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AEC Research and
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UC-81, Reactors - Power
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**comparison of gaseous waste handling
systems for PL-3**

Contract No. AT[30-1]-2900
with U. S. Atomic Energy Commission
New York Operations Office

ALCO PRODUCTS, INC.
NUCLEAR POWER ENGINEERING DEPARTMENT

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Development Report
UC-81, Reactors, Power
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COMPARISON OF
CASEOUS WASTE HANDLING SYSTEMS
FOR PL-3

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Issued: February 28, 1962

Contract No. AT(30-1)-2900
With U. S. Atomic Energy Commission
New York Operations Office

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ABSTRACT

This report compares gaseous waste handling systems for direct and indirect boiling water and pressurized water reactors for PL-3 application. Areas that are common to the various concepts are not discussed since they do not enter into a comparison study. The major differences present are in the handling of active gases released to or held in the primary system coolant. These gases which could be present, their possible release from the system, and the necessary processing requirements are discussed in detail. Sufficient information is presented to enable the reader to analyze the methods required to remove gaseous activity present in other size and type pressurized and boiling water reactors.

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1.0 INTRODUCTION AND DISCUSSION OF PL-3 SPECIFICATIONS

Since the gaseous waste schemes are for particular reactors operating under restricted conditions, discussion will necessarily be specific and limited. Release of radioactive gases from a PL-3 type reactor to the Antarctica environment in concentrations that would adversely affect scientific studies must be avoided. This report discusses methods of gaseous waste containment, dilution or dispersion to arrive at tolerance levels from three reactor types investigated for PL-3 application: direct and indirect boiling water reactors and the pressurized water reactor. Several problem areas common to all concepts have little effect upon concept selection; these areas have been deferred to Phase II and will be covered by appropriate development or design efforts. A description of these areas follows:

1. Any gaseous activity present in the pools might be released to the surroundings. Equipment will be provided to control any such release.
2. Gaseous activity will be present in any leakage from the primary system.
3. Sampling and automatic analysis equipment will be designed to prevent the release of gaseous activity.
4. Any other potential sources such as tank vents must be controlled.

The technical provisions, Appendix B to Contract No. AT(30-1)-2900 (PL-3), establish the requirements and objectives for research, development, design, construction, installation and testing of a nuclear steam power plant, capable of being transported by air, and of being operated in a sub-surface installation in Antarctica. It is specified therein that equipment and design shall provide sufficient ventilation to keep radioactive gas concentrations in all areas, outside the containment, below $4 \times 10^{-14} \mu\text{c/cc}$. This article has been interpreted (as of 1/'62) to mean that the gaseous waste, after being diluted with the air blast cooler flow, will have an instantaneous activity of $4 \times 10^{-14} \mu\text{c/cc}$ or less. No credit is taken for averaging higher and lower levels with time or for the atmospheric dispersion of a radioactive cloud.

In addition, the reactor complex shall be designed to allow for safe routine operation even in the event of simultaneous release to the coolant of one percent of the activity of the end-of-life fuel elements. This article was interpreted to mean that a step function of release after two years' continuous

reactor operation would transfer one percent of the core gases accumulated at that time. *

Since the gaseous waste schemes are for particular reactors operating under restricted conditions, discussion will necessarily be specific and limited. No attempt will be made to cover the subject material in general, though the test will be based on current knowledge of the problem. Expected results are preliminary; revisions will occur as design work continues and additional information becomes available.

* It is probably true that fission product gases released from a rod-type UO_2 clad fuel element will be much greater than found in a matrix and clad UO_2 -SS plate. (1) (2) However, from the interpretation made, it must be assumed that the plate matrix type element is capable of releasing the same quantity of gas as the rod-non-matrix type element.

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2.0 DESCRIPTION OF THE PROBLEM

Each plant in turn will be analyzed to provide an understanding of how radioactive gas releases would affect the operation of the particular plant concept under consideration. Relative to all types is the fact that during normal operation, radioactive gases evolved are limited to induced short-lived isotopes of nitrogen and oxygen, and trace amounts of hydrogen and argon. Isotopes of krypton, xenon, iodine, bromine and cesium appear from smeared fuel in contact with the coolant or from diffusion through the cladding of these fission gases. However, should a fuel cladding failure occur, such fission gases with much higher activities will evolve with the coolant, whether in the steam of the DBWR and IBWR or in the water of the PWR core. In addition, radiolytic decomposition of the reactor water in the form of O_2 and H_2 takes place in varying degrees in all three cores, resulting in additional non-condensables.

2.1 THE DIRECT BOILING WATER REACTOR

In the DBWR, any noncondensable gases present in the core, either active or non-active, will be quickly stripped from the water and carried with the steam to the turbine and condenser. Any noncondensables which find their way to the condenser will be extracted by the air ejector. This ejector discharge, or "off gas" as it is called, represents a continuous flow of active gas requiring processing and disposal. Since the main condenser operates at a vacuum, air in-leakage is present which increases the volume of gas requiring processing.

During the hypothetical one percent release of gas activity accumulated over a two-year full power period, only a short transfer time occurs between emission of the gas to the coolant and its appearance at the processing equipment.

2.2 THE INDIRECT BOILING WATER REACTOR

IBWR core characteristics relative to off-gas are essentially the same as the DBWR except that more fission product gases are present at the end of 2 years due to a higher thermal power output.

Under normal operation, the IBWR handles and vents less non-condensables than the DBWR, because in-leakage to the condenser of the DBWR is eliminated through the use of a boiling heat exchanger operated above atmospheric

pressure. (Only the nonactive secondary steam is cycled through the condenser.) This permits processing of a much smaller amount of gas, and makes possible gas concentration and storage for shipment off-site. The H_2 and O_2 can be recombined as a first stage of the off-gas process and returned to the primary system.

2.3 THE PRESSURIZED WATER REACTOR

The PWR, though operating at higher thermal power than the DBWR and IBWR with slightly higher two year accumulation of fission product gases, has the inherent characteristics of the IBWR in that air in-leakage is eliminated. Also, the addition of H_2 to the coolant will suppress complete water decomposition. If venting is not required during normal operation, non-condensables will remain in solution until the reactor is shut down. During the one percent fission product gas release, the volume of gas is still small enough to remain in solution in the primary system.

2.4 SUMMATION

The problems found in each of the discussed reactors, as shown in Table 2.1, indicates the problem areas and advantages of the various reactors to the off-gas problem.

TABLE 2.1

SUMMATION OF OFF-GAS PROBLEM IN THE THREE REACTORS

REACTORS	DBWR	IBWR	PWR
1. Core			
a. Fission Product Gases	Yes	more than DBWR	more than IBWR
b. Induced Gases	Yes	Yes	Yes
c. Radiolytic Decomposition Products	Yes	Yes	No
2. At Vent or Ejector			
a. Fission Product Gases	Yes	more than DBWR	(optional) more than IBWR
b. Induced Gases	Yes	Yes	Yes
c. Radiolytic Decomposition Products	Yes	Yes	No
d. Air In Leakage	Yes	No	No
3. How Handled			
a. Vented Continuously	Yes	Yes	No
b. Vented Intermittently	No	No	Yes (Optional)
c. Recirculated	No	Yes	Yes
d. Removed at Shutdown	No	No	Yes
e. Recombination	Yes	Yes	No
4. How Processed			
a. Continuously	Yes	Yes	No
b. Intermittently	No	No	Yes (Optional)
c. At Shutdown	No	No	Yes
d. Discharged to Stack	Yes	Yes (Optional)	Yes (Optional)
5. Advantages	Gaseous activity removed continuously; therefore less activity present at shutdown.	Less air in-leakage, pulse of activation delayed.	Least air in-leakage, least water decomposition, pulse of activity can be delayed.

3.0 ANALYSIS OF GAS RELEASE

Many active and nonactive gases are present or created in the core of a water-moderated reactor. A compilation of all possible gases present in the cores contemplated is shown in Table 3.1. The usual method by which these gases appear and the half-life of radioactive isotopes are also listed with comments to reflect relative importance.

3.1 LOWER ATOMIC WEIGHT GASES

The lower atomic weight gases are identified as those with weights less than 50, while higher weight gases are considered as those having atomic weights greater than 50. The object of discussion here is to establish volume activity and processing requirements for the light gases.

3.1.1 Air In Core and Feed Water

Air present in the primary system of any of the three reactors will produce a small portion of the N_2O_2 , and A_2 gas from induced processes in varying amounts. Additional oxygen and hydrogen gas will be produced in much larger quantities from radiolytic decomposition and N^{13} from an unknown source, both gases to be discussed later. The volume of N_2 , O_2 , H_2 and A_2 generated both in active and nonactive form depends not only on the core characteristics, but on the quantity of air emitted to the reactor. Argon isotope production will be considered here while O_2 and N_2 production from air in-leakage will be grouped with decomposition volumes in the following subsection.

The maximum possible activity and volume of argon in the three reactors will be found in the DBWR where air in-leakage is present with an assumed value (to be discussed in Section 5.0) of 0.5 scfm. By showing that the argon activity is of little consequence in the DBWR, the problem automatically resolves itself in the IBWR and PWR.

If it is assumed that 2.83×10^{-3} scfm air (0.1 ppm O_2) is allowed to pass through the core, an argon activity can be found. An exit steam flow of 7.10 lb/sec, normalized virgin flux of $1.29 \times 10^{13} \frac{n}{cm^2 - sec}$, a core transient time of .56 sec and a recirculation time of 9.02 sec was used with the method discussed in reference 11. The volume of air seems reasonable, since the greatest portion of in-leakage is removed through the air ejector before the feedwater enters the reactor.

TABLE 3.1

PROBABLE NONCONDENSABLE ISOTOPES IN CORE OF U²³⁵ FUELED WATER
MODERATED REACTOR

Radioactive Noncondensables

Isotope	Half Life	Formed	Comment	Isotope	Half Life	Formed	Comment
¹ H ³	12.26y	Induced	*	⁵³ I ¹³⁴	52.5m	Fission Product	Induced *
⁷ N ¹³	10m	Unknown		¹³⁵ I	6.7h	"	" *
¹⁶ N	7.4s	O ¹⁶ (p,)N ¹³	1	¹³⁶ I	86s	"	" *
¹⁷ N	4.14s	Induced	*	¹³⁷ I	24.4s	"	" *
¹⁹ O	29s	"	*	¹³⁸ I	6.3s	"	" *
³⁷ A	35d	"	*	¹³⁹ I	2s	"	" *
³⁹ A	260y	"	*				
⁴¹ A	1.82h	"	1				
⁴² A	3.6y	"	*				
⁸³ Br		Fission Product		^{131m} Xe	12d	"	"
⁸⁴ Br	2.4h	"	*	^{133m} Xe	2.3d	"	" -1
⁸⁵ Br	31.8m	"	*	¹³³ Xe	5.27d	"	" -
⁸⁷ Br	3m	"	*	^{135m} Xe	15.3m	"	" *
⁸⁸ Br	54.5s	"	*	¹³⁵ Xe	9.2h	"	" 1
⁸⁹ Br	16.3s	"	*	¹³⁷ Xe	3.9m	"	" *
⁹⁰ Br	4.4s	"	*	¹³⁸ Xe	17m	"	" *
⁹⁰ Br	1.6s	"	*	¹³⁹ Xe	41s	"	" *
				¹⁴⁰ Xe	16s	"	" *
^{83m} Kr	114m	"	1	¹⁴¹ Xe	1.7s	"	" *
^{85m} Kr	4.4h	"	-	¹⁴² Xe	1.5s	"	" *
⁸⁵ Kr	10.27	"	1-	¹⁴³ Xe	1.0s	"	" *
⁸⁷ Kr	78m	"	1	¹⁴⁴ Xe	1s	"	" *
⁸⁸ Kr	2.8h	"	-			Neutron Capture	" *
⁸⁹ Kr	3.2m	"	*	^{134m} Cs	3.2h	Fission Product	" *
⁹⁰ Kr	33s	"	*	¹³⁴ Cs	2.0y	"	" *
⁹¹ Kr	10s	"	*	¹³⁵ Cs	3.x10 ⁶ y	"	" *
⁹² Kr	30s	"	*	¹³⁶ Cs	13d	"	" *
⁹³ Kr	2s	"	*	¹³⁷ Cs	26.6y	"	" *
⁹⁴ Kr	1.4s	"	*	¹³⁸ Cs	32m	"	" *
¹²⁸ I				¹³⁹ Cs	9.5m	"	" *
¹²⁹ I	25m	Neutron Capture	*	¹⁴⁰ Cs	66s	"	" *
¹³⁰ I	1.7x10 ⁷ y	Fission Product	*	¹⁴¹ Cs	1s	"	" *
¹³¹ I	12.6h	Neutron Capture	*	¹⁴² Cs	1m	"	" *
¹³² I	8.05d	Fission Product	*	¹⁴³ Cs	1s	"	" *
¹³³ I	2.3h	"	*	¹⁴⁴ Cs	1s	"	" *
¹³³ I	20.8h	"	*				

Nonactive

Description	How Formed	Comment
¹ H ²	Radiolytic Decomposition or inserted in PWR	Usually appears as H ₂ gas
¹⁴ N	(Present in air leakage and from radiolytic decomposition)	Appears as N ₂ , O ₂ , and A ₂ gas
¹⁸ A	Br, Kr, Xe, Cs Fission Product and Some Neutron Capture -	

* = minor importance

1 = important

- = very important

1- = MAJOR IMPORTANCE

The activities of the argon isotopes are listed in Table 3.2 and compared to the design data on larger (reference) DBWR's in the 500 to 600 MW class. The larger DBWR data is scaled down for this purpose.

TABLE 3.2
ARGON ACTIVITY IN DBWR CORE

<u>Isotope</u>	<u>DBWR Activity (μc)</u>	<u>Reference DBWR Activity (μc)</u>
A ³⁷	3.214×10^{-7}	6.11×10^{-7}
A ³⁹	6.410×10^{-11}	--
A ⁴¹	2.169×10^{-2}	6.94×10^{-3}
A ⁴²	~ 0	--

The air blast coolers will provide approximately 250,000 cfm or 1.18×10^8 cc/sec air to the stack (See Section 4.0). This dilution factor can be applied to the activity of each argon isotope to determine if minimum effluent activity levels have been met. The various activities upon dilution will be: $A^{37} = 2.724 \times 10^{-15} \mu\text{c/cc}$, $A^{39} = 5.43 \times 10^{-19}$ and $A^{41} = 1.838 \times 10^{-10}$. Some holdup time is required for A⁴¹ in order to permit this activity to decay below the required $4 \times 10^{-14} \mu\text{c/cc}$ limit; this holdup time is 22.19 hours.

3.1.2 Radiolytic Decomposition Products

Water as a reactor coolant has the tendency to decompose in part into O₂ and H₂ gas when subjected to core radiations. This decomposition is suppressed by increasing reactor pressures or by adding H₂ gas in the coolant of pressurized water reactors^{(7)*}. In the case of the DBWR, the vessel pressure is only 600 psig so that evaluation of the effect in the DBWR will prove to be the worst possible case. Table 3.3 lists the dissociated gas volumes expected from DBWR's at 7.5 tMw and various vessel pressures. Scaling from larger reactors was made where necessary. Nitrogen gas basically derives from induced oxygen activity and to a small extent by air in-leakage. Most of the nitrogen is active while much of the oxygen and hydrogen is in stable form.

* H₂ addition in a DBWR could have the effect of reducing decomposition; however, it will not be considered here.

TABLE 3.3

RADIOLYTIC DECOMPOSITION PRODUCTS (7) (8) (9)

Reactor	(psig)	Approx. Standard Liters/Min.		
		H ₂	O ₂	N ₂
EBWR	600	3.93	2.95	0.14*
BORAX 4	300	9.15*	4.73	1.37*
VBWR	1000	3.10*	1.60	0.46*
BORAX 3	300	12.36	6.39	1.85
DBWR (used)	600	10.00	5.00	1.50

*Calculated

As can be seen from the table, rather high values of decomposition products for the DBWR have been selected from the data presented.

It has been assumed in the calculation for O¹⁹ and H³ by the method of reference 11 that all active isotopes so created appear in the decomposition gases. This is not true in either case, but as will be shown, it has little bearing on the fact that the activities are easily removable. Nitrogen 16 and 17 activities were found by scaling EBWR data⁽¹¹⁾ using 1.12, 22.92, and 1 second as time in chimney, mixed residence time in the steam dome and time beyond steam dome respectively. Table 3.4 shows the activities after leaving the core, diluted activities in the stack, and decay or hold-up times necessary to decrease the activity to within limits.

Even from the pessimistic viewpoint that all of the activated isotopes listed in Table 3.4 do release to the off-gas, only a few minutes are necessary to decay these active species to within discharge limits.

3.1.3 Nitrogen-13 Analysis

Nitrogen-13 has been detected in the coolant of some pressurized and boiling water reactors.⁽¹⁰⁾⁽²⁰⁾ It has been proposed that this 10-minute position activity having the chemical behavior of nitrogen derives from the reaction O¹⁶(P, alpha) N¹³. A calculation has been made of this activity based on the suggested equations in reference 10.

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TABLE 3.4

ACTIVITIES OF H³, O¹⁹, N¹⁶ and N¹⁷

Isotope	Release Rate ($\mu\text{c/sec}$)		Diluted Activity ($\mu\text{c/cc}$)	Hold-up (Min.)
	DBWR	Ref. DBWR		
H ³	4.05×10^{-6}	1.41×10^{-9}	3.43×10^{-14}	0
N ¹⁶	7.20×10^4	1.39×10^{-2}	6.10×10^{-4}	5.4
N ¹⁷	5.12	1.45×10^{-9}	4.34×10^{-8}	1.4
O ¹⁹	5.07×10^2	1.10×10^{-4}	4.29×10^{-6}	13.1

The saturated activity in a 7.5 MW reactor coolant is $1.31 \times 10^5 \mu\text{c}$. Dresden workers reported detecting 500 $\mu\text{c/sec}$ N¹³ in the off-gas.⁽⁶⁾ If it is assumed that all saturated activity, in this case $1.3 \times 10^5 \mu\text{c/sec}$, is emitted continuously; the holdup time required would be 348 minutes, still much less time than that required to hold-up argon-41. Since the reported N¹³ activity in the off-gas is much less than the saturated activity, the assumption made is basically pessimistic.

3.1.4 Light Gas Summation

In summing up the contribution of light gases to the over-all core activity and gas volume, the results as discussed in parts 1.1 to 1.4 of Section 3 are tabulated in Table 3.5.

TABLE 3.5

SUMMATION OF LIGHT GAS CONTRIBUTION

Total Light Gas Core Activity, microcuries	2.03×10^5
Total Light Gas Core Volume Flow Rate, Liters/min.	17.82 Standard
Release to Stack Activity with 1 day holdup, $\mu\text{c/cc}$	$< 4 \times 10^{14}$

3.2 HIGHER ATOMIC WEIGHT GASES

As shown in Table 3.1, the higher atomic weight gases generated in the core at normal reactor operating temperatures will consist of bromine, krypton, iodine, xenon, and cesium. The analysis of heavy gases is based upon a DBWR core; while the IBWR and PWR cores differ slightly in power and construction, there is no significant difference in gas production.

A method based on ORNL computer calculations was used to find the concentrations of the heavy gases after a two year full power buildup. (4)

The general equation(4) is:

$$N_C(t) = y_A P L_A L_B \left(\frac{1 - e^{-u_A t}}{u_A (u_B - u_A) (u_C - u_A)} + \frac{1 - e^{-u_B t}}{u_B (u_A - u_B) (u_C - u_B)} + \frac{1 - e^{-u_C t}}{u_C (u_A - u_C) (u_B - u_C)} + \dots \right) \quad (1)$$

N_C = number of atoms at time (t) present of gas (C)

y_A = yield of precursor (A) per fission

P = Power in fissions per second

L = disintegration constant of precursors in Sec^{-1} (A & B subscripts indicate precursors)

u = disintegration constant + burnup

It was necessary to determine the effective atom abundance of U^{235} present in the core, thermal flux, and fission cross section in the fuel to use the ORNL tables. Results checked by hand calculations were quite comparative. For example: the total two-year activity of Kr and Xe by hand was found to be 1.210×10^{17} dps, while ORNL tables produced a value of 1.164×10^{17} . The atom abundance, activity, and volume of the various species as listed in Table 3.6 is based on a DBWR operating at full power (7.5 tMw) for two years. These results compare favorably with the data reported in reference 18 where the reactor power was taken as 7.48 tMw, but without all the isotopes listed in Table 3.1 considered.

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TABLE 3.6

CHARACTERISTIC VALUES OF THE HEAVY GASES BASED
ON TWO YEAR OPERATION

	<u>Atoms Present</u>	<u>Activity - dps</u>	<u>Activity - Curies</u>	<u>SCF</u>
bromine	3.022×10^{22}	1.950×10^{16}	5.270×10^5	0.0397
krypton	5.811×10^{23}	4.771×10^{16}	1.289×10^6	0.7640
iodine	1.840×10^{23}	8.000×10^{16}	2.162×10^6	0.2418
xenon	3.486×10^{24}	7.099×10^{16}	1.919×10^6	4.5800
cesium	2.162×10^{24}	4.056×10^{16}	1.096×10^6	2.8407

3.2.1 Cesium, Bromine and Iodine

It has been shown that at least part of the iodine released to the water during EBWR I defective operation is retained in solution. This is also probably true for Cs and Br. However, since there is a lack of information in the literature as to the percent of these gases relative to water and steam, it will be assumed that the activity levels corresponds to the iodine and cesium levels found in the EBWR I. The worst possible case of release would be from a one percent emission of all two-year radioactive products. From Table 3.6, the one percent characteristics of these gases are repeated in Table 3.7.

TABLE 3.7

Br, Cs, and I CHARACTERISTICS
WITH A ONE PERCENT RELEASE OF ACTIVITY

	<u>Atoms Released</u>	<u>Activity - Curies</u>	(includes) <u>SCF (non-active)</u>
bromine	3.022×10^{20}	5.27×10^3	0.0004
iodine	1.840×10^{21}	2.16×10^4	0.00242
cesium	2.16×10^{22}	1.096×10^4	0.02841

With a 0.0155 percent average defective release in the EBWR I 20 tMw reactor, the amount of gaseous activity to the stack was reported as 4.69×10^{-5} curies/sec. Cs^{139} , $0.68 \times 10^{-5} Cs^{138}$, and $5.81 \times 10^{-5} I^{131}$ with no gaseous processing equipment in use. The instantaneous release rate to the processing system of the scaled-up one percent two year accumulation of the PL-3 is from Table 3.7 1.806×10^{-1} curies/sec., 2.373×10^{-2} , and 2.014×10^{-1} respectively.

Iodine can be retained in a chemically treated activated charcoal bed with an efficiency of 99.9 percent for long periods of time. (15) (16) (17) With this retention, the activity leaving the activated bed would be 1.806×10^{-4} curies/sec Cs^{139} , $2.373 \times 10^{-5} Cs^{138}$, and $2.014 \times 10^{-4} I^{131}$. This assumes that Cs and Br are held up as efficiently as iodine in the activated bed. Such an assumption appears reasonable if the physical properties and reaction rates of the three elements are compared. Table 3.8 indicates the results of scaling these values to a one percent release of all isotopes of iodine, bromine, and cesium. This table also includes the percent of activity allowed to remain in the water and core based on the EBWR I data and the present calculation.

TABLE 3.8
Br, Cs, and I ACTIVITY IN GAS STREAM
WITH ONE PERCENT RELEASE
(curies/sec)

	<u>At Air Ejector</u>	<u>After Activated Bed</u>	<u>% Activity in Coolant and Core</u>
bromine	7.02×10^{-1}	7.02×10^{-4}	99.9868
iodine	2.88	2.88×10^{-3}	99.9868
cesium (ave.)	5.41×10^{-1}	5.41×10^{-4}	99.9951

Even with a dilution factor of 1.18×10^8 and a 100 second smear of the instantaneous release of one percent of the accumulated activity (to be discussed later), the stack effluent would be:

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bromine $5.949 \times 10^{-8} \mu\text{c/cc}$

iodine $2.441 \times 10^{-7} \mu\text{c/cc}$

cesium $4.576 \times 10^{-8} \mu\text{c/cc}$

This, of course, exceeds specification limits. However, since the longest half life isotopes, I^{129} and Cs^{135} are in such low concentrations at the end of two year operation, they can be emitted directly to the stack below an activity of $4 \times 10^{-14} \mu\text{c/cc}$. With the exception of Cs^{137} and the low concentration species noted above, all other influent would require an additional holdup of 152 days before limits could be reached. In the case of Cs^{137} its concentration is high enough and its half life long enough to result in an activity of $7.73 \times 10^{-10} \mu\text{c/cc}$ even after years of hold-up. Therefore complete retention must be provided. Since the speed with which a gas passes through a carbon bed depends to some extent on the partial pressure of the gas and since the partial pressure of Cs, I, and Br are all lower than the partial pressures of krypton and xenon, it should be expected that Cs, I, and Br gases will still be retained within a bed when it is removed from the system due to high level breakthrough readings from krypton and xenon active isotopes. ^{*(19)} Therefore, under these conditions it can be assumed that Cs, I, and Br are completely removed from the system by retention and physical storage for off-site shipment.

Under normal operation with an activated charcoal bed in use, a hold-up time of 17 minutes would be required of effluent leaving the chemically treated activated bed to reach limits. The calculations for such a conclusion are based on the percent retention of these gases in the coolant and core of Table 3.8 and the discussion of calculations under normal operation, Section 3.2.3.

3.2.2 One Percent Defective Release Operation

From Table 3.6, the effective concentrations and activities of krypton and xenon for one percent release of activity are shown in Table 3.9 and include the results for Kr^{85} separately.

From the hold-up point of view, little can be done for Kr^{85} due to its long half life. On the other hand, hold-up of all other krypton and xenon isotopes for a sufficient time will allow their emission at the prescribed level. An instantaneous pulse (1 sec) can be assumed to be emitted after hold-up or as a uniform pulse of 100 Sec. duration (to be discussed in Section 5.0) since

* See Sections 4.0 and 5.0 for further discussion of these topics.

TABLE 3.9

RELEASE CONCENTRATIONS AND ACTIVITIES FOR ONE PERCENT
AT 7.5 MW_t AT END OF 2 YEARS

	<u>Atoms Released</u>	<u>Activity-dps</u>	<u>Curies</u>	<u>SCF</u>
krypton	5.811×10^{21}	4.77×10^{14}	1.289×10^4	0.00764
xenon	3.486×10^{22}	7.099×10^{14}	1.919×10^4	0.0458
Kr ⁸⁵	3.772×10^{20}	8.072×10^{11}	2.182×10^1	0.000496

the gases in question leave the reactor, they are created only by decay chain radioactive gas precursors. It is assumed that these precursors are released to the coolant and that the gaseous daughter activity continues to be produced after release. * The general equation for the description of N₂ atoms of gas present after fission production has stopped, but with N₂(0) initial and N₁(0), the precursor, in equilibrium after two year operation from ORNL calculations in Section 3.2 is:

$$N_2(t) = N_2(0) e^{-L_2 t} + L_1 N_1(0) \left(\frac{e^{-L_1 t}}{L_2 - L_1} + \frac{e^{-L_2 t}}{L_1 - L_2} \right) \quad (2) \quad (13)$$

The nomenclature being the same as described in equation (1).

From Figure 1, 8.6 days are required to decay krypton to suitable levels for dilution with an instantaneous release and 7.43 days with a 100 second smear. For xenon these values are 502.4 and 422.9 days respectively. The longest krypton half life being only 4.36 hours while the longest xenon considered having a half life of 12 days.

3.2.3 Normal Operation With Heavy Gas Emission

In Part 1 of Section 3, it was shown that under normal operating conditions all light gas activity could be handled with approximately a one day hold-up

* Though these precursors are permitted to exist, they contribute little to the decaying activity after a period of a few days.

Figure 1. Krypton & Xenon Decay after 2 Year 7.5 MWt
Operation with One Percent Release to System
Kr⁸⁵ Omitted - Gas Precursors Present

period. The light gases will be present in the same amounts previously specified. It is inconceivable that a large portion of these gases could be held up and then released when the one percent emission takes place. Therefore, with either normal or defective (1 percent release) operation the effect of the light gases is minor and has already been considered in its entirety. Emission of krypton and xenon isotopes will be considered for normal operation; iodine, bromine and cesium already being covered.

In the absence of a gross clad defect, the krypton and xenon release rate should be negligible. With defects, the upper limit of one percent release has already been specified whether from a matrix or rod type element. With negligible release under normal operation, it may be assumed that a quantity of fuel is smeared on the elements, that the amount of smeared fuel is not depleted, and that the krypton and xenon gases are released from this smear and leave the reactor core with the steam of a DBWR or IBWR as fast as they are created. Similar approximations have been made with other reactors and the results of the amount of smear necessary to produce the measured activity is listed in Table 3.10.

TABLE 3.10
SMEAR EQUIVALENTS IN VARIOUS REACTORS(12)

<u>Reactor</u>	<u>Milligrams Exposed U^{235}/Ft^2</u>	<u>Value in DBWR, Milligrams in 500 Ft^2</u>
LITR	0.01152	5.76
PWR	0.0318	15.90
ALPR (SL1)	0.0119	5.95
<u>EBWR I</u>	<u>0.0148</u>	<u>7.40</u>
DBWR	0.01751 Average	8.76 Average

Table 3.10 assumes 8.76 milligrams of U^{235} to be smeared on the fuel plates. 25 Kg U^{235} loading and 500 Ft^2 of heat transfer surface area is prescribed. The loading and transfer area will vary with each type reactor, but as before, the fission gases will appear immediately in the DBWR and it must be considered as the worst case.

The applicable equation to describe this smear occurrence is

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$$\text{Activity in microcuries} = \frac{L \ y \ P}{3.7 \times 10^4} \frac{.00876}{25 \times 10^3} \quad (3)$$

L = disintegration constant - sec⁻¹

y = yield/fission

P = Production rate in fissions/sec.

$$\frac{.00876}{25 \times 10^3} = \text{ratio of } U^{235} \text{ smear to total } U^{235}$$

Only the isotopes with fairly long half lives are listed, since short half life species (in seconds) will decay to low activities before emission to any processing equipment. Table 3.11 tabulates the data as discussed.

TABLE 3.11

NORMAL OPERATING CORE ACTIVITIES

<u>Isotope</u>	<u>Atoms Produced/Sec</u>	<u>Activity Released - μc/sec</u>
Kr ^{83m}	4.01 x 10 ⁸	1.09
Kr ^{85m}	1.25 x 10 ⁹	1.50
Kr ⁸⁵	2.45 x 10 ⁸	1.42 x 10 ⁻⁵
Kr ⁸⁷	2.26 x 10 ⁹	9.04
Kr ⁸⁸	3.10 x 10 ⁹	5.82
Kr ⁸⁹	4.50 x 10 ⁹	4.42 x 10 ²
Xe ^{131m}	2.51 x 10 ⁷	4.54 x 10 ⁻⁴
Xe ^{133m}	1.34 x 10 ⁸	1.26 x 10 ⁻²
Xe ¹³³	5.43 x 10 ⁹	2.23 x 10 ⁻¹
Xe ^{135m}	1.51 x 10 ⁹	3.01 x 10 ¹
Xe ¹³⁵	5.19 x 10 ⁹	2.96
Xe ¹³⁷	5.17 x 10 ⁹	4.13 x 10 ²
Xe ¹³⁸	4.78 x 10 ⁹	8.74 x 10 ¹
13	3.40 x 10 ¹⁰	9.93 x 10 ²

It should be noted from Table 3.11 that the isotopes with the highest activities have the shortest half lives. Therefore, if a hold-up mechanism was incorporated it would be the isotopes of $\text{Xe}^{131\text{m}}$, $\text{Xe}^{133\text{m}}$ and Xe^{133} which would determine the release activity to the stack. Very little can be done to Krypton 85 since its half life is 10.27 years, but it should be noted that upon dilution of normal activity Kr^{85} the release rate would be $1.203 \times 10^{-13} \mu/\text{cc-sec.}$ * This figure could easily be within limits if either a smaller smear or a greater dilution factor was used in this approximate method. In the case of the xenons just mentioned, $\text{Xe}^{131\text{m}}$ is the determining factor requiring a 79.1 day decay period to reach effluent limits.

3.2.4 Summation of Data Presented in Section 3.0

Table 3.12 summarizes the data as presented in Section 3.0.

TABLE 3.12

SUMMARIZATION OF SECTION 3.0 DATA -

Totals of Both Light and Heavy Gases

Gas activity available in 2 year core	6.993×10^6 curies
Gas activity released to steam with one percent defect	2.352×10^5 curies
Gas activity released to steam with normal operation	$2.041 \times 10^5 \mu/\text{cc-sec}$
Gas volume flow rate with one percent defect for 1 sec.	$19.324 \frac{\text{Liters}}{\text{min.}}$
Gas volume flow rate with normal operation	$17.820 \frac{\text{Liters}}{\text{min.}}$
Released activity to stack less Kr^{85}	
1% defect and 423 day hold-up	$< 4 \times 10^{-14} \mu/\text{cc}$
Normal with 80 day hold-up	$< 4 \times 10^{-14} \mu/\text{cc}$
Released activity to stack, Kr^{85} 1% defect	$1.85 \times 10^{-1} \mu/\text{cc}^{**}$

* If 23 percent of the $\text{Kr}^{85\text{m}}$ is allowed to transfer to Kr^{85} while in an hold-up scheme as in reference 18, the effluent would have an activity of $2.671 \times 10^{-13} \mu/\text{cc}$.

**An actual gaseous waste processing system would include provision for the collection of Kr^{85} to prevent its release from the plant.

4.0 GASEOUS WASTE PROCESSING

Any system designed for the processing of gaseous activity must accomplish one or more of the following:

Dilution of active gas

Containment of active gas

Decay of active gas

Dilution is probably the easiest method of disposing of radioactive gas. By this method, a gas with an activity above limits is mixed with a larger quantity of non-active gas with the activity of the resulting mixture within limits and suitable for discharge from the plant. In the case of the PL-3 plant, the air blast glycol coolers provide a source of dilution air varying between 200,000 and 400,000 cfm depending upon air temperature and plant load. For design purposes, a flow of 25,000 cfm or 1.18×10^8 cc/sec is used.

The release of activity can be prevented by the containment or storage of all gas containing activity. High pressure storage and liquefaction are the two most applicable storage methods. Liquefaction is preferred for large volumes of gas. One variation on containment is to separate out and contain only the active components.

The use of decay requires holdup of active gas or active components for a given time permitting the activity to decay. The holdup of the entire gas volume is applicable where the volume is small or the required holdup time short. Where a large volume is involved or the required holdup time long, it is more desirable to holdup only the active components, allowing the non-active components to pass directly to a discharge point. The operation of a system employing decay requires an accurate prediction of holdup time required and holdup time available through the use of specific system components.

4.1 ADSORPTION

The processing of active gas by adsorption is a procedure whereby the active components become attracted to and attached to the surface of an adsorber and are held-up. There are several possible mechanisms for the operation of an adsorption bed.

1. As a gas flow enters the bed, the active components are adsorbed, using up capacity. This process continues until the bed is saturated.

At this point, the bed is no longer effective and must be regenerated or replaced.

2. The second possibility starts in the same manner, with the bed adsorbing the active gas components. However, an additional active gas enters the bed, it displaces those active components already adsorbed. The displaced activity is readsorbed a short distance along the bed. In this manner, the entering active components act to push the previously adsorbed activity through the bed. When activity finally breaks through, it is the oldest activity in the bed. If this mechanism is correct, then an adsorption bed may be used continuously to provide for holdup and decay of activity. (18)

In reality, the mechanism of an adsorption bed is somewhere between 1 and 2. The prediction of holdup time for continuous operation is a little uncertain. However, it is possible to predict the earliest time at which activity will appear in the effluent when a new bed is put into operation. This prediction of "breakthrough time" is used as the design basis for the DBWR adsorption systems. (19)

The temperature of an adsorption bed greatly effects its operation. The lower the temperature, the smaller the bed for a given set of conditions. The two remaining bed variables are pressure and total gas flow rate. Where the active components represent only a small fraction of the total gas present, the bed design is controlled by the "sweep gas" or total gas flow rate. (19) It is desirable to hold this sweep gas flow rate at a minimum, since the bed size is directly proportional to the total gas flow rate. The size of the bed is inversely proportional to the total pressure.

4.2 CHEMICAL COMBINATION

Noble gases represent the major portion of the gaseous activity released from a reactor during normal operation. These components are essentially chemically inert. However, also present are traces of active elements such as iodine and cesium which are active chemically and can be removed from the gas flow through the use of chemically treated adsorption media which is quite effective. (15) (16) (17)

4.3 RECOMBINATION

Recombination is not a means of processing activity. However, it is a means to reduce the total volume of gas requiring processing. Where the off-gas contains hydrogen and oxygen (as in the case of a DBWR), it can be com-

bined to form water vapor, then condensed, reducing the gas volume. This combination is accomplished by passing the gas through a catalyst bed.

4.4 DISTILLATION

Fractional distillation of air after it has been liquefied can be used for the removal of krypton from air. The krypton content of the gas after distillation can be limited to 0.1 ppm. (20)

4.5 OTHER METHODS

Other processing or collection methods such as clathrate formation and liquid stripping are available for use with active gas. (21) If it appears advisable, they will be investigated at a later date, however, sufficient information is not available at present for immediate application to PL-3.

5.0 DISPOSAL SYSTEMS DESCRIPTION

The gaseous waste disposal requirements and available processing methods have been established. It is now possible to project a complete gaseous waste disposal system for any concept. Due to their many differences, the three reactors are treated separately.

5.1 BOILING WATER REACTOR (DBWR)

In the case of a DBWR, any gaseous activity present in the reactor coolant will be stripped from the coolant by boiling. This activity will be carried with the steam to the turbine and hence to the condenser. The non-condensable gaseous activity is removed from the condenser by a steam jet ejector. Also present at the air ejector are other non-condensables such as hydrogen and oxygen from radiolytic decomposition of reactor coolant, and any air in-leakage to the condenser. For a plant PL-3 size, the total volume of hydrogen and oxygen would be approximately 0.5 scfm. (7) (11) It is known that some air in-leakage to the system will be present. An exact quantity is difficult to establish, however, engineering judgement and an investigation of other small plants indicates that 0.5 scfm would be an upper limit. Under most conditions, the in-leakage would be virtually nil. This value assumes that a turbine shaft seal arrangement similar to Dwg. AES-594 is used to prevent shaft air in-leakage from reaching the condenser. The non-condensables present at the air ejector, or "off-gas" as it is called, would be:

1. Fission gas activity present through fuel cladding failure or from tramp U-235 present on the cladding exterior.
2. Induced activity resulting mainly from activation of oxygen, nitrogen, and hydrogen in the core. This volume is less than 10^{-6} of number 1 above.
3. Hydrogen and oxygen resulting from decomposition of water in the core. Total volume of 0.05 scf (Section 3.1.2).
4. Air-in-leakage to the below atmospheric pressure areas of the primary system.

The volume of nonactive gas from 3 and 4 above is very much greater than the active components, 1 and 2. An instantaneous release of activity to the reactor coolant has been discussed. However, for purposes of practical

system design, this activity release must have a time value. The significant time is that period over which a pulse of activity is released from a processing system. It has been assumed that any sudden release of activity to the reactor coolant will appear as a 100 second slug at the processing system discharge. The processing systems wherein eventual release is contemplated are fairly large and the 100 second value appears reasonable and conservative when mixing and diffusion in the system are considered.⁽¹⁹⁾ For smaller systems, where complete containment is proposed, the release time has little significance, since no active gas release is contemplated.

The DBWR gaseous waste system resolves to the processing of a steady flow of non-active gas containing a trace of active gas. This trace, however, represents an activity much too great for direct discharge from the plant.

5.1.1 Cycling Absorber System

As previously discussed, it is possible to predict with reasonable accuracy the minimum breakthrough time for an adsorption bed. This being the case, one bed can be used for processing the off-gas with a second bed on standby. When activity breaks through, the second bed is put into operation and the first is degassed. The desorbed active gas is collected and shipped off-site for disposal. In this manner, the adsorption beds are alternated. No active gas is discharged to the atmosphere and the net result is complete containment of activity.

Drawing AES-601, shows a schematic of a gaseous waste disposal system employing cycling or alternating absorption beds. Operation of the system is as follows:

1. The off-gas is first recombined to allow elimination of the 0.5 scfm of hydrogen and oxygen produced through radiolytic decomposition of the reactor coolant. Here, the ejector steam dilutes the gas below the explosive limit and cools the recombiner. The remaining non-condensables are 0.5 scfm air plus active gases.
2. A condenser removes the major portion of the water vapor and steam. This condensed water is drained back to the primary system.
3. Since the condenser operates at above freezing temperature, some moisture still remains in the off-gas. The gas is passed through small freezers operating at tunnel temperature. When one freezer becomes loaded, the flow is switched to the other. The first freezer is then heated, melting the ice. The resulting water is drained back to the primary system.

4. The off-gas then flows to two of the adsorber beds in series. Each bed consists of two sections. A third bed is available for standby. A three position selector switch controls the adsorption beds operation. Position #1 indicates that the bed receives the gas directly from the freezers. Position #2 indicates that the bed is receiving gas from another bed or is in a secondary position. Position "S" indicates that the bed is on standby. This position is also used for regeneration or degassing of the beds.
5. A monitor and flow meter after the bed indicates activity being discharged to the air blast cooler discharge stack. This information is used to determine breakthrough of activity through the beds.
6. If a breakthrough occurs, the primary bed is removed from service. The secondary bed is changed to the primary position, and the standby bed placed in the secondary position. This changing of beds takes only a few seconds and essentially continuous flow is maintained.
7. The bed just removed from service is degassed as follows:
 - A. The bed pressure is lowered to approximately 1 mm Hg and heated. This low pressure and higher temperature will desorb the absorbed active gas.
 - B. A nitrogen flow through the bed displaces the desorbed gas and carries it to a cold trap.
 - C. A very small liquid nitrogen cooled adsorption trap removes the active gas from the nitrogen purge. The cold adsorption trap would be shipped off-site for disposal.
8. An alternate method of desorbing a bed might be to use superheated steam. (18) In this case, the steam would be removed from the desorbed active gas by condensation; the active gas would then be compressed into bottles for off-site disposal. One advantage of steam regeneration is the elimination of low temperature. However, problems could be encountered with condensation and freezing of steam in the beds.

While the cycling capability must be included to provide for the processing of high off-gas activity, it may be necessary only infrequently during plant operation. If the Kr^{85} activity is low enough for direct discharge to the cooler stack, the two beds might provide sufficient holdup and decay for the shorter half life activity when operated on a continuous basis.

There is some uncertainty in the exact sizing of both the large series beds and the small cold trap. However, information available on the design of charcoal adsorption systems indicates that the 3 series beds if operated at tunnel temperature (-10°F) would each contain 2000 pounds of activated charcoal to give a 6-10 day cycle. (18) (19) (22) The small cold trap, if operated at -259°F or lower, would require 70 pounds for a bed giving 6 months capacity. The same size beds should be capable of operating on a continuous basis, without cycling to provide more than the required 79 day hold-up for $\text{Xe}^{131\text{m}}$ which will allow discharge of the bed effluent directly to the cooler discharge during normal operation.

5.1.2 Continuous Adsorption System

A continuous adsorption system is based on the principle that an absorption bed will provide a definite holdup time for the active gas components. Available information indicates that if the beds are operated at -10°F , approximately 4000 pounds of charcoal will be required to provide the maximum xenon holdup of 423 days. Such a system is of little use for noble gas activity with an extremely long half life. Kr^{85} and Cs^{137} are the only isotopes that fall into this category. All of the remaining active gases can be decayed to an acceptable level or contained by providing a xenon delay time of 423 days. This being the case, a continuous adsorption system is dependent upon the Kr^{85} activity of the off-gas. To make the system workable under all conditions, an additional Kr^{85} collection system must be provided.

The continuous adsorption system is broken into 2 sections. The first section represents a basic adsorption system. The last section shows alternate concepts to provide for Kr^{85} disposal. Drawing AES-600 shows the basic adsorption system. The recombiner condenser and freezer operate identical to that described in 5.1.1. After the freezer is a small replaceable bed designed to remove any remaining moisture and collect the chemically active components of the off-gas, such as the halogens and cesium. This bed would be periodically replaced before breakthrough of these elements could occur. Following this small primary bed are the secondary beds, which provide holdup time for decay of the radioactive noble gases. A flow meter and monitor measure activity discharged to the cooler stack. In the event of high activity (this represents Kr^{85} , since all other activity has decayed) the discharge to the stack is discontinued and the bed effluent is directed to one of the three following alternates.

One positive method of preventing the discharge of high activity to the stack is to store the entire off-gas flow. Since a rather large volume is involved, 2.6×10^5 scfg, this can best be accomplished by storing it as a liquid. The off-gas flow is liquefied and stored until the activity of the bed effluent is

once again capable of being discharged to the cooler stack. The stored liquid must be shipped off-site for disposal. Drawing AES-598 shows such a method. If it was necessary to liquify and store the off-gas for an entire year, 2720 gallons would be accumulated.

Fractional distillation of liquid air can be used to limit the krypton content in air at 0.1 ppm.⁽²⁰⁾ If we assume a 0.5 scfm off-gas flow into a 250,000 cfm cooler stack flow then to meet the final discharge limit of 4×10^{-14} μ /cc, 6×10^{-6} ppm of Kr⁸⁵ in the off-gas flow is allowable. There are two additional considerations:

1. The portion of krypton in the off-gas from the reactor is greater than that normally in air.
2. The krypton normally in air is greater than that from the reactor.

The following analysis is based upon case #1. If case #2 applies, which would normally be true, then removal of Kr⁸⁵ is more complete. Thus, case #1 represents the worst possible case and the maximum design criteria.

If the off-gas is liquified and functionally distilled to 0.1 ppm krypton, the maximum possible Kr⁸⁵ concentration is 6.5×10^{-3} ppm.* This is above the allowable concentration of 2×10^{-7} ppm.** The 100 ppm of non-active krypton is added from an external source. The off-gas is again distilled to 0.1 ppm krypton. Assuming good mixing of the off-gas and added krypton, the maximum Kr⁸⁵ concentration in the second still effluent would be 6.5×10^{-6} ppm, which is also above the required 2×10^{-7} ppm. If a third distillation is performed after adding 10 ppm of krypton, the Kr⁸⁵ concentration would then be 6.5×10^{-8} ppm, which is satisfactory. 30 ft³ of bottled krypton would be required to operate such a system continuously for a full year. It can be seen that should case (2) above apply, there would be more dilution of active krypton resulting in a more effective system. The Kr⁸⁵ is concentrated in a small quantity of liquid air. This liquid must then be shipped off-site for disposal. The triple distillation is shown in Drawing AES-599. It is recognized that the system as described here would be quite complicated and possibly not practical. However, if higher discharge limits were allowable a system using the same approach might be acceptable.

Through the use of very low temperatures, it is possible to design a small absorption bed with a breakthrough time of over 6 months. Drawing AES-597 shows a system designed upon this basis.

* Ratio of total fission Kr to Kr⁸⁵ is 15.4:1, Table 3.8.

** If the 0.5 scfm off-gas contains 2×10^{-7} ppm Kr⁸⁵ the activity of the air blast cooler discharge will be 4×10^{-14} μ c/cc.

In the event of high activity due to Kr^{85} or possibly some other source, the entire off-gas flow is diverted through a small super-cooled absorption bed. A cold trap preceding the bed removes any water vapor or carbon dioxide. The bed is maintained at a temperature in the range of -260°F to -295°F with either liquid nitrogen or liquid methane. It is shipped off-site for disposal.

The system just described would also be suitable for a complete gaseous waste disposal system. In this case, all fission gas activity would be retained in the adsorption bed. However, considerable reliability would be lost due to complete dependence upon low temperature equipment operation.

5.2 INDIRECT CYCLE BOILING WATER REACTOR (IBWR)

The IBWR is very similar to the DBWR with one important exception. The entire primary system is operated above atmospheric pressure, which eliminates air-in-leakage. The primary side of the steam generator must be vented to remove non-condensables and maintain proper heat transfer. This gas would consist of fission gas, include activity gas, and hydrogen and oxygen resulting from radiolytic decomposition. Fission and induced gases represent a very small volume, less than 10 std. cu. ft. per year. As in the case of a DBWR, hydrogen and oxygen can be eliminated as non-condensables through the use of a recombiner. The following disposal system provides for the containment of all active gas with final disposal by off-site shipment.

Drawing AES-595 shows the schematic of a proposed IBWR gaseous waste disposal system. Operation of the system is as follows:

1. The non-condensables and sufficient steam for dilution are vented from the primary side of the steam generator.
2. A recombiner is used to reunite the hydrogen and oxygen back to water. This result is virtual elimination of non-condensables.
3. The water vapor is condensed and returned to the primary system.
4. The remaining non-condensables which are essentially active gas are reinjected back into the steam generator. The active gases are thus contained in the primary system and allowed to decay.

Also, it is possible that some hydrogen and oxygen will pass through the recombiner without being reunited. If this is the case, then reinjection will provide for another opportunity for recombination. The recombiner does not need to be 100% efficient to result in the net recombination of all the hydrogen and oxygen.

5. Periodically it will be necessary to remove the accumulated active gas. This is accomplished by diverting it to pressure shortage bottles instead of back to the primary system. This bottling of gas would be infrequent with very little total accumulation on a yearly basis.

5.3 PRESSURIZED WATER REACTOR (PWR)

The PWR concept is considerably different from the DBWR concept previously discussed. Air in-leakage is eliminated through operation of the system at greater than atmospheric pressure. It also differs from the IBWR in that radiolytic decomposition is eliminated through the practice of maintaining a hydrogen overpressure in the primary system. This hydrogen, in the order of 30-40 cc/liter of water, has the effect of causing recombination of the hydrogen and oxygen product through radiolytic decomposition.

The non-condensables in the primary system resolve themselves to fission gas, induced activity gas, and hydrogen added to suppress decomposition. At primary system operating pressure, all of the gas will remain in solution. Venting should not be required during normal operation. For these reasons the PWR has a decided advantage over DBWR concepts when considering gaseous activity release during normal operation.

There is one special problem associated with a PWR. In the DBWR concepts, any active gas in the primary system will be stripped from the coolant by boiling and carried to a known point for removal from the system. This is not the case with a PWR. The gas will remain in solution until the pressure is lowered. At this time, some gas could be released from the coolant. If we consider the case of a considerable number of cladding failures with the need for refueling, then it would be highly desirable to remove any active gas in the primary system before attempting to remove the reactor head. In the case where allowable limits are on the order of 4×10^{-14} c/cc, as with PL-3, this removal of active gas before removing the reactor head becomes more important.

Drawing AES-596 shows a gas stripping and collection system for a PWR concept. Since such a system might also be used for decay heat removal and cool-down, it is a very small penalty on the over-all plant concept. System operation after plant shutdown is as follows:

1. The primary system is vented to a condenser. Initially, a little water will be blown down until a steam dome is formed. The primary water is slowly allowed to boil at a rate slightly above that required to remove decay heat. The active gas will be stripped from the reactor and carried to the condenser with the steam.

2. The steam is condensed and returned to the primary system.
3. A vacuum pump removes active gases from the condenser and transfers them to a surge tank.
4. From the surge tank, the gas is compressed into bottles for off-site shipment and disposal. If the activity is low enough, the collected gas might be slowly released to the cooler discharge stack.

Such a system could be operated whenever removing the reactor head was anticipated. There would be little need for accurately determining fission gas content of the primary system. The major gas collected would be hydrogen. The total quantity of gas is less than 4 cu. ft. STP per cycle.

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6.0 CONCLUSIONS AND RECOMMENDATIONS

From the presentation herein it was determined that the PWR concept was most easily adaptable to waste gas handling; the IBWR system was simpler in design and operation than the various DBWR waste gas schemes. However, specific designs for gas handling in all three plants are feasible. The proposed systems are of a preliminary nature and suitable only to demonstrate that there are possible systems that could provide gaseous waste disposal for all concepts. Other points which have been concluded from this topical report and recommendations felt necessary are listed below:

1. Under normal operation all gases, including the induced light gases, can be emitted from the processing equipment of the DBWR after an 80-day xenon hold-up to meet limits of $4 \times 10^{-14} \mu\text{c/cc}$. Krypton-85 will be released under these conditions at $2.671 \times 10^{-13} \mu\text{c/cc}$ based on present assumptions. It is therefore required to provide complete holdup of Kr^{85} or raise the activity level of this one isotope. However, further development work may indicate that under normal operation without complete hold-up, Kr^{85} is within the prescribed specification limits.
2. Under the one percent release of all gaseous activity, assumed to be one percent of fission gases after a two year buildup, only Kr^{85} will be above limits after 423 days of hold-up in an activated bed, Cesium-137 is believed to be held longer than xenon isotopes so that it is required that only Kr^{85} be separated from the effluent. It should be noted that the percentage release of fission gas whether one percent or one hundredth of a percent has little effect upon system design when considering a release limit of $4 \times 10^{-14} \mu\text{c/cc}$. To design any bed for 423 day holdup of xenon isotopes, it will require extensive research and development programs to accurately predict gaseous breakthrough times in activated charcoal adsorption beds.
3. Existing equipment necessary to meet effluent activity of $4 \times 10^{-14} \mu\text{c/cc}$ could be materially reduced if design criteria was that of R. C. G. ($1 \times 10^{-10} \mu\text{c/cc}$) for a mixed reactor gas with guaranteed I^{129} retention.
4. One area of development which has as yet not been mentioned is the perfection of an accurate system for measuring very low level activity.

Accurate design information of adsorption beds is lacking in the literature. A program similar to the program cited in reference (18) should be initiated to remove such an obstacle. In addition other disposal methods such as clathrate and liquid stripping should be investigated for future application.

DBWR TURBINE SHAFT
SEAL ARRANGEMENT

AES-594

IBWR GASEOUS
WASTE DISPOSAL

AES-595

PRELIMINARY

PWR GASEOUS WASTE
DISPOSAL SYSTEM

AES-596