SESSION III

AIR CLEANING SYSTEM DESIGN CONSIDERATIONS

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CALCULATION OF THE RADIATION DOSE FROM AN UPSET CONDITION IN THE
    OFF-GAS SYSTEM FOR A BOILING WATER POWER REACTOR
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ENGINEERED-SAFETY-FEATURE AIR CLEANING SYSTEMS FOR COMMERCIAL LIGHT-
    WATER-COOLED NUCLEAR POWER PLANTS
                    C. A. Burchsted

VERMONT YANKEE ADVANCED OFF-GAS SYSTEM (AOG)
                    P. S. Littlefield, S. R. Miller
                    H. DerHagopian

SAFETY EVALUATION OF BWR OFF-GAS TREATMENT SYSTEMS
                    R. J. Schultz, R. C. Schmitt

CALCULATION OF THE RADIATION DOSE FROM AN UPSET CONDITION IN THE
OFF-GAS SYSTEM FOR A BOILING WATER POWER REACTOR*

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Abstract

A study has been made which considered the upset conditions to result in a rupture of the delay line or charcoal adsorber portions of the radioactive off-gas treatment system for a boiling water power reactor. Radiation dose calculations were made for an individual at a 300-meter boundary fence. The doses calculated were the whole body immersion dose and the thyroid, bone and lung doses due to inhalation. The relationship between the various operating and upset parameters of the off-gas system and the radiation doses were investigated. A semi-infinite cloud model with a ground level release was assumed.

For a delay line rupture, the calculated gamma immersion dose varies from a high of 9 rad for a break at the condenser to a low of 0.2 rad for a break at the maximum end of a 300-minute delay line. The thyroid dose from inhalation of radio-iodine was calculated to vary from 3 to 6 millirem for a delay line rupture and be 0.6 rem for a charcoal bed rupture. The highest gamma immersion dose from a charcoal adsorber bed rupture was calculated to be 1.5 rad for the low flow rate condition with either an ambient or chilled bed system. Curves have been constructed which show the variation of the calculated doses with the various input parameters.

I. Introduction

Section 50.34 of 10 CFR, Part 50, "Contents of Applications in Technical Information", requires each applicant for a construction permit or operating license for a nuclear reactor provide an assessment of the risk to the public health and safety resulting from operation of that plant. Of particular concern are the consequences of the release of radioactivity as a result of operational upset or accident conditions in the waste gas treatment system. Following an extensive review of the available data, it became apparent that definition of the interaction between the various contributors to the off-site dose would be a helpful tool. The extensive review and a detailed description of the off-gas treatment system are presented in another paper for this conference[1]. This study is a compilation of the important interacting parameters in defining the off-site dose from an off-gas system accidental release. Only the doses associated with accident or upset conditions for a delay pipe and charcoal adsorber system were considered.

II. Problem Definition

The "worst case" accident involving a BWR waste gas treatment system may change dependent upon system operating parameters for specified accidents. The evaluation presented herein contains a series of parametric studies to identify which operating variables are significant for the identified accident cases. The accidents and associated off-site doses considered in this study are:

(a)   the immersion dose (both gamma and total or beta + gamma) from the rupture of an off-gas system delay line, as a function of break position and delay pipe length;

(b)   the immersion dose (both gamma and total) from the rupture of a particulate filter with a one-year inventory of noble gas daughter products as a function of delay line length (or decay time) before the particulate filter;

(c)   the immersion dose (both gamma and total) from the activation gases as a function of break location and delay pipe length;

(d)   the dose to the thyroid through inhalation of the iodine release as a function of delay pipe rupture position;

(e)   lung and bone doses from inhalation of the noble gas daughter products for the cases presented in items (a) and (b);

(f)   the immersion dose (both gamma and total) from the rupture of the charcoal adsorber system. The parameter variables for this portion of the study are dynamic adsorption coefficient (K_d), flow rate, number of adsorber beds, adsorber release time, and system type (ambient temperature vs. chilled);

(g)   thyroid dose from inhalation of the iodine release from the rupture of the charcoal adsorber system. A one-year inventory of iodine gases is considered to be contained in the charcoal bed.

The assumption and specific input data used in the dose calculations are presented in Tables I through V. Table I outlines the general assumptions, Table II the noble gas source term, Table III the activation gas source term, Table IV the iodine gas source term, and Table V the decay chains used in the calculations. The noble gas and iodine gas source terms agree very well with data reported by Pelletier[2]. A variable multiplicative spike of variable time duration after the delay line break can be imposed upon the noble gas source term from the condenser.

The downwind calculations were done using the semi-infinite cloud model currently being used by the AEC in their reactor siting evaluations. It is imperative to keep in mind that the calculations have assumed no decay of the fission products and resulting daughters after release from the ruptured delay line or charcoal bed. The activation gases have been decayed during downwind transport.

III.   Results of Parametric Studies

Doses Associated with Delay Line Rupture

Off-gas treatment systems typically contain a delay line to allow for partial nuclear decay of the radioactive gases prior to final processing. The delay line is provided to keep the dose rates in the process system as low as possible. The length of the delay time varies for different off-gas treatment systems, but in general ranges from a minimum of ten minutes to a maximum of 300 minutes. The gas processed through the off-gas system is removed from the main condenser of the nuclear power plant. The primary components of this off-gas are oxygen and hydrogen from primary coolant radiolytic decomposition, air inleakage and the small amounts of activation and fission gases. As the H_2 and O_2 are major constituents of the process stream, a potential exists for ignition and explosion or detonation; for this reason accidents associated with delay line rupture have been studied. It

Table I   General assumptions

Source Term:	Nominal 2.0×10^6 µCi/sec, zero decay for noble gases*. Table II gives fission product mix. Activation gases as listed in Table III. Iodine gases as listed in Table IV.
Condenser Inleakage:	0.1, 1, 10 and 70 scfm.
Delay Times:	Delay pipe holdup times of 10, 30 and 300 minutes. Zero minutes delay at steam jet air ejector. No decay of fission products and resulting daughters during downwind transport.
Downwind Distance to Site Boundary:	300 meters.
Release Height:	Ground level release.
Meteorology:	Pasquill Class F, 1 m/s, wind speed of uniform direction; i.e., Regulatory Guide 1.3[3].

Dynamic Adsorption Coefficients (K_d Values):	Ambient		Chilled	
	Xe min.	150	Xe min.	150
	max.	1000	max.	8000
	Kr(Xe/Kr ratio 15.4)[4]		Kr(Xe/Kr ratio 24)	

Particulate Filter Rupture:	100% release of noble gas daughter products with one-year inventory for particulate filter downstream of delay line.
Gas Desorption Time from Charcoal:	Evolving times of 0, 60, 120, 300 and 480 minutes were used.
Iodine on Charcoal Bed:	100% release of iodine gases with one-year inventory on first part of first charcoal bed.
Operator Action Time (Shutdown Condenser):	60 minutes.

All organ doses from inhalation were calculated using a breathing rate of 347 cc/sec.

Calculation Techniques:	The doses were calculated using the semi-infinite cloud model as discussed in AEC-Regulatory Guide 1.3, Reference 3. The doses from beta and gamma radiation were calculated as separate doses and subsequently combined for total whole body exposures. All the decay scheme data were from NEDO-12037[5]. The thyroid, bone, and lung doses due to inhalation of the radioisotopes were calculated using conversion factors from NAA-SR-8884[6].

*This is equivalent to 1×10^5 µCi/sec, 30-min cooled for noble gases.

Table II   Noble gas source term

Isotope	Half-Life		Source Term, Microcuries per Second	
			0 Decay	30-Min Decay
Xe-140	13.7	s	3.0×10^5	---
Kr-90	33.0	s	2.8×10^5	---
Xe-139	41.0	s	2.8×10^5	---
Kr-89	3.2	m	2.6×10^5	3.6×10^2
Xe-137	3.8	m	2.1×10^5	9.2×10^2
Xe-138	14.0	m	1.1×10^5	2.6×10^4
Xe-135m	15.6	m	3.2×10^4	8.6×10^3
Kr-87	76.0	m	2.0×10^4	1.5×10^4
Kr-83m	1.86	h	3.5×10^3	3.0×10^3
Kr-88	2.8	h	1.8×10^4	1.8×10^4
Kr-85m	4.4	h	5.7×10^3	5.2×10^3
Xe-135	9.2	h	1.92×10^4	1.83×10^4
Xe-133m	2.3	d	2.0×10^2	2.00×10^2
Xe-133	5.27	d	5.4×10^3	5.4×10^3
Xe-131m	11.9	d	1.2×10^1	1.2×10^1
Kr-85	10.76	y	8.1	8.1
		Total	$\sim 2.0 \times 10^6$	$\sim 1.01 \times 10^5$

Table III   Activation gas source terms

Isotope	Half-Life		Source Term 0 Decay (Microcuries per sec)
N-13	10.0	m	1.2×10^4
N-16	7.35	s	1.7×10^8
N-17	4.14	s	2.6×10^4
O-19	29.0	s	1.4×10^6
F-18	109.0	m	7.2×10^3

Table IV   Iodine gas source term

Isotope	Half-Life		Source Term 0 Decay (Microcuries per sec)
I-131	8.05	d	0.22
I-132	2.28	h	0.29
I-133	21.0	h	0.28
I-134	52.0	m	0.39
I-135	6.7	h	0.26
		Total	1.44

Table V   Decay chains with $T_{\frac{1}{2}}$ for xenon, krypton and daughters

Xenons

Xe-140 $\xrightarrow{13.7s}$ Cs-140 $\xrightarrow{65.0s}$ Ba-140 $\xrightarrow{12.8d}$ La-140 $\xrightarrow{40.2h}$ Ce-140

Xe-139 $\xrightarrow{41.0s}$ Cs-139 $\xrightarrow{9.0m}$ Ba-139 $\xrightarrow{83.0m}$ La-139 $\longrightarrow$

Xe-138 $\xrightarrow{14.0m}$ Cs-138 $\xrightarrow{32.2m}$ Ba-138

Xe-137 $\xrightarrow{3.8m}$ Cs-137 $\xrightarrow{30.2y}$ Ba-137m $\xrightarrow{153.0s}$ Ba-137

Xe-135m
$\downarrow$ 15.6m
Xe-135 $\xrightarrow{9.2h}$ Cs-135 $\xrightarrow{3\times10^6 y}$ Ba-135

Xe-133m
$\downarrow$ 2.3d
Xe-133 $\xrightarrow{5.27d}$ Cs-133

Xe-131m
$\downarrow$ 11.9d
Xe-131

Kryptons

Kr-90 $\xrightarrow{33.0s}$ Rb-90 $\xrightarrow{2.6m}$ Sr-90 $\xrightarrow{28.8y}$ Y-90 $\xrightarrow{64.4h}$ Zr-90

Kr-89 $\xrightarrow{3.2m}$ Rb-89 $\xrightarrow{15.0m}$ Sr-89 $\xrightarrow{50.6d}$ Y-89

Kr-88 $\xrightarrow{2.8h}$ Rb-88 $\xrightarrow{17.8m}$ Sr-88

Kr-87 $\xrightarrow{76.0m}$ Rb-87 $\xrightarrow{4.7\times10^{y}}$ Sr-87

Kr-85m
$\downarrow$ 20%   80%
     4.4h
Kr-85 $\xrightarrow{10.76y}$ Rb-85

Kr-83m
$\downarrow$ 1.86h
Kr-83
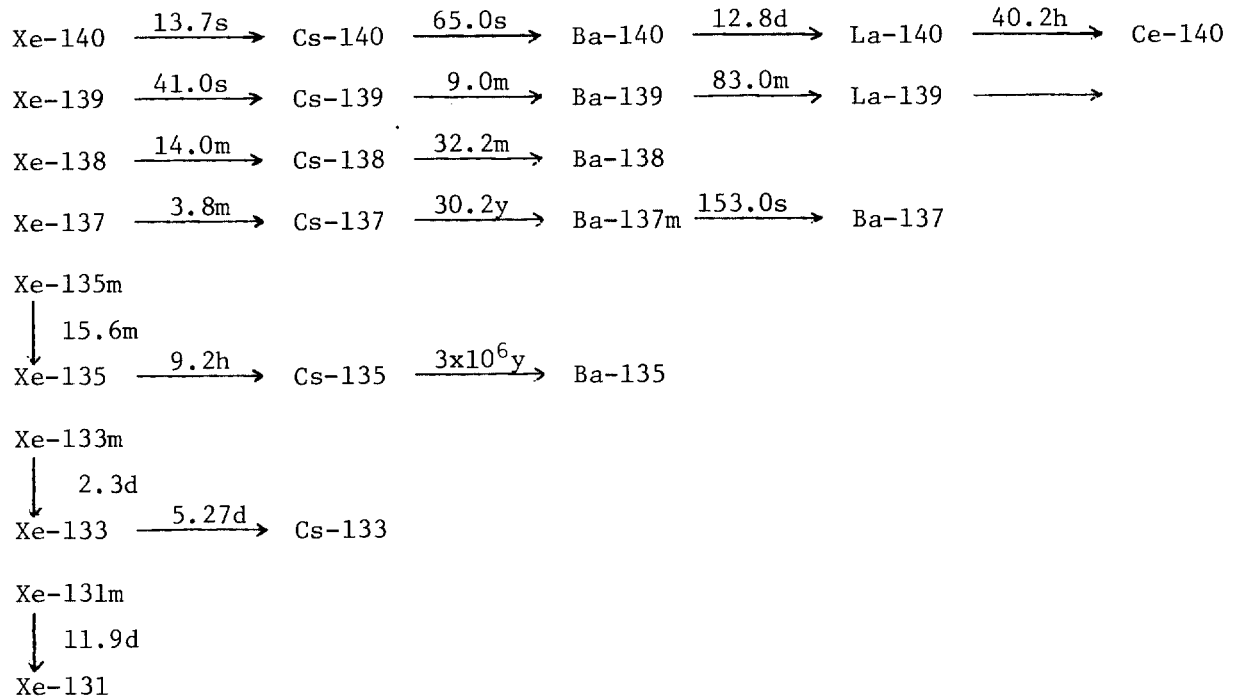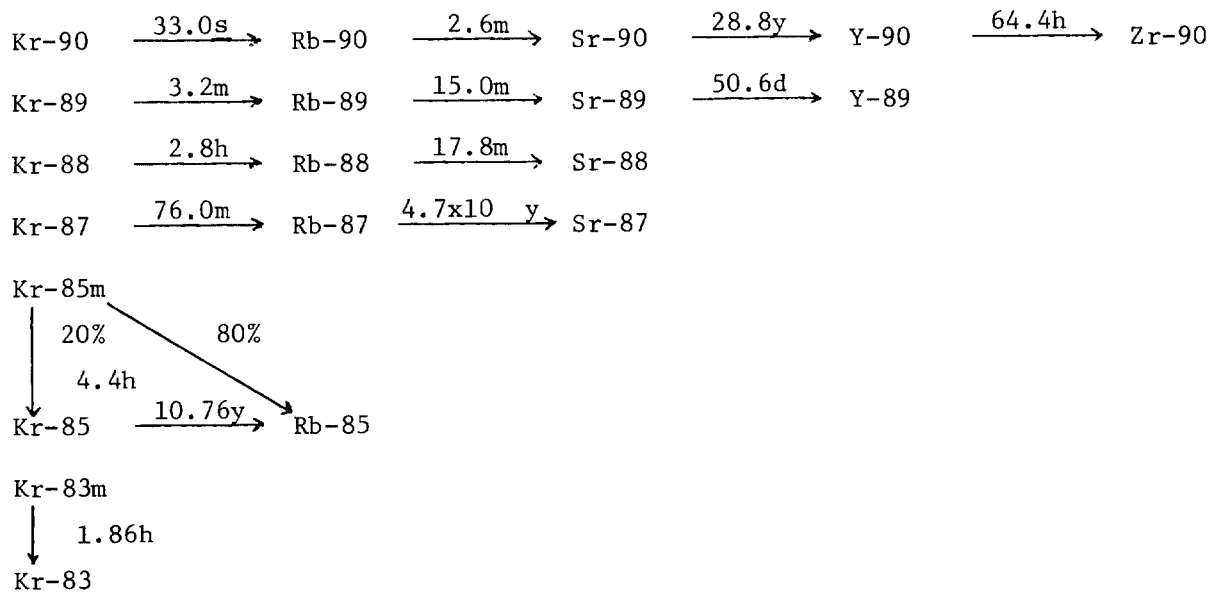
was assumed for these calculations that the main condenser continued to vent to the atmosphere for one hour and the delay pipe is sealed five hours after the accident. Twenty percent of the contents of the delay line was assumed to be released over this five-hour period. Break positions in the delay line were considered as fractional parts of the total length. The break positions used were 0, 0.05, 0.10, 0.25, 0.50, 0.75, 0.99 and 1.0. The zero position break was between the main condenser and the delay line.

The immersion, lung and bone doses presented in the following figures and tables are from the release of the noble, activation and iodine gases plus their daughter products. Figures 1 and 2 depict the summation (condenser + delay pipe) and delay pipe immersion doses vs. fractional break position up to 0.99 of the total length. The total immersion doses presented in these and following figures are a simple summation of the gamma and beta doses from the released radionuclides. For a spike release of ten times the normal fission product gases starting when the delay line breaks at the condenser and continuing for 30 seconds after the break, the gamma immersion dose for the ten-minute delay line case would increase from 9.0 rads to 9.8 rads. Figures 3 and 4 give the lung and bone doses associated with these rupture conditions.

The delay line is normally equipped with a high efficiency particulate filter at the exit end to remove noble gas daughter products which have been produced enroute. The filter is normally changed out once a year. A high energy event, such as an explosion or detonation, could destroy the filter, releasing the entrained particulates as well as rupture the delay line. Table VI gives the doses associated with rupture of the delay line at its maximum length and release from the particulate filter.

The iodines are also of concern in an accidental release from a BWR off-gas treatment system, mainly because of their biological significance. To better understand the contribution to the overall dose from iodine, parametric studies were conducted to determine what the thyroid dose from inhalation of radioiodine would be in a typical situation. The thyroid dose as a function of delay line break position was calculated for the iodine source terms presented in Table IV. Figure 5 presents the calculated thyroid dose for radioiodine releases from the condenser and delay line.

The contribution to the off-site immersion dose in a delay line rupture accident from the activation gases has been separated from the total. The activation gases exhibit short half-lives but are produced rather abundantly. Figure 6 presents the off-site dose from the activation gases as a function of break position. It should be noted that the activation gases have been decayed enroute to the boundary site limit. Even though the activation gases comprise about 98 percent of the assumed activity rate being released by the condenser, they only contribute from one to four percent to the calculated immersion dose.

Doses Associated with Adsorber Bed Rupture

Dose calculations have been done for the release of the trapped noble and iodine gas radioisotopes from ruptured charcoal beds. The charcoal bed adsorbers can be classified into two types of systems as to operational temperature. The ambient temperature systems usually consist of 12 beds, with 3 tons of charcoal each, that are connected in series. The chilled temperature system, for purpose of this study, is composed of one charcoal bed of eight tons. For the ambient system, the accident or rupture conditions have been investigated for the first bed after the delay line and for the rupture of each succeeding bed up to the 12

FOR: PASQUILL TYPE F WEATHER CONDITIONS
GROUND LEVEL RELEASE
SITE BOUNDARY: 300 METERS
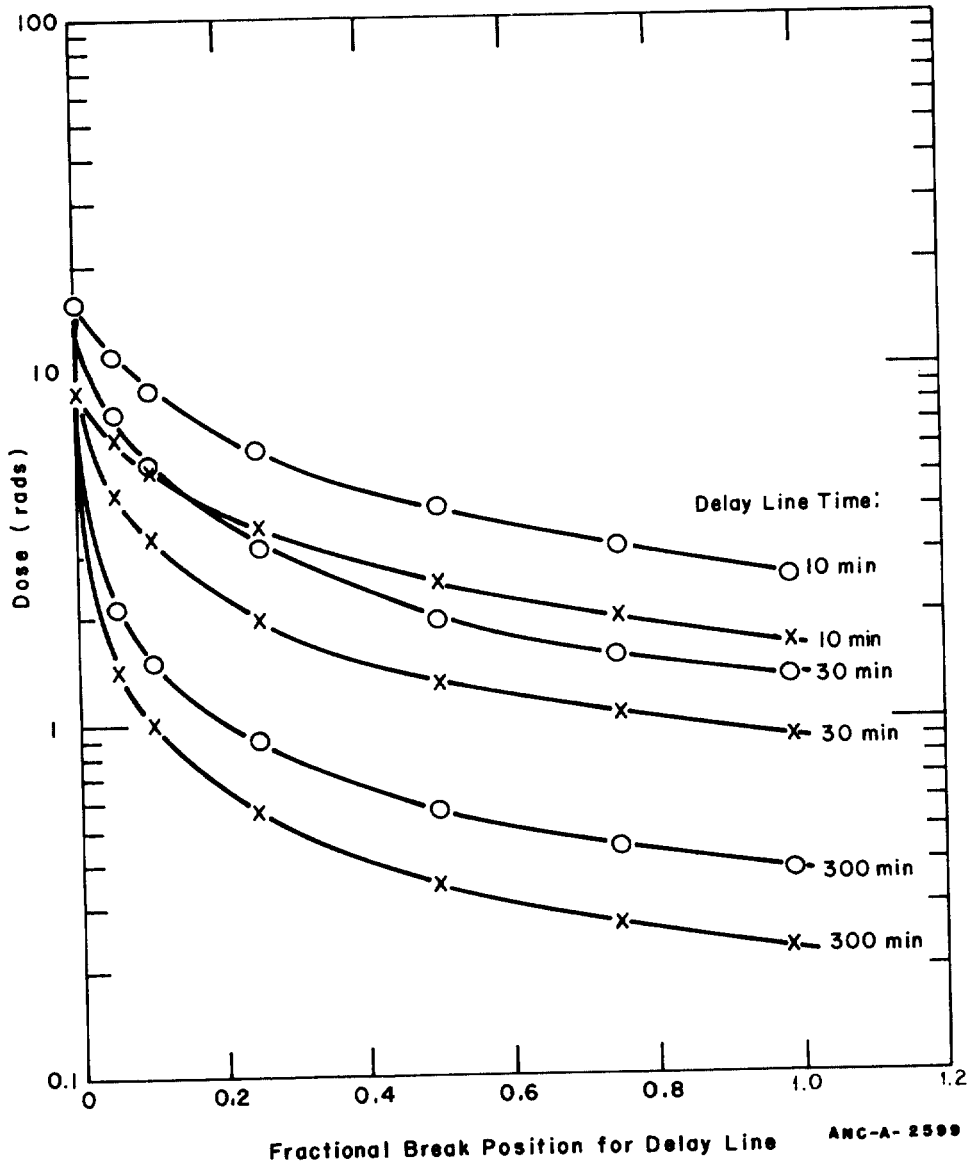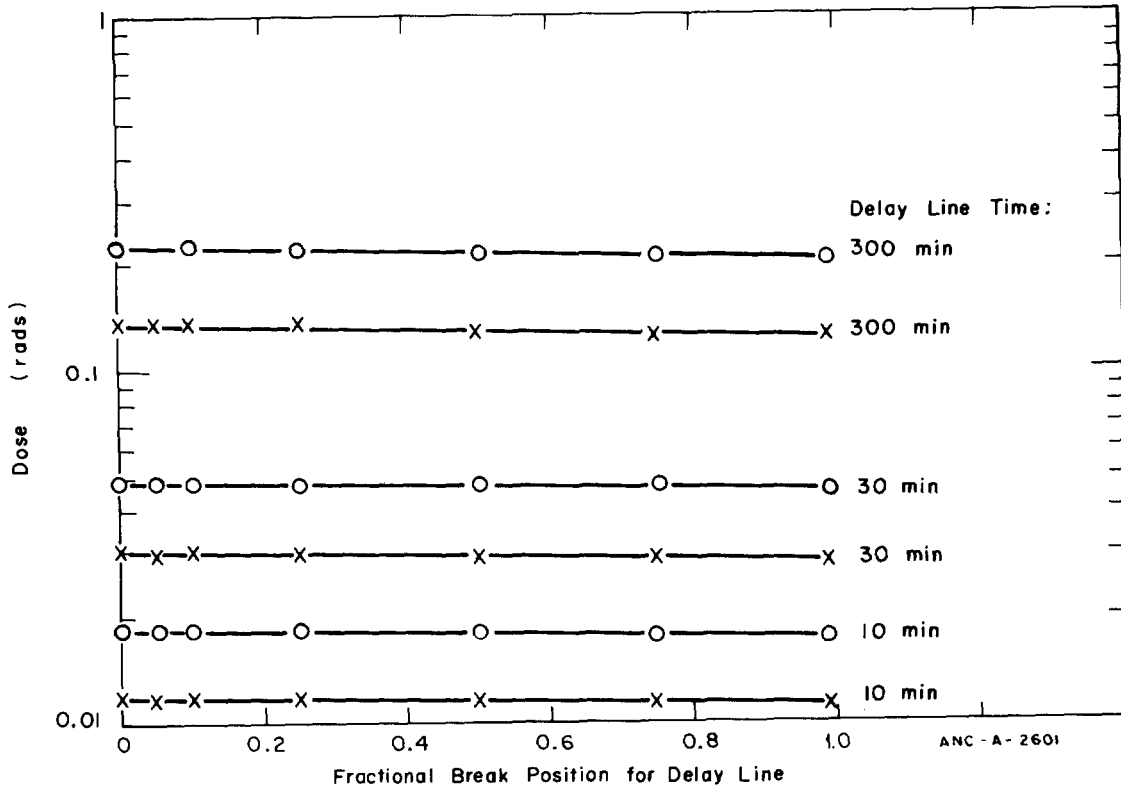NEAR ATMOSPHERIC PRESSURE DELAY LINE

x: GAMMA DOSE
o: TOTAL DOSE

Fractional Break Position for Delay Line   ANC-A- 2599

FIGURE 1

IMMERSION DOSE FROM BREAK IN BWR OFF-GAS
DELAY LINE FROM RELEASE RADIOACTIVITY

65

FOR: PASQUILL TYPE F WEATHER CONDITIONS
GROUND LEVEL RELEASE
SITE BOUNDARY: 300 METERS
NEAR ATMOSPHERIC PRESSURE DELAY LINE

x: GAMMA DOSE
o: TOTAL DOSE

FIGURE 2

IMMERSION DOSE FROM BREAK IN BWR OFF-GAS
DELAY LINE FROM RELEASED RADIOACTIVITY
DELAY LINE CONTRIBUTION

66

FOR: PASQUILL TYPE F WEATHER CONDITIONS
      GROUND LEVEL RELEASE
      SITE BOUNDARY: 300 METERS
      NEAR ATMOSPHERIC DELAY LINE
      BREATHING RATE: 347 cc/sec

      o: TOTAL (CONDENSER + DELAY LINE)
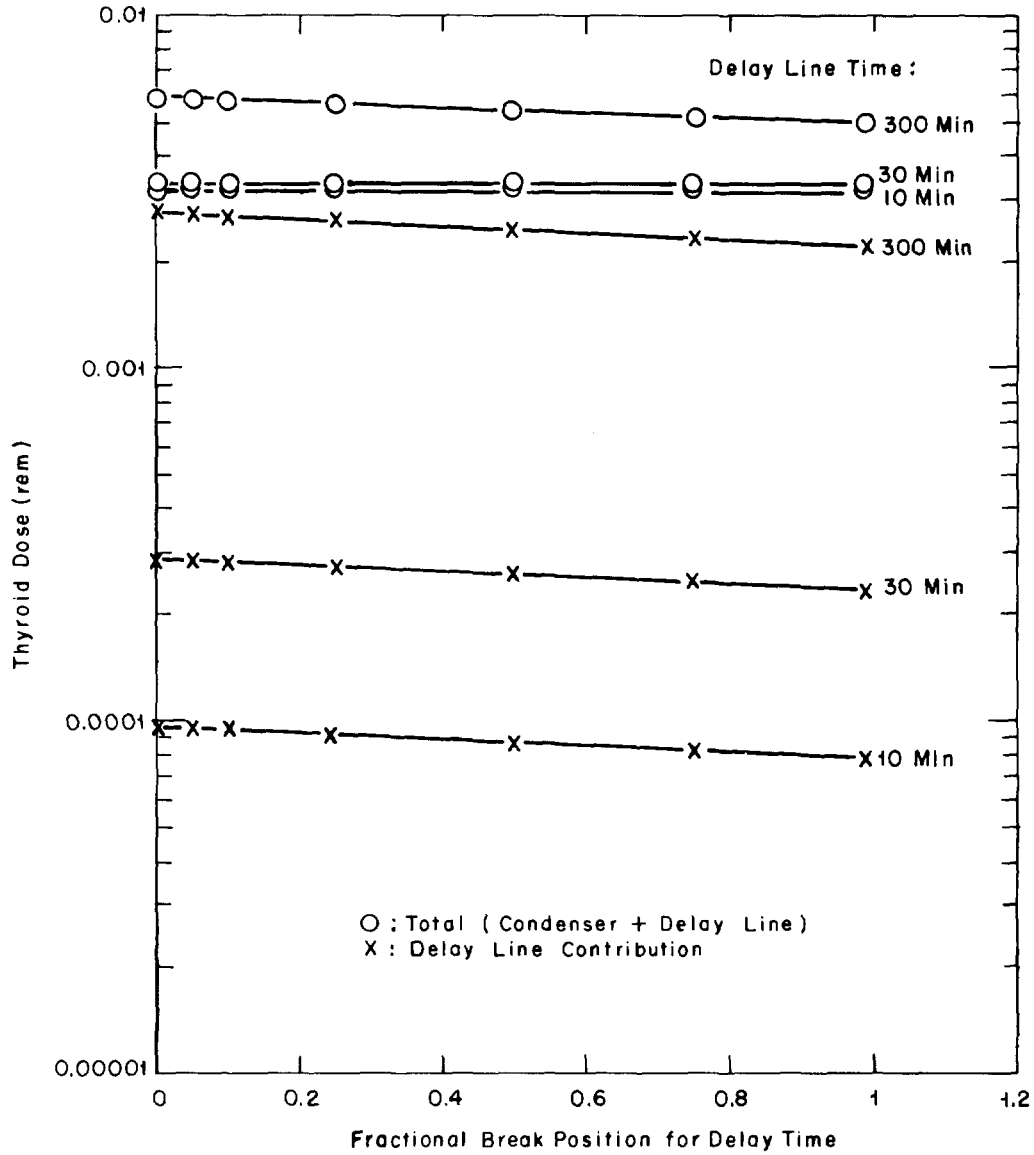   x: DELAY LINE CONTRIBUTION

FIGURE 3

LUNG DOSE FROM INHALATION OF Xe AND Kr DAUGHTERS
FROM BREAK IN BWR OFF-GAS DELAY LINE

FOR: PASQUILL TYPE F WEATHER CONDITIONS
GROUND LEVEL RELEASE
SITE BOUNDARY: 300 METERS
NEAR ATMOSPHERIC DELAY LINE
BREATHING RATE: 347 cc/sec

o: TOTAL (CONDENSER + DELAY LINE)
x: DELAY LINE CONTRIBUTION
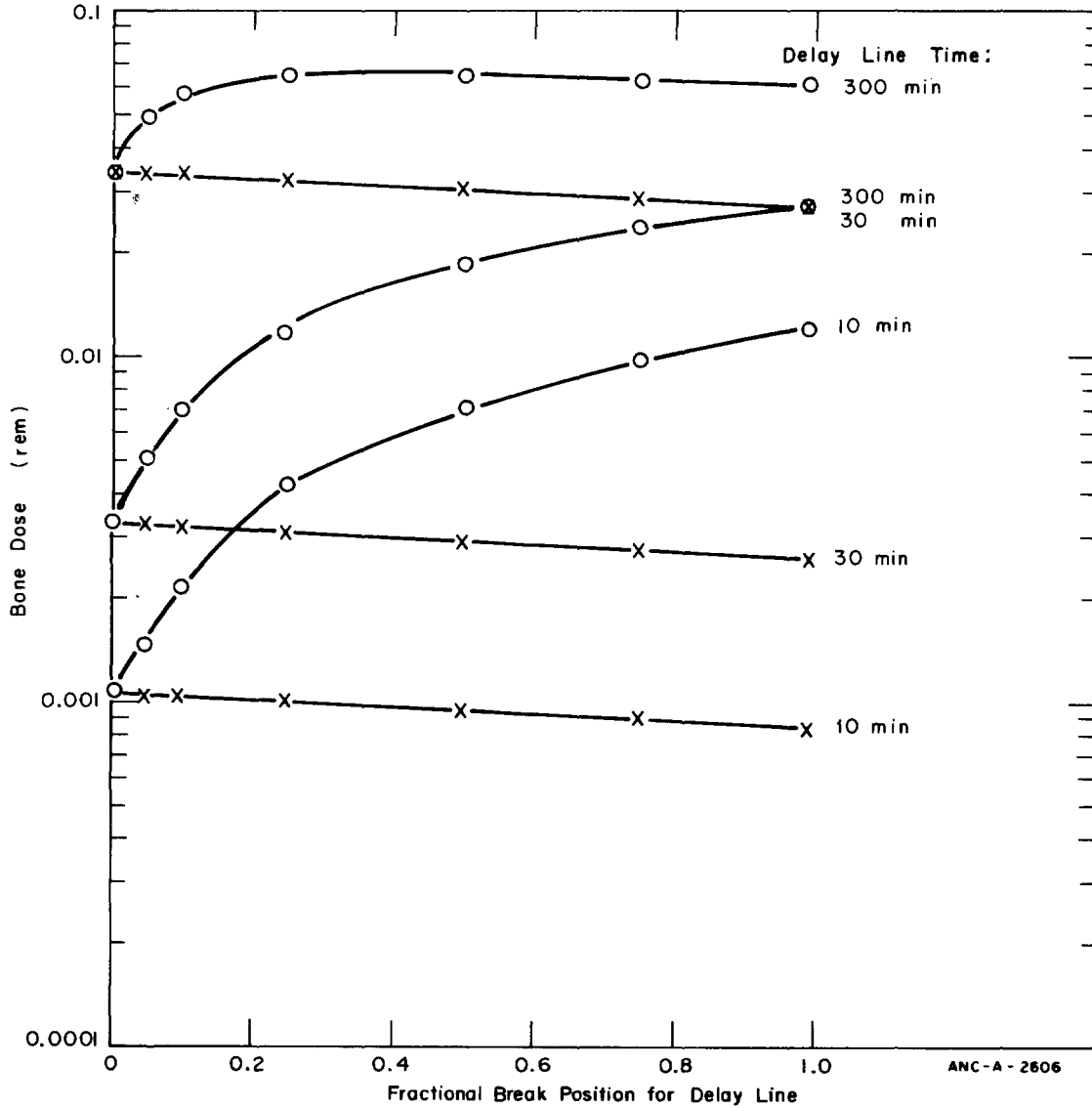
FIGURE 4

BONE DOSE FROM INHALATION OF Xe AND Kr DAUGHTERS
FROM BREAK IN BWR OFF-GAS DELAY LINE

Table VI   Doses associated with delay line rupture and loss of filter integrity

Delay Line Time	Combined Immersion Dose		Filter Rupture Immersion Dose		Combined Inhalation Dose		Filter Rupture Inhalation Dose	
	Gamma (rad)	Total (rad)	Gamma (rad)	Total (rad)	Lung (rem)	Bone (rem)	Lung (rem)	Bone (rem)
10 min	1.98	3.08	0.35	0.53	23.4	68.3	23.3	68.3
30 min	1.25	1.89	0.36	0.55	26.1	74.1	26.0	74.1
300 min	0.31	0.54	0.09	0.17	25.9	74.1	25.9	74.0

FOR: PASQUILL TYPE F WEATHER CONDITIONS
GROUND LEVEL RELEASE
SITE BOUNDARY: 300 METERS
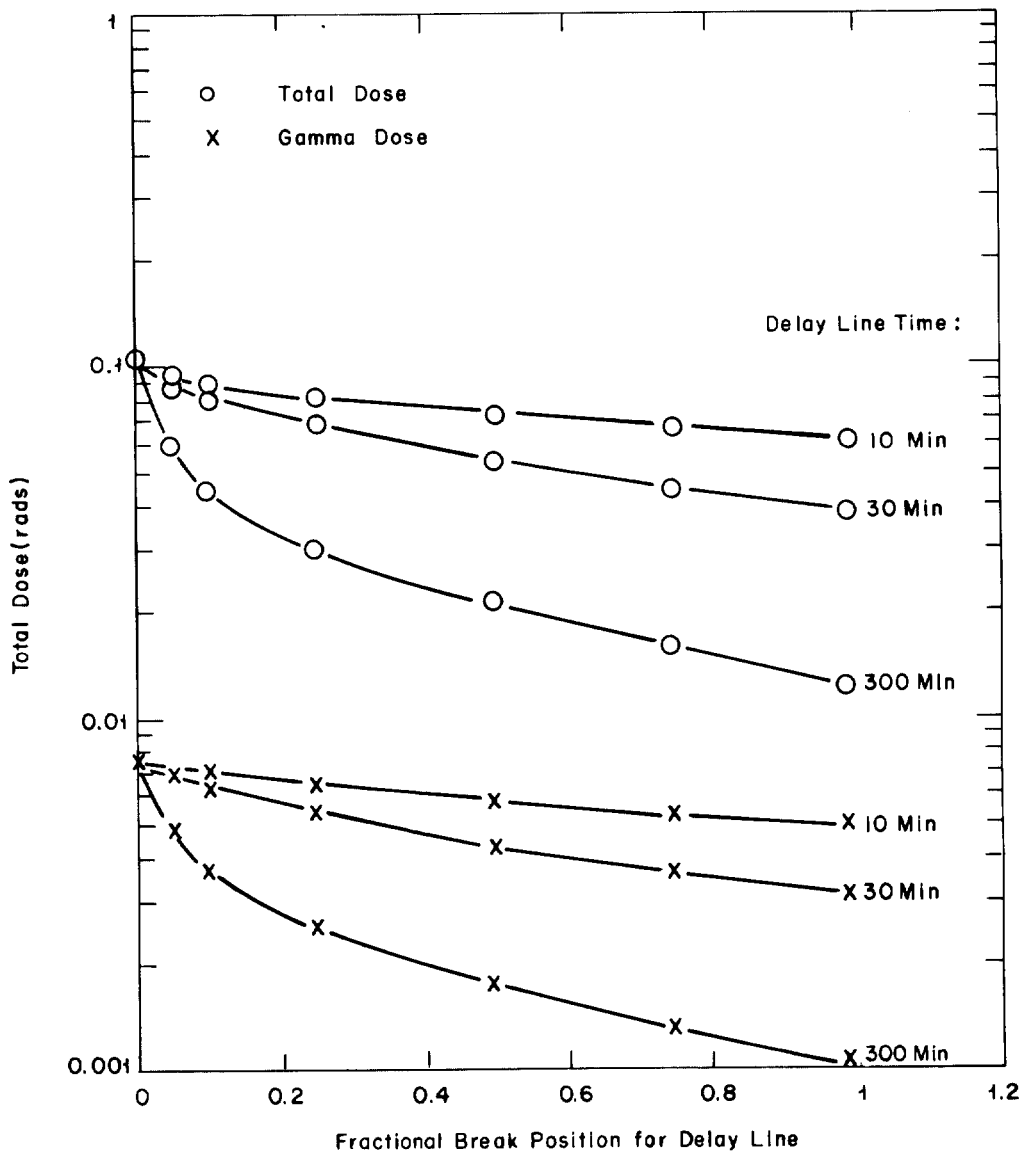NEAR ATMOSPHERIC DELAY LINE
BREATHING RATE: 347 cc/sec.

FIGURE 5

THYROID DOSE BY INHALATION OF IODINE GASES
FROM BREAK IN BWR OFF-GAS DELAY LINE
PELLETIER IODINE SOURCE TERM

ANC-A-2611

FOR: PASQUILL TYPE F WEATHER CONDITIONS
GROUND LEVEL RELEASE
AT 300 METER SITE BOUNDARY
NEAR ATMOSPHERIC PRESSURE DELAY LINE

ANC-A-2613

FIGURE 6

IMMERSION DOSE FROM BREAK IN BWR OFF-GAS
DELAY LINE FROM ACTIVATION GASES RELEASED

71

total. A parametric study of resultant immersion dose with activity release times from the beds varying from instantaneous up to eight hours has been considered. The delay line times prior to the noble and iodine gas activities reaching the charcoal beds used were 10, 30 and 300 minutes. When the delay pipe time was held constant, the 10-minute delay time was used because this would result in the highest dose. The flow rates used for the calculations were 0.1, 1, 10 and 70 scfm. These are the flow rates through the beds prior to the adsorber bed rupture. For the ambient temperature system, the xenon adsorption coefficient, $K_d(Xe)$, was varied from 150 to 1000 with the $K_d(Kr)$ being 1/15.4 of the $K_d(Xe)$[4]. For the chilled system, the $K_d(Xe)$ was varied from 150 to 8000 with the $K_d(Kr)$ being 1/24 of the $K_d(Xe)$. The semi-infinite cloud model, weather, and site boundary conditions used are the same as were used for the delay line rupture dose calculations as outlined in the general assumptions given in Table I. Also, the noble and iodine gas source terms were as indicated in Tables II and IV. Since the iodine gases will be trapped on the first fraction of the first charcoal bed after the delay line, the doses from release of the iodine gases are only a function of the delay line time and the activity release time from a rupture of the first bed after the delay line.

The immersion doses as a function of adsorption coefficient are presented in Figures 7 through 12 for varying flow rate, bed type and number of beds ruptured with a delay line time of ten minutes. Figure 7 is for the first ambient bed rupturing and Figure 8 is for the release from all 12 ambient beds, both for the low flow rate of 0.1 scfm. It is interesting to note that the respective curves in both figures are the same and flat. This indicates that at the low flow rate of 0.1 scfm, most of the activity is trapped on the first bed of three tons, irrespective of the adsorption coefficient. For a high flow rate of 70 scfm, the immersion dose for a rupture of the first ambient bed is shown in Figure 9 and for all 12 beds rupturing in Figure 10. For the case of high flow rate there is an increased adsorption on the beds with increasing adsorption coefficient, and thus an increase in the resulting dose. It is interesting to note that even the 12-bed case does not reach the saturation level indicated in Figure 8. Therefore, a small fraction of the noble gas activity is not being delayed by adsorption on the complete 12-bed system for the high flow rate of 70 scfm. For a chilled bed rupture, Figures 11 and 12 show the variation of the immersion dose with adsorption coefficient for 0.1 and 70 scfm flow rates, respectively. The same comments apply to the chilled bed case as for an ambient bed rupture.

The variation of the immersion doses with delay line times are shown in Figures 13 through 15 with specific conditions of bed types for low flow rate and adsorption coefficients. This combination of flow rate and adsorption results in the highest doses. Also, the highest doses are for the shortest delay line times of ten minutes because the noble and iodine gas bed input activities to the adsorber beds would be the largest. The thyroid dose from inhalation of iodine gases released by a bed rupture is presented in Figure 16. Since the radioiodine has been assumed to be trapped on the first fraction of the first bed, the thyroid doses are only a fraction of the delay pipe time.

Figures 17 through 22 present the variation of immersion dose with flow rate prior ot a rupture of the ambient beds and a chilled bed for both low and high adsorption coefficients. It is interesting to note that in Figure 22 the dose does not decrease appreciably with increasing flow rate indicating that the single chilled bed of eight tons is adequate to delay most of the noble gas activity if a maximum adsorption coefficient is assumed.

The integrated immersion doses per ambient bed are shown in Figures 23 and 24 for high flow rate and low and high adsorption coefficients, respectively. That is,

FOR: PASQUILL TYPE F WEATHER CONDITIONS
GROUND LEVEL RELEASE
300 METER SITE BOUNDARY
FIRST BED OF 3 TONS (AMBIENT)
FLOW RATE: 0.1 scfm
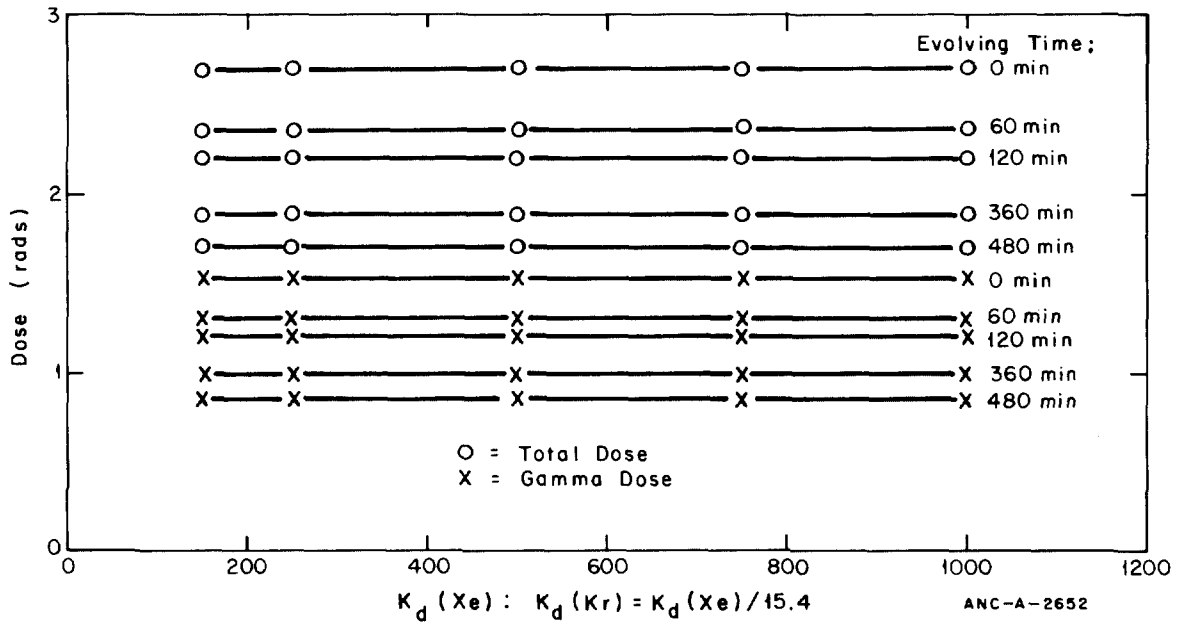DELAY PIPE TIME: 10 min.

FIGURE 7

IMMERSION DOSES FOR Xe, Kr AND I
ISOTOPES FROM RUPTURE OF CHARCOAL BED

FOR: PASQUILL TYPE F WEATHER CONDITIONS
      GROUND LEVEL RELEASE
      300 METER SITE BOUNDARY
      12 BEDS OF 3 TONS EACH (AMBIENT)
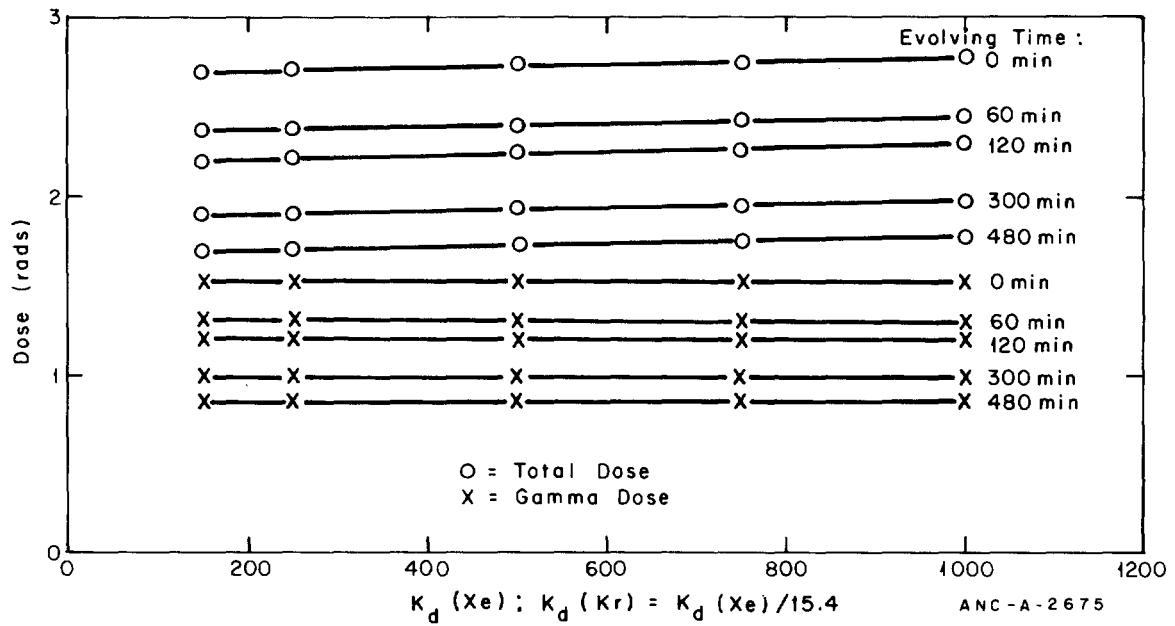   FLOW RATE: 0.1 scfm
      DELAY PIPE TIME: 10 min.

FIGURE 8

IMMERSION DOSES FOR Xe, Kr AND I
ISOTOPES FROM RUPTURE OF CHARCOAL BED

FOR: PASQUILL TYPE F WEATHER CONDITIONS
      GROUND LEVEL RELEASE
      300 METER SITE BOUNDARY
      FIRST BED OF 3 TONS (AMBIENT)
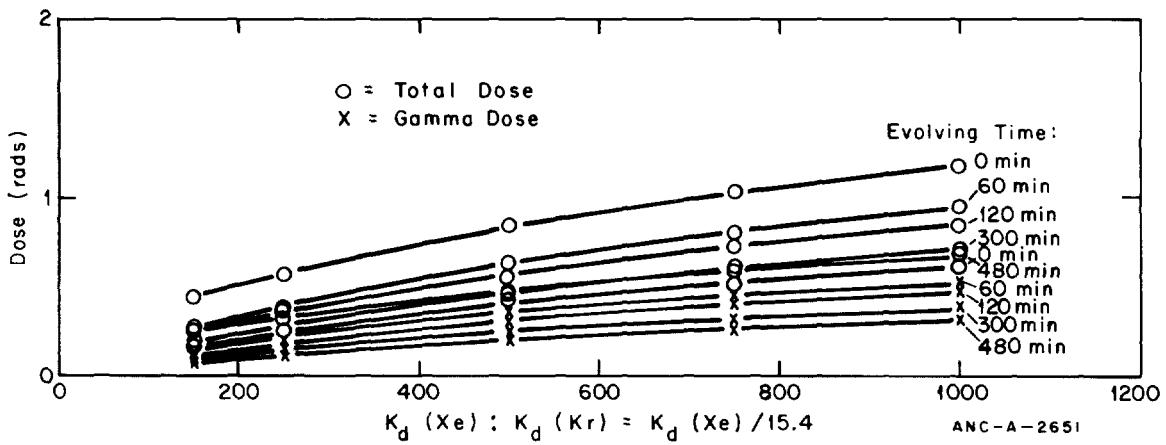   FLOW RATE: 70 scfm
      DELAY PIPE TIME: 10 min.

K_d (Xe) : K_d (Kr) = K_d (Xe) /15.4   ANC-A-2651

FIGURE 9

IMMERSION DOSES FOR Xe, Kr AND I
ISOTOPES FROM RUPTURE OF CHARCOAL BED

75

FOR: PASQUILL TYPE F WEATHER CONDITIONS
GROUND LEVEL RELEASE
300 METER SITE BOUNDARY
12 BEDS OF 3 TONS EACH (AMBIENT)
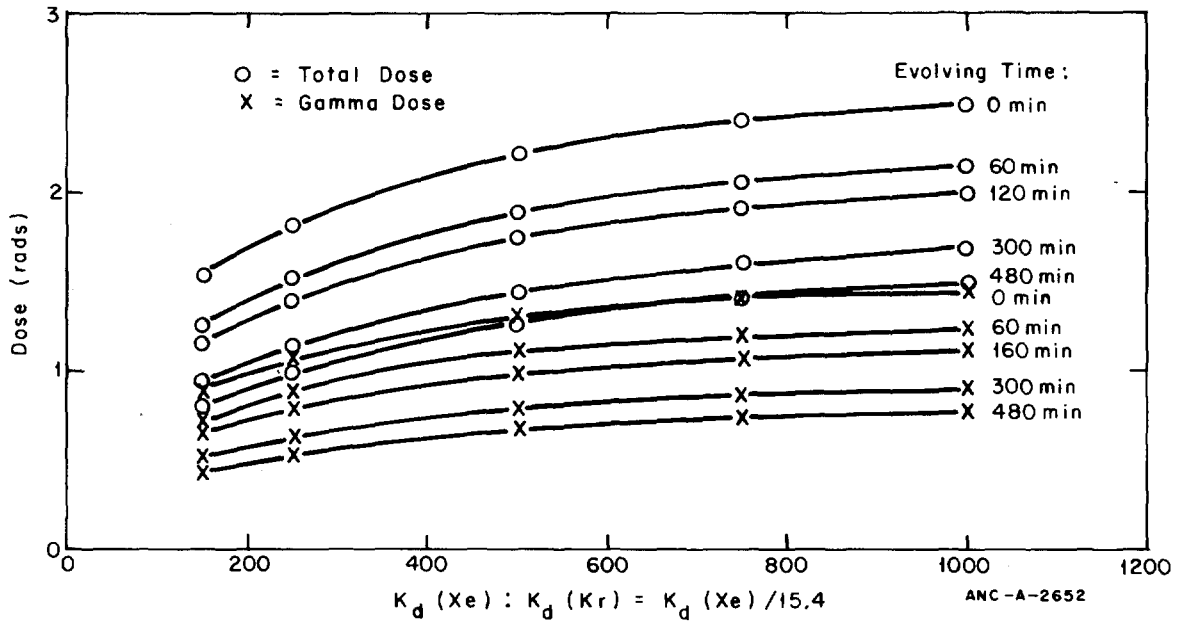FLOW RATE: 70 scfm
DELAY PIPE TIME: 10 min.

K_d (Xe) : K_d (Kr) = K_d (Xe) /15.4   ANC-A-2652

FIGURE 10

IMMERSION DOSES FOR Xe, Kr AND I
ISOTOPES FROM RUPTURE OF CHARCOAL BED

FOR: PASQUILL TYPE F WEATHER CONDITIONS
      GROUND LEVEL RELEASE
      300 METER SITE BOUNDARY
      ONE BED OF 8 TONS (CHILLED)
      FLOW RATE: 0.1 scfm
      DELAY PIPE TIME: 10 min.

FIGURE 11

IMMERSION DOSES FOR Xe, Kr AND I
ISOTOPES FROM RUPTURE OF CHARCOAL BED

FOR: PASQUILL TYPE F WEATHER CONDITIONS
GROUND LEVEL RELEASE
300 METER SITE BOUNDARY
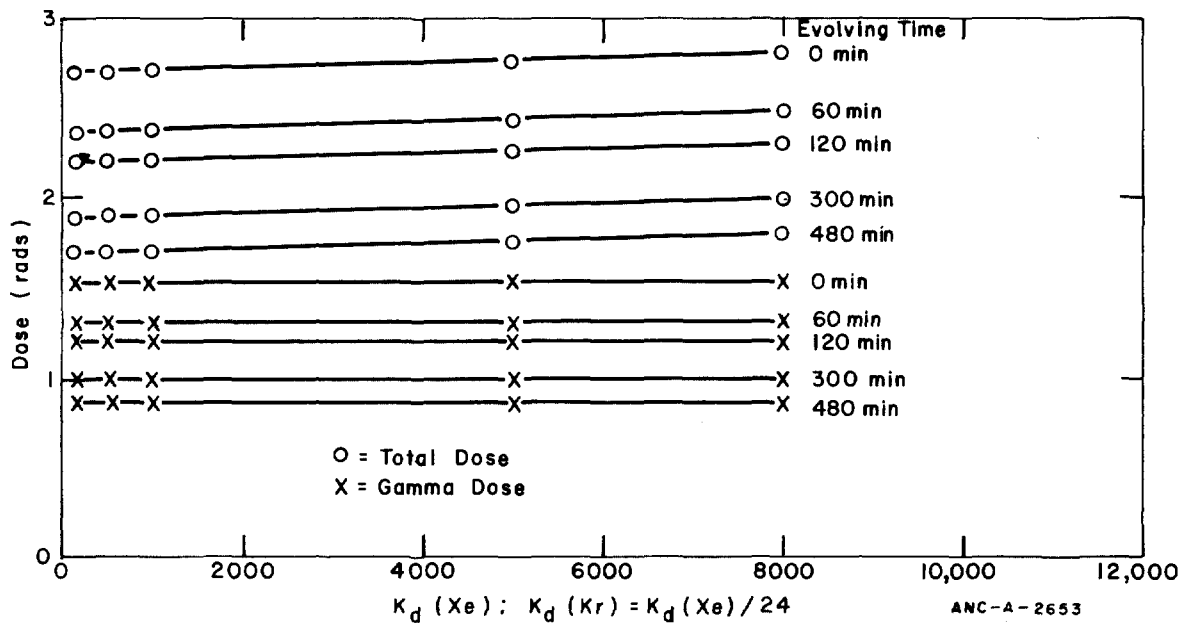ONE BED OF 8 TONS (CHILLED)
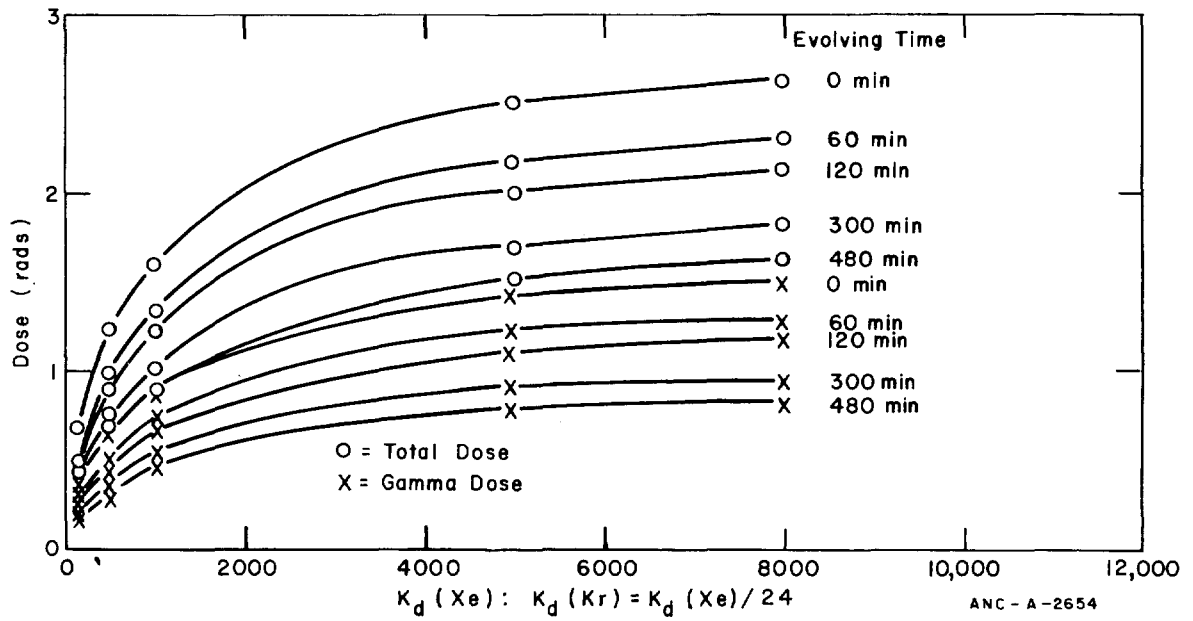FLOW RATE: 70 scfm
DELAY PIPE TIME: 10 min.

FIGURE 12

IMMERSION DOSES FOR Xe, Kr AND I
ISOTOPES FROM RUPTURE OF CHARCOAL BED

FOR: PASQUILL TYPE F WEATHER CONDITIONS
GROUND LEVEL RELEASE
300 METER SITE BOUNDARY
FIRST BED OF 3 TONS (AMBIENT)
FLOW RATE: 0.1 scfm
K_d (Xe) - 150
K_d (Kr) - 9.74

FIGURE 13

IMMERSION DOSES FOR Xe, Kr AND I
ISOTOPES FROM RUPTURE OF CHARCOAL BED

79

FOR: PASQUILL TYPE F WEATHER CONDITIONS
      GROUND LEVEL RELEASE
      30 METER SITE BOUNDARY
      12 BEDS OF 3 TONS EACH, ALL RUPTURE (AMBIENT)
      FLOW RATE: .1 scfm
      K_d (Xe) - 150
      K_d (Kr) - 9.74

FIGURE 14

IMMERSION DOSES FOR Xe, Kr AND I
ISOTOPES FROM RUPTURE OF CHARCOAL BED

FOR: PASQUILL TYPE F WEATHER CONDITIONS
      GROUND LEVEL RELEASE
      300 METER SITE BOUNDARY
      ONE BED OF 8 TONS (CHILLED)
      FLOW RATE: 0.1 scfm
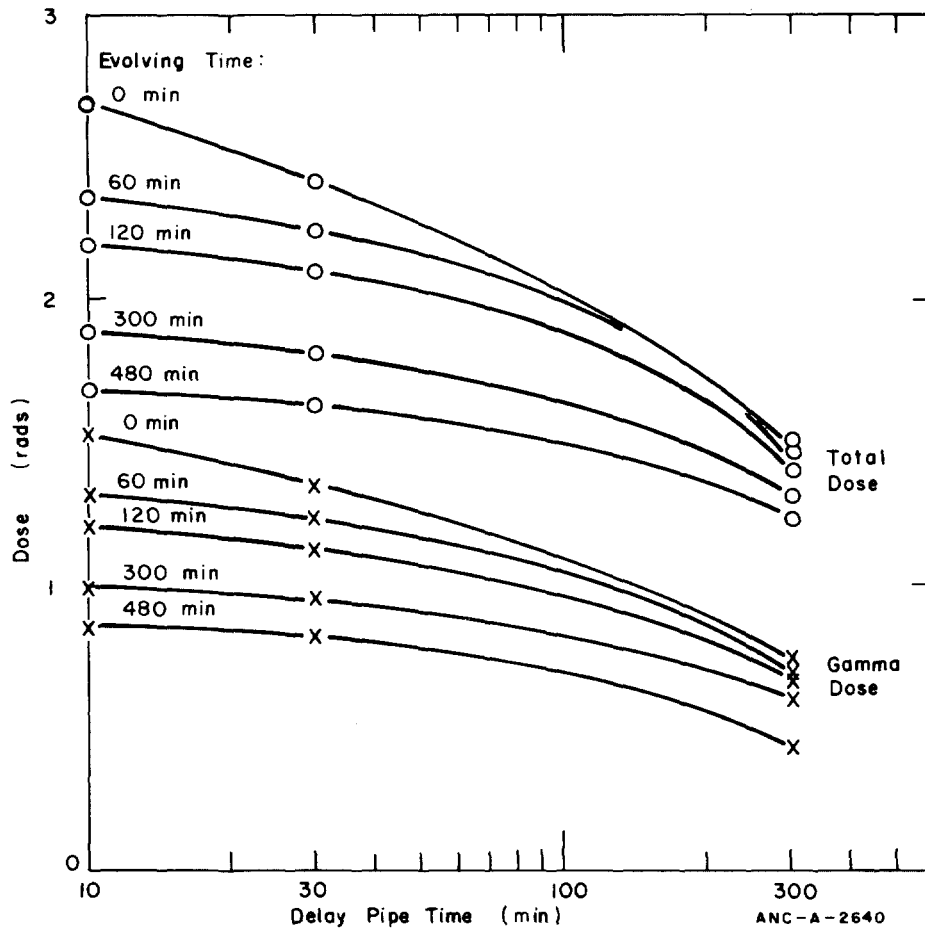 K_d (Xe) - 150.
      K_d (Kr) - 6.25

FIGURE 15

IMMERSION DOSES FOR Xe, Kr AND I
ISOTOPES FROM RUPTURE OF CHARCOAL BED

FOR: PASQUILL TYPE F WEATHER CONDITIONS
GROUND LEVEL RELEASE
300 METER SITE BOUNDARY

FIGURE 16

THYROID DOSE BY INHALATION OF IODINE ISOTOPES FROM RUPTURE OF CHARCOAL BED
PELLETIER IODINE SOURCE TERM

FOR: PASQUILL TYPE F WEATHER CONDITIONS
GROUND LEVEL RELEASE
300 METER SITE BOUNDARY
FIRST BED OF 3 TONS (AMBIENT)
K_d (Xe) - 150

K_d (Kr) - 9.74

DELAY PIPE TIME - 10 min.

FIGURE 17

IMMERSION DOSES FOR Xe, Kr AND I
FROM RUPTURE OF CHARCOAL BEDS

FOR: PASQUILL TYPE F WEATHER CONDITIONS
GROUND LEVEL RELEASE
300 METER SITE BOUNDARY
12 BEDS OF 3 TONS EACH (AMBIENT)
K_d (Xe) - 150.

K_d (Kr) - 9.74

DELAY PIPE TIME - 10 min.
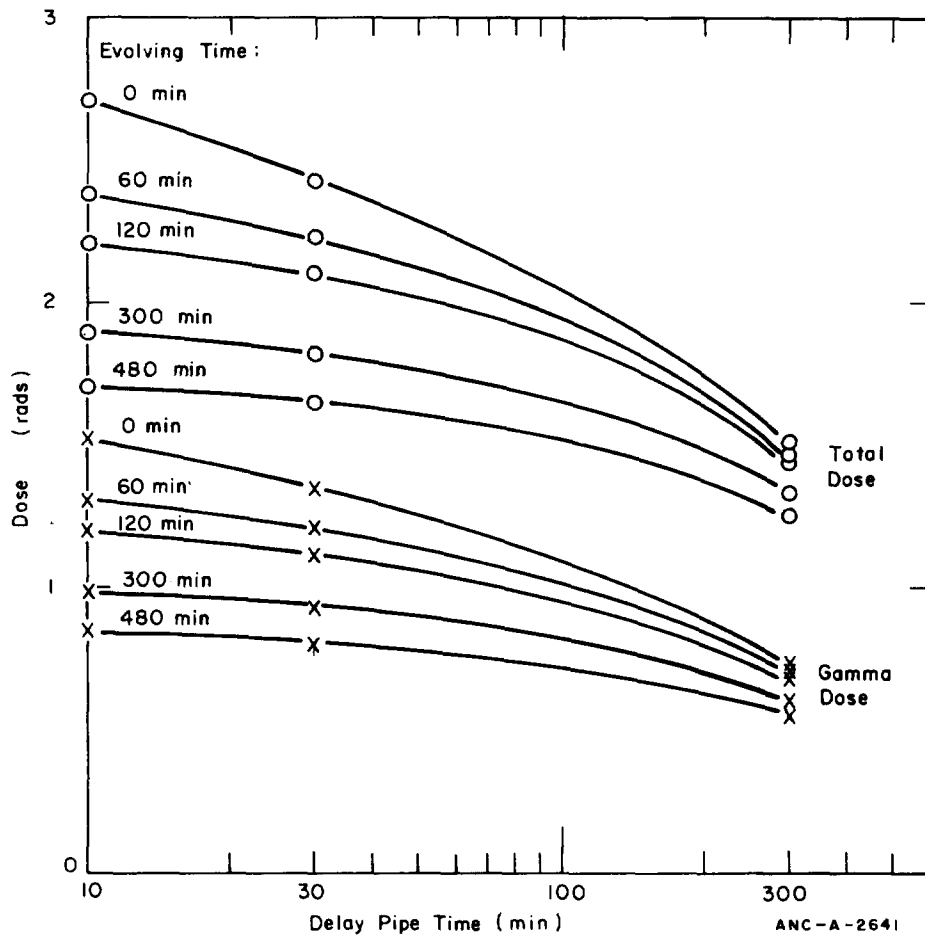

FIGURE 18

IMMERSION DOSES FOR Xe, Kr AND I
FROM RUPTURE OF CHARCOAL BEDS

FOR: PASQUILL TYPE F WEATHER CONDITIONS
GROUND LEVEL RELEASE
300 METER SITE BOUNDARY
FIRST BED OF 3 TONS (AMBIENT)
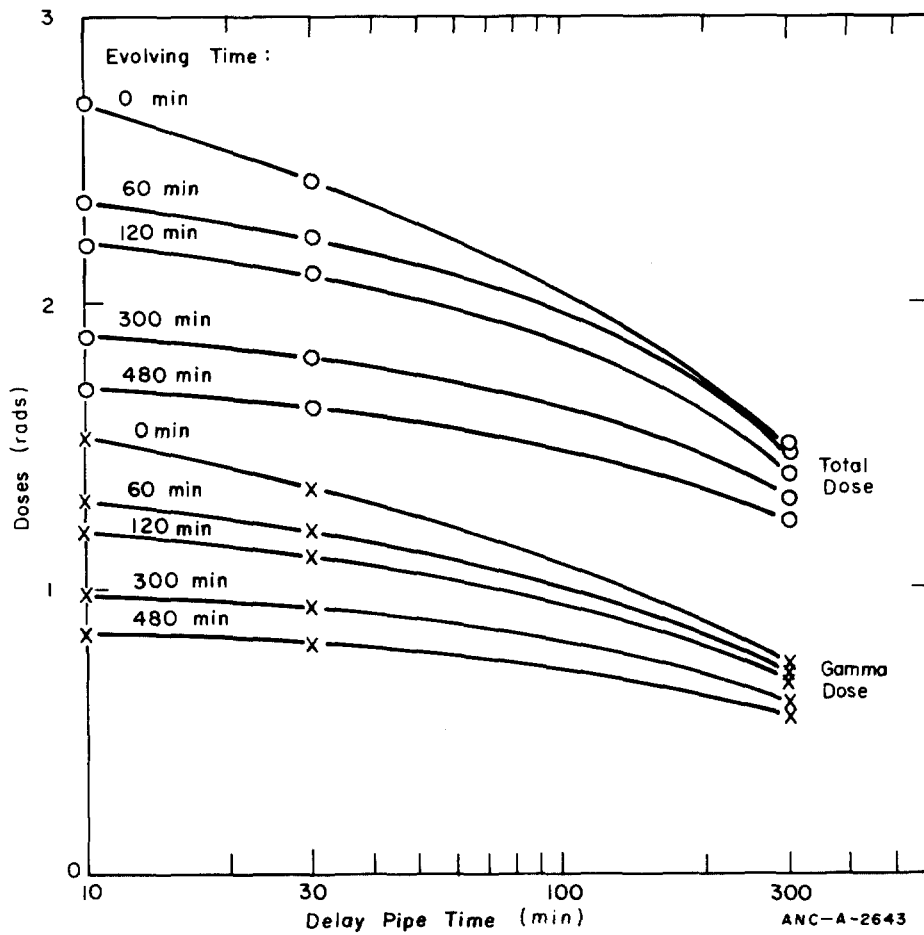K_d (Xe) - 1000.

K_d (Kr) - 64.9

DELAY PIPE TIME: 10 min.
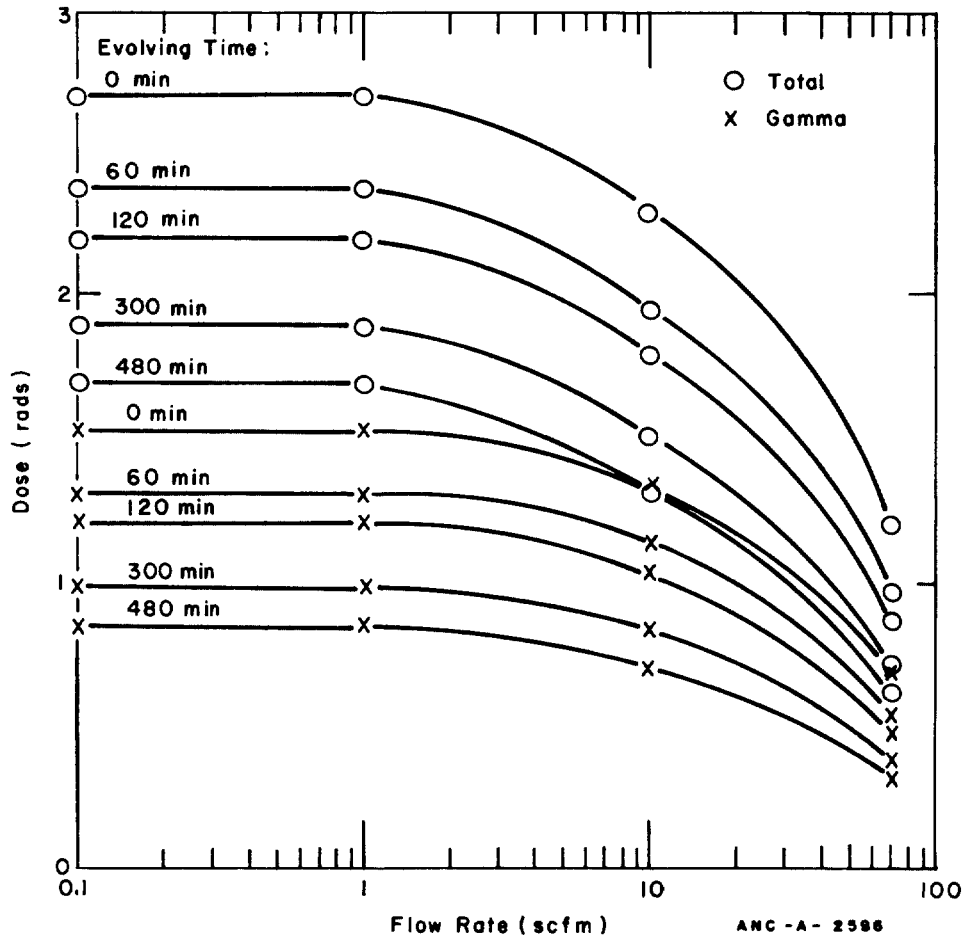
FIGURE 19

IMMERSION DOSES FOR Xe, Kr AND I
FROM RUPTURE OF CHARCOAL BEDS

85

FOR: PASQUILL TYPE F WEATHER CONDITIONS
GROUND LEVEL RELEASE
300 METER SITE BOUNDARY
12 BEDS OF 3 TONS EACH (AMBIENT)
K_d (Xe) - 1000.
K_d (Kr) - 64.9
DELAY PIPE TIME - 10 min.
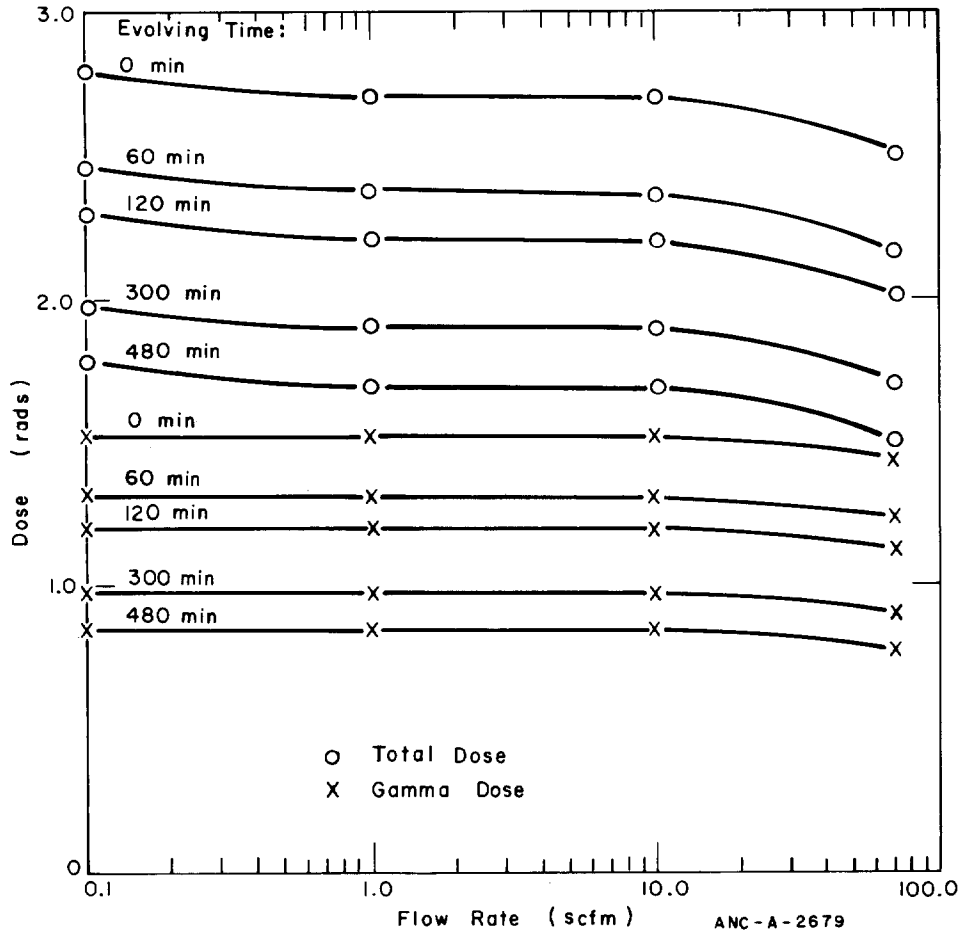
FIGURE 20

IMMERSION DOSES FOR Xe, Kr AND I
FROM RUPTURE OF CHARCOAL BEDS

FOR: PASQUILL TYPE F WEATHER CONDITIONS
      GROUND LEVEL RELEASE
      300 METER SITE BOUNDARY
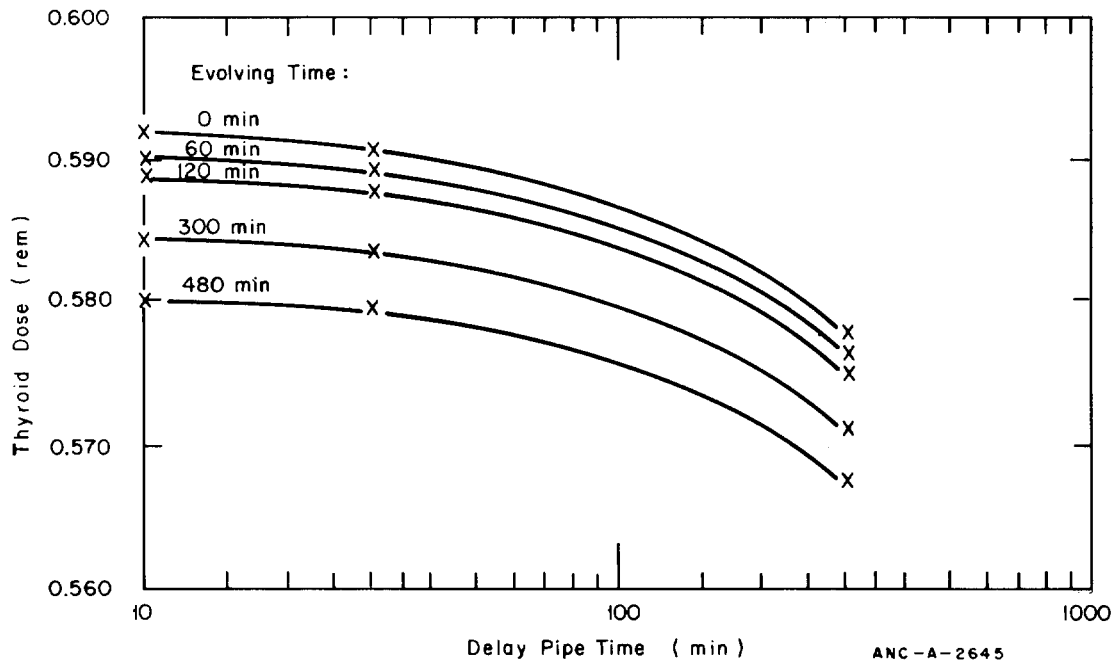   ONE BED OF 8 TONS (CHILLED)
      K_d (Xe) - 150.
      K_d (Kr) - 6.25
      DELAY PIPE TIME: 10 min.
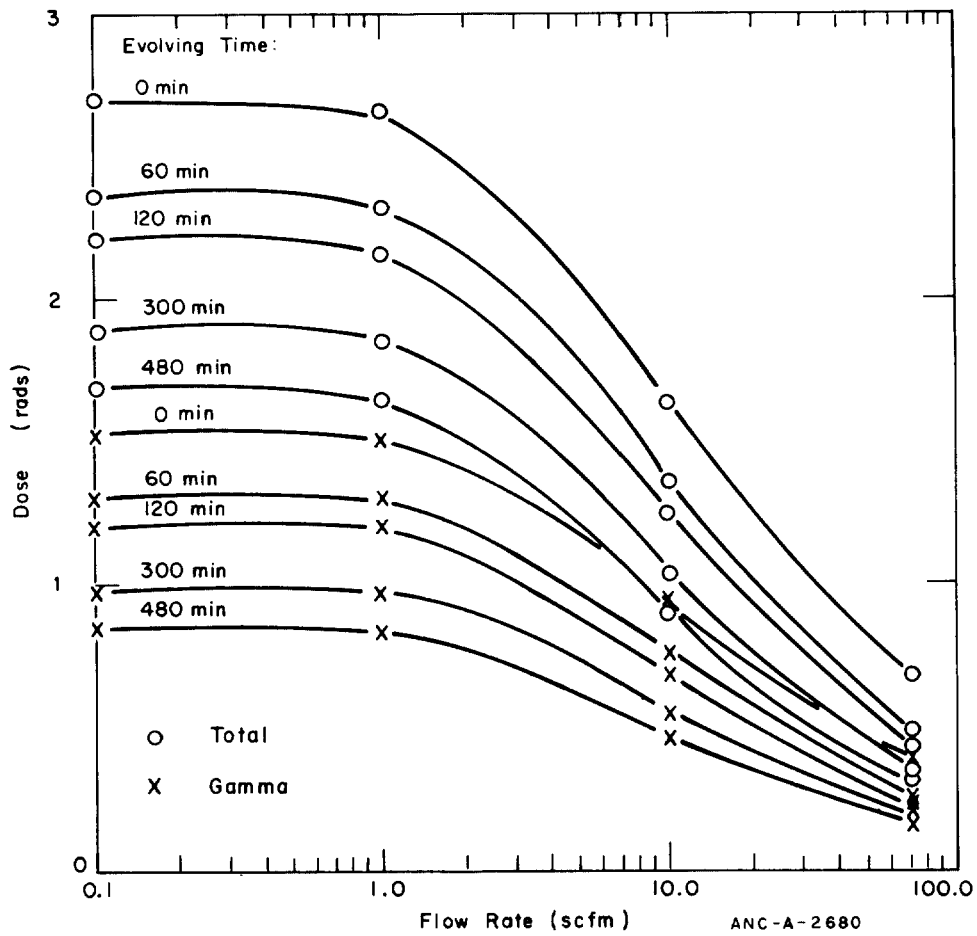
FIGURE 21

IMMERSION DOSES FOR Xe, Kr AND I
ISOTOPES FROM RUPTURE OF CHARCOAL BEDS

FOR: PASQUILL TYPE F WEATHER CONDITIONS
GROUND LEVEL RELEASE
300 METER SITE BOUNDARY
ONE BED OF 8 TONS (CHILLED)
K_d (Xe) - 8000.

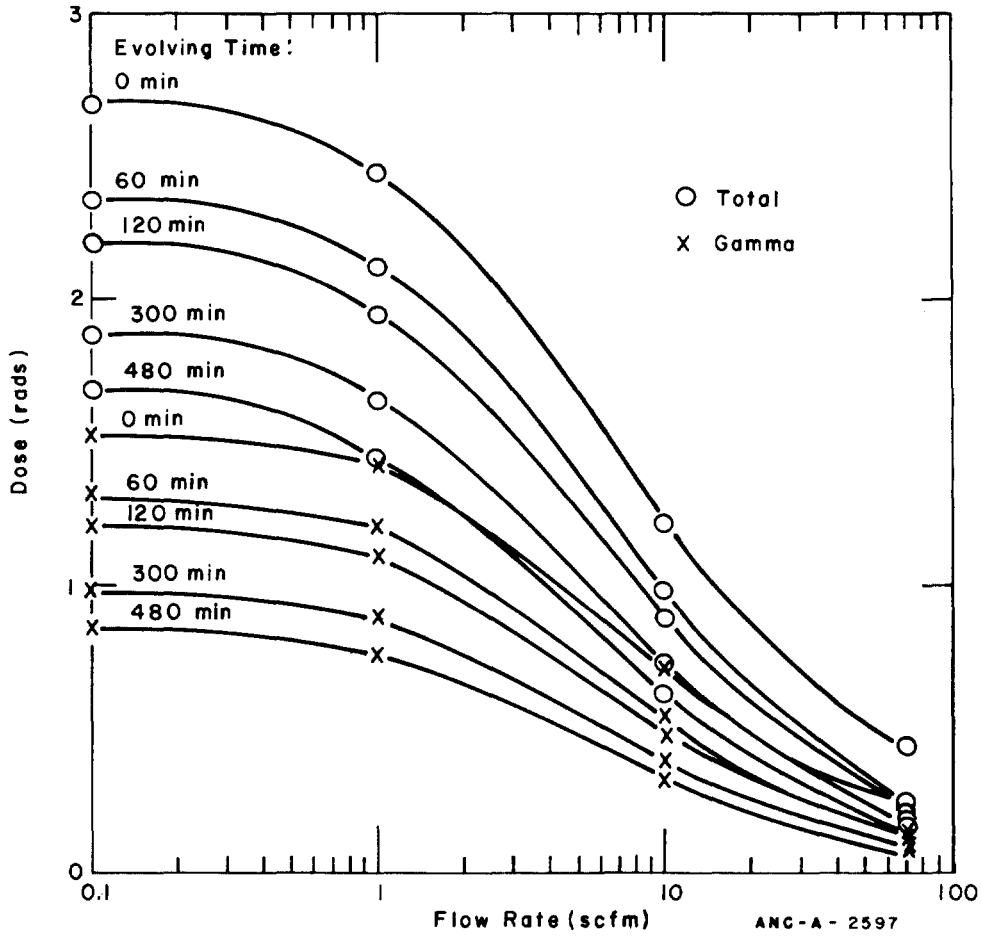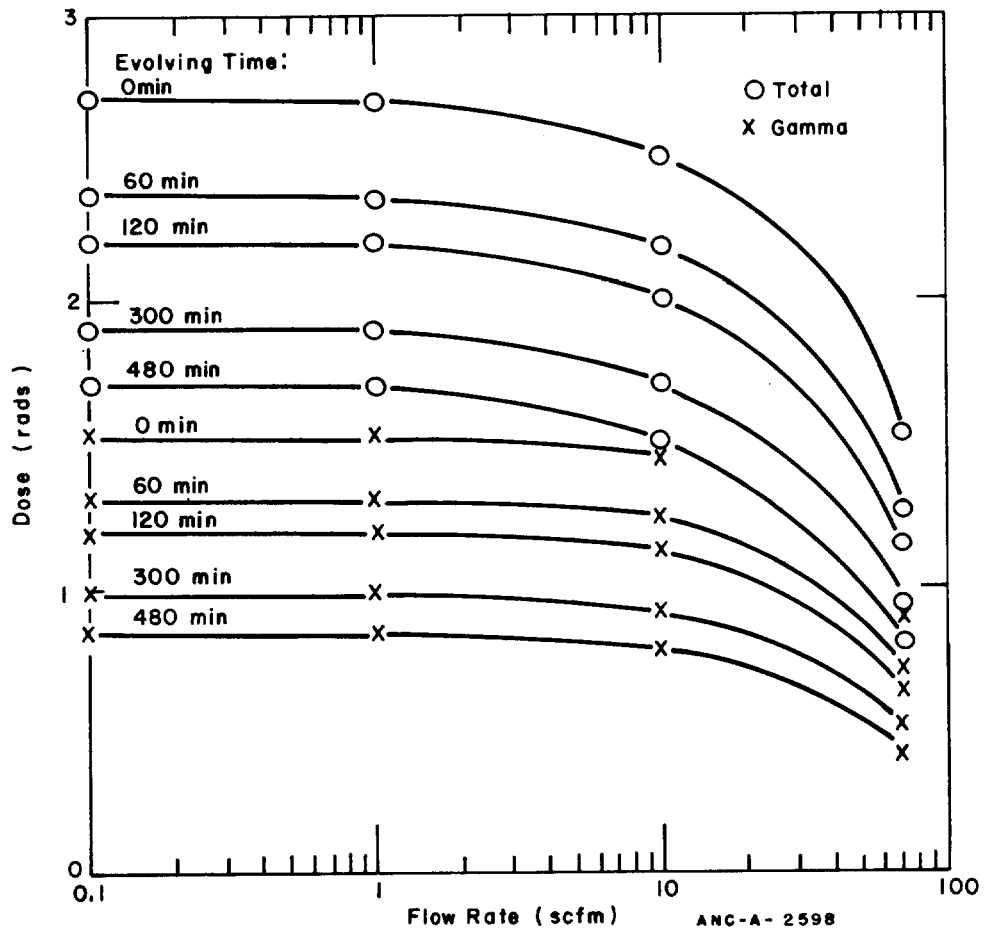K_d (Kr) - 333.33

DELAY PIPE TIME: 10 min.
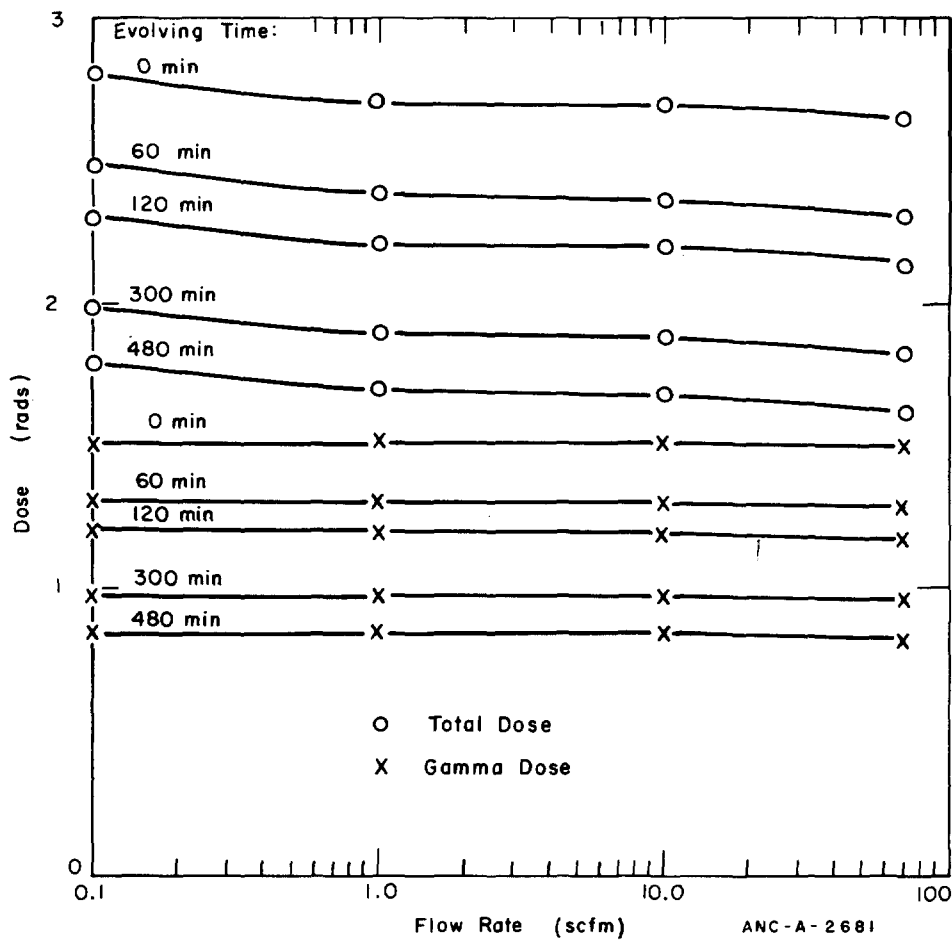
FIGURE 22

IMMERSION DOSES FOR Xe, Kr AND I
FROM RUPTURE OF CHARCOAL BEDS

FOR: PASQUILL TYPE F WEATHER CONDITIONS, GROUND LEVEL RELEASE
AT 300 METER SITE BOUNDARY
FLOW RATE: 70 scfm
DELAY PIPE TIME: 10 min.
K_d (Xe) - 150 (AMBIENT)
K_d (Kr) - 9.74
INSTANTANEOUS RELEASE OF ACTIVITY

N Number of Beds (each with 3 tons of charcoal)   ANC - A - 2682
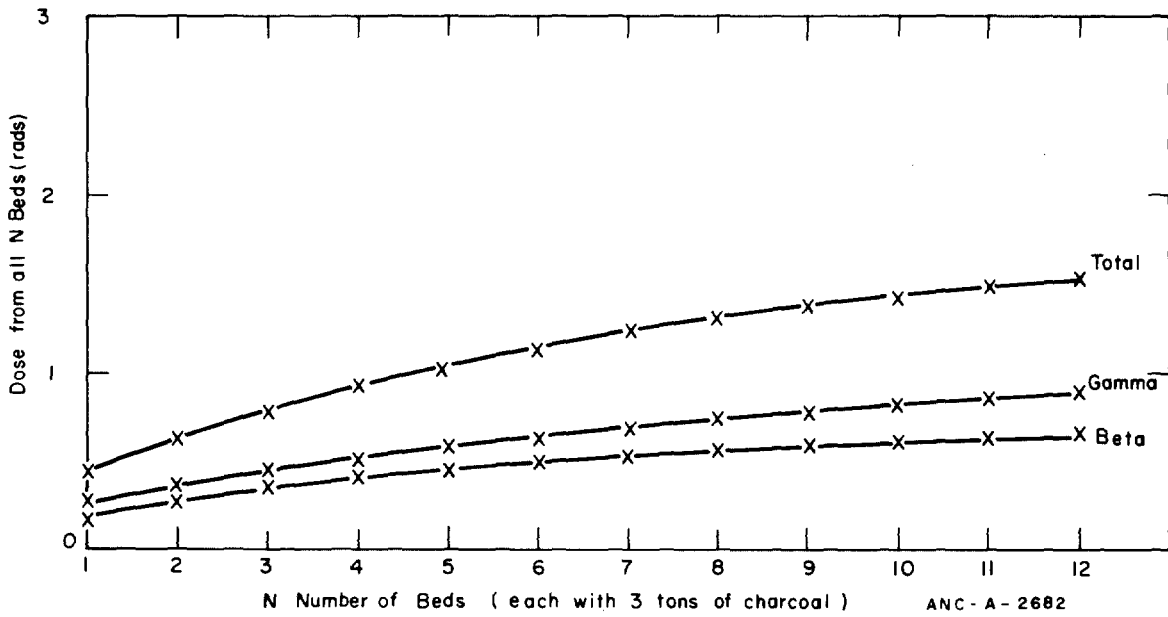
FIGURE 23

IMMERSION DOSES FOR Xe, Kr AND I
ISOTOPES FROM RUPTURE OF N CHARCOAL BEDS
BED #1 NEAREST DELAY PIPE OUTPUT

FOR: PASQUILL TYPE F WEATHER CONDITIONS
GROUND LEVEL RELEASE
AT 300 METER SITE BOUNDARY
FLOW RATE: 70 scfm
DELAY PIPE TIME: 10 min.
K_d (Xe) - 1000 (AMBIENT)
K_d (Kr) - 64.94
INSTANTANEOUS RELEASE OF ACTIVITY

ANC-A-2683
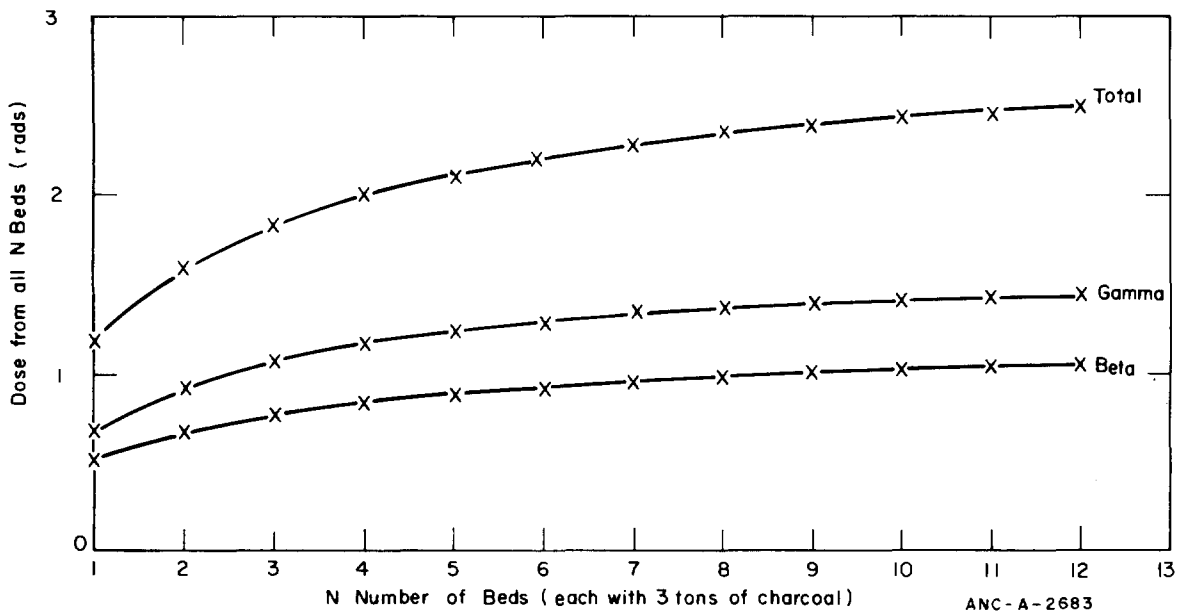
FIGURE 24

IMMERSION DOSES FOR Xe, Kr AND I
ISOTOPES FROM RUPTURE OF N CHARCOAL BEDS
BED #1 NEAREST DELAY PIPE OUTPUT

if one desires to know the calculated gamma immersion dose from the rupture of the fourth bed for a low K_d situation, this can be determined by subtracting 0.444 rads from 0.518 rads as shown on the gamma curve in Figure 23 for a value of 0.074 rads.

IV. Summary

The parametric studies have quantified contributions to the off-site doses from various sources under potential accident conditions associated with BWR off-gas systems.

The maximum calculated off-site immersion dose occurred for a delay line rupture at the main condenser steam jet air ejector. The values were about 9 rads gamma and 16 rads total for the varying delay line times considered. The maximum contribution to the total immersion dose from the activation gases was 4% and from the iodine gases it was less than 0.01%. For the noble gas particulate daughters, their maximum percentage contribution to the total dose was 40% without a filter rupture and 60% with a filter rupture. The maximum bone and lung doses from inhalation of the radioisotopes were calculated to be 0.065 and 0.13 rem, respectively, without a filter rupture. It should be noted that the maximum bone dose occurred at a break position of 110 minutes from the condenser on a 300-minute delay line while the maximum lung dose occurs at a break position of about 15 minutes on the same delay line. The interactions between the delay line times, decay schemes of the radioisotopes, and their biological metabolism cause the stated break positions of maximum lung and bone doses to occur. The maximum thyroid dose from inhalation of radioiodine was calculated to be 0.0058 rem for a rupture at the condenser SJAE of a 300-minute delay line.

The highest off-site doses associated with simultaneous rupture of the delay line and particulate filter was for the 10-minute delay line. This case yielded a gamma dose of 2.0 rad, and a total dose of 3.1 rad. The contribution from the filter rupture was 0.35 rad and 0.53 rad gamma and total dose, respectively. The bone and lung doses associated with this case were 23.4 and 68.3 rem, respectively.

The maximum off-site total dose for the adsorber portion of the off-gas treatment system was 2.8 rad for both the ambient temperature system and the chilled system. Both of these cases assume instantaneous release of the noble gases from the adsorber. The maximum K_d and low flow rate were used as input parameters. The maximum off-site total dose associated with rupture for the first of the 12 beds in series for the ambient temperature system was 2.7 rad. The maximum thyroid dose from a release of a one-year inventory of iodine isotopes was found to be 0.59 rem. This assumed a 10-minute delay line time and instantaneous release of the activity from the charcoal.

The calculated doses for a rupture in the off-gas system of a BWR are to a standard man at the 300 meter site boundary for the duration of the accident conditions, about 5 hours. The immersion doses calculated are exposure doses determined using the semi-infinite cloud model. The organ doses are from inhaled radionuclides which become deposited in the organ. Since the calculations are based upon accident conditions with the associated conservative assumptions and not normal operating conditions, the doses calculated are not excessively high. For example, if a mixture of Pasquill Type C, D, and F conditions and windspeeds of 2 to 3 m/sec were assumed instead of Pasquill Type F with 1 m/sec, the calculated doses would be lower by a factor of 50[3]. The model developed for the calculation will allow the simulated variance of the pertinent operating parameters of the BWR waste gas treatment system and thereby indicate improvements in design and operating procedures to minimize the doses from an accident condition.

V.   References

(1) R. J. Schultz and R. C. Schmitt, "Safety evaluation of BWR off-gas treatment
     systems", 13th AEC Air Cleaning Conference (August 12-15, 1974).

(2) C. A. Pelletier, "Results of independent measurements of radioactivity in
     process systems and effluents at boiling water reactors", Preliminary report,
     Environmental Protection Branch, Directorate of Regulatory Operations, U. S.
     Atomic Energy Commission (May 1973).

(3) Regulatory Guide 1.3, "Assumptions used for evaluating the potential radio-
     logical consequences of a loss-of-coolant accident for boiling water reactors"
     (June 1973).

(4) S. P. Siegwarth, C. K. Neulander, R. T. Pao and M. Siegler, "Measurements of
     dynamic absorption coefficients for noble gases on activated carbon", 12th AEC
     Air Cleaning Conference, CONF-72023, Vol. I (August 28-31, 1972).

(5) M. E. Meek and R. S. Gilbert, "Summary of gamma and beta energy and intensity
     data", NEDO-12037, Nucleonics Laboratory, General Electric, Pleasanton, Calif.
     (1970).

(6) G. P. Kenfield, W. R. Lahs, W. B. Sayer, R. M. MacAdams and N. A. Harris,
     "Curie-Dose-Thunderhead - a digital computer program for external and internal
     radiation dose calculations", NAA-SR-8884, Atomics International, Los Angeles,
     Calif. (1965).

DISCUSSION

B.A. SMITH: Correct me if I'm wrong, but it seems to me that
an extremely critical assumption in your analysis of the consequences
of a holdup pipe break is the actual time the system continues to
operate after the pipe rupture. I was wondering where the figure
of one hour of operation after the holdup pipe is broken, which I
thought I heard you quote, comes from?

DYER: Your point is well taken. The assumption of opera-
tion for one hour after the incident does cause the dose to be
larger than if one assumes an instantaneous shut down of the reactor.
Due to the problems involved in removing a 1000 MW electric plant
from the power grid, experience has shown that the shutdown time is
approximately one hour rather than instantaneously.

B.A. SMITH: I can't imagine any utility is going to be very
reticent about shutting down even a 1000 MW system in the event of
a rupture in the holdup pipe.

DYER: My information on this comes from the incident
reports referred to by an earlier paper. Would anyone else care to
comment on this?

BENAROYA: I think we have had quite a few discussions with
GE on this subject. I would be delighted to discuss this with any-
body who is interested but it might take some time.

KOVACH: I would like to find out if you took into consideration that some of the holdup pipes are buried and some of the noble gases and daughter products would have to diffuse through soil. Additionally, do you have any experimental data for iodine release. In fact, one wouldn't expect the adsorber beds to release iodine. Is the release strictly a postulated one?

DYER: No consideration was taken for diffusion through the soil other than the diffusion release of 20 percent of the delay pipe contents over five hours. The iodine release from the beds is assumed to be 100 percent over the varying time periods mentioned in the talk. This is a conservative assumption based on a lack of definitive data, which is not desirable. This is a very pertinent point and it was not considered. This calculation, of course, is a calculational model which considers maximum fuel effect. All of the iodine was assumed lost from it.

KOVACH: I was trying to establish if we are talking about a maximum credible or a maximum incredible accident.

DYER: One can play with those semantics quite well.

WILHELM: We loaded iodine on unimpregnated charcoal and tried to get the iodine off. It was completely impossible. The chemical form sitting on the charcoal doesn't change and you can't remove it. So, no iodine which is adsorbed on charcoal will come off.

DYER: That's very interesting data you're commenting on. I think what this points up is that more information is needed as to how much iodine is released, how much stays, what criteria one can assume in a credible accident situation. When we get more information on these points, there is no reason why the calculational model can't be modified.

ENGINEERED-SAFETY-FEATURE AIR-CLEANING SYSTEMS

FOR

COMMERCIAL LIGHT-WATER-COOLED NUCLEAR POWER PLANTS

(A Review of Past and Current Practices in Their Design,
Construction, and Standardization)

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Abstract

Substantial improvement has been observed in the design and construction of ESF air cleaning systems in some of the newer power plants, as compared to earlier practice, but there is still much to be done. Adequate space must be provided for these facilities in the earliest containment and building layout, and system designers, equipment designers, and building layout engineers must give adequate consideration to easy access to facilitate maintenance and testing. Finally, constructors and utilities must provide for proper storage of critical components such as HEPA filters and adsorber cells during construction and during the period awaiting startup of the plant.

Introduction

The effectiveness of a high-efficiency air-cleaning system depends on the quality of the HEPA filters, adsorbers, and other primary components of the system. During the 1950's and 1960's, the main thrust of the AEC gaseous effluent program was directed toward development of these components, and in establishing minimum requirements for them. Today there are a number of nationally recognized standards covering these items, including, for HEPA filters and HEPA filter media:

Military specification MIL-F-51068, Filter, Particulate, High-Efficiency, Fire Resistant.

Military specification MIL-F-51079, Filter Medium, Fire-Resistant, High-Efficiency.

AACC CS-1, Standard for HEPA Filters (available from the Institute of Environmental Sciences, Mt. Prospect, Ill.)

RDT standard M 16-3, HEPA Filter Medium Glass Fiber (MIL-F-51079 with Modifications and Additional Requirements). (RDT M 16-3 updates the military specification, providing, in particular, requirement for radiation resistance of HEPA filter media).

and for adsorbers:

AACC CS-8, Standard for High Efficiency Gas-Phase Adsorber Cells (available from the Institute of Environmental Sciences, Mt. Prospect, Ill.).

RDT standard M 16-1, <u>Gas-Phase Adsorbents for Trapping Radioactive Iodine and Iodine Compounds</u>.

Another RDT standard, E 9-1, HEPA Filters (AACC CS-1 with Additional Requirements, may be available in the near future to update the requirements of both AACC CS-1 and MIL-F-51068.

But high quality, high-efficiency air cleaning components are no better than the system in which they are installed. For years, AEC laboratories and production facilities spent literally millions of dollars in repairing, upgrading, or just living with inadequate and poorly designed air handling systems, designed and built largely by unknowledgeable people. In 1970, to alleviate this condition, ORNL-NSIC-65, commonly referred to as "The Air Filter Handbook" (1), was published. This report attempted to explain some of the problems and special considerations of nuclear air cleaning systems, and to provide a guide for their design, construction, and testing. Although it was written primarily for AEC operations, its message is equally applicable to commercial facilities. Also, although it was written to cover all types of nuclear air cleaning facilities, it contains the information needed for at least the "mechanical design" (as opposed to functional design) of ESF (engineered safety feature) systems.

Considering the experience with AEC "in house" facilities, it was only natural that some concern was expressed with respect to the quality of design and construction of air cleaning systems for power reactors and other commercial nuclear facilities. And this concern was well grounded. None of the commercial-plant air-cleaning systems visited while preparing to write ORNL-NSIC-65 reflected what is considered good design practice for contaminated (or potentially contaminated) systems. All were, in our opinion, under-designed from the standpoints of leak tightness, structural integrity, and operational reliability, and few gave adequate attention to such vital functions as maintainability or testability. As in the earlier AEC installations, air cleaning was a stepchild, and equipment was generally tucked away in back corners of the plant and often inaccessible.

As a first step to correct this situation, AEC Directorate of Licensing issued Regulatory Guide 1.52 (2) which stipulated the use of ORNL-NSIC-65 in the design and construction of ESF air cleaning systems, and provided guidance in acceptable levels of system performance. Then, over the past year and a half, they embarked on a program of site visitation to determine just what has been done and is being done with respect to the design and construction of air cleaning systems in present-day commercial reactors. Members of the ORNL staff participated in this program. In all, 23 reactor sites were visited. Details of the findings of this survey are given in WASH-1234 (3) which is available for $1.40 from the Government Printing Office in Washington, D. C. During the survey, everything from the very worst that had been seen in previous years, to very good, was observed. In general, considerable improvement, particularly in the newest plants. There is still a way to go, however, and it is worth pointing out a few of the factors that still demand additional consideration.

First, greater attention must be paid to location and space provisions for these systems during the layout phase of containment or building design. The location of filter houses in inaccessible areas inhibits proper maintenance and testing, let alone creating hazards to personnel, and often results in a reduction in system reliability. Recommended space requirements, both within and adjacent to filter housings, are given in ORNL-NSIC-65.

Although there are still a good many "tin" housings still around, a very commendable trend toward heavy-gauge, factory-built filter housings was noticed. The design and workmanship of factory-built housings are so much better than field-fabricated installations that there is just no comparison. However, one must avoid placing too many restrictions on the vendor's design -- space limitations on the vendor have resulted in some real "odd ball" configurations. The utilities are also cautioned to enforce proper field practices during the installation of these housings. Gasketed or caulked joints, for example, are not acceptable in ESF systems, and are poor practice in any nuclear air cleaning system. Welding provides the only long-time, reliable, leak-tight joint.

Greater attention should be paid to the aerodynamics of ducts and housings. Inattention to this factor results in poor air distribution through components such as demisters, filters, and adsorbers whose proper performance depends on uniformity of airflow and airflow velocity. It also results in pressure and velocity losses in the system which can adversely affect fan performance and compromise the ability of the system to operate as intended. Fan inlet and outlet design and duct layout are often critical factors in system performance and operating economy. Recommendations on fan layout are given in ORNL-NSIC-65, and recommendations on duct layout are given in the ACGIH's Industrial Ventilation (4).

System bypasses should be mentioned, although we seem to be getting away from this feature. If a system bypass must be used (and it is not recommended), it must be fitted with highly reliable, leaktight isolation valves; louver type dampers are not adequate for this application. More insidious is the inadvertent system bypass caused by an improperly sealed housing drain, or by items such as electrical conduits which penetrate the mounting frames of HEPA filters or adsorbers. Particularly with today's "low as practicable" regulations, even small leaks from the air cleaning system can be significant.

One final item to be mentioned is the storage of filters and adsorber units while awaiting installation. Poor storage practices can mean damaged or deteriorated components when the time comes for installation, with the resultant need for replacement and consequent delays. At $100 to $120 for a HEPA filter, and substantially more for an adsorber cell, not to mention the cost of downtime while you try to obtain replacements, you just can't afford this type of waste. Nor can you afford the poor practices often followed in the installation of these easily damaged items. It is strongly recommended that these items be installed only by personnel who have been properly instructed in their care and handling, by personnel who have been given at least a two to three hour "course" in the subject. In one installation, poor installation practices destroyed 36 HEPA filters in a bank of 48; in another, in which the operator had called in a consultant to indoctrinate his engineers and installers, not one filter was lost in a bank of several hundred -- or in any other of the large installations at that site.

One additional step in the program is on-going participation in the development of nationally recognized standards for nuclear air cleaning and air handling facilities. American National Standard N510, Testing of Nuclear Air Cleaning Systems, has just been published and is available through ASME (5), and N509, Standard for Nuclear Power Plant Air Cleaning Units and Components, will be available in the near future. Both of these deal with the "mechanical" aspects of design which ensure a reliable system. Other standards, covering the functional

aspects of design (e.g., establishing what components are needed, system airflow and pressure, etc.) are in the throes of preparation. In addition, a new edition of ORNL-NSIC-65 is being prepared which will address more closely the special problems of ESF air cleaning systems, multiple filter systems such as required for plutonium and other high-hazard applications, fire protection, and so on. These efforts will go far toward providing the specific guidance needed for the future generations of safety related air cleaning systems for nuclear operations.

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(3) R. W. Zavadoski, H. Gilbert, A. B. Fuller, and C. A. Burchsted, Engineered Safety Feature Air Cleaning Systems for Commercial Light-Water Cooled Nuclear Power Plants, USAEC Report WASH-1234, June 1974.

(4) Industrial Ventilation, American Conference of Governmental Industrial Hygienists, Ann Arbor, Mich. (annual issue).

(5) Testing of Nuclear Air Cleaning Systems, (proposed) American National Standard N510, American Society of Mechanical Engineers, 1974.

DISCUSSION

FIRST: After hearing some of the papers this afternoon, I have the distinct impression that there isn't a good system anywhere in the whole world. I object to seeing large series of horrible examples of what's being done. Rather than tell us what not to do, I think it's a more correct procedure to teach people how to do it right than to tell them how to do it wrong. I would recommend that those who go around inspecting systems train their cameras on all the best examples they see. Maybe, two years from now they can shown us what a perfect system looks like.

BURCHSTED: Show us examples in present day systems that illustrate good practice and we will be glad to take pictures and display them. We just can't find them in the systems we have seen to date. Your point is nice and clear but it does not hold up in practice. On the other hand, the systems we are showing today were designed three or four years ago. I suspect that by the next conference we may be able to start showing examples of satisfactory design practice.

SULLIVAN: Usually back-to-back filter banks are not recommended. However, we still see designs coming through with back-to-back prefilters and HEPA filters, i.e., no access between the banks. Can you elaborate on the problems associated with this arrangement.

BURCHSTED: HEPA filters are the final barrier between you and the great outdoors. Ninety percent of the damage in a HEPA filter can be detected visually. In back-to-back installation you never see the damage. Another aspect is that if you wish to scan, in order to locate a leak somewhere, there's no way to do so if the HEPA and prefilter are back to back. A third point is the possibility of damage to the HEPA filter by the prefilter. We have a beautiful example in Wash. 1234 where a prefilter with wire media support had been pushed back into the space occupied by the HEPA filter; there's no way that that HEPA filter could have survived.

VERMONT YANKEE ADVANCED OFF-GAS SYSTEM (AOG)

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Abstract

Early in 1971 the Vermont Yankee Nuclear Power Corporation decided to modify the existing off-gas delay system to reduce the release of noble gas isotopes from its boiling water reactor. This modification included a subsystem for recombining the radiolytic hydrogen and oxygen from the reactor and a series of adsorber tanks filled with activated carbon to delay the noble gas isotopes from the condenser air ejectors. This paper describes the off-gas system and its operating history from initial operation in November 1973 to the present time.

Data are also presented on the measured dynamic adsorption coefficient of the ambient carbon subsystem. Laboratory adsorption tests were conducted on the carbon prior to AOG startup and the results are compared with the effective coefficients obtained under operating conditions.

I. Introduction

A. Background

The gaseous radwaste treatment system initially installed in the Vermont Yankee plant to process air ejector offgas consisted of an underground holdup pipe (to delay the gas for approximately 30 minutes), absolute and charcoal filters in the stack (to collect the particulates produced by decay of gaseous activity in the holdup pipe and iodine vapor) isolation valves, and appropriate instrumentation (to measure flow, pressure and activity). The air ejector offgas was then vented through the plant stack to the atmosphere to obtain maximum dilution by atmospheric dispersion.

Prior to plant operation, it was recognized from experience at other operating boiling water reactors, similar to the Vermont Yankee design, that most of the site boundary dose resulted from the offgas from the condenser air ejectors.

In 1970, Vermont Yankee was in the completion phase of construction. About this time the States of Minnesota and Vermont became active in establishing plant radioactive discharge limits lower than the operating limits of 10CFR20. Vermont Yankee, in cooperation with Vermont State Officials, agreed to backfit the plant with a modification, called the Advanced Offgas System (AOG), which would delay radioactive fission product gasses from the air ejector and, with the resultant reduction through radioactive decay, enable the plant to meet Vermont's discharge limits.

The AOG modification was designed to reduce the air ejector radioactive gaseous releases rates to low practical levels commensurate with the state of technology, the economics as they are related to the degree

of public benefit, and the availability of the process and the equipment for timely incorporation into an operating power plant.

Four processes for krypton and xenon radioactivity reduction were considered for application to this modification: removal by cryogenic distillation, removal by fluorocarbon absorption, selective retention by charcoal adsorption and total gas retention by compressed storage. The first two of these processes were eliminated from consideration because they were considered to be technologically unavailable for the BWR offgas application at the time. In contrast, there was significant experience with both charcoal and compressed gas holdup systems, and both of these processes can yield equivalent benefits with respect to reduction of radio-activity release, as both processes are capable of effectively decaying the noble gas radioisotopes except krypton-85.

An ambient charcoal system was chosen for Vermont Yankee mainly on the basis of the ability of charcoal to achieve relatively long hold up times for xenon and the obvious advantage of operating the delay portion of the system at a slightly subatmospheric pressure.

B. Design Basis

The design objective of the AOG modification was to reduce the plant boundary dose rates due to airborne releases from the air ejectors to about one percent of the dose rates that would be experienced without the modification. It was estimated that the AOG would be capable of reducing the air ejector offgas release rate by almost a factor of 100.

The charcoal adsorption is designed to provide a retention time of at least 24 hours for krypton and at least 16.6 days for xenon when the air flow rate (after recombination of the radiolytic hydrogen and oxygen) is 30 scfm. The design basis of 77,080 lbs of charcoal was selected since it provides a krypton and xenon delay of 24 hours and 16.6 days respectively under degraded operating conditions. However, the chosen adsorber system described below contains 7 equivalent tanks designed to contain approximately 90,000 lbs of charcoal (6 are required for the 77,080 lbs of charcoal).

Therefore, the following system design bases were established to support a charcoal holdup system:

1. Utilize plant air ejectors to obtain sufficient offgas hydrogen dilution by steam (less than 4 volume percent) to prevent accidental explosions.

2. Remove the radiolytic hydrogen and oxygen which make up approximately 80 percent of the offgas volume by utilizing a catalytic recombiner to promote recombination of the hydrogen and oxygen into water and then condense the water vapor out. This recombination will minimize the volume of gas to be processed and will increase the delay time.

3. Provide sufficient charcoal to assure a retention time of at least 24 hours for krypton and at least 16.6 days for xenon for an inlet air flow rate of 30 scfm at ambient temperature.

4.   The air shall be dried to less than $-4°F$ dew point before entering
     the charcoal beds to achieve large dynamic adsoprtion coefficients
     for krypton and xenon. [The system described below actually dries
     the air to less than $-40°F$ dew point at an ambient temperature of
     $70°F$ (Relative humidity <1%).]

5.   All pressure vessels, heat exchangers, valves, and piping are designed
     to withstand a hydrogen detonation.

6.   The system provides for dual trains of all components with the excep-
     tion of the existing delay pipe and the new charcoal adsoprtion train.
     The standby train is immediately available for use in the event of
     equipment malfunction.

7.   Equipment is located in shielded compartments so that any key piece of
     equipment can be isolated for maintenance and the exposure of maintenance
     personnel to radiation from operating portions of the system will be
     minimized.

8.   The AOG building and vessels containing significant quantities of
     radioactive products, are designed for the design basis earthquake,
     tornado, and probable maximum flood.

9.   The charcoal adsorber section is instrumented with activity measuring
     devices as well as temperature and relative humidity measuring devices.

II. System Description

A. Summary

     The modification to the originally installed offgas system consists
of the addition or modification of the following subsystems:

1.   The second stage air ejector after-condenser is made inactive by
     valving it off and bypassing the offgas and coolant flow. Therefore,
     the second stage steam dilutes the hydrogen content to less than 4
     percent by volume.

2.   The present "30 minute" delay pipe is divided into two sections. The
     initial section consists of 40 percent (approximately 55 minute delay
     based on 30 scfm) of the original length and the final section consists
     of the remaining 60 percent (approximately 80 minutes @ 30 scfm) of
     the original length.

3.   The recombiner subsystems are added after the second stage main steam
     condenser air ejector upstream of the first portion of the present 30
     minute delay pipe.

4.   The offgas moisture removal/dryer subsystem is added at the end of the
     first portion of the present delay pipe.

5.   The charcoal adsorber gas holdup subsystem is added downstream of the
     moisture/dryer subsystem and upstream of the final portion of the
     present delay pipe leading to the stack particulate filters.

Figure 1 is a simplified diagram of the offgas system.

B. Hydrogen Dilution and Recombiner Subsystem

The purpose of diluting the offgas mixture with steam at the air ejector stage is to prevent a flammable mixture (4 percent hydrogen volume) of hydrogen from entering the downstream hydrogen recombiners. The offgas is diluted at the second stage air ejector with approximately 6800 lb/hr H_2O resulting in less than a 3 volume percent hydrogen concentration.

The recombiner subsystem consists of a single path leading from the hydrogen dilution steam jet eductors to two parallel flow paths for hydrogen recombination. Each recombination subsystem is capable of operating independently of the other and each is capable of handling the condenser offgas at a startup design flow rate of 1600 lb/hr air and the normal offgas design flow rate of 371 lb/hr. The major components of each recombiner flow path are a preheater, a hydrogen-oxygen recombiner, and a desuperheating condenser.

The preheater is used to assure that the vapor entering the recombiner is superheated approximately 85°F for effective operation of the recombiner.

The steam-gas offgas mixture enters the catalytic recombiner at 300°F. As the mixture passes through the recombiner, the H_2 and O_2 present in the mixture recombine in an exothermic reaction increasing the exit temperature to about 634°F. When the steam is removed from the offgas mixture, the hydrogen concentration remaining will be less than 0.1 volume percent (v/o) of the gas mixture.

The recombiner consists of a bed of alumina pellets plated with precious metals that catalyze the recombination of hydrogen and oxygen. The bed is supported by a stainless steel grid with wire screening all housed in a vertical chrome-moly steel pressure vessel. The offgas mixture flows vertically down through the bed.

The catalyst lifetime is estimated to be equivalent to plant lifetime when operating in the steam/offgas environment. Since the concentration of poisoning halogens (iodine and bromine) is low, the reduction in active catalytic sites due to halogen poisoning will be insignificant.

To maintain the vessel and bed at the required minimum operating temperature (300°F) after initial warmup while in the standby condition a blanket type electric heater is wrapped around the vessel. A thermocouple attached to the vessel wall is used for control while a thermocouple installed in the catalyst bed is used to monitor bed temperature and also for overtemperature protection. Two additional thermocouples installed in the catalyst bed at different locations also monitor the bed temperature. The three bed thermocouples provide a temperature profile, i.e., as the hottest region of the bed progresses from the inlet side towards the outlet side with lifetime, an assessment of bed depletion is provided.

The pressure vessel will be of chrome-moly steel approximately 68" in diameter and 144" in height. It is designed, fabricated, inspected, and coded in accordance with ASME Boiler and Pressure Vessel Code, Section VIII. Design pressure and temperature are 500 psig and 950°F respectively. Figure 2 is a photograph of one of the installed recombiners.

The desuperheating condenser is designed to remove the heat of recombination and to condense the steam from the remaining offgas. The condensers discharge the offgas through moisture separators into the initial portion of the originally installed underground holdup pipe. The preheaters/recombiners are operated at pressures slightly above atmospheric. The condenser and the subsystems that follow operate at sub-atmospheric pressures.

C. Offgas Moisture Removal/Dryer Subsystem

This subsystem consists of two parallel cooler condenser and gas dryer units. Each condenser is cooled by a mechanical glycol/water refrigeration system that cools the offgas to 40°F as it removes bulk moisture. The dryer is designed to remove the remaining moisture by a molecular sieve desiccant to a dew point of less than -40°F (<1% RH). There are two dryers per train and while one is adsorbing moisture from the offgas, the other is desorbing moisture by circulating heated air through the bed in closed cycle.

The mixed refrigerant/dryer concept improves the reliability of the system. If the refrigerant system fails, the two dryer beds can be operated in parallel to remove the moisture and maintain the offgas near the design dew point (-40°F) while the mechanical systems are repaired. If the dryer beds fail, the 40°F dew point air leaving the mechanical system can enter the guard bed for over 6 hours (each bed) without affecting performance of the downstream charcoal.

Particulate (HEPA) filters (one in each train) with flame suppressent prefilters are located at the exit side of the delay pipe ahead of the moisture removal subsystem to remove radioactive particulates generated in the delay pipe.

D. Charcoal Adsorber Gas Holdup System

This subsystem consists of seven tanks of charcoal preceded by a smaller charcoal guard bed that protects the main tanks from excessive moisture in the event of a malfunction in the moisture removal subsystem and removes other poisons which might hinder Kr/Xe delay. The seven tanks were designed to contain approximately 90,000 lbs of charcoal.

Six tanks assure design performance and seven tanks are normally used. The seventh tank provides additional delay when used with the other six or alternately can be used to store a "high activity" spike if necessary. The first two tanks are valved so that they can be bypassed. The remaining five are all in series with no bypassing features so that the offgas cannot be discharged to the stack without significant delay.

The seven adsorber vessels are 6' diameter by 20' high carbon steel cylinders. The guard bed cylindrical carbon steel vessels are 3' diameter

by 6' long. They are designed, fabricated and inspected in accordance with ASME Boiler and Pressure Vessel Code, Section III, Class 3. The design temperature and pressure are 200°F and 500 psig respectively. Figure 3 shows one of the adsorber tanks being installed.

Each of the seven main vessels are supplied with charcoal fill and withdrawal ports sealed with gasketed blank flanges. Air flow is vertically down and ceramic balls (approximately 1/2" diameter) installed over the charcoal together with flow baffle plates will assure the flow is evenly distributed and preclude channeling. The charcoal is supported by stainless steel grids with 20 mesh wire screens to prevent loss of charcoal particles.

Redundant particulate (HEPA) after-filters are used to remove charcoal fines prior to the vacuum pumps. In addition, the stack filters will continue to be utilized to further prevent radioactive particulates from being released to the atmosphere.

E. Vacuum Pump

A liquid ring seal vacuum pump boosts the offgas pressure from 10 psia at the outlet of the after-filters to over atmospheric pressure at a maximum flow capacity of 75 scfm. The pump is a 50 psia non-coded assembly driven by a 5 hp, 1750 rpm, motor with an inlet check valve, water trap silencer, seal flow control valve, strainer and upstream pressure regulating control. The seal water is contained in a closed loop system and is continuously recirculated through the pump. During startup, the two pumps can be operated in parallel. The vacuum pump maintains a zero offgas leakage by providing a water seal at the motor/pump bearings. Water flows inwards into the offgas mixture preventing air leakage through the motor/pump bearings. The seal water is subsequently removed by the downstream moisture separator and returned to the closed loop system.

F. Radiation Monitoring

All radiation monitoring is performed by remote chambers using small sample streams of the process gas. There are seven radiation monitors located as follows in the process system:

        Inlet of each guard bed (2)
        Common outlet of guard beds (1)
        Outlet of adsorber beds 1 and 2 (2)
        Outlet of system to the remaining 24" diameter delay pipe (2)

Each of the activity monitors are offline flow-through samplers with beta (β) scintillators. These detectors are located external or internal to the sample pipe as required to achieve the required sensitivity. The sampler/detector assembly is shielded to minimize background interference.

G. Instrumentation and Control

Each recombiner train is equipped with sufficient remote instrumentation and control equipment to permit remote operation from the reactor control room. Alarms are provided to alert the control room operator to any abnormal condition in the recombiner train, dryer train, or adsorber beds.

The operating recombiner train is automatically shut down if the inlet super-heat is insufficient, or if the hydrogen content at the train outlet exceeds 2 percent by dry volume. In the event of insufficient air inleakage and consequent lack of excess oxygen for proper hydrogen recombination, air can be bled in by remote manual means from the instrumented air bleed systems.

The offgas passing through the cooler condenser and the dryer beds is monitored for temperature, pressure, and moisture content. These parameters are monitored in the reactor control room and alarms will sound if these conditions are out of tolerance so that corrective action can be taken.

The charcoal adsorber beds are remotely monitored and/or recorded for temperature, moisture content, and radioactivity levels. Radiation monitors currently in the stack and at the air ejectors will alarm at high activity levels. Radiation monitors at the exit end of the adsorber train will be connected to close the offgas stack valves at high activity levels (the final portion of the original delay line provides approximately 80 minutes delay time at 30 scfm flow when the gas transverses to the exit from the adsorber train).

H. Arrangement, Structure, and Ventilation

The AOG system is located in a new building outside the east wall of the machine shop in the turbine building. Figures 4 and 5 are photgraphs of the AOG building. The building is compartmentalized to provide concrete shielding of all components and to allow access for maintenance of one train while the other is operating. In addition, separate shielded rooms are provided for all instrumentation and valves associated with a subsystem. Each component is located within a compartment so that they are easily accessible for maintenance.

The instrumentation is isolated from the valve room by concrete walls. The instrumentation is displayed for quick and easy monitoring in an access area of minimum radiation.

Structures are designed for Class 1 seismic standard, tornado effects, and a maximum probable flood.

Ventilation for the building is designed to maintain the building at a slightly negative pressure. Air flow is from "clean to potentially contaminated" areas. Ventilation air is discharged to the plant ventilation duct through particulate filters for subsequent stack discharge.

III. Design, Construction and Operating History

A specification for an ambient carbon system was prepared and sent out for bids in July 1971. The system manufacturer was chosen in October 1971 and construction work started in the Spring of 1972. Preoperational testing of AOG subsystems started in the summer of 1973.

The loading of carbon into the AOG tanks started on August 20, 1973 and took approximately 1 month to complete. Loading operations continued for

2 shifts per day, 7 days per week during this interval. It had originally been estimated that 10 days to 2 weeks would be required for this procedure, however, achieving high packing densities in the tanks delayed this estimate considerably.

The transfer of carbon from the shipping containers to the AOG tanks was accomplished with a Vac-U-Max loader. The carbon was vacuumed from the containers to a hopper suspended over the tanks (Figure 6). When the hopper was full the carbon was gravity fed to the tank at a controlled rate. As shown in Figure 6, a 4" diameter flexible hose was connected to the hopper and entered the tank through an approximately 8" diameter opening on the top.

The tanks were purged for an extended period with -40°F dew point air prior to filling. The carbon shipping containers were placed in a "tent" prior to opening and remained there during the loading operation. Recirculating air from the Vac-U-Max equipment was returned to the "tent" thus forming an essentially closed system. This technique minimized the amount of moisture pickup by the carbon during loading.

The filling was started with a distribution nozzle attached to the end of the flexible hose. This nozzle consisted of a flat plate which deflected the carbon as it fell. Due to the small diameter of the tank opening, the fact that this opening was offset from top center, and the limited fall height while filling the upper quarter of the tank, poor density was achieved in filling the first 3 tanks. The apparent carbon density ranged from 0.41 - 0.44 in these tanks (laboratory apparent density = 0.52). Subsequently, the distribution nozzle was removed and replaced with a modified distribution mechanism from a rotary lawn spreader. This spreader mechanism, combined with a reduced fill rate (approximately 200 lbs/hr), resulted in a filled density of approximately 0.50. The carbon from the previously filled tanks was removed and replaced at the higher density. Each of the 7 tanks now contain approximately 5450 kilograms (12,000 lbs) of carbon.

The AOG was connected to the air ejector during a fuel reconstitution outage in the fall of 1973. After experiencing a problem with the condensate drains on the recombiners, a successful startup of the AOG was conducted in November 1973. Since that time, the AOG system has operated continuously with only a few, relatively minor problems. Overall the performance of the system has been exceptional.

Figure 7 shows the weekly average stack release rates for noble gases prior to, and following AOG startup. Prior to AOG startup the stack release rate averaged approximately 10,000 μCi/sec in 1973. Since November 1973 the average release rate has been approximately 1000 μCi/sec with a corresponding worst site boundary fence post dose of less than 5 mrem/year. Of the 1000 μCi/sec total stack release rate, less than 100 μCi/sec is from the condenser air ejector via the AOG system.

<div align="center">IV. Adsorption Bed Evaluation</div>

A. Carbon Suppliers Laboratory Tests

The carbon supplier removed a small sample from each of the 465 drums

that were to be shipped to Vermont Yankee. These samples were composited
and tested for apparent density, moisture, particle size, CCl_4 activity,
hardness, ignition temperature and krypton adsorption coefficient. The
results of these tests are shown in Table 1.

The krypton adsorption tests were conducted on 750-800 gram samples
of carbon at a laboratory temperature of 77°F. Nitrogen zero gas contain-
ing 100 ppm of krypton and 350 μCi/m^3 of krypton -85 was diluted with air
dried to -50°F dew point prior to entering the test chamber. The resultant
gas mixture contained 7.6 x 10^{-3} mmHg of krypton.

<div align="center">

Table 1
Carbon Suppliers Test Results

</div>

Test Type (No. Samples Tested)	High	Low	Average
Apparent Density (19)	0.536	0.508	0.521
Percent Moisture (19)	1.2	0.5	0.92
Ignition Temperature, °C (2)	363	350	357
CCl_4 Activity, Percent (2)	64.8	64.4	64.6
Percent Hardness (2)	99.6	99.4	99.6
Particle Size (19)			
On 8 mesh, percent	4.7	1.8	2.88
On 12 mesh, percent	58.4	47.6	54
On 16 mesh, percent	49.1	37	42.3
On 20 mesh, percent	2.0	0.9	1.3
K_D for Krypton*, cc/g (2)	50.1	47.8	49

*Tests conducted at 25°C, 7.6 x 10^{-3} mmHg krypton

B. Equipment Manufacturer's Laboratory Tests

The AOG system manufacturer conducted a series of krypton delay tests
designed to determine the effect of moisture level on the adsorption coef-
ficient. These tests were run on the same carbon, but not on any of the
production lots supplied to Vermont Yankee. A krypton -85 tracer in air
at a total pressure of 621 mmHg was used for the measurements. The results
are shown in Figure 8[1]. All data on this curve have been corrected to 70°F.

The krypton dynamic adsorption coefficient at 1 percent carbon moisture
is approximately 55 cm^3/g as determined from these data.

C. Independent Laboratory Tests

Since the laboratory tests described above had determined the adsorption

<div align="center">107</div>

coefficient for krypton only, it was decided to submit a sample of the carbon for laboratory testing with both krypton and xenon. An accurate determination of the Xe/Kr delay ratio was important since it was anticipated that good operating data for xenon would be difficult to obtain. It was not expected that steady state xenon input levels from the reactor would be maintained long enough to reach an equilibrium condition in the AOG carbon beds. These tests would also provide baseline data if any future measurements of carbon degradation were to be made.

The carbon received by the laboratory was analyzed for moisture and was found to have a water content of 2.45 percent. Delay tests were performed on this "as received" carbon and also on a sample partially dried to 1 percent moisture to correspond to the moisture level of the carbon delivered to Vermont Yankee. The laboratory tests were performed on a 1400 gram sample in a test column with approximately the same L/D ratio as the AOG carbon tanks. Krypton 85 and xenon 133 were used as tracers with air at a dew point of -40°F as the carrier. The tests were performed at 70°F.

The results of these laboratory tests are shown in Table 2, taken from the test report.[2]

Table 2
Laboratory Test Results – Xe/Kr Ratio

2.45 + 0.05% Moisture Content

Run No.	Krypton Dynamic K	Xenon Dynamic K	Ratio
1	60.6	1,080	
2	60.5	1,065	
3	60.5	1,092	
Average	60.5	1,078	17.82

1.0 + 0.05% Moisture Content

Run No.	Krypton Dynamic K	Xenon Dynamic K	Ratio
1	68.8	1,112	
2	68.6	1,097	
3	68.8	1,103	
Average	68.7	1,104	16.07

D. Preoperational Adsorber Train Performance Test

A krypton performance test was conducted on the adsorber train prior to startup of the AOG system. This test consisted of injecting a pulse of krypton -85 tracer upstream of the guard bed and following its progress through remainder of the system via the radiation monitors.

The adsorber beds were preconditioned by passing 60 scfm of air dried to a -40°F dew point through them for 12 hours prior to krypton -85 injection. While this preconditioning would not result in an equilibrium moisture

level in the carbon, the test results would be conservative since prolonged operation at this dew point would result in lower carbon moisture and therefore greater delay times.

Following the preconditioning, approximately 40 mCi of krypton -85 was injected into 60 scfm of air over a 5 minute time period. The progress of the krypton pulse was monitored by radiation monitors before the first adsorber bed, following the first two adsorber beds, and following the seventh adsorber bed. The readings taken from these radiation monitors are plotted in Figure 9.

The adsorber beds were maintained at approximately 70°F throughout this test. System pressures were maintained at 13.5 psia at the inlet to the first adsorber bed, and 13.1 psia at the outlet of the last bed.

The krypton delay times shown in Figure 9 are 2.5 hrs for the first bed, 2.2 hrs for the second, and 11.3 hrs for the last 5 beds. When corrected to the design flow rate of 30 scfm these delay times become 5 hrs, 4.4 hrs, and 22.6 hrs respectively, thus meeting the design delay time of the system of 24 hrs for 6 out of 7 adsorber beds in operation.

E. Operational Performance Evaluation

The operational performance evaluation of the adsorber beds started in December 1973, shortly after system startup, and has continued until the present time. Throughout this evaluation period, the adsorber beds have operated at a temperature of 70 - 72°F and with an input air stream cycling between -35°F and -50°F dew point. Thus, the relative humidity of the entering gas has been in the area of 0.5 percent which would result in an equilibrium carbon moisture level of less than the initial value (as loaded) of 1 percent. The total flow rate through the AOG has ranged from 11 to 17 scfm at steady-state operating conditions.

Gas sampling lines are installed upstream and downstream of each adsorber tank. A gas sampling system, consisting of a vacuum pump and appropriate pressure guages and valves, is attached to the desired line and is used to fill a 14 cm^3 glass vial. The radioactivity in the vial is then counted on a 40 cm^3 GeLi detector and a 1000 channel analyzer. A mini-computer, hard wired to the analyzer, is used to calculate the isotopic concentrations of the off-gas stream.

The delay time in each adsorber bed is then calculated from basic principles:

$$C = C_o e^{-\lambda t}$$
$$t = (\ln C_o/C)/\lambda$$

where: t = effective delay time
C_o = concentration of isotope at adsorber bed inlet
C = concentration of isotope at adsorber bed outlet
λ = isotope decay constant

109

The adsorption coefficient for the carbon is calculated by:

$$K = \frac{t\ F}{M}$$

where: K = adsorption coefficient, cm^3/g
t = effective delay time, sec
F = total flow rate, std. cm^3/sec
M = mass of carbon, gm

The above method for determining adsorption coefficients is valid only when the adsorber beds are operating at isotopic equilibrium with a steady-state input. It takes approximately one week to reach equilibrium with respect xenon isotopes in one adsorber bed and as steady-state input to the AOG system for that period of time occurs infrequently, delay data for xenon is difficult to obtain. Krypton isotopes reach equilibrium levels in approximately 12 hours and therefore data of isotopic delay can be readily obtained.

Krypton-85m and Kr-88 are the only two krypton isotopes that consistently have concentrations that can be measured with acceptable counting errors. The performance data shown in Table 3 are based on these 2 isotopes and for the first two adsorber beds only. Isotopic concentrations downstream of the third bed are too low to be measured with the above procedure. No gas samples were taken downstream of adsorber bed No. 1 during the month of May and the values shown on Table 3 for this period are average values across the first two beds.

The evaluation data for the first bed for the period June 10 through June 20 was lost due to counting problems with the inlet sample. The exceptionally high coefficient values obtained for the second bed on June 24 – June 28 and on both beds on July 1 may be due to counting errors since the outlet concentrations for these samples were lower than normal.

The Kr-85m and Kr-88 data from Table 3 were averaged and are shown plotted in Figure 10. As expected, the data shows no significant degradation of the carbon during the seven months of this evaluation. The apparent improvement in the adsorption coefficient over the last four months of this period may be due to further drying of the carbon by the low relative humidity air stream.

All of the adsorption coefficients reported in Table 3 and Figure 10 have been evaluated at the operating pressure of the first two adsorber beds – approximately 708 mmHg (13.7 psia) – and have not been corrected to standard pressure.

Data on xenon-133 delay was obtained on 6/24/74 – 6/28/74. The plant had been operating at a steady power level for 7 days prior to this period and this represents the best xenon data obtained to date. The xenon adsorption coefficients ranged from 1010 – 1280 cm^3/g with an average value of 1160 cm^3/g.

Table 3
Carbon Bed Evaluation

Dynamic Adsorption Coefficient, cm^3/g

Date	1st Adsorber Bed		2nd Adsorber Bed	
	Kr-85m	Kr-88	Kr-85m	Kr-88
December 28	68	61	67	--
January 16	62	64	66	--
January 21	61	61	62	--
January 29	--	--	59	60
February 4	48	53	--	--
February 15	55	61	--	--
March 12	51	53	60	60
March 20	51	55	--	--
April 10	51	54	59	61
April 24	52	56	50	53
April 26	56	60	54	56
May 14	55*	58*	55*	58*
May 15	59*	62*	59*	62*
May 16	62*	64*	62*	64*
May 17	58*	62*	58*	62*
June 10	--	--	60	63
June 11	--	--	63	63
June 12	--	--	71	68
June 14	--	--	69	69
June 17	--	--	67	70
June 18	--	--	76	76
June 20	--	--	71	71
June 21	65	71	--	--
June 24	68	75	80	80
June 25	71	71	82	84
June 26	71	71	82	82
June 28	71	72	86	85
July 1	84	84	86	86
July 3	67	78	--	--
July 12	65	65	68	68
July 15	70	70	78	78
July 16	71	69	76	78

*Average value across first 2 beds

F. Summary

The results of the carbon adsorption testing described above has been summarized in Table 4. The coefficients reported there have all been corrected to 760 mmHg total pressure and, with the exception of the 1st source, were all obtained at approximately 70°F. The carbon suppliers laboratory tests were all conducted at 77°F.

The operational coefficients agree closely with the independent laboratory test values and are higher than the equipment manufacturer's and carbon supplier's test values. The pre-operational test

coefficient was significantly lower. This result was probably due to a higher carbon moisture level at the time of the test. The low coefficient obtained by the carbon supplier is thought to be due to the higher temperature of the carbon bed, a higher krypton concentration in the carrier gas and possibly a higher carbon moisture level.

Table 4
Summary of Adsorption Coefficient Data

Data Source	Krypton Adsorption Coefficient, cm^3/g
1. Carbon Supplier Laboratory Test	49*
2. Equipment Manufacturer Laboratory Test	
a. 1 percent moisture	55
b. 0 percent moisture	58
3. Independent Laboratory Test (1 percent moisture)	69
4. AOG Pre-op Test	48
5. AOG Operation	70**

*Bed temperature = 77°F, krypton
partial pressure= 7.6 x 10^{-3} mmHg

**Average of all evaluations, corrected to 760 mmHg

References

1. Parish, H. C., CVI Corporation, Letter Report to P. S. Littlefield, dated 7/2/74.

2. "Column Evaluation of Kr/Xe Delay Ratios of the VYNPS Off-Gas Carbon", NUCON 080, 1/25/74.
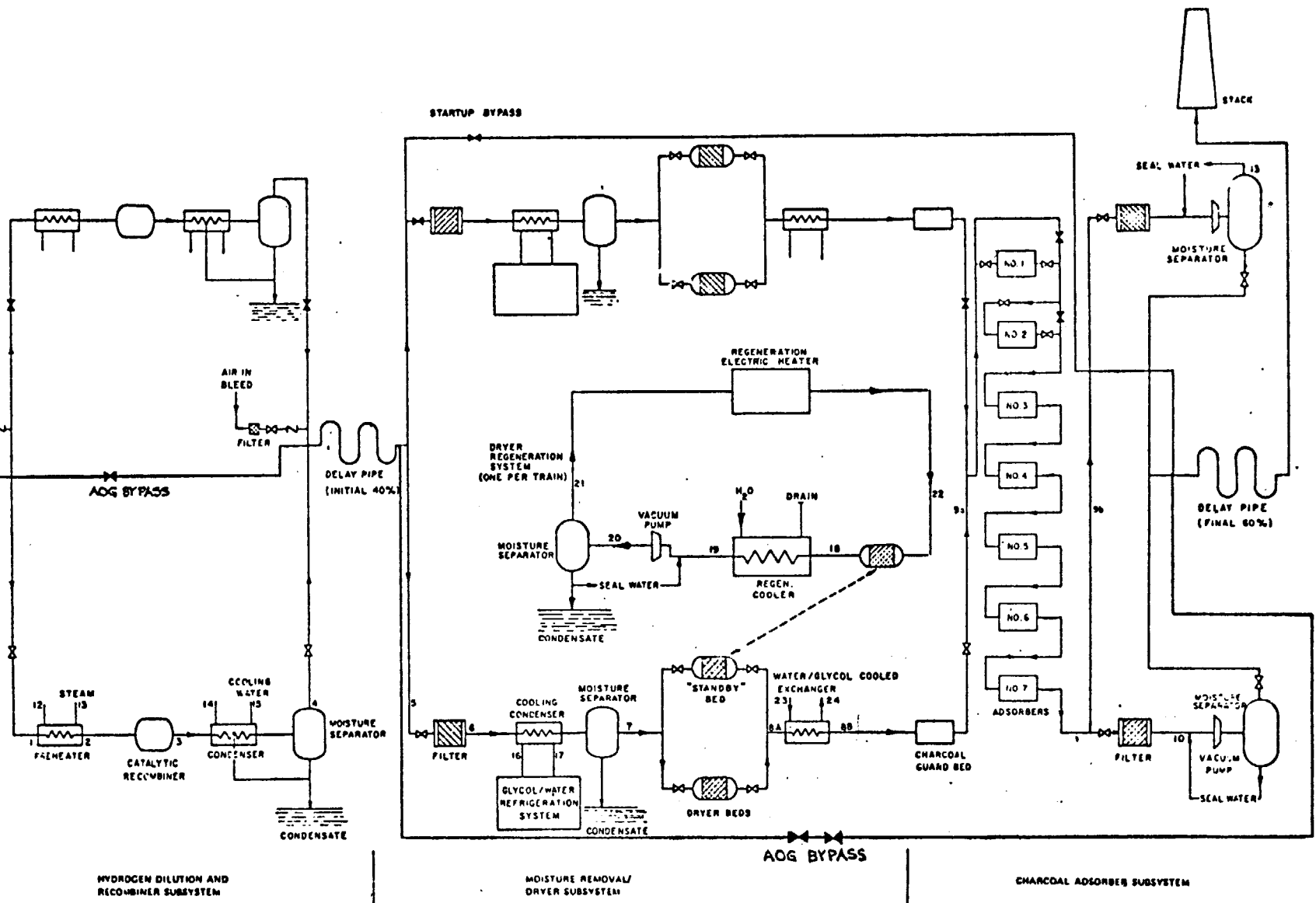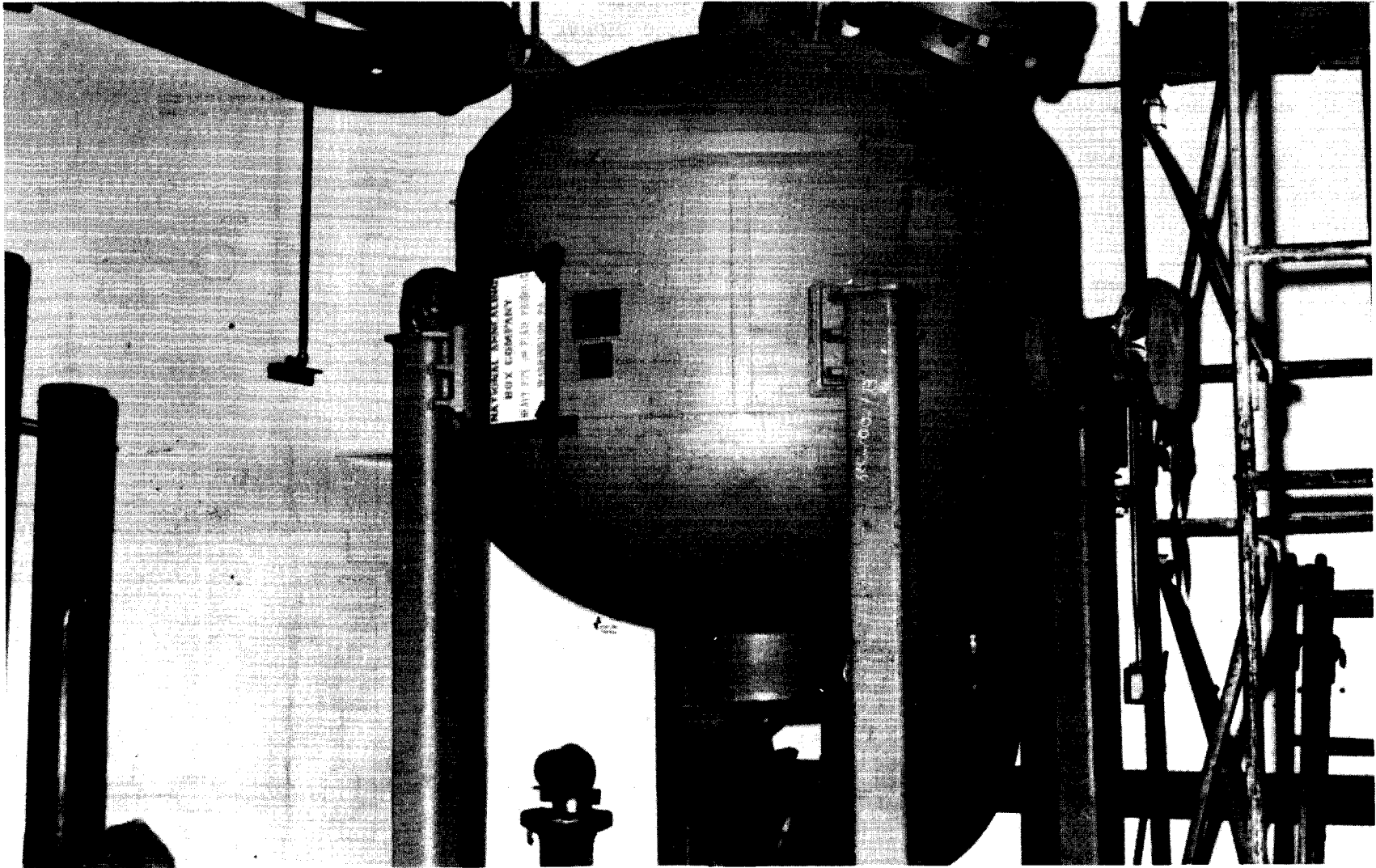
STARTUP BYPASS

STACK

SEAL WATER

MOISTURE SEPARATOR

REGENERATION ELECTRIC HEATER

NO. 1
NO. 2
NO. 3
NO. 4
NO. 5
NO. 6
NO. 7

ADSORBERS

AIR IN BLEED

AIR IN BLEED

FILTER

FILTER

FROM AIR EJECTORS

AOG BYPASS

DELAY PIPE (INITIAL 40%)

DRYER REGENERATION SYSTEM (ONE PER TRAIN)

DELAY PIPE (FINAL 60%)

VACUUM PUMP

MOISTURE SEPARATOR

SEAL WATER

CONDENSATE

H_2O DRAIN

REGEN. COOLER

MOISTURE SEPARATOR

VACUUM PUMP

SEAL WATER

FILTER

STEAM

COOLING WATER

MOISTURE SEPARATOR

PREHEATER

CATALYTIC RECOMBINER

CONDENSER

CONDENSATE

FILTER

COOLING CONDENSER

MOISTURE SEPARATOR

GLYCOL/WATER REFRIGERATION SYSTEM

CONDENSATE

"STANDBY" BED

DRYER BEDS

WATER/GLYCOL COOLED EXCHANGER

CHARCOAL GUARD BED

FILTER

AOG BYPASS

HYDROGEN DILUTION AND RECOMBINER SUBSYSTEM

MOISTURE REMOVAL/ DRYER SUBSYSTEM

CHARCOAL ADSORBER SUBSYSTEM

FIGURE 1

VERMONT YANKEE OFF-GAS SYSTEM MODIFICATION
SIMPLIFIED SCHEMATIC

- 9 -

FIGURE 2

VERMONT YANKEE NUCLEAR POWER STATION
VERMONT YANKEE ADVANCED OFF GAS SYSTEM
Recombiner And Installation Of Associated Piping.

FIGURE 3
VERMONT YANKEE NUCLEAR POWER STATION
VERMONT YANKEE ADVANCED OFF GAS SYSTEM
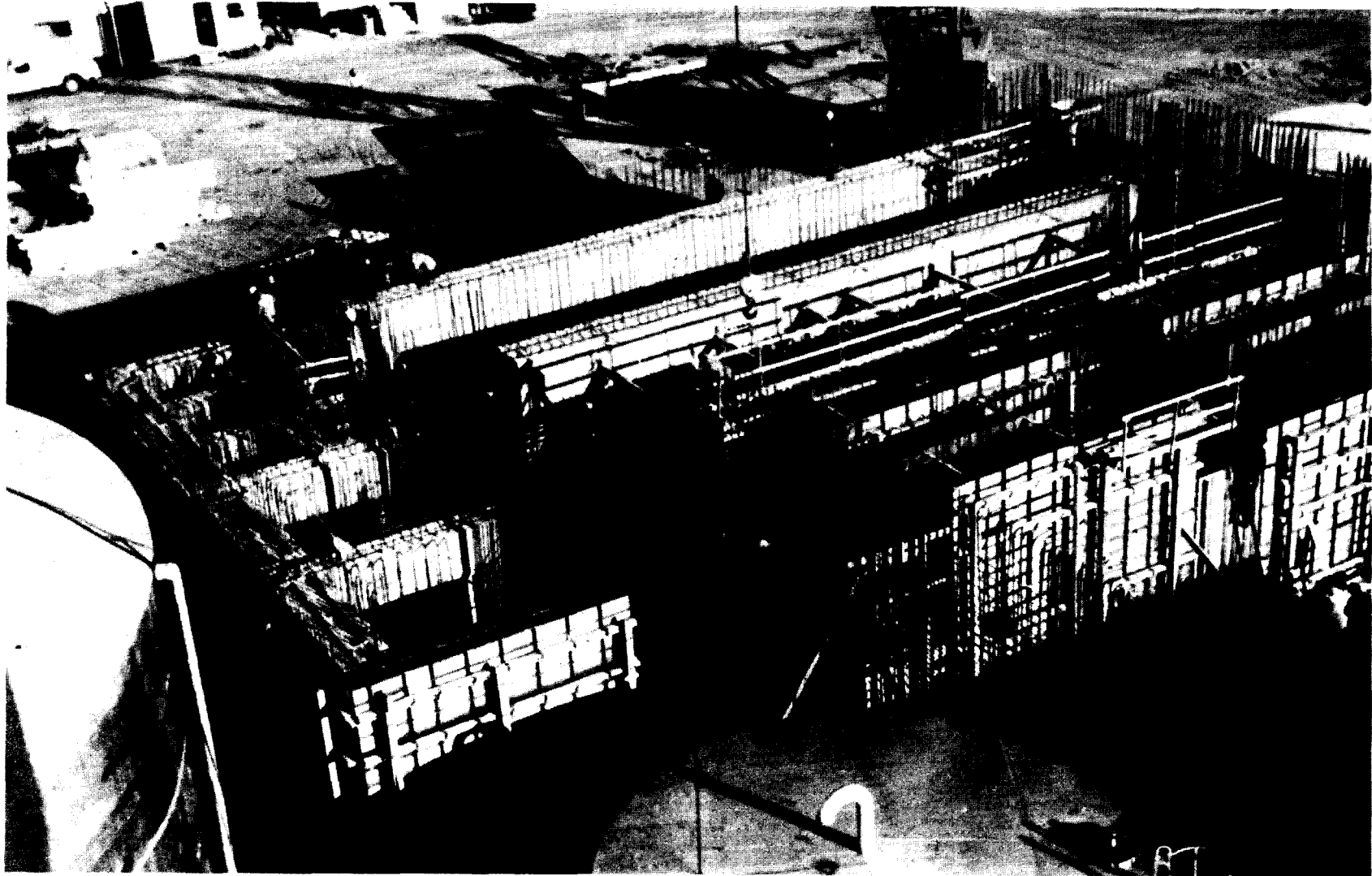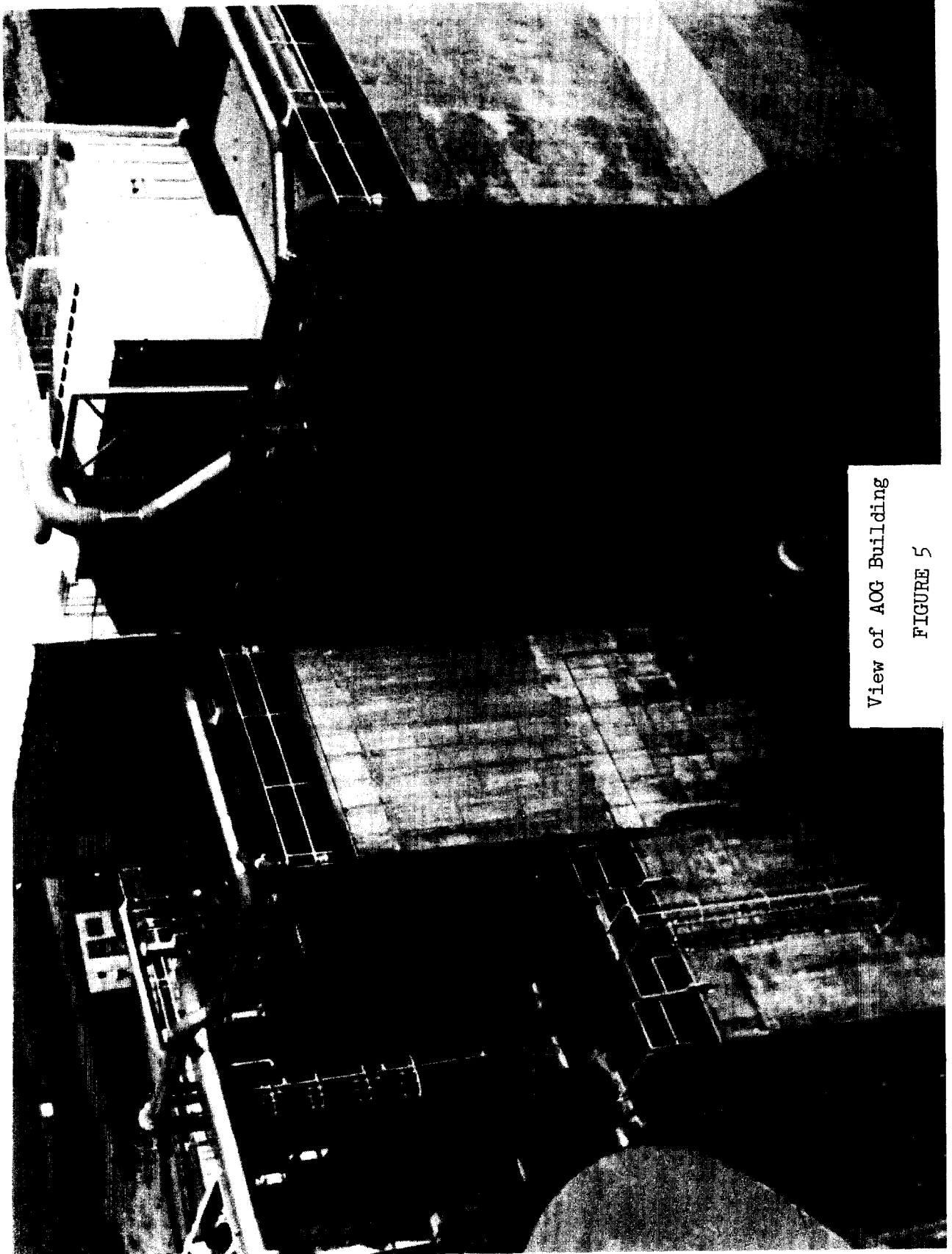Installation Of Absorber Tank TK 101-1G.

FIGURE 4

VERMONT YANKEE NUCLEAR POWER STATION

VERMONT YANKEE ADVANCED OFF GAS SYSTEM

View looking East at the Advanced off gas building.
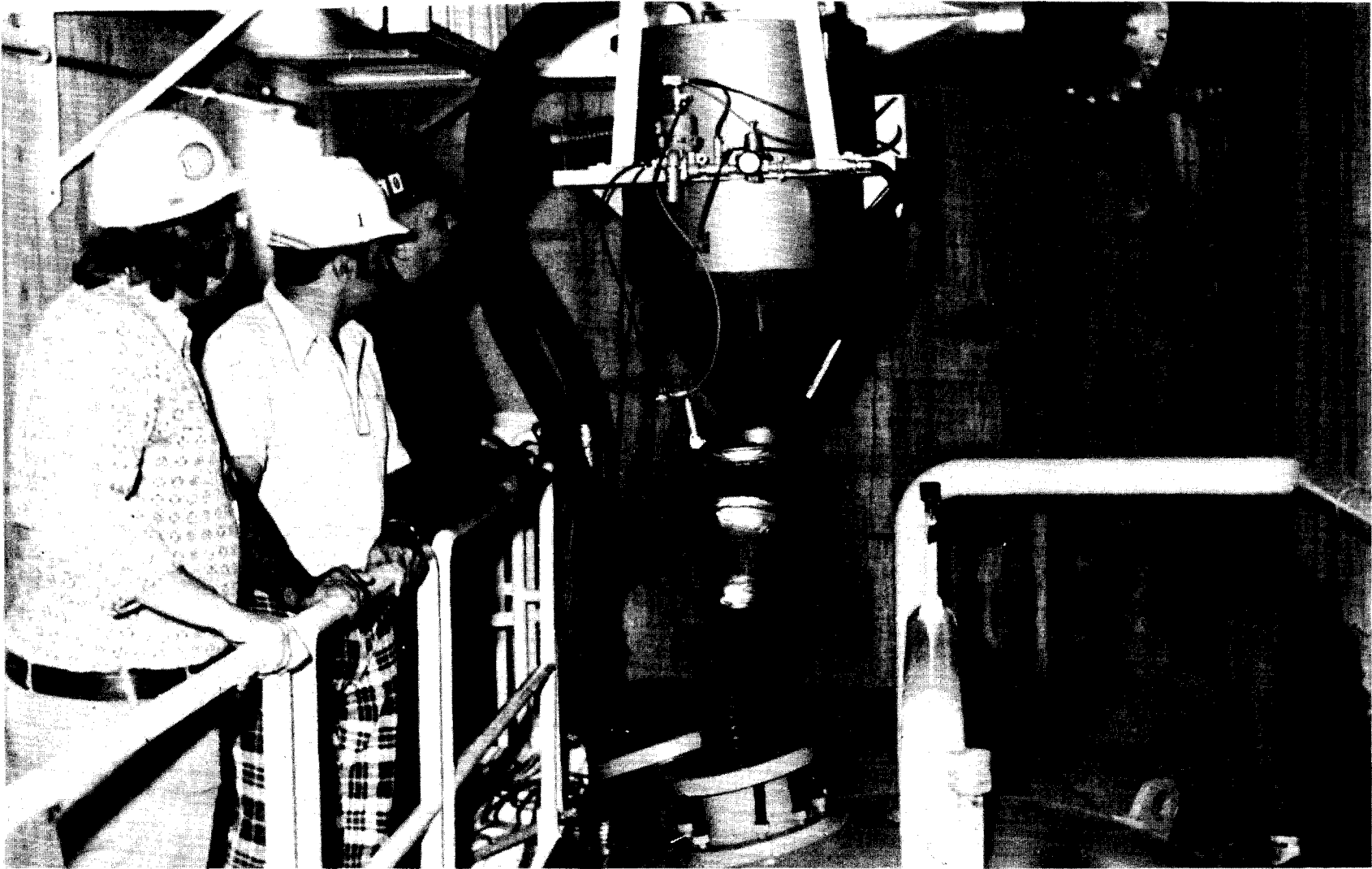
View of AOG Building

FIGURE 5

FIGURE 6
VERMONT YANKEE NUCLEAR POWER STATION
VERMONT YANKEE ADVANCED OFF GAS SYSTEM

LOADING OF ACTIVATED CARBON WITH A VAC-U-MAX SYSTEM HAS STARTED
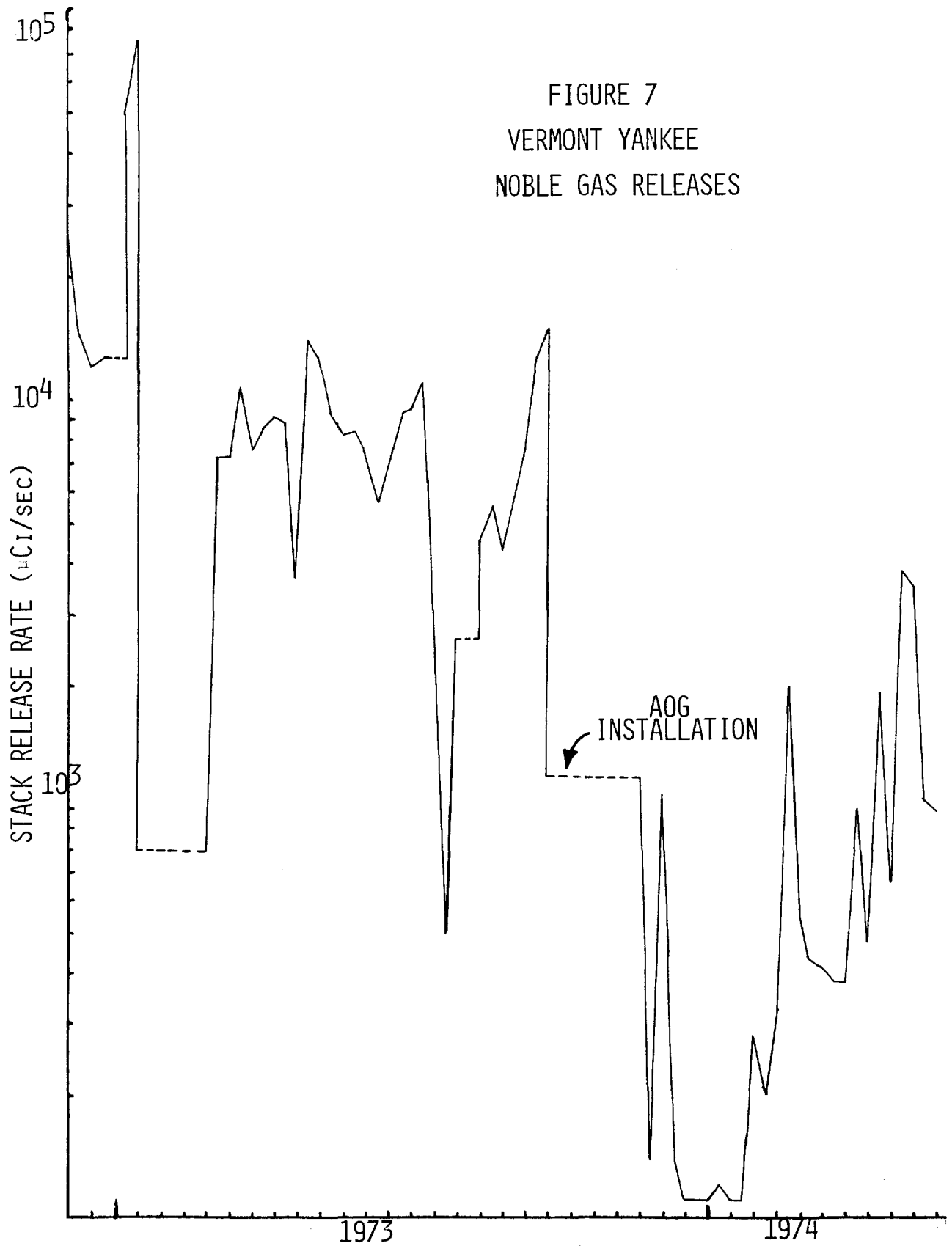
FIGURE 7
VERMONT YANKEE
NOBLE GAS RELEASES

FIGURE 8
EQUIPMENT MANUFACTURER'S
KRYPTON ADSORPTION TESTS

FIGURE 9
PRE-OP TEST
KR-85

⊙ INLET MONITOR – 1ST CARBON BED
✕ OUTLET MONITOR – 1ST CARBON BED
⊡ OUTLET MONITOR – 2ND CARBON BED
▽ OUTLET MONITOR – 7TH CARBON BED

FIGURE 10
AOG CARBON BED
EVALUATION

LEGEND:

O   K VALUES FOR 1ST ADSORBER

△   K VALUES FOR 2ND ADSORBER

⊗   AVE. K VALUES FOR ADS. 1 AND 2

NOTE: K VALUES AVE OF Kr-85m AND Kr-88

K_R ADSORPTION COEFFICIENT, CM^3/G

JAN.   FEB.   MARCH   APRIL   MAY   JUNE   JULY

1974
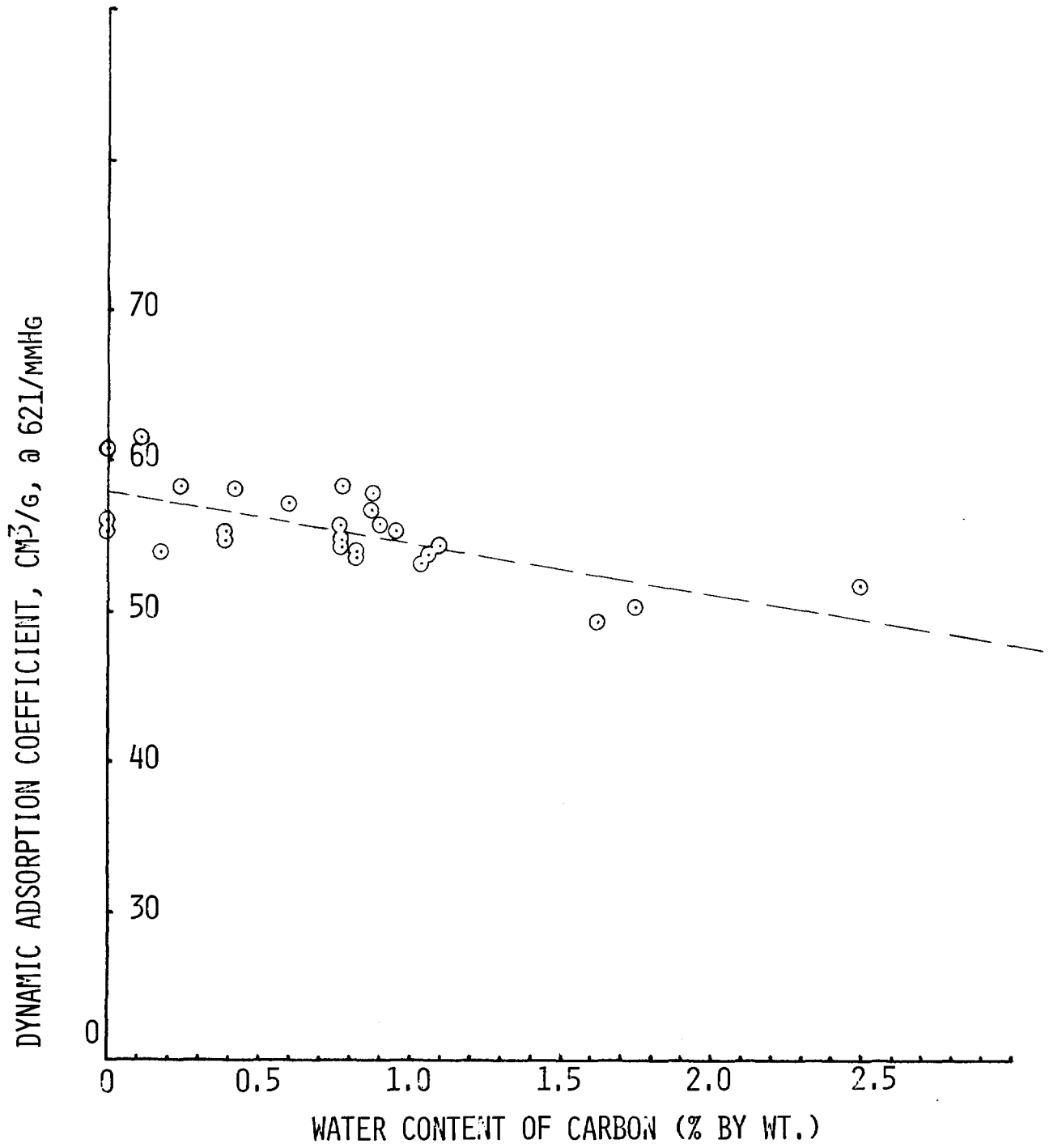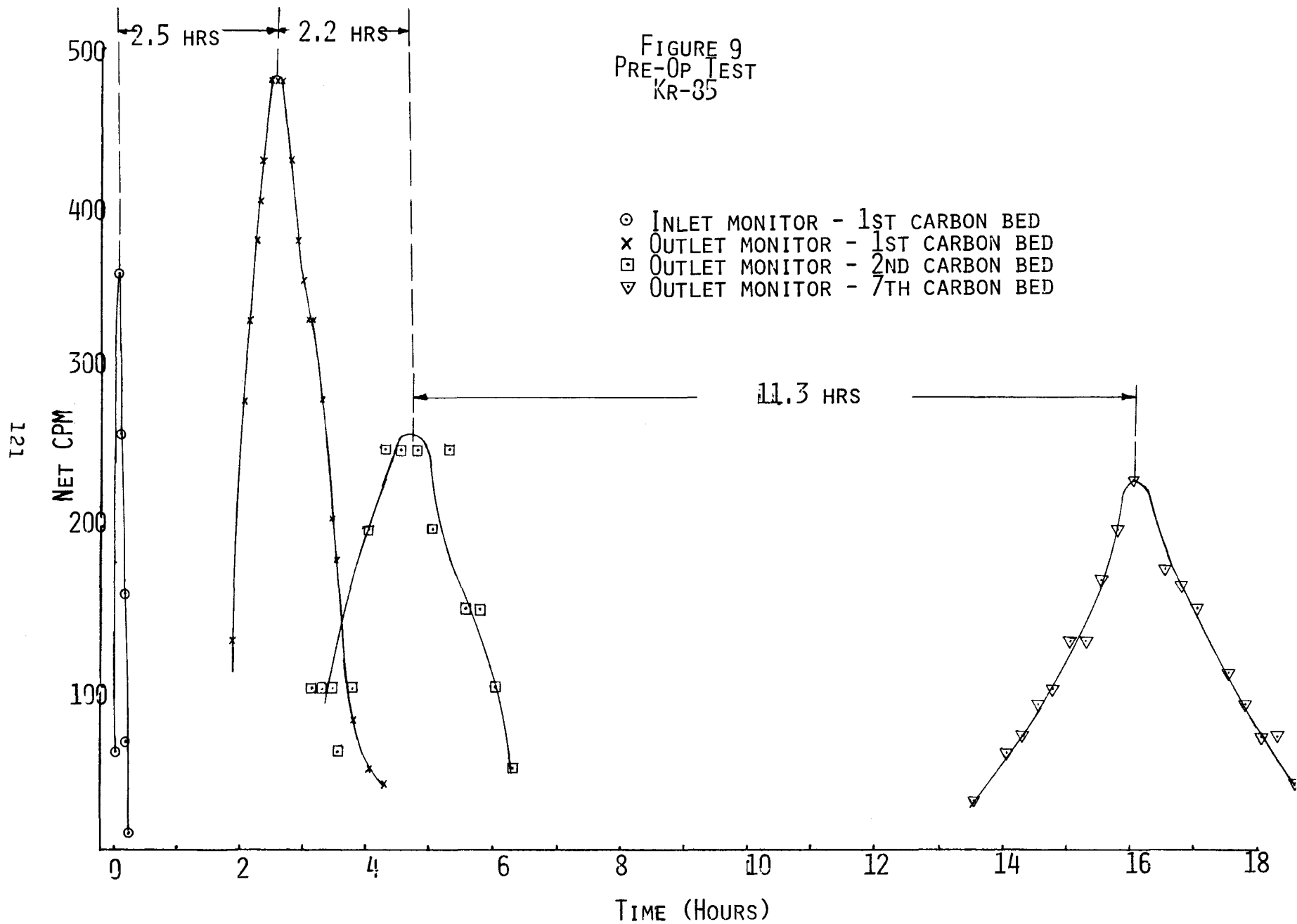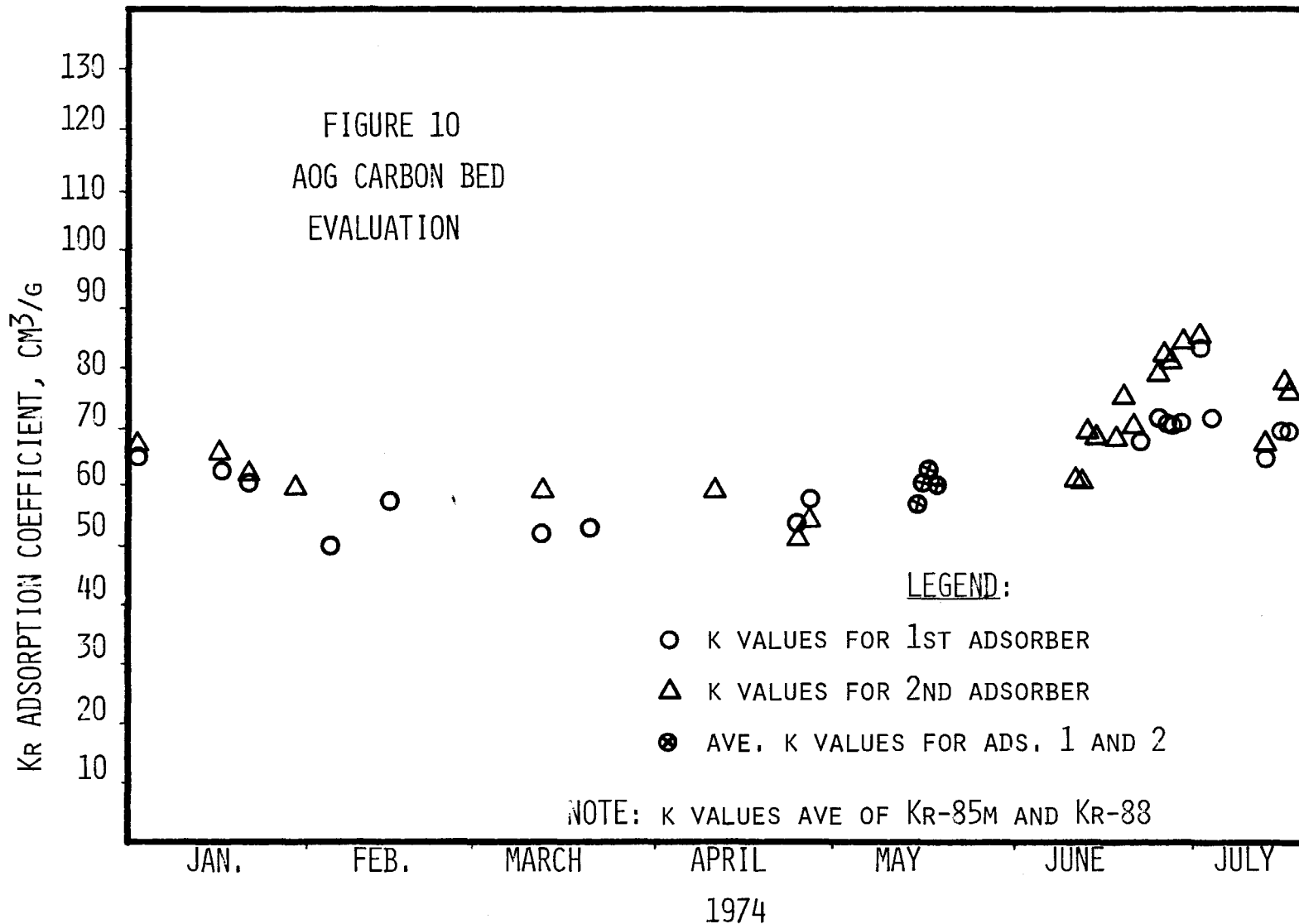
DISCUSSION

KHANDHAR: This was an excellent and useful paper. My
question is in three parts: The offgas temperature at recombiner
effluent is 634°F. However, the vessel was designed for 950°F. AOG
operates at near atmospheric pressure and the generally-accepted
protection against hydrogen explosion is about 15 to 20 times the
operating pressure, which makes the design pressure requirement
about 300 PSIG. However, the recombiner vessel was designed for
500 PSIG.
                   The high alarm point for hydrogen at recombiner
effluent was set at two percent by volume (on a dry basis). However,
the catalyst was sized for a low effluent concentration of only 0.1
percent. In light of the foregoing, would you say that if you have
to design such a system for another similar plant, this conservatism
could be reduced and significant savings could be effected? If not,
will you please discuss these high safety factors?

LITTLEFIELD: As I understand the question it concerns over-
design or apparent over-design of the system with regard to both
temperature and pressure. At the time we designed this system,
the AEC had not established an acceptable over-pressure design for
any system carrying hydrogen. We therefore asked several indepen-
dent parties to calculate what conceivable detonation shock wave we
could achieve from this system. The answer is, "No, I don't think
that you would save a considerable amount of money by designing for
a slightly lower pressure." As for temperature, the same answer
would have to apply. I'm not really sure why the temperature de-
sign is as high as it is. Does that answer the whole question?

KHANDHAR: Hydrogen at 2 percent seems to be high.

LITTLEFIELD: The hydrogen entering is in the range of two to
three percent.

KHANDHAR: And leaving the recombiner at the range of .1
percent?

LITTLEFIELD: But the system is designed for a total failure of
the recombiner. Maybe I can talk to you later about this.

STEWART: Since you have purchased and operated this system,
I wonder if you have any suggestions about short cuts or modifica-
tions. For example, could you operate the charcoal at lower tempera-
tures in a refrigerated room? What improvements would you suggest?

LITTLEFIELD: I guess I couldn't suggest any improvements on
this system. Seriously, the system has operated exceptionally.
You always have some problems; but there were a minimum of problems
with this system and I don't think I would change it at all.

_____: I'm curious as to why there is no recycle pipe built into the system. It seems to me that with the monitor in the stack, if something goes wrong, you won't know what is happening. If I designed it, I would consider a recycle possibility from the stack. Is there any reason why this design is not considered?

LITTLEFIELD: I'm not too sure what you mean. I can't conceive of ever needing any more holdup time than three and a half days for krypton and something in the order of two months for xenon as the system is operating right now.

SAFETY EVALUATION OF BWR OFF-GAS TREATMENT SYSTEMS

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Abstract

This paper presents some of the results of a safety evaluation performed on current generic types of BWR off-gas treatment systems including cooled and ambient temperature adsorber beds and cryogenics. The evaluation covered the four generic types of off-gas systems and the systems of five major vendors. This study was part of original work performed under AEC contract for the Directorate of Regulatory Standards.

The analysis techniques employed for the safety evaluation of these systems include:

(1) Fault Tree Analysis

(2) FMECA (Failure Mode Effects and Criticality Analysis)

(3) General system comparisons, contaminant, system control, and design adequacy evaluations

(4) Resultant Off-Site Dose Calculations.

The salient areas presented are some of the potential problem areas, the approach that industry has taken to mitigate or design against potential upset conditions, and areas where possible deficiencies still exist. Potential problem areas discussed include hydrogen detonation, hydrogen release to equipment areas, operator/automatic control interface, and needed engineering evaluation to insure safe system operation.

Of the systems reviewed, most were in the category of advanced or improved over that commonly in use today, and a conclusion from the study was that these systems offer excellent potential for noble gas control for BWR power plants where more stringent controls may be specified - now or in the future.

1. Introduction

Current boiling water reactors operate with cracks or pinhole leaks in a significant number of fuel pins. As a result, a fraction of the noble gases and more volatile fission products generated in the fuel during operation, escape from the fuel pins to the reactor coolant. In the direct cycle of the BWR's, a fraction of the noble gases and the more volatile fission products flash into the steam phase and along with other noncondensible gases in the coolant pass with the steam into the condenser vapor space. Some of the noncondensibles are radioactive. The radioactive components consist of both the fission products released from the fuel and the short-lived gaseous activation products such as N-13, N-16, and N-19. Air introduced by leakage into the condenser, and hydrogen and oxygen produced by radiolytic decomposition of the coolant are the principal constituents of the noncondensible gases. The noncondensibles are removed from the main condenser via a steam jet air ejector and transferred to the plant off-gas system. Boiling water reactor off-gas systems have the objective of reducing the gaseous effluent off-gas activities to acceptable limits. The processing systems

have changed with time as BWR's have increased in size and the release limits have become more stringent. Early systems featured a buried holdup pipe and HEPA filter with gas discharge through an elevated stack. The more recent off-gas systems employ catalytic recombiners, which reduce the gas volume by recombining the radiolytic hydrogen and oxygen, and other equipment and techniques which either selectively holdup xenon and krypton to permit decay or remove the noble gases for subsequent processing or storage.

In late fall of 1972, Aerojet Nuclear Company (ANC) was contracted by the Design Standards Branch of AEC-Regulatory Standards to perform a study concerning the consequences of upset or accident conditions which could potentially occur during operation of a BWR off-gas processing or storage system. The study was broken into two technical subtasks, a system performance evaluation subtask, and a dose evaluation subtask. The results of the dose evaluation study were reported in the paper presented early in this session by Dr. W. C. Dyer entitled, "Calculation of The Radiation Dose From an Upset Condition in the Off-gas System for a Boiling Water Power Reactor"[1]. The system performance evaluation subtask was further subdivided into two tasks: a comprehensive review of existing and proposed waste gas processing systems, and operational upset and accident sequences evaluations.

This paper presents part of the results of the system performance subtask. A brief description of the systems, a discussion of the analysis techniques, some of the results of the evaluation, and the conclusions reached in the study on the relative safety of the systems are given.

Information from several areas of design considerations has not been included in this paper as most of the problems related to these areas are being resolved through better definition and application of codes and standards. These areas include seismic design, quality assurance, codes and standards.

II. System Discussion

During the review and evaluation of the improved BWR off-gas systems, discussions were held with four current vendors of BWR off-gas systems. Detailed reviews were made on five vendors' off-gas systems including the four major generic types of systems now under consideration for use in BWR plants:

(1) Adsorber systems operated at ambient or slightly reduced temperature

(2) Adsorber systems operated at cryogenic temperatures

(3) Cryogenic distillation systems with oxygen removal prior to liquefication, and

(4) Cryogenic distillation systems without oxygen removal prior to liquefication.

To date the lack of definition of what is necessary to meet the 10 CFR, Part 50, Appendix I, "lowest practical release" has created wide variations in the approach to the design of the systems. The efficiency by which the various system operations are performed appeared to be basically a matter of design philosophy. The various vendor's systems, with exception of the slightly cooled or ambient temperature adsorber system, all have the capability of changing their design as necessary to meet a large range of release levels depending upon

126

the requirements placed upon them. Designs for "zero" release or minimum release were apparently equally achievable, with exception of the ambient temperature bed system unless a cryogenic system is tagged onto the exit stream.

A brief description and block diagram highlighting the pertinent features of each system is presented below:

Adsorber System Operated at Ambient or Slightly Reduced Temperatures

This generic type of system, shown in Figure 1, employs carbon beds for delay of noble gases prior to release to the atmosphere. In this type of system a delay line offering from 10 to 300 minutes delay time is used to reduce the quantity of short-lived fission products and activation gases. The hydrogen and oxygen are catalytically recombined and part of the moisture contained in the gas stream is removed. The gas is then passed through large charcoal beds at ambient or at subcooled (0 to 40°F) temperatures. The charcoal beds delay the noble gases through the adsorption/desorption process. The relative decontamination factors (DF) for the adsorber system are: from 16 to 250 for the ambient temperature charcoal system, and approximately 2000 for the chilled charcoal system when operated at -40°F.

Adsorber System Operated at Cryogenic Temperatures

This generic type of system, shown in Figure 2, employs either carbon or zeolite adsorber beds operated at cryogenic temperatures. This type of system can be designed and operated as a noble gas delay/decay system or as a noble gas concentration and storage system. A delay line, typically of short duration, may be used prior to system entry. Hydrogen and oxygen are catalytically recombined prior to adsorption. Additional hydrogen is added to the gas stream prior to recombination to insure complete removal of oxygen. Moisture and carbon dioxide are removed to a high degree from the gas stream on adsorber beds. The unique features of this type system are: (1) feed gas system operates with no rotating mechanical equipment in the process gas stream, (2) single failure in an adsorption bed does not render the system inoperative (dependent upon system design), and (3) the system offers its own nitrogen delay. The advertised decontamination factor for the system is 10^3 when operated in the delay/decay mode and 10^4 if operated in the recovery mode.

Cryogenic Distillation Systems With Oxygen Removal Prior to Liquefication

This generic type of system, shown in Figure 3, employs cryogenic distillation as its basis of noble gas processing. Following a typical delay line this type of system employs hydrogen addition to the feed gas stream prior to hydrogen oxygen recombination. This is to insure that low levels of oxygen are maintained throughout the system. Following recombination, moisture and CO_2 are removed to a high degree of purity by utilizing freezeout on reversing heat exchangers. The feed gas is then introduced into cryogenic distillation columns where the noble gases, argon and small amounts of nitrogen, are liquefied and via gravity more to the bottom of the column. The remainder of the nitrogen moves up the column and is removed as a noncondensible gas. A small addition of heat is continually applied to the solution in the column bottom to control the amount of nitrogen in the column bottom. Typically a small stream of liquid is continually withdrawn from the column bottom for purification and recycle through the system. The recycle stream is used to control the impurity level in the column bottom solution. On a batch type basis the column bottoms are removed for further processing. The noble gases withdrawn from the column can be either held for a short period of
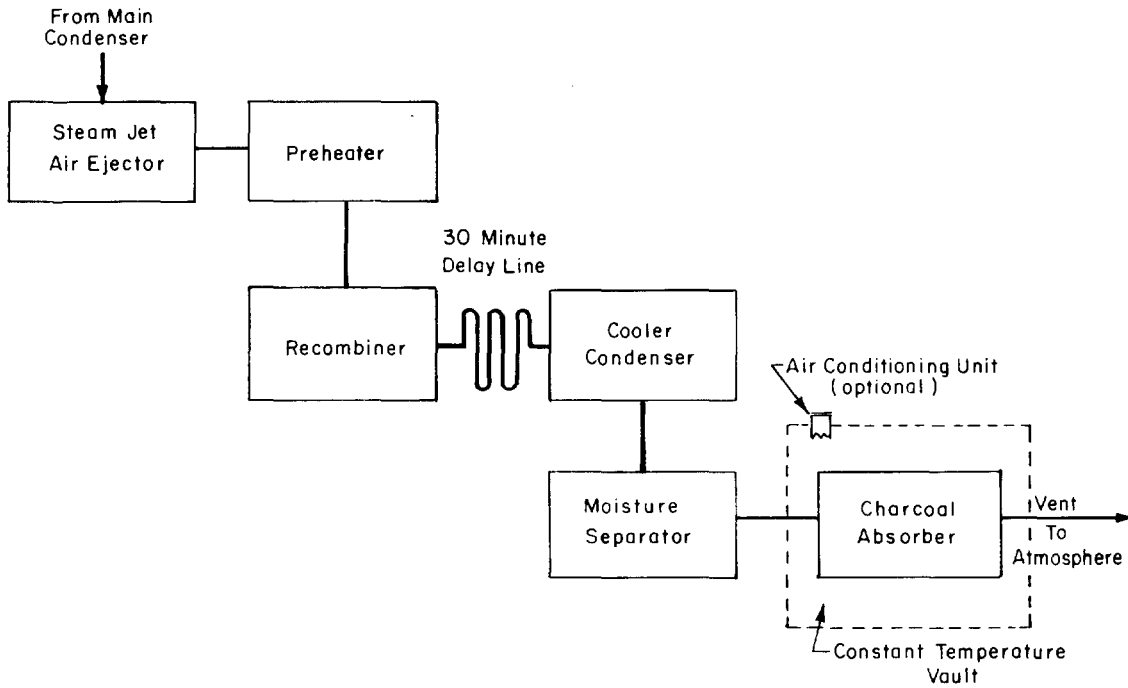
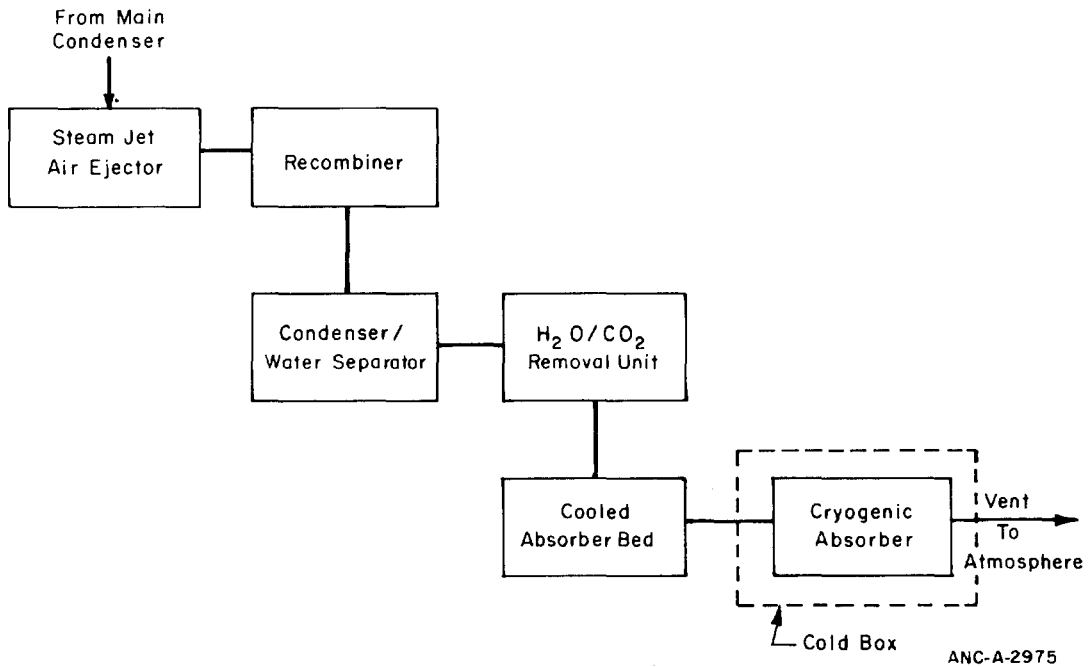Figure 1   Adsorber System Operated at Ambient or Slightly Reduced Temperature

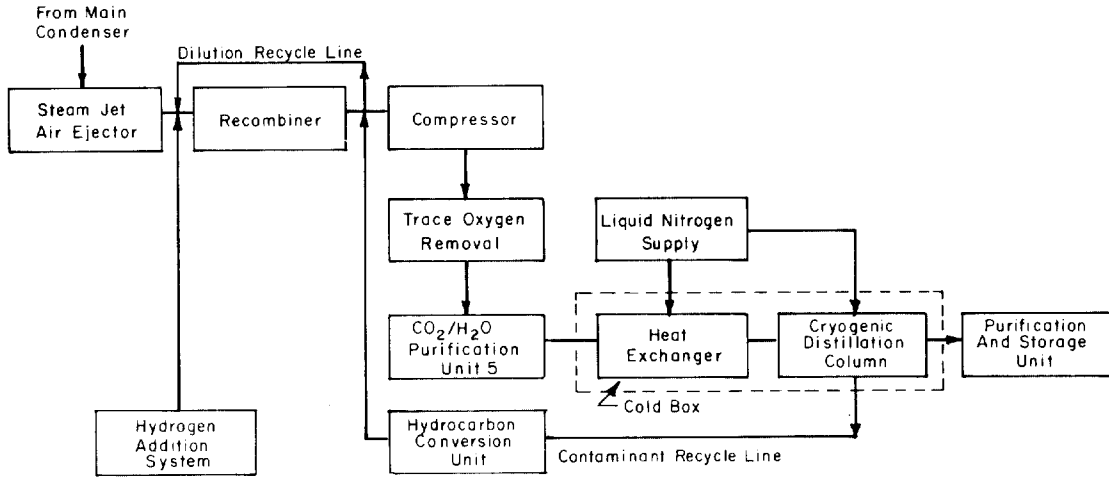Figure 2   Adsorber System Operated at Cryogenic Temperature

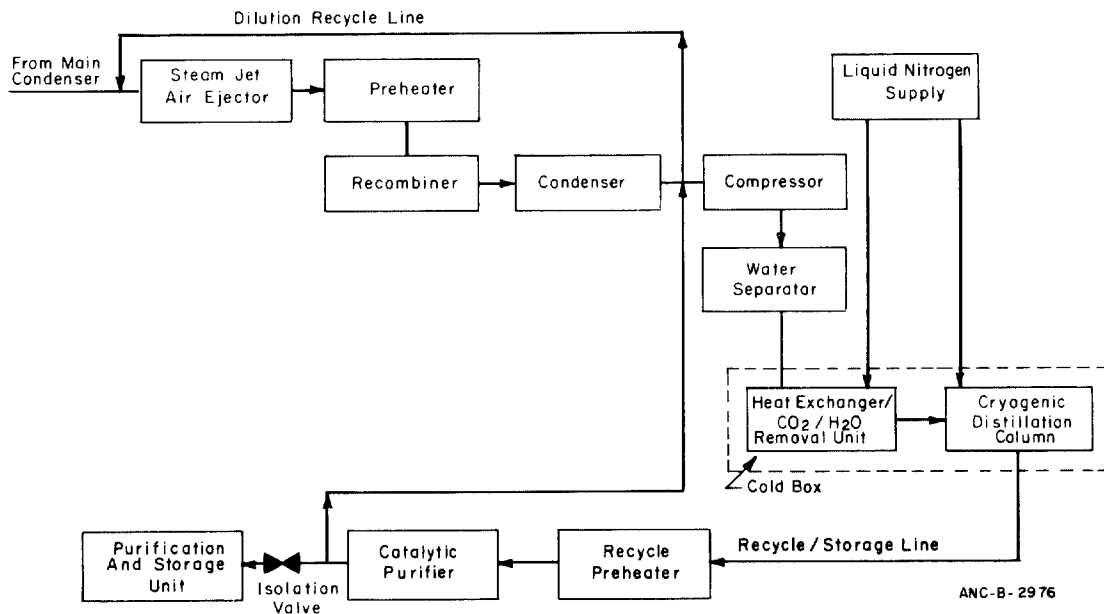**Figure 3   Cryogenic Distillation System With O_2 Removal**

Figure 4   Cryogenic Distillation System Without O_2 Removal

time, for xenon decay, and then released, or they may be processed for long-term storage. The advertised decontamination factor is 10^4 for krypton when operated in the recovery mode.

Cryogenic Distillation System Without Oxygen Removal Prior to Liquefication

This generic type system, shown in Figure 4, also employs cryogenic distillation as its basis of noble gas processing. The system operates in essentially the same manner as the system described in (3) above with exception that hydrogen is not added to the feed gas stream prior to recombination. As oxygen will be present in the distillation column bottom liquid, recycling of the liquid is accomplished at a greater rate and is of greater importance for safe and proper operation of the system.

III. Analytical Techniques

Several analytical techniques were used to evaluate the relative safety of the systems reviewed. The techniques used were complimentary in nature in that a broad spectrum of potential accidents were analyzed, generic components were reviewed in depth, and a rigorous analysis was done on a typical system design for each generic type of system reviewed. In addition, as previously referenced, dose rate calculations were made. The types of system analyses that were performed are: (1) fault tree analysis, (2) failure modes, effects, and criticality analysis (FMECA), and (3) a general system safety evaluation.. The three analysis techniques are briefly presented below. The results of the fault tree analysis and the FMECA are not given due to the proprietary nature of the data. Some results of the general system evaluation are presented in the "Results of Evaluation" section.

Fault Tree Analysis

Fault tree analysis was applied to each off-gas treatment system under study as a means of obtaining a rigorous, disciplined analysis to determine potential hazardous areas.

Fault tree anlysis is a deductive analytical method in which the analyst defines a particular system output state (in this study, this was the release of the concentrated radioactive noble gases to the atmosphere), and then determines all the failure modes that can produce the given system output state.

The development of a fault tree begins with a definition of the system output fault condition. This is typically the most undesired event that might occur if the system fails to perform as it was designed to perform. The system is analyzed to determine all the logical combinations of fault events that can cause the undesired event. Each of the contributory events is further analyzed to determine the combination of fault events that could cause it. This process results in a "tree" of logical relationships among fault events. The tree is expanded only to a point at which a subsystem has failed, at which the analyst deems the fault events to be incredible, or at which the analyst has determined that no fault can affect another channel and thus produce a credible single event.

Failure Modes Effects and Criticality Analysis (FMECA)

To provide an overall review and summary of the off-gas systems evaluated in the program, a failure modes effects and criticality analysis was performed

on off-gas processing and waste gas storage systems. This inductive analysis is a generalized, but comprehensive, compilation of the various types of equipment and subsystems employed in BWR off-gas processing systems. Only modes of potential failure and possible equipment malfunction which could potentially cause major equipment damage or increased fission product release were considered.

The failure modes, effects and criticality analysis lists the equipment or subsystem considered, the failure mode considered, the possible or potential effects of the failure, the probability of failure as estimated by the authors, the criticality or hazard category of the failure, and the design compensation or means of preventing or mitigating the potential problems.

General System Safety Evaluation

The analysis techniques applied in this generalized portion of the analysis are all inductive analysis methods. These methods include:

(1) Postulation of the occurrence of various component/operation faults and analyzing to determine their effects on the system

(2) Analysis using an "a priori" process (i.e., from cause to effect)

(3) A nonparametric approach to determine the preliminary and operating hazards

(4) The fundamental approach of "what happens if...?" was also applied as an analysis technique.

IV. Results of Evaluation

Some of the prominent areas of investigation in the generalized evaluation of BWR Off-Gas Systems are listed in Table I. Results in each case are discussed in the following sections.

Table I Prominent Areas of Investigation in BWR Off-Gas System Evaluation

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1. Contaminant Reactions

2. Control Systems and Operator - System Interactions or Operator Errors

3. Hydrogen Design (Either in the Room Housing the System or in the System)

4. Ability of Off-Gas System to Withstand a Loss of Support System (Primarily Coolant)

5. Result of Equipment Malfunction and/or Failure

Contaminant Reactions

The contaminants included for consideration in this study were:

(1) Organics

(2) Ozone

(3) Trace O_2 or Trace H_2

(4) Nitrogen Oxides

(5) Halogens

The primary concern regarding contaminants was that some of these materials are sensitized fuel which can become explodable if allowed to concentrate sufficiently at any point within the system. In the case of the halogens, poisoning or loss of efficiency in the recombiner or beds was a further consideration. Thus, this part of the investigation revolved around the ability of the systems to eliminate or control the amount of contaminant materials at any given time or operating condition.

Organics. Light hydrocarbons will be present in the inleakage in concentrations comparable to the noble gases. Heavier organics will be present in a quantity which depends on air purity at the site location and plant housekeeping. Typical organic concentrations are 1 ppm CH_4 and 0.25 ppm higher order organics. For a typical system, many heavy hydrocarbons will either be altered to paraffins or oxidized to CO_2 plus H_2O in the recombiner. However, CO_2 and H_2 can react to form a small amount of methane in a recombiner operating with a large temperature rise across the unit. The heavy hydrocarbons which pass through the recombiner will mainly be trapped in heat exchangers, prepurifier beds or dryer units depending on design. The organics removed in this way are then generally recycled or vented during regeneration steps. In some cases regeneration may not expel these materials and accumulation may occur until regular maintenance is performed (annually for example). The beds, etc. are generally oversized to retain the hydrocarbons for a year's operation without loss of function, but caution needs to be exercised that initial purging is with nitrogen and not with air for systems or components that may have a concentration of organics. Purge temperatures are generally in the range of 400°F, and at this elevated temperature, a high concentration of organics in combination with oxygen from air can constitute a hazardous condition.

The light hydrocarbons and trace amounts of the heavy hydrocarbons that pass beyond the dryer, heat exchanger, prepurifier stages (depending on system) will concentrate in the column bottoms if the system is made up of a distillation column. Methane for example will behave like krypton in the concentrating process. Concentrations of these hydrocarbons in the column are expected to be small, and in the case of the oxygen deletion systems, should present no hazard because of the lack of oxygen or other oxidizing agents to cause reaction. The major hazard which exists with methane in an oxygen system is the formation of solid methane in the liquid phase. When a solid exists in liquid, the fuel concentration at the solid/liquid interface can become much greater than the system average. Thus, maintaining concentrations below the solubility limits is imperative. In the case of the oxygen-rich column, a suitable stream is withdrawn from the column bottom and recycled through a hydrocarbon converter unit to keep the hydrocarbon levels in the column at sufficiently low levels. This recycle feature is also found on the oxygen deletion systems.

For the charcoal delay systems, hydrocarbons which pass beyond the recombiner and dryer steps will primarily be deposited in the beds. The trace level of

heavy hydrocarbons may be removed prior to the beds, depending on system design, but the lighter order organics such as methane and ethane will behave like the noble gases in that they will be preferentially absorbed, concentrated and delayed in passing through the absorbers. Beds are sized such that buildup of organics over an annual or other operating period can be tolerated. The organic buildup would be discharged during the system shutdown, purge, and maintenance period.

Ozone. When oxygen is permitted to enter the concentrating steps of an off-gas system, the possibility of ozone being formed by ionization and thus the potential for ozone detonation must be considered. In the case of the off-gas systems where hydrogen is added to delete oxygen, this problem is effectively controlled, and multiple failures of instruments, etc. would appear necessary to arrive at an ozone problem. In systems operating without hydrogen addition, ozone may be controlled by catalytic action to promote ozone destruction, such as a molecular sieve, or charcoal, in the concentrating process[2,3]. But in the case where oxygen is permitted in the concentration step; e.g., oxygen rich, cryogenic columns, control of ozone is based on a recycle stream from the bottom of the column. This stream is passed through a unit which elevates temperature thus promoting decomposition of the ozone. Recycle flow rates sufficient to keep ozone levels in the column at low levels may be determined from analysis (and experimentation). Ozone buildup in the column is a function of oxygen levels, curie content, ionizing energy, and recycle or removal rates. Control of ozone under such conditions is not difficult in theory. Analyses for a typical off-gas system design in the case of an emergency shutdown with loss of refrigeration (worst case conditions) has indicated many hours (up to one or more days) are available to take corrective action before ozone concentrations approach hazardous levels. Literature surveys indicates a reasonable G value (formation rate) for ozone formation is 6 to 8 molecules of ozone formed per 100 mev of energy adsorbed. Detonable mixtures for ozone are approximately 16% in the gas form and 90% in the liquid form. One caution that must be observed in handling ozone in a system is that fractional distillation must be prevented.

Trace O_2 and H_2. The trace contaminant which must be monitored or cared for depends on the type of off-gas system; i.e., hydrogen removal or oxygen removal system. In practice either radiolytic hydrogen or oxygen is removed in the recombiner, and recombiner performance is monitored by recombiner temperature behavior and downstream oxygen or hydrogen analyzers. Generally these parts of the off-gas systems have received considerable attention on the part of vendors and multiple failures are necessary to develop a hazardous situation.

Nitrogen Oxides. A small level of nitrogen oxides (NO, NO_2, N_2)) may be carried into the system in the feed gas stream. The formation of additional nitrogen oxides in the recombiner section will be at a low level in an oxygen-lean system but may be significant for systems where excess oxygen is not removed. NO_2 and N_2O are water soluble and removable to some degree in condensers and water separators downstream from the recombiner. Depending on system design, removal may also be accomplished to some extent in dryers, heat exchangers and adsorbers. In these cases, discharge to the atmosphere during regeneration cycles can be expected.

NO_2 and N_2O which escapes these removal mechanisms along with essentially all of the NO will pass to the column or charcoal bed depending on the system design. For a column in an oxygen deletion operation mode, further formation of the oxides of nitrogen will be low. However, in an oxygen-rich system, some additional nitrogen oxides can be formed, primarily in the column sump. Formation rate of these contaminants is approximately an order of magnitude lower than for

ozone. Molecules formed/100 mev absorbed are about 1.5 for NO_2 and 0.6 for N_2). Control of nitrogen oxide levels for a column system is by the recycle stream from the column bottoms. The NO in this stream is oxidized to NO_2 for subsequent removal, the NO_2 is unchanged except for removal during recycle through the system, and the N_2O is decomposed. For an absorption system any N_2O reaching the absorber will be adsorbed approximately three times longer than krypton with buildup at a level of concentration roughly 1000 times the entrance concentration. NO will pass through with a very small retention time. A portion of the NO and NO_2 may be irreversibly adsorbed on a molecular sieve and be permanently bound. In addition to loss of bed capacity, this could potentially create problems in that nitrogen oxides are sensitized fuel and control of contamination levels are important.

Iodine (Halogens). In addition to the noble gases released from leaking fuel pins, the more volatile elements such as the halogens are also released. To a large degree they are scrubbed or removed from the gas stream prior to processing by the waste gas system. On a mass basis a small quantity of the halogens (iodine, chlorine, bromine and fluorine) do reach the off-gas processing stream. This discussion will be centered around iodine since iodine is biologically the most significant, and since generally any physical process which will remove iodine will more effectively remove the other naturally occurring halogens. The majority of the iodine will reach the processing unit in one of three basic chemical forms, elemental iodine (I_2), hypoidious acid (HIO) or as an organic iodide. The organic iodide will primarily be methyl iodine (CH_3I)[4]. Due to physical and chemical stability, the organic iodides should be the principle chemical form.

The elemental iodine reaching the off-gas treatment system will be acted upon by several removal mechanisms. The catalytic surface of the recombiner will remove some I_2, the condensation of the steam will remove I_2, and the adsorber bed for CO_2 and H_2O removal will also remove I_2. Typically most systems employ an iodine removal column which will effectively remove the elemental iodine. The extremely small amounts of elemental iodine left in the gas stream will either be removed in the noble gas delay beds or will be frozen out in the heat exchanger leading to the cryogenic distillation column. Thus, the off-gas systems will effectively remove elemental iodine.

The hypoiodious acid entering the off-gas system will be effectively decomposed by the elevated temperature of the recombiner. Elemental iodine or an organic iodide will be formed upon decomposition of the HIO.

The organic iodides (mainly methyl iodine) will be the most persistent species in the off-gas system.

Some decomposition of CH_3I will occur in the recombiner. A portion of the remaining CH_3I will be removed during the steam condensation following the recombiner. The majority of the CH_3I will reach the CO_2/H_2O dryer column and will be chromatographically delayed on the column. The iodine removal column which typically follows the dryer column may yield significant removal rates dependent upon adsorber material. If used, unimpregnated charcoal is not a suitable methyl iodide removal mechanism. Methyl iodide should be completely removed from the gas stream in the noble gas concentration or removal system.

A degree of caution should be used in the placement of an iodine removal adsorber. The unit should be placed downstream of the recombiner and the water

removal system because: (1) moisture will degrade the performance of an iodine adsorber, and (2) the inorganic iodine adsorbers (such as silver zeolite) will act as a catalyst for the H_2/O_2 exothermic reaction. If placed before the primary recombiner, sufficient heat of formation can occur to cause a hazardous situation.

Summary of Contaminants

Thus, for contaminants, satisfactory removal mechanisms exist to keep levels in control. Generally, no serious difficulties for operation of the systems were encountered during these evaluations, primarily because contaminants are at a low level in the off-gas stream and because removal mechanisms exist in essentially every system. Nevertheless, a recommendation is that the vendors of off-gas systems should prepare hazard evaluations for contaminants and identify expected deposition of contaminants throughout their system or be prepared to discuss these questions at the licensing level.

Operation and Controls

The area of BWR off-gas system operation, control and operator action spans a wide range of philosophies. There are a number of problems that arise between vendors and the utilities related to operation of these systems. Some vendors may wish to rely on operator action for system shutdown whereas in other cases the vendor may design a nearly 100% automatically controlled system. In some cases, the control room will contain essentially only alarms, either lights or annunciators, to monitor system performance. In this case, complete system control is usually provided at a local control panel near the off-gas system. In other system control designs, the operator at the control room may have alarms, indicators and controllers for partial system control. Some system designs included as little as one automatic shutdown feature, others as many as 20.

The problems or differences outlined above relate to philosophies and economics. Some vendors or utilities believe final decisions should rest with the operator. The utilities in general do not want systems which will shutdown the overall plant if some minor release problem developes with the off-gas system. Also clearly, these problems of control philosophy are compounded by each system being tailored to the particular installation and the costs of duplicating instrumentation and controls between local control panels and control rooms. It is obvious that the instrumentation required increases with the complexity of the system, and for some systems more instruments and controls, may be required.

The degree of operator interaction in the event of upset conditions for the more sophisticated or complicated systems should be reviewed for each type of system. The depth of review should depend upon the complexity of the system and the criticality of the upset condition. Although the BWR off-gas processing systems are not complicated from a chemical processing standpoint, nor when compared to the operation of a nuclear power reactor, there are still potential operator difficulties. Since the system normally operates with little operator interaction, the operator's familiarity with the system can wane, unless periodically refreshed, to the point of taking improper action upon notification of upset condition. In addition, certain operations, such as concentrate processing, are done only on a periodic basis which also leads to unfamiliarity of the process.

Control of process variables which can change rapidly during upset conditions should be through instrumentation. Changes in process variables which occur slowly may be via operator interaction as many of the changes in process conditions can

exist for hours prior to reaching hazardous conditions. Administrative control through the use of proper troubleshooting manuals and operating procedures, and by providing periodic refresher courses on system operations can increase the assurance that proper operator action will be taken during upset conditions.

Hydrogen Design Review

Several problems related to hydrogen design philosophy were apparent from the discussions with vendors during this study and consistent guidelines are needed. The limits of hydrogen in mixtures of nitrogen, oxygen and steam which are possible to obtain in a BWR off-gas system are shown in Figure 5. These limits are a function of the volumes of the components in the stream. From this curve it can be seen that no mixture at one to two atmospheres of pressure can propagate flame if it contains less than 4.9% oxygen[5]. This figure shows, for example, that a mixture containing 20% H_2 and 10% O_2 and 70% diluent gas is flammable but would drop below flammability limits if the gas was diluted by a factor of 3 with steam or nitrogen. This lowers the H_2 to approximately 7% but the O_2 would drop to 3.3% which is below flammable limits.

Explosions and Detonations. Several pressure relationships are being used in the design of systems with regard to hydrogen explosions. Theory and empirical data are incomplete and design pressure "correlations" ranging from 18 to 25 times the absolute operating pressures are used. These pressure multiplying factors appear confortably conservative to account for hydrogen explosion. However, if a series of equipment and instrument failures are to be postulated which will lead to explodable mixtures, then the possibility of detonations should also be considered.

Two distinct processes are possible in chemical explosions[6]:

(1) Smooth burning, or normal explosion, which is controlled by chemical reaction rate and mixing processes, and is characterized by a relatively low velocity of flame propagation

(2) Detonation, which is largely a hydrodynamic phenomenon, and is characterized by a shock wave which travels through the unburned gas at a velocity greater than that of sound.

A detonation wave can be expected when a strong compression wave, which may result from a shock impact or from a rapidly propagating flame front, progresses essentially unidirectionally into a tube of unburned gas. As the compression waves progress and compress the unburned gas, the sonic velocity of the compressed mixture becomes successively greater, and the more recent compression waves overtake the earlier ones to form a shock wave. Due to the sudden large and irreversible compression of the gases in a shock front the temperature may rise momentarily to the order of $2000^{o}K$, sufficient to ignite the gas and cause it to burn at a very rapid rate. If the wave receives sufficient energy from combustion to overcome losses to the system, then a stable detonation wave results which propagates through the system at a velocity greater than that of sound.

According to the study in Reference 6, a stable detonation wave is a strong function of the geometry of the system, and detonation of a combustible mixture in spheres, vessels, expanding systems or systems with irreversible energy losses is extremely unlikely. Therefore, explosions, not detonations are applicable for the recombiner, tanks and vessels. However, detonation in piping, capillaries, etc. upstream or downstream of the recombiners must be considered. The pressures
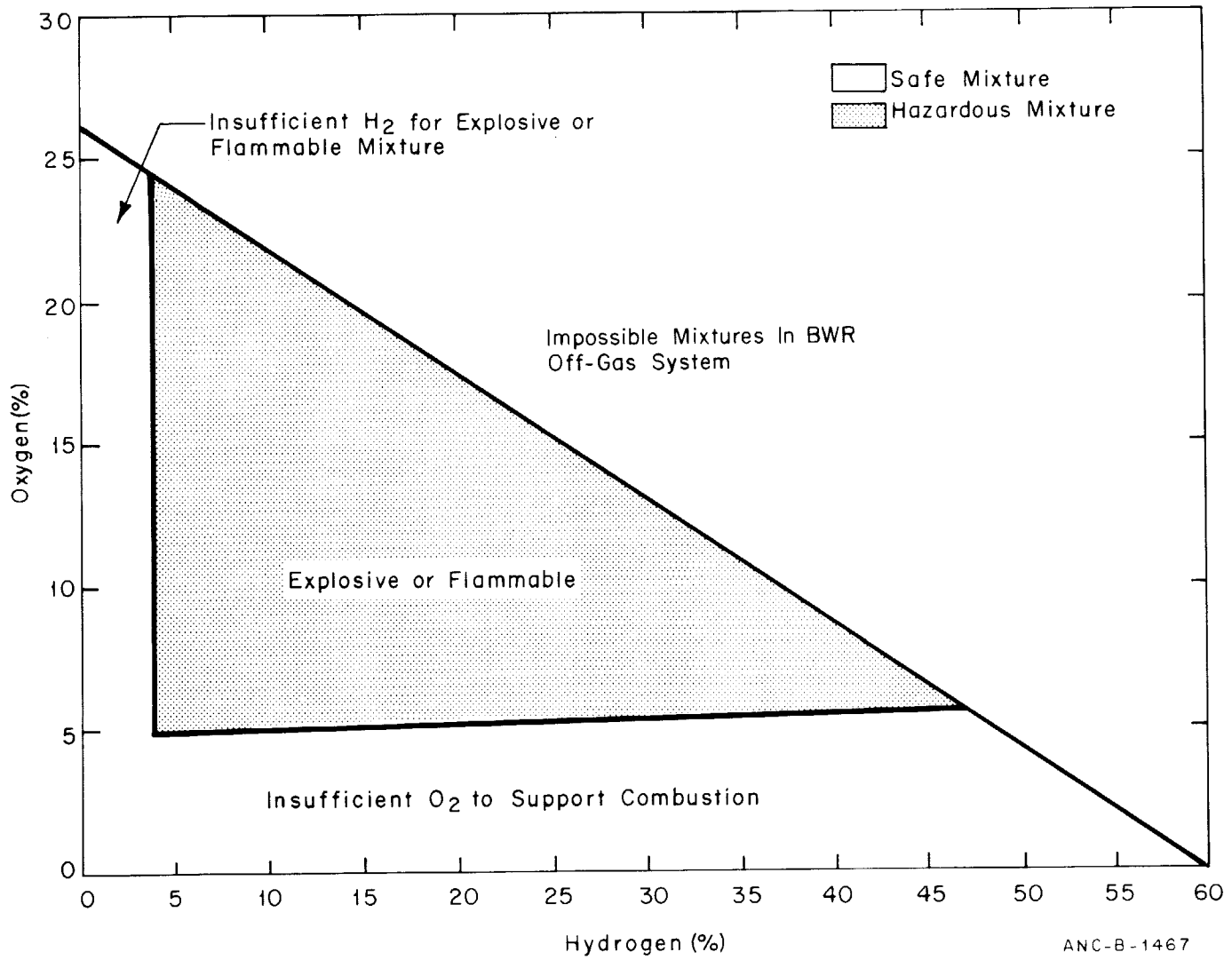
FIG. 5   RELATION BETWEEN O_2 , H_2 N_2 AND STEAM COMPOSITION IN A BWR OFF-GAS SYSTEM

resulting from detonations are much larger than those resulting from explosions. In some cases, the vendor's designs would withstand either explosions or detonations, but in other cases design might be marginal. If explosion proof designs are to be specified, then also, detonations need to be evaluated. One of the more probable areas for such an occurrence is the off-gas line leading to the recombiner. Another area, if failure of instrumentation or equipment is postulated, is in piping downstream from the recombiner.

The concepts just discussed have been confirmed by facts in the short period since conclusion of this study. A number of explosions in recent months in the off-gas systems of BWR's have been recorded with several of these being classed as detonations. In several cases air ejector rupture discs have been fractured or blown out; in other cases high efficiency filters have been charred, or damaged and filter support beams deformed. Lightning strikes have been identified as the ignition source for several of these incidents, but in others there was no evidence of electrical storms in the area. System electrical components are suspect in some cases. Corrective actions have included improvements to the lightning arrestor systems, improved grounding of components to eliminate static charges, ground conductivity checks, instrumentation tests, air purges to reduce hydrogen concentrations, and establishing modified operating procedures. Although the plants were required to shut down from these incidents and some radioactive discharge through the ventilation system was generally encountered, no abnormally large releases exceeding technical specifications, nor overexposure to plant personnel were experienced.

Loss of Hydrogen Bearing System Integrity. Another hydrogen problem for an off-gas system that utilizes hydrogen addition could be leaks from the hydrogen system to the room housing the hydrogen system or to the room housing the off-gas system with the accompanying buildup to hazardous or explodable mixtures in the rooms. Such leaks might result from seismic activity, valve failure or other unspecified failures. Precautions against this possible hazard could be Class I design of the hydrogen system, instruments on the hydrogen system, hydrogen detectors in the equipment areas or room ventilation.

Buildup of an explodable mixture (4% hydrogen) in a room can be fairly rapid if all of the output from a hydrogen supply system or off-gas feed stream is exhausting into the room volume. Scoping calculations were completed to determine the time required to accumulate sufficient hydrogen for an explodable mixture for rooms having dimensions of 20 x 20 x 60 ft (maximum expected size) and 10 x 30 x 30 ft (minimum). Several possible sources of hydrogen leakage are evaluated for each room: (Case 1) 100% of the output from a typical hydrogen delivery system, (Case 2) the radiolytic hydrogen normally entering the recombiner, (Case 3) Cases 1 and 2 combined, and (Case 4) Case 3 with the addition of a break in a typical hydrogen bottle backup system. Each of the these cases are evaluated for two assumptions regarding room ventilation: (1) the room ventilation system is inoperative or does not exist (Cases 1-4), and (2) a room ventilation system is operative at six changes of the room air per hour (Cases 5-7). Thus, Cases 5-7 correspond to 1-3 but with the addition of room ventilation. Also for every case considered there are two operating conditions evaluated, one off-gas system train processing the effluent from one plant which is the normal model of operation, and one off-gas system train processing the effluent from two plants which is an emergency mode of operation for some vendors; i.e., until a backup system is brought online, etc.

The following equation was used for the cases with ventilation:

$$\frac{dx}{dt} = Ra - \frac{x}{V} Rv \qquad (1)$$

where:

x = amount of hydrogen in room (ft^3)

Ra = hydrogen addition rate (ft^3/min) (various possible sources)

V = room volume (ft^3)

Rv = room ventilation rate (ft^3/min)

for six changes per hour, this equation becomes $dx/dt = R_a - 0.1x$ regardless of room size and has the solutions

$$x = 10 \ Ra \ e^{-0.1t} + 10 \ Ra \qquad (2)$$

$$\text{or} \quad t = 10 \ \ln \frac{10 \ Ra - x}{10 \ Ra} \ \text{min.} \qquad (3)$$

The assumptions for these calculations and the results are given in Tables II and III, respectively.

For explodable hydrogen concentrations of 4% in the maximum and minimum size rooms, $x = 1440 \ ft^3$, and $360 \ ft^3$, respectively. From the solution for x, it is clear that the hydrogen addition rate, Ra, must exceed $144 \ ft^3/min$ for the maximum size room and $36 \ ft^3/min$ for the minimum room to achieve an explodable mixture for the given ventilation rate. For hydrogen leaks less than these amounts, the hydrogen concentration achieves an equilibrium value which is less than the explodable mixture. The results for the time, t, to an explodable mixture in cases 5-7 are based on the solution for t in the equation above.

Table II   Off-Gas Room Hydrogen Buildup Assumptions

Maximum Room Size:	20 x 30 x 60 ft = 36,000 ft^3
Minimum Room Size:	10 x 30 x 30 ft = 9000 ft^3
Condenser Air Inleakage:	40 scfm per plant
Radiolytic Hydrogen:	150 scfm per plant
H_2 Addition Rate:	18 scfm per plant
Room Ventilation Rate (if present):	Six changes of room air per hour
Explodable Mixture:	4% hydrogen
Maximum Room	1440 ft^3 H_2
Minimum Room	360 ft^3 H_2
Homogeneous mixtures throughout the room atmosphere	

Table III   Off-Gas Room Hydrogen Buildup Results

		Time to Explodable Mixture			
		Maximum Room Size		Minimum Room Size	
		One Plant on One System	Two Plants on One System	One Plant on One System	Two Plants on One System
Case 1	100% Break in Hydrogen Supply System Output	80 min	40 min	3.2 min	1.6 min
Case 2	Break in Off-Gas Line, Radiolytic Hydrogen Leaks to Room	9.6 min	4.8 min	23 sec	11.5 sec
Case 3	Case 1 and Case 2 Combined	8.6 min	4.3 min	20.4 sec	10.2 sec
Case 4	Case 3 Plus Break in Hydrogen Backup System	7.7 min	3.9 min	18.6 sec	9.3 sec
Case 5	Same as Case 1 but with ventilation at 6 changes of room air per hour	-------	-------	-------	-------
Case 6	Same as Case 2 but with Case 5 Ventilation	32.2 min	6.5 min	2.7 min	1.3 min
Case 7	Same as Case 3 but with Case 5 Ventilation	19.4 min	5.6 min	2.4 min	1.1 min

It should be emphasized that the results below are for an assumed homogeneous mixture or complete dispersal of the hydrogen throughout the room volume. Clearly for cases with rapid discharge of hydrogen, this assumption may be erroneous. There could be preferential concentration of the hydrogen in some areas in the room thus compounding the problem for possible hydrogen explosions. Also in some cases hydrogen releases might behave like a gas bubble rapidly rising to the top of the room where ignition sources may exist in the room electricals.

Facility Safety. A related problem with hydrogen leaks is the electricals associated with either the rooms housing the off-gas system or with the system itself. There appears to be cases where electrical systems which are not hydrogen proof exist in areas where hydrogen leaks cannot be eliminated. In some instances the equipment (i.e., lights, valve actuators, switches, etc.) are standard, commercially available equipment not designed for hydrogen service. Also, the hydrogen supply system and the room housing the off-gas system should be evaluated to insure satisfactory instrumentation is installed or ventilation is adequate to guard against explodable mixtures developing in the room in case of a leak in the hydrogen supply system.

Most of the cases tabulated above for hydrogen sources represent complete system breaks and are of low probability. Leaks, instead of breaks, would lead to much lesser hazards. Also, in most systems, some form of protective measures exist; e.g., room ventilation, housing of the hydrogen supply unit in a room separate from the overall off-gas system, and hydrogen detection instruments. These problems are also dependent on installation from plant-to-plant. A recommendation is that a hydrogen detector be included with every system and that the detector be connected through control circuits and valves to terminate the hydrogen sources in case of high hydrogen levels in the rooms associated with the overall system.

The necessity of precautions in these areas of potential hydrogen problems are important. Vendors should be able to assure that potential hydrogen leaks are accounted for in the overall system design and installation. The wide range of options available to insure system safety make definite recommendations impractical beyond that related to the existence of adequate detection to shut off hydrogen supplies or sources as recommended above.

Loss of Support System Review

There are five support systems required for operation of a typical BWR off-gas system: coolant, power, steam, hydrogen, and instrument air. However, hydrogen is not used for systems where oxygen is not removed. The effect of the loss of each of the systems is discussed below.

Loss of Coolant. The coolants for BWR off-gas systems consist of cooling water and liquid nitrogen. Cooling water is commonly used in any of several coolers, condensers/water separators, and compressors that may be associated with these systems. Loss-of-coolant to any coolers/condensers or aftercoolers generally lead to high temperatures in the feed gas or process stream. Temperature sensing instruments may trigger alarms for operator action or trigger shutdown of the system. Loss of cooling water to compressors lead to overheating and to automatic shutdown in most cases. Thus in general, loss of cooling water will result in shutdown and system isolation. However, certain subtle effects from loss of cooling water appear possible from system-to-system. These basically involve plugging problems resulting from failure to remove water vapor. Apparently, in most of these cases the system is reduced in effectiveness, but release of the concentrated product would not be involved.

The liquid nitrogen for the BWR off-gas systems is normally supplied via storage dewars (tanks) located on site and commercially replenished. The capacity of these tanks is usually sufficient for ten days to a month of normal operation. Failure of the liquid nitrogen supply must be postulated by whatever means (seismic events, line rupture, valve failure, strikes, sabotage, etc.) and regardless of probabilities. Typically the systems have temperature sensors on the concentrating unit sensing warmup or low liquid level sensors which will alarm and isolate the column or cold box by valve action in this event. Thus, the concentrated product is isolated and contained. The columns have sufficient liquid nitrogen inventory, and the cold boxes enough thermal insulation, to maintain cryogenic temperatures for several hours to several days depending on the system. Eventually warmup will commence but most of these systems have a secondary containment which is sized and rated to contain expansion of the contents of the column to ambient temperature without rupture. The secondary containment may be in the form of a coded containment vessel housing a cryogenic column, a pressure rated cold box, or surge tanks and related vessels that can be opened to the expanding liquid as it warms. In addition, the contents of a column or cold box can typically be transferred to a different operating system or to other storage vessels. Thus, loss of liquid nitrogen while serious in principle does lead to automatic isolation of the system components containing the concentrated product, considerable time for corrective action, containment, and alternatives for handling the expanded liquid in case of an extended liquid nitrogen outage and system warmup. No serious difficulties from a release standpoint are envisioned, but in an oxygen-rich system, fractionation of gases during the in situ warmup can potentially lead to ozone detonation possibilities if not carefully controlled.

Loss of Power. A loss of power to the typical BWR off-gas system will affect instrumentation, controls, alarms, and various heaters and compressors. In all cases, system shutdown and isolation of the concentrated product (column, cold box, charcoal beds) will result although the exact sequence may vary between systems according to design. Most generally, valves are designed to fail closed with loss of power for isolation purposes except those needed to keep the liquid nitrogen supply on line. In the latter case, the valves fail open. Thus, for all systems reviewed, loss of power places the system in an isolated, cold standby condition which can be maintained for an extended period of time. Remote monitoring of the system during this period will not be possible because of loss of function of instrumentation. The BWR off-gas systems are not typically supplied power by the critical bus.

Loss of Steam. Response of the BWR off-gas systems to a loss of steam differs slightly for the various systems. But characteristically loss of steam affects a steam jet air ejector (usually more than one) and causes a low flow signal to alarm or initiate system isolation. In most systems, immediate shutdown of the system and isolation of the concentrated product is the case. In at least one system, isolation of the recombiner followed by continued operation of the rest of the system using internal recycle can occur for a period of time. No difficulty with release of the concentrated product is envisioned for loss of steam in the systems reviewed.

Loss of Hydrogen. For those systems where hydrogen is added to eliminate excess oxygen, the hydrogen supply is typically monitored as is the oxygen levels downstream of the recombiner. Failure of the hydrogen supply leads to high oxygen levels, alarms and shutdown of the system. In some cases, depending on the installation, the recombiner may continue to function with the off-gas stream switched to a decay pipe prior to atmospheric release or vented directly

to the stack. Thus, for these systems, loss of hydrogen in itself does not lead to hazardous operation since continued operation of the complete system would require a double failure.

Loss of Instrument Air. In most of these systems valves are pneumatically operated and fail in the closed position or in the fail-safe position. Exceptions are valves designed to fail-open for continued supply of liquid nitrogen. In some cases continued supply of nitrogen to the column may be manually controlled. In any event, loss of instrument air leads to a fail-safe configuration without significant loss of radioactive material from the system.

In summary, the vendors appear to have done an adequate job in designing the off-gas systems to fail in a safe configuration in case of loss of support systems. A safety guide on these systems should reiterate this philosophy.

Result of Equipment Malfunction and/or Failure

Several evaluations related to equipment malfunction and/or failure and the effect this event would have on a BWR off-gas system are provided below. These discussions are representative but not all-inclusive of similar evaluations on equipment in the overall BWR off-gas study.

Recombiner. The function of the recombiner in the BWR off-gas system is: (1) to combine radiolytic hydrogen and oxygen into water for removal by condensation thus reducing the volume of the process stream, and (2) to combine added hydrogen with free oxygen to eliminate the hazard of processing with oxygen if such philosophy is being followed. From a safety or hazard standpoint, assurance that satisfactory recombiner performance is being achieved is required as discussed below.

A variety of different recombiner designs and catalysts could be selected dependent on vendor or utility preferences and system operating conditions. Consequently, the basis doesn't exist to identify one in preference to another. For any recombiner, there are various inhibitors and poisoning agents which will lead to catalyst deactivation and, subsequently, decline or loss of recombiner performance. In some cases, reactivation is relatively simple. Causes, effect, and remedial actions for decline in performance are listed in Table IV for some cases[7].

All catalysts may not respond exactly the same to inhibitors and poisoning agents or to the same remedial actions as listed in Table IV. Experience with recombiners and the expected composition of the off-gas process stream does not indicate that difficulties should be encountered. Characteristically, vendors have supplied oversize beds which will handle the small amounts of catalyst deactivation anticipated, and reactivation or replacement could be undertaken if necessary during maintenance periods. Also characteristically, recombiner deactivation is a slow, easily identified process. The exception could be the stream condensation and catalyst wetting problem. Normally, preheaters or steam superheat are utilized to insure suitably high temperatures for correct recombiner and catalytic function. Supposing loss of the preheater or a steam system with a small amount of superheat, condensation could occur along with wetting and partial or total deactivation of the catalyst. Low inlet temperature may be indicated but the process could occur fairly fast. A possible more rapid development of this problem could occur during startup or switching of a unit. The latter case would probably involve an operator error since the recombiner system should be brought to operating temperature prior to being placed online.

Table IV Catalyst Deactivation and Poisoning Agents

Cause	Effect	Remedial Actions
Coating Agent - rust dirt, other inorganic oxides	Covers active catalyst site	Detergent Washing
Coating Agents - ("glass" forming materials) - phosphorous containing materials, silicones, organic silicates	Covers active catalyst site	Usually factor reactivation or replacement
Poisons - heavy metal elements (mercury, lead, tin...) arsenic	Kills catalyst	Factory reactivation
Inhibitors - halogens (fluorine, chlorine, bromine and iodine)	Temporary deactivation	Remove source of halogen (usually recovers in short time)
Inhibitor - Sulfides	Deactivation	Remove source, detergent washing, or factory reactivation (dependent on concentration)
Organic droplets and aerosols	Possible coating, burnup of catalyst and deactivation	Usually factory reactivation
Steam condensation and wetting	Partial or total deactivation	Warming and drying

From a safety standpoint, monitoring, alarm, and shutdown for recombiner parameters outside of specified limits are of primary importance and necessary. If the recombiner fails to function in an oxygen removal system, hazards such as ozone production are encountered. Otherwise failure of the recombiner when coupled with steam dilutent condensation can lead to a flammable mixture down-stream. Most vendors have provided inlet (low) and outlet (high) temperature instruments, TC's at various bed depths, and monitoring of oxygen or hydrogen levels following the recombiner. Monitoring of the recombiner to insure adequate performance and shutdown of the off-gas system when limits are exceeded should be

required, included in a safety guide, and reviewed in the licensing process, but types of catalysts, problems with inhibitors, deactivating agents, regeneration, and effect on continued operation of the plant should not be addressed in depth. These problems are essentially utility-vendor concerns related to keeping the plant online.

Pipe Breaks. Pipe breaks have generally not been identified with immediate massive releases of fission products except possibly in areas of concentrated products such as column bottoms, recycle lines, and product storage lines. Lines used for hydrogen supply and liquid nitrogen supply are additional areas critical to the continued and safe operation of the system, but instrumentation is normally associated with the hydrogen and liquid nitrogen supplies which will provide sufficient warning for operator intervention. Exceptions are possible and need to be kept in perspective for any given system or installation such as the discussion on loss of hydrogen bearing system integrity or heat exchanger failures. The decontaminated gas stream is often used in cryogenic heat exchangers, depending on the system, to cool the process gas stream prior to being vented. An internal leak or rupture of the heat exchangers could allow the off-gas stream to mix with the decontaminated stream if the latter is at lower pressure, thus bypassing the removal-concentration step. This problem is offset by adequate design and is of low probability except perhaps in the frame of overall plant lifetime when corrosion could eventually be a factor. Radiation monitors would detect such problems, but diagnosis and repair could be troublesome. The primary area of concern in the following discussion is the pipe runs associated with the concentrated product. Scoping calculations have been completed to determine blowdown times for a cryogenic distillation column. The column was assumed to be operating at 50 psig and to contain concentrated noble gas in approximately one- to two-cubic feet of liquid gas (N_2-Ar or O_2-Ar). Blowdown was assumed to be through a one-half inch line having typical valves, bends, and fittings. Blowdown times of one to two minutes for complete discharge of the concentrated product were obtained for these conditions. On this time scale, operator intervention as a result of system alarms may be meaningless.

In the review of systems using distillation columns, the possibility of pipe breaks that could lead to column blowdowns or other discharge of concentrated product could not be entirely eliminated. Some columns may operate at pressures higher than 50 psig, others lower. Orifices (or valves) limiting blowdown rates, automatic column isolation and other features may be installed in some cases. The physical layout of valves and plumbing is important and may vary from vendor-to-vendor or plant-to-plant for a given vendor. Releases related to site boundaries can be a function of the system location in the plant, ventilation system, etc.

Recommendations related to pipe break problems where concentrated products may be involved, such as column bottoms, recycle lines, and transfer lines, either to secondary concentration steps or product bottling, are listed as follows:

(1) The column should have an automatic isolation feature which could most conveniently be a valve located at the secondary containment or cold box wall or at the column bottom. The isolation valve should automatically close by change of an operating parameter such as pressure drop in product transfer or recycle line.

(2) The vendor should satisfactorily describe the physical design of the system during licensing to insure that necessary features are built into the design to mitigate and prevent massive release from pipe ruptures in and around the concentrated product handling stages.

Vessel Ruptures. The design pressure of the recombiner vessel for most BWR off-gas systems is of the order of 300-350 psig, or about 21 times operating pressure to withstand rupture in the event of a hydrogen explosion. Ruptures downstream of the recombiners, but prior to the concentrating or holdup steps, would not lead to release of substantial radioactive materials because of low inventory. A rupture of a vessel in the concentrating or delay step would normally be contained by the secondary containment vessel. However, in the case of an explosion, missiles could be of concern but have not been evaluated in this study. For adsorber systems, vessel ruptures may not result in blowing absorber materials out of the vessel and radioactive materials would continue to be confined. But this could be altered for violent ruptures. In the case of a rupture of a vessel in the off-gas systems, parameters out-of-tolerance would typically initiate alarms, shutdown, and isolation of the system to retain the concentrated product.

There can be exceptions on a system-to-system basis to the general observations given above regarding vessel rupture. For example, rupture of a vessel or tank used for storage of the concentrated product, although of low probability, could lead to a massive release of radioactive inventory. The vendor's solutions to both pipe or vessel ruptures appear reasonably adequate in current designs, but there is a lack of consistency throughout the industry regarding what should be done or what is required. A safety guide should address this subject and provide consistent guidelines. Piping and vessels through the recombiner steps could logically be required to withstand a hydrogen explosion. Less restrictive requirements should be adequate for the vessels following the recombiner and up to the concentration steps. To be within the practices of the nuclear industry, secondary containment vessels should be coded if credit is to be taken. These vessels are not coded in some cases at present. All primary containment vessels, such as cryogenic columns, should be coded. Storage tanks for the concentrated product should be coded. The vendors should be prepared to define their choice of design pressures and vessels and be able to assure the adequacy of design.

V. Conclusions

The basic design philosophy applied to the improved or advanced BWR off-gas systems is to reduce the gaseous effluent release to a level which is compatible with the plant environment and to insure licensability. The efficiency by which the various system operations are performed appear to be basically a matter of design philosophy. The BWR off-gas systems may also provide the necessary margin for earlier public acceptance of a given site, closer siting to metropolitan areas, earlier startups and plant operation at higher power levels. The costs of the systems, both capital and operating, appear to be nominal when compared to these potential advantages. In general, the off-gas system vendors have devoted considerable attention and expertise to design practices and have produced high quality well-engineered systems. A number of specific areas where potential problems could arise in the industry are summarized below.

(1) The operation and control philosophies encountered in this study spanned a wide range in the requirements for operator interaction vs. automatic control. Although the degree of operator control and the reliance that is to be placed upon the operator should be arrived at by mutual agreement between vendor and utility, certain critical process and safety functions should be required to be controlled or initiated automatically. Automatic control is particularly important for those processes which will change rapidly under upset conditions. In addition to the automatic features which may be required

for system safety, assurance that the proper action will be taken under upset conditions can be improved by operator familiarity and well-defined operations procedures. Sufficient instrumentation must exist to detect and indicate upset conditions and automatic controls should be provided for process variables which may change rapidly under upset conditions.

(2) Several facets related to the philosophy governing the design of hydrogen bearing portions of the BWR off-gas systems were identified.

Precautions should be taken to minimize the potential for obtaining hazardous or explodable mixtures of hydrogen in the off-gas facility or hydrogen storage room. These can include instrumentation, room ventilation and quality design and fabrication. Quality design should include adequate system design to minimize leak potential and hydrogen proof design of electrical systems in the associated facility.

(3) The behavior of contaminants in off-gas systems is a function of system design and must be evaluated on a system-to-system basis. Generally, no serious areas of concern were encountered during this study, primarily because the contaminants are at a low level in the off-gas stream and because removal mechanisms have been included into the design in essentially every system.

(4) Pipe breaks and vessel ruptures are generally considered low probability events but when associated with the concentrated product handling portions of the system or with the hydrogen bearing parts of the system, potential hazards exist. Piping and vessels through the recombiner steps could logically be required to withstand a hydrogen explosion. To be within practices of the nuclear industry, secondary containment vessel should be coded if credit is to be taken. All primary containment vessels should be coded, storage tanks should be coded, and seismic design consideration should be required for all potentially hazardous design areas.

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(6) T. H. Pigford, "Explosion and Detonation Properties of Mixtures of Hydrogen, Oxygen and Water Vapor", Oak Ridge National Laboratory Report, ORNL 1322 (August 1952).

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DISCUSSION

FIRST: I'm referring to one of the slides you showed on the buildup of hydrogen in a building. You gave some times and I wanted to ask if the times were based on complete mixing of hydrogen.

SCHULTZ: The answer is, yes. It's probably a very poor assumption but it's the best we could do at the time.

FIRST: You said you did not consider the fact that the distribution might not be uniform?

SCHULTZ: That's very true. We just allowed the hydrogen to come into the room. There was no allowance for stratification.