

SESSION V

REACTOR SYSTEM GAS CLEANING

Tuesday, August 29, 1972

CHAIRMAN: C. Burchsted

IMPROVED BWR OFF-GAS SYSTEMS

L. R. Michels, N. R. Horton

EFFECTIVENESS OF FISSION PRODUCT REMOVAL SYSTEMS IN PWR CONTAINMENTS

W. F. Pasedag

FISSION GAS CONTROL AT FFTF

C. J. Foley

ANALYSIS OF POWER REACTOR GASEOUS WASTE SYSTEMS

F. T. Binford, T. P. Hamrick

G. W. Parker, T. H. Row

CHAIRMAN'S OPENING REMARKS:

Session 5 is basically concerned with reactor-plant gas-treatment. I'm fortunate because the introduction for this session was provided by Dr. Biles and Dr. Liverman yesterday morning. The "low as practicable" philosophy and the proposed Appendix I to 10-CFR-50 will dramatically reduce gaseous emissions below present legal requirements and provide an aiming point for future gas-treatment system design.

To achieve these objectives, we must answer several questions that can be summed up as What? Where? How much? and How?

1. What are the radioactive effluents we must contend with?
2. Where and how are they evolved in the plant, under normal and abnormal (i.e., accident) conditions?
3. How much radioactive effluents are produced under normal and abnormal conditions?
4. How do we treat these radioactive effluents, i.e., what measures do we employ and what facilities must we provide to reduce them to permissible levels?

The purpose of this session is to provide some thoughts for developing answers to these questions. The first paper is addressed primarily to the last question as it relates to BWR's.

12th AEC AIR CLEANING CONFERENCE

IMPROVED BWR OFFGAS SYSTEMS

by

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ABSTRACT

All Light Water Reactors in general produce radioactive fission, activation, and corrosion products which are eventually discharged from the various plant systems. In a BWR, the potential release paths for gaseous effluents include the steam jet air ejector offgas system, the gland seal system, the mechanical vacuum pump and miscellaneous building vents. Of these, the offgas system processes the largest quantity of radioactive material. Early SJAE systems feature a buried 30-minute holdup pipe and HEPA filter with gas discharge through a stack about 100 meters high. Decay daughters of radioactive kryptons and xenons are removed with holdup pipe condensate or are trapped in the filter media. The improved offgas system comprises catalytic recombiners which reduce gas volume by removing the radiolytic hydrogen and oxygen plus dynamic charcoal absorbers which operate at ambient temperature and provide selected holdup to permit Kr and Xe decay and trapping of daughters within the charcoal matrix. A roof vent may replace the plant stack. The ambient system has been in successful operation for about 5 years at the KRB reactor in Germany. G.E.'s newest offgas system features catalytic recombiners along with desiccant type air driers and dynamic charcoal adsorbers operated in the range from 0°F to minus 40°F. Relative performance of the systems is as follows:

<u>System</u>	<u>Gamma Dose Reduction Factor*</u>
30 min. H.U. Pipe & Filter	1
Recombiner + Ambient Charcoal	~22-1140
Recombiner + Low Temp. Charcoal	>10,000

*Based on 100,000 $\mu\text{Ci/sec}$ of a 30 minute old modified diffusion gas mixture and an air leakage of 18.5 SCFM.

For relatively large charcoal systems, the holdup time for a particular isotope at a given temperature varies directly with charcoal mass and inversely with gas flow. For this reason, it is important to keep air leakage into the main condensers at a minimum.

Data are provided on BWR main condenser air leakage, summarized literature values of dynamic adsorption coefficients (K-values), along with calculations of activity and gamma dose reduction factors as a function of several of the system parameters.

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I. Introduction

The current environmental objective is to reduce liquid and gaseous emissions from all sources to values which are compatible with the proposed Appendix I of 10 CFR 50. While typical gaseous emissions for operating Boiling Water Reactors presently add only a few millirem to the approximately 140 mrem per year which a person receives from natural background, the present objective is to reduce these exposures to as low as practicable. While many systems are presently capable of performing this task, the General Electric Company believes that the Recombiner-Charcoal system is the most promising from the viewpoint of:

- a) Meeting the proposed Appendix I dose criteria
- b) Operating reliability, and
- c) Lowest exposure from hypothetical accidents

This paper summarizes the offgas system design, potential fission product release paths, BWR offgas operating experience, activity and cloud gamma reduction factors, and hypothetical accident exposures.

A. Fission Krypton and Xenon Release from Fuel

1) Summarized Experience

Typical offgas emission rates from operating BWR's are presented in Table I. As noted, for holdup times of 18-30 minutes the annual average release rates vary between 10,000 - 90,000 $\mu\text{Ci/sec}$ with the average being 18,000 $\mu\text{Ci/sec}$. The resultant nearest neighbor dose varies between 0.1 and 19 mr/yr with an average exposure of about 4 mr/yr. The activity released to the environment and the hypothetical dose received are dependent upon such parameters as effective delay time provided between release from the reactor vessel and receptor exposure, effective release height, average annual meteorology, distance to the receptor, occupancy time, and value of incidental shielding.

2) Offgas Isotopic Composition

The design basis gas composition for present offgas equipment was obtained from measurements on current generation operating BWR's. The composition, which is referred to as a 30-minute old diffusion mix, is shown in Table II for both time zero and 30 minutes. These values are modified as required to reflect the specific gas holdup time prior to entry into the offgas system of a given plant.

B. Potential Release Paths

1) Steam Jet Air Ejector (SJAE)

The SJAE is a steam driven evacuator which removes non condensable gases from the main turbine condenser during normal power operation. The principal radioactive effluent to the atmosphere from the plant during normal operation is from this source. The treatment of this source is discussed in greater detail in subsequent sections of this paper.

TABLE I
BWR OPERATING OFFGAS EXPERIENCE

Plant	Nominal Power Rating (MWe)	Nominal Holdup Time (min.)	Average Annual Emission Rate (mci/sec)		Calculated Nearest Neighbor Dose (mrem/year)	
			1970	First Half-1971	1970	First Half-1971(b)
Big Rock Pt.	75	18	9	10	0.4	0.4
Dresden I	210	20	30	33	5	6
Dresden II	850	30	9	14	0.9	1.4
Fukushima I	460	~1440	--	3	---	<1
Garigliano	160	30	16	37	2	4.6
Humboldt Bay	70	18	16	21	13	10
KRB	250	(a)	1	<1	0.07	<.07
Millstone Pt.	680	30	--	3	---	0.4
Monticello	568	30	--	0.1	---	0.05
Nine Mile Pt.	649	30	--	3	---	0.4
Oyster Creek	575	30	--	11	---	5
Tarapur 1&2	420	30	--	90	---	19
Tsuruga	357	~1440	--	8	---	---

- a) Recombiner plus charcoal adsorption system - Holdup ~1 day krypton and 2 weeks xenon.
- b) Projected annual dose based on first half year experience.

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TABLE II

GE-BWR DESIGN BASIS NOBLE RADIOGAS SOURCE TERM - MODIFIED DIFFUSION MIXTURE

Radiogas	Approx. Half-Life	Source Term, microcuries per second	
		0 Decay	30 min Decay
Kr-95	0.5 s	2.1×10^3	--
Xe-143	1.0 s	1.2×10^4	--
Kr-97	1.0 s	1.4×10^1	--
Kr-94	1.0 s	2.3×10^4	--
Xe-142	1.2 s	7.3×10^4	--
Kr-93	1.3 s	9.9×10^4	--
Xe-141	1.7 s	2.4×10^5	--
Kr-92	1.8 s	3.3×10^5	--
Kr-91	8.6 s	3.3×10^5	--
Xe-144	9.0 s	5.6×10^2	--
Xe-140	13.6 s	3.0×10^5	--
Kr-90	32.3 s	2.8×10^5	--
Xe-139	40.0 s	2.8×10^5	--
Kr-89	3.2 m	1.3×10^5	1.8×10^2
Xe-137	3.8 m	1.5×10^5	6.7×10^2
Xe-138	14.2 m	8.9×10^4	2.1×10^4
Xe-135 m	15.7 m	2.6×10^4	6.9×10^3
Kr-87	76 m	2.0×10^4	1.5×10^4
Kr-83 m	1.9 h	3.4×10^3	2.9×10^3
Kr-88	2.8 h	2.0×10^4	1.8×10^4
Kr-85 m	4.4 h	6.1×10^3	5.6×10^3
Xe-135	9.2 h	2.2×10^4	2.1×10^4
Xe-135 m	2.3 h	2.9×10^2	2.9×10^2
Xe-133	5.3 d	8.2×10^3	8.2×10^3
Xe-131 m	12.0 d	1.5×10^1	1.5×10^1
Kr-85	10.7 y	$1-2 \times 10^1$	$1-2 \times 10^1$
Total		$\sim 2.5 \times 10^6$	$\sim 1 \times 10^5$

2) Mechanical Vacuum Pump Operation

During the startup of a plant and before operation of the steam jet air ejectors is initiated, a mechanical vacuum pump is utilized for gas evacuation of the main condenser system.

The initial rate of removal of radioactive noble gases by the vacuum pump on a plant restart is significant but rapidly decreases as a vacuum is attained in the system. The net result is that the dose contributor to nearest neighbors is relatively small, on the order of 0.2 mrem/yr or less.

3) Building Ventilation

During all phases of plant operation, various portions of the reactor building and turbine building are provided with fresh air for the comfort of employees and the cooling of process equipment. Ventilation gases are discharged to the atmosphere via building vents and/or the plant stack. It is estimated that less than 50 $\mu\text{Ci/sec}$ of noble radiogases and 0.001 to 0.01 $\mu\text{Ci/sec}$ of Iodine 131 are released via this pathway. These small releases of radioactive material are estimated to contribute a whole body dose of less than about 0.1 mrem/yr to the nearest neighbor and a thyroid dose in the range of a few mrem/yr if the milk exposure pathway exists in the immediate off-site environment.

4) Turbine Gland Seal

The main turbine is provided with a special gland seal system into which nuclear steam is usually supplied to seal the turbine. The exhaust gas from this system is passed to a condenser where the steam is removed. The non-condensable gases are retained in a holdup pipe for a short period of time to allow for decay of short half life gases. The remaining gases are then exhausted to the atmosphere. If nuclear steam is used to seal the glands, the resulting dose to the nearest neighbor is of the order of 0.7 mrem/year. This dose is reduced to zero if separate (non-nuclear) steam is employed.

II. Steam Jet Air Ejector Offgas Delay SystemsA. Gas Sources

As mentioned previously, offgas from the main turbine condenser is the principal potential source of emission of radioactive material from a BWR. The main constituents of this source are hydrogen and oxygen (formed by radiolysis of water in the reactor), air inleakage into the main condenser, fission krypton and xenon isotopes, activation gases, and water vapor.

As a design basis, 0.065 CFM (at 70°F and 1 atmosphere) of hydrogen plus oxygen are formed per megawatt thermal, with the gases produced in a stoichiometric ratio. Air inleakage is dependent upon plant housekeeping, however typical values are 1-5 CFM per condenser shell. The composition of total krypton and xenon both radioactive and inert is on the order of 1-2 ppm by volume in the air stream.

For an 1100 MWe reactor, the principal activation gases in the reactor steam are shown in Table III.

TABLE III

<u>Isotope</u>	<u>Half Life</u>	<u>Concentration ($\mu\text{Ci/g}$)</u>	<u>Release From Reactor Vessel ($\mu\text{Ci/sec}$)</u>
N-13	9.99 min	6.5×10^{-3}	1.2×10^4
N-16	7.13 sec	1.0×10^2	1.7×10^8
N-17	4.14 sec	1.6×10^{-2}	2.6×10^4
O-19	26.8 sec	8.0×10^{-1}	1.4×10^6
F-18	109.8 min	4.0×10^{-3}	7.2×10^3

Of the above gases, N-16 is of importance because of its influence on shielding of the offgas treatment facility. N-13 is of interest due to its 10 minute half life and potential contribution to off-site dose.

Downstream of the catalytic recombiner condenser the Nitrogen-13 is reduced to about $1.0 \times 10^3 \mu\text{Ci/sec}$.

B. System Descriptions1. Thirty-Minute Holdup Pipe System

The offgas system used in early BWR's is shown in Figure I. Offgas from the main condenser passes through a large diameter pipe designed to delay the gas for a nominal 30 minutes and through a high efficiency filter which removes particulate daughters formed by decay of the krypton and xenon radioisotopes. The exit gas is then discharged to the atmosphere from the plant stack.

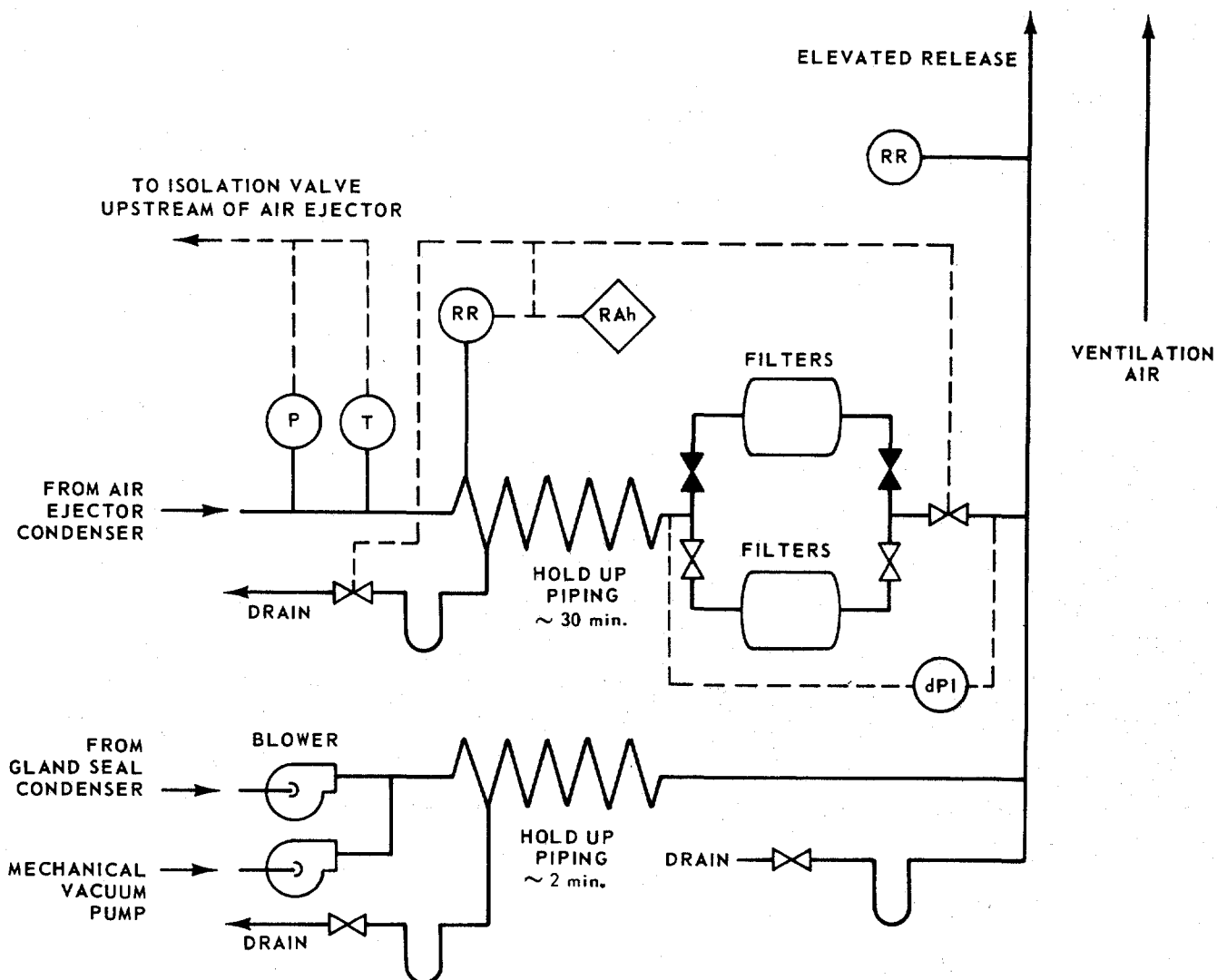


FIGURE I
EARLY BWR OFFGAS SYSTEM

Instrumentation is provided to alarm in the Main Control Room and to shut off the gas flow in the event of high pressure, high temperature, or high radiation levels in the pipe. The resulting loss of vacuum in the Main Condenser will eventually scram the reactor.

2. Ambient Temperature Charcoal System

The addition of a catalytic recombiner to reduce gas flow and a charcoal adsorber to delay krypton and xenon isotopes provides the means for major reduction in radioactive gas emission. Figure II shows the recombiner charcoal adsorber system which is under construction at many BWR plants.

Noncondensable gas removed from the main condenser, including air in-leakage, is diluted with steam to less than four percent (by volume) hydrogen in the last stage noncondensing jet of the air ejector assembly. In addition, the last stage ejector provides a motive force of about 5 psig to overcome pressure drop in the recombiner-adsorber system. The steam-diluted offgas is superheated to 350°F and passed through a catalytic recombiner. The heated recombiner effluent, containing only traces of hydrogen, is passed through a condenser cooled with reactor feedwater to remove bulk moisture. After a 30-minute holdup for the decay of N-13, N-16, O-19 and short-lived krypton and xenon isotopes, the decay daughters are removed through condensation on the walls of the holdup pipe and by filtration. The offgas is further processed by a chiller serviced with refrigerated glycol solution to remove additional moisture, a deentrainer and a reheater to heat the gas to 77°F and reduce the relative humidity to about 30 percent. The gas then passes through high-efficiency filters, charcoal adsorbers and additional filters prior to discharge from the plant stack or roof vent.

In passing through the charcoal adsorbers, the krypton and xenon isotopes are delayed relative to the passage of the air carrier gas to permit noble gas decay and deposition of daughter products on the charcoal. Sufficient charcoal is provided to reduce the off-site dose contribution to the desired level. Charcoal bed operation is continuous and bed regeneration is not required. To minimize back pressure during reactor startup when high air flow occurs, the charcoal adsorbers may be valved to provide two or more parallel trains. For normal reactor operation, all adsorber vessels are valved for series flow with system pressure drop less than 2 psig. Adsorber vessels are installed vertically in a constant temperature vault maintained at the desired temperature by vault air conditioning equipment.

An ambient charcoal system has been operated very successfully for the past 5 years at the KRB Plant in Germany. This plant uses 10 metric tons of charcoal to delay krypton and xenon for about 1 day and 14 days, respectively.

3. Low Temperature Charcoal System

By reducing the temperature of the charcoal adsorber beds and drying the inlet gas, a marked improvement in krypton and xenon holdup can be achieved. The new General Electric Company system shown in Figure III provides flexibility to operate the charcoal adsorbers in the temperature range from 0°F to minus 40°F.

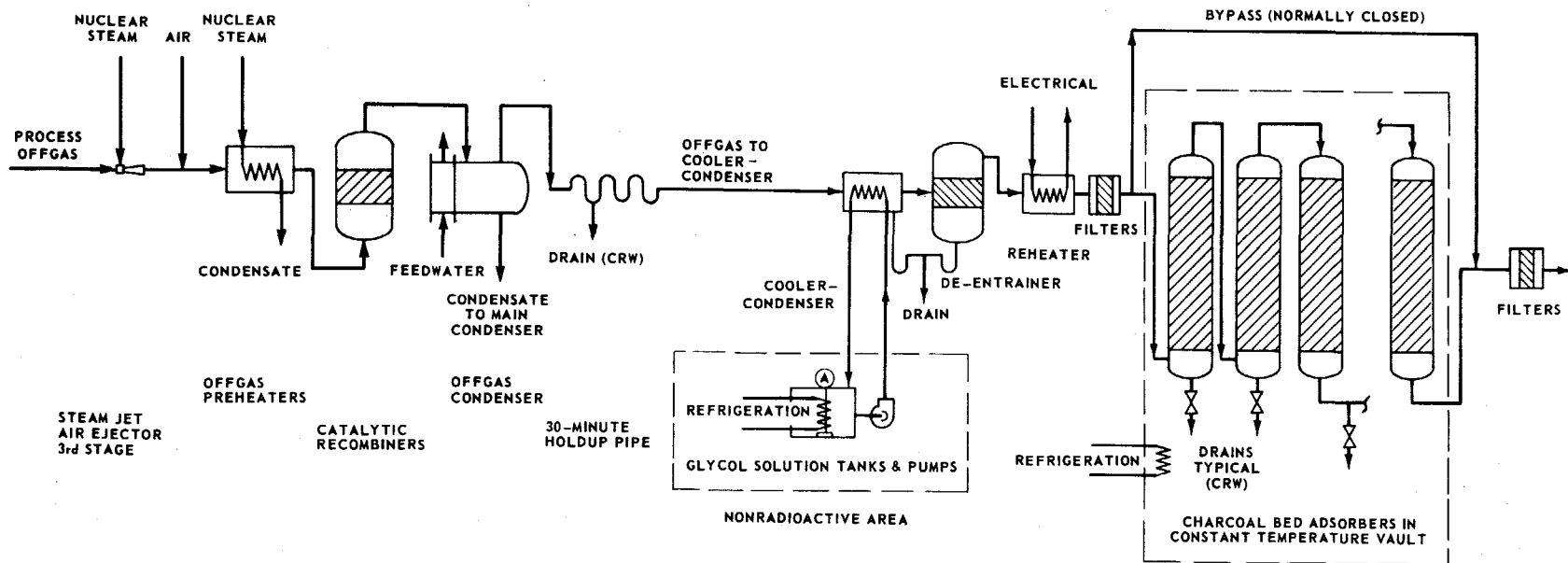


FIGURE II
CATALYTIC RECOMBINER - AMBIENT TEMPERATURE CHARCOAL ADSORBER SYSTEM

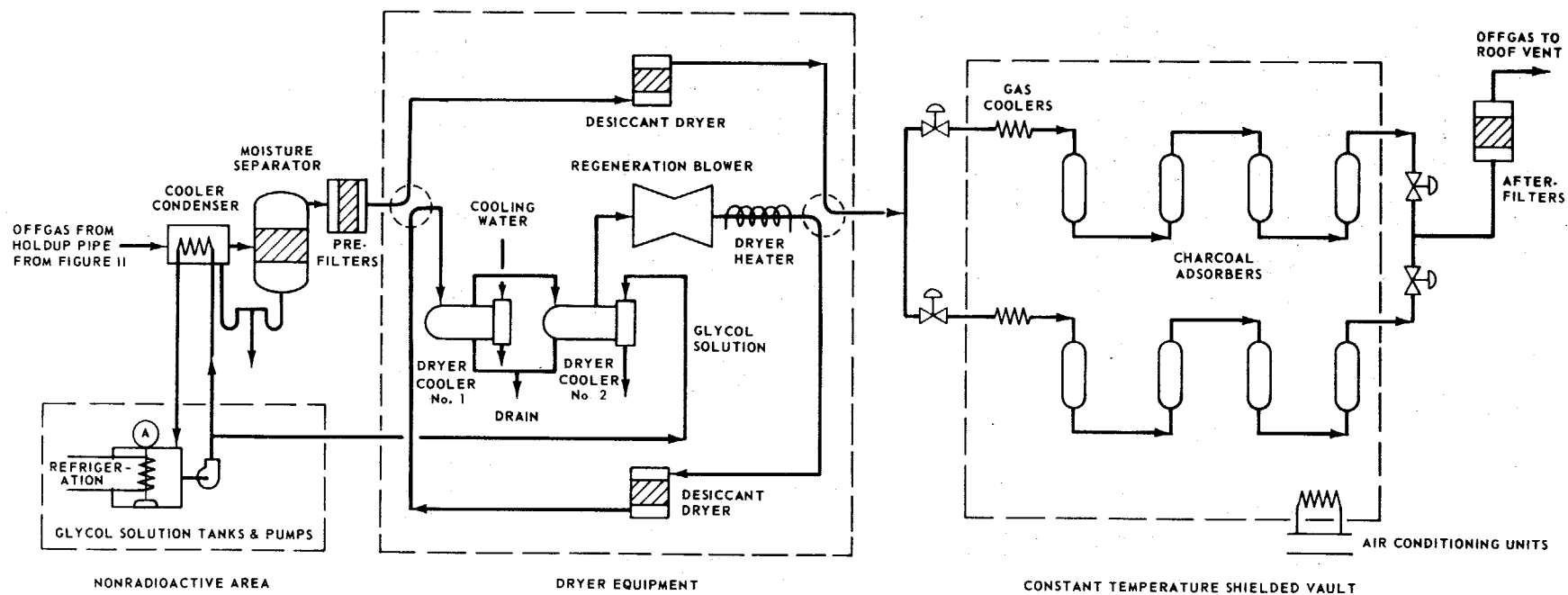


FIGURE III
LOW TEMPERATURE CHARCOAL ADSORBER SYSTEM

The system may also be operated in the range from 0°F to ambient temperature, if desired.

Catalytic recombiner facilities remain the same as for the ambient charcoal system, with the exception that the holdup pipe delay has been reduced from 30 to 10 minutes. With reference to Figure III, offgas discharged from the holdup pipe is chilled, filtered and dried. Drying to a dewpoint of about minus 90°F is achieved through use of Mol Sieve beds. These beds are switched and periodically regenerated by recycle of heated captive gas, with moisture removed by condensation. Charcoal adsorbers are installed in a shielded vault maintained at the desired operating temperature by air conditioning equipment. Gas discharged from the dryers is cooled to approximately the bed temperature by means of finned heat exchangers which are in turn cooled by vault gases. Two carbon trains are installed in parallel to reduce pressure drop under startup flow conditions. Overall system pressure drops for startup and normal operation are about 5 and 1.5 psig, respectively. Gas discharged from the charcoal vessels is filtered prior to discharge to the atmosphere.

All equipment and piping in this system, as well as earlier G.E. systems, is designed to withstand a hydrogen-oxygen explosion.

4. Cryogenic Add-On Systems

The whole body dose to any neighbor in the plant environment from the 10.5 year krypton-85 component of the feedgas is less than 5.10^{-4} mrem/year. Because of the large mass of charcoal required, it is uneconomic to delay Kr-85 in a dynamic continuous flow-through system. For those utilities that desire Kr-85 removal for political or other reasons, the General Electric Company offers a cryogenic tail system downstream of the charcoal adsorption system. This system removes at least 95 percent of the residual krypton and xenon from the tail gas for bottling and disposal. The relative immobilization of the bulk of the radioactive constituents in the upstream charcoal beds enhances the overall safety of the cryogenic separation process.

C. Relative System Performance

A comparison of the performance of the offgas systems, based on a continuous design source of 100,000 $\mu\text{Ci/sec}$ of a 30 minute old modified gas mixture is given in Table IV. The larger reduction factors for dose relative to activity result from the less energetic decay characteristics of the residual longer lived isotopes.

TABLE IV

Relative Design Performance Of Offgas Systems^(a)

System	Reduction Factors		Offsite Dose ^(b) mrem/year
	Curie	Gamma Dose	
30 Minute Holdup Pipe & Filter	1	1	-----
Recombiner Plus Ambient Charcoal	16-250	22-1140	35-0.7
Recombiner Plus Low Temp Charcoal	8000	>10,000	<0.05

(a) Above values based on Air inleakage of 18.5 SCFM

(b) Estimated fence past dose - Roof vent discharge with Monticello-type meteorology, 300 meters from release point.

III. Relationships Governing Charcoal Performance

A. General

The fundamental relationships which govern the performance of dynamic charcoal adsorbers are given by Browning.^{2,3} Briefly, when the number of theoretical stages is large, the following equation defines adsorber operation:

$$T_m = \frac{KM}{F} \quad (1)$$

where:

T_m = Mean holdup time

F = Gas flow rate

M = Mass adsorbent, and

K = Dynamic adsorption coefficient (commonly referred to as K_d)

The value of K depends on 1) type of gases involved, 2) temperature, 3) type of charcoal, 4) partial pressure of the rare gases, and 5) charcoal moisture as a function of gas relative humidity. Of these, temperature, gas flow, and moisture content are perhaps the most important variables.

B. Air Inleakage

Design standards for inleakage into the main condenser system are given by the Heat Exchanger Institute.⁴ These state that "for venting equipment with design capacity exceeding 40 CFM, the non-condensables should not exceed:

- a) 20 CFM for 42 ppb
- b) 10 CFM for 14 ppb
- c) 6 CFM for 7 ppb"

with ppb referring to oxygen in the condensate.

Our survey of condenser air inleakage indicates that with good to average "housekeeping," inleakage within the utility industry varies from about 3 to 5 SCFM per condenser shell and remains at that level during extended plant operation.

Air inleakage for BWR plants with augmented offgas systems, featuring catalytic recombiners for gas volume reduction, is shown in Table V.

TABLE V

Condenser Air Inleakage for BWR Plants With Augmented Offgas Systems

<u>Plant</u>	<u>MWe</u>	<u>Main Condenser Shells</u>	<u>Type System</u>	<u>Total Air Inleakage SCFM</u>
KRB	250	1	Recombiner-Charcoal	4.1
Tsuruga	342	1	Recombiner-Compressed Gas	4.7
Fukushima 1	440	2	Recombiner-Compressed Gas	7

The standard 30-minute holdup pipe for early BWR's handles radiolytic hydrogen and oxygen plus condenser air inleakage. Air inleakage is usually a small fraction of total flow and exerts only a minor effect on gas residence time, such that there is only a minor incentive for low air inleakage for these systems.

C. Dynamic Adsorption Coefficients (K-Values)

K-values for various charcoals have been provided by Browning,² Förster⁵ and Underhill⁶. Figure IV shows the krypton K-values at 25°C for dry charcoal and charcoal with up to six weight percent moisture. The curves show a marked reduction in adsorption coefficient with increasing moisture.

Published xenon K-values for dry charcoal at 25°C are as follows:

<u>Investigator</u>	<u>Type Charcoal</u>	<u>Xenon K-Value cc/gm</u>
Browning	Columbia-G	1,000
Förster	Coal & Wood	500-1,000
Underhill	PCB-(Argon Carrier)	750

Published data are unavailable on the effect of moisture on the xenon K-value.

K-values for krypton and xenon for dry charcoal as a function of temperature are shown in Figure V. The marked advantage of low temperature in increasing K-values (and in reducing charcoal requirements) is apparent.

D. Charcoal Moisture as a Function of Air Relative Humidity

Since K-values are reduced with increasing charcoal moisture, it is necessary to predict the range of charcoal moisture during operation. Charcoal moisture is in turn a function of gas relative humidity and type of charcoal. Figure VI shows an equilibrium water adsorption-desorption isotherm for North American Carbon NACAR-G210 after repeated adsorption and desorption.

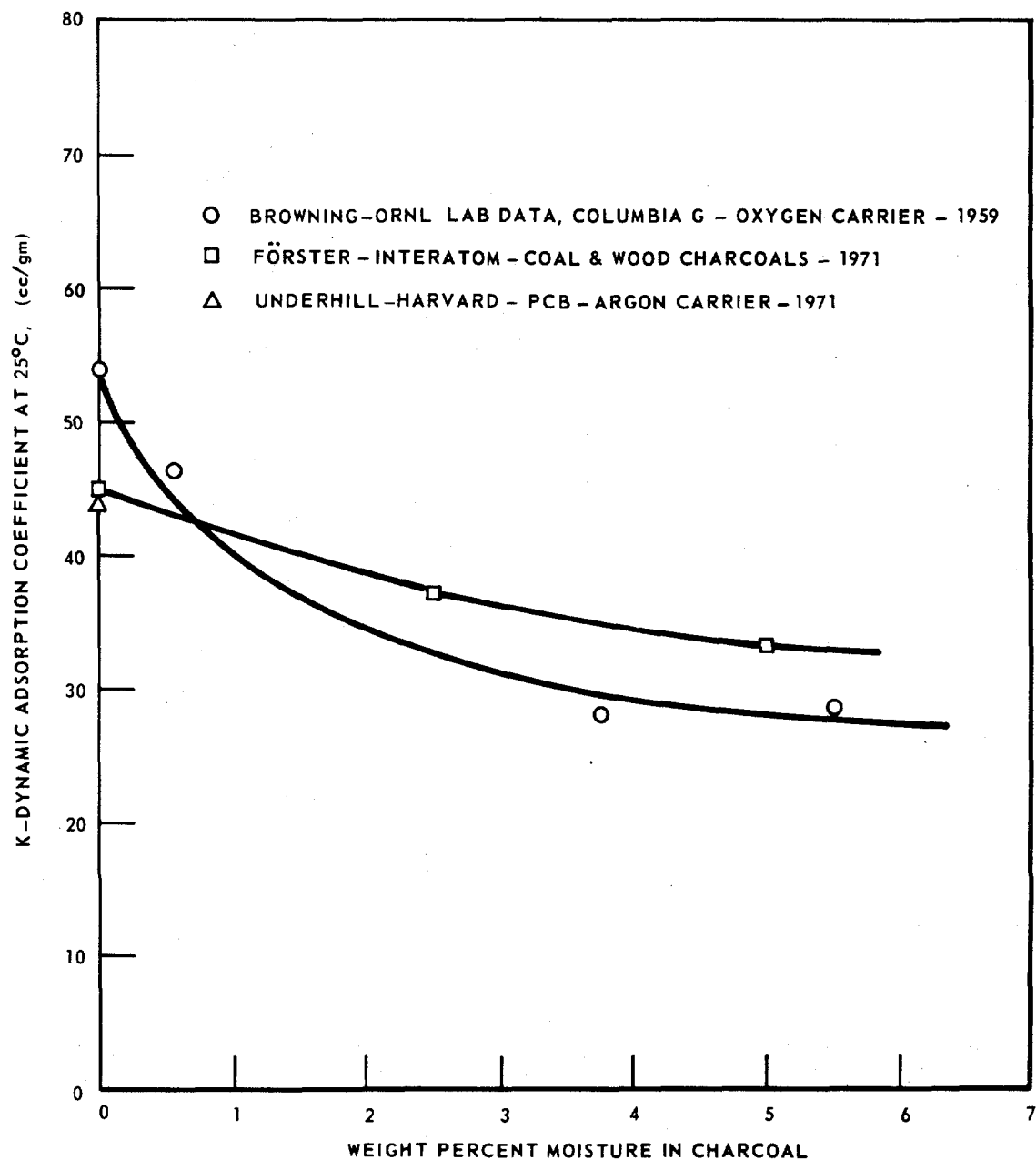


FIGURE IV
KRYPTON DYNAMIC ADSORPTION COEFFICIENTS AT 25°C
AS A FUNCTION OF CHARCOAL MOISTURE

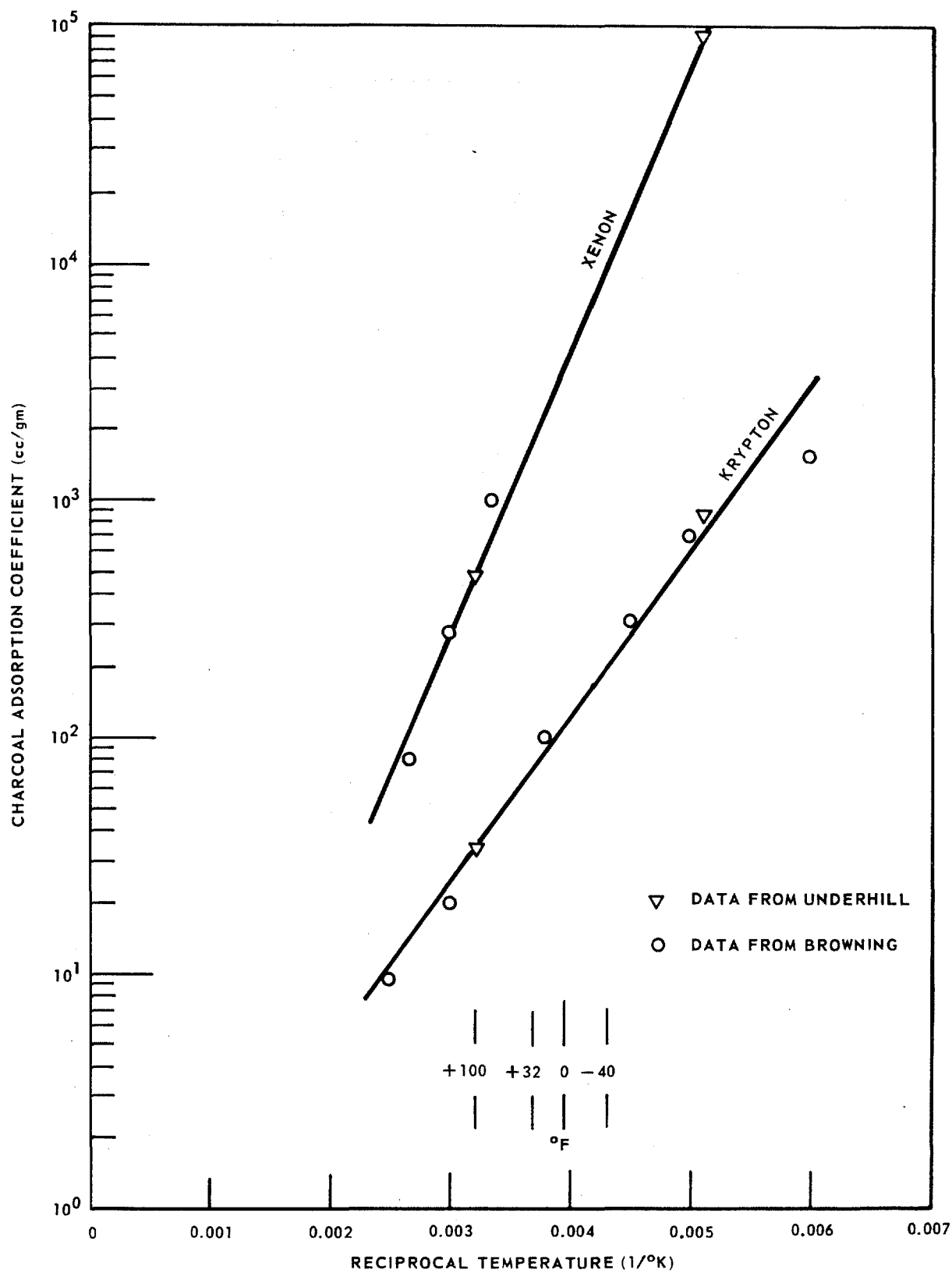


FIGURE V
KRYPTON AND XENON K-VALUES AS A FUNCTION OF TEMPERATURE

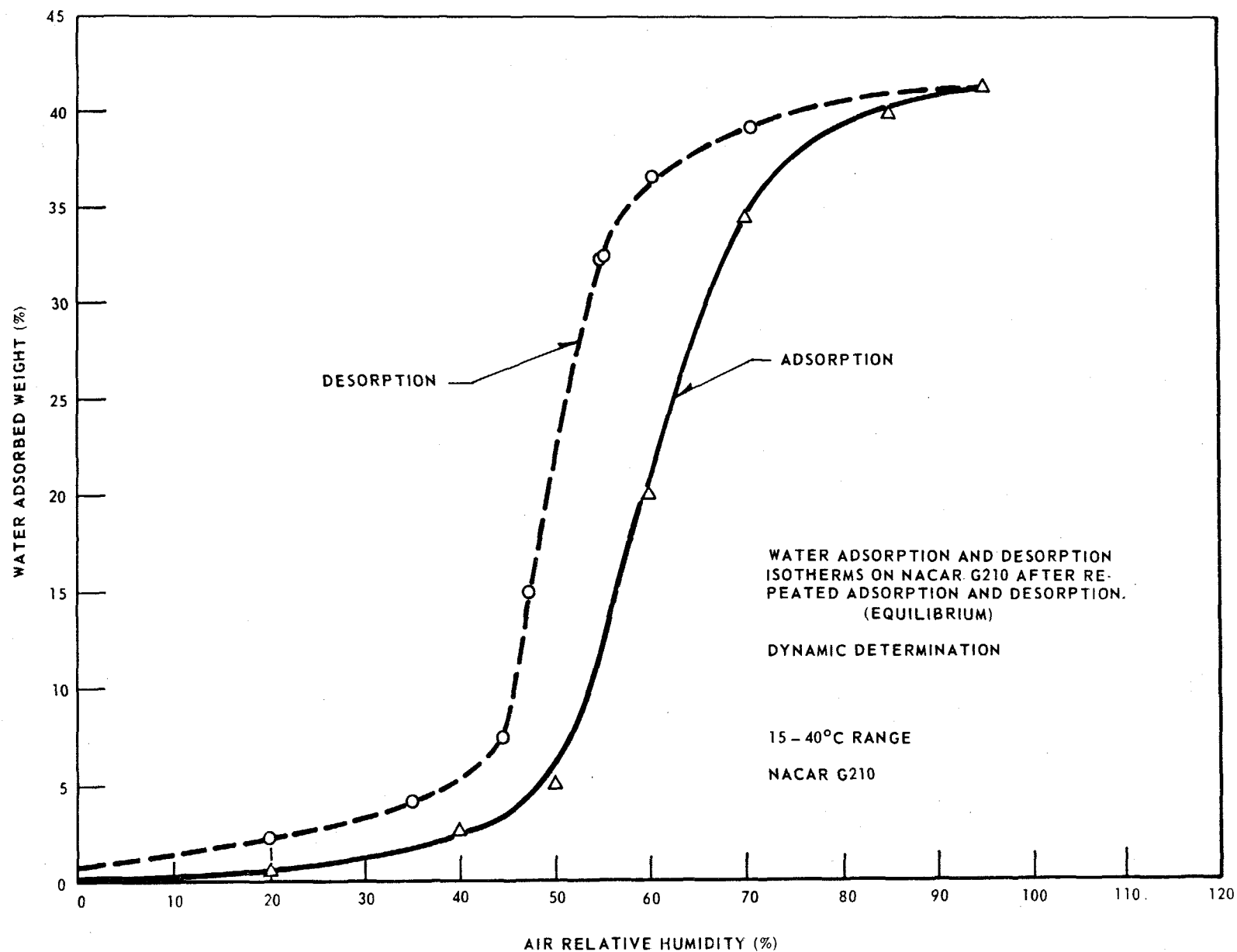


FIGURE VI
CHARCOAL MOISTURE AS A FUNCTION OF AIR RELATIVE HUMIDITY

IV. Curie and Gamma Dose Calculational Methods

As noted in Section III, the noble gas activity leaving the offgas system, and hence the subsequent radiological effects, are a function of the charcoal mass, flow rate, and dynamic adsorption coefficient. The activity of any isotope leaving the system is defined as follows:

$$N_L = N_0 e^{-\lambda T} \quad (2)$$

where: or $N_L = N_0 e^{-\left[\frac{\lambda KM}{F}\right]} \quad (3)$

N_L = Activity leaving the charcoal bed

N_0 = Activity entering the charcoal bed, and

λ = Decay constant

Other parameters are previously defined.

The overall activity (or curie) reduction factor is therefore defined as:

$$DF_{ci} = \frac{\sum N_{0-i}}{\sum_i N_{L-i}} \quad (4)$$

where the subscript i denotes summing over all isotopes.

The average annual gamma dose to any neighbor is a function of not only the isotopic release rate but also the isotopic gamma energy spectrum, the effective release height, the average annual meteorology, the distance to the dose receptor, and the appropriate occupancy and shielding factors.

V. Charcoal Curie and Gamma Dose Reduction Factors vs System Parameters

Typical curie and gamma dose reduction factors as a function of charcoal mass and for a system flow rate of 18.5 scfm and temperature of 25°C are presented in Figure VII. Figure VIII shows the effects of condenser leakage for a 24.6 ton charcoal system at 25°C.

Curie and dose reduction factors as a function of condenser leakage for a low temperature (-18°C) 24.6 ton charcoal system are presented in Figure IX.

VI. Accident Considerations

The ambient and low temperature charcoal systems have been evaluated with respect to hypothetical radiological exposures which may be received as a consequence of a system failure. The results of these analyses indicate that the whole body and thyroid exposures will be less than the permissible exposures set forth in 10CFR20. The actual values of these exposures are dependent upon the distance to the site boundary.

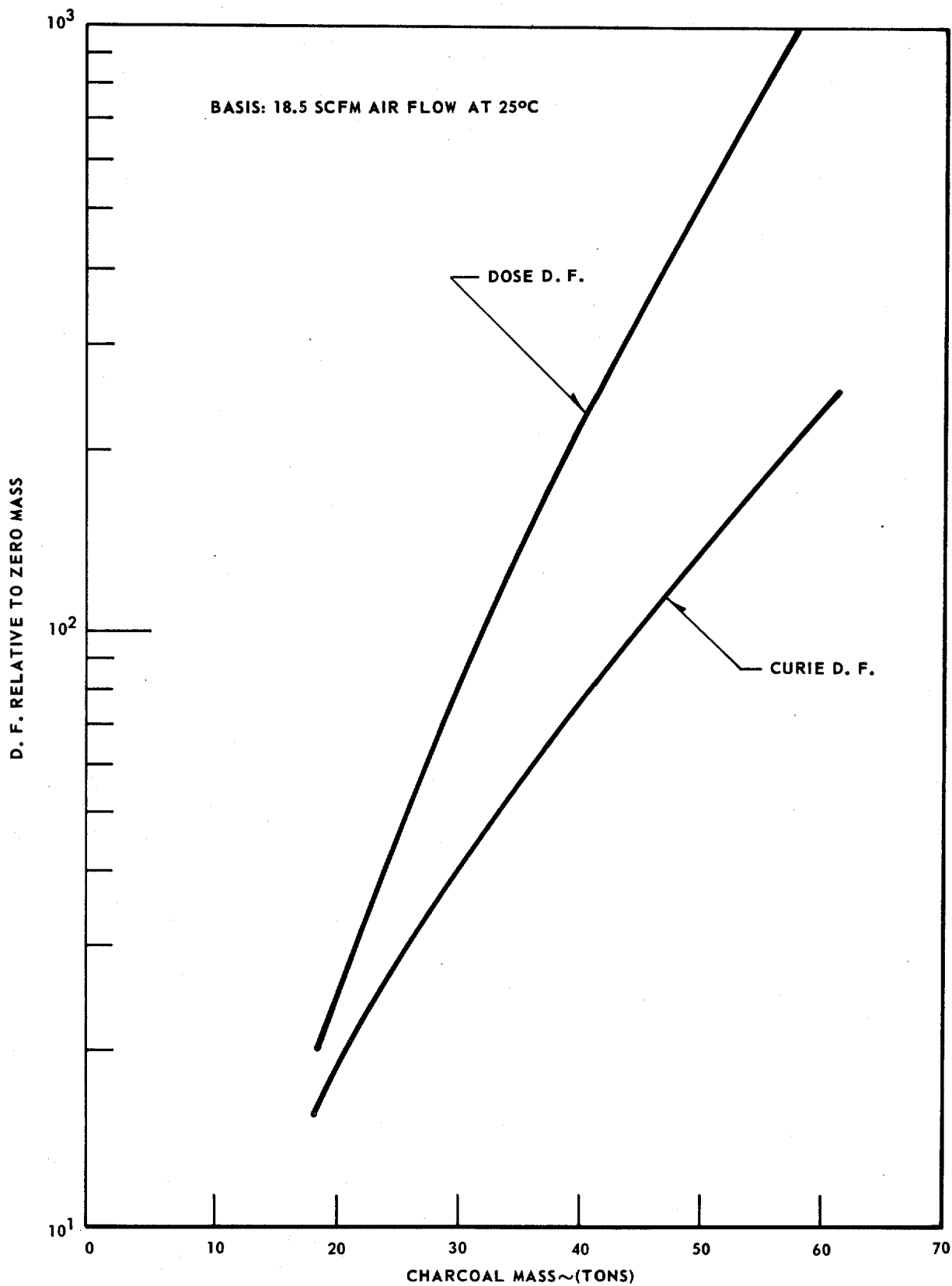


FIGURE VII
CURIE AND GAMMA DOSE REDUCTION AS A FUNCTION OF CHARCOAL MASS

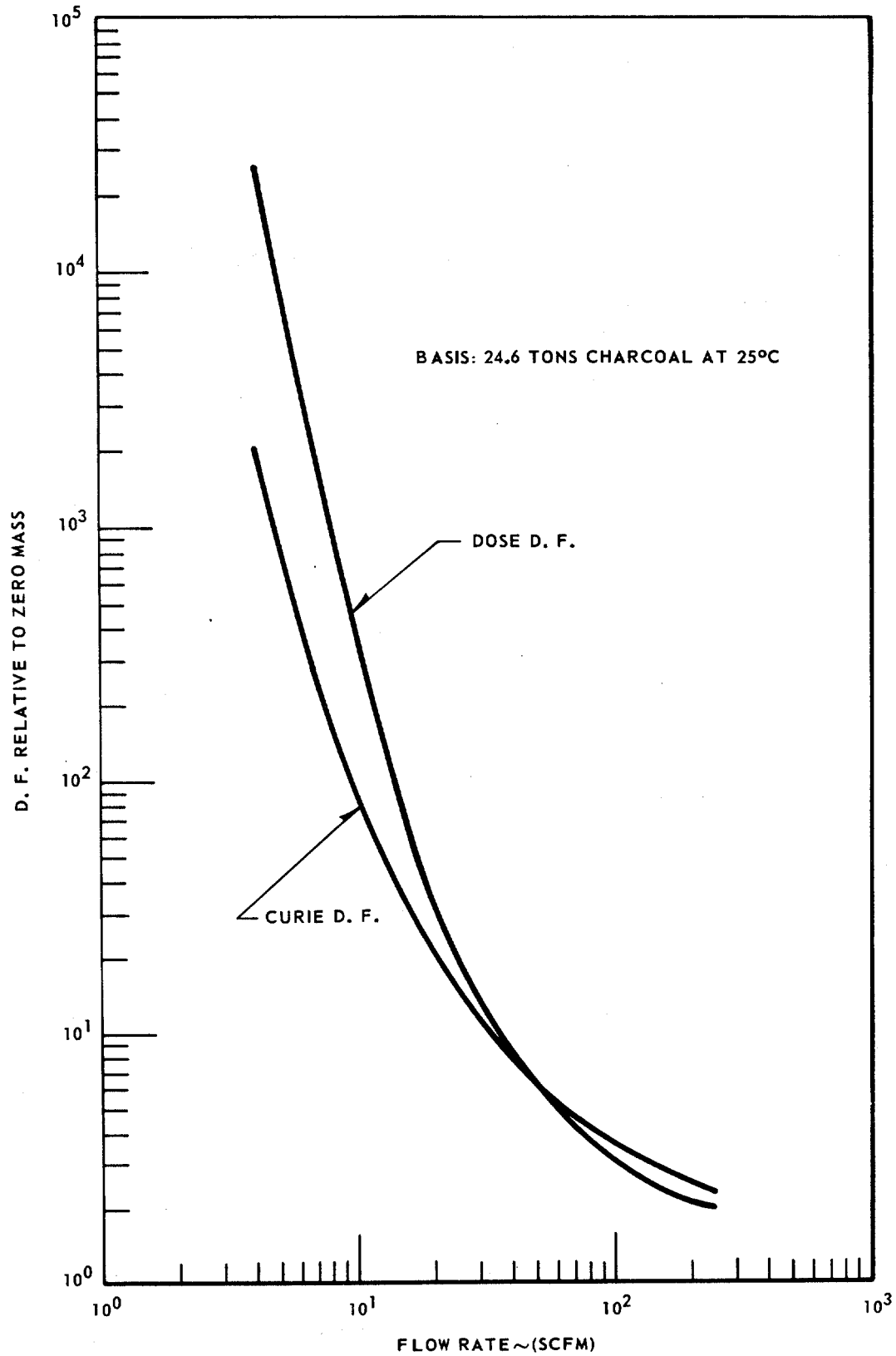


FIGURE VIII
CURIE AND GAMMA DOSE REDUCTION AS A FUNCTION OF AIR FLOW – AMBIENT TEMPERATURE

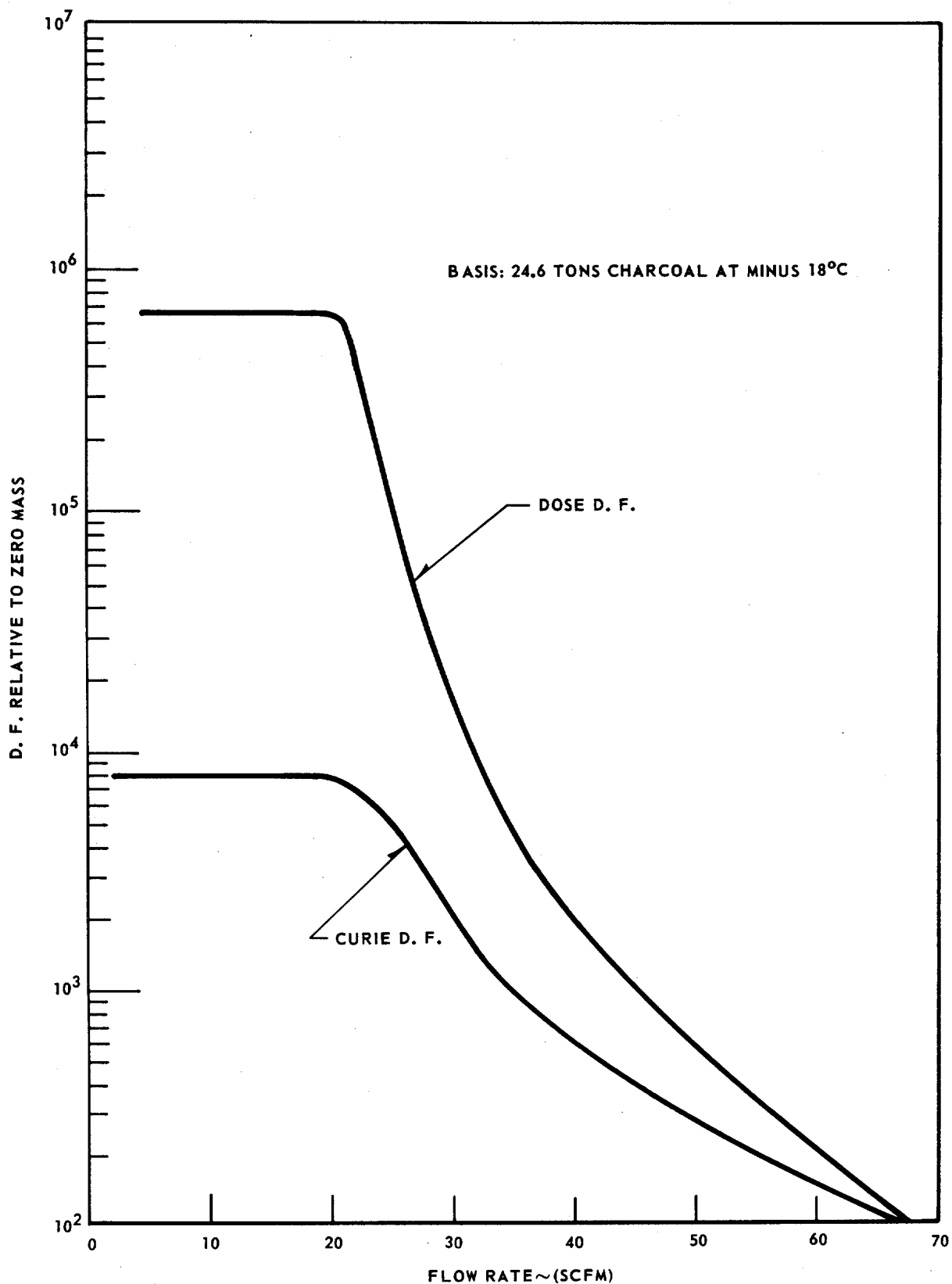


FIGURE IX
CURIE AND GAMMA DOSE REDUCTION AS A FUNCTION OF AIR FLOW—LOW TEMPERATURE

VII. Summary

Boiling water reactors now in service which were designed to pre-1970 emission control criteria perform well with respect to current release objectives.

Catalytic recombiner-charcoal adsorption systems provide emission control capability for BWR's beyond that required to meet the dose design objectives of the proposed Appendix I of 10CFR50. These systems which are mechanically simple and reliable utilize passive equipment components. The collected radioactive noble gases and their decay daughters are maintained in a relatively fixed, non-mobile form in the event of an accident. However, even in the event of an accident the hypothetical dose effects are below the guidelines set forth in 10CFR20. The new low temperature charcoal system provides a very high degree of flexibility for extended radiogas holdup under a wide range of operating conditions.

VII. Acknowledgement

The authors wish to thank C. F. Falk for his assistance in design of the offgas systems.

IX. References

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5. Förster, K., "Delaying Radioactive Fission Product Inert Gases in Cover Gas and Offgas Streams of Reactors by Means of Activated Charcoal Delay Lines," Kerntechnik 13. Jahrgang (1971) No. 5, p. 214.
6. Underhill, D. W., Harvard School of Public Health, Private Correspondence, May 21, 1971.

DISCUSSION

SCHUERMAN: What was the data source or the basis for the activation gases and the fission gases in terms of concentration, both in the paper and on the slides?

MICHELS: These are direct, General Electric Company, measurements at operating reactors.

FRANZEN: I would like to ask you two questions. On one of your first slides you showed a value for iodine exposure in the environment of boiling water reactor plants. The value was, as I recollect, 1 to 3 mRems per year?

MICHELS: Right.

FRANZEN: This value seems to be rather low, at least in my judgment, because our licensing authorities always are in doubt whether this will be possible. So my question is, is this a measured value, or is this an assumed value?

MICHELS: These are measured values from our operating plants in the United States.

FRANZEN: My second question is whether the iodine dose in the environment is mainly determined by activity coming from the ventilation system rather than from off-gas activity, i.e., leakage of activity-containing systems and components? If so, it will be mandatory to cut down on leakage rates. How do you judge prospects in cutting down leakage rates for activity-containing systems and components, including leakages into the turbine buildings?

MICHEL: Good housekeeping is required to tighten up steam leaks. I might mention that in both the ambient and low-temperature charcoal systems, essentially zero iodine will be released through a steam jet air ejector system. Such a system should be essentially quantitative for iodine removal. We feel that the numbers that we showed; roughly, 1 to 3 mRem per year, would be reasonable numbers for building ventilation. Ned Horton, would you want to comment on that?

HORTON: The ventilation systems are now one of the potential sources of concern, especially when we're talking about "as low as practical" limits (whatever these might turn out to be). Presently, G.E. is in the process of evaluating a number of boiling-water reactors; in particular, the ventilation systems of the turbine building and the reactor building, to see, from a practical standpoint, what are the absolute values of iodine and noble gas release numbers. To date, I believe they have evaluated Nine-Mile Point and Oyster Creek. Although the numbers have not been released officially, iodine emissions from the Oyster Creek plant indicate that

there should not be a great deal of concern about the ventilation systems considering reasonable site boundary distances of 500-800 meters and the cow as the primary exposure pathway. As Lloyd Michels has mentioned, it's really dependent upon the degree of system tightness. If a utility employs good housekeeping and maintains their systems relatively free of leaks, this would not be a potential source of concern.

KOVACH: Lloyd Michels, I have three questions for you. One, concerns your prefilter location. It's after the glycol refrigeration system. I was wondering why you don't want to take the particulate daughter products out of the system before the heat exchanger? Second, do you mean that your lines are designed to withstand a hydrogen-oxygen explosion or only pressure from the component vessels? Third, are your dose reduction factors based on a G.E. design, or are they on a DRL credit basis? There seems to be a discrepancy between those two values.

MICHEL: Let's take the second one first; are the lines designed for full detonation? Yes, they are. Piping runs are designed for equivalent static pressures of about 400 psig and pipe ends for about 1000 psig. With regard to the first question concerning location of the filter. In the ambient system, we show it downstream of the reheater. In the new, low-temperature system we show it downstream of the cooler condenser. Particulate material wash-out will occur with condensation on the cooler-condenser surfaces. We are not particularly concerned about filter location in the low temperature system since some reheat will occur. As a matter of fact, we run the current 30-minute holdup pipe system, i.e., the holdup pipe and filter, under saturated conditions all the time and we have not had any problem with it. In answer to the third question, (Are our dose reduction factors based on design values or on what we can get credit for?) the dose reduction factors are based on theoretical values; on the radiation characteristics of the gas.

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EFFECTIVENESS OF FISSION PRODUCT REMOVAL SYSTEMS IN PWR CONTAINMENTS

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Abstract

In order to apply the body of information concerning individual fission product removal processes to the design of engineered safety systems for a full-sized reactor application it is necessary to evaluate the simultaneous performance of these systems in the loss-of-coolant accident environment. A time-dependent, multi-volume model of the containment, which incorporates mathematical models of all significant transport and removal processes, is used for this analysis. The off-site iodine inhalation doses obtained from this model are used as a criterion for comparison of the iodine removal effectiveness of the various systems. A comparison of the results obtained from this analysis with the results of the traditional dose reduction factor concept show that the integrated approach of this analysis is a more conservative method of the evaluation of safeguards systems.

I. Introduction

An extensive body of information, both experimental and analytical, has been accumulated in the past several years to demonstrate the effectiveness of various fission product removal systems. In order to apply this knowledge to the selection and design of the engineered safety systems for a full-sized reactor containment system, it is necessary to analyze the performance of these safety systems during a postulated design basis accident.

The criterion for evaluation of the performance of any fission product hold-up or removal system is the degree of mitigation of the radiological consequences of the postulated accident. For this reason the dose reduction factor concept has come into general use for the evaluation and comparison of the effectiveness of fission product removal systems. The dose reduction factor (DRF) is defined as:

$$\text{DRF} = \frac{\int_0^t A(t) dt}{\int_0^t A'(t) dt} \quad (1)$$

where $A(t)$ and $A'(t)$ are the fission product activities, as functions of time, without and with the engineered safety feature in operation, respectively.

This definition implies a single node model of the attenuation of the fission product activity. This activity is assumed to be available for leakage to the environment immediately (i.e., at $t = 0$). The off-site doses resulting from this source, therefore, are directly proportional to the activity integral.

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If the removal process is assumed to be exponential, with a rate constant of λ_1 , and $A(t)$ is constant, the dose reduction factor is a function of the removal constant of the process, λ_1 , only:

$$DRF = \frac{\lambda_1 t}{1 - \exp(-\lambda_1 t)} \quad (2)$$

This concept allows a quick evaluation of the effectiveness of a removal process, and has been used frequently to estimate the benefit of engineered safety systems, such as containment spray^(1,2) and internal filtration systems³. For such purposes this concept is a useful one. It must be qualified, however, by the assumptions stated above. For situations deviating significantly from these assumptions, as is the case for many current generation reactor containment systems a more detailed analysis is required.

Several multi-node models of fission product transport have been developed, particularly for the analysis of multiple-barrier containments (e.g. the MUNDO code,⁽⁴⁾ developed in 1967).

A major shortcoming of these models is the need to supply the removal coefficients for each node as input. These coefficients, however, may be strong functions of the fission product concentrations which are to be determined.

The analytical model used for the results reported herein combines the multi-node approach with mathematical models for all significant fission product hold-up and removal processes.

This model has been programmed for a digital computer as the TITAN code. A description of the mathematical models incorporated in this code, as well as a comparison of the predicted and observed iodine concentrations of the Containment System Experiment (CSE) have been reported previously.⁽⁵⁾

II. FISSION PRODUCT TRANSPORT AND REMOVAL MODEL

A five node representation of the containment forms the basis for the calculation of the transport of fission products to the environment. Each node corresponds to a structurally defined region of the containment. Homogeneity is assumed within each of these volumes, with the exception of the node representing the secondary containment (annulus). (The modelling of the double containment system is discussed separately below).

A separate volume has been included for an ice condenser system, in order to represent the most general case. (For conventional "dry" containments this volume could be deleted as a separate node). The fission products are assumed to be released into volume one, while the source term for the calculation of the off-site doses consist of the releases from volumes 2 and 5 for the most general case of a partial secondary containment.

If it is assumed that there are no sources after the initial release of fission products, the remaining processes are removal and transfer, so that the multi-volume containment is described by a system of first order differential equations of the form

$$\frac{da_i}{dt} = - \sum_{k=1}^m \lambda_{ki} a_i - \sum_{j=1}^{n-1} \frac{Q_{ji}}{V_i} a_i + \sum_{j=1}^{n-1} \frac{Q_{ij}}{V_i} a_j \quad (3)$$

where a_i = fission product activity in volume i
 n = number of volumes (nodes) considered in the model
 Q_{ij} = transfer rate to volume i from volume j
 V_i = volume of i^{th} compartment
 λ_{ki} = removal coefficient of the k^{th} removal process in volume i

This system of equations is solved readily if the coefficients are known. It is apparent that the major task in the analysis of the post-accident fission product transport lies in the calculation of the removal coefficients, λ_{ki} , of equations (3). The major portion of the TITAN code, therefore, is devoted to a detailed description of all major removal processes.

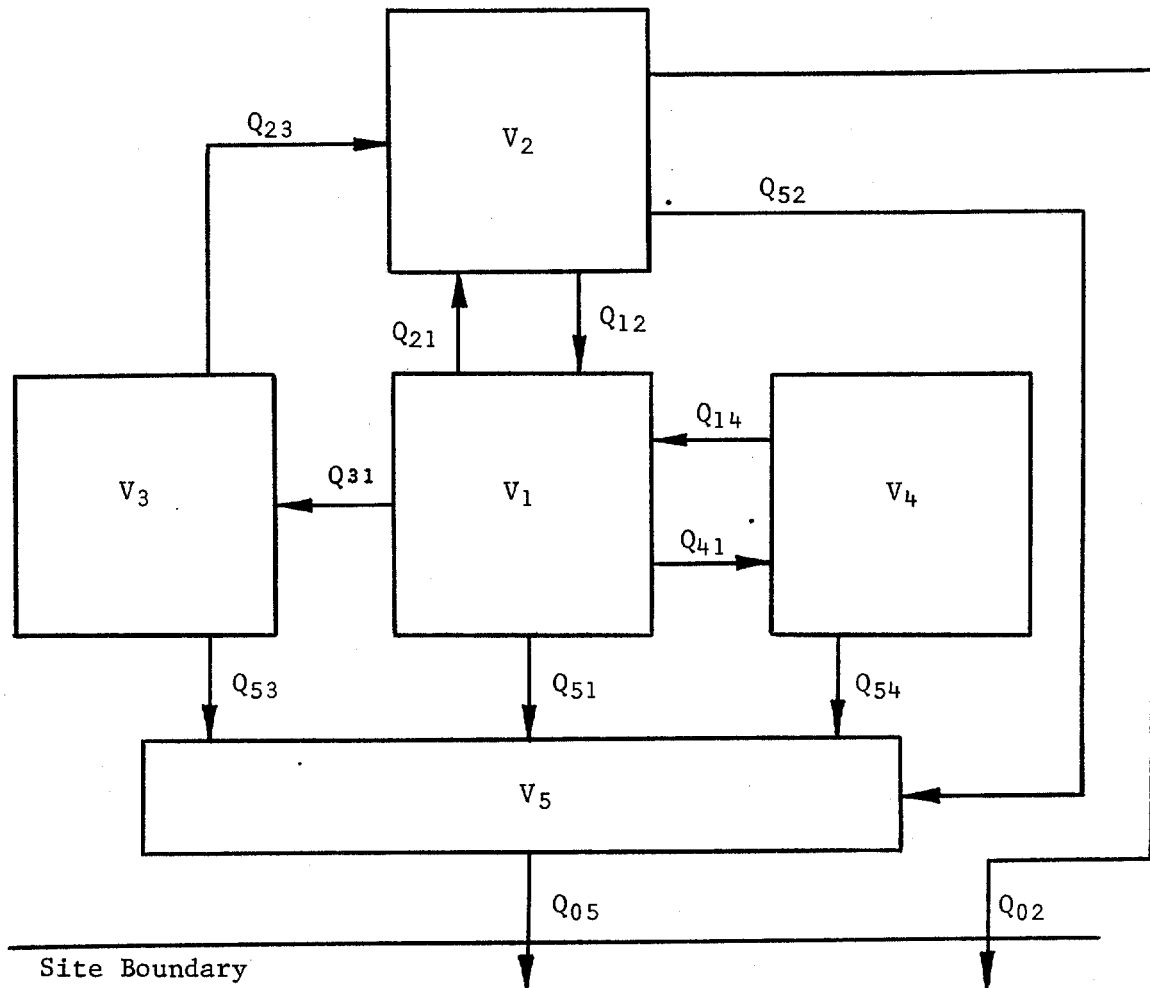
Particular emphasis is placed on the accurate modelling of the rapid iodine removal processes, i.e. the ice condenser and containment spray systems, since radioiodine most frequently is the fission product of primary concern in a DBA dose analysis. The calculation of the removal coefficients for these systems are based on models described elsewhere,^(6,7) and are verified by the extensive experimental work performed at the Nuclear Safety Pilot Plant⁽⁸⁾ and Containment Systems Experiment⁽⁹⁾ for the case of containment spray, and by Westinghouse⁽¹⁰⁾ for the ice condenser system.

For the noble gases no removal process other than decay is considered. Maximum benefit is obtained from the radioactive decay of the noble gas isotopes, however, by controlled purge and recirculation systems employed with secondary containment applications.

III. ENGINEERED SAFETY SYSTEM EFFECTIVENESS

For a typical application of the fission product transport and removal analysis summarized above, consider a PWR plant with a maximum power rating of 3600 MWt. The modelling of the containment follows the schematic representation shown in Figure 1, except that, for the purpose of this calculation, the secondary containment (i.e. Volume 5) will be considered separately as one of the engineered safety systems discussed below.

FIGURE 1
SCHEMATIC OF FIVE-NODE CONTAINMENT MODEL



Legend:

- V_1 = Lower Containment Volume (Reactor Compartment)
- V_2 = Upper Containment Volume
- V_3 = Ice Condenser compartment (where applicable)
- V_4 = Dead-Ended Compartments
- V_5 = Secondary Containment (where applicable)
- Q_{ij} = Transfer Rate to node i from node j
- Q_{0j} = Release Rate from volume j to environment

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1. Iodine Removal Systems

The effectiveness of iodine removal systems is evaluated on the basis of the calculated thyroid doses resulting from a DBA for the hypothetical plant described above. Although typical parameters are used for each engineered safety system analyzed, it should be noted that the calculated values are intended for the purpose of comparison of the methods used in their evaluation only. An "unreduced" dose is calculated without any safety systems in operation, (and without a secondary containment) to serve as a base-line for the comparison. The thyroid doses calculated for the independent operation of the ice condenser, containment spray and internal charcoal and high efficiency particulate filtration systems are shown in Table I.

Ice Condenser

The ice condenser iodine removal effectiveness is calculated on the basis of minimum performance of the ECCS. A flow rate of 40,000 cfm, which corresponds to one out of two air return fans operating, is assumed to pass through the ice condenser compartment (i.e. volume 3). The ice beds contain sodium tetraborate ice, with a melt solution pH of 10. The iodine removal effectiveness of the ice condenser is assumed to terminate 42 minutes after initiation of the loss-of-coolant accident, in order to reflect the earliest possible melt-out of the ice beds.

A two-hour thyroid dose of 280 rem is calculated for this case, compared to 693 rem without any credit for iodine removal by the ice condenser.

Containment Spray

For the analysis of the effectiveness of the containment spray system volumes one and two represent the unsprayed and sprayed regions of the containment, respectively. The spray system is assumed to deliver 3400 GPM of a spray solution containing sodium hydroxide, with a pH of 10.

For this, as well as all other iodine removal analyses, the radioiodine is assumed to exist in three forms, elemental (85%), organic compounds, mainly consisting of methyl iodide (10%), and absorbed on airborne particulate matter (5%). The organic and particulate forms of iodine are assumed to be unremovable by the containment spray. In addition, the elemental iodine removal capacity of the spray is conservatively limited to a decontamination factor (DF) of 100 in the containment atmosphere.

The two-hour thyroid dose with the containment spray system in operation is calculated as 179 rem.

Internal Filtration

To determine the effect of iodine filters in the containment, a filtration system consisting of high efficiency particulate air and impregnated charcoal filters was assumed to operate in volume two of the containment. A flow rate

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of 50,000 CFM, and filtration efficiencies of 0.9, 0.7 and 0.9 for elemental, organic, and particulate iodine, respectively, were assumed. A two-hour thyroid dose of 233 rem is calculated for this case.

2. Double Containment System

The double containment system, as used in this context consists of a secondary enclosure of the primary containment, and the air handling systems required to maintain the secondary containment at a pressure slightly below atmospheric.

It is generally recognized that the double containment system has the greatest potential for minimizing post-accident fission product releases to the environment. This potential is readily demonstrated by the results of a fission product transport analysis in which the secondary containment is modelled as an additional node (i.e. Volume 5 in Figure 1) in the fission product transport chain from the point of release in volume one to the environs.

Complete Mixing Model

The modelling of the secondary containment as an additional volume of the containment includes the assumption of homogeneity of concentration of the fission product inventory within the secondary containment volume. In order to maintain a slight negative pressure in the secondary containment volume, a continuous purge is necessary. If this exhaust flow is set at 30 cfm, a two-hour thyroid dose of 3.1 rem is calculated with this "complete mixing" model. A further reduction of this dose to less than 0.2 rem is achieved by passing the exhaust through HEPA and charcoal filters with filtration efficiencies of 95-90-95 percent for elemental-organic-particulate iodines.

A significant reduction, due to decay and dilution in the secondary containment, also is achieved in the two-hour release of noble gases. The total whole-body dose at the exclusion radius is reduced from a value of 3.8 rem calculated without the secondary containment, to less than 15 millirem calculated with the complete mixing model.

No Mixing Model

The calculation described above demonstrates the potential benefit of the double containment system. The assumptions made, however, do not reflect the degree of conservatism desired for calculation of the consequences of the DBA. In order to arrive at a more conservative model, it has been postulated that the leakage path from primary to secondary containment is such that only a minimal degree of mixing and dilution occurs within the secondary containment. The fission products leaking from the primary containment, therefore, would be drawn into the

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TABLE I

EFFECTIVENESS OF IODINE REMOVAL SYSTEMS IN SINGLE BARRIER CONTAINMENTS

CASE	SYSTEM	2 HR THYROID DOSE	TOTAL DOSE REDUCTION FACTOR
1	None	693	1.0
2	Ice Condenser	280	2.5
3	Containment Spray	179	3.9
4	Internal Filters	233	3.0
5	Ice Condenser and Spray	174	4.0
6	Ice Condenser, Spray and Filters	126	5.5

TABLE II

EFFECT OF MODEL ON DOUBLE CONTAINMENT EVALUATION

CASE	CONTAINMENT MODEL	2 HR DOSES AT SITE BOUNDARY	
		THYROID	WHOLE BODY
a	Single Barrier Cont.	693	3.8
b	Complete Mixing	3.1	.015
c	Complete Mixing with Purge Filters	0.2	.015
d	No Mixing, 5 min. transient	6.8	3.8
e	Recirculation, 5 min. transient	30.	0.5

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secondary containment air handling (purge) system essentially at the primary containment concentration, and with negligible transport (hold-up) time. The only benefit of the secondary containment system, under these assumptions, is due to the filtration of iodines prior to their discharge to the environment.

An additional factor of conservatism may be introduced by considering the effects of possible direct (unfiltered) leakage from the secondary containment during the initial positive pressure transient expected for most secondary containment designs. This positive pressure transient results from the heat input to the secondary containment atmosphere, and is usually terminated (i.e. the pressure becomes sub-atmospheric) within two to five minutes by exhausting an equivalent mass of air via the air handling system. If a "worst case" calculation of the leakage during a 5 minute positive pressure transient is postulated, a maximum of approximately 29 rem could be added to the two-hour thyroid dose at the exclusion radius of the hypothetical plant analysed.

Recirculation Model

It is apparent that the complete mixing and no mixing models represent two extremes of the possible modelling of the secondary containment system. An alternate model, which is based on a recirculation air handling system, is suggested as a suitably conservative model. With a recirculation air handling system a larger quantity of air is drawn from the secondary containment and passed through charcoal and HEPA filters. Downstream of the filters the flow is split such that only a small fraction of the total flow is exhausted to the environs, to maintain the sub-atmospheric pressure, while the remainder is returned to the secondary containment volume.

Since it is prudent to consider the "worst possible" case in a DBA analysis, the conservative assumption that the primary containment leakage enters the suction of the air handling system undiluted is maintained in the recirculation model. With the flow rates considered in this application (i.e. 4000 cfm recirculation flow, 30 cfm exhaust) less than one percent of the fission products entering the air handling system is exhausted, while better than 99% of these fission products are returned to the secondary containment, where they are assumed to be uniformly distributed. (The latter assumption can be justified by a proper design of the air return system).

If the worst-case modelling of the initial five-minute positive pressure period is retained, the two hour thyroid and whole-body doses calculated with this model are 58 rem and 0.5 rem, respectively.

3. Combined Safety Systems Effectiveness

The doses calculated for the hypothetical 3600 MWt PWR with each of the above mentioned safety systems are listed in Table I, cases 1 through 4. The effect of the modelling of the secondary containment on the calculated doses is summarized in Table II. Dose reduction factors, which are simply the ratio of the actual dose calculated for each case to the base value (case 1), are also shown in the Table.

One of the significant advantages of the TITAN analysis used for these calculations is the possibility to analyze the simultaneously operation of any of these safety systems. The doses resulting from the simultaneously operation of the ice condenser, containment spray, and internal filtration systems are also shown in Table I (Cases 5 and 6).

All values shown in Table I are based on a single barrier containment. The results of operation of the same iodine removal systems in a double containment are shown in Table III for several combinations of containment model and iodine removal systems. The dose reduction factors shown in this table apply to the iodine removal systems only, and, therefore, are normalized for each containment model.

IV. DISCUSSION OF RESULTS

From a comparison of the results presented in Tables I through III several observations may be made.

First, consider the relative effectiveness of the several engineered safety features analysed. Although the parameters used for the evaluation of each engineered safety system are typical for the systems analysed, they would not represent the optimum values for all applications. An optimization of the system parameters for a specific plant and site may result in an improved performance of the system. However, a comparison of the order of magnitude of the doses shown in Tables I and II clearly support the supposition of the superiority of the dose reduction effectiveness of the double containment system over any other engineered safety feature considered. This conclusion holds even for a very conservative modelling of the double containment system.

All iodine removal systems considered in this evaluation result in significant reductions of the thyroid doses. Diminishing returns, however, are apparent for the simultaneous operation of any of these systems. The result is expected if one considers the fact that the various systems are competing for the iodine within the primary containment.

The trend of diminishing dose reduction effectiveness of the iodine removal systems with increasing secondary containment effectiveness is shown in Table III. Although this trend is not quite as obvious as that of competing systems within the primary containment, it is readily explained by an examination of Figure 1. Since the source for the off-site doses, in absence of any direct leakage from the containment to the environment is the discharge from Volume 5, it is apparent that any changes in the concentrations of Volumes 1 or 2 are less significant in the presence of a secondary containment.

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TABLE III

EFFECTIVENESS OF IODINE REMOVAL SYSTEMS IN DOUBLE BARRIER CONTAINMENTS

CASE	IODINE REMOVAL SYSTEMS, CONTAINMENT MODEL	2 HR THYROID DOSE	IODINE REM. SYSTEM DOSE REDUCTION FACTOR
1d	No Iodine Rem. Systems No Mixing Model (case d)	68	1.0
2d	Ice Condenser No Mixing Model	44	1.5
5d	Ice Condenser, Spray No Mixing Model	38	1.8
1e	No Iodine Rem. Systems Recirculation Model	30	1.0
2e	Ice Condenser Recirculation Model	27	1.1
5e	Ice Condenser, Spray Recirculation Model	26	1.15

TABLE IV

VARIATION OF DOSE REDUCTION FACTORS

MODEL	DRF OF CONTAINMENT SPRAY SYSTEM
From equation(2)	6.2
From TITAN code, single containment	3.9
Single containment, with ice condenser	1.6
Double containment, no mixing model, with ice condenser	1.2
Double containment, recirculation model, with ice condenser	1.04

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A third observation is the strong dependence of the dose reduction factor for any given engineered safety feature on the assumptions concerning both the operation of other systems and the modelling of the containment. The effect of the assumptions made in the analysis is particularly strong for the double containment system, as demonstrated by the results shown in Table II. The effectiveness of the iodine removal systems similarly is a strong function of the assumptions made in the analysis of the system. This fact may be illustrated by the dose reduction factors calculated for the containment spray system. A calculation of the two-hour thyroid DRF for the spray system analyzed in section III using the traditional definition of the DRF, as given by equation (2) results in a DRF of 6.2. The values determined from the doses calculated with the TITAN analysis are summarized in Table IV. A total variation in the DRF from the maximum of 6.2 to 1.04 is possible for the several different assumptions reflected in the doses calculated in section III.

It is apparent that the concept of a dose reduction factor associated with a given engineered safety system is an imprecise one. Although the assumptions concerning the operation of other systems and the containment could be reflected in the derivation of an accurate dose reduction factor equation for each application, this process could be tedious, and, in some cases, such as ice condenser system, an exact solution to such an equation for the DRF would be impossible. The effectiveness of any engineered safety system, however, is readily determined with an integrated fission product attenuation chain approach, such as the TITAN analysis described in section II.

V. CONCLUSIONS

The results of the analysis of the engineered safety systems for a typical 3600 MWt PWR containment show the significant effect of the models used in the evaluation. In order to determine the true effectiveness of any combination of fission product hold-up or removal systems, a detailed analysis, which accounts for the interactions between safety systems in multi-volume containment systems, is required. The traditional dose reduction factor concept appears to be unsuitable for an accurate assessment of fission product removal systems in current-generation PWR containments. A time-dependent, multi-node fission product transport and removal analysis of the type described herein, is suggested as a suitable method for the evaluation of safety systems effectiveness.

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FISSION GAS CONTROL AT FFTF

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Abstract

The two processing systems designed to control radioactive gases at the USAEC Fast Flux Test Facility are described and discussed. One system, the Radioactive Argon Processing System, is used to remove fission product xenon and krypton from the argon cover gases of the reactor and closed loop systems. The other system, the Cell Atmosphere Processing System, is used as a plant off-gas system.

I. Introduction

The Fast Flux Test Facility (FFTF) is a sodium-cooled reactor, being designed and constructed at Hanford under the management of the Westinghouse Hanford Company for the USAEC Division of Reactor Development and Technology. It will provide a test facility with which to extend engineering technology in support of the Liquid Metal Fast Breeder Reactor Program. Special areas of emphasis for FFTF testing will be: effects of fast neutron on fuels and materials, fast reactor fuel performance, and performance of large, high temperature sodium systems and components. In keeping with these objectives, the design will allow reactor operation with continuous noble gas release to the primary system from up to one percent of the fuel, although it is not within present plans to operate the reactor with defected or vented fuel. Additionally, four sodium-cooled closed loops will permit full capacity testing of vented or defected fuel. At the same time, FFTF will release essentially zero amounts of radionuclides to the environment. These capabilities will be achieved through use of high-integrity sealing of the primary sodium systems, and through use of gas processing systems designed to remove radioactive xenon and krypton from the contaminated argon cover gas. In addition, effluents from cells that could become contaminated by leakage of radioactive systems are processed before discharge to the environment.

In a sodium cooled reactor, the vapor pressure of the coolant is low at operating temperatures. The reactor at FFTF will operate at a maximum outlet temperature of approximately 1050°F. At this temperature the vapor pressure of sodium is only 0.018 atmospheres absolute. In order to prevent leakage of air into the reactor, it is necessary to pressurize the reactor with an inert gas. At FFTF, argon has been chosen for this service; the reactor cover gas pressure is nominally 10 inches (water gage) or approximately 1.025 atmospheres absolute. The closed loops are similar in principle. However, due to the layout and design of the system, it is necessary to set the closed loop argon cover gas pressure at a nominal 55 psig in order to prevent sodium pump cavitation. The argon lays on top of the sodium in the reactor, and closed loops, hence it is called a cover gas. Noble fission gases released from defected or vented fuels disengage from the sodium and mix with the argon cover gas.

Gas buffered seals are used in the reactor head in a number of places where welding or weld-lip seals are impractical. Simplistically, the buffered seal installations consist of two seals in series, with positive gas pressure (2 psig) held between the two. This positive pressure prevents cover gas from leaking out of the reactor. Since all seals leak to an extent, there is some argon continuously leaking into the reactor from the inter-seal space. Consequently, it is necessary to vent argon cover gas from the reactor essentially at a continuous rate in order to

maintain cover gas pressure in the proper range. Thus, the result of providing the capability for the reactor at FFTF to operate with defected fuel, is a requirement to cope with a continuous stream of argon cover gas contaminated with fission product xenon and krypton. The total flow rate of argon from the reactor due to the buffered seals, is approximately four standard cubic feet per minute. The closed loops also will have a continuous effluent flow of cover gas, although at a much lower rate, on the order of 0.02 standard cubic feet per minute.

II. Radioactive Argon Processing System

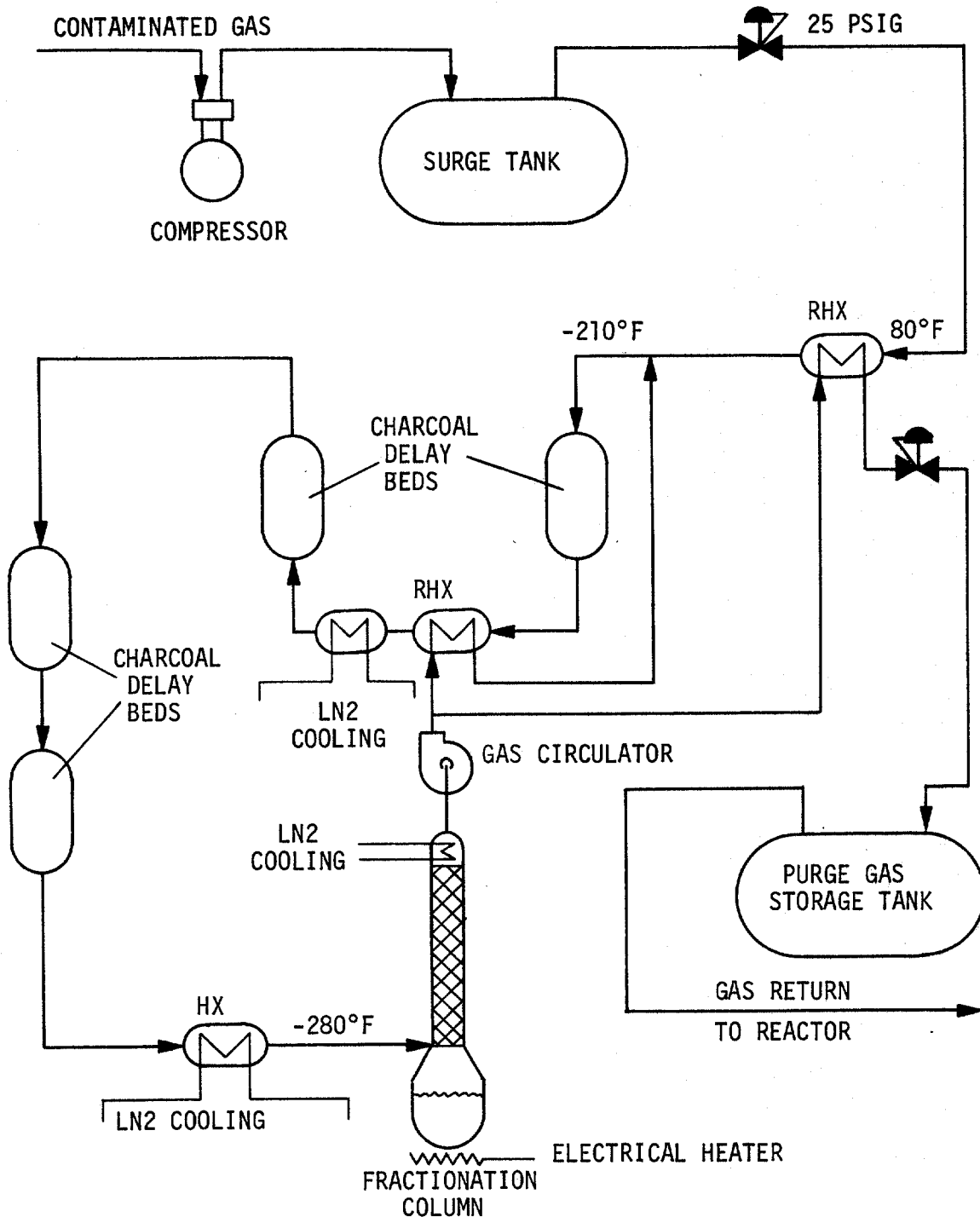
The Radioactive Argon Processing System (RAPS) is designed to receive the contaminated argon from the reactor and closed loops, and to process it on a continuous basis. The total design inflow of radioactivity into the RAPS is approximately 700,000 curies of noble gases per day. Processed gas leaving the RAPS must have a low specific activity, approximately maximum permissible concentration (MPC) because it is reused as cover gas in the reactor and as pressurizing gas for the buffered seals.

The basic configuration of the RAPS is shown on Figure 1. Contaminated argon from the reactor and closed loops is pumped into a surge tank, from which it is metered into a processing loop consisting of charcoal filled tanks (delay beds), heat exchangers for removal of decay heat, a fractionation column, gas circulators, and appropriate control elements. An accumulation of radioactive gases will release heat within the delay beds. In order to control the temperatures of the delay beds, argon is circulated through the beds at a rate of approximately 150 pounds per hour; the circulating argon is cooled in heat exchangers located downstream of the first delay bed, and also downstream of the last delay bed. Processing is performed at low temperatures because the adsorptive capacity of charcoal is thereby substantially enhanced, reducing the required size of the delay beds. In addition, the final element of the processing system, the fractionation column, requires low temperatures to separate xenon/krypton from argon. Liquid nitrogen is used as the coolant for this system.

Operation of this system is as follows: contaminated argon from the surge tank is cooled to approximately -210°F in a regenerative heat exchanger, and is introduced into the processing loop upstream of the first delay bed. The contaminated argon mixes with the recirculated argon, and enters the first delay bed at a temperature of approximately -210°F . At design conditions, the decay heat released in this bed, plus a certain amount of heat leak from the ambient, heats the argon passing through the bed to an outlet temperature of $+10^{\circ}\text{F}$. The argon leaving the first bed is re-cooled to approximately -175°F before introduction into the second bed. It passes sequentially through the remaining beds, rising to a temperature of approximately -125°F at the outlet of the last bed. The last two beds are provided to obtain more time for krypton decay and to protect the fractionation column from high radioactive xenon loadings in the event of a control system malfunction.

Delay beds are quite effective in holding up xenon, less so for krypton. Table 1 summarizes the delay times under design conditions. Delay times are somewhat longer when operating at less than design conditions. Essentially all radioactive xenon, and most of the short-lived radioactive krypton is eliminated in the delay beds.

Argon leaving the last delay bed is re-cooled to -280°F , essentially a saturated vapor, and is injected into the fractionation column. A pool of liquid argon resides in the bottom of the column. Heat is applied to vaporize some of the argon from the pool. The rising vapor is condensed by a liquid nitrogen cooled heat exchanger in the top of the column. The condensed argon flows down through the column packing, scrubbing xenon and krypton from the argon vapor entering the column. Since argon is considerably more volatile than xenon and krypton, the noble gases tend to remain in the argon pool. As a result, the stable and radioactive xenon and



RADIOACTIVE ARGON PROCESSING SYSTEM

FIGURE 1

TABLE 1

RADIOACTIVE ARGON PROCESSING SYSTEM PARAMETERS

<u>Parameter</u>	<u>Delay Bed No. 1</u>	<u>Delay Bed No. 2</u>	<u>Delay Bed No. 3</u>	<u>Delay Bed No. 4</u>
Xenon Delay, Days	9	45	42	40
Krypton Delay, Days	0.27	0.78	0.76	0.73

krypton are concentrated in the bottom of the column. The purified argon effluent from the fractionation column has a specific noble gas activity of 10^{-5} microcurie per standard cubic centimeter or less.

Argon leaving the column passes through the processing loop circulation blowers. A portion of the argon stream, as governed by the loop back-pressure regulator, then leaves the processing system for reuse in the reactor. The remainder of the column effluent is recycled through the delay beds for decay heat control.

When it becomes desirable to remove the xenon and krypton that has accumulated in the argon pool in the bottom of the fractionation column, the column is drained. The argon/xenon/krypton mixture is gasified, and is compressed into an ambient temperature tank for long term storage. Capability is provided to remove the gases accumulated in this tank for off-site disposal.

Basically, the delay beds are 3 foot diameter tanks, approximately 8 feet long with appropriate screens to support the charcoal in such a way as to permit the tank heads to function as inlet and outlet flow plenums. This design was selected as a result of a tradeoff. In principle, decay heat could be removed by radial conduction from the charcoal to a cooled bed wall. If that approach were selected, it would be possible to eliminate the gas circulator from the system. However, the thermal conductivity of charcoal is low, and an undesirably large radial temperature gradient would be required to drive the heat from a large diameter bed by conduction. The effect of the gradients would be to increase the average temperature of the charcoal, resulting in a substantial loss of adsorptive capacity. Consequently, it would be necessary to package the charcoal in relatively small diameter pipes to limit the temperature gradients, to retain a high adsorptive capacity of the charcoal. In order to provide the total mass of charcoal required by the design, it would be necessary to provide a large number of charcoal-filled pipes in parallel in each bed. This approach would present design and fabrication difficulties, and would enhance the possibility of gas flow channeling due to improper bed packing. As a result of these considerations, it was decided to proceed with relatively large diameter beds, using carrier gas to remove decay heat by internal convective cooling.

Coconut charcoal, mesh size 14 x 30, is used as the adsorbent. Measurements of the adsorptive capacity of the charcoal have been made at Harvard Air Cleaning Laboratory for the gas mixtures over the range of operating temperatures. Scale model delay beds have been constructed at Hanford Engineering Development Laboratory to measure parameters such as mass transfer efficiency over the expected temperature range, and to obtain data on other factors such as bed packing, flow distribution, movement of charcoal fines, etc.

The fractionation column is approximately 20 feet tall. The column is used chiefly to eliminate krypton 85 which is not affected by the delay beds because of its 10.4 year half-life. In principle, the column (or columns) could be used to purify the argon without the delay beds. However, experience with fractionation equipment is basically limited to essentially stable gas separations. The decay heat from the radioactive xenon and krypton is on the order of 3500 BTU/hour. The separation could well be affected by an intrinsic heat generation rate of that magnitude. A basic groundrule followed in FFTF is to make best application of existing technology wherever possible. Therefore, it was decided to adopt a system design that utilized both delay beds and a fractionation column.

III. Cell Atmosphere Processing System

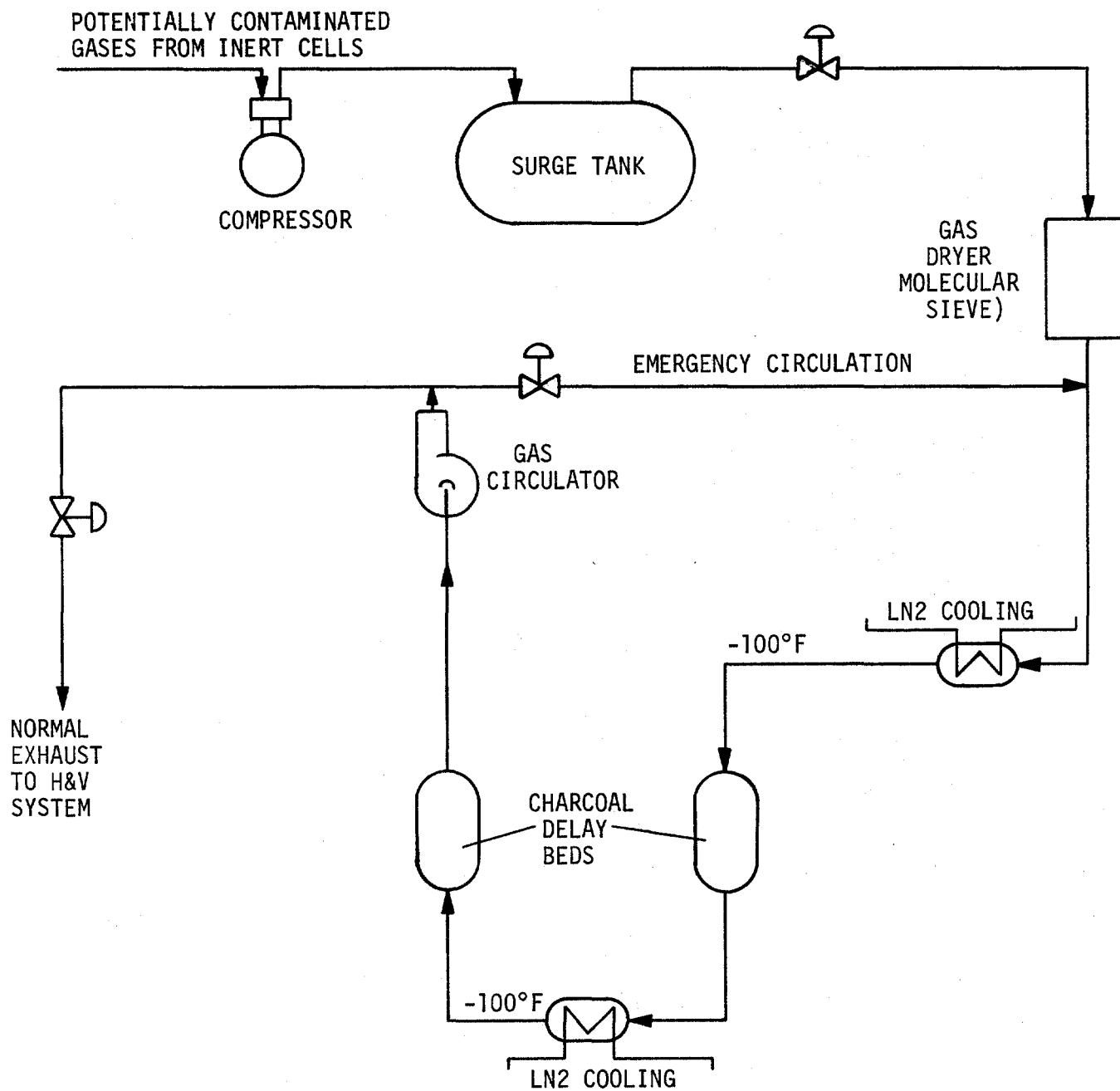
The primary sodium equipment cells at FFTF are provided with essentially inert atmospheres, consisting of nitrogen with approximately one percent oxygen. This is done to minimize the effects of potential radioactive sodium fires that could occur in event of leakage of a primary system. The cells are sealed, and the atmosphere is maintained by feed-and-bleed pressure controls. Effluents from these cells are

processed by the Cell Atmosphere Processing System (CAPS) before release to the environment. This approach was selected to minimize radioactive releases to the environment due to minute primary system gas leakages, and to permit an earlier commencement of maintenance activities in event of development of a significant primary system gas leak.

The basic configuration of the CAPS is shown on Figure 2. Gas vented from the inert atmosphere cells is pumped into a surge tank, from which it is metered into the processing equipment, consisting of a desiccant unit, two charcoal filled delay beds, liquid nitrogen cooled heat exchangers for removal of decay heat, and appropriate control elements.

Operation of this system is as follows: gas from the surge tank is dried to a dewpoint of -100°F or less, and is then cooled to approximately -100°F in the first heat exchanger. The cold gas flows through the first delay bed, and is re-cooled to -100°F before introduction to the last bed. In event that the gas at the outlet of the last delay bed has an undesirably large specific activity, the effluent from the last bed can be recycled through the beds for reprocessing. Design of this system is still underway. The specific activity concentration at the outlet of the last bed during normal operation is several orders of magnitude below MPC levels. At maximum post-accident design conditions, the specific activity of the gas discharged from this system is less than 0.01 microcurie per cubic centimeter, which, when mixed with the air passing through the heating and ventilating system central exhaust, results in a specific activity concentration that is less than MPC. It should be emphasized that, normally, there is no detectable activity in the discharge from the CAPS since there is no normal release of radioactivity from the primary systems.

With these processing systems, and other plant design features, FFTF will have the capability to operate with a significant amount of defected or vented fuel. At the same time, FFTF will release essentially zero amounts of radioactivity to the environment.



CELL ATMOSPHERE PROCESSING SYSTEM
FIGURE 2

DISCUSSION

FIRST: Perhaps I missed it Mr. Foley, but I was interested in how the gases coming from both areas would be cleared of sodium content prior to going to the coolers, etc. I realize that the cover gas will start out by having a vapor pressure of sodium related to the temperature in the pool; and, in the event of leakage in the closed loop cell, there would be some sodium oxide present.

FOLEY: In the cover gas processing system, all fluid from sodium systems passes through a sodium vapor trap (which calls for two to three papers, itself). At present, we have a vapor trap for the reactor that is pretty well proven. It eliminates sodium from argon to a level of fractional parts per million and, at operating temperature, vapor content entering the filter trap is 10,000 - 20,000 parts per million. So that takes care of it there. Additionally, we have filters upstream of the compressor. As for the other systems, normally, there is no sodium in the cells. If we can't use the heat exchangers as filters when an accident occurs and if cell pressure and temperature rises, we just stop cell ventilation and let the sodium agglomerate and settle before we start purging. It would be a bad scene and we would be waiting for awhile before we could do anything.

KERR: In your fractionation column, do you know if you have any azeotrope of xenon and krypton freezing out in argon? We have a cryogenic unit at the Idaho Chem Plant and xenon and krypton freeze out in oxygen, making transfers out of the fractionation column very difficult. I wonder if you have any information on that.

FOLEY: We have no information on that. What do you do, thaw it out?

KERR: We only allow a certain amount of accumulation in the bottoms of the fractionation column; then, we transfer to a still and do a fractional distillation there, so the freeze-out is in the still and not in the fractionation column.

FOLEY: It is inescapable that it will freeze out at the temperature range of liquid argon.

PANEK: With respect to your fractionation column, do you have an estimate of the frequency of draining?

FOLEY: It is not schedulable because it would depend on how much fuel we worked with. The criterion is that it will be drained after one year's run at maximum conditions. Realistically, it would be at varying frequencies.

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CHAKOFF: On your flow diagram, Figure 1, you showed xenon and krypton recycled back to the cover gas. Is that correct?

FOLEY: There's only a very low concentration in argon. The xenon and krypton are essentially removed and held in the column.

DAVIS: Regarding Mr. Kerr's question on xenon and krypton freeze out, I think you will find that the levels of xenon and krypton are well below what would be considered solubility limits as compared to fuel reprocessing in which air is present. I think you will not find any such type of freezing problem here.