SESSION 2

FIRE, EXPLOSION, ACCIDENT ANALYSIS

MONDAY: August 18, 1986
CHAIRMEN: K.S. Murthy
Battelle Pacific Northwest
R.T. Kratzke
U.S. Department of Energy

INVESTIGATIONS ON THE INFLUENCE OF COMBUSTION PRODUCTS ON THE RETENTION OF RADIOIODINE BY ACTIVATED CARBONS
H. Deuber, V. Giraud

CONCLUSIONS FROM FIRE TESTS IN ACTIVATED CARBON FILLED ADSORBERS
M. Mathewes

A CURRENT EVALUATION OF FIRE LOSS CONTROL SYSTEMS FOR CHARCOAL MEDIA
W.D. Holmes

REVIEW OF FIRES AND FIRE CONTROL METHODS FOR NUCLEAR AIR CLEANING SYSTEMS
J.L. Kovach

MEANS USED TO MAKE SURE THAT THE CONFINEMENT IS MAINTAINED IN CASE OF FIRE
J. Savornin

RELEASE OF RADIOACTIVITY OUT OF WASTE PACKAGES UNDER THERMAL STRESS
D. Gruendler, H.W. Brenig, W. Wurtinger

SIMULATION OF EXPLOSIONS IN AIR CLEANING SYSTEMS AND COMPARISON OF THE RESULTS WITH COMPUTER CODE PREDICTIONS
W.S. Gregory, B.D. Nichols, R.D. Wade, P.R. Smith, D.L. Fenton

FIRE-ACCIDENT ANALYSIS CODE (FIRAC) VERIFICATION
B.D. Nichols, W.S. Gregory, D.L. Fenton, P.R. Smith

METHODS FOR AIR CLEANING SYSTEM DESIGN AND ACCIDENT ANALYSIS
W.S. Gregory, B.D. Nichols

OPENING COMMENTS OF SESSION CO-CHAIRMAN MURTHY

Air cleaning systems assume special importance in minimizing the adverse environmental impacts of unplanned events such as fires, explosions, and accidents in nuclear facilities, thereby adequately protecting the public from the effects of these events. This session on fire, explosion, and accident analysis will provide you with results of recent investigations in this important field.

The session features a total of ten speakers: three from West Germany, one from France, and six from the United States. All five papers in the first part of the session deal with the results of investigations on confinement-retention in the event of fire. Most of these papers deal with carbon-base adsorbent fires. The opening paper deals with an introductory review of fires and fire control methods in nuclear air cleaning systems, outlining experiences from carbon-base adsorbent fires that have occurred in the history of the nuclear power industry.

The last five papers take on a different flavor in that you will be listening to three papers on computer code development and testing by Los Alamos National Laboratory in cooperation with the New Mexico State University. You will also be listening to West German developments on a procedure for determining source terms from waste packages (such as cemented waste) subjected to thermal stresses from accidental fires. Finally, the session will hear from Brookhaven National Laboratory and the US NRC on the current status of Monitoring, Sampling, and Analysis of Reactor Atmosphere Effluents in Post-Accident Concentrations. All in all, we will have a technical feast, and how well we have digested it all will be summarized in the closing remarks of the Co-Chairman, R. T. Kratzke.

INVESTIGATIONS ON THE INFLUENCE OF COMBUSTION PRODUCTS ON THE RETENTION OF RADIOIODINE BY ACTIVATED CARBONS

H. Deuber, V. Giraud

Kernforschungszentrum Karlsruhe GmbH
Laboratorium für Aerosolphysik und Filtertechnik
Postfach 3640, D-7500 Karlsruhe 1
Federal Republic of Germany

Abstract

Investigations were performed on the influence of gaseous combustion products from four relevant materials used in nuclear power plants on the retention of methyl iodide (CH_3I-131) by four commercial impregnated activated carbons. It is concluded that with iodine filters of large bed depths (residence time: e.g. 0.5 s), when containing a usually employed impregnated activated carbon of good quality, a sufficiently high retention of radioiodine should be achievable even with a high challenge of gaseous combustion products from relevant materials used in nuclear power plants.

I. Introduction

Numerous investigations are described in the literature on the various factors that influence the retention of radioiodine by impregnated activated carbons used in iodine filters of nuclear power plants (NPPs). /1,2,3/ However, as for the influence of combustion products, no corresponding investigations are known /4/, although, in the case of a fire in a NPP, this influence could be of concern. To fill this gap of knowledge, we are performing corresponding investigations.

In the present paper, investigations are covered on the influence of gaseous combustion products from four relevant materials used in NPPs on the retention of methyl iodide (CH_3I-131) by four commercial impregnated activated carbons. It should be kept in mind that organic iodine species other than methyl iodide, which may be more difficult to retain /5/, may be formed in the event of a fire in a NPP, e.g. by reaction of elemental iodine (I_2) with combustion products. As for I_2, its retention should be of no concern in the present context. /6/ Fires in iodine filters are beyond the scope of our investigations.

II. Relevant Materials and Combustion Products

As in many industrial installations there are many combustible materials in NPPs. In the present context only those are of interest which are to be found in rooms that are exhausted with iodine filters. Such rooms are e.g. the containment rooms in pressurized water reactors (PWRs). The materials of interest are cables with insulations, in particular PVC or more modern FRNC materials (flame retardent, non-corrosive). Additionally, lubricants (mineral oils) and paints (epoxy resins) must be considered. /4/

The types of combustion products produced depend on the types of materials combusted and on the combustion conditions. Apart from carbon oxides, hydrocarbons and water, which are generally produced, HCl will be generated in large proportions in the combustion of PVC cables. With FRNC cables organic acids such as CH_3COOH may occur. With mineral oils, in addition to evaporated oil, SO_2 and NO_x may be generated in small proportions. In the case of epoxy resins amines and HCN may occur. These compounds may originate from ancillary compounds (e.g. hardeners).

As for the challenge of iodine filters with combustion products in the case of a fire in a NPP, it is difficult to indicate realistic general figures. The following example, relating to a modern German 1300 MWe PWR, may be useful. It may be assumed that the inventory of PVC cables in the containment rooms is 10 000 kg half of which is combustible. The largest iodine filters, featuring a total throughput of about 130 000 m^3/h at a residence time of 1 s, contain roughly 20 000 kg of activated carbon in total. Thus, if these iodine filters were challenged with the combustion products from all the PVC cables in the containment rooms, the loading would be 0.25 g of combustion products per g of activated carbon or 25 %. Obviously, other figures can be calculated with other assumptions.

III. Experimental

As representatives of the relevant materials used in NPPs four materials were employed to generate the combustion products for the investigations:

a) a PVC cable;
b) a FRNC cable;
c) a mineral oil;
d) a paint.

The materials were combusted in a standard combustion apparatus. /7/

As representatives of the impregnated activated carbons used in iodine filters of NPPs the following four carbons were employed in the investigations:

a) 207B (KI);
b) 207B (TEDA);
c) 208C (KI);
d) 208C (TEDA).

The base material of the first two carbons is coal, that of the other two carbons coconut shell. The grain size of all the carbons was 8 - 12 mesh. /8/ The impregnants, as indicated, were either KI or TEDA.

The retention of CH_3I-131 by the carbons was determined in our standard test apparatus. /3/

The procedure pursued was as follows: First the carbon bed (consisting of 20 sections) was preconditioned over night in the test apparatus. Then it was challenged in the combustion apparatus with the combustion products over a period of generally 0.1 h. The combustion was performed at 700 °C in a stream of air. In front of the carbon bed the air stream was diluted (so that the flow was equivalent to that used in the subsequent CH_3I-131 test) and passed through a glass wool filter. Generally immediately afterwards, when the test conditions were again established, the CH_3I-131 was loaded on the carbon bed in the test apparatus, also over a period of 0.1 h. In some cases, to investigate the influence of the duration of the impact of the combustion products, the CH_3I-131 was injected 20 h after the loading of the combustion products. (The "purging time" was 20 h.) More data of the tests with CH_3I-131 are contained in Table I.

As indicated in Table I, the material combusted was either 0.1, 1 or 10 g. Thus, the maximum loading was nominally about 0.1 g of combustion products per g of carbon and of the same order of magnitude as calculated in the example in Chapter II. Of course, the major fraction of combustion products in non-gaseous form was removed by retention with the glass wool (and by deposition on the wall of the tube). However, this seems to be of minor importance with respect to the retention of CH_3I-131 as was shown by comparison tests with and without glass wool.

For comparison also tests with 1 g of HCl were carried out. As mentioned earlier, this compound is generated in the combustion of PVC. Moreover, the retention of CH_3I-131 by the unchallenged (fresh) carbons was determined.

In addition to the investigations described, some measurements were also performed to determine the organic combustion products on the carbon beds. To this end the CCl_4 extracts were analyzed by mass spectrometry. Moreover, both the pH values /9/ and the Cl^- concentrations of the H_2O extracts of the carbon beds were measured after challenge with combustion products from the PVC cable and after loading with HCl.

IV. Results

In this chapter first the results are presented of the investigations with CH_3I-131 using the combustion products and impregnated activated carbons indicated in Chapter III. The test parameters are contained in Table I. Detailed results are given for the carbons 207B (KI) and 207B (TEDA) only because the results for the carbons 208C (KI) and 208C (TEDA) were not decisively different (see below). The results are generally presented in terms of penetration by CH_3I-131.

Figures 1 to 8 display the penetration of the carbons 207B (KI) and 207B (TEDA) as a function of the bed depth at different amounts of combustion products. Without challenge by combustion products (amount: 0 g) the usual linear decrease in penetration with increasing bed depth was found (semilogarithmic plot). For amounts of combustions products of 0.1 g the penetration curves were also nearly linear. Compared with the unchallenged carbons, the penetration was somewhat higher in some cases, in particular for 207B (TEDA).

For amounts of combustion products of 1 and 10 g, a nonlinear course of the penetration curves was obtained: flat at small bed depths and steep at large bed depths. In general, at large bed depths the penetration curves were nearly parallel to the penetration curve of the unchallenged carbon. This form of the penetration curves, as is well known from aging experiments /10,11/, corresponds to a decrease in impact on the carbon with an increase in bed depth, with a negligibly small impact at a large bed depth for parallel penetration curves.

Figures 1 to 8 show that at the same amount of combustion products, for large bed depths ($\geq$ 12,5 cm) the increase in penetration was similar for all the combustion products, both for 207B (KI) and 207B (TEDA). At the maximum challenge, the increase in penetration was mostly 1 to 2 orders of magnitude, with a tendency for lower values for 207B (KI) and higher values for 207B (TEDA).

As for small bed depths, an overview is given in Figures 9 and 10. These show the penetration of 207B (KI) and 207B (TEDA), respectively, at a bed depth of 5 cm for different amounts and types of combustion products. It is obvious that the combustion products from the PVC cable exerted the most adverse effect on the carbons. For 207B (KI), at the maximum challenge the penetration was between 70 and 80 % with the combustion products from the PVC cable and between about 20 to 40 % with the combustion products from the other materials. For 207B (TEDA) the corresponding values were 60 to 70 % and 30 to 40 %, respectively. (The higher value in the case of the combustion products from the oil may be due to an experimental error.)

The strong adverse effect of the combustion products from the PVC cable at small bed depths is also obvious from Tables II and III, which contain the removal efficiencies of the first five beds of 207B (KI) and 207B (TEDA), respectively, at different types and amounts of combustion products.

From all the results obtained for small and large bed depths it is evident that in general the combustion products from the PVC cable exerted a strong impact over a small bed depth, whereas the other combustion products exerted a weaker influence over a larger bed depth, with a resulting increase in penetration of similar magnitude at large bed depths.

As for the carbons 208C (KI) and 208C (TEDA), the increase in penetration due to the impact of the combustion products was similar to that observed with the other carbons. (The results were closest to those obtained with 207B (TEDA).)

As mentioned earlier, in some tests the CH_3I-131 was not injected immediately after the loading of the combustion products, but after a purging time of 20 h only. Some results in terms of penetration versus bed depth are illustrated in Figures 11 an 12. It is obvious that the duration of the impact of the combustion products from the PVC cable was of minor importance in the range investigated, both for 207B (KI) and 207B (TEDA). Analogous results were obtained for the other combustion products.

The results of the comparison tests with HCl are displayed in Figures 13 and 14, both for no purging and purging over 20 h after the injection of HCl. With no purging, at large bed depths the penetration was similar to that obtained with the same amount of the combustion products (compare Figures 1 to 8.) At small bed depths, however, the penetration was much higher. At a bed depth of 5 cm the penetration was about 90 % for 207B (KI) and about 60 % for 207B (TEDA). Similar values were obtained with much higher amounts of combustion products from the PVC cable only (compare Figures 9 and 10).

Thus, the impact of HCl was strong, but over a small bed depth only, as was in principle the case with the combustion products from the PVC cable. It can be concluded that HCl constituted a major factor in the impact of the combustion products from the PVC cable on the retention of CH_3I-131 by the carbons. This is in agreement with other measurements (see below).

The results of the mass spectrometric analyses of the CCl_4 extracts of carbon beds after challenge with combustion products are summarized in Table IV. The results relate to the combined first and second beds of 207B (KI). It is to be seen that alkyl derivatives of benzene were among the main organic combustion products from all the materials used. From aging experiments it is

well known that these compounds (and other organic compounds) contribute to the deterioration of carbons with respect to the retention of CH_3I-131. /12,13,14,15,10,11/ Obviously these compounds played also an important part in the impact of the combustion products. The similarity of the compounds would account for the similarity in impact by the combustion products from various materials.

Some results of the pH value measurements in the H_2O extracts of carbon beds after challenge with the combustion products from the PVC cable and after loading with HCl are shown in Figures 15 and 16. It is to be seen that the extracts of the front beds had a lowered pH value. For the combustion products from the PVC cable the decrease of the pH value was 2 to 3 units, for HCl 6 to 7 units, both for 207B (KI) and 207B (TEDA). The stronger decrease of the pH value for HCl correlates with the stronger impact of this compound on the retention of CH_3I-131.

It is mentioned that a higher Cl^- concentration was also only found in the H_2O extracts of the front beds, both for the combustion products from the PVC cable and for HCl.

The measurements of the pH values and the Cl^- concentrations confirm that HCl constituted a major factor in the impact of the combustion products from the PVC cable on the retention of CH_3I-131 by the carbons. The adverse effect of acidic compounds in this context has been observed earlier. /13,15/

V. Summary and Conclusions

Investigations were performed on the influence of gaseous combustion products from four relevant materials used in nuclear power plants (NPPs) on the retention of methyl iodide (CH_3I-131) by four commercial impregnated activated carbons. The materials used to produce the combustion products were a PVC cable, a modern FRNC cable (flame retardent, non-corrosive), a mineral oil and a paint. The carbons differed in base material (coal or coconut shell) and/or impregnant (KI or TEDA).

It was found that at small bed depths (residence times: ≈ 0.05 s) the increase in total (cumulative) penetration by CH_3I-131 was higher for the combustion products from the PVC cable than for the other combustion products. At larger bed depths (residence times: ≈ 0.25 s) the increase in penetration was similar for all the cumbustion products and nearly independent of the bed depth. The increase in penetration was not decisively different for the different activated carbons. At larger bed depths, in general the increase in penetration was 1 to 2 orders of magnitude at the maximum challenge with combustion products (nominal loading: 0.1 g of combustion products per g of carbon). The combustion products were found to contain large proportions of alkyl derivatives of benzene and, in the case of the PCV cable, hydrochloric acid.

It is concluded that with iodine filters of large bed depths (residence time: e.g. 0.5 s), when containing a usually employed impregnated activated carbon of good quality, a sufficiently high retention of radioiodine should be achievable even with a high challenge of gaseous combustion products from relevant materials used in NPPs.

Acknowledgment

The following coworkers participated in performing and evaluating the tests:
K. Bleier, E. Becker, M. Dehm, S. Engelhardt, A. Ladanyi and S. Winkler.

VI. References

/1/ HOLLADAY, D. W.;
"A Literature Survey: Methods for the Removal of Iodine Species from Off-Gases and Liquid Waste Streams of Nuclear Power and Nuclear Fuel Reprocessing Plants, with Emphasis on Solid Sorbents".
ORNL/TM - 6350 (1979).

/2/ KOVACH, J.L.;
"The Evolution and Current State of Radio-Iodine Control".
CONF 801 038 (1981) p. 417.

/3/ WILHELM, J.G.;
"Iodine Filters in Nuclear Installations".
Commission of the European Communities, V/2110/83 (1982).

/4/ GIRAUD, V.;
"Die Abscheidung von Iod mit Iodfiltern in Kernkraftwerken bei Bränden (Literaturstudie)."
KfK 3867 (1985).

/5/ KOVACH, J.L.;
"Adsorbent Removal Efficiencies for Organic Iodine Compounds".
CEC European Conference on Gaseous Effluent Treatment in Nuclear Installations,
Luxembourg, 14.-18.10.1985.

/6/ DEUBER, H.;
"Investigations on the Retention of Elemental Radioiodine by Activated Carbons at High Temperatures".
Nucl. Techn. 72 (1986) 44.

/7/ Normenausschuß Materialprüfung im DIN;
"Erzeugung thermischer Zersetzungsprodukte von Werkstoffen unter Luftzufuhr und ihre toxikologische Prüfung."
DIN 53 436 (1981).

/8/ British Standard Institution;
"Specification for Test Sieves".
BS 410 (1976).

/9/ American Society for Testing and Materials;
"Standard Test Method for pH of Activated Carbon".
ASTM D 3838 (1980).

/10/ DEUBER, H.; GERLACH, K.; KAEMPFFER, R.;
"Investigations on the Aging of Activated Carbons in the Exhaust Air of a Pressurized Water Reactor".
Nucl. Techn. 70 (1985) 161.

/11/ DEUBER, H.; GERLACH, K.; GIRAUD, V.; KAEMPFFER, R.;
"Investigations on the Aging of Various Activated Carbons in the Exhaust Air of a PWR over an Extended Period of Time".
19th DOE/NCR Nuclear Air Cleaning Conference,
Seattle, 18.-21.8.1986.

/12/ FURRER, J.; KAEMPFFER, R.; WILHELM, J.G.;
"Alterung und Vergiftung von Iod-Sorptionsmaterialien in Kernkraftwerken/Aging and Poisoning of Filters in Nuclear Power Plants".
Kerntechnik 18 (1976) 313.

/13/ KOVACH, J.L.; RANKOVIC, L.;
"Combustion and Control of Poisoning of Impregnated Carbons Used for Organic Iodide Removal".
CONF 780 819 (1979) 368.

/14/ WILHELM, J.G.; FURRER, J.; KAEMPFFER, R.;
"Untersuchung zur Ertüchtigung von Iod-Sorptionsfiltern zur Reinigung der Abluft von Kernkraftwerken."
KfK 3194 B (1981).

/15/ DEITZ, V.R.;
"Effects of Weathering on Impregnated Charcoal Performance".
NUREG / CR-2112 (1981).

Table I: Parameters of the tests with CH_3I-131

Parameter	Unit	Value
Temperature	°C	30
Relative humidity	%	70
Throughput	m^3/h	0.88
Face velocity	cm/s	50
Preconditioning time	h	$\geq$ 16
Injection time [a]	h	0.1
Purging time [b]	h	2
Bed depth [c]	cm	50
Residence time	s	1
Combustion products injected [d]	g	0; 0.1; 1; 10
I-131 injected	mCi	0.1
I-127 injected	mg	1

[a] Both for combustion products and CH_3I (injection of combustion products generally immediately prior to that of CH_3I)

[b] after injection of CH_3I

[c] 20 beds of both depth and diameter of 2.5 cm (weight: ca. 5 g per bed)

[d] material combusted

Table II: Removal efficiency of 207B (KI) for CH_3I-131 at different types and amounts of combustion products (Test parameters: Table I)

Combustion product [a]		Removal efficiency of individual beds (%) [b]				
Type	Amount (g)	Bed 1	Bed 2	Bed 3	Bed 4	Bed 5
None	-	70	67	69	62	63
PVC cable	0.1	63	65	67	67	69
	1.0	21	55	60	51	60
	10.0	5	21	43	55	57
FRNC cable	0.1	63	69	69	72	73
	1.0	47	63	64	66	65
	10.0	43	46	52	55	55
Mineral oil	0.1	66	71	68	62	62
	1.0	51	62	70	69	71
	10.0	48	54	53	55	57
Paint	0.1	65	70	74	74	75
	1.0	52	58	63	63	65
	10.0	32	37	42	46	52

[a] Type and amount of material combusted

[b] Beds counted in direction of flow; residence time per bed: 0.05 s

Table III: Removal efficiency of 207B (TEDA) for CH_3I-131 at different types and amounts of combustion products (Test parameters: Table I)

Combustion product [a]		Removal efficiency of individual beds (%) [b]				
Type	Amount (g)	Bed 1	Bed 2	Bed 3	Bed 4	Bed 5
None	-	82	81	83	84	83
PVC cable	0.1	72	81	83	84	83
	1.0	25	68	75	78	79
	10.0	7	29	70	73	77
FRNC cable	0.1	67	70	82	87	87
	1.0	54	74	78	81	83
	10.0	36	51	62	68	72
Mineral oil	0.1	69	76	83	83	86
	1.0	57	74	80	83	84
	10.0	18	29	45	59	66
Paint	0.1	75	84	83	87	84
	1.0	51	69	75	77	79
	10.0	33	48	70	74	77

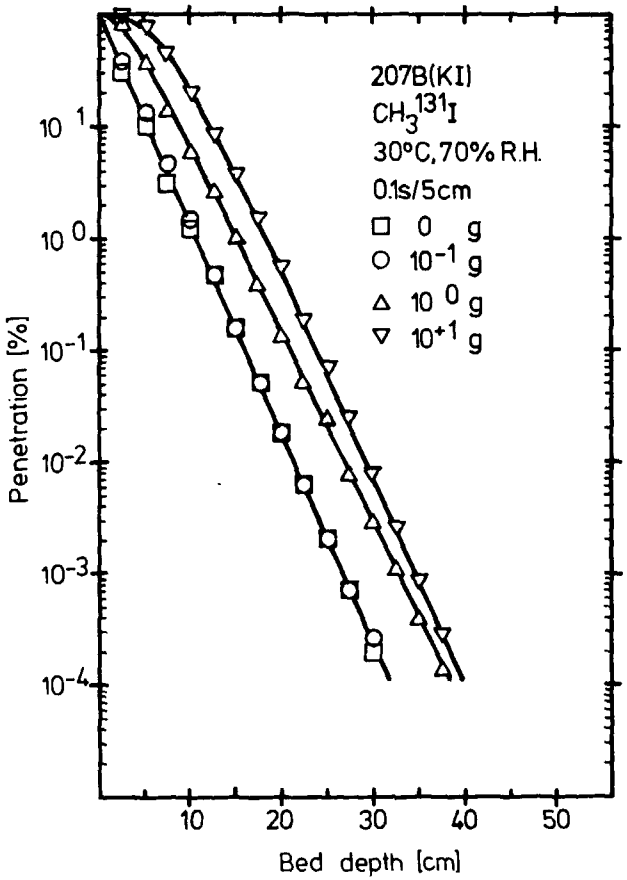
[a] Type and amount of material combusted

[b] Beds counted in direction of flow; residence time per bed: 0.05 s

Table IV: Organic combustion products from the materials used [a]

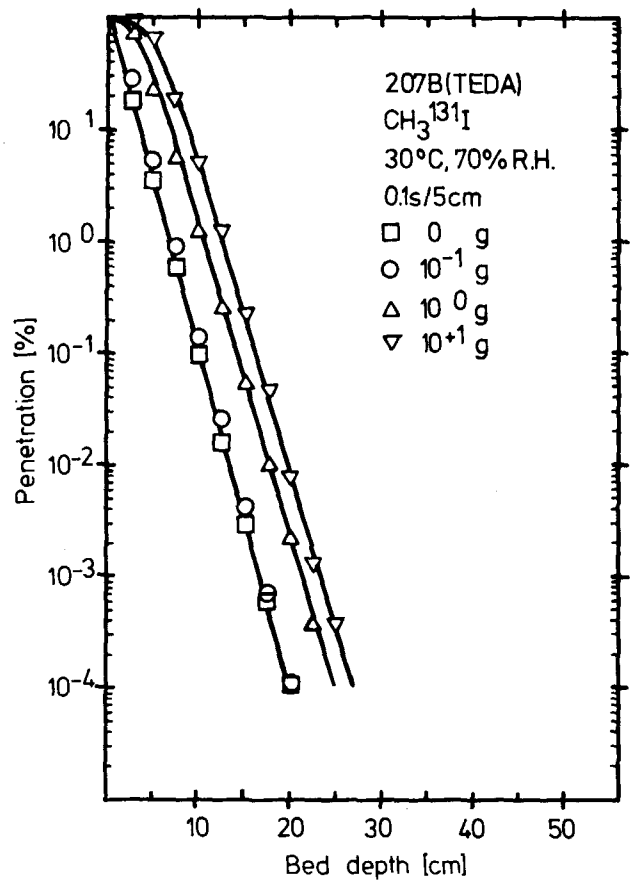
Material	Main compounds		Additional compounds (selection)
	Aromatic compounds	Non-aromatic compounds	
PVC cable	benzene, methyl-	cycloheptatriene	benzene, chloro-; napthalene
FRNC cable	benzene, methyl-; ethyl-	hydroxylamine, alkyl-; bicyclooctatriene; octane, methyl-; decene, methyl-; napthalene	straight and cyclic unsaturated hydrocarbons (C_6 - C_{14}) and alkyl derivatives thereof
Mineral oil	benzene, methyl-	-	benzene, alkyl-
Paint	benzene, methyl-, ethyl-; benzaldehyde; benzofuran	bicyclooctatriene	cyclohexene, alkyl-; heptane (straight, cyclic), alkyl-

[a] Organic products found in the CCl_4 extracts of the combined first and second beds of 207B (KI) after challenge with combustion products



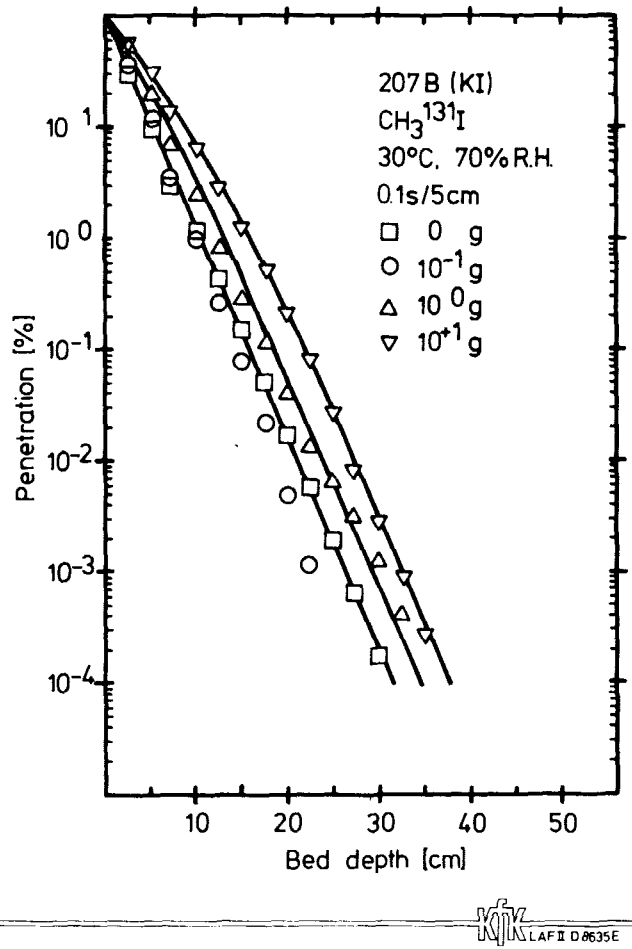
Penetration as a function of bed depth
at different amounts of combustion products
(PVC cable)

Fig. 1



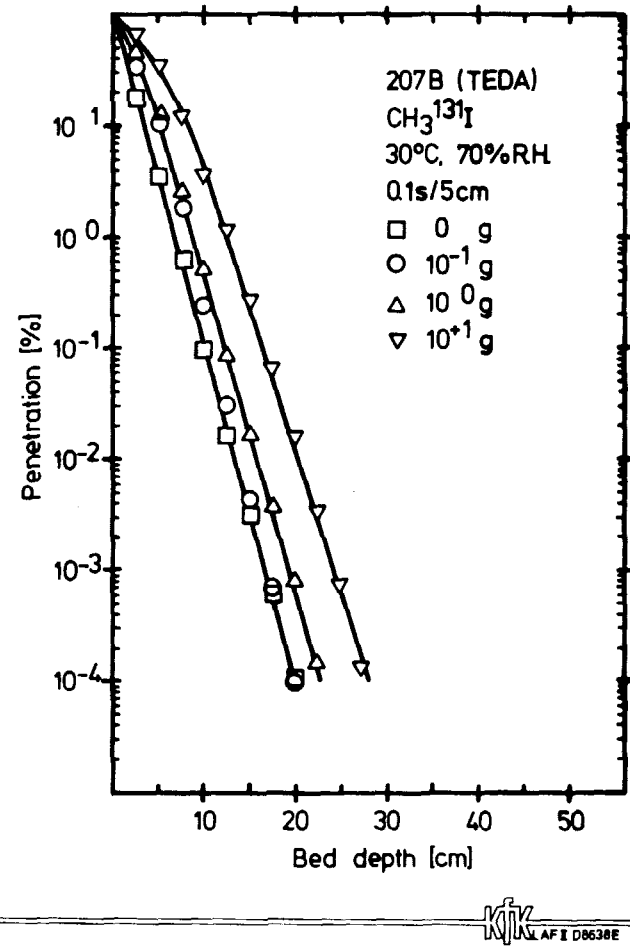
Penetration as a function of bed depth
at different amounts of combustion products
(PVC cable)

Fig. 2



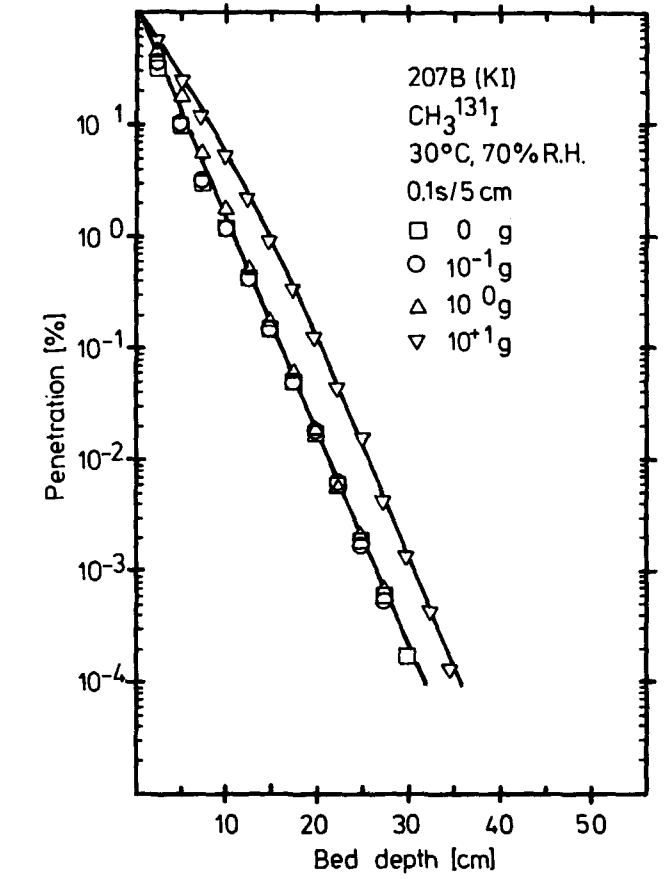
Penetration as a function of bed depth
at different amounts of combustion products
(FRNC cable)

Fig. 3



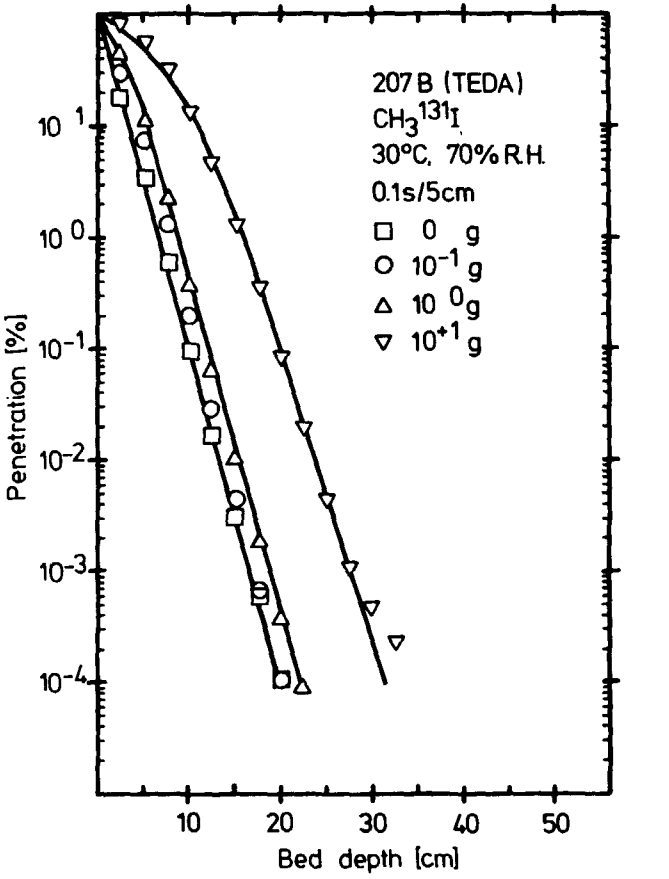
Penetration as a function of bed depth
at different amounts of combustion products
(FRNC cable)

Fig. 4



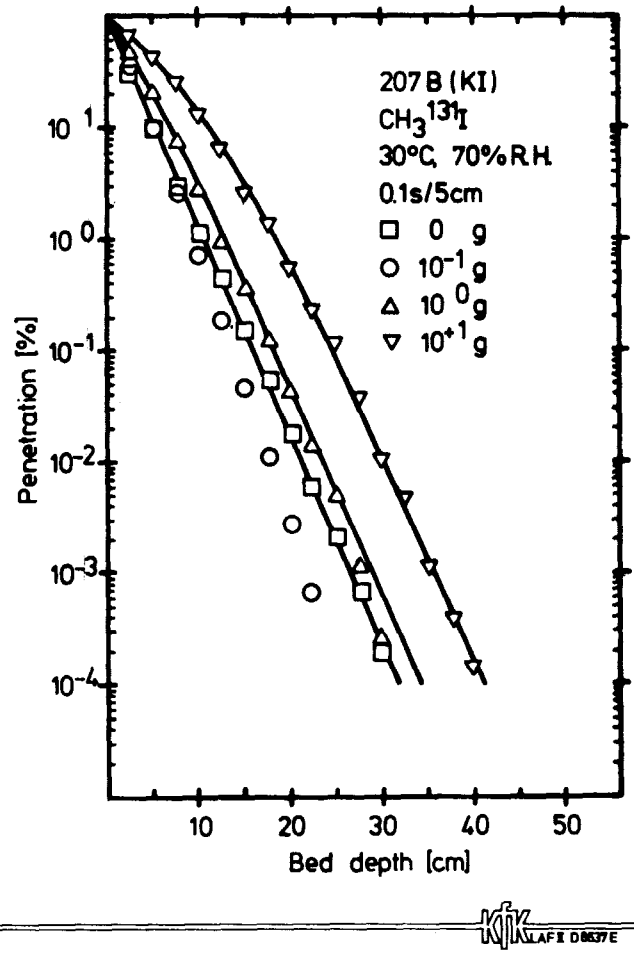
Penetration as a function of bed depth at different amounts of combustion products (mineral oil)

Fig. 5



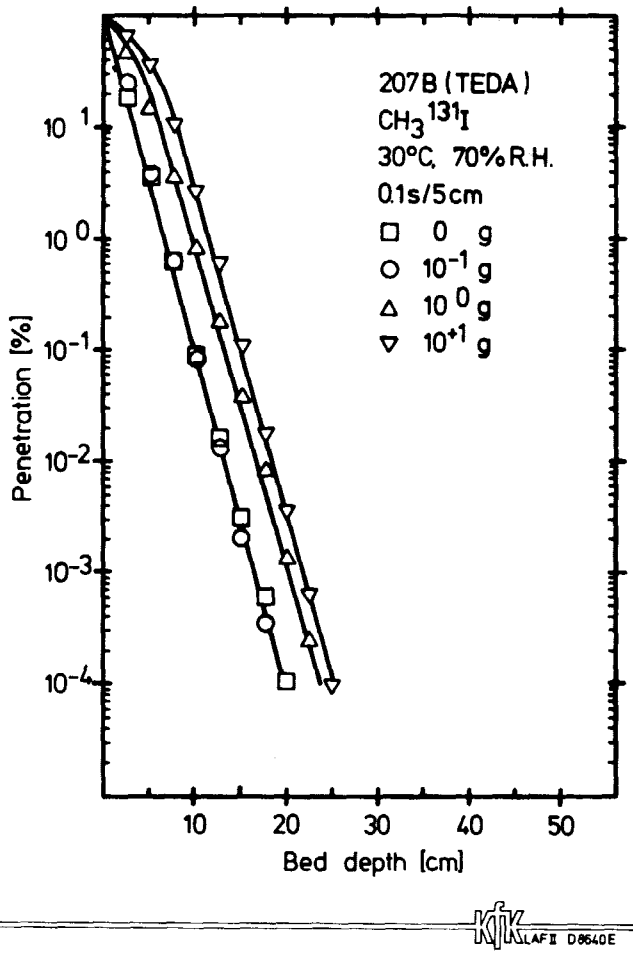
Penetration as a function of bed depth at different amounts of combustion products (mineral oil)

Fig. 6



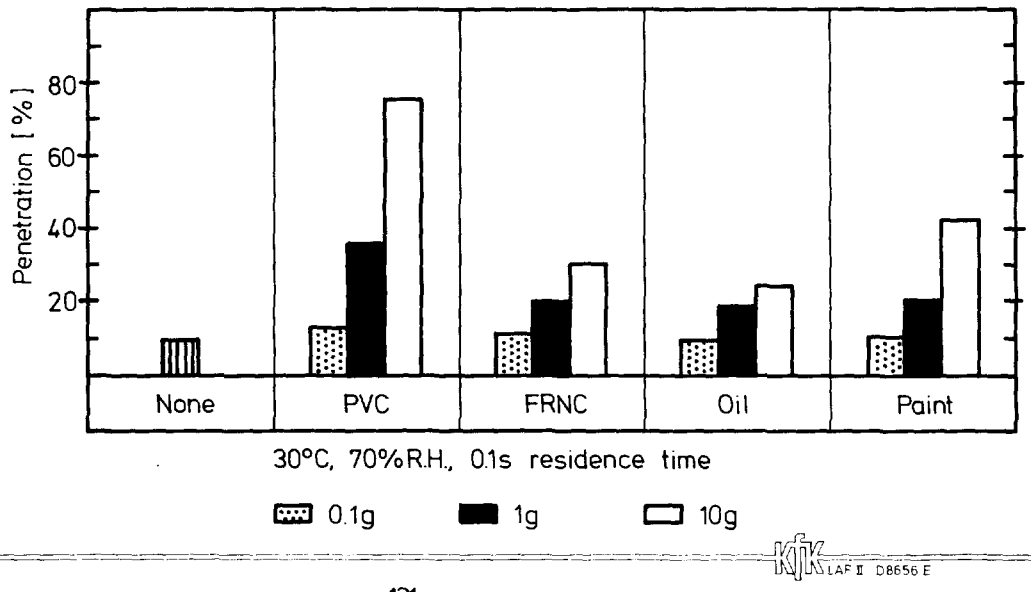
Penetration as a function of bed depth at different amounts of combustion products (paint)

Fig. 7



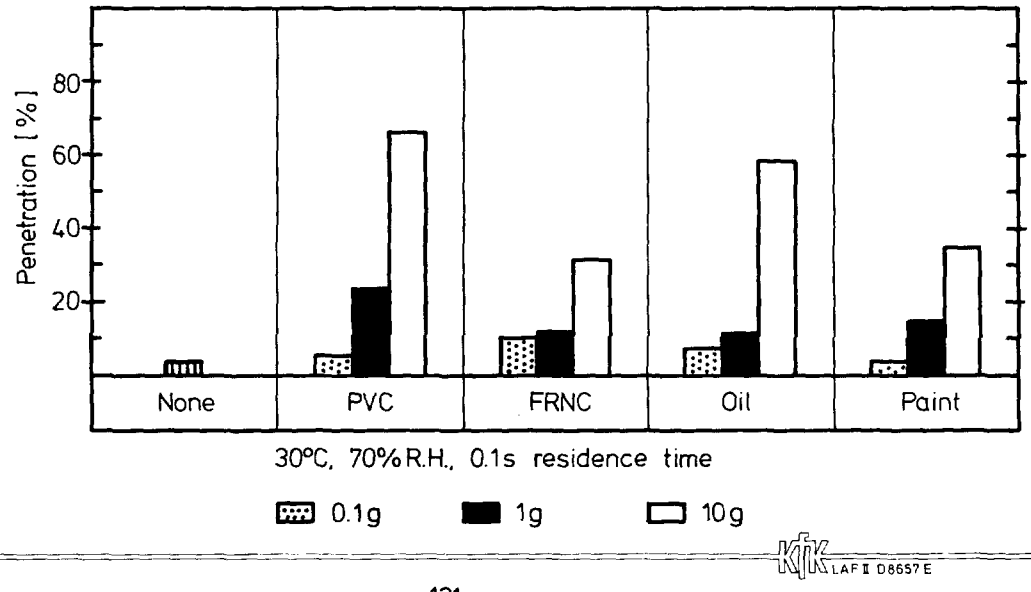
Penetration as a function of bed depth at different amounts of combustion products (paint)

Fig. 8



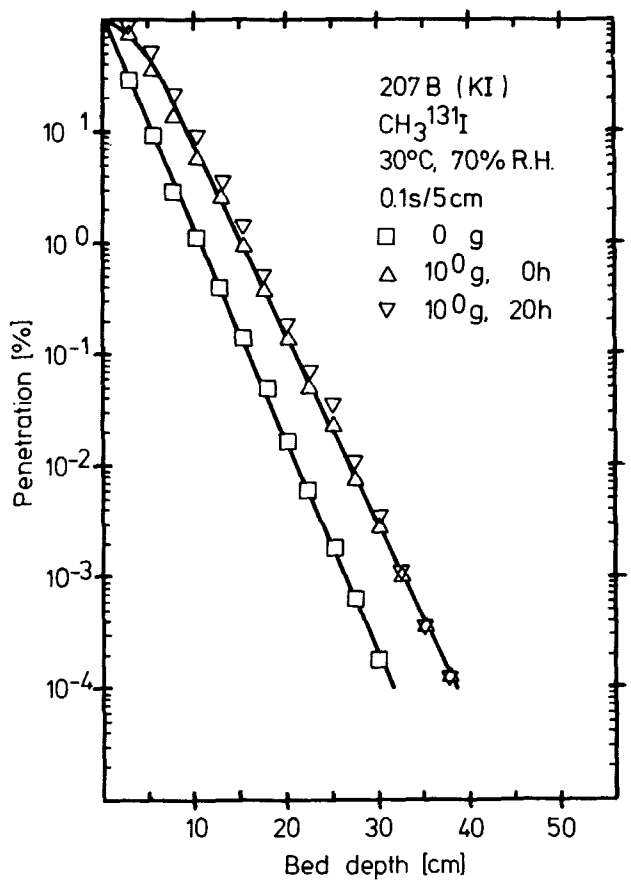
Penetration of 207B(KI) by $CH_3^{131}I$ at different amounts of combustion products

Fig. 9



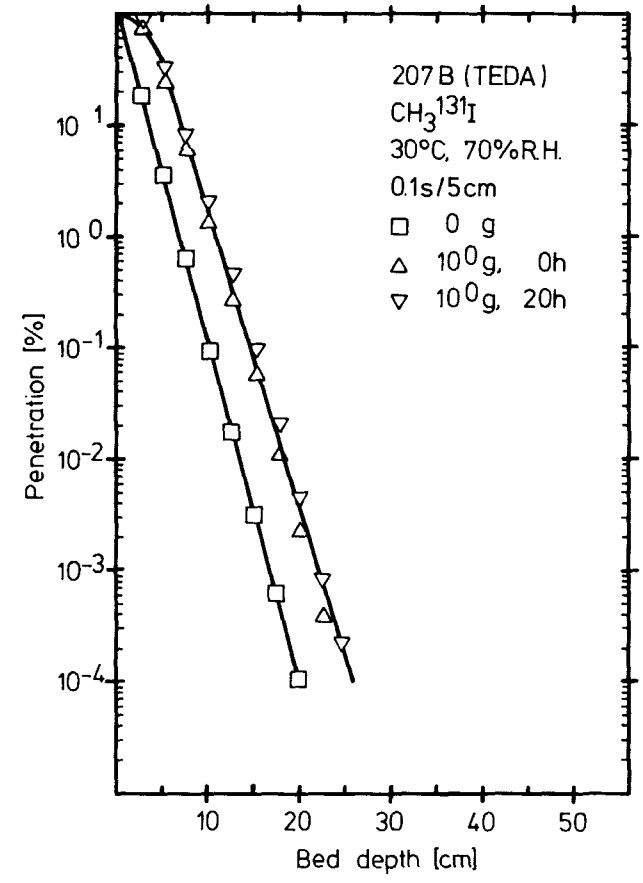
Penetration of 207B(TEDA) by $CH_3^{131}I$ at different amounts of combustion products

Fig. 10



Penetration as a function of bed depth at different amounts of combustion products and purging times (PVC cable)

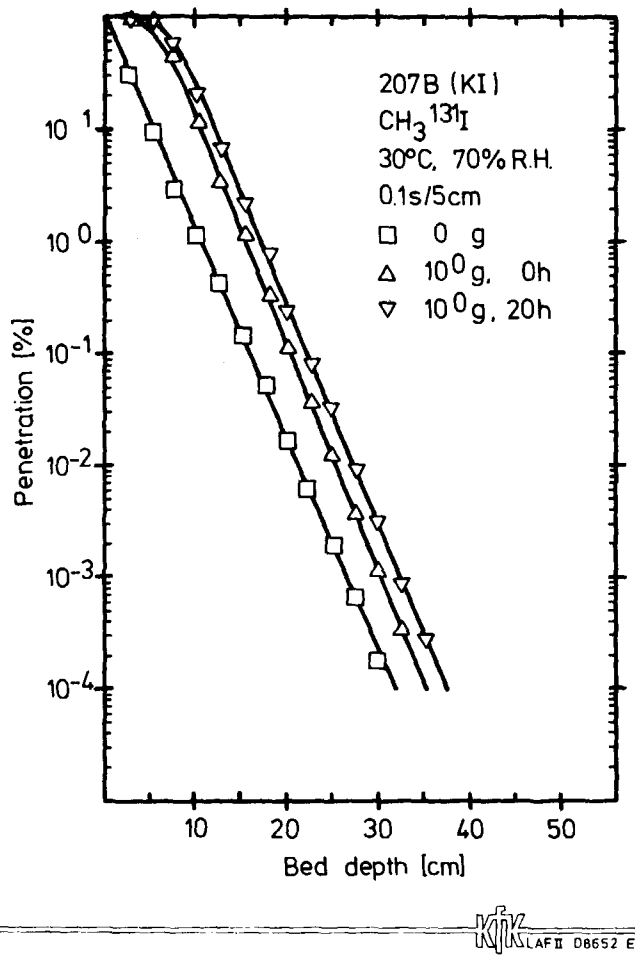
Fig. 11 [a]



Penetration as a function of bed depth at different amounts of combustion products and purging times (PVC cable)

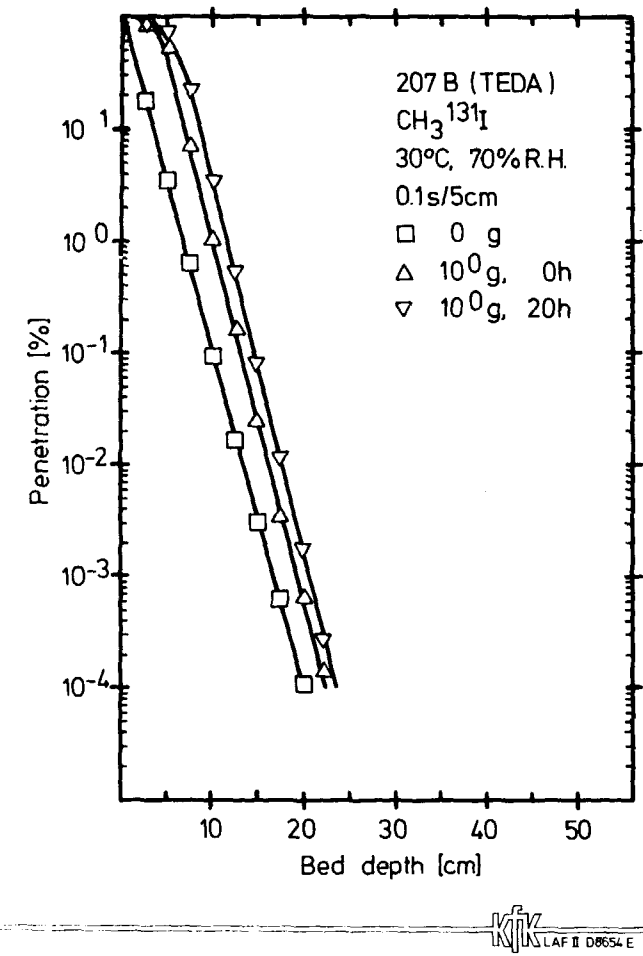
Fig. 12 [a]

[a] Purging, if any, between injection of combustion products and injection of $CH_3{}^{131}I$



Penetration as a function of bed depth
at different amounts of HCl and purging times

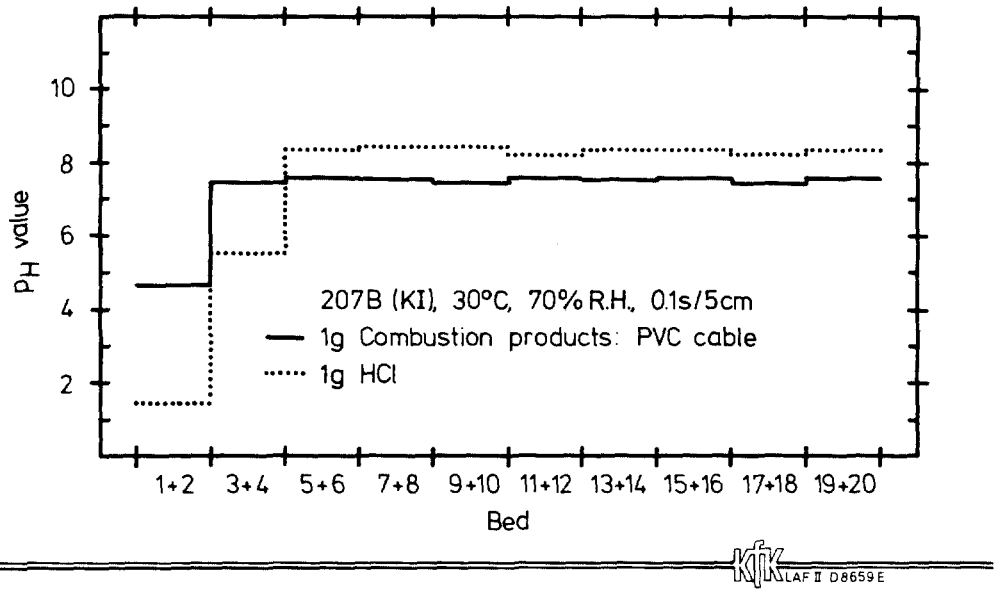
Fig. 13 [a]



Penetration as a function of bed depth
at different amounts of HCl and purging times

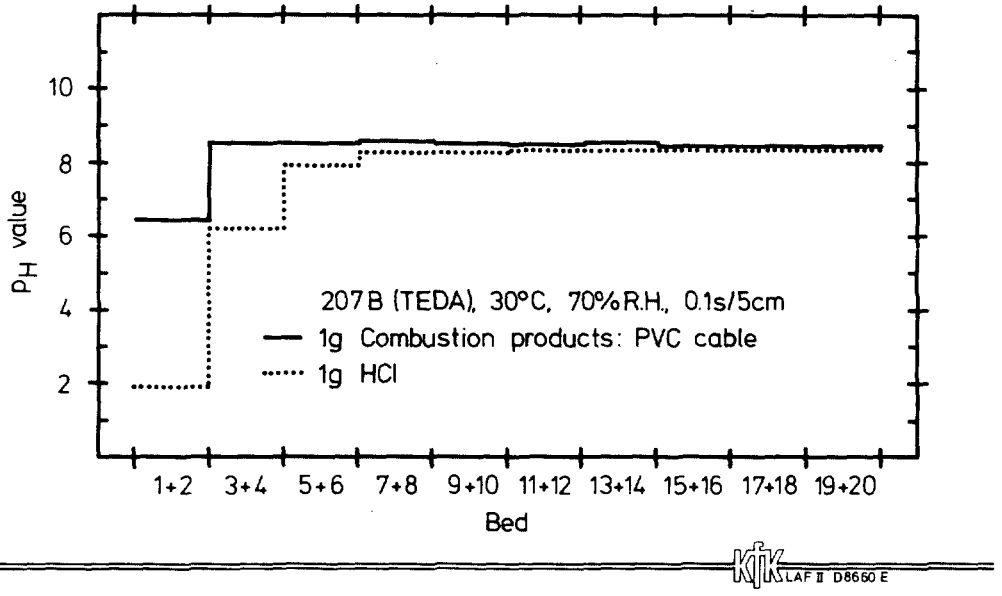
Fig. 14 [a]

[a] Purging, if any, between injection of HCl and injection of $CH_3{}^{131}I$



p_H value of the aqueous extracts of activated carbon beds after challenge with gaseous combustion products

Fig. 15



p_H value of the aqueous extracts of activated carbon beds after challenge with gaseous combustion products

Fig. 16

DISCUSSION

VIKIS: Were the combustion products distributed evenly over the charcoal?

DEUBER: No, the distribution was as it would be in the case of a fire: the loading decreased with increasing bed depth.

ALVARES: Why is there a difference in the behavior of TEDA and KI impregnated carbon?

DEUBER: It is generally found that the penetration of new TEDA carbon by methyl iodide is lower than that of new KI carbon. As for the increase in penetration due to the influence of combustion products, there was no decisive difference.

CONCLUSIONS FROM FIRE TESTS IN ACTIVATED CARBON FILLED ADSORBERS

W. Mathewes
Kraftwerk Union Aktiengesellschaft
Offenbach, W-Germany

Abstract

Activated carbons as used in gas-phase adsorption may be subjected to heating, either from heat applied externally to the carbon bed, or heat generated by radioactive contaminants, or by the adsorption process itself.

This report presents results of artificially ignited beds of activated carbon.

This report also considers results concerning the self-ignition of non-contaminated carbon and such of solvent-contaminated carbon subjected to external heating in beds with an air flow and in beds without an air flow.

An estimation is given for the heat generation caused by radioactive contaminants as well as by the adsorption process.

Studies of handling of endangered components and studies of alarm indicating systems give guidance for the contemporary lay-out and design.

Introduction

The nuclear plant ventilation and air exhaust systems, including the air cleaning systems are of some importance for the licensing authorities, the plant operating personnel and the public.

The protection of the environment of controlled areas as well as the releases to the environs have to be kept sufficiently low to assure compliance with relevant guidelines.

Therefore exhaust air systems must be designed, tested and maintained so that they will perform effectively and reliably under normal or emergency conditions to which they might be subjected.

In order to comply with requirements regarding fire hazards, activated carbon and carbon filters were tested under anticipated modes of operation most closely related to actual service conditions.

General considerations

Activated carbon filter systems should be installed in areas isolated by fire-proof walls, doors and dampers, which divide the building into its chief parts. These fire areas serve to maintain an effective barrier for heat and smoke. Contaminants as combustion products should be exhausted by cleanup systems. Smoke detectors in these areas and in the connecting duct work initiate the isolating function of dampers and preclude entrance of combustion products into other areas, or following filter installations.
Easy access for fire guards must be cared for.

Results of Calculations

The calculation of the effect of ignition on activated carbon through heat generation by radioactive contaminants in a normal operation mode operated stand-by unit shows only a negligible temperature rise.
The temperature rise originating from the adsorption process itself is less than 1 °C.

Test Facility

For the investigation of fire hazards in beds of activated carbon a test facility was to be designed and built to supply experimental data.

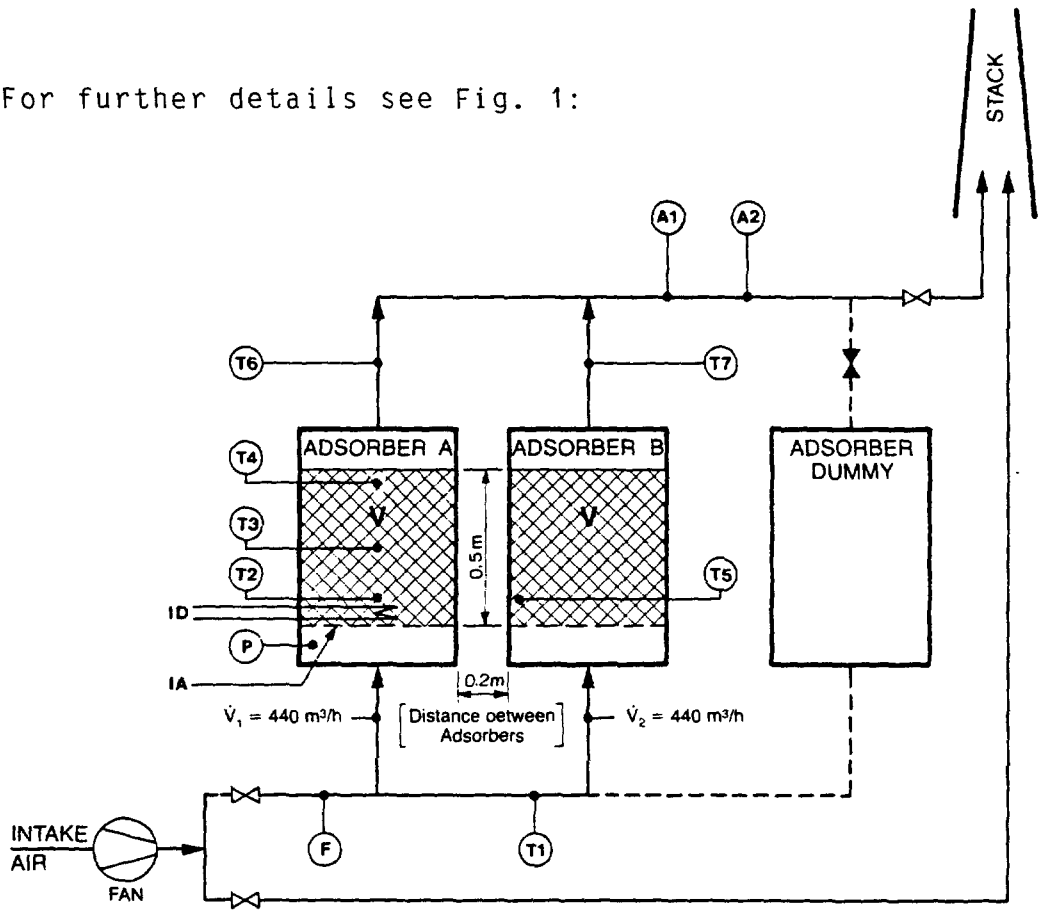
The most essential parts of the equipment were the adsorbers. The inflow surface area (IA = o,35 m^2) corresponded to a quarter of the original adsorber as in the NPP Philippsburg 2. The volumetric air flow rate was calculated to be $\dot{V}$ = 44o m^3/h per test adsorber, the inflow velocity was equal to o.35 m/s based on the inflow area of the adsorber.

The bed depth selected was 5oo mm as in the original adsorber in Philippsburg.

The volume of activated carbon amounted to o.175 m^3 per adsorber.

The carbon was supported by a grate, the air flow was directed from the bottom to the top of the carbon bed. The activated carbon (8-12 mesh) satisfied ANSI/ASME N 5o9.

For further details see Fig. 1:



LEGEND:

A1 = Analysis of Combustion Gas (see Table 3) (intermittent sampling)
A2 = CO-Monitor (0–250 ppm.) – (see Figure 13) (continuous sampling)
F = Flow Meter (m/s)
P = Pressure Drop (mm WG)
T = Temperature Measurements (°C) – (see Figure 5 through 11)
ID = Ignition Device (W)
IA = Inflow Area = 0.35 m²
$\dot{V}$ = Volumetric Air Flow/Adsorber Hour = 440 m³/h
V = Activated Carbon Volume/Adsorber = 0,175 m³
⋈ = Damper open
⋈ = Damper closed

Figure 1 Flow Diagram of Test Facility

Instrumentation

Appropriate instrumentation (fig. 1) was set up to obtain measurements of the following.

1. Ambient pressure and temperature
2. Air temperature evaluated for this report at 7 locations; 27 measuring points at the actual trial installation
3. Average volumetric air flow rate in the duct
4. Filter pressure drop
5. Sampler for intermittent analysis of combustion gas
6. CO-Monitor for continuous sampling
7. Ionization measuring instrument for continuous sampling

Experimental Results

It was necessary to ignite the activated carbon artificially by electrical resistance heating. In general we had a pinpoint resistance ignition device (ID) to generate the electrical heat output.
At an input of 6o W no ignition occurred even when the heating time was extended to more than 24o s. For ignition of activated carbon we had to apply 8o W capacity input for 18o s.

We found the lowest ignition temperature of activated carbon impregnated with calium iodide in a bed with an air flow and with a volume of o.17 m^3 to be at 3oo °C.

The lowest ignition temperature of carbon contaminated with solvent (12 weight % of toluene), ranged up to 25o °C.

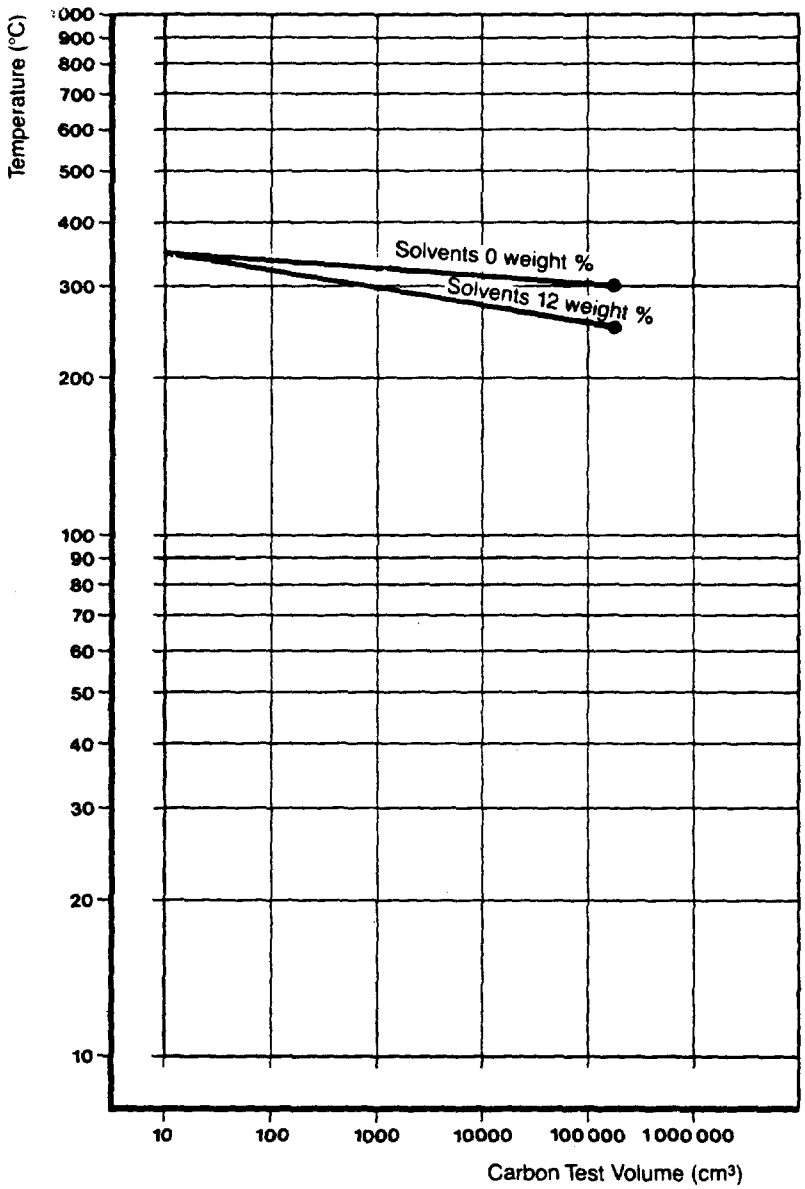


Figure 2 Ignition Temperature of Activated Carbon as a Function of Test Volume of Carbon

Figure 2 shows the relation between ignition temperature and contamination of solvents, and the volume of carbon in beds with an air flow.

The reference ignition temperature of activated carbon in flowing air based on a volume of 1o cm³ was determined by the Standard Test Method ANSI/ASTM D 3466-76. The report shows, that ignition occurred at 35o °C. No real difference in ignition temperature was found between the unused carbon and the carbon contaminated with solvent (12 weight %), (figures 3 and 4).

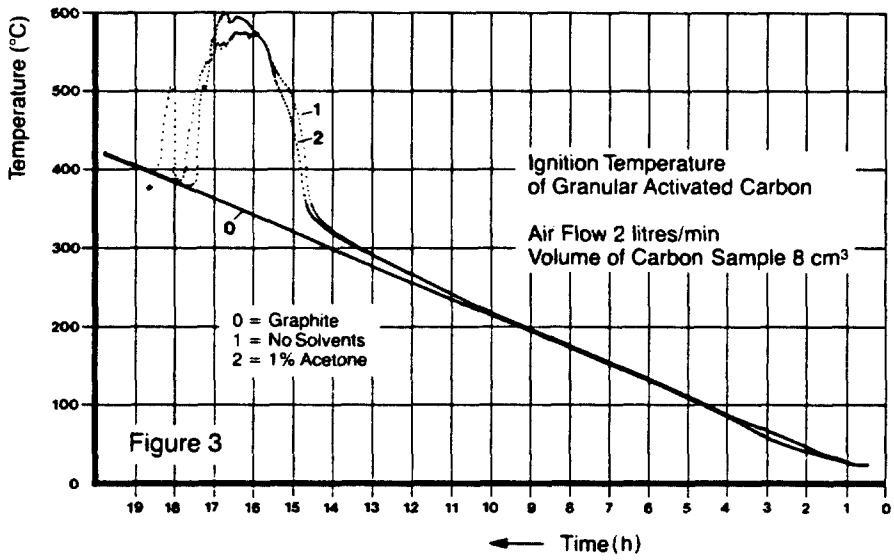


Figure 3

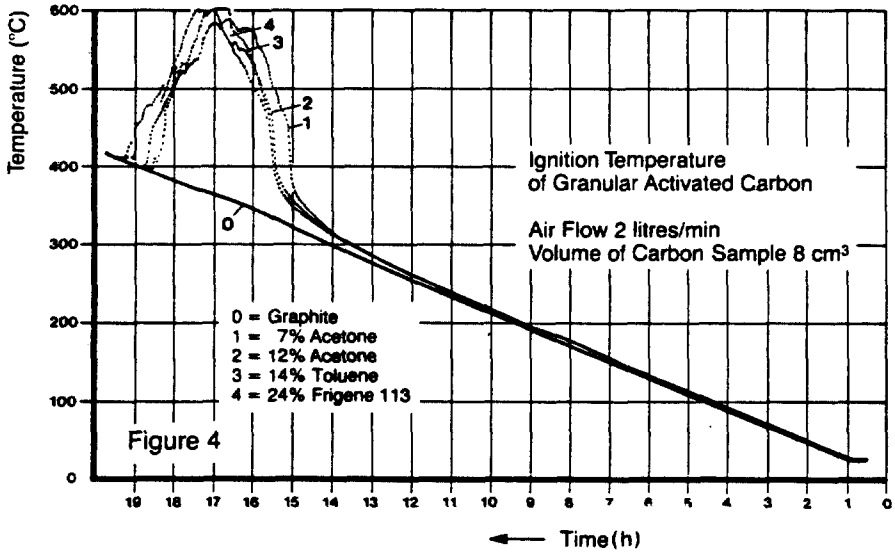


Figure 4

We also considered the possibility of self-heating through the reaction of solvents in beds of activated carbon without air flow subjected to external heating, rendered in Table 1.

We wanted to obtain conservative test results. In this case we decided on acetone instead of other solvents, we also chose 12 weight % as a maximum figure although we knew from experience that the contamination of activated carbon in operational processes does not exceed 8 weight % in general and for acetone in particular does not exceed 2 weight %.

We realised that the test contained two steps as regards the self heating reaction, i. e.:

First step: thermal reaction of solvent through temperature rise to such an extent as to ignite the carbon

Second step: thermal reaction of carbon

TEST	CARBON + ACETON	TEMP. OF BED	SELF-HEATING REACTION	CARBON TEST START	WEIGHT TEST STOP	COMMENTS
No	WEIGHT %	°C		g	g	
1	12	45	t_1 = 4,5 ΔT = 2,9 t_2 = 48,8	323	288	No visible change in material
2	12	70	t_1 = 5,8 ΔT = 0,9 t_2 = 107	322	290	No visible change in material
3	12	90	t_1 = 4,5 ΔT = 1,3 t_2 = 108	324	289	No visible change in material
4	12	140	t_1 = 2,0 T = 348 t_2 = 2,1	323	282	No visible change in material
5	1	140	t_1 = 4,8 ΔT = 10 t_2 = 0,8	370	296	No visible change in material

LEGEND:

t_1 = Heating Time up to ambient Temperature = Temp. of Bed (h)
t_2 = Time up to Maximum Temperature Rise (h)
ΔT = Temperature Rise above Temperature of Bed (°K)
T = Temperature of Sample (°C)

Table 1 Self Heating Reaction of Carbon in Beds with no Air Flow

In test No. 1, 2, 3, 5 there were no indications of any exothermic reaction of aceton or of carbon.

Only test No. 4 showed a rise in temperature responsible for the self heating reaction of solvents (step 1).

In tests Nos. 1-5 we noticed no real loss of carbon weight, so we concluded that no exothermic reaction of the carbon took place (step 2).

After studying the different possibilities of self-ignition of activated carbon, we had to learn to handle this hazard for carbon filter systems.

To ensure that the test procedures simulated as closely as possible our installation conditions, we had to provide an additional volume of air contained in a stand-by vessel in order to account for parallel adsorbers including their connecting duct work (see fig. 1).

To study radiation heating, we installed the parallel adsorbers at a distance of 2oo mm to the test adsorber (fig. 1).

So prepared, we ran 12 tests. For this report the most interesting one for handling the components at risk and for restoring safe conditions, involved the interruption of airflow by shutting the upstream damper.

After ignition as described before and before shutting the damper we reached a top temperature of 14oo °C (fig. 6). At this, a maximum temperature of 42 °C was induced by radiation in the parallel adsorber (fig. 7).

The figures 5 through 11 show the distribution of temperatures we found.

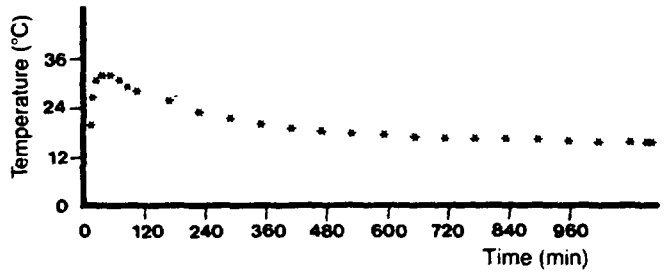


Figure 5 Temperature of Inflow Air T1

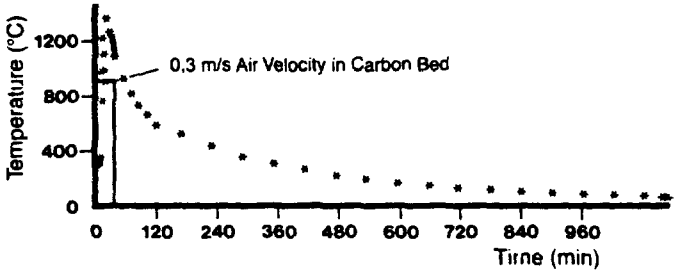


Figure 6 Temperature of Lowest Bed T2

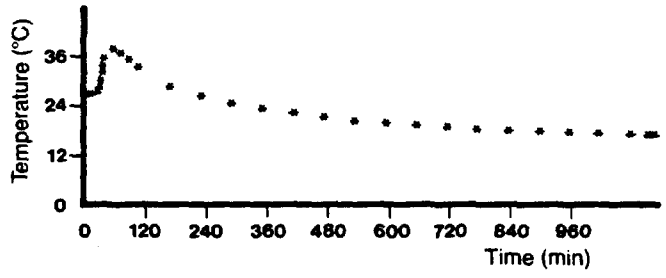


Figure 7 Temperature Near Wall
of Parallel Adsorber T5

All figures show temperature peaks 3o mins after kindling the carbon.

Due to convection the temperature rise above the fire core moved towards the next layer and amounted here to a maximum of about 1000 °C (fig. 8).

At the same time the upper bed layer registered a peak of about 90 °C (fig. 9), and the adsorber outlet temperature reached 44 °C (fig. 1o).

A tendency towards temperature rise can also be noted in the neighbouring adsorber B (fig. 11).

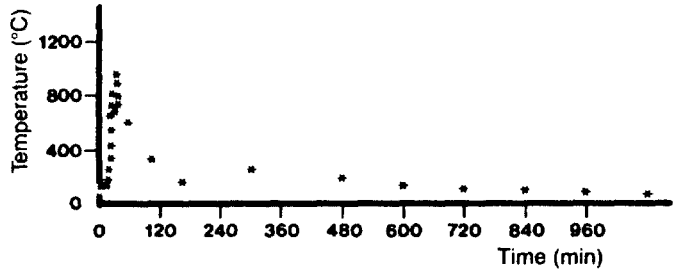


Figure 8 Temperature of Midbed T3

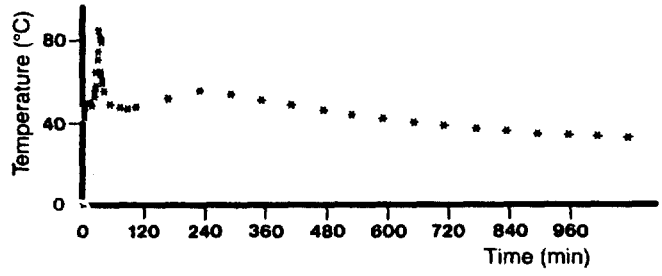


Figure 9 Temperature of Upper Bed T4

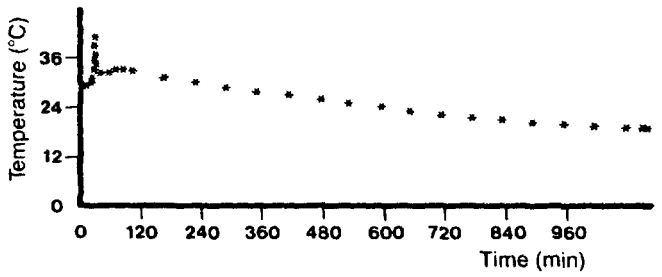


Figure 10 Temperature of Outlet Air
Adsorber A T6

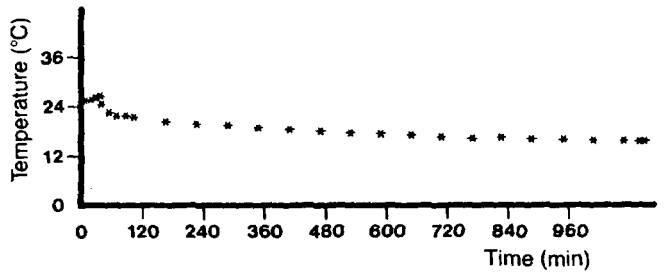


Figure 11 Temperature of Outlet Air
Adsorber B T7

After the shut-down of the upstream damper the measurements listed in Table 2 point to a general decrease in temperatures and to a circulation of air passing the trial installation (fig. 12).

TEST STEP	TEST TIME	TIME BETWEEN STEPS	ENTRY TEMP SYSTEM T1	MAX. TEMP. INVOLVED ADS. "A" T2	OUTL.TEMP. INVOLVED ADS. "A" T6	MAX. TEMP. PARALLEL ADS. "B" T5	EXIT TEMP. PARALLEL ADS. "B" T7	EVENT
No	(h)	(h)	(°C)	(°C)	(°C)	(°C)	(°C)	
1	2pm		18	20	20	20	20	TEST START
		0.5						
2	230pm		32	>1400	44	40	26	CLOSING UPSTREAM DAMPER
		1.5						
3	4pm		30	550	34	28	22	
		1						
4	5pm		26	500	30	26	28	
		4						
5	9pm		18	200	24	20	18	
		11						
6	8am		18	>100	20	20	18	
		3						
7	11am		18	<90	20	20	18	
		3						
8	2pm		18	<80	18	18	18	TERMINATION OF TEST

Table 2 Thermal effects of circulated air passing the adsorbers A and B and returning via dummy-adsorbers

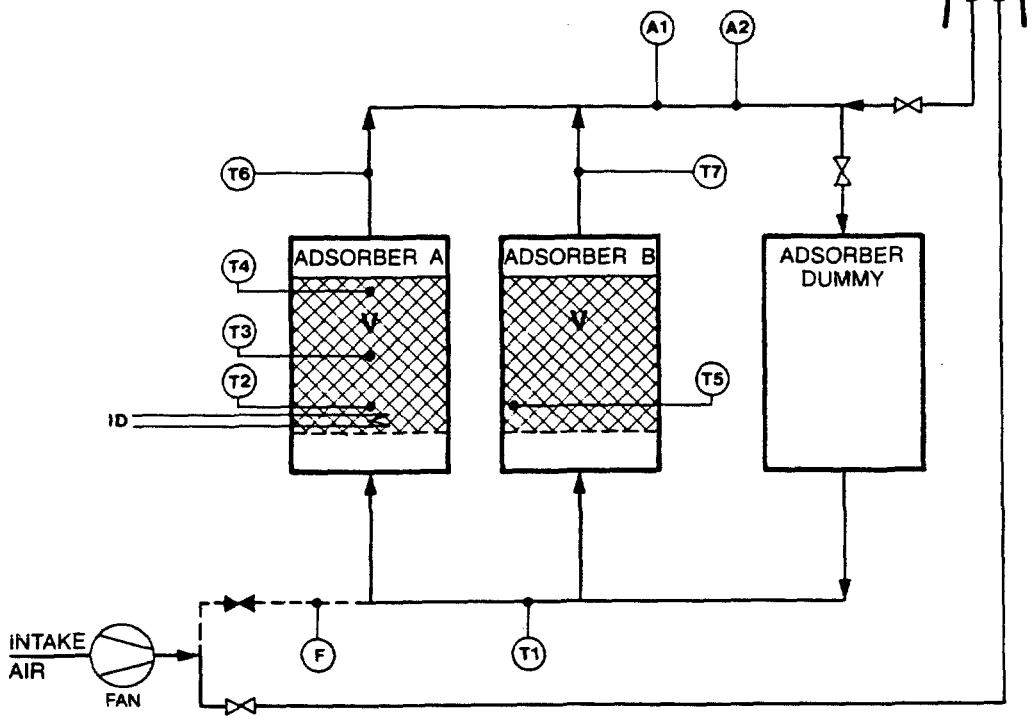


Figure 12 Air passing the pair of Adsorbers and heading back via the Dummy-Adsorber

Table 3 presents the results for the composition of gases found by intermittent sampling in A1.

Wherein test-step 3 shows a fairly good combustion and a near to 2 Vol. % consumption in oxygen. From test-step 4 onwards there is a gradual increase in carbondioxyde and likewise a decrease in oxygen, pointing to an internal current of gas being set at motion by thermal forces, thus conveying additional oxygen originating from the adjacent volumina contained in the second adsorber, the dummy adsorber and the connecting ductwork as well as the oxygen being desorbed by heat.
These sources delivered oxygen for the thermal reaction of the carbon (test steps 4, 6, 7).

It can also be deduced, that the atmosphere of the inflicted adsorber was inertised after closing the upstream damper, in the course of about 2o hours.

TEST STEP	TEST TIME	TIME BETWEEN STEPS	MAX. TEMP. INVOLVED ADSORBER T2	GASEOUS COMBUSTION PRODUCTS A1 CO_2	GASEOUS COMBUSTION PRODUCTS A1 CO	N_2	O_2 A1	EVENT
No	(h)	(h)	(°C)	Vol. %	Vol. %	Vol. %	Vol. %	
1	2pm		20					TEST START
		0,5						
2	230pm		>1400					CLOSING UPSTREAM DAMPER
		1,5						
3	4pm		550	14	5	79	2	1. GAS ANALYSIS
		1						
4	5pm		500	6,6	9,9	79	4,5	2. GAS ANALYSIS
		4						
5	9pm		200					
		11						
6	8am		>100	8	8,8	79	4,2	3. GAS ANALYSIS
		3						
7	11am		<90	10	7,2	79	3,8	4. GAS ANALYSIS
		3						
8	2pm		<80					TERMINATION OF TEST

Table 3 Gaseous Combustion products after Shut down

Temperatures dropped to less than 8o °C after a spell of 23.5 test hours (compare relevant figures and tables), in general the graphs point to a temperature loss in the heated carbon. In all tests, no damage was caused to the structures of the inflicted adsorber or to the other components except in some cases to the thermocouples near the fire core and the grate.

To keep fire accidents under control a quickly acting alarm annunciating system was needed to protect the facilities on the whole. Therefore the time lapse between the start of the fire-induced accident and the actuation of protection equipment resulting from measurements should be as short as possible.

To find out the time within which a distinct rise in temperature occurred, the temperature curve was compared with the CO-curve (fig. 13).

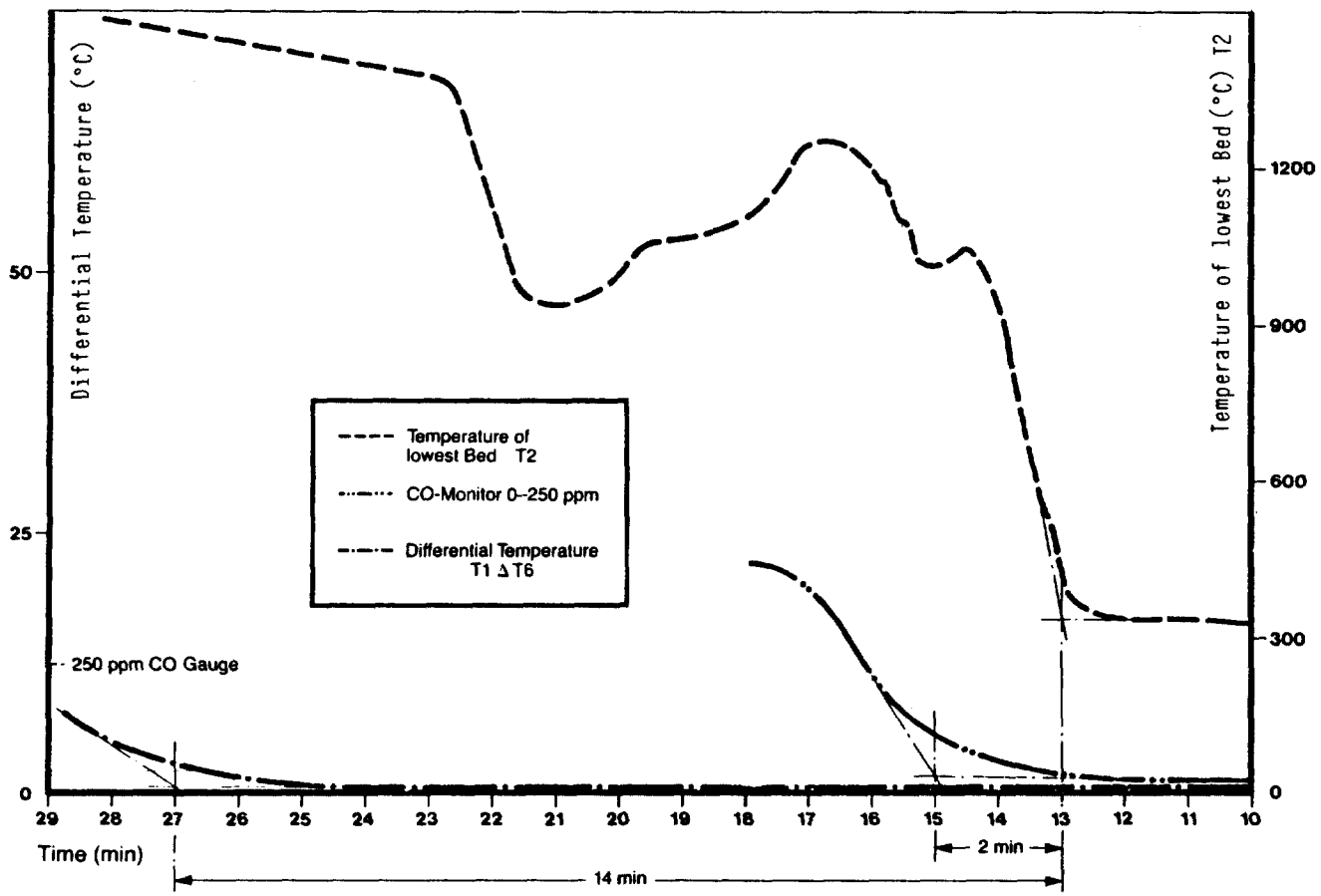


Figure 13 Time Difference between Temperature Rise and CO-Monitoring

We found the time required for a distinct temperature rise in the exhaust duct work resulted in a slow signal. On the base of CO-monitoring in the exhaust duct work (same position as the measuring point for temperature) actuation was obtained after a spell of 2 minutes.

An ionisation control device was tested as well. Although a quick signal was derived from the exhaust, no statement can be given regarding the possibility of dust-pollution of the sensor for its service life, since fine particles of carbon are expected downstream of the filters.

Concluding remarks

Our conclusions regarding these experiments are as follows:

1. A quick-acting and reliable fire detection annunciator must be provided for monitoring the exhaust ductwork, preferably a CO monitoring device.

2. Sufficient protection of carbon filters at risk can be accomplished by closing only one damper of a system thus preventing a pressure rise in the filter and thus reducing further thermal reaction by accumulating the content of gaseous carbon dioxide, therefore effectively combating the fire.

3. Self-ignition temperatures of activated carbon depend on its bulk volume and the content of solvents being adsorbed. In general greater volumes of carbon and a higher solvent content decrease the self-ignition-temperature.

4. No risk of self-ignition was noted for adsorber-filters in the stand-by mode for ambient temperatures up to 9o °C and 12 weight-% of solvents in the carbon.

5. With the presented results of our investigations on the subject of artificially ignited filter beds of activated carbon and the study of different alarm indicating systems, the carbon filter systems will be no risk to the environment or the building structures.

DISCUSSION

VOGAN: Has there been any air cleaning system fire anywhere in Europe that you have been aware of that generated the type of testing that you have undertaken.

MATHEWES: No.

VOGAN: We are looking at the need for fire protection systems for our standby air treatment systems, and we are looking for evidence of self-sustaining fires in air treatment systems. My second question stems from the first, would your testing show that there would be any continuing ignition of a carbon bed type of air treatment system?

MATHEWES: I have presented to you what we tested. It was a deep-bed filter. This type of filter system has been realized in Philipsbourg, but I am happy to say, we haven't had any chance to test its performance in real life.

A CURRENT EVALUATION OF FIRE LOSS CONTROL SYSTEMS FOR CHARCOAL MEDIA

Wayne D. Holmes
American Nuclear Insurers
Farmington, Connecticut

Abstract

Activated charcoal in use in nuclear facilities presents a significant loading of combustible material. There exists within nuclear facilities, numerous sources of ignition of combustible materials. If a fire may occur, it is important to detect the fire and suppress it, thus limiting the consequences of fire.

The arrangement of adsorber units and the mode of combustion of the charcoal media make the extinguishment of charcoal fires quite difficult. Automatic water spray systems have been proven to be an effective, reliable, and inexpensive means of extinguishing charcoal fires. Properly designed, installed, and maintained automatic water spray systems do not fall on a frequent basis and the effects of such failures have been overstated.

I. The Fire Problem Presented by Charcoal Adsorbers

The charcoal media in gas treatment systems in nuclear power plants presents a significant loading of a material which is nearly totally combustible and which has been reduced to a readily burned form. In some areas, many tons of charcoal may be present, representing a fire loading approaching 250 MBTU of potential heat release under fire conditions. Because of the mode by which combustion occurs within charcoal arrays and the means of enclosure of the adsorber systems, charcoal fires in such systems may be extremely difficult to extinguish. In tests performed by the Factory Mutual Research Corporation for the U.S. Navy on the combustibility of charcoal filter units it was noted that the charcoal media burned vigorously and once ignited, will burn to completion (1). Smoke obscuration was moderate to dense during the fire test.

The "Defense-in-Depth" approach to firesafety subscribed by the nuclear power industry is a multi-level approach. The first step in this approach is to prevent fires from occurring. The second step involves detecting fires quickly, suppressing those fires which do occur, and limiting fire damage. These principles apply to charcoal adsorbers as well as to any other plant systems that may contain combustible materials.

II. PREVENTION OF IGNITION

How or when charcoal may be ignited in nuclear plant systems is a subject which has been vigorously debated for many years and which is likely to continue to be debated for many years to come. What is clear is that the charcoal media is a combustible material which may be subject to ignition from numerous sources.

The actual ignition temperature is a function of a number of variables. Among those factors which may have an effect on the ignition temperature are: the ash content of the charcoal, any impurities within the media, the internal surface area of the charcoal, the specific characteristics of the impregnating material, the depth of the charcoal bed, and the air flow rate (2). Moderate heating of bulk activated charcoal may result in a spontaneous exothermic reaction resulting in ignition. Depending upon the depth of the charcoal bed, critical temperatures leading to spontaneous ignitions of activated charcoal have been reported from as low as 60°C. to 125°C. with times to ignition from 1.3 hours to several days (3).

Perhaps too much emphasis has been placed upon the probability of the decay heat of radioiodine as resulting in a cause of ignition of charcoal. It is reasonably clear that desorption of radioiodine is initiated at temperatures below the published standard ignition temperatures for charcoal. The adsorption systems are designed such that the decay heat generated by collected fission products cannot cause ignition of the charcoal nor significant desorption of the collected fission products under normal air flow. However, forced air circulation may provide the only significant cooling method and calculations and laboratory tests have shown that ignition temperatures may be reached under post-accident conditions if the airflow is reduced below 5 FPM (2). Even if decay heat does not, in itself, produce ignition temperatures within the charcoal, the effect of the elevated temperature produced by the decay heat will reduce the amount of additional energy which must be applied to initiate ignition and may also produce temperatures which will initiate self-sustained, spontaneous heating as mentioned previously.

There exists sufficient other possible sources of ignition of charcoal for there to be a concern for protection against fire. External fires may present an exposure to filter units either through direct contact or indirectly through duct systems. Welding and burning operations present another possible source for ignition. Electric heaters, or failures of other electrical systems might serve as a source of ignition. Flammable gases, as might be generated under post-accident conditions, introduces another possible source of ignition.

While the safety concerns associated with charcoal fires are greatest during plant operation, or more specifically during post-accident operations, the highest potential for ignition and resultant direct fire damage occurs during maintenance operations. During maintenance, one might anticipate cutting and welding being performed, solvents being used, portable heaters being utilized, unapproved temporary electrical systems being introduced, or other potentially hazardous operations being performed; all of which increases the potential for ignition of charcoal.

Preventing potential ignition sources is important in overall fire protection programs. The reasonably conservative approach, which is consistent with the fire protection defense-in-depth approach, is to assume that where concentrations of combustible materials are located, fires may occur. It then becomes prudent to design to detect and

ultimately suppress those fires which may occur.

III. SUPPRESSION OF CHARCOAL FIRES

The mode of combustion of charcoal is quite different than that of most ordinary combustible materials typically present in nuclear facilities. In the form in which it is used, the charcoal will undergo a glowing combustion rather than a fire burning process. There is a very important and distinct difference between these two processes. Charcoal undergoes a different form of combustion by combining directly with oxygen, as evidenced by glowing. This is an important distinction, since many chemicals which are effective flame inhibitors have little or no effect in retarding flameless combustion (4). Therefore, by the basic mode of combustion of charcoal, fires involving charcoal may be much more difficult to extinguish than free burning fires in ordinary combustible materials.

Aside from basic problems associated with the diffulty in suppressing the glowing combustion process, manual fire fighting, i.e. fire brigades with portable fire extinguishers, may be exceptionally difficult for systems utilizing charcoal. The charcoal is generally located in substantial housings which are not readily accessible, particularly under fire conditions. In addition to physical obstructions to fire fighting, there may be considerable smoke obscuration or radiological conditions which may limit access for manual fire fighting. The use of hoses external to the housing can only help to prevent further damage to the building or adjacent equipment. It cannot extinguish the internal fire nor prevent contamination. By the time ignition occurs, containment has been lost due to desorption.

By the deep-seated nature of charcoal fires, the only reasonable means for manual fire suppression may require dismantling the charcoal array in order to quench the fire at its source. This is likely to be accomplished only after considerable time delay and damage.

With the difficulties presented for manual fire suppression of charcoal fires, it is therefore wise to design charcoal units with fixed, fire extinguishing systems. One must, however, choose the fire suppression medium with care for an effective system.

Dry chemical fire suppression agents applied to the surface of charcoal will not be effective on fires which may be deep within the array. Such systems have not been proposed for protection of charcoal beds.

Gaseous fire suppression agents such as carbon dioxide and Halon 1301 are not considered to be adequate for extinguishing deep-seated fires such as in charcoal. Carbon dioxide would have to be provided in such high concentraions and for such long durations to be effective that it would not be practical and might pose serious life safety problems. (5) Attempts to use carbon dioxide to extinguish charcoal adsorber fires have been unsuccessful. (6) Deep-seated fires are, by definition, not extinguished by a normal, 5%, concentration of Halon 1301 within 20 minutes. (7) To extinguish fires in charcoal beds, an excessive quantity of Halon 1301 would be required.

Liquid nitrogen extinguishing systems have been proposed and their effectiveness has been demonstrated by test. (6) However, under the conditions of the test, a flow of seven liters per minute of liquid nitrogen was required to be maintained for extinguishment of a fire in a 24" X 24" X 12" cell. Such systems would require a constant inventory of a relatively large volume of liquid nitrogen for emergency use.

It may be of interest to note that in the same tests, carbon dioxide was unsuccessfully used to attempt to extinguish the charcoal fire. When the carbon dioxide failed, water was used for final extinguishment.

Water is an optimum fire suppression agent for charcoal fires. It is proven effective on deep seated fires, it is abundantly available, and it is inexpensive.

It has been claimed that water has never been demonstrated effective on charcoal adsorber fires nor have designs for water-based fire extinguishing systems for charcoal fires been proof-tested. These claims are not based upon fact.

An extensive experimental program was conducted to develop an effective water spray system for fire protection of activated carbon adsorber beds. (8) These tests established that the extinguishment by water sprays will vary as a function of the air flow rate, the water injection rate, the nozzle height, the bed thickness, and the preburn time.

The most important factor in extinguishment appears to be the air flow rate. While it is important to maintain airflow for cooling in the pre-burn state, it is equally important to interrupt the air flow once ignition has occurred. Previous attempts by other investigators to extinguish charcoal fires failed because air flow was continued. (6)

The tests established that the water flow rate must be optimized. Too low a water flow rate reduced the saturation time thus reducing the effectiveness of the water spray as a fire suppressant. Too high a water flow rate resulted in an excessive amount of water run-off which would require waste processing without increasing extinguishing efficiency. A water flow rate from nozzles of 3.5 GPM (3.2 gal./cu. ft.) soaked the entire charcoal bed within one minute. The charcoal fire was extinguished within three minutes despite an extended pre-burn period. Repetitive tests clearly demonstrated that water sprays can be used to extinguish charcoal fires rapidly and reliably when properly introduced into the burning medium.

IV. ACCIDENTAL WATER DISCHARGE

As reported by the Department of Energy, automatic, water-based fire suppression systems have an outstanding record of limiting fire damage with an equally outstanding record of a low rate of inadvertent actuations. (9) Fears that automatic systems are frequently subject to unwarranted actuation is unfounded. Nuclear industry data bases for fires and fire systems do not support the position that inadvertent

actuations occur frequently. (9) (10) (11)

Within the nuclear industry, INPO and NRC bulletins have perpetuated the perception that serious inadvertent actuations of fire protection systems may be a frequent occurrence. (12) (13) (14) Prompted by the NRC bulletin, a graduate student at the Worcester Polytechnic Institute Center for Firesafety Studies completed a comprehensive study of inadvertent operations of fire protection systems in the nuclear power industry. (15) The resultant thesis included a review of the frequency, causes, and effects of inadvertent actuations.

It was reported in that thesis that the total number of incidents of inadvertent actuations of fire protection systems affecting the safe operation of plants was small. Of those few inadvertent actuations which did occur, less than one-third affected a safety related component in some way. Only one had some potential for affecting more than one redundant, safety related system. Nearly half of the inadvertent actuations resulted from personnel error and, of those, a majority occurred during maintenance and testing.

The thesis cited the low cost of damage resulting from inadvertent actuations as well as the low frequency. EPRI has reported an annual probability of occurrence for the false opening of a deluge valve of 7.85×10^{-4}. (16) The thesis concluded that the low rate of inadvertent actuation could be further reduced by thorough design review of proposed fire protection systems, proper installation and test by qualified personnel, and periodic maintenance by trained technicians. It is further concluded that the problem associated with inadvertent actuations of fire protection systems is not a major one.

V. CONCLUSIONS

The use of activated charcoal in nuclear facilities presents a potential for deep-seated fires.

The defense-in-depth approach to nuclear fire safety requires that if an ignition should occur, fires must be detected quickly and subsequently suppressed.

Deep-seated fires in charcoal beds are difficult to extinguish. Manual fire fighting may be extremely difficult and most common fire suppression agents may be ineffective on these fires.

Automatic water sprays can be used to extinguish fires rapidly and reliably when properly introduced into the burning medium.

The problem associated with inadvertent actuations of fire protection systems is not a major one and it can be further reduced by proper design review, installation, testing, and maintenance. Eliminating automatic fire extinguishing systems for the protection of charcoal adsorbers is not justified.

Removal of automatic fire protection systems due to fear of inadvertent fire protection system operation is a case of treating the

effect rather than the cause. On the other hand, properly maintaining automatic fire protection systems will preserve the risk of fire loss at acceptable levels while at the same time reducing the risk of damage presented by inadvertent operation of fire protection systems.

References

(1) Newman, R.M., "Test of Fire Retardency of Charcoal-Filled Gas Filter for Fire Retardency", Laboratory Report Serial No. 16286, Factory Mutual Research Corporation, Norwood, MA, 1966

(2) Burchsted, C.A., Kahn, J.E., Fuller, A.B., Nuclear Air Cleaning Handbook, ERDA 76-21, Oak Ridge National Laboratory, Oak Ridge, TN, p. 57, 1976

(3) Drysdale, D.D., An Introduction to Fire Dynamics, John Wiley and Sons, New York, N.Y., p. 259, 1985

(4) Shaw, J. R., Ph.D., "Fire Retardant and Flame Resistant Treatments of Cellulosic Materials", NFPA Handbook, 15 ed., National Fire Protection Association, Quincy, MA, p. 12-35, 1986

(5) NFPA 12, Standard on Carbon Dioxide Extinguishing Systems, National Fire Protection Association, Quincy, MA

(6) Murrow, J.L., Carbon Adsorber Fire Extinguishment Tests, Lawrence Livermore Laboratory - University of California, Livermore, California

(7) NFPA 12A, Standard on Halogenated Fire Extinguishing Agent Systems-Halon 1301, National Fire Protection Association, Quincy, MA

(8) CVI Technical Note No. 32, A Report on the Extinguishment of Activated Carbon Fires in CVI HECA Adsorber Beds, CVI Corporation, Columbus, OH, 1975

(9) U.S. Department of Energy, Automatic Sprinkler System Performance and Reliability in United States Department of Energy Facilities, 1952-1980, DOE/EP-0052, 1982

(10) Dungan, K.W., Nuclear Power Plant Loss Data, EPRI NP-3179, Electric Power Research Institute, Palo Alto, CA, 1983

(11) ANI Property Loss Data System, American Nuclear Insurers, Farmington, CT

(12) Institute of Nuclear Power Operations, Inadvertent Actuations or Failures of Fire Protection Systems, Draft SOER, INPO, Atlanta, GA, 1983

(13) Institute of Nuclear Power Operations, Inadvertent Openings of Fire Protection Deluge Valves, SER 57-84, INPO, Atlanta, GA, 1984

(14) U.S. Nuclear Regulatory Commission, Actuation of Fire Suppression System Causing Inoperability of Safety-Related Equipment, IE Information Notice 83-41, USNRC, Washington, D.C., 1983

(15) Sawyer, E.A., Failure Analysis of Inadvertent Operations of Fire Protection Systems Including Design Recommendations, Master of Science Thesis, Worcester Polytechnic Institute, Worcester, MA, 1985

(16) Hall, D.T., and Clayton, T.C., Turbine Generator Fire Protection by Sprinkler System, EPRI NP-4144, Electric Power Research Institute, Palo Alto, CA, 1985

DISCUSSION

JACOX: I would like to dwell on two issues. One, you mentioned many times inadvertent actuation but you totally neglected leaks. I know from personal experience over the last twenty years, that leaks are an extreme problem. Admittedly, it does not always happen during operation, but when it does, it is very expensive, given the corrosion that results from the impregnant on the carbon. Therefore, I think any analysis must include leakage through the valves, not just accidental actuation. Second, you addressed in the early part of your paper the ability to halt the ignition source. I would like to differentiate between offgas and air treatment systems. We agree that when there is a failure of a recombiner containing a hydrogen-oxygen mixture, there is a credible ignition source. When we consider nuclear air treatment systems, which represent the vast majority of systems around the world in power plants, I know of no credible way that a fire can start. There is an excellent flame arrester in the perforated stainless steel, there are numerous components upstream that would stop sparks, wherever they may come from. When we consider maintenance caused by welding or flamework, standard OSHA requirements included a fire watch, various manual extinguishers, etc. I admit that there is a very low, but at least an arguable, probability of a fire during maintenance. But during operation, I simply have never seen a credible ignition source over twenty years experience in actual plant systems. Therefore, to me, it is not a realistic approach to require automatic deluge systems because of an infinitesimal threat from an undefined and incredible source of ignition.

HOLMES: I tend to take a more conservative approach by assuming that when you have combustible materials somebody may do something careless that is going to result in a fire. That is a very conservative approach, but I think that is the only way you can expect to have a fire under most reasonable conditions in an occupancy, whether it be a nuclear power plant or a home.

JACOX: I would agree in the abstract, and I certainly agree that it is exceedingly conservative, but I would think that, given the conservatism, one could logically make the same point by backing off from automatic systems and going to manual systems. I think here is where we could get into some statistical and probabilistic countdowns.

HOLMES: I think that statistical and probabilistic studies are worth pursuing further.

KOVACH: I am going to refrain from discussing my disagreements because there is a rather long list and we will try to clear them up during the panel session. But I feel that it is unfair in this context to consider automatic fire control systems throughout an entire nuclear power plant versus strictly looking at the question of air cleaning systems alone. I think that sort of dilutes the issue. If we are evaluating automatic fire control in air cleaning systems, let us look only at air cleaning systems. A number of them have been damaged in about every utility that has automatic water systems. Almost without exception, at least one of multiple units was, in fact, flooded. In some cases, with very serious consequences. I have not read your particular masters thesis, but just on the basis of your abstract I feel that it was an incomplete survey if it shows only a few such cases. The conclusion that somebody reading it draws is that there was little familiarity with what is actually happening in the power industry.

HOLMES: I don't think there is much room for discussion whether the fire suppression systems installed in charcoal should be different than other fire suppression systems. I think fire protection systems for charcoal should be designed just as well as the other fire protection systems in the rest of the plant and should be just as reliable.

GILBERT: Mr. Holmes, I am a bit puzzled by your statement that auto-ignition of a carbon bed from decay heat could occur under low air flow. This might become a matter of how low is "low", or when low becomes nonexistent. During the 1965 to 1970 period, Bob Adams at Oak Ridge National Laboratory, was unable to load sufficient fission products onto a charcoal bed to achieve auto-ignition. Do you know of any more recent results?

HOLMES: I don't think I have anything more recent then that which was quoted in my paper, as previously reported in the Nuclear Air Cleaning Handbook, which goes back to 1976, and includes data from previous Nuclear Air Cleaning Conferences. That is where the data come from. As to how low is "low", I say it is 5 fpm.

ORNBERG: I second Kovach's comments about air cleaning systems and offgas systems. Along that line of thought, do you have any statistics on how many fires or potential fires have taken place, or have been suppressed in air cleaning systems? You talked about the low probability of inadvertent actuation. I think there is a much higher chance of it happening than you do and I have proof that it has been happening and damaging tons and tons of carbon in air cleaning systems, whereas the fires do not take place. I would be interested in knowing what your statistics are.

HOLMES: I could ask the same question in reverse. I hear ghost stories of every utility having twenty or more inadvertent actuations. I hear various sources say there have been over two hundred such actuations, yet I don't see any data that indicate it is factual.

ORNBERG: I will give you one example, Clinton Power Station. Just last week, while getting ready to load the control room carbon for their filter test (right before fuel load) an inadvertent actuation doused all their control room filter carbon.

HOLMES: Perhaps it would be worthwhile, if the information is available, to examine it to see why these events are occurring. Is it because the detection systems are improperly designed? Is it because maintenance procedures are not being followed? Is it because technicians don't seem to know enough to tag out a system or shut a valve when they are going to work on it? I think those are the more important questions.

ORNBERG: Maybe all the complexities we are designing into these systems make them that much harder to operate correctly. If we can reduce the amount of complexities by not having to provide protection for an event that has very little possibility of happening, I think that would be the step we should be taking.

HOLMES: I think we do need to keep it simple, maybe some of these systems have become dinosaurs.

ORNBERG: Second question, on the Factory Mutual tests that you talked about, when were they run and were they on air cleaning systems? What sort of parameters were examined? Did they compare with those typically found in air cleaning systems?

HOLMES: I believe they were 24 x 24 x 12 in. single cells. As to date, I am going to say 1966. Air flow was maintained during the test.

ORNBERG: Other than what the gentleman from Germany discussed, there have been no tests, to your knowledge, on the effect of reducing air-flow on the temperature?

HOLMES: None, other than the water spray tests, which I mentioned, that CVI, Grinnell, and Factory Mutual conducted. They did vary airflow rate, as well as water ejection rate.

REVIEW OF FIRES AND FIRE CONTROL METHODS FOR NUCLEAR AIR CLEANING SYSTEMS

J. Louis Kovach
Nuclear Consulting Services, Inc.
Columbus, Ohio

I. Abstract

The nuclear power industry has experienced four carbon based adsorbent fires in its history, one was of the Monticello Standby Gas Treatment System and other three were in various off-gas delay beds. Although, some of the latter may not be classified as a full fledged fires. There were a number of experiments performed relating to igniting carbon beds and experiments relating to attempts at extinguishing set fires reported in the literature. Review of these experiments indicates that fire resulting from decay heat of adsorbed radioactive iodine is not justified even under the somewhat unrealistic source terms still in effect. At the same time the non-nuclear chemical industry application of carbon base adsorbents for solvent recovery has resulted in numerous fires and significant property losses.

Fire control systems installed in nuclear air cleaning systems in the US consists of water deluge. Accidental initiation of these systems has occurred in excess of one hundred times in US plants, causing safety problems and non-availability of critical engineered safeguards.

The current stance of the US NRC Regulatory Guide 1.52 is that water deluge is not a requirement for nuclear air cleaning units. Although simce the last NRC reorganization, there is confilict within the NRC divisions regarding water deluge for air cleaning systems. Water delute system installation and maintenance has been a requirement from the insurance companies, based mainly on experience in entirely different systems and not based on experience of fire losses in nuclear air cleaning units.

The events leading to the past nuclear air cleaning system fires and several chemical industry adsorption system fires are reviewed.

Experimental data supports that;

a) initiation of water spray in case of radioiodine loaded adsorber rather than cooling adsorber and retaining radioiodine will release already adsorbed radioiodine.

b) many of the current methods used to signal fire would not indicate fire detection early enough.

c) initiation of the water sprays will not necessarily extinguish the fire.

d) there is no justification for the installation of automatic water deluge units for safety class nuclear air cleaning systems.

e) alternate, safer and more reliable methods such as isolation, inerting, manual spray, etc., should be evaluated for the very remote possibility of fires.

f) the current practice of temperature tripped water deluge when evaluated in plant context can be, in fact, a safety hazard.

II. Review of the Nuclear Industry Adsorbent Fires.

Fire 1) Monticello (BWR) air cleaning unit fire (1)

Standard tray type adsorbers were equipped with heating elements to prevent condensation in the carbon (which event would lower methyl iodide removal efficiency). The electric heaters directly attached to the trays heated the carbon above its ignition point. The air flow was stopped and the trays removed from the housing. The fire was extinguished externally using water.

Fire 2) Browns Ferry Off-Gas System Fire (17 July 1977) (2)

From the initial startup in September 1976, until June 1977, the unit 3 off-gas system appeared to operate properly. On June 17, 1977, the unit was shut down for a forced outage. From the time the unit was returned to service on June 20, 1977, until July 8, 1977, off-gas system performance appeared to be slightly abnormal. On July 8, 1977, the unit tripped due to high temperature in the main steam vault and remained shutdown until July 15, 1977, due to high river water temperature, technical specification limits, and cooling tower problems.

The restart of unit 3 on July 15, 1977, was the beginning of a series of events that resulting in the carbon bed temperature excursion. From the time the plant started up on July 15, at 2100 hours until 1200 hours on July 17, the off-gas recombiner was not working properly. The off-gas system received excessive moisture and a combustible mixture of hydrogen and oxygen. At 1200 hours on July 17, with unit 3 operating as 560 MWs, a transfer from the A steam jet air ejector (SJAE) to the B SJAE was executed. At approximately the same time, off-gas flow to the holdup line pegged offscale at greater than 300 scfm (10 times the design value), off-gas reheater inlet temperature spiked from 47 degrees F (normal value) to 81 degrees F, off-gas reheater outlet dewpoint pegged offscale at greater than 100 degrees F (approximately 50 degrees F above normal), and all of the off-gas carbon adsorber bed temperatures spiked in the range of from 4 degrees F to 25 degrees F above the normal bed temperature of 68 degrees F.

From 1202 hours until 1230 hours on July 17, the B SJAE was in service with the off-gas system receiving (1) excessive dilution steam flow due to the malfunctioning third stage SJAE pressure regulator and (2) a combustible mixture of hydrogen and oxygen due to lack of recombination. At approximately 1230 hours a transfer from the B to A SJAE was executed and various system parameters showed spikes or were pegged offscale.

From 1232 hours until 1400 hours on July 17, the A SJAE remained in service, the recombiner continued to operate with low bed temperatures, and the off-gas system continued to receive excessive moisture and a combustible mixture of hydrogen and oxygen. At approximately 1400 hours the drain line on the A recombiner was opened, and by 1420 hours the recombiner bed temperature had

increased from 220 degrees F to 430 degrees F indicating that the recombination process had begun again. At approximately this same time (1420 hours) various system parameters spiked and pegged offscale.

System parameters remained essentially constant from 1430 hours on July 17 until 1630 hours. At this time the "B" carbon bed temperature pegged offscale at greater than 150 degrees F. Temporary instrumentation (i.e., potentiometer) installed shortly thereafter indicated the "B" carbon bed temperature was 500 degrees F and increasing steadily. At approximately 1900 hours on July 17, this temperature was still increasing, and steps were initiated to isolate the carbon beds and to continue unit 3 operation with the off-gas passed directly up the stack after holdup. The stack emission rate was still very low, approximately 5 percent of the technical specification limits for all three units. Unit 3 remained in operation at approximately 560 MWs throughout the event.

The "B" carbon bed temperature continued to rise, so at approximately 0430 on July 18 a decision was made to begin a nitrogen (N_2) purge on the carbon beds. At approximately 0520 the site initiated an N_2 purge through the "B" and "C" beds using onsite N_2 bottles connected to the carbon bed drain piping located outside the adsorber vault. The purge was begun at a 5 cfm rate and increased to 10 cfm and subsequently to 20 cfm. By 1300 on July 18 the N_2 purge had reversed the temperature excursion by reducing the "B" bed temperature from 1060 degrees F to 1000 degrees F. At this time, preparations were begun to enter the adsorber vault room. The vault would normally be considered unaccessable due to high radiation levels. However, since the unit had little operating time the fuel was relatively "clean" and fission product, activation and radiolytic gas generation were minimal. Therefore, the radiation levels within the adsorber vault were also minimal. Subsequent entry and inspection revealed the following:

1. The middle 1/3 of the "B" vessel had discolored paint. Few, if any, paint blisters were visible. The "B" vessel in this area was warm to the touch. Contact pyrometer readings indicated the skin temperature was 125 degrees F.

2. The "D" vessel surprisingly had a discolored area around the very bottom of the vessel. The paint in this area was visibly oxidized and charred in the shape of a concentric ring around the bottom of the tank. This area was hot to the touch. Contact pyrometer readings indicated that the temperature was approximately 140 degrees F. None of the other ("A", "C", "E", and "F") beds were warm to the touch. Upon recognizing the condition of the "D" bed, the N_2 purge alignment was shifted to include the "D", "E", and "F" beds. Also, at this time the N_2 supply was shifted from onsite bottles to tube trailers which had been summoned from offsite.

The N_2 purge continued in this alignment and at 20 cfm flow rate until 0900 on July 27. During the period from 1515 on July 19 until 0715 on July 20, temperature readings taken once an hour at various locations on each vessel indicated that a temperature wave was moving through the beds in series due to the 20 cfm purge flow rate. The N_2 purge was terminated July 27 after all internal and external temperatures had stabilized at near normal values.

After termination of the N_2 purge, the charcoal beds were opened and inspected for carbon damage. None was found. Samples were sent to Nuclear

Consulting Services, Incorporated, for analyses. The NUCON analyses received August 8, 1977 showed that carbon samples were within specification on particle size, percent moisture, percent ash, flashpoint, and ignition temperature. Metallurgical inspection of the carbon vessels revealed that the maximum vessel skin temperature attained during the event was approximately 500 degrees F and that no structural damage had been incurred.

Physical damage was observed on a prefilter element and an after filter element.

Fire 3) KKP (Philippsburg) Off Gas System Fire (14 Sept 1984) (3)

On September 14, 1983, the following incident occurred in the Nuclear Plant at Philippsburg 1.

The train A steam jet air ejectors (SJAE), preheater and recombiner were switched on in parallel with the already operating drain B of the off gas system to detect air in-leakage in the condenser. Eight minutes later, the H-concentration set-point (3 v%) was reached as indicated at an alarm in the control room. Subsequently train A was taken out of service. Train A operated less than 20 minutes.

Four hours later, the temperatures in the first charcoal adsorber beds reached the alarm point of 50°C. An inspection of the charcoal vessels was ordered.

After another four hours, bubbles were noticed in the paint on the vessel wall. Plant shut down was initiated. At the beginning of shut down the temperature detector for the first vessel indicated 130°C. During shut down a maximum surface temperature of 480°C was measured for the vessel.

First the vessel was cooled by blowing air on the surface. After plant shut down, SJAEs were shut off, the charcoal beds were isolated and nitrogen was fed into the beds to extinguish the slow burning fire. When this method was not successful, carbon dioxide was fed into the beds to fight the fire and cool the beds. Because of the low thermal conductivity of the charcoal and the low heat-capacity of the carbon dioxide, the temperature in the middle of the vessel decreased very slowly. Therefore, the first vessel was bypassed and its inlet and outlet were sealed.

The malfunction of the off-gas system was caused by a defective condenser drain at the preheater of recombiner A. The condensate in the preheater could not drain and prevented proper heating of the preheater by auxiliary steam.

The mixture of steam, air in-leakage, and radiolytic gases (H_2, O_2) coming from the steam jets was not preheated, so that the recombiner did not ignite because of low temperature and high moisture. As a result the radiolytic gases were not recombined to water.

The SJAEs also provide sufficient steam to dilute the hydrogen to a concentration less than the 4% flammability limit. Since the steam was condensed in the condenser and the undercooler, and the non-condensible gases H and O_2 had not been combined, the ignitable mixture was fed into the off-gas system charcoal beds.

Several possibilities for root cause of the ignition appear possible:

- Ignition of the charcoal because of recombination of the oxygen and hydrogen on the carbon surface. This cause appears most likely. Although the charcoal ignition temperature in air is about 200°C, the charcoal of the first vessel was assumed to have a lower ignition temperature because of impurities accumulated from years of operation. Recombination of hydrogen and oxygen has lead to local overheating and then to a slow burning fire.

- Ignition of the charcoal by detonation or explosion of the ignitable H_2/O_2 mixture in the off-gas system. Evaluation of the trend records and the plant computer output indicated that such an explosion might have happened. The recombiner or the H detector may have provided the ignition source. For this possibility, the flame front from the detonation must penetrate the sand-prefilter to ignite the charcoal.

Fire 4) The Perry NPP Off Gas System Fire (19 June 1986 and 6 July 1986) (4)

The Perry NPP Off-Gas System is a 0°F vault temperature delay bed. The vault refrigeration system acceptance test was completed in May 1985. The test showed that the refrigeration system was capable of achieving temperature pull down from 150°F to 0°F with charcoal filled into the vessels in less than 20 hours. However, a field change request was generated to heat the contents of the vault (i.e. the filled carbon vessels) also to 150°F, simulate process flow through vessels and check the pull down time from 150°F to 0°F.

To accomplish the heat up of contents 4 each 6 KW and 2 each 13.5 KW infrared heaters were lowered into the vault. The testing commenced on 18 June 1986 and the sequence of event was as follows:

SEQUENCE OF EVENTS

EVENT 1		
June 18	1100	Initial heatup commenced
June 19	0600	Instrument air flow initiated
	2041	14B center T.E. >250°F
	2110	All heaters de-energized
June 20	0100	Started off-gas vault refrigeration system in pull down mode
	1145	Unusual event declared, Instrument Air Flow Stopped
	1219	N_2 purge initiated
June 20 June 21 > June 22		N_2 purge and vault cooling continued
June 23	1100	All T.E.'s reading <250°F
	1125	Unusual event terminated

J : 27	1852	N_2 purge secured with N_2 blanket retained sampled 14A & 14B vessels through top, and vessels resealed. Restarted N_2 purge.
June 28	0958	N_2 purge secured with N_2 blanket retained.
July 2		Sampled 12B & 14B vessels through bottom T.E.'s
July 3		Sampled 12A vessel through bottom T.E.

EVENT 2

July 3		Vessels remaining under N_2 blanket
		Preliminary metallurgical and chemical test results satisfactory
		NRC concurrence obtained to retest from ambient temperature conditions
July 6	1800	Instrument air flow initiated
	1910	Center T.E.'s on vessels 14A & 14B indicate greater than 250°F
	1942	Instrument air flow secured
	2037	Center T.E. on 14A reading 656°F and center T.E. on 14B reading 578°F
	2037	Unusual event declared
	2307	N_2 purge initiated
July 7-8		N_2 purge continued - temperatures dropping
July 8	1645	Unusual event terminated.

ROOT CAUSE EVALUATION

EVENT 1

0 Ignition temperature of 14A & B vessel charcoal determined to be as low as 307°F and 428°F respectively, at the system air flow rate of four (4) lineal feet per minute.

*** Charcoal was overheated during preparation for testing, resulting in combustion. Calculation of the temperature at various distances from the 13.5 KW heater were:

1 foot	1200°F
2 feet	1050°F
3 feet	700°F

EVENT 2

- Charcoal thought to have been cooled to ambient temperature as indicated by vessel thermocouples.
- Nitrogen purge/blanket removed and instrument air readmitted.
- Combustion again occurred within one (1) hour.
- *** Vessels contained hot spots that led to reignition upon reintroduction of oxygen (instrument air).

Paint blistering was observed at several vessel locations. Analysis of the data indicates that definite fire existed in vessels 14A and 14B with limited fire in vessels 15A and 15B.

Metallurgical inspection of the vessel indicated no vessel damage. The carbon was removed from all of the vessels and replaced with new carbon.

III. Review of Fire Causes and Events

The evaluation of the events leading to the fire can also be made in the following categories.

1. Original design or procedure related (Fires 1 and 4)
2. Upstream equipment failure initiated (Fires 2 and 3)

In fires 2, 3, and 4, long delays existed between the initial event causing carbon oxidation and the termination of the air flow. Feeding air through an oxidizing or fully burning carbon bed is one of the worst actions. Mankind discovered iron smelting using carbon, thousands of years ago and it is not required to rediscover this event in nuclear power plants. Whenever carbon fire is suspected, the vessel or unit should be isolated and any air entrance to the isolated unit prevented.

Fire 1 was extinguished by adsorber removal and external quenching.

Fire 2 was extinguished by nitrogen purge.

Fire 3 was extinguished by isolation and consumption of available oxygen.

Fire 4 was finally extinguished by nitrogen purge.

None of the nuclear power related fires were caused by organic compound accumulation on the carbon bed. Typical "used" carbon samples removed from air cleaning systems show ASTM (5) ignition temperatures near or in excess of "new" carbon ignition temperatures. However, most of the systems are operated at much lower velocities than those used in the ASTM test and the typical bed depths are also larger.

Both of these deviations from the ASTM test conditions result in lower ignition temperatures (6)(7). When alarm set points are selected and process parameter ranges established, the ignition temperature of the carbon bed should be determined under worst case and not best case conditions.

Due to the low thermal conductivity of the carbon, in the adsorbent bed temperature measurements are not reliable indicators of carbon oxidation or fire. Temperature measuring devices should be placed in the inlet and outlet gas streams of the adsorber units and backed up by either CO or CO_2 monitoring units. (8)(9)

The uniform packing of the carbon bed also influences the uniformity of both heat and mass transfer. Improperly designed adsorbent bed underdrain supports result in "dead spots" in the carbon beds which enhance ignition probability and prevent the effectiveness of adequate extinguishing procedures.

When evaluating the behavior of carbon - particularly in off gas systems - the basic tenets of adsorption processes should be known, i.e. that all gases progress through the carbon bed by adsorption and desorption, and that the carrier gas components are also adsorbed on the carbon.

Thus if in a four bed series system, it fire occurred in bed 1 and 3 and then nitrogen purge was initiated, the CO detection at the system outlet will not be instantaneous because the CO has to penetrate through bed 4 first. After a certain time (depending on flowrate, temperature, bed size, etc.) the CO concentration shall rise and then fall to zero, if, for example, the bed 3 fire was extinguished and some later time it will rise again when the CO generated in bed 1 progresses through beds 2, 3, and 4. Therefore, if CO or CO_2 monitoring is used for fire detection only at the outlet of large carbon beds in series, fires occurring in the first bed may not be detected in time.

As an example, using the dynamic K values common for Kr, Xe delay bed design the following approximate K values can be used for other gases.

Xenon	1200
Krypton	60
Carbon Dioxide	50
Carbon Monoxide	18
Oxygen	14
Nitrogen	12

If under system conditions a 40 hour delay of krypton occurs, a five hour delay of nitrogen can exist when the flow is switched to pure nitrogen. Hot spots generate their local pressure boundary and the normal purge flow condition penetrates the hot spot inadequately to extinguish the fire. Therefore, false "extinguishing" of the fire can occur and upon resumption of the air flow reignition can take place.

The frequent lack of bypass capability of off gas system delay beds also means that the heat generated by fire in an upstream bed can be driven into subsequent beds and in turn igniting these adsorber beds also.

Hydrogen as a fire preventer agent. In several carbon based off-gas systems, hydrogen detonation took place instead of partial hydrogen burn or deflagration. In none of those cases did a carbon fire result because most of the oxygen was consumed by the hydrogen detonation and the residual O amount was insufficient to initiate carbon fire. (10)(11)(12)

Naturally, the lower is the temperature of the operation, the larger is the quantity of oxygen physically adsorbed in the carbon which has to be displaced in case a fire is to be extinguished. (13)

IV. Differences Between Solvent Recovery & Air Cleaning Applications

Activated carbon is used in many diverse air cleaning applications. One of the classification into subcategories can be done by the level of inlet organic concentration to the adsorbent. Inlet concentrations above 100 vppm of flammable solvents, particularly ketones, in regenerative systems has resulted in many fires in the past. Most of these fires are caused by incorrect process and equipment design. Activated carbon fires in low concentration air cleaning systems are very rare. The understanding of the adsorption, the solvent decomposition and the carbon oxidation process has to be understood and the properties of both the adsorbent and the adsorbate (the compounds adsorbing on the carbon) properties known, to permit a correct evaluation of the system fire hazards. Ignoring any of these parameters will result in the installation of either unnecessary or incorrect fire control methods.

Nearly all of the activated carbon based solvent recovery fires occurred with ketones which can be catalytically decomposed by carbon (to a varying degree depending on carbon type). The normal ketone inlet concentrations were in excess of 1000 vppm and the carbon was hot steam stripped periodically to remove the adsorbed ketones. If the adsorber bed design is such that "dead spots" i.e. areas with low air velocity exist, the carbon bed temperature can reach the ignition temperature of the solvent and subsequently that of the carbon. If sufficient oxygen is present without any heat removal means, the result is a runaway ignition. (14)(15)

These conditions are not normally present in nuclear air cleaning systems. First of all, the solvent quantity adsorbed on the shallow (2-4 inches deep) carbon beds never approaches that of solvent recovery system loading, even at the 100 vppm level versus the 1000+ vppm levels of solvent recovery systems. The heat loss of the shallow beds to the air stream is always higher than that of the 2-3 feet deep carbon bed solvent recovery units. (16)(17)(18)

The nuclear air cleaning adsorbers are not periodically "regenerated" which eliminates the temperature cycling of 100+ C temperature rise to the adsorbent.

The typical "dead spot" unperforated areas of nuclear adsorbers is on the order of 1-2 inches versus the 4-16 inches of blanked off areas of solvent recovery units.

The adsorbent used in solvent recovery systems is not damaged by wetting, thus the carbon is left in place and no significant economic or process loss exist if the adsorbent is wetted.

The solvent recovery system does not serve a per se safety function. Failure of the unit or its non-availability does not create a significant safety hazard to the public.

V. Similarities Between Solvent Recovery & Air Cleaning Applications

Numerous solvent recovery systems had fire propagation to significant safety and economic loss level when fire detection method was by temperature rise detection. Fire in a small area of the adsorbent will not generate high enough temperature rise to be detected early enough by temperature alone.

A solvent recovery fire which melted the exhaust duct was not detected by 32 thermocouples installed in the midlevel of a 3 feet deep (30' X 8' area) bed, because the fire started downstream or not in immediate vicinity of any of the installed thermocouples.

Nearly all nuclear air cleaning fire detection methods for carbon beds are temperature based. In some cases, with the thermowells installed in the carbon beds themselves.

Water sprays installed in solvent recovery systems for fire control were found ineffective when incomplete water spray coverage exist, even for a single horizontal (slab shape) carbon beds.

The nuclear air cleaning system fire control water sprays almost always result in incomplete coverage of the individual adsorbent trays.

Solvent recovery systems vessels were found to fail from fire control water pressure due to inadequate drainage and low pressure housing design. The drainage systems and housing pressure design of nuclear air cleaning systems is rarely matched to the pressure of the fire control water. Water penetration through ducts to critical areas can occur resulting in significantly higher safety hazard due to water transfer to unplanned areas, than the presumed fire in the air cleaning system.

VI. Specific Nuclear Air Cleaning Related Problems

1) The adsorbed radioiodine is released from the carbon before it reaches its ignition temperature.

2) Introduction of water to carbon at 130°C results in an initial temperature rise of 50-80°C due to the heat of adsorption of water (~31,000 J/mole).

3) The adsorbed and converted iodides are water soluble and the radioiodine will be transmitted by the water to tanks where, depending on pH conditions, the iodine can be released into uncontrolled areas.

4) Accidental (or incorrectly designed) initiation of the fire control sprays destroys the adsorbent (requiring replacement). The wetted carbon bed per se is not available for its design safety function.

5) Standard ignition test procedures in both the US and Europe where the carbon is forced to an ignition temperature by heating, use nitrogen flow to extinguish the fire. The CO, CO and temperature levels start to drop within 10 seconds of nitrogen flow initiation. (19)(20) Fires which occurred in well isolatable carbon beds have been extinguished by nitrogen flow.

6) Isolation of nuclear air cleaning systems and consumption of only the available oxygen in the housing may not be adequate due to inadequate damper and housing leak criteria.

7) Standard (ASTM) ignition temperature determination is performed on a 1.0 inch deep bed at 100 fpm which results in significantly higher ignition temperature than 2-4 inch bed depth at 40 fpm. (6) Ignition temperature of nuclear adsorbent should be determined at design conditions.

8) No fires in nuclear air cleaning systems extinguished by the installed water deluge systems.

9) There were in excess of 200 nuclear air cleaning units damaged by accidental initiation of water sprays.

10) Regulatory Guide 1.52 Rev 2 does not require water sprays for adsorber beds.

11) The ANI recommends water sprays for adsorber beds (21), verbal communication with ANI indicates that proof tests are needed for alternate fire control methods, even though no proof testing of water sprays was performed.

12) Most moisture separators (if not all) will prevent burning debris from reaching adsorber stages.

13) HEPA filters are more susceptible to fire damage than activated carbon beds.

14) The lowest ignition temperature of carbon beds occurs if they are heated in no air flow and then air (oxygen) is introduced. (22)

15) Uniform packing of adsorbers assures not only uniform mass transfer, but also uniform heat transfer.

REFERENCES

1. Personal Communication from W. Fair to J. L. Kovach (1972)

2. Crisler, H.E. "July 17, 1977 Off Gas System Charcoal Adsorber Bed Fire at Browns Ferru Nuclear Plant". OECD CSNI Report 83, USDOE Report LA-9911-C (1983).

3. Kotthoff, K. and Simon, M. "Presentation of Selected Incidents in German Nuclear Power Plant". NEA/IAEA Meeting for the Exchange of Information on Incidents in Nuclear Power Plants. Paris, July, 1984.

4. Perry Nuclear Power Plant Docket Nos. 50-440; 50-551 "Off Gas System Unusual Events", Final Report. 29 July 1986.

5. ASTM D-3466 Standard Test Method for Ignition Temperature of Granular Activated Carbon.

6. Kovach, J.L. and Green, J.E. "Evaluation of the Ignition Temperature of Activated Charcoals in Dry Air". Nuclear Safety Vol. 8 No. 1 pp. 41-46 (1966).

7. Freeman, W.P. et.al. "Ignition Properties of Nuclear Grade Activated Carbons". OECD CSNI Report No. 83, USDOE Report LS-9911-C (1983).

8. Factory Mutual Technical Advisory Bulletin 7-2 FMELPC Apr. 1979.

9. Kovach, J. L. "Operation and Maintenance of Adsorption Systems". NUCON Report.

10. Vermont Yankee IOG Operation 1973. Personal Observations.

11. Verna, B.J. "Off Gas System Explosions Parts 1, 2, 3". Nuclear News. Nov. 1976, Jan 1977, March 1977.

12. Hydrogen Chemistry Studies at Dresden Plant. 1984.

13. Dubinin, M.M. "Surface Oxides and Adsorption Properties of Activated Charcoals". English Translation in US Report AEC-TR-3750. (1957)

14. Boiston, D.A. "Acetone Oxidation". British Chemical Engineering. Vol. 13 No. 1. pp. 85. (1968)

15. Bratzler, K. "The Autoignition of Carbon Products as a Process Problem". Chem. Ing. Techn. Vol. 28 No. 8/9 pp. 569 (1956)

16. Bernard, E.A. and Zavadoski, R.W. "The Calculation of Charcoal Heating in Air Filtration Systems". USAEC Report CONF 740807. (1974)

17. Shields, R.P. "Ignition of Charcoal Adsorbers by Fission Product Decay Heat". USAEC Report CONF-700816 (1970).

18. Lorenz, R.A. "The Behavior of Highly Radioactive Iodine on Charcoal". USAEC Report CONF-740807 (1974).

19. Chevalier, G. et.al. "Thermal Evaluation of Activated Carbons Used in the Nuclear Industry". French Report CEA-N-2285 (1982).

20. Hardman, J.D. et.al. "Studies of Spontaneous Combustion in Beds of Activated Carbon". Fuel Vol. 59 pp. 151-156 (1980)

21. Personal Communication from American Nuclear Insurers (ANI) to J.L. Kovach (1985)

22. Kovach, J.L. "Evaluation of Activated Carbon Ignition Under System Application Conditions". NUCON Report 240 (1986).

Table 1

Fire Extinguished by

Fire 1	External quenching by water
Fire 2	Nitrogen purge
Fire 3	Isolation
Fire 4	Nitrogen purge

Table 2

Time After First Fire Indication when

		Airflow Stopped	N_2 Purge Start
Fire 1		<0.25 Hrs.	N/A
Fire 2		5+ Hours	15+ Hours
Fire 3		8+ Hours	10+ Hours
Fire 4	Event 1	13 Hours	13.75 Hours
	Event 2	.5 Hours	4.5 Hours

Table 3

First Remedial Action

Fire 1	Remove adsorber
Fire 2	Bypass and isolate
Fire 3	Blowing air on vessel exterior
Fire 4	Vault refrigeration started

Table 4

Assuming All of Air Reacting

Air Flow	Carbon Consumed lb/m	BTU* generated per minute
5 CFM	.0326 lb/min	460 BTU/min
10 CFM	.0652 lb/min	920 BTU/min
20 CFM	.1304 lb/min	1840 BTU/min
40 CFM	.2608 lb/min	3680 BTU/min
80 CFM	.5216 lb/min	7360 BTU/min

*assuming $C + O_2 = CO_2$ reaction

Table 5

Oxygen Present Per Kg of Carbon*

At 25°C	1.75 g
At 0°C	2.35 g
At -20°C	3.65 g
At -185°C	560 g

Typical quantity of carbon in Off Gas Systems 25,000 to 40,000 Kg.

*calculated on basis of standard air passing through 800 m^2/g surface area coconutshell carbon.

Table 6

Heat Transfer Related Carbon Properties
Coconut Carbon

Average Particle Size	0.128 cm
Average Particle Surface	0.10 cm^2
Average Particle Volume	0.00205 cm^3
Average No. of Particles	280/cm
Bed Void Fraction	0.42
Sphericity	0.719
Carbon Thermal Conductivity	3.1 X 10^{-4} cal/cm sec ^oC
Carbon Heat Capacity	0.20 cal/g ^oC

Table 7

Fire Location/100 year reactor operation*

Reactor Building	40
Auxiliary Building	38
Service Building	34
Turbine Building	45
Diesel Gen. Bldg.	3
Other Bldgs.	15
Building HVAC Systems Affected	7

*Canadian Data

DISCUSSION

BITT: As stated, the first action in the event of a suspected fire in a charcoal delay system should be to stop the supply of oxygen. Residual oxygen in the system will not support combustion more than a very few hours. Purging with nitrogen will reduce the amount of oxygen in the system and shorten combustion duration as well as aid in cooling. Even with no added heat of combustion, as evidenced at Perry, due to the low charcoal thermal conductivity, the bed could stay hot for weeks.

As an example of the difficulty in cooling following a fire, calculations indicate that a single hot spot in a bed that is being nitrogen purged at 6 ft/min will migrate at a rate of ½ to 1 ft/day. The much higher heat loss from the interconnecting pipes terminates the migration at a connecting pipe with no more than one tank involved, i.e., in the Perry case, a maximum of one twenty foot high tank in each train, or about twenty days.

Experience with three delay tank fires supports my statement that the best charcoal delay system fire detection method is a smoke detector in the charcoal vault exhaust duct.

GILBERT: Mr. Murrow, do you recall if the experiments at Livermore used any "wetter water" as an extinguishing agent?

MURROW: At times we did use a wetting agent in the water. We had a number of different spray patterns and we tried to get water into all parts of the absorber. It didn't help.

PEDERSON: I work for the Office of Inspection and Enforcement and we manned the incident response center for the whole weekend of the initial Browns Ferry fire. Needless to say, there was a lot of concern by my management, because the plant couldn't readily put the fire out. It was pretty tight.

MEANS USED TO MAKE SURE THAT THE CONFINEMENT IS MAINTAINED IN CASE OF FIRE

J. SAVORNIN, head of Fire Protection Section
CEA - IPSN - DAS

Abstract

In case of fire in nuclear facilities, the ventilation and filtration systems have to be designed to exclude any radioactive release to the environnement. For this purpose it's necessary to maintain the extraction ventilation running. As a result, smoke ant heated air will be introduced into the ducts towards the HEPA filters.

Consequently we must know the threshold from which, either filters will stop going their part, either ducts will be partly destroyed.

Tests and experiences are led or provided to give answers to those questions. Informations are provided about tests already drawn and scheduled with the two available apparatus.

I. INTRODUCTION

In a nuclear facility, the units which are very radioactive are separated from the environnement by confinement barriers of which one at least would remain efficient in case of fire. The principles which have been set and the means which have been suggested have often been exposed and espacially in the paper which I have presented at Los Alamos in April 1983 at the CSNI meeting.(1)

The ventilating systems are the weakest parts as regards fire risks and consequently the level at which they would be destroyed must be determined. Experiments are drawn by several services at CEA to try to obtain exact answers to those questions.

I'll present you the chief places where there is a major problem and, for each of them, the experiments which are presently carried out or scheduled.

II THE WEAK PARTS OF A VENTILATION SYSTEM

In the event of an important fire inside a fire zone the exctracting ventilation system of which is organised with the principle of double filtration with dilution (figure n°1), several problems exist due to smoke and very hot gaz circulating in the system. Those problems are presented here under following the stream of air flow (figure n°2).

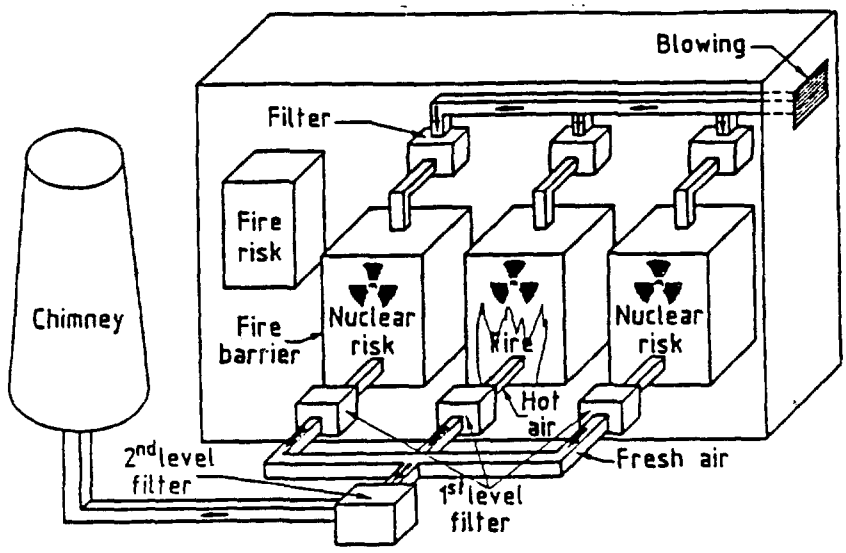


Fig. 1 - DRAWING OF THE VENTILATION SYSTEM OF A NUCLEAR FACILITY WITH FIRE ZONES AND DOUBLE FILTRATION WITH DILUTION

2.1 Duct crossing through a fire barrier

The iron duct crosses the fire barrier through a hole where it supports on the interior face of the fire barrier, a fire whose developpement is defined to follow the program for the temperature growth specified by the ISO norm. It is represented on the figure n°3 which is designed by the relation $T-To = 345 \log (8t + 1)$ where :

T is the temperature at the "t" time
To is the starting temperature

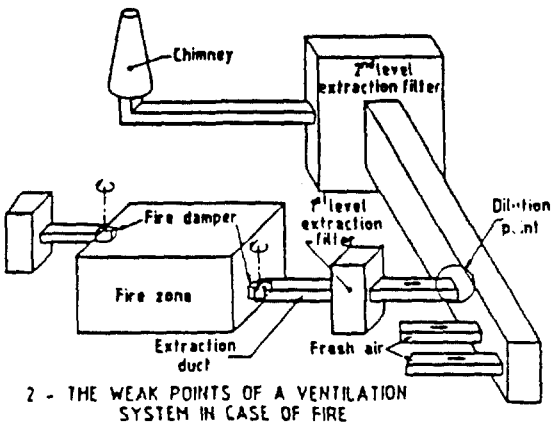
If the thermic insulation given by the material across the fire barrier were perfect, the overheating due to fire would be transmitted in totality, by conduction way, to the part of duct outside of the fire barrier so that the duct may be spoiled or destroyed as soon as the temperature rises to 600°C. This needs a series of tests driven with an oven where they may run the ISO programm. We feel safer since we made a test of this kind about another experiment but we need a global series of experiments abou this problem, so as to define the right data to know the permissible level.

2.2 Fire dampers

Fire dampers settled on the extracting air apertures are currently built to shut down at a rather low temperature by the mean of a device fusing towards 70°C.

On the contrary, when the ventilation net is designed with dilution and double filtration system (figure n°1), the fire damper will work only at the moment when the first level filter is just to be spoiled. Since many HEPA filters have a rather good behaviour at high temperatures, and since as the distance between the fire damper and the concerned filter is long, so the fire damper may be worked at very high temperatures which may rise to 500 or 600°C.

We have to make sure that the chosen fire dampers will shut down at the temperature that they may have to undergo. The tests will be made by using an oven designed to draw the temperature programm according to the drawing n°3.



2 - THE WEAK POINTS OF A VENTILATION SYSTEM IN CASE OF FIRE

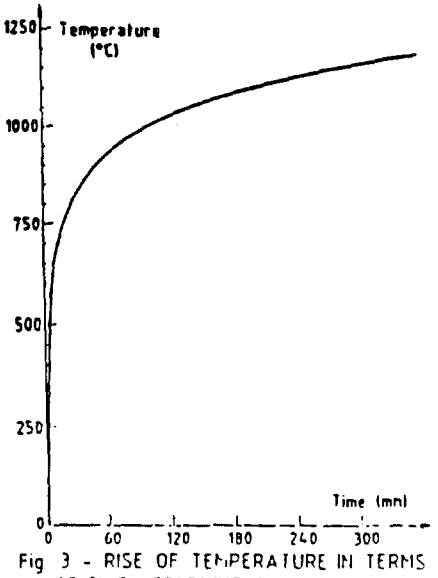


Fig 3 - RISE OF TEMPERATURE IN TERMS OF TIME ACCORDING TO THE ISO NORM

2.3 Ventilation ducts

Fires may initiate inside ventilation ducts where dusts are deposited and often covered by greasy films of oils of many apparatus, among which you find health physics controls. This risk grows together with the age of facilities. Information concerning the way followed by the fire in a ventilation duct, and about the fighting methods have to be collected. The schedule of experiments driven would give good answers.

Fire will be put inside a rig placed at a position depending of the filter, of the dilution point, and of the blowing or extrating fan. The material which is to be burnt will lay on the bottom.

The material which is to be burnt is chosen to comply with the previoused test ; it may deliver either smoke, or heat, or both. Figurative deposit is currently used which has been defined to be similar to the one to be found in a particularly dirty duct. For 65% it is made of three mixed componemts : 50% lucolfex, 25% wood, 25% cotton.

The combustible material will be put in the loop, ventilator working. Fire will be put upstream, then downstream with various air speeds, so as to define wether the fire comes upstream or not. Tests will be made to find the extinguisher appropriate and the mean to apply it.

Other tests of duct fire behaviour will be done by connecting the rig to a little fire room where high temperature will be obtained. The temperature gradient will be measured along the duct and compared with the calculated results.

2.4 Filters

Filter may be submitted either to a hot air stream coming from a room fire, or to a fire of dusts covering it, or both. Experiments concerning those topics are running. Few tests concerning extinguishing means have also been realized.

A covered with dust and alcohol wetted filter is settled in its box whose front part is fitted with two apertures to introduce the extingtuisher, which can be applied in the duct also through several other openings at several distances ahead. The ventilator is running.

Fire is put inside the loop at several different distances upstream of the filter previously covered with the figurative deposit, so as to appreciate the risk of having the fire running from the duct down to the filter. Fire extinguishing tests will be carried on.

A research of convenient fire detectors inside the ducts has to be driven with this opportunity.

2.5 Dilution point

The dilution principle means that the ventilation duct conveys hot air, smokes and unburned gases up to a chief duct in a stream of fresh air. It is an evidence that you find ther a fire or explosion risk due to unburned hot gases melted to a large amount of oxygen.

We have to know if it is an actual risk and in case of an affirmative answer it will be a necessity to point the level where the risk begins. A series of experiments on this topic will be driven.

The piece of loop where the material is burning, will be brought nearer and nearer to the dilution point during several tests while increasing temperature and amount of unburned gases. A pilot flame may be burning at the dilution point.

III AVAILABLE EXPERIMENT DEVICES

3.1 Objectives

Two experiment devices are available in FRANCE for tests of ducts and filters at high temperature. The biggest is the SIMOUN rig (2,3) built on the Saclay plant to test filters in air stream at temperature so high as 400°C. This apparatus cannot be ed with fire or smoke.

The other is the BEATRICE rig which was formerly built on the Marcoule nuclear plant, then recently taken to SACLAY to be close to the facilities of DPT/SPIN which has taken it in charge in 1985. It has been designed to carry out fires in vent ducts. We wanted it to be a flexible tool which will be convenient with every kinds of tests on fire and smoke. Repairing has to be quick and cheap.

3.2 Description of the BEATRICE rig (Figure n°4)

The loop is made of pieces which are all similar. They are all two meters long with a square cross section of 400 x 235 mm fixed together with flats joins. Those pieces are built with blackiron plate 2mm thick. They are covered with a plate fixed with join-pressers so as to be easily taken out. On the covers, controllers and experiment apparatus are disposed. You may have window on it. The elements are cheap ; they may be replaced transfered, inserted, and so on without problem. Ventilators fiter box and dilution point cannot be removed easily.

Ventilation is made by the means of a fan blowing 3000 m3/h so as it will not be harmed by smokes and hot gases. When experiments want that the duct is exhausded the fan can be deplaced at the other end of the rig.

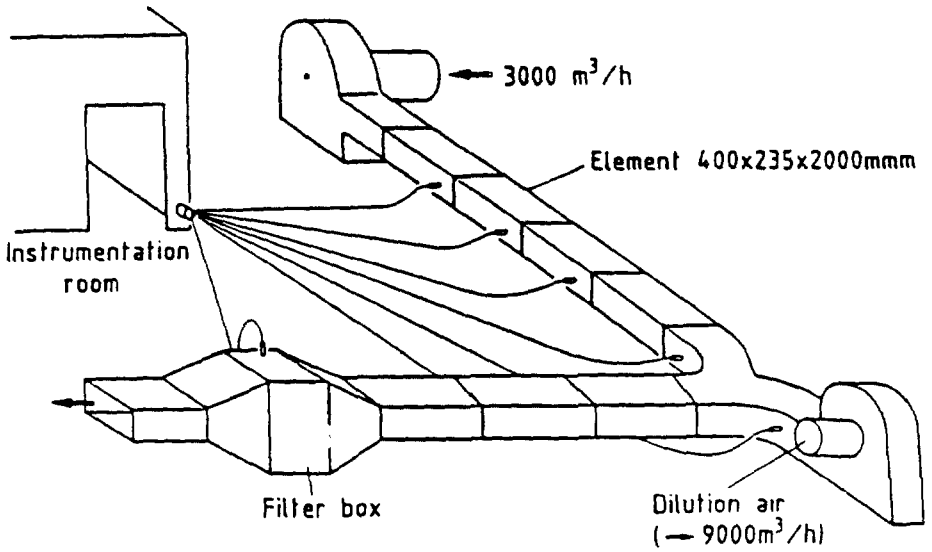


Fig. 4 - THE BEATRICE RIG

An other fan may blow up to 9000 m/3h at a point of the loop to represent the dilution. The speed of the air stream may reach 26,6 m/s.

3.3 Lessons drawn from the first BEATRICE experiments

The first experiments driven with BEATRICE concerned the automatic fire detection systems and the extinguishing means on fire filters.

To test automatic fire detectors, the material to be burned was chosen according to the dust deposit actually found in ducts (see 2.3). This material could never make the detector work and it was necessary to use cartoon boards used currently to test the automatic fire detection systems. So it appears that the detection of fires in ventilation ducts is probably much more difficult than it could be imagined.

Speaking of fire filters, no extinguishing mean was efficient when the fan was on. Though it is often difficult or unpossible to stop the ventilation in nuclear facilities, there is a big problem which have to be solved.

IV CONCLUSION

The experiments which have been driven up to now though very approximate show that fire in ventilation ducts is a serious risk which is rather unknown and against which we have no efficient fighting means.

It appears indeed that the phenomenas concerned are much more complicated than what could be imagined at the beginning.

We have proposed a method to continue the ventilation as long as possible to maintain the confinement of a nuclear facility in case of fire. This supposes that the ventilation system is able to assume his fonction a time long enough to allow to the fire fighters to extinguish definitely the fire. It is the reason why we have tried to define the weak parts of a ventilation system in such circonstances and to develop a serious research program to solve those problems which may be severe in our ancient facilities.

REFERENCES

1. J. SAVORNIN

"General considerations on fire and explosion in a nuclear facility Interaction with ventilation". CSNI specialist meeting on interaction of fire and explosion with ventilation systems in nuclear facilities - Los Alamos - April 1983.

2. A. BRIAND, JC. LABORDE, Ph. MULCEY

"Limits of HEPA Filters operation under high temperature conditions" - 19 th DOE, Nuclear Air Cleaning Conference Seattle - August 1986 - (To be published).

3. J. DUPOUX, Ph. MULCEY, JL. ROUYER, X. TARRAGO

"SIMOUN high temperature dynamic test rig for industrial air filters" - 18 th DOE Nuclear Air Cleaning Conference - Baltimore 1984.

DISCUSSION

ALVARES: I noticed that the ventilation system for the Beatrice test rig is an injection device and not an extraction device. Most of the facilities that we have are balanced, but they do have an extraction fan so that the pressure on the downstream side of the filter can be less than on the upstream side of the filter. Is that something that you are considering adding to your systems?

SAVORNIN: Yes, we are. We designed the test rig the way I showed because we wanted to make tests to determine the direction the fire may take. When we want to test fire extinguishers, we locate the fan so that it is exhausting instead of blowing

RELEASE OF RADIOACTIVITY OUT OF WASTE PACKAGES UNDER THERMAL STRESS

D. Gruendler, H.W. Brenig, W. Wurtinger
Gesellschaft fuer Reaktorsicherheit (GRS) mbH
Schwertnergasse 1, 5000 Köln (Cologne) 1

Abstract

The release of radioactivity out of waste packages under thermal stress is generally determinded by complex processes, which cannot be formulated mathematically. However essential parameters such as mechanisms and heat transfer parameter can be simplified so far, that the determination of the released activity can be carried out analytically. Examples of calculations show release fractions between 10^{-6} and 10^{-3}. Although these results are conservative, the values confirm the thermal behavior of the wastes and thus, the presented models are suitable for the performance of safety analyses.

I. Introduction

In recent years, there has been a worldwide increase in research activities in the field of nuclear waste management. Apart from the analysis of long-term safety, one of the major aspects of research is the investigation of the safe manipulation of these wastes, for example during transport, handling and storage. A comprehensive safety analysis requires a great number of various individual analyses which can all be dealt with along the same lines, cf. Figure 1.

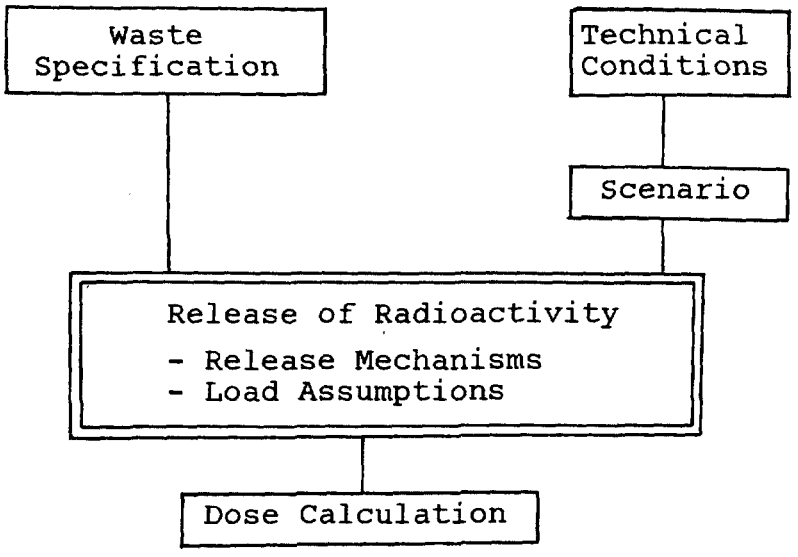


Fig. 1: Scheme of safety analyses

The basic requirements to be met are, on the one hand, the specifications of the radioactive waste and, on the other, the existing technical boundary conditions. These technical boundary conditions are the background of accident scenarios which determine the loads assumed to act upon the radioactive waste. With respect to accidents involving radioactive wastes, the relevant load assumptions are mechanical stresses, thermal stresses or a combination of the two. The load assumption and the specification of the radioactive waste under review determine the activity that is released (source term determination). The last step is the calculation of the dose on the basis of the source term.

The present paper focuses on the determination of source terms. While dose calculations have almost been standardized as a result of various computer codes, there are no comparable algorithms for the determination of source terms.

The paper describes certain elements of a source term determination which may become part of a possible standardized procedure for the determination of source terms.

These are

- release mechanisms,
- the relevance of release mechanisms for certain wastes,
- load assumptions
- temperature fields.

Based on these elements, results of source term determinations are presented as examples with respect to cemented wastes, scrap and compacted wastes in concrete and steel sheet containers.

II. Release Mechanisms

There are four relevant mechanisms for release as a result of thermal stress:

- release due to pyrolysis of the waste product,
- release due to combustion of the waste product,
- release due to the vaporization of water in the waste product,
- release due to sublimation or vaporization of radioactive substances.

Pyrolysis

Pyrolysis is understood as the thermal decomposition of a material. In waste packages, this process takes place if the temperature of the product exceeds a certain threshold, e.g. approx. 300 °C, with a restricted admission of air, and the waste product contains thermally instable constituents. The gaseous decomposition products - the so-called pyrolysis gases - escape from the waste package and burn outside the waste package if they are ignited. With the pyrolysis gases, a certain percentage of activity is released.

In experimental investigations of the percentages of activity released by pyrolysis, results of approx. 5 x 10^{-3} are obtained for Cs /JOH 85/.

As far as less volatile nuclides are concerned, the released percentage of activity is smaller.

Combustion

In the event of the assumed thermal stress condition, combustible waste products will burn if a sufficient amount of air is supplied to the waste product.

Quite a number of experimental investigations have been carried out to determine release percentages due to combustion /RÄM 79b/, /MIS 70/, /MIS 73/, /SUT 74/, /SEE 82/, /VEJ 82/. In these experiments, the release percentages are between 10^{-2} and 0.4. The great variations are a result of the different experimental boundary conditions.

Added to these released percentages may be the resuspension of the residues of combustion.

Vaporization of Water

Due to co-vaporization, the vaporization of water also causes a transition of radioactive substances into the gaseous phase. In investigations of the evaporization of liquids /MIS 68a/, /MIS 68b/, results of approx. 10^{-5} to 10^{-3} are obtained with respect to the shares released. This release mechanism is particularly relevant for cemented wastes and concentrates. These wastes contain great amounts of vaporizable water in their pore volume, water of crystallization, or the like.

Investigations of cemented wastes in 200 l drums /JOH 85/, /VEJ 83/ confirm the results of the evaporization experiments.

Sublimation of Radioactive Substances

Apart from the release of radioactive substances by means of co-vaporization, radioactive substances are also subject to direct vaprorization or sublimation. In general, this release pathway determines the release of volatile substances such as iodine or tritium. However, it can also be of importance for other elements, in particular Cs. The released percentage of activity depends on the duration and the temperature level of sublimation. The amount of released activity can be theoretically estimated on the basis of the thermodynamic data of the substance and Lewis' law.

III. Relevance of Release Mechanisms for Various Wastes

In the case of cemented wastes, a combination of the release mechanisms of pyrolysis (in hot surface layers) and co-vaporization is possible. For the quantification of the individual contribu-

tions it is assumed that pyrolysis takes place in those parts of the volume where the temperature is higher than 300 °C, and that co-vaporization is the main process in those parts of the volume where the temperature is higher than 100 °C.

As far as scrap is concerned, the only relevant process is that of release by sublimation of the radionuclides.

Crude compacted wastes may consist of pure scrap or mixed wastes, for example textiles and paper. In the case of an overwhelmingly metallic composition (scrap), the relevant release process is that of sublimation of the radionuclides, in all other cases it is that of pyrolysis.

Apart from the above-mentioned mechanisms for the release of radionuclides, the release of easily volatile compounds such as organic iodine is determined by sublimation in all kinds of waste flows.

The release by combustion, which was mentioned when describing the possible release mechanisms, will usually be of no effect. This is due to the fact that, in the scenarios investigated, the integrity of packaging is generally preserved to such an extent that only pyrolysis takes place.

IV. Load Assumptions

The released activity mainly depends on the load assumptions for thermal stresses, and in this context, thermal stresses are always assumed to be due to the impact of a fire. For example, the load assumptions determine the volume percentages which are subject to temperatures of more than 300 °C or more than 100 °C, and/or the waste temperature that is relevant for sublimation.

In general, the load assumptions are stated as a temperature-time function of the fire (primary statement). In order to calculate the heating-up of the waste in the package, the heat transfer coefficients for both convection and radiation (secondary statement) have to be quantified as well. Considering a realistic fire load, other factors have to taken into account as well (tertiary statements), for example to what extent the package is at the source of the fire, or whether or not the package is shielded by other objects or whether or not there are also other heat sinks.

The kinetics of the fire is influenced by a number of parameters of which a few are quoted below as examples:

- distribution and kind of the fire loads,
- radiation properties of confining walls,
- cooling of the source of the fire by air draft,
- limitation of the combustion speed by a limited supply of air,
- unsteady temperature field in a flame.

The consideration of all these parameters makes it impossible to furnish a theoretical description of the temperature-time function.

This is the reason why mean model curves are used for a realistic description of the effects of a fire on a waste package, although peak values of the expected realistic temperature-time history are not reached. A well-known example of such a model curve is the load assumption of 800 °C for a period of 30 minutes as contained in the IAEA transport regulations /IAEA 73/. Another curve considering 800 °C for a period of 60 minutes is stated in /ILL 85/ with respect to the accident covering all possibilities in the final disposal of radioactive wastes.

As a result of the numerous influencing factors, even the theoretical determination of the heat transfer coefficient is almost impossible.

The main parameters for the convection transfer coefficient are:

- temperature differential between source of fire and package,
- geometry of the package,
- flow field within the source of the fire.

The following are important for the radiation coefficient:

- soot concentration in the flame,
- chemical composition of the flame,
- geometry of the flame,
- absorption properties of the package.

As in the case of the model curve, the heat transfer coefficients must be described in a model. For example, the transport regulations are based on a radiation coefficient of 0.9 and an absorption coefficient of 0.8 and assume calm environmental air as another boundary condition. The resulting total heat transfer coefficient is approx. 30 ... 110 W/m^2K, depending on the surface temperature of the waste package.

V. Temperature Fields

On the basis of the given temperature-time model curves and the heat transfer coefficients, the calculation of the unsteady temperature fields in the waste package with the available computer codes does not pose any problem. Figure 2 shows a comparison between a calculation using the IAEA model curve and the IAEA heat transfer coefficient and a fire experiment taken from /JOH 85/ for the heating-up of a drum of cemented wastes. This shows that the fixed parameters are sufficient for an adequate description of the effects of a realistic fire.

As examples, two other calculations using the IAEA boundary conditions are presented below.

Figure 3 shows the heating-up of scrap in a drum. The mean product temperature is quoted.

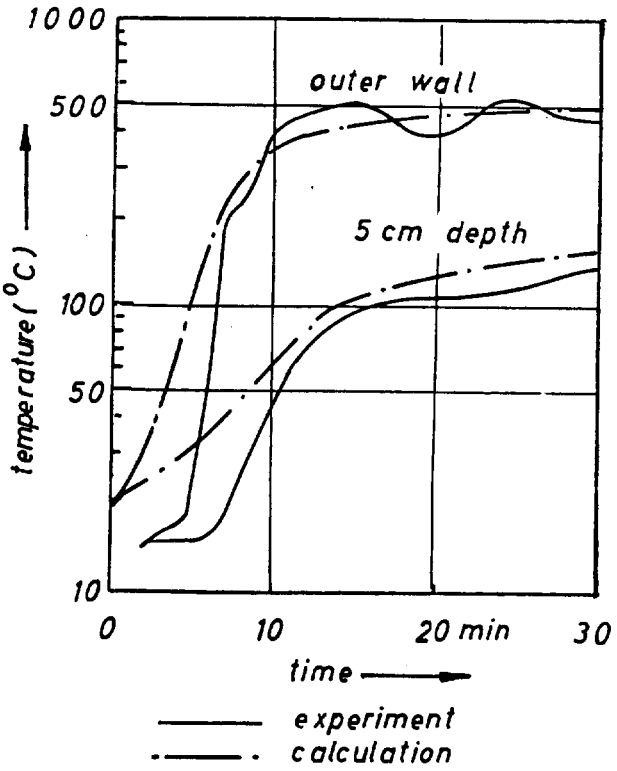


Fig. 2: Comparison between Calculation and Experiment for the heating-up of a drum

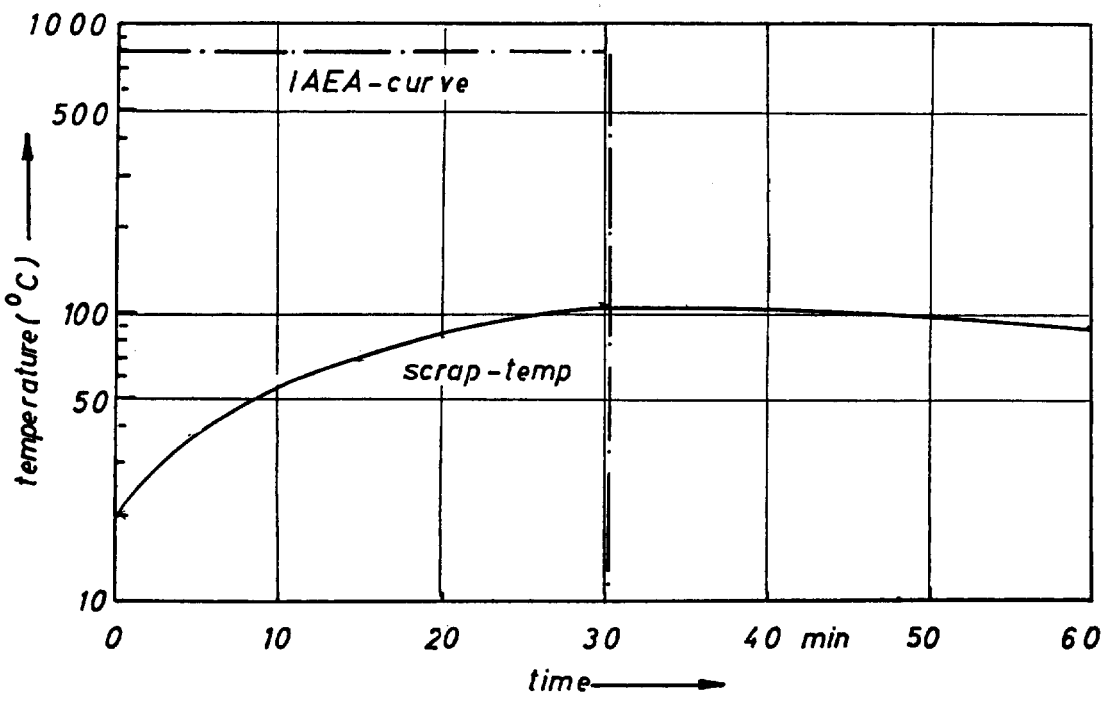


Fig. 3: Heating-up of scrap

Figure 4 shows the wall temperatures of an empty concrete container having a wall thickness of 23 cm. The waste products need not be taken into account, since the course of the inner wall temperature indicates that there can only be an insignificant heating-up of the waste product.

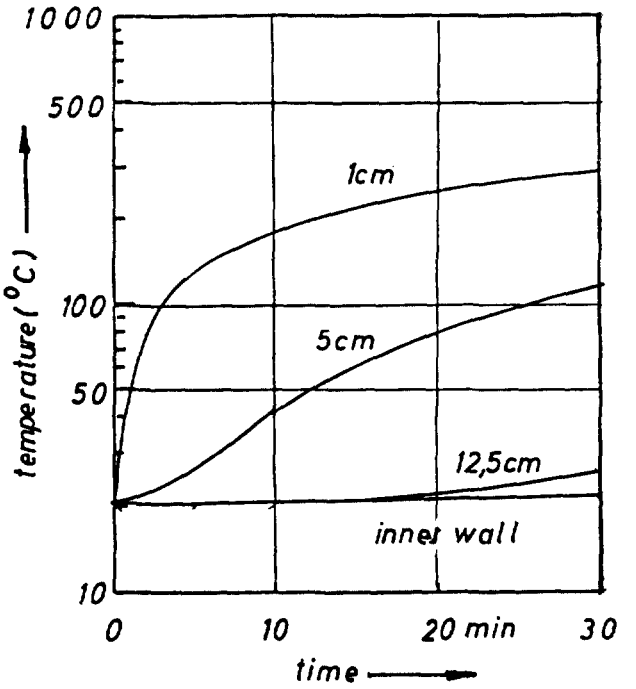


Fig. 4: Temperature in the Wall of a concrete container

VI. Examples of Source Term Determination

The following is an exemplary discussion of the source term determination for

- cemented waste,
- scrap, and
- compacted waste

in

- concrete containers and
- drums.

The simplest case of a source term determination is that of wastes in concrete containers. As can be seen in Figure 4, none of the release mechanisms addressed will apply as a result of the low inner wall temperature and thus, no activity will be released. This applies even if the calculations are based on a model curve of 800 °C and 60 minutes.

Temperature field calculations of cemented wastes in drums show an 8% volume percentage greater than 300 °C and a 20% volume percentage greater than 100 °C and smaller than 300 °C. With the release mechanisms relevant for cemented wastes, a maximum release factor of 5×10^{-4} results.

A calculation of temperature fields in packages containing compacted wastes is impossible due to the heterogeneous structure of the packages. Experiments concerning the release from compacted wastes subjected to thermal stresses show that approx. 30% of the waste is affected by pyrolysis. A value of 1.6×10^{-3} was measured as a release factor for Cs /JOH 85/.

For the sublimation of Cs, a release percentage of less than 2×10^{-6} results from the temperature curve shown in Figure 3 with respect to scrap in drums. For iodine and tritium, the release factor may be higher, depending on the chemical form, while it is smaller by a number of orders of magnitude for all other nuclides.

VII. Evaluation and Summary

The present paper used typical wastes and packages in order to show how the release of activity out of waste packages under thermal stresses can be calculated. Some of the necessary steps were simplified to such an extent that they may form the basis of a general pattern for the calculation of activity releases under thermal stress.

Thus, the complex release mechanisms are reduced to four basic release mechanisms the release behavior of which is known phenomenologically and which cover the entire spectrum of the behavior of all wastes.

Although, in reality, the thermodynamic boundary conditions of heat transfer are a many-sided phenomenon, they can be simplified by model parameters to such an extent that the effects on the packages can be described realistically, and standardized computer codes can be used.

Linking these simplified calculations with the combination of release mechanisms that are relevant for the waste concerned results in the activity percentages that are released.

An evaluation of the examples presented indicates that although the results, compared with experimental investigations, show a conservative tendency, they do confirm the thermal behavior of the wastes as determined in experiments. Thus, the procedure proves to be a useful tool for the performance of safety analyses in connection with radioactive wastes.

VIII. References

/IAEA 73/ IAEA Safety Series No. 6
Regulations for the Safe Transport of Radioactive Materials, Revised Edition, International Atomic Energy Agency, Vienna, 1973.

/ILL 85/ Illi, H.: Sicherheitsaspekte bei der Endlagerung in in "Neuere Entwicklungen zur Sicherheit von Kernkraftwerken und Anlagen des Kernbrennstoffkreislaufs" KTG Meeting in Düsseldorf, Sept. 24/25, 1985.

/JOH 85/ Activity Release from Waste Packages Containing LL and IL Waste Forms under Mechanical and Thermal Stresses, Waste Management 85, Tucson, 1985.

/MIS 68a/ J. Mishima, L.C. Schwendiman, C.A. Radasch: "Plutonium release studies; IV. Fractional release from heating plutonium nitrate solutions in a flowing air stream", BNWL-931 (1968).

/MIS 68b/ J. Mishima, L.C. Schwendiman, C.A. Radasch: "Airborne release of particles in overheating incidents involving plutonium metal and compounds", BNWL-SA-1735 (1968); CONF-680811-1.

/MIS 70/ Mishima, J. et al.: "The amount and characteristics of plutonium made airborne under thermal stresses", BNWL-SA-3379 (1970); Proc. Symp. Health Physics Soc., Idaho Falls, Idaho, Nov. 3-6 (1979).

/MIS 73/ J. Mishima, L.C. Schwendiman: "Interim Report: The Fractional Airborne Release of Dissolved Radioactive Materials During the Combustion of 30 Percent Normal Tributyl Phosphate in a Kerosine Type Diluent" BNWL-B-274, June 1973.

/RAM 79b/ Rämö, E. et al.: "Damage of Reactor Waste Packages in Transport Accidents", NKA, AO (79) 17, 1979.

/SEE 82/ Seehars, H.D., Hochrainer, D.: "Durchführung von Experimenten zur Unterstützung der Annahmen zur Freisetzung von Plutonium bei einem Flugzeugabsturz; Zusatzbericht über Experimente ... zur Freisetzung ... während eines Kerosinbrandes", BMI-Auftrag SR 0205 A, FhG ITA, Grafschaft, 1982.

/SUT 74/ S.L. Sutter, J. Mishima, L.C. Schwendiman: "Fractional Airborne Release of Strontium During the Combustion of 30 Percent Normal Tributyl Phosphate in a Kerosin Type Diluent", BNWL-B-358, June 1974.

/VEJ 82/ Vejmelka, P., et al.: "Endlagerspezifische Charakterisierung der für eine Endlagerung in der Grube "Konrad" zu betrachtenden Abfallprodukte", KfK-Primärbericht 05.11.0.3. P01A, Karlsruhe, Feb. 1982.

/VEJ 83/ Vejmelka, P., et al.: "Activity Release from Waste Packages Containing ILCW-Cemented Waste Forms Under Mechanical and Thermal Stresses".

SIMULATION OF EXPLOSIONS IN AIR CLEANING SYSTEMS AND COMPARISON OF THE RESULTS WITH COMPUTER CODE PREDICTIONS

W. S. Gregory, B. D. Nichols, and R. D. Wade
Los Alamos National Laboratory
Los Alamos, New Mexico

P. R. Smith and D. L. Fenton
New Mexico State University
Las Cruces, New Mexico

Abstract

Experimental testing and development of computer codes for predicting the effects of explosions in air cleaning systems are being done for the Department of Energy. The work is a combined effort by the Los Alamos National Laboratory and New Mexico State University (NMSU). Los Alamos has lead responsibility in the project and is developing the computer codes; NMSU is doing the experimental testing. Obtaining experimental data to verify the analytical work is the main goal of this effort. Of secondary importance are the experimental data showing the combined effects of explosions within air cleaning systems that contain all of the important air cleaning elements (blowers, dampers, filters, ductwork, and cells). This work will result in tools that safety analysts can use to study the effects of hypothetical explosions in nuclear facility air cleaning systems.

The experimental apparatus is a small version of a large experimental system that was installed at NMSU. The small system is used to obtain gas-dynamic data (temperatures and pressures) throughout the system (such as within the cells, along the ductwork, and before and after dampers and filters). Gas explosions are simulated in the experiments using a unique system of gas-filled balloons. The experiments will yield information on the degree of protection a system offers in attenuating explosive effects within air cleaning systems.

Analytical predictions were made using computer codes that predict gas-dynamic values such as flows, temperatures, and pressures throughout the system. The gas explosions were compared with the predicted results, and good agreement was found for most of the pressure measurements. Future experiments will involve small explosive charges using blasting caps or squibs. Future experiments also will couple material transport with the explosive gas dynamics.

Introduction

There is a potential for accidental explosions within nuclear facilities. (The recent reactor explosion at Chernobyl, Russia, is a case where a catastrophic explosion actually occurred.) In this country, safety analyses for nuclear facilities are required to evaluate the possibility and effects of accidental explosions thoroughly. Therefore, we want to develop computer codes that can be used to evaluate the effect of possible explosion-induced releases from a facility, perform scoping studies involving a multitude of explosion scenarios, and evaluate the effectiveness of various protective designs. To simulate these explosive effects accurately, we must be sure that the computer codes in use will perform as expected. This can be done by comparing the calculated simulations with small-scale experiments.

This paper describes computer codes being developed by the Los Alamos National Laboratory for the Department of Energy to simulate the effects of explosions within nuclear facilities. Particular emphasis is placed on explosive propagation in the plants' nuclear ventilation and air cleaning system. The experimental apparatus and results of tests using gas-filled (hydrogen/air) balloons to create gaseous detonations also are described. Finally, the test data are compared with computer code simulations.

Test Equipment Description

Figure 1 is a plan view of the experimental ventilation system located on the New Mexico State University (NMSU) Campus in Las Cruces. The ventilation system has two steel tanks simulating rooms. One tank is cylindrical and 2.74 m (9 ft) in diameter with a volume of 24.3 m^3 (859 ft^3). The second tank is essentially rectangular and 3.3 by 2.1 m (10.9 by 6.9 ft) on the sides with a volume of approximately 17 m^3 (600 ft^3). The tanks are connected by 0.305-m (1-ft)-diam ducts as shown in Fig. 1. Air is drawn through the system by a 28.4 m^3 (1000-ft^3/min) centrifugal blower attached to the exit duct of the cylindrical tank. Just upstream of the blower is a 30.5- by 30.5-cm (12- by 12-in.) high-efficiency particulate air (HEPA) filter and a 23.5- by 35.2-cm (9.25- by 13.875-in.) parallel-blade damper (fully open).

Shock waves are created in the system by exploding hydrogen/air-filled latex rubber balloons nominally 50.8 cm (20 in.) in diameter. The balloons are filled using a Matheson model 7372T gas proportional flowmeter through which the hydrogen and air flow simultaneously.

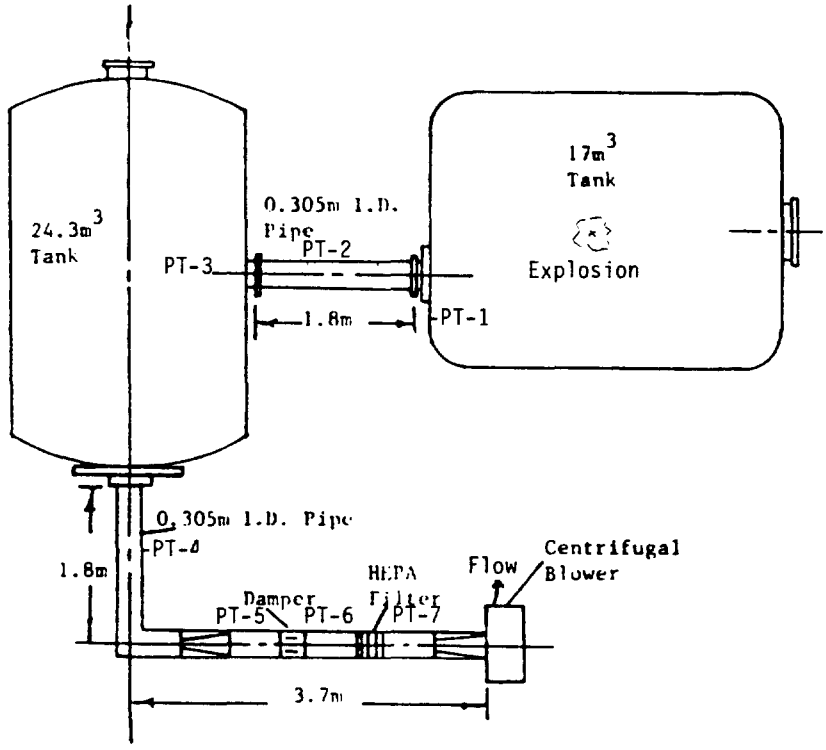


Figure 1. Plan view of the model ventilation system.

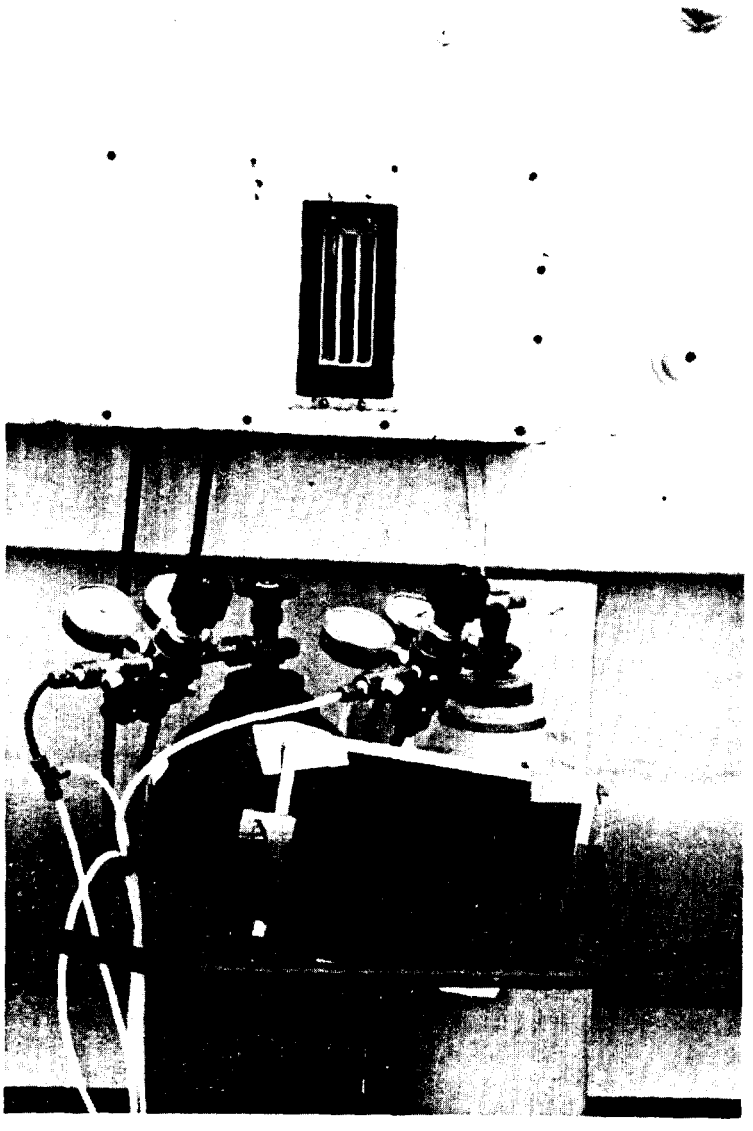


Figure 2. System for filling balloons with gas mixture.

The system for filling the balloons is shown in Fig. 2; Fig. 3 is a photograph of a filled balloon just before an explosion.

The shock wave created by the hydrogen/air explosion was measured by seven Kulite Model XT-190 miniature pressure transducers with a range of 0 kPa to 172 kPa (0 to 25 psia). All pressure measurements except those in the tanks were side-on measurements. The pressure transducer locations are shown by the symbol PT-X in Fig. 1. (X is a digit from 1 to 7.) The data from the pressure transducers were digitized and recorded by a high-speed CAMAC data acquisition system using a DEC PDP11/10 digital computer.

All seven pressure transducers were calibrated against a pressure standard before each experiment. The balloons were filled at a known flow rate for each gaseous component for a measured length of time. A small electrical impulse then caused the hydrogen-air mixture to explode, and the resulting shock wave automatically started the data acquisition system as it encountered a nearby trigger transducer.

Computer Code Description

Two computer codes have been developed at Los Alamos to calculate the gas dynamics associated with confined explosions: EVENT84 and NF85.[1,2] EVENT84 is an updated version of the EVENT computer code and includes an empirical explosion chamber model. Explosions involving TNT, H_2/O_2, acetylene, and red oil are calculated automatically as source terms for the explosion. NF85 is a fully three-dimensional explosion chamber model. It calculates the detailed driver gas dynamics for EVENT84, and its capabilities in simulating shock transmission tests were described earlier.[3]

The emphasis in this paper is modeling the overall system using the EVENT84 computer code. In addition, only gaseous explosions were simulated. Several methods other than NF85 were used to simulate the explosion.

- EVENT84 explosion chamber
- Approximate source-term method
- Pressure-time history

Computer Model for Test Simulation

Certain assumptions are made to model a system using EVENT84: perfect gas (air), compressible flow, momentum balance with friction and inertia, choking, linear and nonlinear filters, certain blower characteristics, and mass and energy addition to the gas phase. The model uses a lumped-parameter formulation; that is, no spatial distribution of parameters within network components is included. In addition, the analytical model must have the same arrangement of components, friction characteristics, capacitance, duct lengths, cross-sectional areas, boundary pressures, and driving forces as the experimental model.

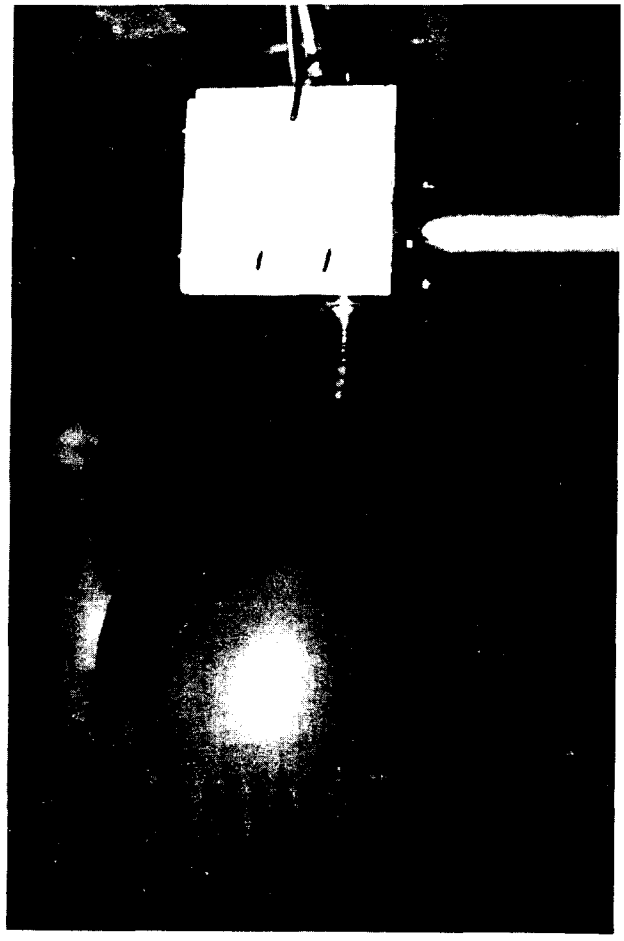


Figure 3. A gas-filled balloon just before an explosion.

The physical system is described first with a schematic consisting of a network of branches and nodes. Network theory defines system elements that exhibit flow resistance and inertia, or flow potential, as branches. The ventilation system components modeled as branches include dampers, ducts, valves, filters, and blowers. The connection points of branches are network system elements called nodes and always have a finite volume. Nodes include specific network components that have a finite volume such as rooms, gloveboxes, and plenums, or the node may contain only the volume of connecting branches. System boundaries, where the volume is practically infinite, also are specified as nodes.

The energy conservation equations are applied to internal (capacitance) nodes using a lumped-parameter formulation assuming homogeneous mixture and thermodynamic equilibrium. A momentum equation that includes the effect of wall friction and inertia is used to relate the flow rate to the pressure drop across a duct; choking is imposed on the duct flow if the conditions warrant it. A filter provides only resistance to the flow. A quasi-steady relation is imposed between the pressure head and the flow rate for a blower.

The network system models for EVENT84 are shown in Fig. 4 and Fig. 5. The inlet on the rectangular tank can be open or closed, as can the inlet on the cylindrical tank. Two arrangements were used for modeling the experiments. In Model 1, the rectangular tank inlet is open and in Model 2, the cylindrical tank inlet is open.

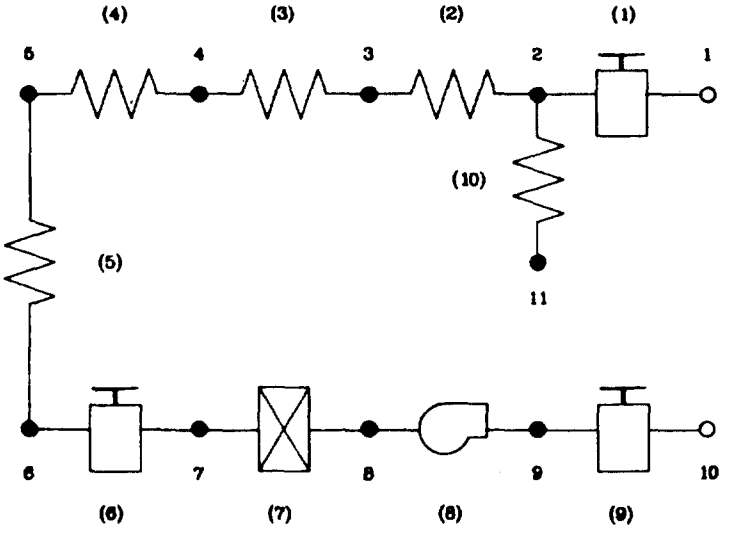


Figure 4. Computer network schematic for Model 1.

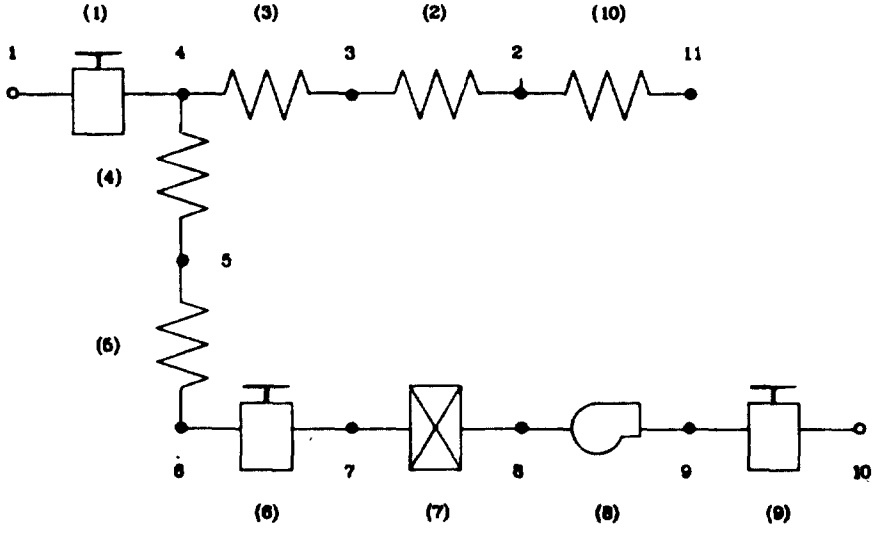


Figure 5. Computer network schematic for Model 2.

Models 1 and 2 consist of 11 nodes, including 2 boundary nodes and 9 internal nodes, and 10 branches. The symbols used on the schematic represent dampers, blowers, duct resistance, filters, and volumes of the ductwork, cylindrical, and rectangular tanks. For example, in Model 1 the numbers enclosed in parentheses represent branches and numbers without parentheses represent nodes. Branches contain blowers, dampers, duct resistance, and filters. The nodes represent points such as the explosion chamber and the cylindrical tank. Pressures and temperatures are calculated at the nodes, whereas flows are calculated for the branches.

To accurately determine the resistance coefficient for each branch, each component (the 90-degree bend, the damper, the filter, and the blower) is modeled as a separate branch. In addition, the entrance and exit for the system are modeled as dampers (branches) to account for the entrance or exit losses. The duct between the two tanks is divided into two branches to accommodate the pressure measurement. The explosions take place within a balloon in the rectangular tank. This balloon is modeled as a separate node, with a flow area into the tank equal to the surface area of the balloon. The explosion is simulated as a mass and energy input into the balloon node, either as user-calculated time functions or through the explosion chamber subroutine.

Experimental and Code Simulation Results

The experimental and code simulation results involve the following.

- Code simulations and comparison with experimental results in the explosion chamber
- Code simulations and comparison with experimental results just before the system filter
- Code simulations of pressures upstream and downstream of the filter
- Experimental results of pressures upstream and downstream of the filter

Both Model 1 and Model 2 were involved in the comparisons.

The first set of experimental and code simulation results is shown in Figs. 6 and 7. Figure 6 shows that the two methods used to simulate the explosion (EXCHAM and SOURCE TERM) over-predict the pressure within the chamber. However, the shape of the pulse is very similar. The peak pressures predicted by the code were 3.174 kPa (0.46 psi), whereas the experimental values were 1.518 kPa (0.22 psi). The peak pressure times were in good agreement. In Fig. 7, Model 2 shows similar results. That is, the peak pressures are approximately twice the values obtained from the experiment. Again, the peak pressure times were in good agreement. Closing the explosion chamber door in Model 2 increases the peak pressure by about 50%. These results were expected using the EVENT84 code. That is, the code is expected to give conservative results in areas where the explosion takes place. That is why the NF85 code has been developed--to more closely simulate explosive effects near the source.

We must point out that the experimental data were smoothed to make the information more presentable. The effect of this process was to take out the highest peaks, which were of the same magnitude as the code results. The high peaks in the experimental data are caused primarily by shock reflections inside the explosion chamber

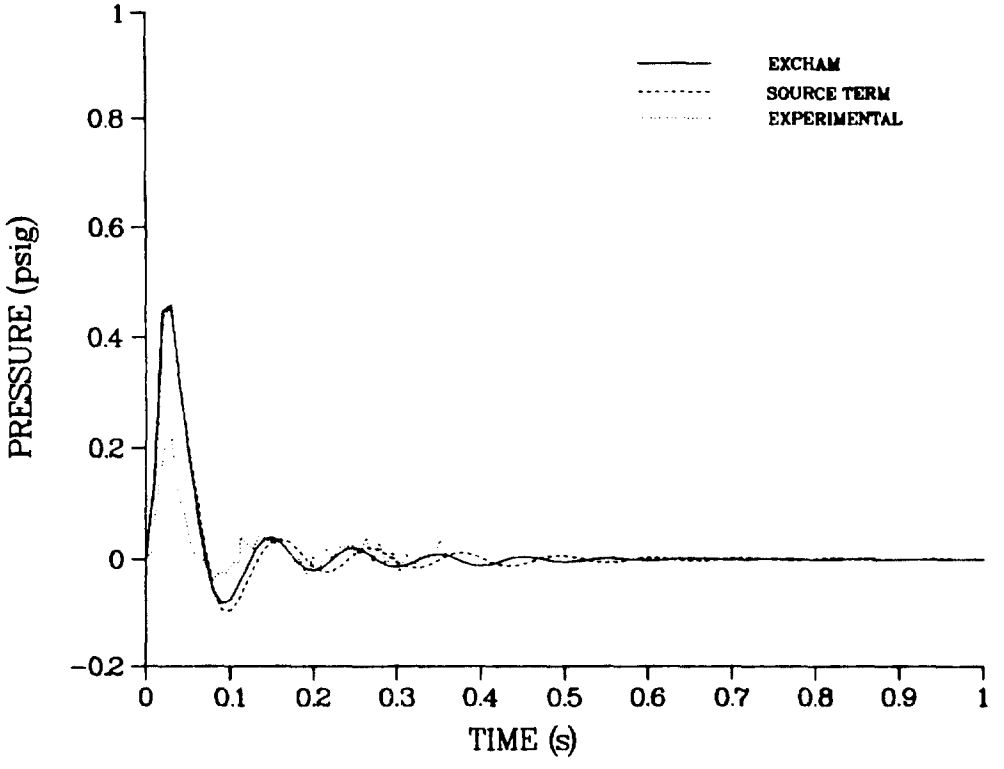


Figure 6. Code simulation of pressure in explosion chamber and comparison with experimental results (Model 1).

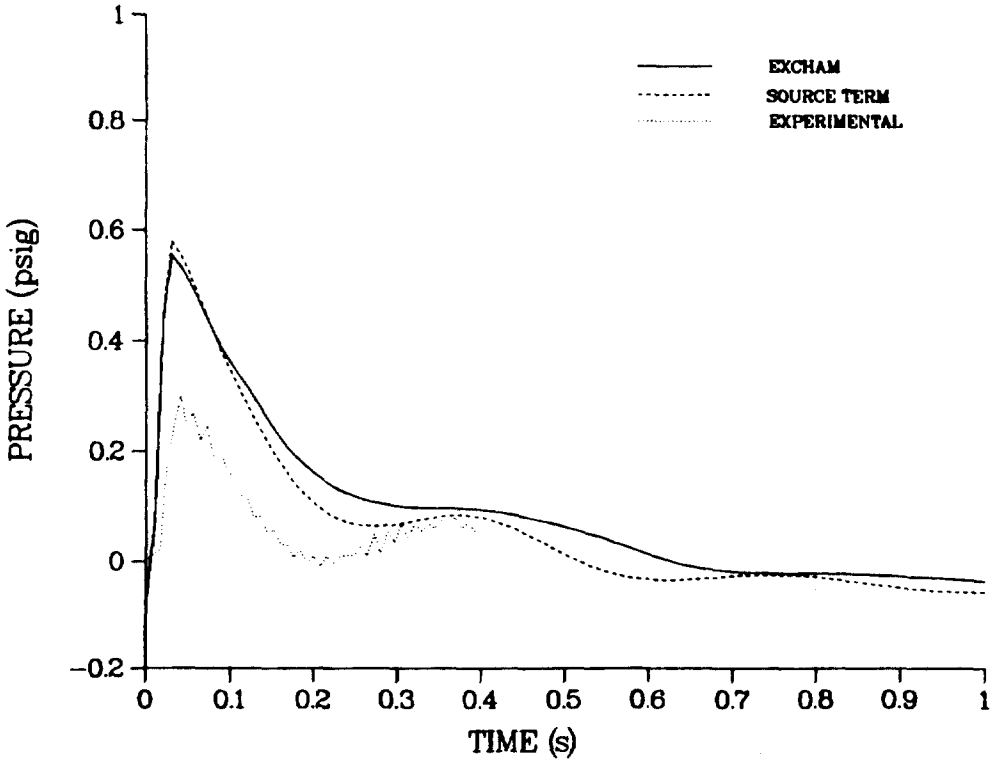


Figure 7. Code simulation of pressure in explosion chamber and comparison with experimental results (Model 2).

Pressure comparisons were made downstream of the explosion (in the chamber right before the filter). This location corresponds to node 7 on Models 1 and 2. As in the results for pressure in the explosion chamber, the code conservatively over-predicts the pressure. However, the analytical and experimental results are much closer. The time at peak pressure is much closer for Model 2 than for Model 1. As shown in Fig. 9, the peak pressure is dissipated to 1.21 kPa (1.208 psi) after passing through the ductwork and the cylindrical tank. The closer EVENT84-predicted pressure transients results supports our claim that the code predicts reasonable pressure levels in regions removed from the explosive source, particularly in areas where the final filters will be located.

Figure 10 is a plot of the pressures upstream and downstream of the filter for Model 2. As shown in Fig. 10, the effect of the filter is to essentially damp out the pressure wave. Figure 11 shows the code simulations of the pressures before and after the filter. These results indicate that the modeling does not indicate a complete dampering of the pressure wave although the peak pressure is reduced from 1.07 kPa (0.155 psi) to 0.345 kPa (0.05 psi).

Summary

Experimental verification of the EVENT84 computer code using hydrogen/air gas mixtures has been performed. The experimental apparatus consisted of two compartments with interconnected ductwork, a damper, a filter, and a blower. EVENT84's methods of simulating explosive events were compared with pressure transients obtained in the explosion chamber. The code predicted results that were conservative by a factor of 2. Comparison of pressure at the system's filter indicate good agreement with the experimental data. Experimental and analytical results show that the effect of the filter is to dampen the pressure wave as it passes through the filter.

Future experiments will use solid explosive and be expanded into a much larger system. These experiments will also use a simulant radioactive aerosol for material transport data.

References

1. Martin, R. A. and Wilson, T. M., "EVENT84 User's Manual--A Computer Code for Analyzing Explosion-Induced Gas-Dynamic Transients in Flow Networks," Los Alamos National Laboratory report LA-10312-M (December 1984).

2. Steinke, R. G., "NF85 Users Manual--A Computer Code to Predict Three-Dimensional Explosion-Induced Gas-Dynamics in Confined Spaces," Los Alamos National Laboratory report in preparation.

3. Smith, P. R., Fenton, D. L., Moore, J. A., and Steinke, R. G., "Experimental and theoretical investigation of shock waves in ventilation systems," in Proc. European Conference on Gaseous Effluent Treatment in Nuclear Installations, Luxembourg (October 1985).

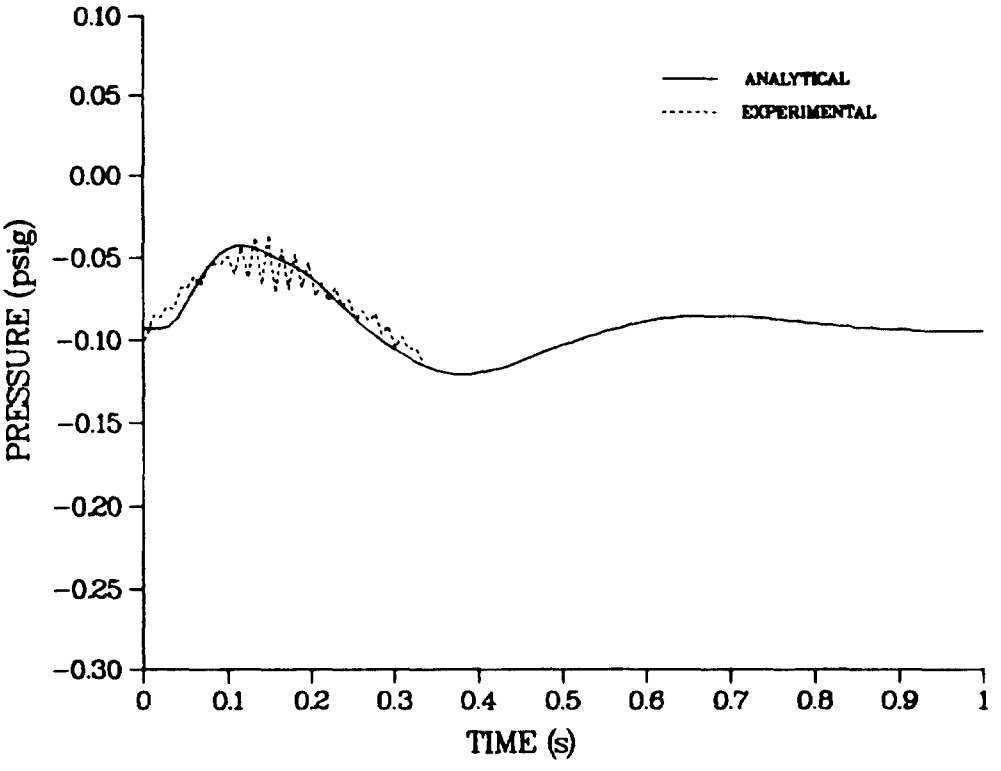


Figure 8. Code simulation and experimenal results of the pressure just before the filter in Model 1.

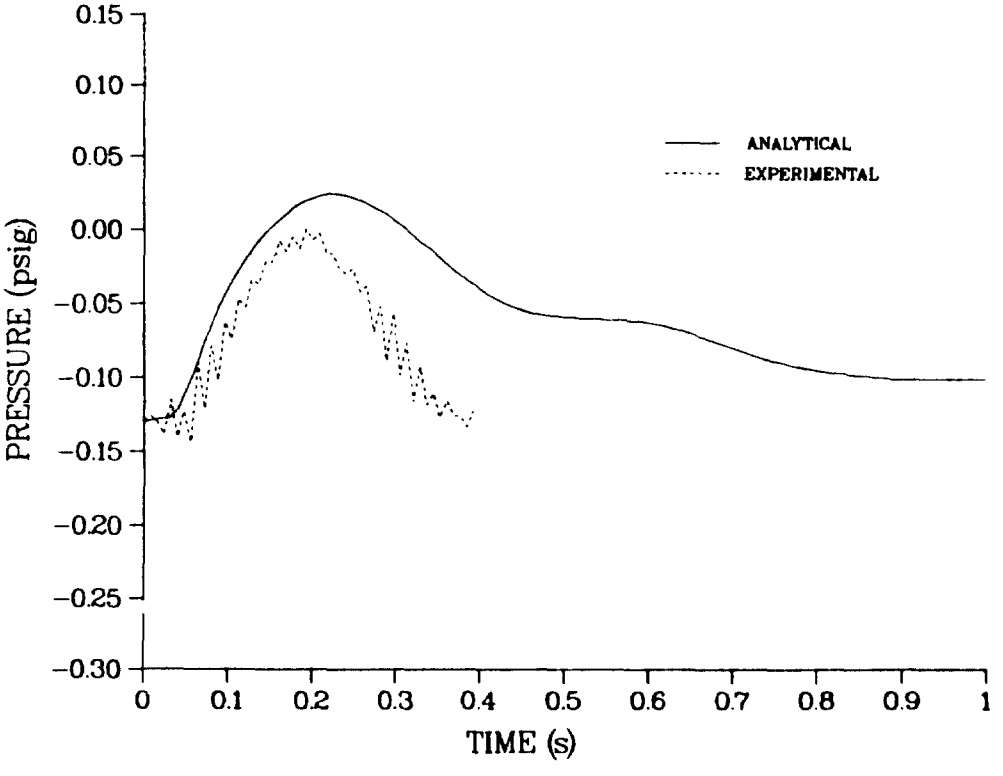


Figure 9. Code simulation and experimental results of the pressure just before the filter in Model 2.

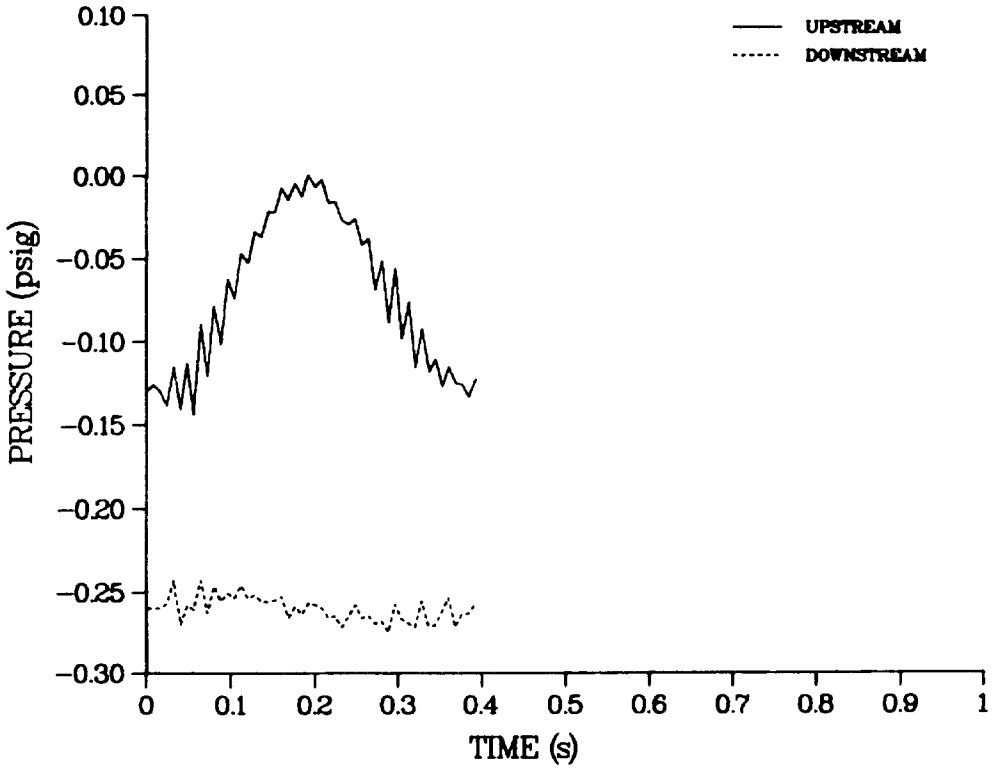


Figure 10. Experimental results for transient pressures upstream and downstream of the filter (Model 2).

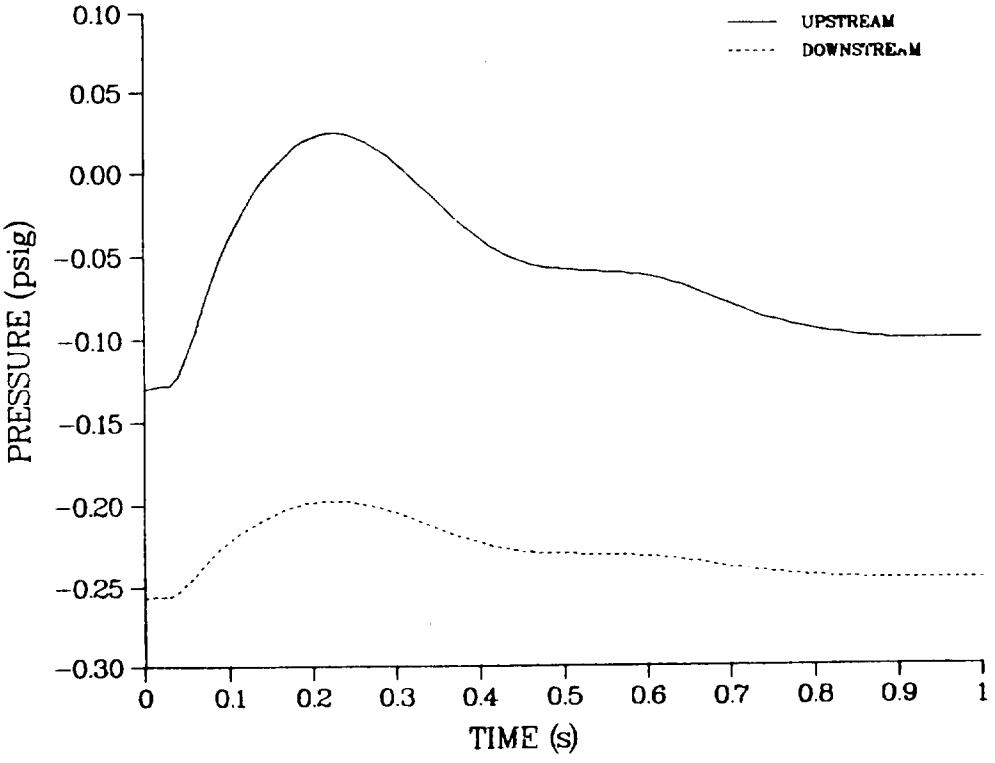


Figure 11. Code simulation results of pressures upstream and downstream of the filter (Model 2).

DISCUSSION

SANDOVAL: Did you measure the performance of the HEPA filters you tested while under shock and environmental loadings? What was the impulse you measured under the pressure loadings?

GREGORY: We didn't do it in these particular tests. We have performed tests like that with a shock tube to look for structural levels where the filter is going to break. We also looked at efficiency whenever we entrained a certain amount of aerosol in the shock pulse itself. Depending upon the filter, we found the filters failed between 0.5 and 2.5 psi across the filter over 0.1 seconds. In the studies discussed here, we were just trying to verify the computer code so we didn't worry about efficiencies or structural levels of the filters.

YAMADA: I am interested in the EVENT code. Is EVENT-84 code the same as the original EVENT code? If not, please tell me what is the advantage of the later version?

GREGORY: As you noted, there is a code called EVENT at Argonne National Laboratory. It is called EVENT-84. The only difference is that EVENT-84 incorporates an explosion chamber model that uses data from the Naval Service Weapons Laboratory. It allows you to create whatever explosive spike you like. Or, you can allow the explosion chamber model to use empirical data that is in the code to calculate the shape and the magnitude of the initiated explosion depending upon the pounds of TNT, or red oil, or whatever you have. That is the only difference.

FIRE-ACCIDENT ANALYSIS CODE (FIRAC) VERIFICATION

B. D. Nichols and W. S. Gregory
Los Alamos National Laboratory

D. L. Fenton and P. R. Smith
New Mexico State University

Abstract

The FIRAC computer code predicts fire-induced transients in nuclear fuel cycle facility ventilation systems. FIRAC calculates simultaneously the gas-dynamic, material transport, and heat transport transients that occur in any arbitrarily connected network system subjected to a fire. The network system may include ventilation components such as filters, dampers, ducts, and blowers. These components are connected to rooms and corridors to complete the network for moving air through the facility.

An experimental ventilation system has been constructed to verify FIRAC and other accident analysis codes. The design emphasizes network system characteristics and includes multiple chambers, ducts, blowers, dampers, and filters. A large industrial heater and a commercial dust feeder are used to inject thermal energy and aerosol mass. The facility is instrumented to measure volumetric flow rate, temperature, pressure, and aerosol concentration throughout the system. Aerosol release rates and mass accumulation on filters also are measured.

We have performed a series of experiments in which a known rate of thermal energy is injected into the system. We then simulated this experiment with the FIRAC code. This paper compares and discusses the gas-dynamic and heat transport data obtained from the ventilation system experiments with those predicted by the FIRAC code. The numerically predicted data generally are within 10% of the experimental data.

Introduction

FIRAC is one of a family of computer codes that has been developed at the Los Alamos National Laboratory to predict the effects of fires, explosions, and tornadoes in nuclear fuel cycle facilities.[1] The FIRAC code was designed to numerically model fire-induced flows, heat transfer, and material transport within ventilation systems and other airflow pathways. Fires may be represented in the code either parametrically or by a fire compartment model, FIRIN1, which was developed at the Pacific Northwest Laboratory[2].

FIRAC and the other accident analysis codes need to be validated. Therefore, a ventilation system model has been constructed at the New Mexico State University (NMSU) to obtain the necessary experimental data. We have performed a series of experiments in which a known rate of thermal energy is injected into the system and have simulated these experiments with FIRAC. In the second part of this paper, we describe the experimental facility and its instrumentation, and in the third part, we present the numerical model and discuss its salient features. In the last part, we discuss the gas-dynamic and heat transport data obtained from the ventilation system experiments and compare them with those predicted by the FIRAC code.

Experimental Facility

The multicompartment ventilation system model is installed in a prestressed concrete building that provides environmental control; the building is at the Mechanical Engineering Test Site on the NMSU campus. The model ventilation system is designed to accommodate thermal, pressure, and aerosol inputs. The thermal inputs are generated by a commercially available duct heater rated at 92 000 kcal/h fired by natural gas and limited to a maximum of 300°C. The duct heater is on casters, which allows thermal input from different locations of the model system. Pressure pulses are limited to a 140-kPa overpressure and must originate in the rectangular volume shown in Fig. 1. The pipe and square ducts are designed to have a mechanical safety factor of 3. The particulate mass input is provided by a commercial dust feeder having variable supply rates between 1 and 40 g/min (particulate material density = 1 g/cm^3). The maximum particulate mass concentration is approximately 1.4 g/m^3 for unit-density particulate material.

The model ventilation system's arrangement of ducts and volumes is shown in Fig. 1. For economy, 30.5-cm-diam Schedule 20 pipe is used for the bypass loop around the two volumes and for the connections between the two volumes. The 0.6-m-square ducts were made from 0.64-cm steel plate and were used for the remainder of the ventilation system. The system's straight length is approximately 24.4 m. The inlet and outlet round duct connections are within the lower third of the rectangular tank and differ in height by 0.69 m vertically. Figure 1 shows one circular duct connecting at the top of the cylindrical volume and the other circular duct connecting at the side of

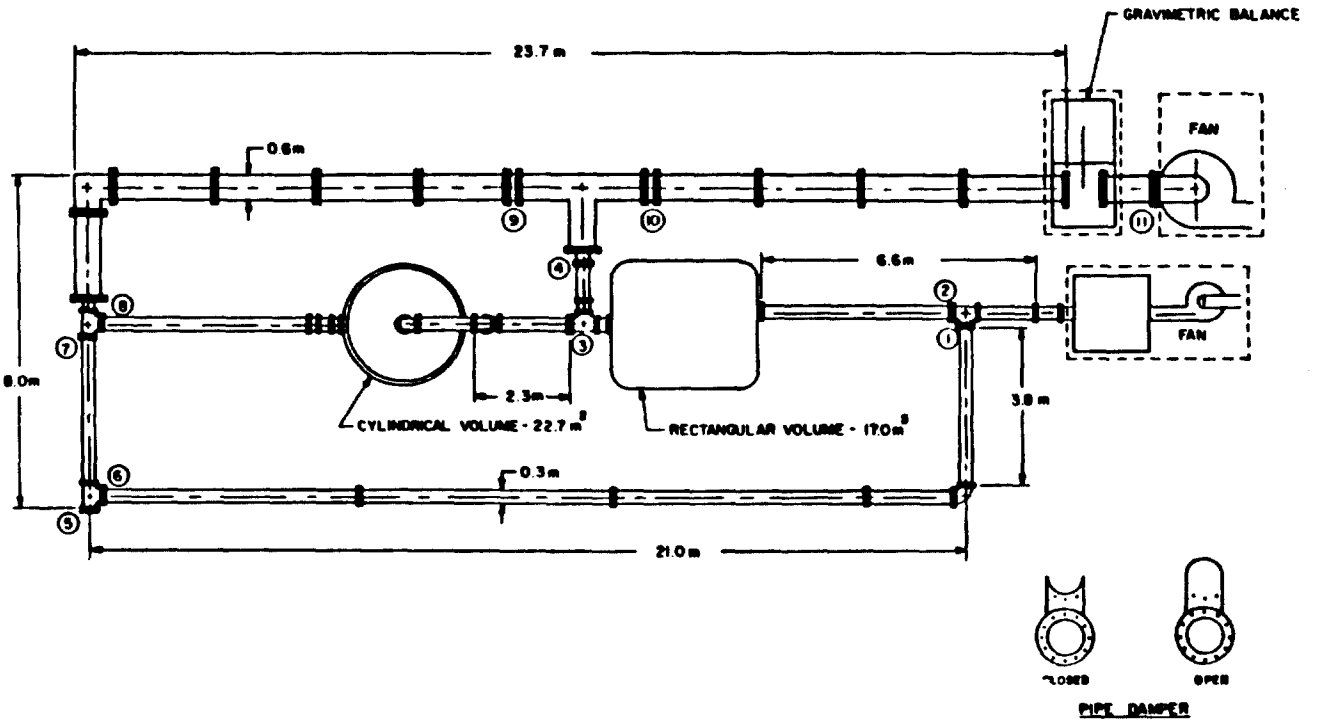


Figure 1. Schematic of the ventilation system model.

the volume (lowest possible location). The centerline distance of both the round and square ducts above the floor is 1.1 m.

The two volumes are steel tanks modified as shown in Fig. 1. The rectangular tank (17.0 m^3 in volume) has 5-cm-thick walls and can withstand the largest pressure pulses. The remainder of the system limits the maximum pressure pulse to about 140 kPa over-pressure. The cylindrical tank (22.6 m^3 in volume and 4.6 m high) is upright to provide the maximum possible stratification and serves as a location for thermal and/or particulate mass input. The two fans in the facility provide positive or negative pressures in the model ventilation system.

The round-duct dampers are numbered in Fig. 1 and are reversible 1.27-cm steel plates secured by the pipe flanges. These dampers are either full open or closed. Additionally, three dampers are located in the square duct between the high-efficiency particulate air (HEPA) filter gravimetric balance and fan, upstream from the square-duct tee, and downstream from the square-duct tee. Dampers 9 and 10 are commercial models and thus are adjustable, but damper 11 is conceptually similar to the round-duct dampers. Numerous model system configurations can be obtained by opening and closing the dampers. The HEPA filter gravimetric balance is designed especially to measure the collected mass on a HEPA filter installed in the system. The balance uses a null technique and an electronic force transducer to achieve a resolution of 2 g.

This model ventilation system is three-dimensional because of the vertical height associated with the cylindrical volume. Thus, thermal loads or "test fires" (possibly in conjunction with a particulate mass) can be input to the base of the cylindrical volume, and the transport of both thermal energy and particulate material can be observed in the model ventilation system. Additionally, the gravimetric balance can determine the collected particulate mass on the HEPA filter. Careful collection of particulate material on the internal surfaces yields information on total deposition.

The thermal tests reported in this paper used only a portion of the ventilation system model shown in Fig. 1. The subsystem used comprises the section of 30.5-cm-diam pipe between dampers 5 and 7 (indicated on Fig. 1), the pipe tee joint adjacent to dampers 7 and 8, and the entire section of the 0.6-m-square duct. The gravimetric balance and the exhaust fan are not included. The commercial duct heater, which includes the supply blower, injects thermal energy into the system at damper 5. Dampers 4, 6, and 8 are closed for these tests.

The internal and external wall temperatures are measured at the longitudinal center of each segment of pipe and duct. The thermocouple generally is placed on the vertical center of one wall. In one section of duct, thermocouples are placed on each vertical wall, in the top, and in the bottom of the duct to measure any thermal gradients in the duct cross section. Pipe and duct wall temperature measurements are made at 15 locations. In addition to the wall temperature measurements, the gas flow temperature is measured at the center of each segment of the 0.6-m-square duct. Twenty gage, type J thermocouple wire was used for these measurements, and the external and internal wall thermocouples were mounted by peening. The internal gas flow thermocouple assemblies were made of a 0.64-cm-diam stainless steel sheath with an aluminum head and with a type J thermocouple. All internal thermocouple wire insulation was replaced by a fiberglass

sleeve. The gas flow was obtained by a pitot tube in a five-section traverse of equal concentric areas at the system outlet duct with the pressure readings made with an inclined manometer.

The pressure is measured with a 0.0- to 62.3-Pa manometer at the center of each segment of the 0.6-m-square duct and other selected locations, such as on each side of the 90° elbow and on each side of the commercial dampers. These locations were chosen to provide data spatially compatible with data output by the FIRAC code.

The Numerical Model

The FIRAC computer code initially was designed to predict fire-induced transients in nuclear fuel cycle facility ventilation systems. FIRAC simultaneously calculates the gas-dynamic, material transport, and heat transport transients that occur in any arbitrarily connected network system subjected to a fire. The network system includes ventilation system components such as filters, dampers, ducts, and blowers. These components are connected to the rooms and corridors to complete the network for moving air through the facility.

We used the lumped-parameter method to describe the airflow system. No spatial distribution of parameters within the network components is included in this approach. Network theory defines system elements that exhibit flow resistance and inertia, or flow potential, as branches. The ventilation system components contained in branches include dampers, ducts, valves, filters, and blowers. The connecting points of branches are network system elements called nodes and always have a finite volume. Nodes include specific network components that have finite volumes, such as rooms, gloveboxes, and plenums, or the node may contain only the volume of the connecting branches. In addition, system boundaries, where the volume is practically infinite, are specified as nodes. Fluid mass and energy storage at the internal nodes is taken into account by using the equations for conservation of mass and energy. The conservation equations are applied to the room nodes using the lumped-parameter formulation assuming a homogeneous mixture and a thermodynamic equilibrium. An implicit numerical scheme is used to solve for the pressure and density at each node. In the solution algorithm, the flow rate through branches is modeled as a function of the differential pressure and friction factors.

The material transport model in the code estimates the movement of material through the network of ventilation system components. The code calculates material concentrations and material mass flow rates at any location in the network. This model includes convective transport, depletion by gravitational settling, entrainment from ducts, and filtration. No phase transitions or chemical reactions are modeled.

The code's heat transfer model predicts how the combustion gas in the system cools as it flows through the network ducts. The model predicts the temperature of the gas leaving any section of the duct if the inlet temperature and gas properties are known. The following heat transfer processes are modeled.

- Forced convection between the gas and the inside duct walls
- Radiation between the gas and the side duct wall
- Heat conduction through the duct wall
- Natural convection from the outside duct wall to the surrounding air
- Radiation from the outside duct wall to the atmosphere

The total amount of energy removed from the gas as it flows through the duct is given by the solution of a set of four coupled nonlinear algebraic equations. These equations are solved using an iterative procedure.(1)

The network system model of the experimental system is shown in Fig. 2. The model consists of 25 nodes (including 2 boundary nodes) and 24 branches. We divided the 30.5-cm-diam pipe into 4 branches and the duct into 14 branches (typically 2.44-m segments). We modeled each tee joint and bend as a separate branch because this allows an accurate determination of the resistance coefficients for these branches. The heater is simulated by a temperature-time and mass-time history input at Node 8.

Discussion of Experimental and Computational Results

The experimental sequence began with the duct heater blower running until steady-state flow was reached. with the blower continuing to run, a 30-min heat pulse then was injected into the system at a predetermined thermal rate. The blower then remained on, and the system returned to ambient conditions. Gas flow and wall temperatures typically were recorded by the data acquisition system at 40-s intervals throughout the experiment, and pressures and flow rates were measured manually during each phase of the experiment. The steady-state volumetric flow rate measured before the heat pulse was 0.085 m^3/s, and the pressure drop across the system was about 38 Pa. At the end of the 30-min heat pulse, the flow rate was 0.179 m^3/s with a pressure drop across the system of 100 Pa. As the system cooled, the measured flow rate decreased to 0.080 m^3/s.

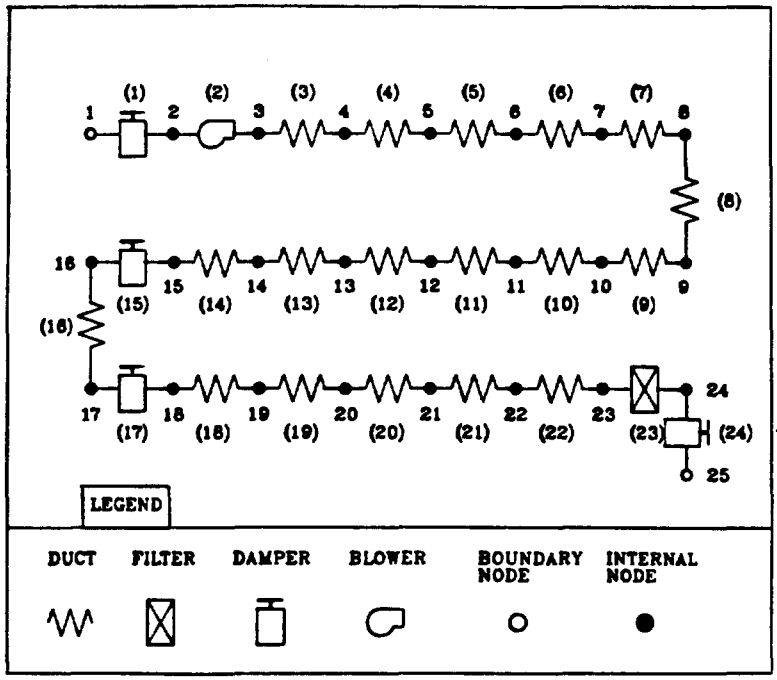


Figure 2. Network system model of the experimental system.

The numerical simulation of the experiment using FIRAC began with the experimentally determined steady-state flow, temperature, and pressure as initial conditions. A temperature-time function representing the measured temperature during and after the heat pulse was input into the network model node 8 (Fig. 2), which corresponds to the temperature at the center of the first section of the 0.6-m-square duct. This is the section of duct connected to the 30.5-cm-diam pipe.

A comparison of the experimental and the FIRAC-generated temperatures as a function of time and space showed generally good agreement. In Fig. 3, the gas flow temperature as a function of time is shown for nodes 11, 14, and 22. (In Fig. 1, node 11 is in the center of the section of duct downstream of the 90° bend, node 14 is in the center of the section of duct upstream of commercial damper 9, and node 22 is in the center of the section of duct just upstream of the filter and gravimetric balance). The code predictions for the temperatures at nodes 11 and 22 are within 5% of the experimental data during the heat pulse and consequent rise in temperature. The node 11 error increases to nearly 12% as the temperature decreases. Because the nodes with the highest and lowest temperatures agree relatively well with the experimental values during the heat pulse, we were surprised that node 14 showed a larger error--about 12% at the peak temperature. We checked the nodes adjacent to node 14, and this indeed is the error pattern, which is shown in Fig. 4. Here the temperature is plotted as a function of duct length at three selected times: at the end of the heat pulse, 150 s after the heat pulse, and 830 s after the heat pulse. The largest errors (up to 12%) are between 9 and 18 m, which corresponds to the locations of nodes 11 through 16.

The FIRAC code duct heat transfer model simulates the amount of thermal energy the gas loses as it passes through a section of duct. This energy loss is a function of radiation and convective processes on the inside and outside of the duct wall and heat conduction through the wall. The computed temperature loss is directly proportional to the energy loss and inversely proportional to the mass flow rate. Heat loss is not modeled at branches other than ducts. The model for heat conduction through the duct wall is based on standard models such as Patankar's.[3] Temperatures at several nodal points through the wall can be calculated with this model. Because the wall is only 0.64 cm thick, the measured temperature differential across the wall is always less than 1.0°C. Therefore, we modeled the wall with only one nodal point; thus, the calculated temperature is the average duct wall temperature.

The measured temperature-time history for the internal duct walls at node 14 is shown in Fig. 5. The general temperature difference at the walls is the pattern expected; however, the magnitude of the temperature difference (23°C) between the top and bottom walls of the duct is larger than expected. The front and back (vertical) walls should have the same value and are within 2°C at all times. The four wall temperatures at node 14 were averaged to compare them with the computed average. The experimental and computed temperatures as a function of time are shown in Fig. 6. The slope of the computed curve is less than that of the experimental curve both during and after the heat pulse. A maximum error of about 10% is seen at late times.

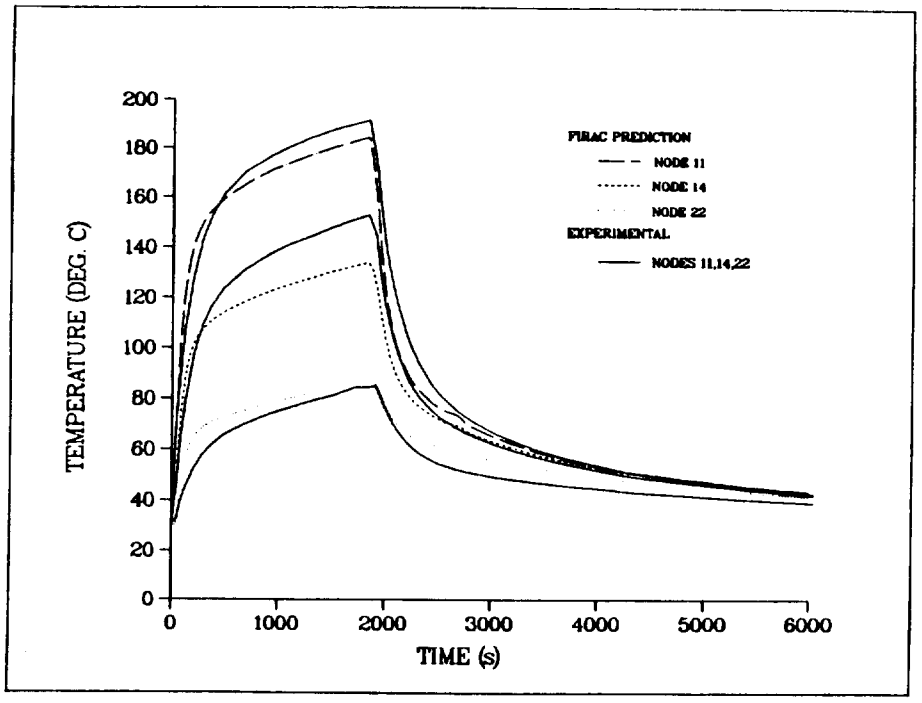


Figure 3. Experimental and FIRAC generated gas flow temperature-time histories for network system nodes 11, 14, and 22.

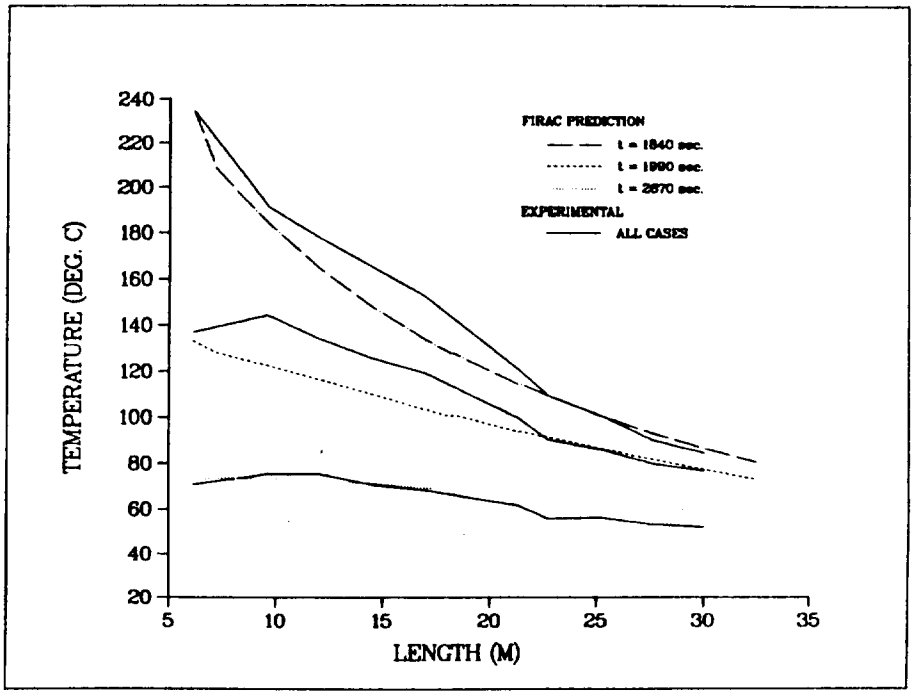


Figure 4. Experimental and FIRAC generated gas flow temperatures as a function of duct length at times 1840, 1990, and 2670 seconds after beginning of heat pulse.

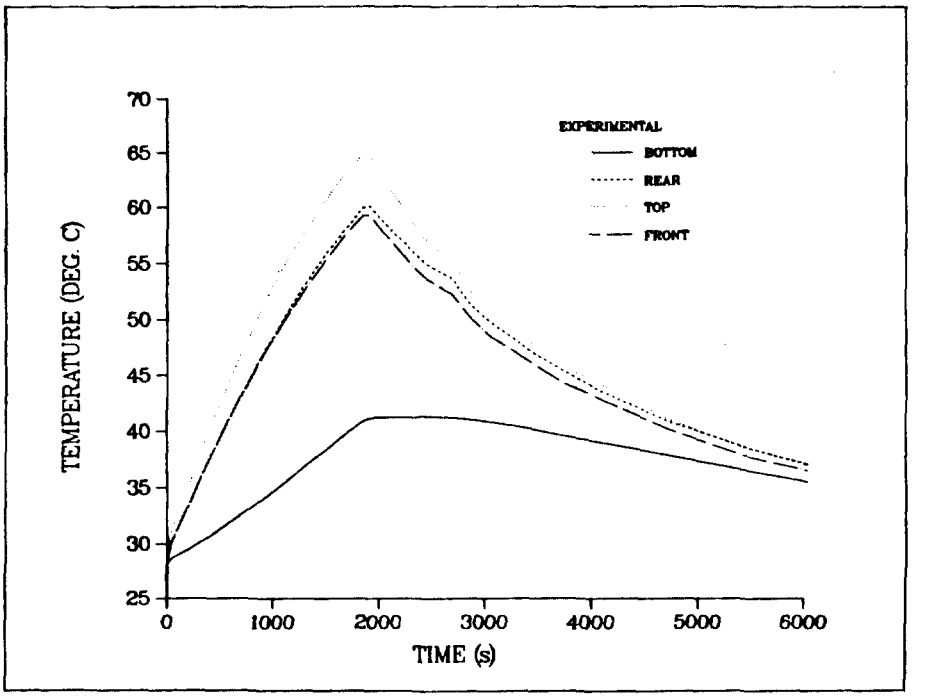


Figure 5. Measured temperature-time histories for the internal duct walls at network system.

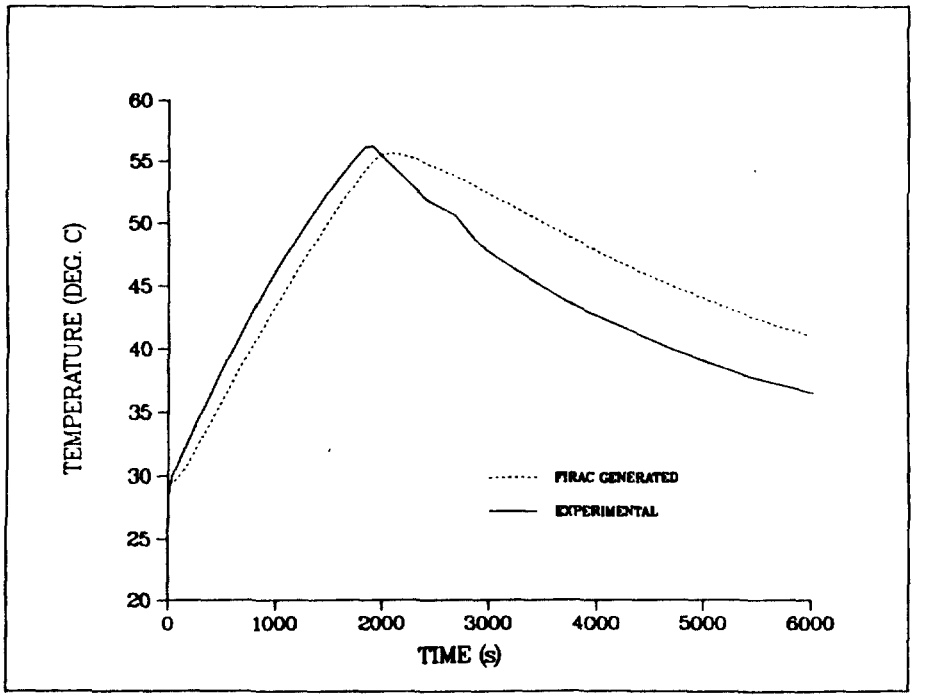


Figure 6. Experimental and FIRAC generated average wall temperature-time history at network system node 14.

Conclusion

The FIRAC computer code has successfully simulated the heat transfer measured in a single experiment with the ventilation system model at NMSU. This suggests that the heat transport model in FIRAC is a reasonable one; however, we need to perform additional experiments at different flow rates and thermal injection rates to further test this model. We then need to verify the other code capabilities, specifically, the material transport model.

References

1. Nichols, B. D. and Gregory, W. S., "FIRAC User's Manual: A Computer Code to Simulate Fire Accidents in Nuclear Facilities," Los Alamos National Laboratory report LA-10678-M (April 1986)

2. Chan, M. K., Ballinger, M. Y., Owczarski, P. C., and Sutter, S. L. "User's Manual for FIRIN: A Computer Code to Estimate Accidental Fire and Radioactive Source Term Releases in Nuclear Fuel Cycle Facilities," Pacific Northwest Laboratory report NPNL-4532 in preparation.

3. Patankar, S. V., Numerical Heat Transfer and Fluid Flow, McGraw-Hill Book Company, Inc., New York, Chap. 4, 1980.

DISCUSSION

PARTHASARATRHY: In the beginning of the paper you referred to material transport, does the code have a capability to predict size distribution and mass concentration of aerosols generated in a fire?

NICHOLS: The FIRIN code, developed at Pacific Northwest Laboratories, predicts the mass generation rate and the size distribution of the particles, and then the information is used as input into the FIRAC code. The FIRAC code does calculate the transport of multiple species of particles of different densities and different sizes, up to about 20 or so different species.

PARTHASARATHY: Will further experiments be concluded to verify this aspect?

NICHOLS: Yes. As soon as we conclude these experiments, we will try in the next series to test the particle flow model.

METHODS FOR AIR CLEANING SYSTEM DESIGN AND ACCIDENT ANALYSIS

W. S. Gregory and B. D. Nichols
Los Alamos National Laboratory
Los Alamos, New Mexico

Abstract

This paper describes methods, in the form of a handbook and five computer codes, that can be used for air cleaning system design and accident analysis. Four of the codes were developed primarily at the Los Alamos National Laboratory, and one was developed in France. Tools such as these are used to design ventilation systems in the mining industry but do not seem to be commonly used in the nuclear industry. For example, the Nuclear Air Cleaning Handbook is an excellent design reference, but it fails to include information on computer codes that can be used to aid in the design process. These computer codes allow the analyst to use the handbook information to form all the elements of a complete system design.

Because these analysis methods are in the form of computer codes, they allow the analyst to investigate many alternative designs. In addition, the effects of many accident scenarios on the operation of the air cleaning system can be evaluated. These tools originally were intended for accident analysis, but they have been used mostly as design tools by several architect-engineering firms.

The Cray, VAX, and personal computer versions of the codes, an accident analysis handbook, and the codes' availability will be discussed. The application of these codes to several design operations of nuclear facilities will be illustrated, and their use to analyze the effect of several accident scenarios also will be described.

Introduction

Ventilation and air cleaning systems can be highly complicated and involve many interconnected flow pathways, rooms, flow controllers, filters, and blowers. The flow arrangement may use parallel and series systems, separate supply and exhaust systems, recirculation, and makeup air. Heating, ventilating, and air conditioning (HVAC) analysts and designers are capable of designing a highly complicated ventilation system. However, the ventilation and air cleaning systems for nuclear facilities require special design considerations and must be analyzed for the effects of hypothetical accident situations.

The "Nuclear Air Cleaning Handbook" provides information of special interest to designers of nuclear air cleaning systems.[1] The possibility of and concern for accidents such as earthquakes, tornados, fires, and explosions are discussed, but no methods are offered to analyze the entire ventilation system for these accident conditions. We believe that there are analytical tools in the form of handbooks and computer codes that will allow ventilation system designers and safety analysts to perform the necessary accident effect calculations. Further, there is no reason why the steady-state portions of the computer codes could not be used to aid the designer in determining the pressures, flows, and temperatures throughout the ventilation system. In addition, these codes would allow the designer to examine many alternative arrangements and subsystems. Perhaps the best part of these methods is that the analyst then can

use the same codes to evaluate the potential effects of hypothetical accidents on the system design. In other words, both the system design and the safety analysis could be performed in parallel.

We will describe several computer codes that are available to perform both design and safety analyses. Several examples of applications of these codes will be illustrated.

Computer Code Descriptions

Computer codes that have been developed at the Los Alamos National Laboratory and at the Commissariate a l'Energie Atomique (CEA) in France will be described. All of these codes require a steady-state or normal operating condition calculation. This part of the analysis can be used by designers to verify designs or examine alternative ones. The transient calculations performed by the codes are optional and are especially developed to simulate large pressure surges, explosions, and fires. The codes are presented according to which accidents they are designed to model.

Tornado Modeling, the TORAC Code[2]

TORAC is an improved version of the TVENT computer code, which was developed at Los Alamos.[3] There are three basic differences between TVENT and TORAC:

- material transport capability,
- blowers can be turned on and off, and
- dampers can be controlled with an arbitrary time function.

The TORAC code can model large pressure surges or simulate the effects of a tornado depressurization at the inlet and exhaust points of a ventilation system. The capability to modify the effects of blowers and dampers within the system gives the designer a tool to examine alternative system designs, effects of equipment failure, and multiple damper control points.

The material transport aspects of the code are very basic. That is, only the convection, gravitational settling, entrainment, and filter depletion mechanisms are modeled. The complex interactions between material species and within material species are not modeled. TORAC and TVENT are available from the National Energy Software Center (NESC). CDC 7600 and CRAY versions are available.

Explosion Modeling, EVENT84[4] and EXPAC[5]

Two Los Alamos codes can be used to simulate explosions within air cleaning systems. EVENT84 simulates the gas dynamics of an explosion; EXPAC adds material transport to the calculation. The explosion codes are more complicated than the TORAC code because more detailed data are needed to complete the calculation. Like TORAC, these codes also obtain the flows, pressures, and temperatures in a normal operating condition before any transient calculations are performed. These codes can calculate the propagating effects of solid or gaseous explosions within an air cleaning system or through any air pathway. EVENT84 and EXPAC currently are being verified by selected experimental studies. EVENT84 is available from the NESC, but the EXPAC code is still under development. CDC 7600 and CRAY versions are available.

Fire Modeling, PIAF[6] and FIRAC[7]

Two computer codes have been developed to simulate the effects of fires within nuclear facility air cleaning systems. One was developed at CEA and is named PIAF. It was developed to study the responses of ventilation networks to mechanical or thermal perturbations.

Using the PIAF code to model mechanical systems in facilities has proven useful because it can identify events that are of safety concern and quantify the possible damage within the facility. A steady-state analysis of a large ventilation network is described in Ref. 6. A separate paper describing the PIAF modeling of the ventilation network operation is to be presented at this conference. This code's availability is unknown.

A second code to simulate fire conditions was developed by Los Alamos. This code is named FIRAC and soon will be available from NESC. It has been modified to run on a personal computer. CRAY, VAX, and CDC 7600 versions are available. FIRAC includes material transport and uses a burn room model developed by Battelle Pacific Northwest Laboratories. The code uses the basic gas dynamics available in EVENT84 but adds heat transfer from the system ductwork.

Handbook

An accident analysis handbook has been developed to assist safety analysts in modeling and analyzing nuclear facilities.[8] The emphasis has been placed on fuel cycle facilities, but other facilities also can be modeled. The handbook contains information on fuel cycle operations and processes as well as methods to develop radioactive source terms for fire and explosion events. Modeling techniques, many sample problems, and information on how to use particular computer codes are also included. This handbook is available in draft form from the Nuclear Regulatory Commission and currently is being revised for final form. (A completion date of October 1986 is planned.)

Applications

Design Simulation

An example of a design simulation using one of the TVENT codes involves determining the effect of a recirculation blower shutting off and the effect on room key pressures when the main supply blower slows down.[9] A study of these situations and their effects on part of the Los Alamos Plutonium Processing Facility are reported in Ref. 9. The results of this study showed that loss of the recirculation blower did not have a significant effect on the overall system pressures. (A 10% slowdown in the main supply blower caused a sharp reduction in corridor and compartment pressures.) This information allowed the analyst to identify certain control dampers to control large pressure fluctuations. These calculations could aid in the design of the system and the placement of system controllers.

A second design simulation involves using the FIRAC code to simulate the operation of a proposed radioactive waste incinerator. In this case, the FIRAC results were not the same as the design (because of a lack of extensive design data) but were within a reasonable

range. Using FIRAC in parallel with the incinerator design can prevent design flaws that could appear when a safety analysis is performed after the incinerator is constructed.

Accident Analysis

The design simulation of the incinerator discussed above can be used to illustrate how an accident analysis can be performed in parallel with the design phase. In this case, we examined the possibility of an inadvertent injection of an explosive mixture into the pyrolysis chamber of the incinerator. In this accident scenario, we have assumed that a container of 100 cm^3 of toluene is inserted into the process line. After performing the analysis to determine the effects of this scenario, we found that a positive pressure is created in the pyrolysis and combustion chambers. This accident analysis scenario shows that a positive pressure in the pyrolysis and combustion chambers causes a flow reversal through the pyrolysis and combustion inlet air paths. Therefore, protective devices would have to be designed into the system to prevent a radioactive release to the atmosphere when the incinerator chambers overpressurize. A second accident scenario also was examined. This involved failure of the exhaust blower for the system. Again, this caused a pressure increase in the incinerator chambers.

In Ref. 6, an accident analysis using the PIAF computer code is described. The report discusses evaluations of the effects of a 9-kg and a 26-kg fire in gloveboxes. The effects of cell temperature, pressure, exhaust flow rate, and filter pressure drop are determined in these calculations. Future modifications to the code will include aerosol release calculations.

Summary

We have described analysis methods that can be used in the design and accident evaluation of nuclear ventilation and air cleaning systems. Applications of these analytical methods, in the form of computer codes, are given for both design and accident analysis. Four of these computer codes have been developed by Los Alamos, but one code developed in France also is discussed. We feel that future editions of the Nuclear Air Cleaning Handbook could benefit greatly if a chapter is devoted to use of analytical methods that bring the entire nuclear air cleaning system together for analysis. Evaluation of the system as a whole for both design effectiveness and accident analysis could lead to more efficient and safer designs.

References

1. Burchstead, C. A., Fuller, A. B., and Kahn, J. E., "Nuclear Air Cleaning Handbook," Oak Ridge National Laboratory report ERDA 76-21 (March 1976).

2. Andrae, R. W., Tang, P. K., Martin, R. A., and Gregory, W. S., "TORAC User's Manual--A Computer Code for Analyzing Tornado-Induced Flow and Material Transport in Nuclear Facilities," Los Alamos National Laboratory report LA-10435-M, NUREG/CR-4260 (May 1985).

3. Duerre, K. H., Andrae, R. W., and Gregory, W. S., "TVENT--A Computer Program for Analysis of Tornado-Induced Transients in Ventilation Systems," Los Alamos National Laboratory report LA-7397-M (December 1984).

4. Martin, R. A. and Wilson, T. L., "EVENT84 User's Manual--A Computer Code for Analyzing Explosion-Induced Gas-Dynamic Transients in Flow Networks," Los Alamos National Laboratory report LA-10312-M (December 1984).

5. Nichols, B. D. and Gregory, W. S., "EXPAC User's Manual--A Computer Code to Predict Gas-Dynamics and Material Transport in Flow Networks," Los Alamos National Laboratory report in preparation.

6. Perdriau, Ph., Pourprix, M., Rabain, S., Rouger, J. L., and Tarrago, X., "Safety Evaluation of Ventilation Networks in Case of Fire," Proceedings of the CSNI Specialist Meeting on Interaction of Fire and Explosion with Ventilation Systems in Nuclear Facilities, Los Alamos National Laboratory report LA-9911-C (April 1985), Vol. 1.

7. Nichols, B. D. and Gregory, W. S., "FIRAC User's Manual: A Computer Code to Simulate Fire Accidents in Nuclear Facilities," Los Alamos National Laboratory report LA-10678-M, NUREG/CR-4561 (April 1986).

8. "Fuel Cycle Facility Accident Analysis Handbook," US Nuclear Regulatory Commission report NUREG/CR-2508 (Draft) (March 1982).

9. Andrae, R. W. and Rojas, V. A., "Analytical Study of Ventilation System Behavior Using TVENT1 Under Simulated Blower Malfunctions," Los Alamos National Laboratory report LA-9653-MS (February 1983).

CLOSING COMMENTS OF SESSION CO-CHAIRMAN KRATZKE

There were four papers in the first part dealing with iodine and iodine retention in a fire situation. We learned about various points of view. One is held by those engaged in design. They cited tests conducted to look at the characteristics of the releases from a burning carbon bed. From the insurers point of view, once a fire starts, there will be serious problems. Therefore, every effort must be made to contain and reduce the problem. It is important to inquire whether basic theoretical studies have been conducted to examine these phenomena theoretically and then to extrapolate the findings broadly rather than merely looking at individual systems from a purely operational perspective. In other words, do we thoroughly understand the mechanisms that are associated with the phenomena? That, I believe, covers the first four papers.

The next five papers are closely related. They seek to model accidents and thereby to assist analysis and design. The first paper, from France, looked at confinement and the maintenance of confinement. They examined ventilation systems and pointed out weak points. Next, we heard three papers from Los Alamos that dealt with computer simulation and the use of that technology for design and accident analysis.

I want to conclude by saying something about the paper by Dr. Gruendler from West Germany. He looked at the release of radioactivity from a waste package, a different topic than air cleaning systems. However, he is looking at the generation of a source term that could challenge air cleaning systems. I thought the paper was interesting because it looked at some of the basic factors and consolidated them into simplified mechanisms that could become useful calculational tools.