumps and valves in the auxiliary building. This has been estimated to result in an additional contribution to the two-hour EAB thyroid dose of approximately 100 rem. Therefore, the total resultant dose is about 284 rem or only 16 rem less than the allowable limit of 300 rem.

The two-hour EAB whole body dose is only affected by the net system inleakage to the EGTS. The final measured net inleakage of 2.83 cubic meters per minute (100 cubic feet per minute) results in an increase of approximately 1.0 rem. Then the total two-hour EAB whole body dose resulting from the design release flows of the EGTS and ABGTS plus the measured system leakages is 8 + 1 = 9 rem total. This is less than half of the allowable limit of 25 rem.

Summary

There were several significant lessons to be learned from our experiences in this preop test program. The more significant lessons can be summarized as follows:

- A renewed emphasis on the level of Quality Assurance and Quality Control is needed to preclude future problems. A major part of the problems encountered in the preop test phase were quality assurance problems. The quality needed for leaktight enclosures was not there when the tests were initiated. After

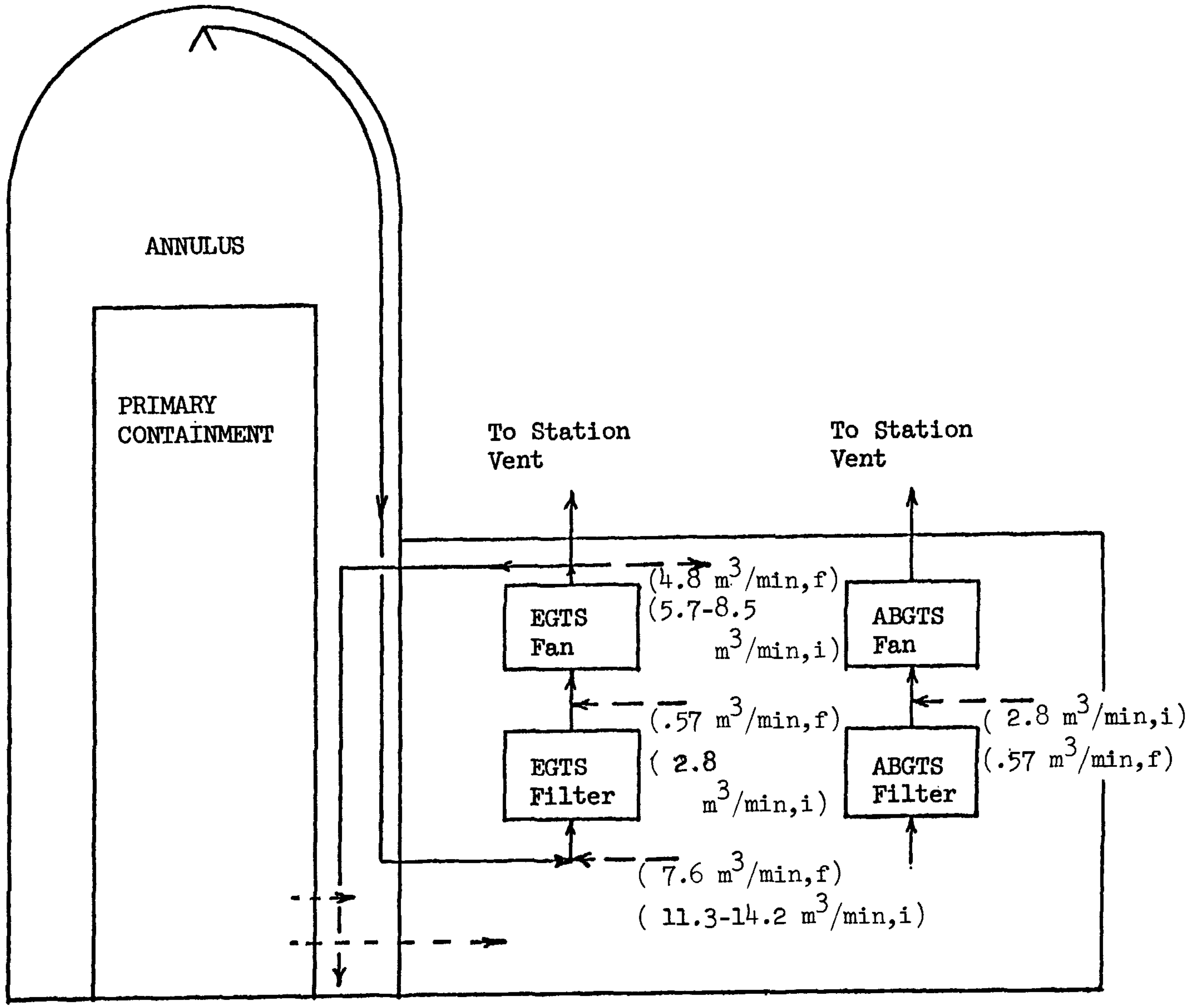

ANNULUS
PRIMARY CONTAINMENT
To Station Vent
To Station Vent
EGTS Fan
EGTS Filter
ABGTS Fan
ABGTS Filter
(4.8 m3/min,f)
(5.7-8.5 m3/min,i)
(.57 m3/min,f)
(2.8 m3/min,i)
(2.8 m3/min,i)
(.57 m3/min,f)
(7.6 m3/min,f)
(11.3-14.2 m3/min,i)

FIGURE 11

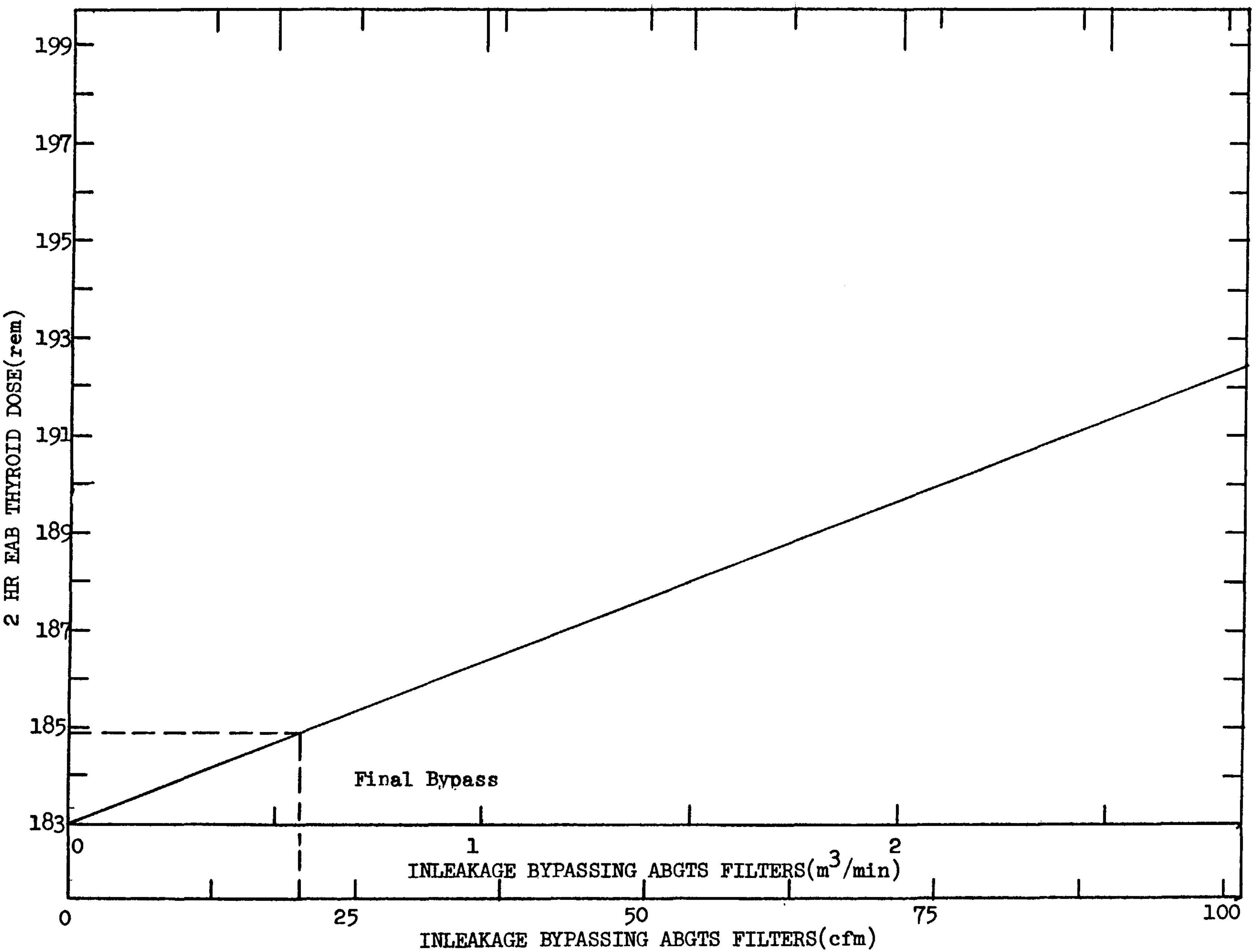

2 HR EAB THYROID DOSE(rem)
199
197
195
193
191
189
187
185
183
Final Bypass
0
1
2
INLEAKAGE BYPASSING ABGTS FILTERS(m3/min)
0
25
50
75
100
INLEAKAGE BYPASSING ABGTS FILTERS(cfm)

FIGURE 12

tedious investigation, rework, and adjustments on the systems and the pressure boundary leakage paths, the needed quality was incorporated and the tests were successfully completed. TVA's recently reorganized Quality Assurance and Quality Control branches are expected to more effectively meet these needs.

- Recognizing that system components naturally became degraded with time and usage, some provision must be made to retest the systems to assure that they continue to meet their design bases.

- The importance of leaktightness in system isolation dampers was originally underestimated, especially at the interface boundaries between redundant components. Although ANSI N509 did not exist at the time of design of the Sequoyah Nuclear Plant, these dampers were essentially internal to the system and were dealt with as equivalent to Class II dampers in accordance with ANSI N509. We now believe that much of the difficulty in reaching a satisfactory leakage rate could have been avoided if these dampers had been designed and installed as equivalent to leakage Class I of ANSI N509.

- Potential system leakage paths need to be considered in the calculation of the offsite dose.

- As noted in the previous discussion, many significant leakage paths were identified in the test phase. With a more strict surveillance inspection during construction and a careful inspection of the many envelope barrier items that contribute to boundary leakage prior to the preoperational test, it is believed that the test phase would have proceeded in a more timely manner. To this end, a more detailed surveillance checklist of prerequisites to the test should be implemented on future units prior to initiating the system tests.

- Finally, it must be recognized that these systems, which include the pressure boundary enclosure with many potential leakage paths, indeed, represent very complex total systems; adequate time must be provided in the original schedule to provide the required quality surveillance during design and construction needed to assure the completed system will be "ready" when preoperational testing begins.

DISCUSSION

ANON.: Analysis of your annulus exhaust system was based on the end leakage of the secondary containment. We have found that the considerable enlargement and rapidity of that enlargement following a LOCA seriously affected the annulus pressure and the sizing of our system had to take that into account. Have you done that in your analysis?

KLAES: Yes, the original analysis to determine what the release rate would be was based on an assumption that there would be an expansion of the primary containment. We maintain the pressure at minus five inches of water during normal operation. Then, in the postaccident mode, assuming that we have a short period when there is no offsite power and the normal system fails, this allows the pressure to approach zero with respect to outside atmosphere. But we will have an excess amount of flow, initially, as the pressure drops down to a half inch, and that is figured into the dose.

COLLINS: I was a little concerned about your last comment. You said that you lost offsite power. This being a safety system, isn't it required to be on your emergency diesel?

KLAES: We assume that we lose offsite power, initially, after an accident, and then the diesel comes on. But there is a certain assumed lag between the time that the accident occurs and the diesel comes on the line.

COLLINS: That is a very short lag time. You are talking about seconds to minutes on activation of the emergency diesel.

KLAES: Right.

SELECTED SOLUTIONS AND DESIGN FEATURES FROM THE DESIGN OF REMOTELY HANDLED FILTERS AND THE TECHNOLOGY OF REMOTE FILTER HANDLING. PREVIOUS OPERATING EXPERIENCE WITH THESE COMPONENTS IN THE PASSAT FACILITY.

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Dr.J.Furrer, J.G.Wilhelm - LAF
Kernforschungszentrum Karlsruhe
Federal Republic of Germany

Abstract

In a prototype filter offgas cleaning system for reprocessing plants (PASSAT) built at the Karlsruhe Nuclear Research Center a full-scale filter cell with remotely handled filters for aerosol and iodine removal and the corresponding remote handling systems for exchange, bagging out, packaging and disposal of spent filter elements has been installed and run in trial operation since July 1978.

The filters and the replacement techniques have been tested for the past two years or so and so far have always worked satisfactorily over the test period involving some 150 replacement events. Neither wear nor corrosion phenomena were found in the filter housings and the replacement systems.

The seals and clamping devices were selected so that during operation the prescribed leak rates of $< 10^{-3}$ Torr l/s were always maintained on the filter lid, the seat of the filter element and the cell lock. The total clamping loads for the filter element and the filter lid amount to approx. 20 kN. The force necessary to separate the filter element from the filter housing is approx. 3.5 kN. No ruptures of seals or gaskets were to be detected.

The design of the filters and of the handling systems has been found satisfactorily in the cold test operation so far and can be recommended for use in nuclear facilities.

In all the experiments conducted until now PASSAT has worked without any failure. All operating data required in the specifications were met in the test period. The maximum pressure loss in the system with loaded filter elements amounts to some 3000 mm of water. After operation with iodine and NO_x, plant components exposed to 100 % relative humidity and condensate showed corrosion.

Introduction

Cleaning offgases with high radioactivity inventories in nuclear facilities, such as dissolver offgases in reprocessing plants, requires filters and systems not only reaching the maximum verifiable removal efficiency, but also safe in operation and with facilities for remote handling in replacement, packaging and removal of the loaded filter systems.

With a view to current development and planning in the Federal Republic of Germany of a large reprocessing plant, the PASSAT Research Project was launched in 1975 within the framework of the PWA Project (Reprocessing and Waste Treatment Project) with the following objectives:

- Development and testing of remotely serviceable filter components, including the necessary handling systems.
- Construction and testing of a full-scale prototype offgas cleaning system for dissolver offgas designed for a 1400 t/a reprocessing plant.
- Determination of optimum operating conditions and examination of the influence of malfunction on plant safety and removal efficiency.

The design of PASSAT has been covered in (1) and (2). The removal efficiency and the operating experience accumulated in the different filter components will be topics treated elsewhere at this conference. This paper will briefly explain the filter designs, handling systems and the filter cell and explain in detail, on the basis of a few examples, some selected problems associated with filter design and handling systems.

The operating experience accumulated to date with respect to design, leak tightness, handling and availability will be indicated.

PASSAT Filter Cell

For the retention of aerosols and iodine from the dissolver offgas the PASSAT facility contains the following systems in the order listed here:

one separator for coarse drops, without remote handling capability,

one remotely operated mist eliminator (wet separator),

one remotely operated HEPA filter,

two remotely operated iodine filters,

one HEPA filter without remote handling capability.

Fig. 1 shows the PASSAT filter cell with the filter components to be remotely handled which are arranged in one line. For moving the filters within the filter cell a mono-rail trolley with a grab has been installed. A remotely controlled double lid lock system serves for removal purposes. Outside the filter cell, but shielded from the control room, there are the remotely controlled systems for bolting and reloading the waste drum. The space requirement for the filter cell is approx. 80 m^3.

The reloading procedure is as follows:
The lid of the filter housing is opened by means of the hydraulic system, the loaded filter element is extracted by the mono-rail trolley, moved to the cell lock, to which an empty waste drum is attached, and put into the waste drum. The lock is closed, and the

waste drum is closed with the intermediate lid. The lifting and swiveling system is used to move the waste drum to the screw position and couple it to the screw facility. At this station the lid is screwed onto the waste drum. After screwing the waste drum is put into a shielded container for removal.

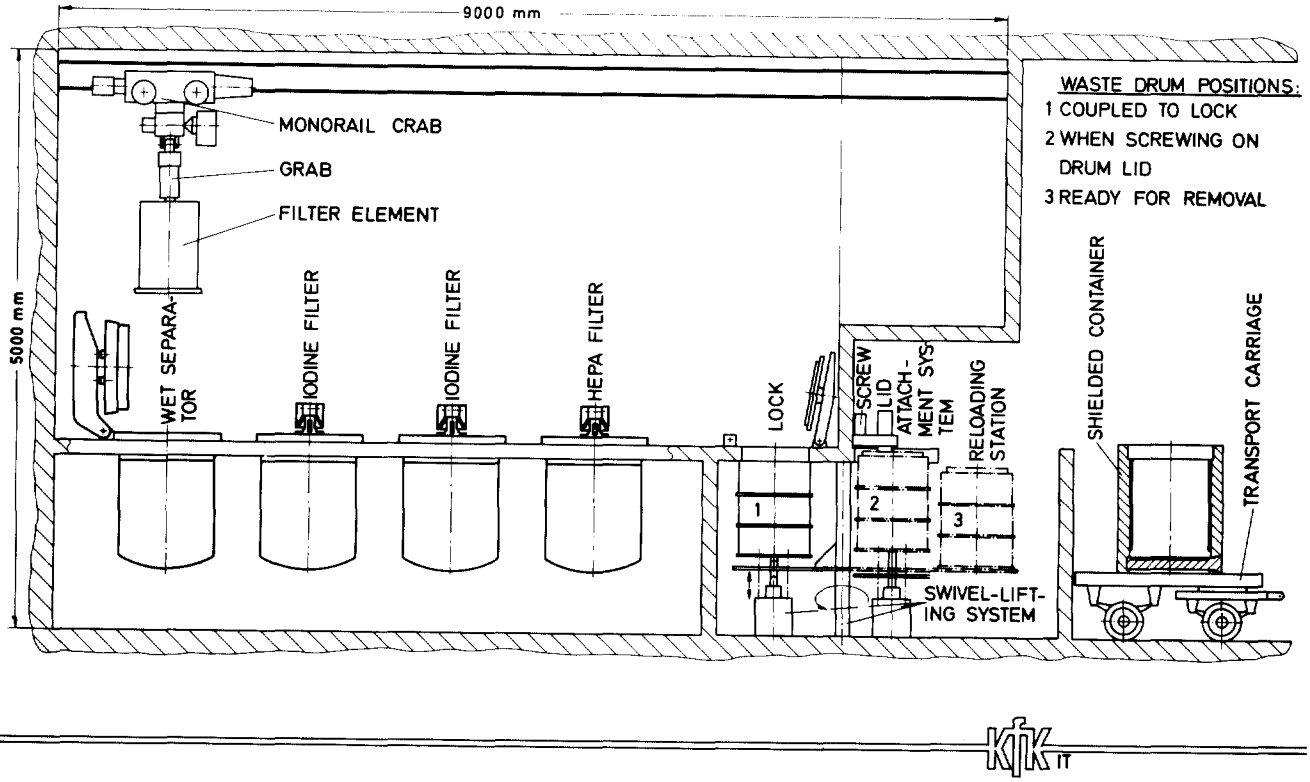


FIG.1 PASSAT FILTER CELL

Universal Remotely Handled Filter Housing

Fig. 2 shows the remotely handled filter housing with thermal insulation, shielded lid and the iodine filter element installed. It consists of the housing (vessel part) and the lid with the clamping mechanism. The vessel part may be designed either suspended, as shown in Fig. 2, or floor mounted. The connections for gas inlet and outlet and for cleaning the inner wall of the housing and monitoring the leak tightness of the seat of the filter element are attached to the vessel part. The filter element is installed in the vessel part so as to constitute a gastight separation between the untreated and the clean air sides. The air stream flowing into the filter element can be directed from below, sideways or from the top. The clamping mechanism is hinged to the shielding plate and is actuated hydraulically. It carries the housing lid. When the housing lid is closed, first the clamping mechanism contacts the catch of the lock. The lid does not yet contact the gasket of the housing. As the hydraulic piston moves on, the clamping mechanism is locked and the lid is moved vertically downward by means of the toggle joint and the guide bolts and forced against the gasket. In the final position of the hydraulic piston the toggle joint is located above the center axis and is self-locking,

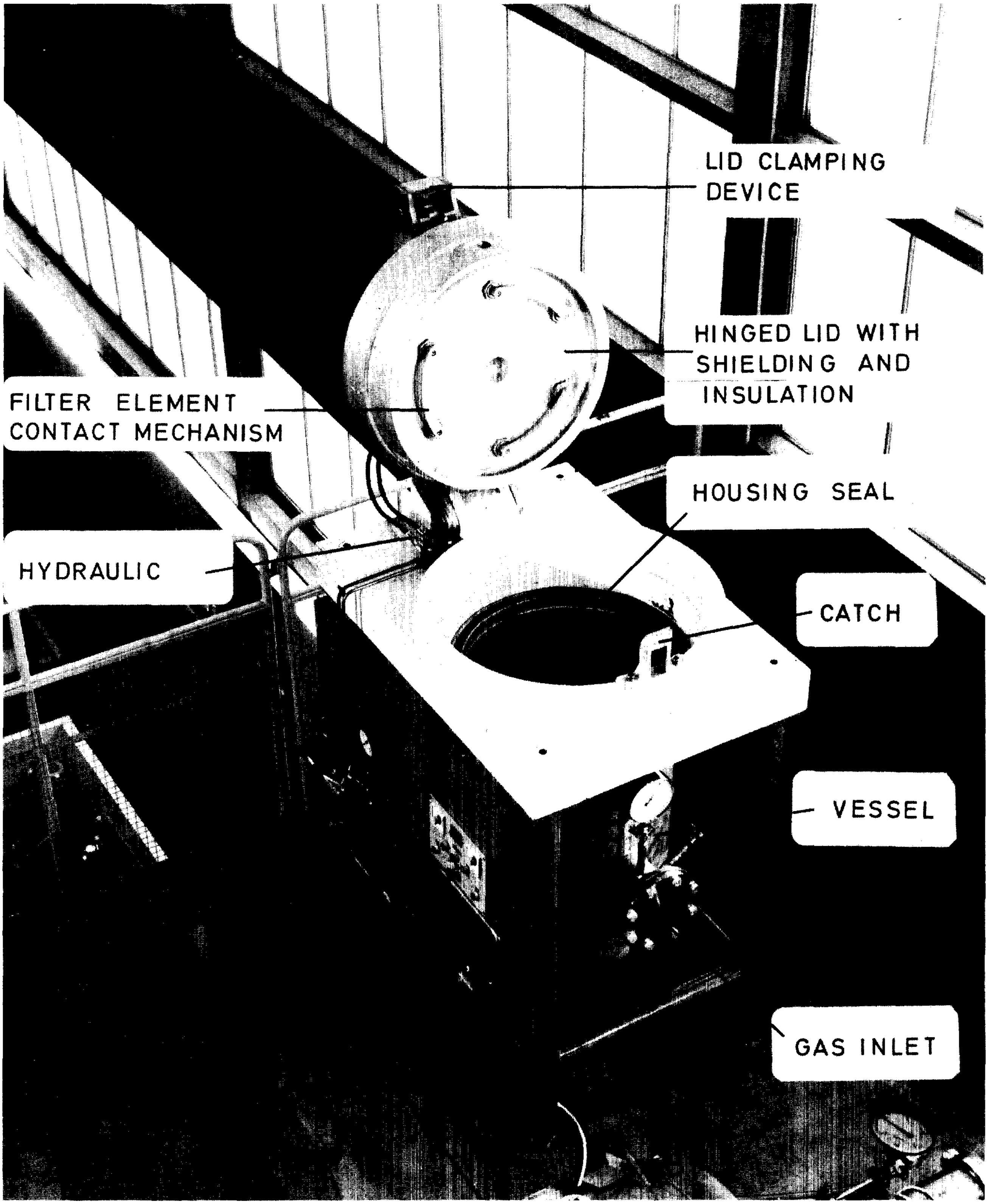
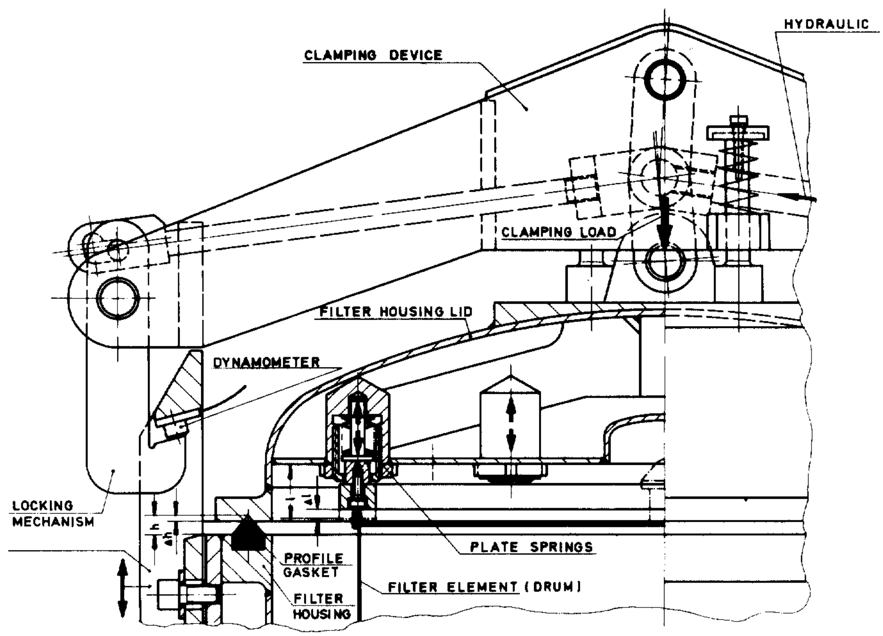


FIG. 2: REMOTELY OPERATED „SUSPENDED" FILTER HOUSING WITH SHIELDING (150mm) AND THERMAL INSULATION; TÜV CLEARANCE NO. 116-597/2-3.5.3-2014C

i.e., if the hydraulic pressure were to fail, the housing lid would remain closed. The filter element is clamped by the lid acting through cup springs. The same springs are used to offset fabrication tolerances or expansion of the filter element during operation. The maximum possible clamping load for the lid and the filter element is approx. 100 kN. The required level is approx. 25 kN. Fig. 3 shows the clamping loads as a function of clamping travel.



CLAMPING DEVICE AND INTERDEPENDENCE
DURING LID AND FILTER ELEMENT PRESSING.

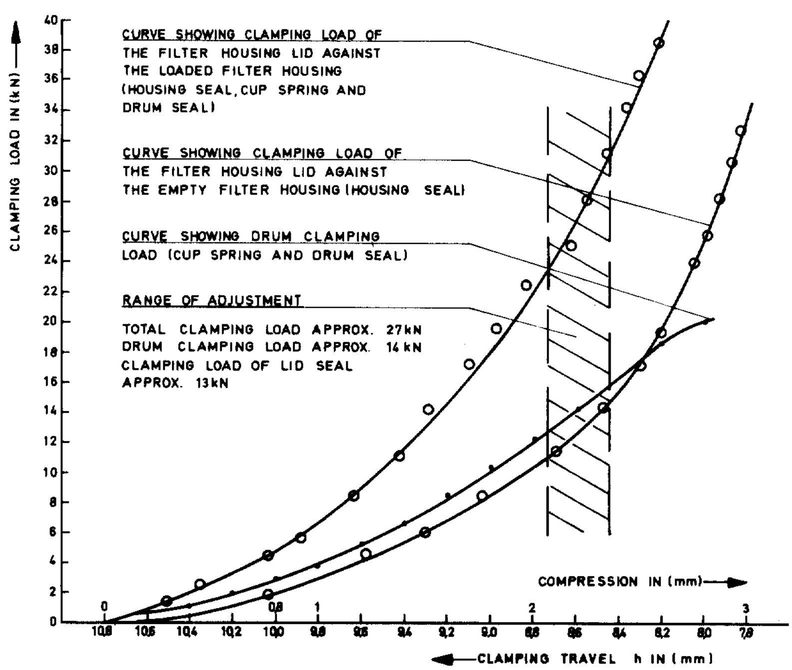


FIG.3 CLAMPING LOADS AS A FUNCTION OF CLAMPING TRAVEL (h)
IN THE PASSAT IODINE FILTER CASING.

The filter housing has been designed and built in accordance with the pressure vessel regulations and has been accepted by the German Technical Inspectorate (TÜV). Material No. 4541 has been chosen for the filter housing and the filter element.

The following design criteria were specified for the development of the universal filter housing and the handling systems with remote control capability:

- Standardization of all filter housings and handling systems installed in the cell.
- The designs must be reliable, maintenance free, simple and easy to repair.
- Sufficient leak tightness (leak rate < 10^{-3} Torr l/s) which, as far as possible, should be verifiable also during operation.
- Small size.
- If possible, no contamination release during replacement.
- Easy decontamination.
- Efficient use of material.
- Low operating and maintenance costs.

The reasons for specifying some of these design criteria and for their observation during development of the filters and the handling systems will be dealt with in more detail below on the basis of some examples.

Standardization

All filters with remote control capability of the PASSAT prototype offgas system (e.g., for removal of wet aerosols, solid aerosols and iodine) should be standardized as far as possible for reasons of easy handling, maintenance and stock keeping.

The filter elements for the removal of wet aerosols, solid aerosols and iodine differ in efficiency, structure and type of loading. Standardization was achieved by selecting a standard lid and clamping mechanism for the filter housings. The filter housings as such do not have to be operated during filter replacement and, for this reason, may differ in design without violating the standardization concept.

Important parameters with respect to uniform handling are the designs of the lid and of the clamping mechanism and the type of transport chosen for the filter system. For all filter elements to be handled in one transport system, a standard coupling piece must be attached to the filter element. Fig. 4 shows the iodine filter element with the coupling piece. The direction of flow is from top to bottom.

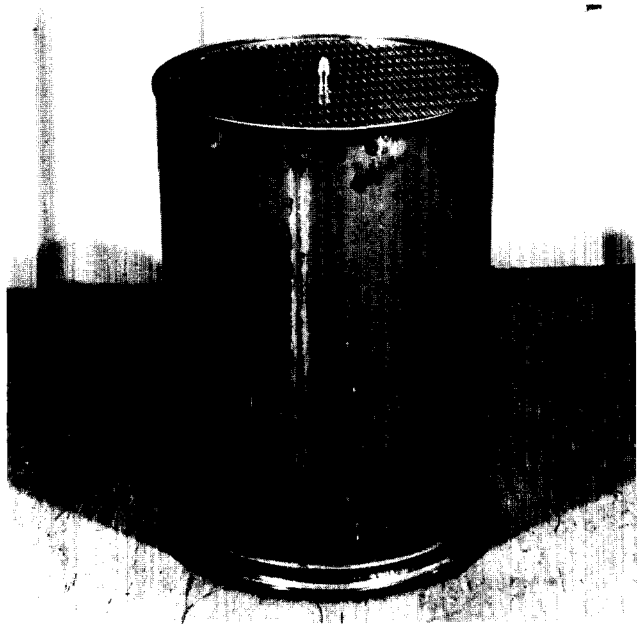


FIG.4: IODINE FILTER ELEMENT (DRUM)

Fig. 5 shows two types of solid aerosol filters (HEPA). In this case, the flow is from the bottom. Besides the different filter elements, the difference relative to the iodine filter (Fig. 2) is in the closing mechanism at the inlet of the untreated gas. In the aerosol filter, this is necessary because the untreated gas side of the filter housing and the filter element are highly contaminated with radioactive particles; in the absence of a closure, this could give rise to contamination of the clean gas side of the filter housing and the filter cell during filter replacement. In alternative I, the closure is moved downward mechanically by the lid of the filter housing acting on a rod, in this way causing the inlet to the aerosol filter to be opened when the lid of the filter housing is closed. When the lid of the filter housing is opened, the actuating rod is moved upward by a spring and the inlets to the filter elements and the clean air side of the filter housing are closed. In this way, any spread of contamination from the untreated gas side of the filter housing and the filter element, respectively, is avoided. In alternative II, only the opening to the filter element is closed during removal. Moreover, there is an additional seal relative to the lid of the housing.

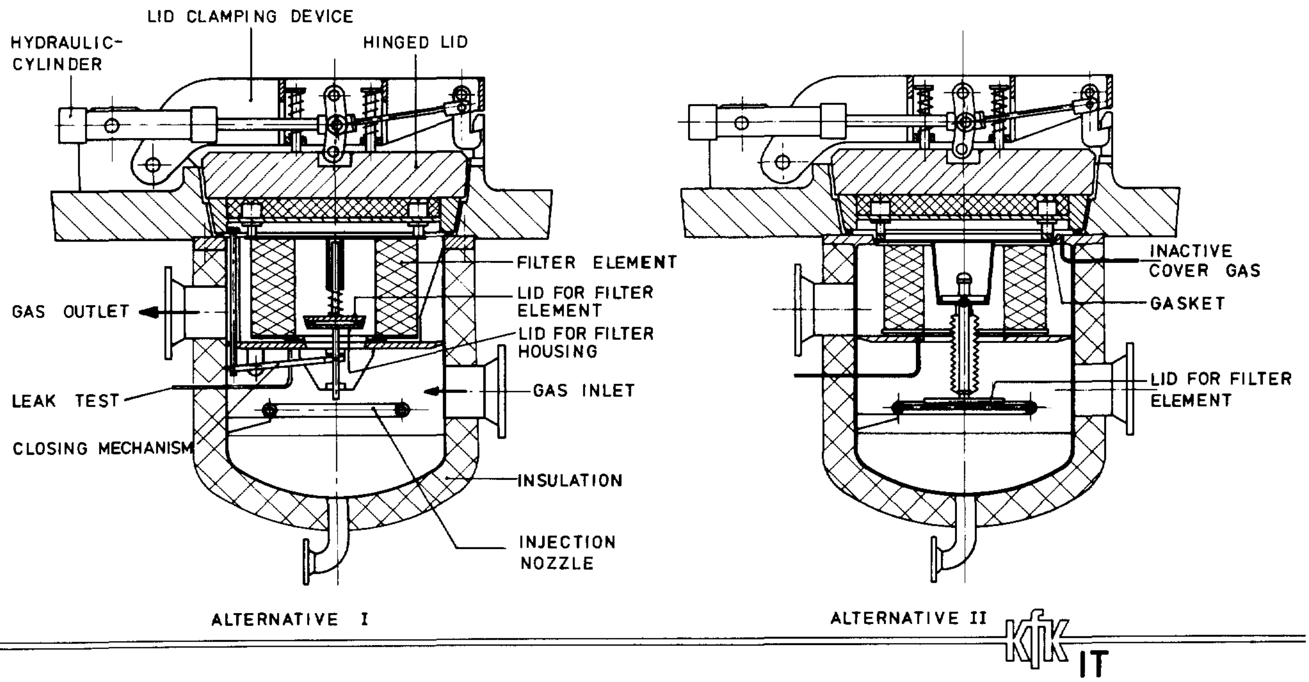


FIG.5 REMOTELY OPERATED AEROSOL FILTER

Safe, Maintenance Free, Simple, Easy to Repair

To meet these conditions, the following technical measures were incorporated:

- Only a minimum of movable parts were included.
- The movement of the lid, clamping, clamping of the filter element, and the closure between the untreated and the clean air sides, were designed in such a way as to be operated by one maintenance free clamping mechanism actuated by a hydraulic cylinder easy to replace.
- Quantitative limits were established in the hydraulic cylinder so that, if a hydraulic line were to fail during opening or closing of the lid, the lid would not drop more quickly than in the standard mode of operation.
- The lid fully opened is moved into a safe position (opening > 90^o), so it cannot tip if the hydraulic system were to fail.
- For easy decontamination of the filter housing the proper shape and installed flushing water lines have been provided.
- The gasket between the untreated and the clean air sides is attached to the filter element and can thus be replaced with every filter replacement (except for iodine filters, where the gasket is used twice).

- The housing gasket is installed so that it can be replaced quickly by manipulators or on the spot by personnel wearing fully protective suits. (See Fig. 6.) The gasket is not glued onto the housing but is held in place by proper shaping of the groove.

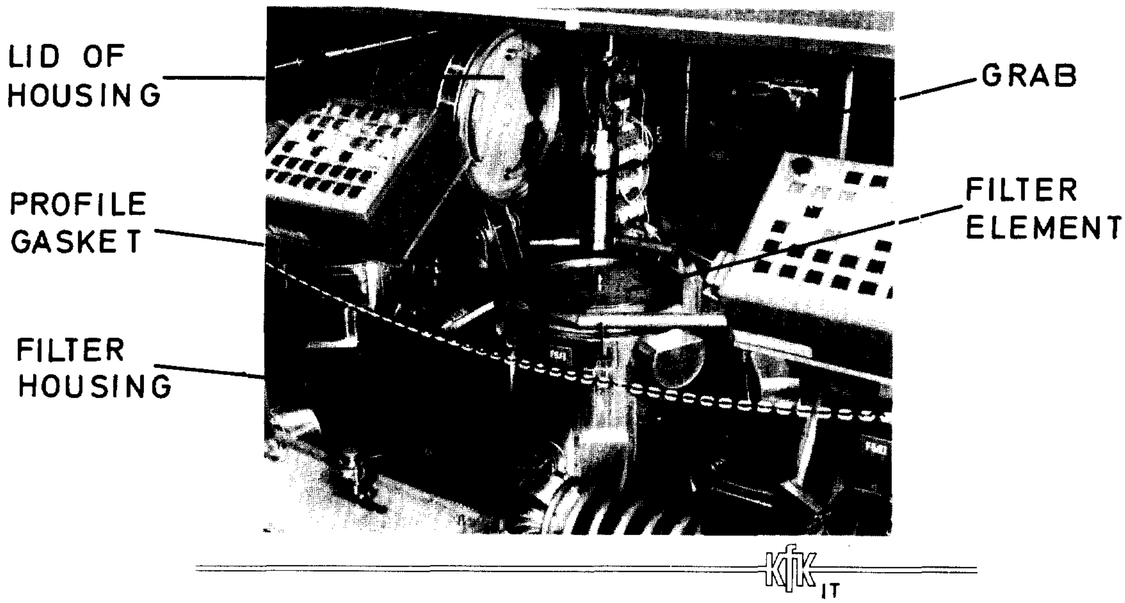


FIG.6 GASKET BETWEEN LID OF HOUSING AND FILTER HOUSING (VESSEL)

Two solutions are possible, and are in fact tested in the PASSAT facility, for repair of the clamping mechanism. The first solution provides for emergency operation of the filter in case of failure of the clamping mechanism, which would allow the lid of the filter housing to be opened and the filter element to be removed. The lid can be closed by emergency actuation and the filter housing, if necessary, can be decontaminated to reduce the radiation dose. Personnel wearing fully protective suits can then repair the clamping mechanism in situ.

Fig. 7 shows a remotely handled filter housing of the same design as shown in Fig. 2, but with emergency operating capability and without lid shielding. Emergency operation requires no additional expenditure in terms of operating equipment, for the lid of the filter housing can be opened via the emergency actuating lever by means of the mono-rail trolley of the cell. For this purpose, the grab is attached to the coupling piece of the emergency actuating lever.

The other solution (Fig. 2) features a shielded lid (approx. 150 mm steel), which allows the filter cell to be entered for repair purposes, without requiring the filter elements to be unloaded. No emergency actuation of the shielded lid is necessary.

None of the components installed in the filter housing needs any maintenance. The hinged points are equipped with dry bearings. Only two retaining plates must be withdrawn for disassembly of the hydraulic cylinder.

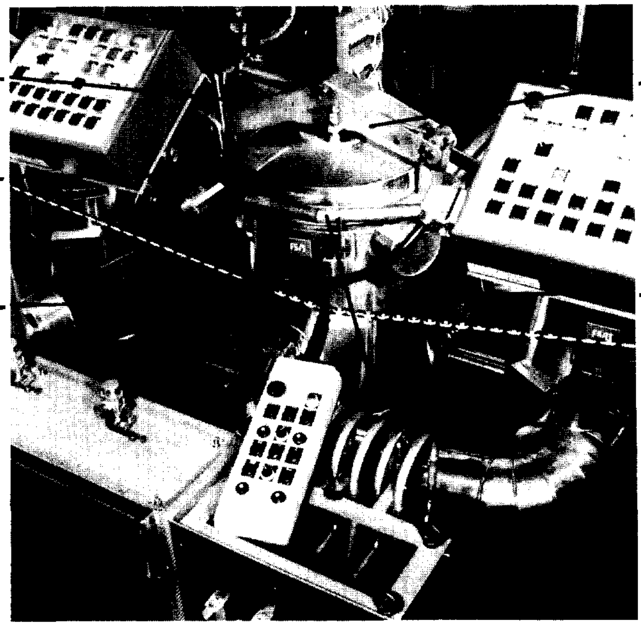


FIG.7: REMOTELY OPERATED FILTER HOUSING WITH IODINE FILTER ELEMENT (VERTICAL DESIGN);
TÜV CLEARANCE NO. 116-597/2-3.5.3-2004

Gaskets/Leak Tests

The gaskets attached to the filter must withstand the levels of temperature and radiation and the gas compositions occurring in practical operation. Mechanical properties must meet the most stringent requirements. After prolonged operation the gasket must still be elastic, show minimum deformation, retain its original strength and not become porous. For the PASSAT filters, gaskets made of silicone and viton were chosen for continuous operating temperatures $\geq$ 150 °C. The test results have not yet been made available. The housing gasket attached to the PASSAT filters now in operation for about one year (total period approx. two years), but only in dry air at 150 °C or in humid air at approx. 80 °C, i.e., without radiation or acid contained in the gas, exhibited almost no changes. In operation so far their leak tightness has always been better than 10^{-3} Torr l/s. Fig. 6 shows the profile and the mode of installation of the filter housing gaskets. The uniform deformation of the filter housing gaskets was approx. 1 mm.

The gaskets of the filter element play an important role inasmuch as they constitute the interface between the untreated air and the clean air. Fig. 8 shows the design and mode of attachment of this gasket. Attachment by means of a ring, in addition to gluing, was selected in order to prevent the gasket from being torn off or fall off the filter element. This gasket is leak tested on both sides (glued and supported sides) as follows:

After installation of the filter element an overpressure of approx. 1 bar is admitted to the leak pipe. The pressure drop as a function of time is a measure of leak tightness. During operation, the leak rate can only be tested after constant temperature levels have been established.

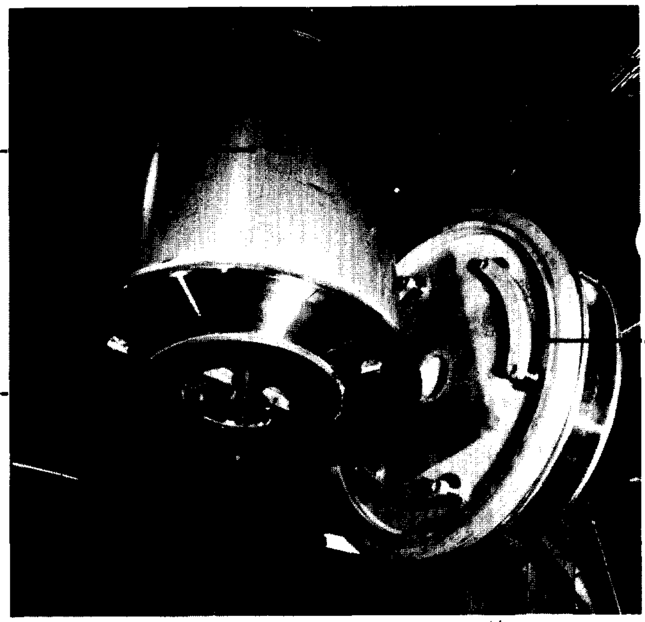


FIG.8 GASKET BETWEEN FILTER ELEMENT AND HOUSING INTERMEDIATE BOTTOM

Fig. 9 shows the condition of this gasket in an iodine filter drum, which had been operated for about 2.5 months at 150 °C with air as the operating medium. Unlike aerosol filtration, the iodine filter drum is used twice. As can be seen from the picture, the gasket is stressed at a different position when used for the second time. In order to be able to test the reserve capacities of the gaskets, the drum, by way of exception, was used twice in each of the two iodine filter housings. The leak tightness remained almost constant, and at the end of the replacement period it was 6.8×10^{-4} Torr l/s. The separating force applied when removing the filter drum was 3.5 kN, the filter drum weighing 1.2 kN.

Operating Experience

Three filter housings of the design described above are used in the PASSAT facility. Here are the operating data for the flowing medium:

Gas	250 std. m^3/h of air
Temperature	30 - 150 °C
Pressure	0.95 - 0.75 bar abs.
Iodine	max. 1,1 g/m^3 - only after February 1980
NO_x	max. 6 % - only after April 1980.

A total of approx. 150 simulated filter replacements have been made so far. The clamping mechanism and the opening and closing of the lid of the filter housing did not fail in any case and even upon closer inspection exhibited no wear or corrosion phenomena. They were

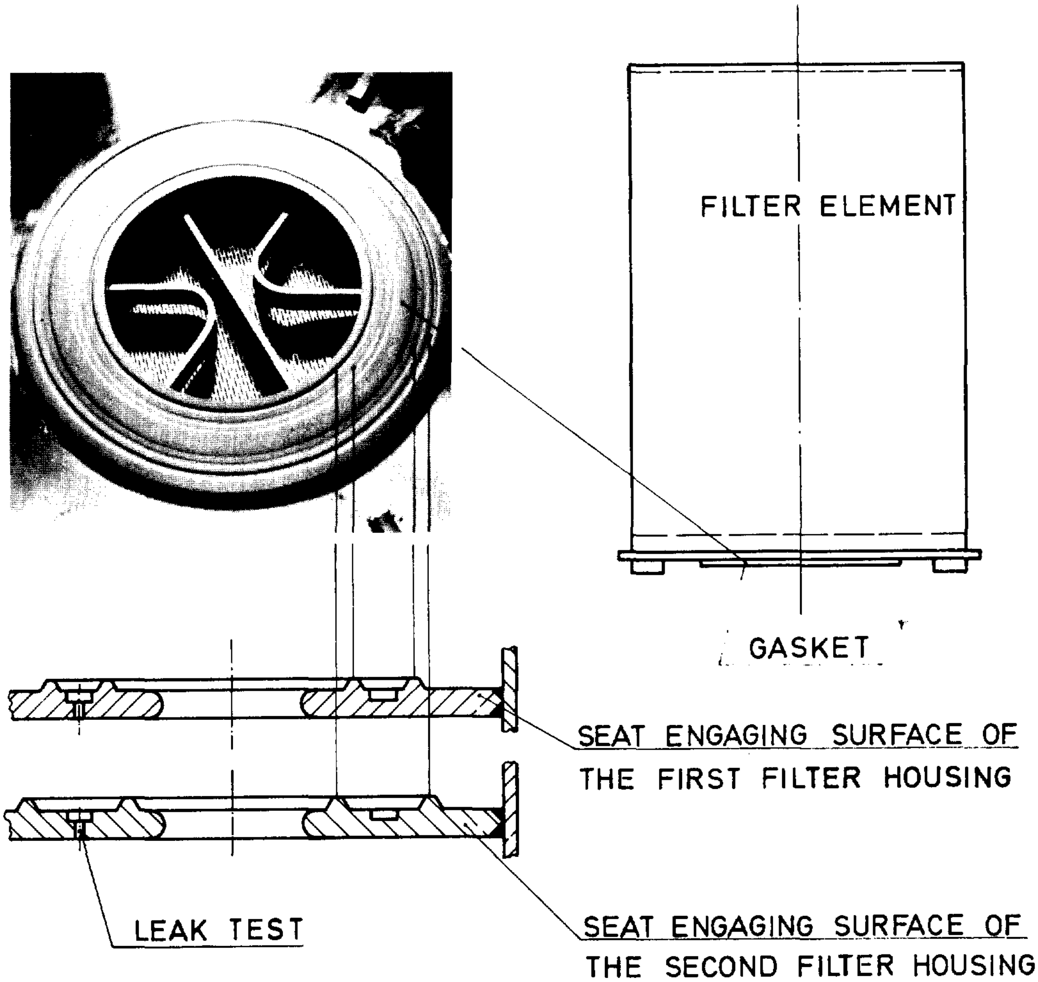


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FIG.9: CONDITION OF THE SEAL OF AN IODINE FILTER ELEMENT AFTER REPEATED FILTER REPLACEMENTS.

ready for operation at any time. For the whole period mentioned above no maintenance or repair work was necessary.

The number of filter replacements mentioned above corresponds to an operating period of approximately two years for a reprocessing plant with an annual throughput of 1500 t; for an annual throughput of 350 t it would correspond to eight years of operation.

Remote Filter Handling

The concept underlying the development of the remote filter handling system was the standardized design of all filters. Aside from this, the same design criteria apply as to the filter housing. The system were to be easy to operate, safe and free from maintenance. The standardized filter housing design was one of the basic preconditions to a standardized approach in the remote handling facilities. Especially the following aspects were borne in mind in designing the remote handling systems:

Frequency of steps to be performed (degree of automation), required precision of work (observation of certain tolerances and conditions),

prescribed safety levels (interlocking, emergency operation),

volume and weight of the filter elements and type of content,

physical arrangement,

rules and regulations to be observed.

One of the main design criteria was the need to complete any filter replacement step once it had been started because of the high radioactivity of the loaded filter elements. This condition was met mainly by installing double driving systems and emergency actuating facilities. Thus, e.g., the following measures were incorporated:

- The mono-rail trolley was equipped with separately actuated double motors for travel and lifting. Moreover, brake venting systems are installed so that the load could be lowered in any case. For repair or inspection work the mono-rail trolley can be pulled or moved into a tight chamber outside the cell.

- The cell lock, Fig. 10, is designed in such a way that it can be operated manually by means of extended shafts from outside the filter cell. The cell lock is maintenance free. The only component requiring external power is the clamping magnet used for close adhesion of the intermediate lid to the lid of the lock. Also interlocking of the intermediate lid is done mechanically.

- The lifting and swiveling device, Fig. 11, has also been designed for manual operation from outside the filter cell. Lifting and lowering is done by electric motors. In case the electric motors were to fail, a shaft coupled to the lifting gear can be used for manual lifting and lowering from outside the shielding. The lifting and swiveling devices require no maintenance.

- The screwing device system is installed above a shield so that repair work can be carried out on the spot. The screws are arrested manually by means of a service shaft from outside the shielding. The screwing device system is maintenance free.

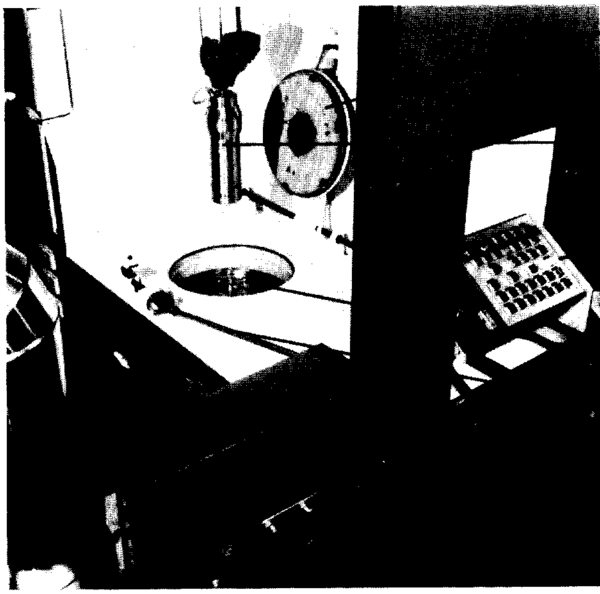

FIG.10 REMOTELY CONTROLLED CELL LOCK

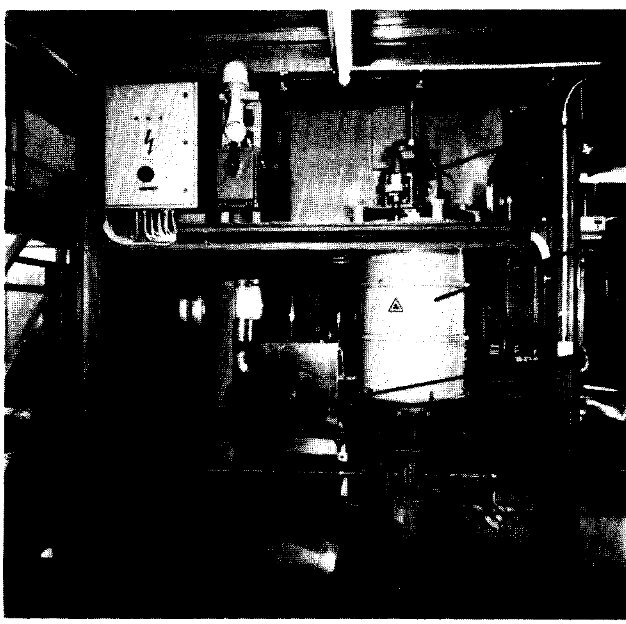

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FIG.11 REMOTELY OPERATED SWIVEL AND LIFTING DEVICE WITH SCREW LID ATTACHMENT SYSTEM

Operating Experience

The remote handling installations mentioned above have so far been used in some 50 complete replacement procedures. In none of these procedures did any difficulties or cases of maloperation occur. In simulated failures of the standard operating systems the secondary drives or emergency operating systems were also tested. They also worked satisfactorily. There have so far been no wear or corrosion phenomena to impair the functioning capability. The concept selected largely excludes operator's errors in filter replacement. Important components, such as the grab, are controlled in such a way that operating instructions are received only if given in the correct sequence.

The operating experience in the cold condition accumulated so far has proved the overall concept of filter cell design and filter handling to be reliable. It can be recommended for use in nuclear installations.

Experience in Operating the PASSAT Facility

The total pressure losses in the plant exposed to a standard volume flow of 250 m^3/h and with filter elements newly installed amount to 2200 mm of water, with filter elements loaded, to some 3000 mm of water. The rating for the blower is 4000 mm of water.

Since its commissioning in July 1978, the plant has worked without any failures over approximately one year of pure operating time in all experiments carried out so far. All the necessary plant data were reached in accordance with design specifications. For wet aerosols, removal efficiencies in excess of 99 %, for iodine, removal efficiencies in excess of 99.99 % were attained.

Although all pipes were installed with sufficient inclinations and also were heated, condensate containing nitric acid was always encountered in valves, stop valves and recesses caused by the equipment design in the plant section operating at 100 % relative humidity. However, this has not yet given rise to any difficulties. It is important to prevent condensate and condensate droplets, respectively, from getting into the aerosol and iodine filters, because they would cause these filters to fail.

Accordingly, it must be ensured in offgas systems that the prescribed plant data with respect to temperature and humidity are observed upstream of and in these filters. Independently, facilities must be provided which can automatically and without impairing the function of the plant discharge any condensation water produced in a facility.

Over a period of approximately three weeks of operation with max. 5 vol. % of NO_x in the gas and with iodine feed (max. 1,1 g/m^3 of gas), pitting corrosion was observed in those sections of PASSAT operated at 100 % relative humidity, i.e., between the inlet cooler and the mist separator. Fig. 12 shows part of a temperature sensor

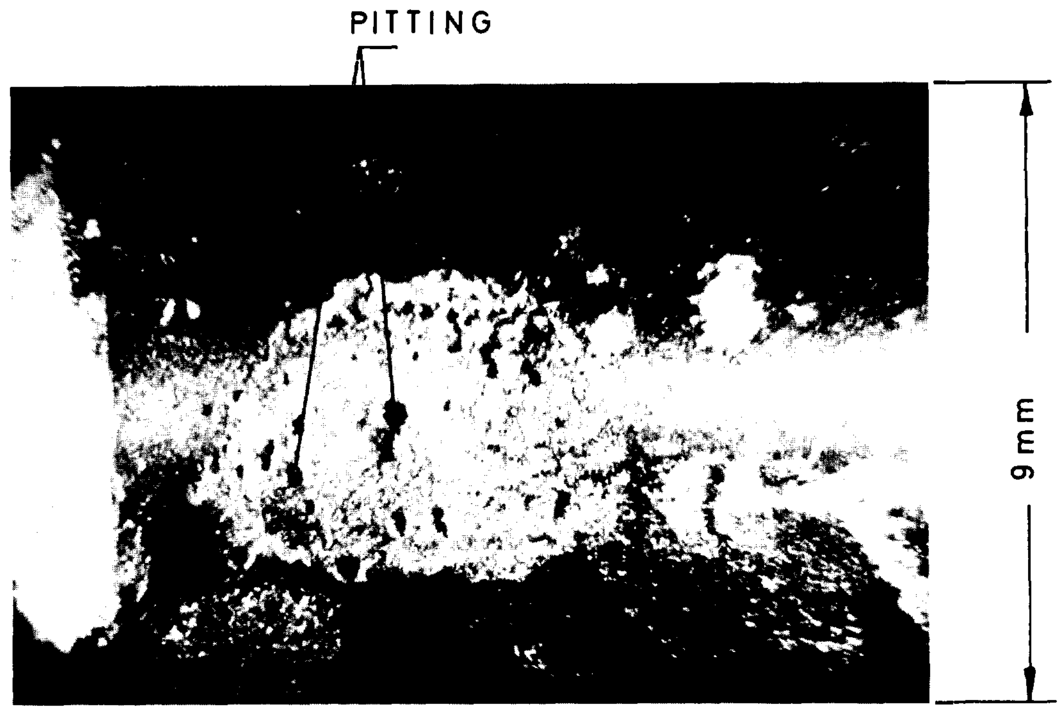

FIG.12 CORRODED SURFACE OF A TEMPERATURE SENSOR OF MATERIAL NR. 4571 AFTER WASHING WITH 10% OXALIC ACID

made of 4571 material, which is highly corroded. In the plant area operated at less than 30 % relative humidity no corrosion was observed. It will yet have to be examined what operating conditions, e.g., iodine content per m^3 of gas in connection with humidity, temperature, nitric acid, gas mixing following iodine feed, caused corrosion in the materials selected and which materials would lend themselves to being used under the plant conditions mentioned above.

PTFE gaskets or PTFE-enclosed gaskets were used in the joints or valves in PASSAT. The condition of these gaskets was satisfactory.

Construction of the PASSAT facility constitutes a major contribution towards the solution of offgas cleaning problems in large reprocessing plants. The results still expected from test operation with respect to handling during filter replacement and packaging of spent filters, reliability and performance of filters and optimization of operation will supplement the experience obtained during construction and will allow safety assessment of the gas cleaning systems for a German reprocessing plant to be based on a comprehensive level of experience.

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