ANALYSIS OF POWER REACTOR GASEOUS WASTE SYSTEMS*

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Abstract

The National Environmental Policy Act (NEPA) of 1969 requires that all major Federal actions significantly affecting the quality of the human environment be given detailed consideration as to their environmental impact. The Calvert Cliffs court decision of 1971 further interpreted NEPA as requiring an independent evaluation of the proposed action rather than a simple review of the utility submission.

This paper considers the operation of radioactive waste processing equipment in a power reactor designed to reduce the effluent concentration to levels at or below those defined in the Federal Regulations. The technique used in system analysis is presented with emphasis on those components critical to effective effluent control.

A listing and instructions for use of the computer code STEFEG used in the analysis is presented in the Appendix.

I. Introduction

As a result of the Calvert Cliffs decision of July 23, 1971,(1) the USAEC Directorate of Licensing embarked upon a major effort to prepare environmental impact statements for the more than 90 nuclear power reactors for which license action was pending at that time; and the more than 20 which have entered the licensing pipeline since that time.

Because of the magnitude of the task, three of the AEC's National Laboratories: Argonne, Pacific Northwest, and Oak Ridge were asked by the Commission to supply personnel to assist the Directorate of Regulation in preparing the statements. Each of the Laboratories was assigned about one third of the plants affected, and work got underway at the three sites in August 1971. This work involves a detailed study of each plant based upon information contained in the docketed documents such as the Preliminary Safety Analysis, the Final Safety Analysis, the Applicant's Environmental Report, and the Amendments thereto. The information contained in the reports is supplemented by direct questioning of the applicant, the reactor vendor, and the architect engineer, and, in most cases, a visit to the reactor site by the team assigned to the preparation of the impact statement for that plant.

It was recognized almost at once that certain aspects of the information-gathering process and of the subsequent analysis could be greatly accelerated if the work were divided in a horizontal rather than a vertical fashion. Accordingly, in January 1972, it was decided that the Oak Ridge National Laboratory would become responsible for generating the radioactive effluent source terms - both liquid and gaseous - for all of the reactors. These source terms, together with the rationale

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used in their development is supplied to the Directorate of Reactor Licensing, which, after appropriate review, passes them on to the impact study teams at the various Laboratories. Thus at ORNL we have two tasks: first to prepare radioactive effluent source terms for all the reactors; and second, to prepare complete impact statements on those reactors for which ORNL is responsible.

In this paper it is our object to describe the methods developed at ORNL for the purpose of estimating the gaseous source terms, to identify the specific information needed in order to implement these methods, and to point out some of the more obvious areas where improvement is needed. The development of the radioactive liquid source terms is described elsewhere.(2)

II. Scope of the Problem

The specific problem involved in determining the radioactive gaseous effluent from a power reactor system can be simply stated as follows:

(i) What radionuclides will be emitted from the system as gases or vapors?

(ii) What are the points of emission of this effluent from the plant under consideration?

(iii) What is the expected annual average release rate of each of these radionuclides from each of these sources?

For the purpose of analyzing the environmental impact of the plant, these questions must be answered in the context of the normal operating conditions which are expected to prevail throughout the lifetime of the facility: the potential environmental impact of accidents or other abnormal situations is handled separately, and the sources of gaseous effluent associated with abnormal conditions are not treated here. This increases the difficulty of the analysis since realistic conditions, the determination of which frequently requires some degree of subjectivity, must be used, and one is not permitted the luxury of utilizing the pessimistic limiting conditions often employed in the analysis of accidents.

The radionuclides which are normally available for escape in gaseous form include the noble fission gases (Kr and Xe), the fission product halogens (Br and I), certain activation products such as ^{16}N, ^{13}N, ^{19}O and ^{41}Ar, and tritium, which may originate either from ternary fission or from activation. Experience has shown that the noble gases and the iodines contribute virtually all of the radiologically significant gaseous activity released from light water moderated power reactors of current design. Thus, at present, only the nuclides shown in Table I are being included in the source term calculations.

To answer the second and third questions requires an extensive investigation into the design and operating characteristics of the plant.

The sources of emission can roughly be divided into two categories: (1) inadvertent leaks from tanks, piping, valves, etc. which allow gaseous activity to escape from portions of the plant which are normally contained, and (2) operational releases in which fluid is deliberately withdrawn from the cooling system of the reactor. The latter category would include steam generator blowdown, (frequently required to maintain boiler water purity), effluent from the main condenser air ejector (used to provide a vacuum on the condenser), releases from various system degassing operations, and in some cases the release of noncondensibles from the condensation of steam used to seal the turbine shafts. Usually some type of decontamination is provided for these operational sources. The equipment used may range

Table 1. Radionuclides Included in the Gaseous Source Term Calculation

Nuclide	Half Life	Yield[(a)] (%)
^{83m}Kr	114 min	0.43
^{85m}Kr	4.44 hr	0.97
^{85}Kr	10.6 yr	0.25
^{87}Kr	78 min	1.82
^{88}Kr	2.8 hr	2.65
^{89}Kr	3.2 min	3.28
^{131m}Xe	12 day	0.023
^{133m}Xe	2.3 day	0.17
^{133}Xe	5.27 day	6.58
^{135m}Xe	15.3 min	1.86
^{135}Xe	9.2 hr	6.74
^{137}Xe	3.9 min	5.61
^{138}Xe	17 min	6.00
^{131}I	8.05 day	3.30
^{133}I	20.8 hr	6.58

(a) based on 43% ^{239}Pu fissions and 57% ^{235}U fissions

all the way from simple holdup tanks or pipes, which permit radioactive decay, to gas recombination systems followed by deep bed charcoal adsorbers or, in some installations, cryogenic distillation and storage.

Inadvertent leakage may, in some instances be directed into closed spaces and eventually vented to the atmosphere through filters or adsorbers of various types. Otherwise the release from these sources may be directly to the atmosphere.

In any case it is necessary to determine what equipment is available, how it will be operated, and to assign realistic values to the parameters which describe the effectiveness of the equipment.

We have developed two mathematical models, one for pressurized water reactors, and one for boiling water reactors. Given the basic design parameters of the systems, these models allow us to calculate the concentrations of the various nuclides of interest in the reactor coolant streams. With these concentrations, and with estimates of the leak and operational release rates, and a knowledge of the operating characteristics of the various decontamination devices, it is possible to estimate the radionuclide release rates. The two models are briefly discussed below. A more complete description, together with a listing of, and operating instructions for, the computer program used in the calculation, is given in the Appendix.

III. Pressurized Water Reactors

A schematic diagram of a pressurized water reactor is shown in Figure 1.

Because this type of reactor system consists of two coolant loops, (the pressurized water primary and the two phase secondary coupled through the steam generators), two coolant concentration calculations must be made.

The radionuclide concentration in the primary coolant system is calculated using a lumped parameter approach. The source of activity is fuel with cladding defects which is assumed to supply the fission gases to the primary coolant system at a constant rate that depends upon the amount of defective fuel, the reactor power, and the escape rate coefficient characteristic of the nuclide under consideration. Losses of activity from the primary system which include leaks, removal by the cleanup demineralizer, losses due to degassing operations, losses to the secondary system through leaks in steam generators, and radioactive decay are all expressed in terms of rate constants having the dimension [time^{-1}].

In most cases it is assumed that the system is always in equilibrium with respect to these loss rates, however appropriate adjustments are made to handle intermittent degassing operations, and for the case of the very long lived ^{85}Kr isotope.

Activity may enter the secondary system through leaks in the steam generator tubes which permit primary water to penetrate into the secondary system. Losses from the secondary system include losses in the steam generator blowdown, through the condenser air ejector, from turbine shaft gland seal steam, removal by ion exchange, as a result of various inadvertent leaks, and by radioactive decay. The concentrations in the various parts of the secondary system are treated as independent variables, and expressions are written which give the relationship between these concentrations, the source term, and the losses. These equations are then solved with the aid of a material balance over the entire system. The scheme used is shown in Figure 2.

Given the coolant concentrations in each system, the rate at which activity escapes by each pathway is obtained by multiplying the leak rate by the concentration. The values thus obtained must be modified by a factor which expresses the fraction of the activity present in the leaking fluid that may potentially become airborne. For noble gases this factor is taken to be unity in all cases. For iodines the values are in general less than one and are determined individually depending upon the conditions (i.e., temperature, pressure, pH, etc.) of the leaking fluid.

When, as is usually the case, some type of decontamination equipment is provided to reduce the amount of activity which is actually released to the atmosphere further reduction factors are applied. The magnitude of these factors will depend upon what equipment is actually present and how it is operated. However, in nearly all cases the effect can be represented mathematically either as a simple numerical factor, as simple decay, as accumulation, static decay, followed by release over a finite period of time, or as a combination of these.

The results of a typical PWR calculation are shown in Table 2.

IV. Boiling Water Reactors

The boiling water system, shown in Figure 3 is quite similar to the secondary system of a PWR except that the source of activity in the steam is directly from defective fuel rather than as a result of steam generator leaks. Consequently the coolant concentration calculation is handled on a material balance basis in exactly the same way as is the secondary system of a PWR. A schematic diagram is shown in Figure 4 and the results of a typical BWR calculation are shown in Table 3.

V. Method of Procedure

The preparation of a source term document for transmittal to the AEC Directorate of Licensing has been reduced to a fairly simple routine. A single individual is assigned to study the gaseous radwaste system of each plant. His first task is to study the applicant's PSAR, FSAR, Environmental Report, and any other information available in order to obtain a clear understanding of how the system works. He then produces a schematic diagram of the system similar to those shown in Figure 5.

Simultaneously a list of questions asking for specific information concerning the design and operating conditions of the relevant portions of the plant is sent to the applicant. Following the receipt of answers to these questions a meeting is held with representatives of the applicant during which any misunderstandings are resolved and any unanswered questions taken care of. At this meeting, which is also attended by an AEC representative, the accuracy of the schematic diagram is verified, the operating characteristics of the various components are finally decided upon, and a list of parameters similar to those shown in Tables 4 and 5 is prepared. This list of parameters is the basic input for the computer program. Occasionally special situations arise where the mathematical models do not properly represent the physical situation. When these circumstances arise, hand calculations are sometimes required to supplement the computer.

In practice two individuals work together on each plant; one handles the gaseous effluent and the other the liquid effluent so that the above steps are carried out simultaneously for each type of radwaste.

PRESSURIZED WATER REACTOR EXAMPLE ONLY

TABLE 2

RELEASE RATE - CURIES PER YEAR

NUCLIDE	COOLANT CONC (MICROCURIES/ML)	AUXILIARY BLDG	CONTAINMENT PURGE	DEGASIFICATION PRIMARY	DEGASIFICATION SHIMBLEED	STEAM GENERATOR LEAK VENT	STEAM GENERATOR LEAK AIR EJECTOR	TOTAL
KR-83M	3.865E-02	1.068E 00	2.643E-03	0.0	0.0	0.0	1.079E 00	2.149E 00
KR-85M	2.076E-01	5.737E 00	3.359E-02	0.0	0.0	0.0	5.796E 00	1.157E 01
KR-85	1.219E-01	3.368E 00	6.751E 00	9.252E 01	7.194E 02	0.0	3.403E 00	8.254E 02
KR-87	1.125E-01	3.110E 00	5.240E-03	0.0	0.0	0.0	3.142E 00	6.257E 00
KR-88	3.604E-01	9.960E 00	3.708E-02	0.0	0.0	0.0	1.006E 01	2.006E 01
KR-89	8.546E-03	2.362E-01	1.665E-05	0.0	0.0	0.0	2.386E-01	4.748E-01
XE-131M	1.518E-01	4.196E 00	1.573E 00	7.729E 00	2.239E 01	0.0	4.239E 00	4.013E 01
XE-133M	3.724E-01	1.029E 01	7.428E-01	2.625E-04	1.623E-04	0.0	1.040E 01	2.143E 01
XE-133	2.775E 01	7.669E 02	1.292E 02	5.277E 01	7.481E 01	0.0	7.747E 02	1.798E 03
XE-135M	2.393E-02	6.614E-01	2.302E-04	0.0	0.0	0.0	6.682E-01	1.330E 00
XE-135	6.003E-01	1.659E 01	2.033E-01	0.0	0.0	0.0	1.676E 01	3.355E 01
XE-137	1.756E-02	4.852E-01	4.109E-05	0.0	0.0	0.0	4.902E-01	9.755E-01
XE-138	8.317E-02	2.298E 00	8.657E-04	0.0	0.0	0.0	2.322E 00	4.621E 00
I-131	6.166E-01	8.519E-02	4.375E-01	0.0	0.0	7.926E-01	1.981E-01	1.513E 00
I-133	6.845E-01	9.458E-02	5.283E-02	0.0	0.0	5.553E-01	1.415E-01	8.553E-01

0.0 APPEARING IN THE TABLE SHOULD BE INTERPRETED AS INSIGNIFICANT

BOILING WATER REACTOR EXAMPLE ONLY TABLE 3

NUCLIDE	COOLANT CONC. (MICROCURIES/ML)	RELEASE RATE (CURIES PER YEAR) REACTOR BLDG.	TURBINE BLDG.	GLAND SEAL	AIR EJECTOR	TOTAL	(CURIES PER SECOND) TOTAL
KR-83M	1.046E-03	0.0	1.103E 01	7.693E 01	6.911E 02	7.791E 02	2.469E-05
KR-85M	1.711E-03	0.0	1.805E 01	1.267E 02	1.729E 04	1.743E 04	5.525E-04
KR-85	8.820E-06	0.0	9.305E-02	6.568E-01	6.567E 02	6.575E 02	2.083E-05
KR-87	5.175E-03	0.0	5.459E 01	3.784E 02	3.737E 02	8.067E 02	2.556E-05
KR-88	5.549E-03	0.0	5.853E 01	4.098E 02	1.787E 04	1.834E 04	5.812E-04
KR-89	2.347E-02	0.0	2.476E 02	1.135E 03	0.0	1.383E 03	4.382E-05
XE-131M	7.688E-06	0.0	8.110E-02	5.724E-01	4.367E 02	4.373E 02	1.386E-05
XE-133M	1.080E-04	0.0	1.140E 00	8.041E 00	1.959E 03	1.968E 03	6.236E-05
XE-133	3.024E-03	0.0	3.190E 01	2.252E 02	1.229E 05	1.232E 05	3.904E-03
XE-135M	9.321E-03	0.0	9.832E 01	6.360E 02	0.0	7.343E 02	2.327E-05
XE-135	8.729E-03	0.0	9.208E 01	6.484E 02	1.581E 02	8.985E 02	2.847E-05
XE-137	3.934E-02	0.0	4.150E 02	2.045E 03	0.0	2.460E 03	7.797E-05
XE-138	2.919E-02	0.0	3.080E 02	2.005E 03	0.0	2.313E 03	7.330E-05
I-131	5.028E-03	1.435E-02	6.365E-01	4.492E-01	2.206E 01	2.316E 01	7.340E-07
I-133	2.642E-02	5.435E-02	3.344E 00	2.358E 00	1.001E 02	1.058E 02	3.354E-06

0.0 APPEARING IN THE TABLE SHOULD BE INTERPRETED AS INSIGNIFICANT

TABLE 4 COMPUTER INPUT - PWR

PWR Card No.	Parameter	Description	Normal	Orig.	Rev-1	Rev-2
1	NAME					
2	KIND		1			
3	POWTH	Thermal Power Level (MW)				
4	OPFRA	Plant Factor	.80			
5	TOSTFL	Total Steam Flow (lb/hr)				
6	GEN	No. of Steam Generators				
7	WST	Wt. Steam/Gen.				
8	WLI	Wt. Liquid/Gen.				
9	PRIVOL	Primary Vol. (cu.ft.)				
10	DEMIFL	Pur. Demin. Flow(gpm)				
11	SRB	Shim Bleed (gpm)				
12	CONVOL	Containment Vol.(cu.ft.)				
13	KID	Kidney Filter				
14	TAU1	Decay Time-PC gas(days)				
15	TAU2	Decay Time-SB gas(days)				
16	TAU3	Fill Time-Decay Tanks				
17	EN	Cont. Purges/yr	4			
18	EM	PC degas/yr	2			
19	PER	Failed Fuel (%)	.25			
20	GENIL	St. Gen. Leak (gpd)	20			
21	CONLR	Contain. Leak (gpd)	40			
22	DEM2	I Escap. B.D. Demin.				
23	TBD	Blowdown (lb/hr)	4.8×10^{3}			
24	KDEM	Condensate Demin.				
25	FPF	P.C. Containment	.1			
26	FVN	P.C. Vent	5×10^{-2}			
27	FEJ	P.C. Ejector	5×10^{-4}			
28	CON	P.C. Steam Gen.	1×10^{-2}			
29	CFM	Kidney Filter Flow(cfm)				
30	PURTIM	Purge Time of Kidney(hr)				
31	AUXLK	Aux. Bldg. Leak (gpd)	20			
32	FAUX	P.C. Aux. Bldg.	5×10^{-3}			

TABLE 5 COMPUTER INPUT - BWR

BWR Card No.	Parameter	Description	Normal	Orig.	Rev-1	Rev-2
1	NAME					
2	KIND		2			
3	POWTH	Thermal Power Level (MW)				
4	GTO	Steam Flow (lb/hr)				
5	PER	Failed Fuel (%)				
6	GDE	Cleanup Demin Fl (lb/hr)				
7	OPFRA	Plant Factor	0.80			
8	GTB	TB Leak (lb/hr)	1.7×10^{3}			
9	GGS	GS Leak (lb/hr)	0or1%GTO			
10	GRB	RB Leak (lb/hr)	4.8×10^{2}			
11	WLIQ	Mass Liquid (lb)				
12	WSTE	Mass Steam (lb)				
13	CON	PC (steam/liq)	1.2×10^{-2}			
14	FEJ	PC (Ejector)	5×10^{-3}			
15	PI	PC RB	1×10^{-3}			
16	P2	PC TB	1			
17	P3	PC GS	1			
18	DCN	Frac. Escape Cond. Demin	1×10^{-3}			
19	DCU	Frac. Escape C.U. Demin	1×10^{-1}			
20	EN	R.B. Purge-(times/yr)	3.65×10^{2}			
21	TIM1	Decay R.B. Gas (hr)	0			
22	TIM2	Decay TB Gas (hr)	0			
23	TIM3	Decay GS Gas (hr)	2.9×10^{-2}			
24	TIM4	Decay Ejt. Gas (hr)	5×10^{-1}			
25	FIL1	Frac. Esc. RB Filter				
26	FIL2	Frac. Esc. TB Filter				
27	FIL3	Frac. Esc. GS Filter				
28	FIL4	Frac. Esc. EJT Filter				
29	KCHAR	Char. Bed or Cryostat				
30	CHTI1	Kr Holdup (days)				
31	CHTI2	Xe Holdup (days)				

Once the source term calculations and the diagram are complete, a brief narrative description is prepared to accompany them. The full analysis is then reviewed by senior members of the ORNL staff prior to transmittal to the Directorate of Licensing for distribution to the various Laboratories.

VI. The Perversities

Undoubtedly the most difficult aspect of the analysis of gaseous radwaste systems is that associated with the selection of the proper values of the parameters which describe the operation of the various components. We seek values which will reflect average expected conditions over the 30 or 40 year lifetime of the plant, not instantaneous values which apply when the components are operating exactly as designed, nor yet pessimistic values which apply when one or more component is malfunctioning.

As anyone who owns an automobile or a household appliance is well aware, mechanical systems seldom perform exactly according to specification. On the contrary, over the lifetime of the system small abnormalities occur which are tolerated until adjustments can be made. Thus charcoal adsorbers which are tested at 99.9% efficiency immediately after installation, may be found operating at 85% efficiency when tested again six months later. Valves which were perfectly tight one day may develop leaks the next. And reactor fuel completely free of defects one month may become defective during the next. Moreover, variation in the operation of one component may require deliberate changes in the operation of another. For example the rate of blowdown from a steam generator is governed to a large extent by the amount of dissolved solids entering the system from leaks or other sources, and changes in the leak rates will affect the required blowdown rate.

It is necessary for us to take into consideration all such possibilities in arriving at a decision concerning the proper value of the operating parameters to use for the numerical computations. Consequently, since it is impractical to try to predict the precise operating characteristics of each component as a function of time over its expected lifetime, great reliance is placed upon experience gained in operating plants by AEC as well as by vendors. As pointed out in the Appendix, we have assigned standard decontamination factors to the various pieces of equipment and these are used unless better information is available. These values may be regarded as our current best estimate, and must of course be continually reviewed and revised as new and better information becomes available.

A second set of parameters required for the calculations involve the partition of iodine between water, steam, and air. These parameters are needed to determine what fraction of the iodine contained in the various effluent streams actually becomes airborne and potentially available for release. Clearly to obtain an absolutely accurate value for any given situation would require exact knowledge of all the conditions all of the time. In default of this knowledge we have again used experience together with experimental information and theory to estimate reasonable, realistic values. These too will undergo reevaluation as more experience becomes available.

In many cases equipment is available which may or may not be utilized at the applicant's option. For example the exhaust from a particular building may be routed directly to the atmosphere if the activity concentration is below a certain level, or otherwise it may be treated in some fashion to decontaminate it prior to release. To assess situations such as this it is necessary to know the exact criteria used in making the decision to use or not to use the optional equipment and to what extent it affects the amount of activity released. Frequently these

criteria are unavailable because the operating procedures are not yet sufficiently developed. In such cases some sort of judgment must be made concerning the conditions under which the equipment will actually be used. The making of such judgments is sometimes aided by the existence of Technical Specifications covering the particular operation. However, with few exceptions, reactor plant operations are conducted well under the limits designated by the Technical Specifications and the use of these limits would likely result in unduly pessimistic conclusions.

Related to the foregoing is the problem which sometimes arises when it is necessary to generate source terms for a reactor plant at the Construction Permit stage. Often the detailed design of the plant has not been firmly established at this stage. Hence it is difficult to get the exact operating data on all of the equipment or, indeed, to learn what equipment will be installed. In such cases it is sometimes necessary to assume that the gaseous source term will approximate that for other similar plants previously studied or for which experience is available. A detailed analyses will, however, be completed prior to the issuance of the Operating License.

We believe that the mathematical models present a reasonably realistic representation of the physical systems, and that within the limitations of the numerical input they give a good approximation of the magnitude of the gaseous source terms for the two types of reactors considered. They are however, still in their infancy and surely can be improved. In particular certain minor sources of activity have been neglected in comparison with the larger ones. This deficiency is unimportant at present, but as more sophisticated cleanup equipment is developed and applied to the large sources, the smaller ones will become relatively more important.

We have not yet completed development of a computerized model of the so-called "hogging" operation which involves the use of a mechanical vacuum pump to pull a vacuum on the main condenser during startup operations. At present this mode of release is being calculated by hand, however, we have it under consideration and expect to produce a computerized model within a few weeks.

The models could be made more sophisticated and complex by including greater system detail, however, until more reliable values of the various parameters become available, we do not feel that any great increase in complexity is justified.

It is our hope that the presentation of this documentation of the methods currently in use to generate radioactive gaseous source terms will stimulate others to address the problem. What we have created may be regarded under present circumstances as a "de facto" standard, and no standard should go unreviewed. We would, therefore, welcome suggestions and constructive criticism which would lead to increased fidelity of the modeling and credibility of the results.

References

(1) Calvert Cliffs' Coordinating Committee, Inc., et al. V. AEC, CA, D of C., 449F. 2d 1109.

(2) Estimates of Radioactive Liquid Effluent from Nuclear Reactors, M. J. Bell (To be presented at the Nov. 1972 Meeting of ANS, Washington, D.C.).

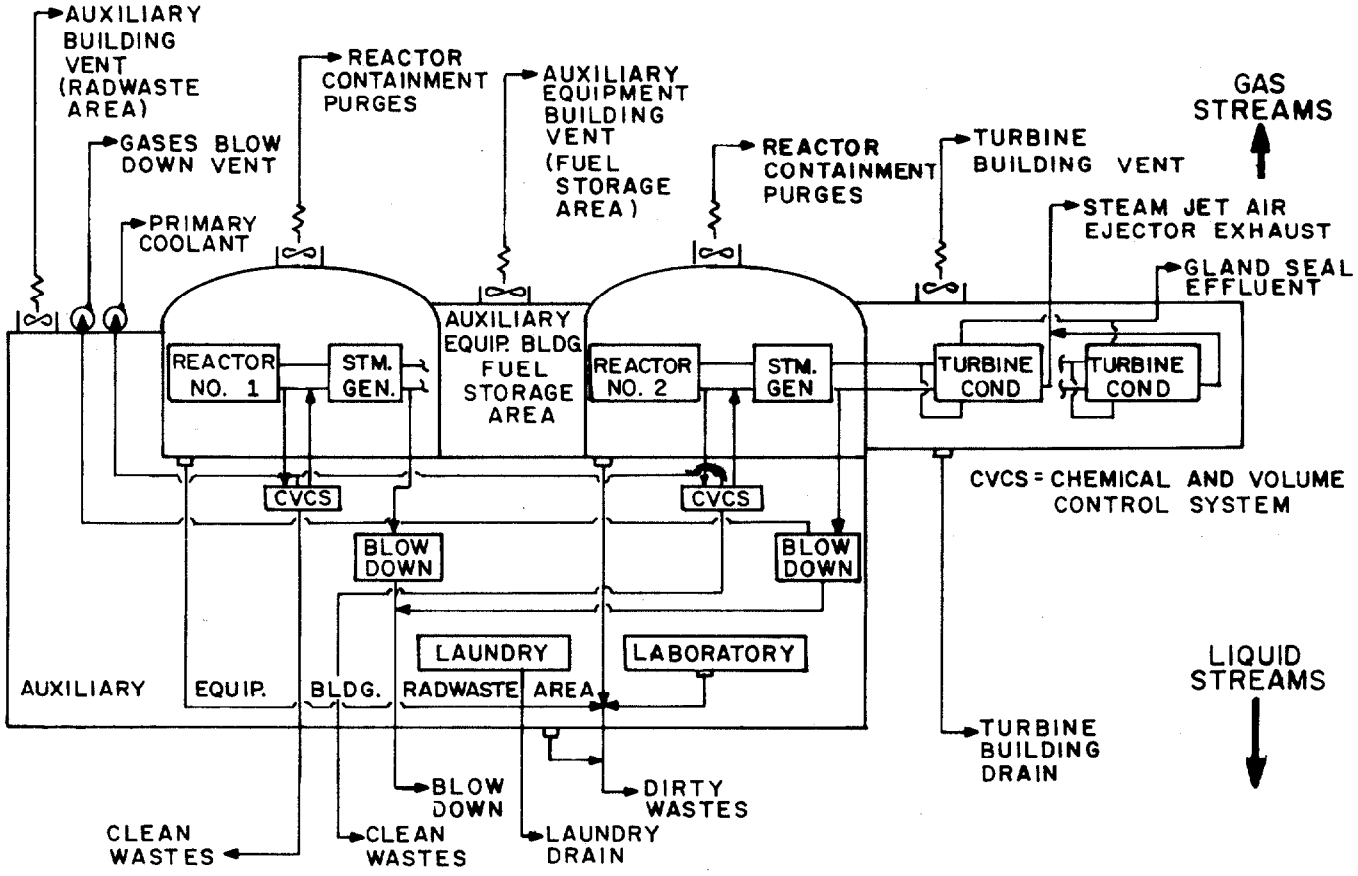

Fig. 1. Liquid and Gaseous Radwaste Effluents from Pressurized Water Reactors.

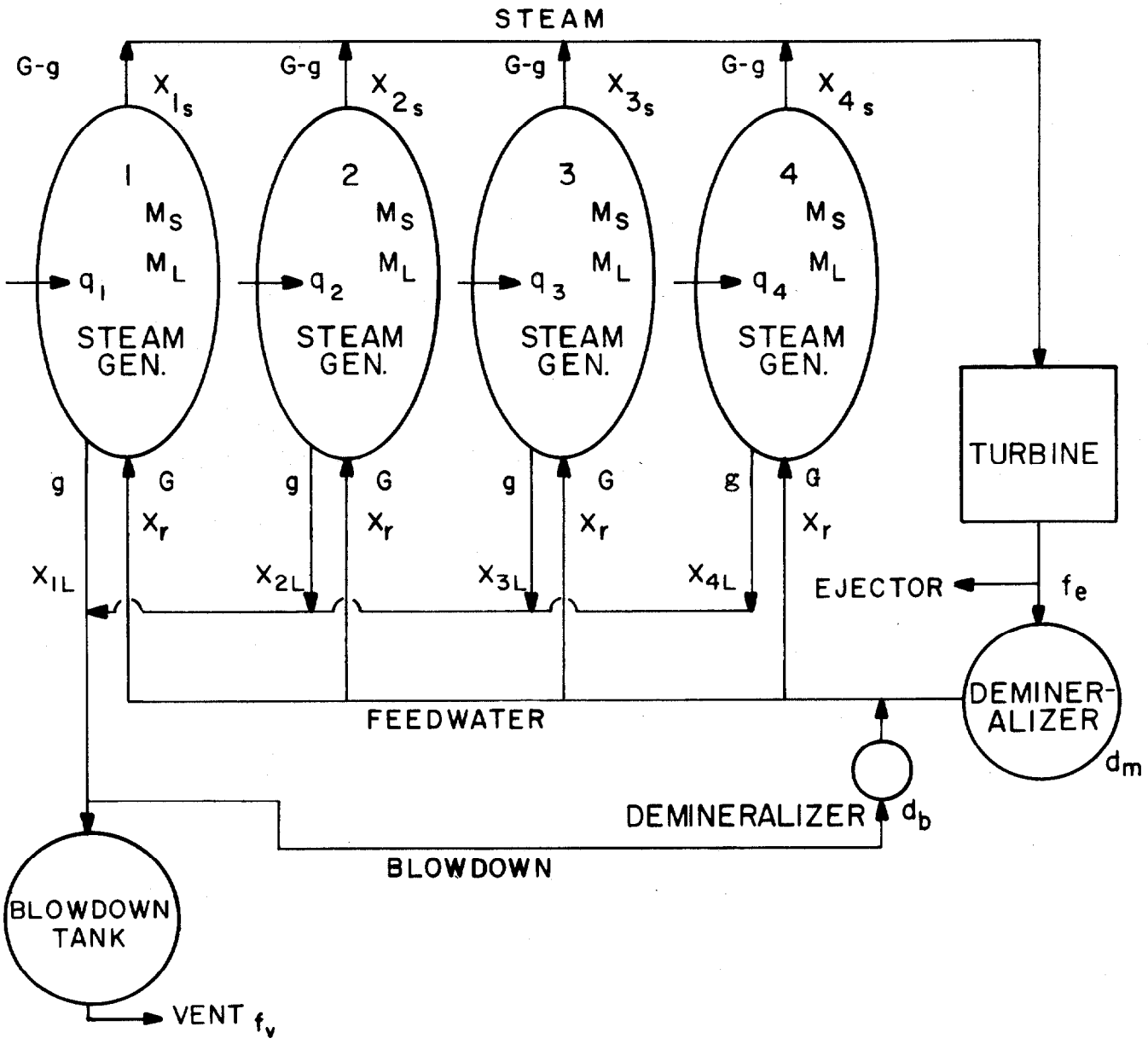

Fig. 2. Pressurized Water Reactor Secondary System Leak Model.

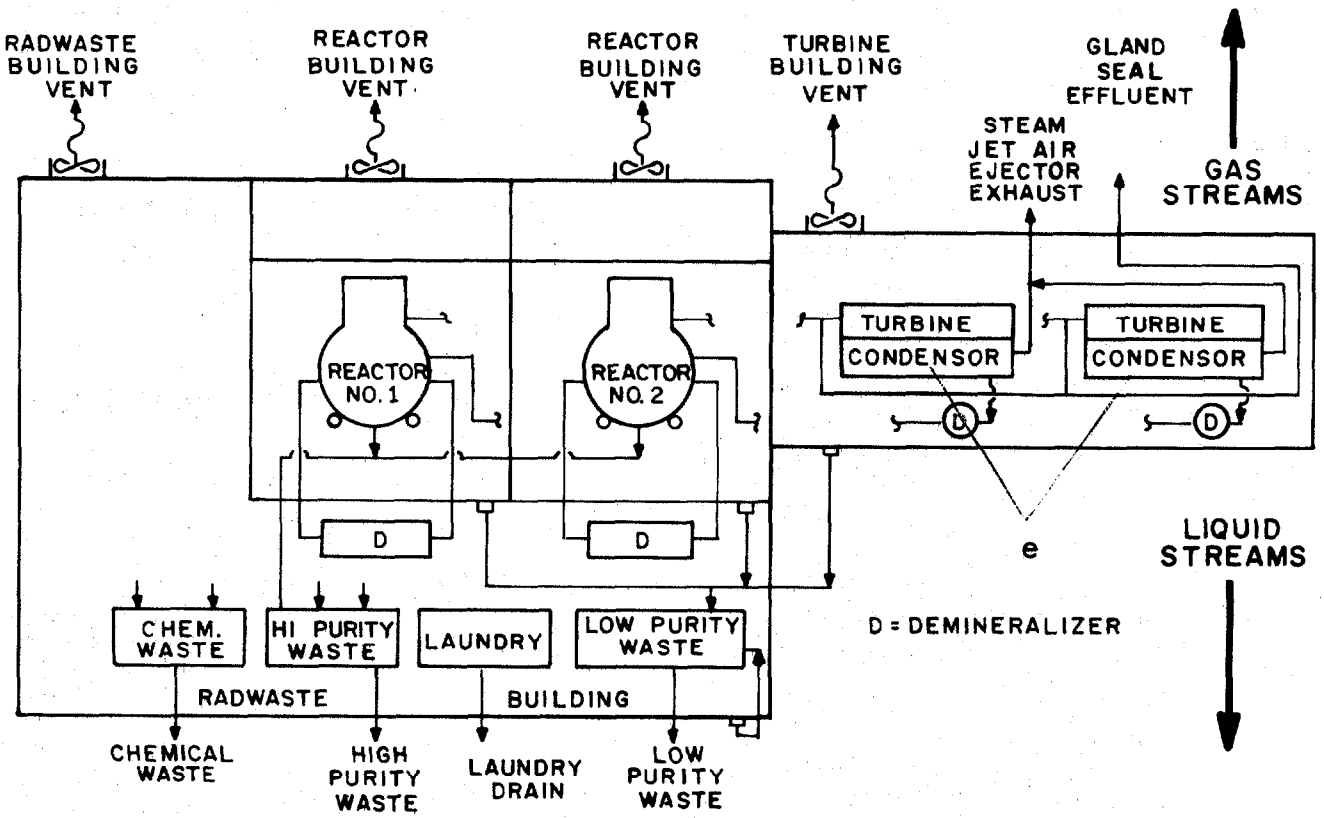

Fig. 3. Liquid and Gaseous Radwaste Effluents from Boiling Water Reactors.

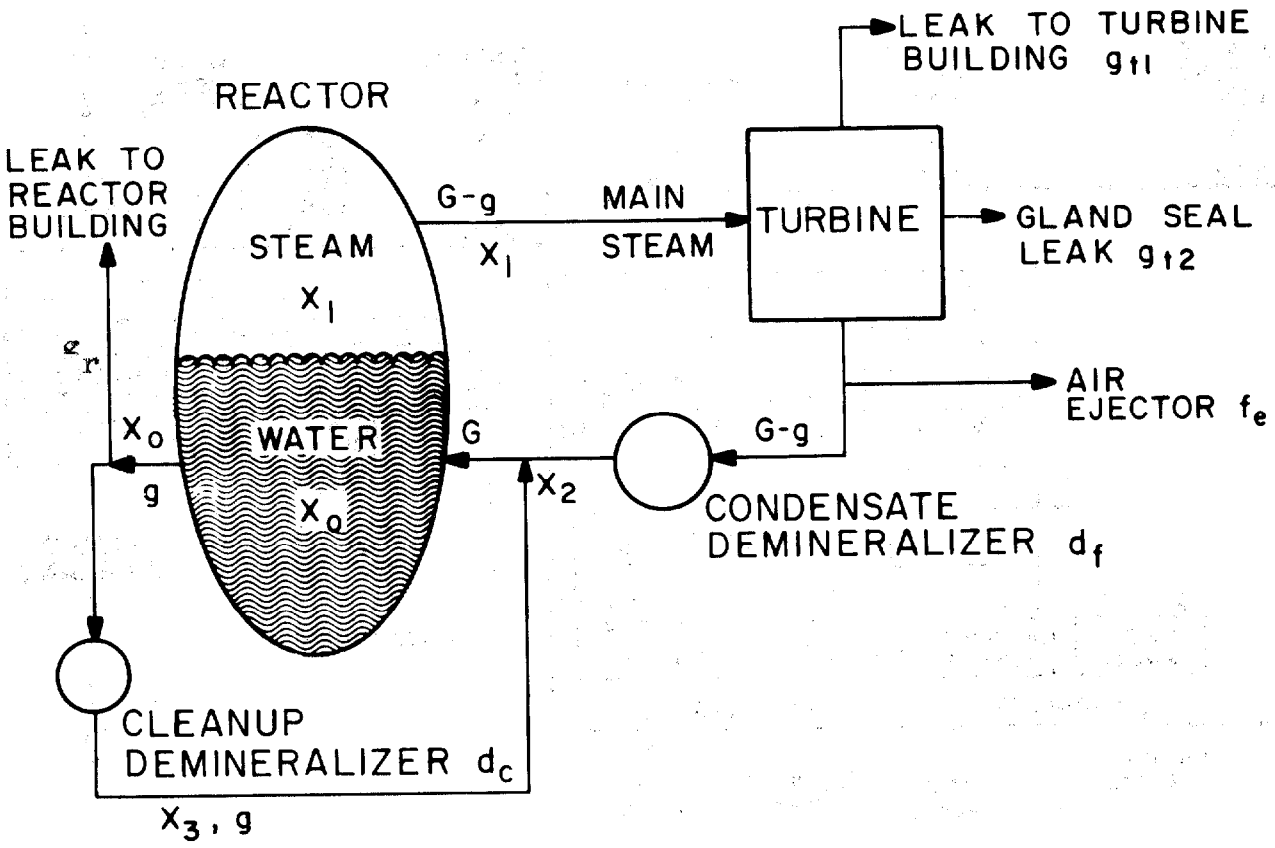

Fig. 4. Boiling Water Reactor Leak Model.

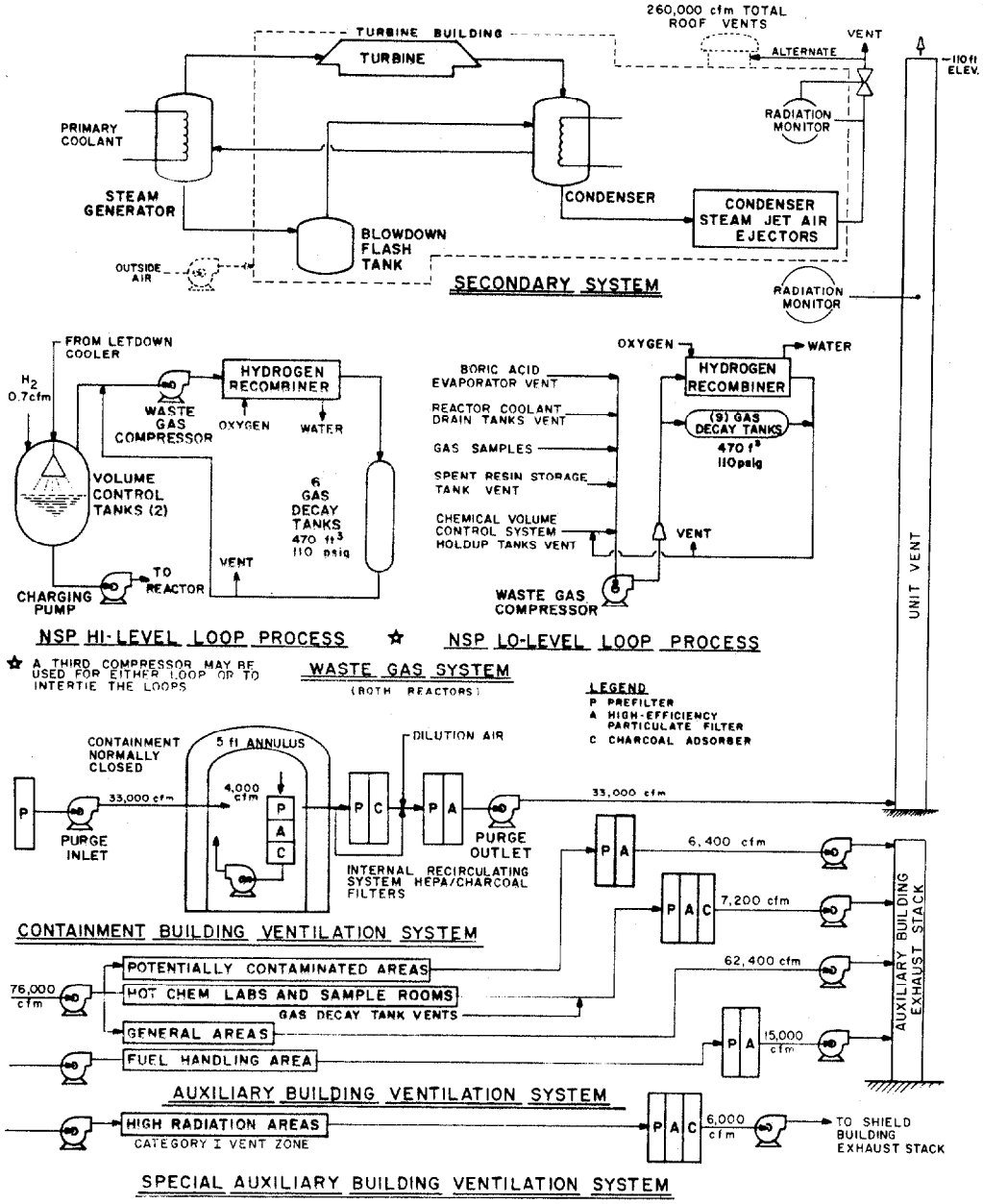

Fig. 5a. Gaseous Waste Disposal and Ventilation System Pressurized Water Reactor.

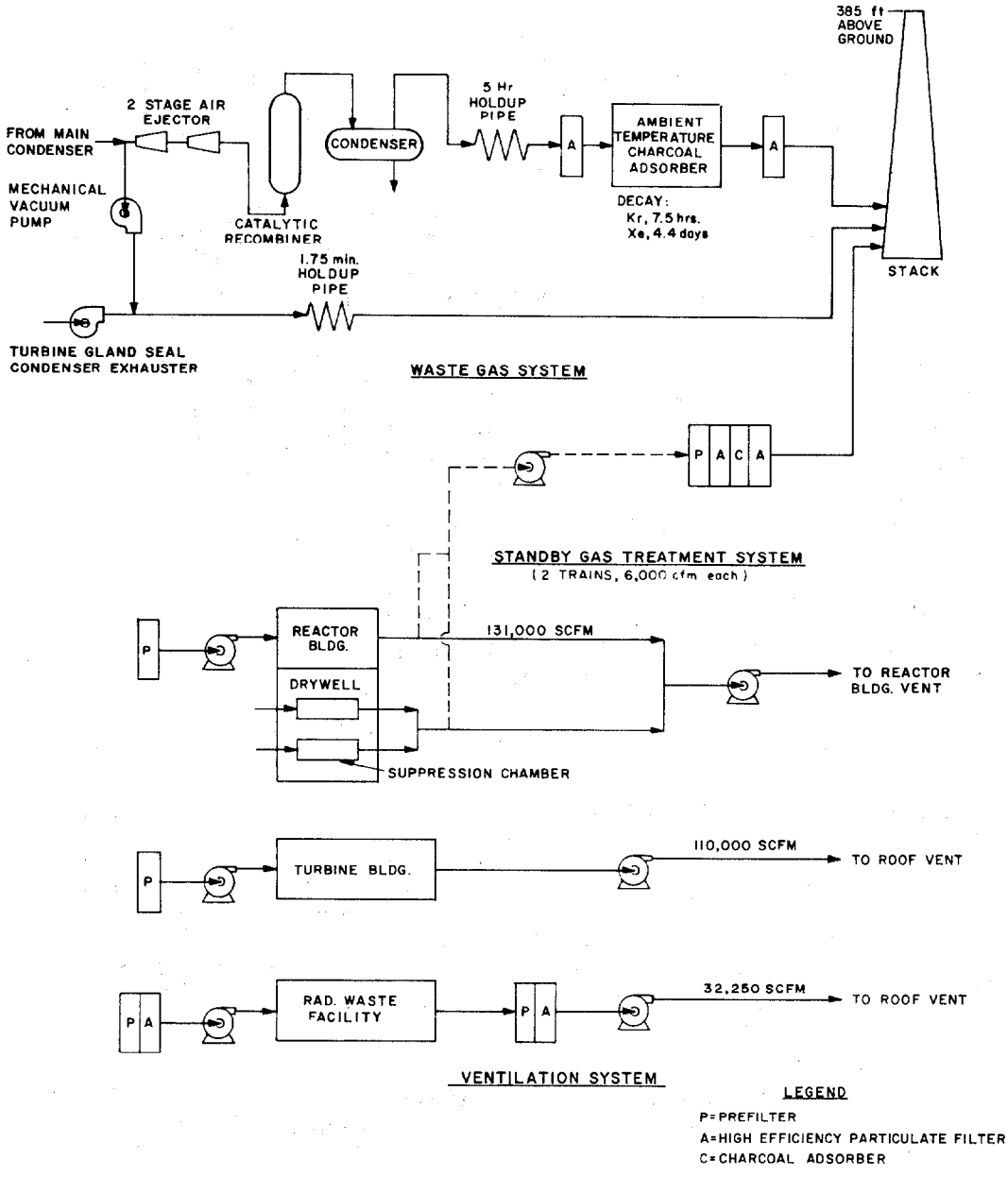

Fig. 5b. Gaseous Waste Disposal and Ventilation System Boiling Water Reactor.

Appendix

Computerized Model

A. Pressurized Water Reactors

1. Introduction

Noble gases and iodines may be released from a pressurized water reactor by four principal pathways: (1) primary coolant leaks into the containment envelope or into the auxiliary building; (2) as a result of the periodic degassing of the primary system during startup, venting of the letdown storage tank, or venting of the pressurizer; (3) continuous degassification of all or part of the shim bleed; (4) loss of primary coolant to the secondary system through leaks in the steam generators. Except where the contrary is specifically indicated, the simplified treatment outlined below contains the tacit assumption that the fission gases are homogeneously mixed with the coolant.

In case (1), the activity which enters the containment as a result of coolant leaks is permitted to accumulate for some period of time before being vented to the atmosphere. In some instances the containment atmosphere may be recirculated through charcoal filters (kidneys) to reduce the iodine concentration prior to purging. The purge may, in some cases, be released to the atmosphere through charcoal to further reduce the iodine emission. Activity entering the auxiliary building may be released directly to the atmosphere through the building vent with or without charcoal filtration.

The activity released during the periodic degassification of the primary system (case 2) is collected and held in tanks for some specified period of time, thus allowing for radioactive decay prior to release to the atmosphere.

Noble gases and a small fraction of the iodines are constantly being removed from the primary system through that fraction of the letdown stream which is processed through the boron recovery system (case 3). Most of the iodine in the letdown stream is removed by, and held on, the purification demineralizer, which is here assumed to process the entire letdown stream. The gases which are stripped in the boron recovery system are collected in the decay tanks and held for a specified period of time to permit radioactive decay prior to release to the atmosphere.

With the exception of leaks to the auxiliary building, all of the foregoing types of releases are intermittent, and may to some extent be controlled by the operators. On the other hand, the noble gases and iodines which enter the secondary system through leaks in the steam generators (case 4) are released continuously through the main condenser air ejector, and suffer little or no decay prior to release unless special equipment is provided. In those cases where steam generator blowdown is required, iodine and some noble gas may be released with the vented liquid and vapor.

The analysis presented below is an attempt to provide a reasonable mathematical model for describing quantitatively the various modes of release.

2. Primary Coolant Activity

The chief source of noble gas and iodine activity in the primary coolant is defective fuel, although some may be generated in "tramp" uranium present in the system. For the PWR systems the "escape rate coefficient" approach* will be used,

*Reference Safety Analysis Report (RESAR I) Table 9.1-5, Westinghouse Electric Corp.

and a lumped parameter model normalized to leaking fuel representing 1 MW of power is employed.

The following nomenclature is used

N_f = atoms/MW of the radionuclide present in the fuel

λ = decay constant (sec^{-1})

ν = escape rate coefficient (sec^{-1})

Y = fission yield

S = fission rate (3.05×10^{16} fissions/MW sec)*

Q = rate of introduction into the primary coolant (atoms/MW sec)

We have at once

$$\dot{N}_f = SY - (\lambda + \nu)N_f$$

so that at equilibrium**

$$N_f = \frac{SY}{\lambda + \nu} \quad \text{atoms/MW} \tag{1}$$

It follows that the rate of introduction of radioactivity into the primary coolant is

$$Q = \frac{\nu SY}{\lambda + \nu} \quad \text{atoms/MW sec} \tag{2}$$

Because the noble gases and the iodines behave somewhat differently, the calculation of their activity in the primary coolant will be treated separately.

We introduce the following additional nomenclature

N_p = atoms/MW of the radionuclide present in the primary coolant

α = fractional rate of loss of primary coolant to the secondary system (sec^{-1})

β_1 = fractional rate of leakage of primary coolant to the containment (sec^{-1})

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*Based on 43% ^{239}Pu fissions, 57% ^{235}U fissions.

**For the nuclides of interest only ^{85}Kr has a half-life sufficiently long so that radioactive equilibrium is not closely approached in the times involved. The value for ν, however, is sufficiently large so that the conservative simplifying assumption, that equilibrium always exists in the fuel, is justified.

β_2 = fractional rate of leakage of primary coolant to the auxiliary building (sec^{-1})

γ = total fractional rate of letdown flow (sec^{-1})

f_c = fraction of letdown flow which is stripped of noble gas

d_c = fraction of the iodine which remains in the coolant after the letdown flow passes through the purification demineralizer.

t = time (sec)

Subscripts

G = noble gas

I = iodine

For the noble gases we have

$$\dot{N}_{pG} = \frac{\nu\, SY}{\lambda + \nu} - (\lambda + \alpha + \beta_1 + \beta_2 + f_c\gamma)N_{pG}$$

so that

$$N_{pG} = \frac{\nu\, SY}{(\lambda+\nu)(\lambda+\mu_G)}\left(1 - e^{-(\lambda + \mu_G)t}\right) \text{ atoms/MW} \qquad (3)$$

where for convenience we have set

$$\mu_G \equiv \alpha + \beta_1 + \beta_2 + f_c\,\gamma \qquad (3a)$$

Similarly for the iodines

$$N_{pI} = \frac{\nu\, SY}{(\lambda+\nu)(\lambda+\mu_I)}\left(1 - e^{-(\lambda + \mu_I)t}\right) \text{ atoms/MW} \qquad (4)$$

where

$$\mu_I \equiv \alpha + \beta_1 + \beta_2 + (1 - d_c)\gamma \qquad (4a)$$

3. Release Rates from the Primary Coolant System

(a) Noble Gases

(1) Intermittent Degassing (Case 2)

Let us assume that the system is degassed at equal intervals M_2 times per year. It is assumed that all of the noble gases are removed from the primary coolant (but none from the fuel) each time this process occurs. Then the appropriate value of t to use in equation (3) is

$$t = t_2 = 3.15 \times 10^7/M_2 \text{ (sec)}$$

and the rate of emission by this pathway becomes $M_2 N_{pG}(t_2)$ atoms per/year. If it is further assumed that the gas is collected and allowed to decay for a time τ_2 prior

MW

to the atmosphere, the release rate by this pathway becomes

$$R_{G2} = M_2 N_{pG}(t_2) e^{-\lambda \tau_2} \text{ atoms/MW year} \tag{5}$$

This intermittent removal of activity from the primary system has an effect on the amount of activity present in the system. Hence, when estimating the magnitude of the releases by other pathways, we use the average value $\bar{N}_{pG}$ of $N_{pG}(t)$ between degassings; that is

$$\bar{N}_{pG} = \frac{1}{t_2} \int_0^{t_2} N_{pG}(t)dt = \frac{\nu \, SY}{(\lambda+\mu)(\lambda+\mu_G)} \left\{ 1 - \frac{[1 - e^{-(\lambda+\mu_G)t_2}]}{(\lambda+\mu_G)t_2} \right\} \frac{\text{atoms}}{\text{MW}} \tag{6}$$

(2) Leak to the Containment and Auxiliary Building (Case 1)

The rate at which primary coolant is leaking to the containment envelope is β_1 (sec^{-1}) and thus the rate of noble gas leakage is $\beta_1 \bar{N}_{pG}$ (atoms/sec). We assume that the containment envelope is purged M_1 times per year so that the total noble gas activity just prior to each purge is

$$\frac{\beta_1}{\lambda} \bar{N}_{pG} (1 - e^{-\lambda t_1}) \text{ atoms/MW}$$

where

$$t_1 = 3.15 \times 10^7 / M_1 \text{ (sec)}$$

Hence the total release of noble gas by this pathway is

$$R_{G11} = \frac{M_1 \beta_1 \bar{N}_{pG}}{\lambda} (1 - e^{-\lambda t_1}) \text{ atoms/MW year} \tag{7}$$

The rate at which noble gas activity leaks into the auxiliary building is $\beta_2 \bar{N}_{pG}$, and since this is usually released continuously without holdup, the release rate from this source becomes

$$R_{G12} = 3.15 \times 10^7 \, \beta_2 \, \bar{N}_{pG} \text{ atoms/MW year} \tag{8}$$

(3) Degassification of the Shim Bleed (Case 3)

The gases which are stripped from that portion of the letdown stream which is sent to the boron recovery system are collected in tanks over a period of time t_3 (sec), held static in order to permit radioactive decay for a period of time τ_3 (sec), and then released to the atmosphere M_3 times per year. Although there is a basic relationship between t_3, τ_3, and M_3 which depends upon the capacity of the available equipment and the volume of gas generated, it is usually necessary to determine the values of these parameters based upon the proposed operating conditions. It is easy to see that the release by this pathway is

$$R_{G3} = \frac{M_3 f_c \gamma \bar{N}_{pG}}{\lambda} (1 - e^{-\lambda t_3}) \; e^{-\lambda \tau_3} \quad \text{atoms/MW year} \qquad (9)$$

NOTE: In considering releases from the degassing operations (Cases 2 and 3) it has been tacitly assumed that the decay tanks are emptied instantly once the static decay period is completed. This is really not the case. These tanks are usually emptied to the atmosphere over a period of time which may be significant compared to the half lives of some of the nuclides under consideration. This can be corrected as follows.

Assume that the tank originally contains gas at a pressure of P(atm) and is being emptied at a constant fractional rate such that the amount of gas present has been reduced to atmospheric pressure in a time T (sec). This fractional rate, which we designate by r, is given by

$$\frac{1}{P} = e^{-rT}$$

so that

$$r = (\ln P)/T$$

The rate of loss of radioactive gas is

$$\dot{N} = -(\lambda + r)N$$

so that, if originally an amount N_o atoms was present, we have at time T in the tank

$$N(t) = N_o \, e^{-(\lambda + r)t}$$

The rate of emission is just $r N_o e^{-(\lambda + r)t}$, so that the total amount released is

$$R = \int_0^\infty r N_o e^{-(\lambda+r)t} \, dt = \frac{r N_o}{\lambda + r} = N_o \left[1 + \frac{\lambda T}{\ln P}\right]^{-1}$$

This suggests that to correct equations (5) and (9) for a finite decay-tank release time, the results of those equations should be multiplied by

$$\left[1 + \frac{\lambda T}{\ln P}\right]^{-1},$$

where T is time to reduce the pressure of the tank to atmospheric.

(b) Iodines

Here it is assumed that the periodic degassing operations do not affect the iodine concentration in the primary coolant, and that only a small fraction of the iodine is removed by these processes. Hence, the iodine content of the primary coolant at equilibrium is

$$\lim_{t \to \infty} N_{pI}(t), \quad \text{or}$$

$$\bar{N}_{pI} = \frac{\nu\, SY}{(\lambda+\nu)(\lambda+\mu_I)} \tag{10}$$

The treatment of the iodine releases differs from that of the noble gases. For the latter it has been assumed that all of the noble gas which accompanies the leaking primary coolant becomes airborne and is then available for release. This is not true of iodine where only a fraction of that contained in the leaking liquid becomes airborne. Moreover, iodine may be removed from gas streams by means of charcoal adsorbers, and from liquid streams by demineralizers. Neither of these mechanisms is assumed to be effective for noble gases.

In the sequel we will denote the fraction of iodine which becomes airborne by the letter f, the fraction of the iodine which remains in the gas stream after passing through a charcoal filter by the letter C, and the fraction of the iodine which remains after passage of the liquid stream through a demineralizer by the letter d. Appropriate subscripts will be used to identify the various components.

(1) Leak to the Containment and Auxiliary Building (Case 1)

The leakage rate to the containment envelope is $\beta_1 \bar{N}_{pI}$. This is collected for a time $t_1 = 3.15 \times 10^7/M_1$ (sec), where, as before, M_1 is the annual purge frequency. Hence, at the time of purging an amount

$$\frac{\beta_1 \bar{N}_{pI}}{\lambda}(1 - e^{-\lambda t_1}) \quad \text{atoms/MW}$$

of iodine activity is present. Of this only a fraction f_1 is airborne, and thus available for release.

In many cases the containment atmosphere is recirculated through a charcoal adsorber (Kidney) for a period of time τ_1 (sec) before the gases are released to the atmosphere. Also, the final release may be directed through a charcoal adsorber.

Let C_K be the fraction of iodine remaining in the gas stream after a single pass through the kidney, and let h (sec^{-1}) be the fractional rate of recirculation (building volumes per unit time per building volume). The amount of activity in the building and available for release after the start of circulation, N_{BI} is given by

$$N_{BI} = -(\lambda + (1 - C_K)h)N_{BI},\ N_{BI}(o) = f_1 \frac{\beta_1 \bar{N}_{pI}}{\lambda}(1 - e^{-\lambda t_1})$$

Thus after recirculation for a time τ_1 the building contains

$$N_{BI}(t_1, \tau_1) = \frac{f_1 \beta_1 \bar{N}_{pI}}{\lambda} \left(1 - e^{-\lambda t_1} \right) \; e^{-(\lambda+(1-C_K)h)\tau_1} \quad \text{atoms/MW} \tag{11}$$

If this is released M_1 times per year through a charcoal adsorber which passes a fraction C_1 of the iodine, the release rate by this pathway becomes

$$R_{I_{11}} = \frac{M_1 C_1 f_1 \beta_1 \bar{N}_{pI}}{\lambda} \left(1 - e^{-\lambda t_1} \right) e^{-(\lambda+(1-C_K)h)\tau_1} \quad \text{atoms/MW yr.} \tag{12}$$

NOTE. If no kidney exists, it is merely necessary to set $\tau_1 = o$. If there is no charcoal filter on the building vent, then C_1 should be set equal to unity (i.e., the fraction passing the filter is one.)

The auxiliary building leak is regarded as continuous with no accumulation, and there is no kidney filter. Thus the annual release rate by this pathway is just

$$R_{I_{12}} = 3.15 \times 10^7 \; C_2 f_2 \; \beta_2 \bar{N}_{pI} \quad \text{atoms/MW yr.} \tag{13}$$

Where here C_2 is the fraction passing the charcoal filter on the building vent if it exists (otherwise $C_2 = 1$) and f_2 is the fraction of the iodine in the leaking fluid which becomes airborne.

(2) Other Iodine Leaks from the Primary System

Because of the holdup received by the gases collected in the stripping operation, and because only a small amount of iodine is collected by this process, the release of iodine from the decay tanks is negligibly small.

(c) Conversion from Atoms to Curies

It will be noted that, up to this point, the entire calculation has been carried out in terms of atoms per MW per unit time. The values obtained can readily be converted to curies per MW per unit time by multiplying by the factor $\lambda/3.7 \times 10^{10}$ (Ci/atom).

4. Secondary Coolant Activity

The secondary coolant system is analyzed using a material balance, rather than a lumped parameter, approach. The noble gas and iodine inventories in the primary system are given by equations (6) and (10). Consequently, since α is the fractional rate of primary system leakage into the secondary system, the rates of introduction of these nuclides into the secondary system become

$$\alpha\bar{N}_{pG} = \frac{\alpha\nu\ SY}{(\mu+\nu)(\lambda+\mu_G)} \left[1 - \frac{1-e^{-(\lambda+\mu_G)t_2}}{(\lambda+\mu_G)t_2}\right] \text{atoms/MW sec} \qquad (14)$$

for the noble gases, and

$$\alpha\bar{N}_{pI} = \frac{\alpha\nu\ SY}{(\lambda+\nu)(\lambda+\mu_I)} \quad \text{atoms/MW sec} \qquad (15)$$

for the iodines.

In the following calculation it is convenient to convert these rates into curies/hour by multiplying by the factor $3.6 \times 10^3\lambda/3.7 \times 10^{10}$ Ci sec/atom hr. We denote the result by q (Ci/MW hr).

The simplified model used is shown in Figure 2. Although the calculation is done for a four loop plant, it is easily generalized to any number of steam generators. Briefly the model consists of an array of steam generators into each of which activity is leaking at a constant rate q_j, ($\Sigma q_j = q$). Steam is withdrawn through the turbine, condensed, and then returned as feedwater to the steam generators. In many cases water (blowdown) is withdrawn from the steam generators. Although the blowdown may be either continuous or intermittent, it is here always treated as continuous. Normally this water is replaced with clean makeup feedwater, however, in some cases it may be cleaned up and returned to the system. Provision is made to handle this, for the presence of a condensate demineralizer, and for two methods of removing activity to the environment: the condenser air ejector and the blowdown vent. Because the activity concentration in the secondary system is generally quite low, small steam leaks in this system are neglected.

The following nomenclature is used:

λ = decay constant (hr^{-1})

G = total flow to and from a single steam generator (lb/hr)

g = blowdown rate from a single steam generator (lb/hr)

X_{js} = activity concentration in steam leaving j'th generator (Ci/lb)

X_{jL} = activity concentration in the water in the j'th generator (Ci/lb)

X_r = activity concentration in the feedwater returning to the generator (Ci/lb)

f_e = fraction of activity removed by the air ejector

f_v = fraction of activity removed by the blowdown vent

d_m = fraction of activity remaining after passing the condensate demineralizer

d_b = fraction of activity remaining after passing the blowdown demineralizer*

*Note that if the blowdown is not returned to the feedwater stream, the value of d_b should be set equal to zero.

K = ratio of activity in steam to that in water

M_s = weight of steam in a single generator (lb)

M_L = weight of water in a single generator (lb)

Consider the first steam generator; the material balance at equilibrium is

$$q_1 + GX_r - (G-g)X_{1s} - g\,X_{1L} - \lambda'(M_s X_{1s} + M_L X_{1L}) = 0 \tag{16}$$

Here the first term represents the inleakage and the second is the activity returned in the feedwater. The third term is the loss by the main steam flow and the fourth is the loss due to blowdown. The last term is the loss by radioactive decay.

We assume that

$$X_{1s} = KX_{1L} \tag{17}$$

where K is a constant. Then equation (16) becomes

$$[KG + (1-K)g + \lambda'(M_L + KM_s)]\,X_{1L} - GX_r = q_1 \tag{18}$$

For convenience we set

$$[KG + (1-K)g + \lambda'(M_L + KM_S)] \equiv A$$

so that

$$\left.\begin{aligned} AX_{1L} - GX_r &= q_1 \\ \text{and similarly} \\ AX_{2L} - GX_r &= q_2 \\ AX_{3L} - GX_r &= q_3 \\ AX_{4L} - GX_r &= q_4 \end{aligned}\right\} \tag{19}$$

Neglecting decay in the circuit, we have the additional requirement that

$$d_m(1-f_e)(G-g)(X_{1s}+X_{2s}+X_{3s}+X_{4s}) + d_b g(1-f_v)(X_{1L}+X_{2L}+X_{3L}+X_{4L}) = 4GX_r \tag{20}$$

which, using equation (17) can be written

$$[K(G-g)(1-f_e)d_m + gd_b(1-f_v)][X_{1L}+X_{2L}+X_{3L}+X_{4L}] - 4GX_r = 0 \tag{21}$$

Let

$$[K(G-g)(1-f_e)d_m + gd_b(1-f_v)] \equiv B \tag{22}$$

so that equation (20) becomes

$$B[X_{1L} + X_{2L} + X_{3L} + X_{4L}] - 4GX_r = 0 \qquad (23)$$

Equation (19) and equation (23) may be solved to yield

$$\left.\begin{aligned}
X_{1L} &= \frac{4(A-B)q_1 + B(q_1 + q_2 + q_3 + q_4)}{4A(A-B)} && \text{Ci/MW lb}\\
X_{2L} &= \frac{4(A-B)q_2 + B(q_1 + q_2 + q_3 + q_4)}{4A(A-B)} && \text{Ci/MW lb}\\
X_{3L} &= \frac{4(A-B)q_3 + B(q_1 + q_2 + q_3 + q_4)}{4A(A-B)} && \text{Ci/MW lb}\\
X_{4L} &= \frac{4(A-B)q_4 + B(q_1 + q_2 + q_3 + q_4)}{4A(A-B)} && \text{Ci/MW lb}\\
X_r &= \frac{B(q_1 + q_2 + q_3 + q_4)}{4G(A-B)} && \text{Ci/MW lb}
\end{aligned}\right\} \qquad (24)$$

For η steam generators, these equations may be generalized to

$$\left.\begin{aligned}
X_{iL} &= \frac{q_i}{A} + \frac{B}{\eta A(A-B)} \sum_{j=1}^{\eta} q_j\\
X_r &= \frac{B}{\eta G(A-B)} \sum_{j=1}^{\eta} q_j
\end{aligned}\right\} \quad (i = 1,2,3 \ldots,\eta) \qquad (24a)$$

Clearly the concentrations in the steam leaving the generators can be obtained from equation (24) and equation (17).

5. Release Rates from the Secondary System

The release of activity from the secondary system comes at two points: the condenser air ejector, and the blowdown vent. The activity so released may or may not receive some treatment or decay prior to release to the atmosphere.

The rate of untreated release from the air ejector is

$$R'_e = (G-g)\, f_e \sum_{j=1}^{\eta} X_{js} = Kf_e(G-g) \sum_{j=1}^{\eta} X_{jL} \quad \text{Ci/MW hr} \qquad (25)$$

where η is the number of steam generators. From equation (24a) it is easy to see that

$$\sum_{j=1}^{\eta} X_{jL} = \frac{1}{A-B} \sum_{j=1}^{\eta} q_j = \frac{q}{(A-B)} \qquad (26)$$

Hence the untreated release rate from the air ejector becomes

$$R'_e = \frac{Kf_e(G-g)q}{A-B} \quad \text{Ci/MW hr} \tag{27}$$

The rate of untreated release from the blowdown vent is

$$R'_v = gf_v \sum_{j=1}^{\eta} X_{jL} = \frac{gf_v q}{A-B} \quad \text{Ci/MW hr} \tag{28}$$

We now consider the effects of treatment on noble gases and iodine.

(a) Noble Gases

It is assumed that all of the noble gases reaching the air ejector or the blowdown vent are removed at that point. Hence the partition coefficients f_e and f_v are both equal to unity. Thus for this case B = 0. It is also assumed that K = 1, i.e. there is no reduction in the noble gas concentration as a result of the phase change. Then

$A = G + \lambda' (M_L + M_s)$ so that

$$R'_{eG} = \frac{(G-g)q}{G + \lambda' (M_L+M_s)} \quad \text{Ci/MW hr} \tag{29}$$

and

$$R'_{vG} = \frac{g\,q}{G + \lambda' (M_L+M_s)} \quad \text{Ci/MW hr} \tag{30}$$

Now G is much larger than either g or $\lambda' (M_L + M_s)$. Hence as a first approximation we take $R'_{vG} = 0$ and

$$R'_{eG} = q \quad \text{Ci/MW hr} \tag{31}$$

That is we assume that all of the noble gas entering the secondary system escapes through the air ejector. In cases where the noble gas leaving the air ejector is held up for some period of time τ_4 hours, prior to release to the atmosphere, the actual release rate would be

$$R_{eG} = q\, e^{-\lambda'\tau_4} \quad \text{Ci/MW hr} \tag{32}$$

(b) Iodines

Here the parameters f_e, f_v, d_e, d_v, and K may have values which are less than unity. Hence the untreated releases are given by equations (27) and (28) for the air ejector and the blowdown vent respectively. The values of the parameters will depend upon the configuration of the actual system under consideration. In some cases the blowdown has no vent but is simply returned to the system through the

demineralizer d_v; hence in this case f_v is set equal to zero. In other cases the blowdown effluent is completely removed from the system so that $d_b = 0$ and f_v has some finite value. For the case of recirculating steam generators, the value of K will be less than unity, but for straight-through generators the value of K is unity.

Releases of iodine to the atmosphere from these two sources may receive various types of treatment, including delay and possibly charcoal filtration. The values of R'_{eI} and R'_{vI} must be reduced accordingly. In general, multiplication by the factor $C\ e^{-\lambda' \tau}$ where C is the fraction of iodine escaping the charcoal adsorber, and τ is the delay time (hr) will provide the proper adjustment.

B. Boiling Water Reactors

1. Introduction

The boiling water reactor system is, in many ways, similar to the secondary system of a pressurized water reactor. Hence, the model utilized here is based upon a material balance. The principal features are illustrated in Figure 4.

Noble gases and iodines may escape from the system by four main pathways: (1) leaks of steam and water into the reactor building, (2) steam or water leaks into the turbine building, (3) removal in steam used in the turbine shaft vacuum seal glands, and (4) removal by the condenser air ejector. In addition to the losses incurred by these leaks, iodine, but not noble gas, is removed by the main condensate demineralizer and by the reactor cleanup system demineralizer. One other source of activity release, which must be treated as a special case, is the emission of activity from the condenser as a result of the action of the mechanical vacuum or "hogging" pump which is used to maintain condenser vacuum during shutdown and start-up operations.

In case 1, the activity which enters the reactor building may be collected for a period of time and then released, in some cases through charcoal filtration. The activity which leaks to the turbine building (case 2) is usually released continuously, but it too may be passed through charcoal adsorbers before being discharged to the atmosphere. The gland seal leakage (case 3) occurs only in those cases where primary steam is used for this purpose. Approximately 0.1% of the primary steam is used to seal the shafts. This steam is generally extracted and condensed in a gland seal exhauster system. Unless the vents on this system are treated, activity can escape by this pathway. Gaseous effluent from the air ejector is delayed for a short period of time (30 min minimum) prior to release, and, in most cases, is subjected to further treatment or decay prior to release to the atmosphere.

2. Activity Concentration in the Primary Coolant

Activity in the primary coolant originates with defective fuel, although some may be present as the result of fission of "tramp" uranium. In the case of Boiling Water Reactors, it has been found that the "escape rate" coefficient approach used to estimate the rate of activity introduction into the primary coolant does not give results which agree with observation. Consequently, a diffusion formulation which expresses the relative escape rates of iodines and noble gases in terms of a dif-

fusion model* is used. This appears to give a spectrum of nuclides comparable to that which has been observed in operating reactors. For the purpose of this analysis, we will initially simply designate the rate of loss of a given nuclide from the fuel by the symbol q (Ci/MW hr) with an appropriate subscript to identify the species.

The following nomenclature is used

q = activity leaking into the coolant system from the fuel (Ci/MW hr)

X_o = activity concentration in the reactor water (Ci/lb)

X_1 = activity concentration in the reactor steam (Ci/lb)

X_2 = activity concentration in the feedwater (Ci/lb)

X_3 = activity concentration in the returning cleanup stream (Ci/lb)

G = feedwater flow (lb/hr)

g = cleanup system flow (lb/hr)

g_r = leakage to the reactor building (lb/hr)

g_{t1} =leakage to the turbine building (lb/hr)

g_{t2} =gland seal steam leak rate (lb/hr)

NOTE: $g_r + g_{t1} + g_{t2} \ll G$, $g_r \ll g$, $g \ll G$

λ' = decay constant (hr^{-1})

f_e = fraction of activity removed by the air ejector

d_f = fraction of activity remaining after the condensate demineralizer

d_c = fraction of activity remaining after the cleanup demineralizer

M_L = weight of liquid in the reactor (lb)

M_S = weight of steam in the reactor (lb)

M = weight of steam in the entire system (lb)

K = ratio of activity in steam to that in air

t = time (hr)

Subscripts I = iodine, G = noble gases.

*Analytical Methods for Evaluating the Radiological Aspects of the General Electric Boiling Water Reactors. N. R. Horton, W. A. Williams, J. W. Holzclaw, APED-5756, March 1969.

Because they behave quite differently the noble gases and iodines will be treated separately. Moreover since the leaks are small compared to the main steam flow and the cleanup system flow, they will be neglected in calculating the primary system concentration. This results in slightly conservative (high) values of the primary system concentration.

(a) Noble Gases

The noble gases are assumed to be all carried out with the primary steam, and to be removed from the system by leaks and by the air ejector. Hence, no noble gas is returned in the feedwater. Thus the material balance in the reactor is, at equilibrium

$$q_G - GX_{oG} - \lambda' (M_S + M_L)X_{oG} = 0 \tag{33}$$

and

$$X_{oG} = \frac{q_G}{G + \lambda'(M_S + M_L)} \quad \text{Ci/MW lb}$$

Since for noble gases K = 1 and the cleanup demineralizer does not affect noble gases

$$X_{1G} = X_{oG} = X_{3G} \tag{34}$$

and since all of the noble gas is removed by the condenser air ejector

$$X_{2G} = 0 \tag{35}$$

(b) Iodines

The material balance at equilibrium is

$$q_I + gX_{3I} + (G-g)X_{2I} - (G-g)X_{1I} - g\,X_{oI} - \lambda'[M_L X_{oI} + M_S X_{1I}] = 0 \tag{36}$$

Now

$$X_{1I} = K\,X_{oI},\ X_{2I} = (1-f_e)d_f X_{1I},\ X_{3I} = d_c X_{oI}$$

So that

$$X_{oI} = \frac{q_I}{K[G-g][1-(1-f_e)d_f] + g[1-d_c] + \lambda'[M_L + KM_S]} \quad \text{Ci/MW lb} \tag{37}$$

$$X_{1I} = K\,X_{oI} \quad \text{Ci/MW lb} \tag{38}$$

$$X_{2I} = K(1-f_e)d_f\,X_{oI} \quad \text{Ci/MW lb} \tag{39}$$

$$X_{3I} = d_c X_{oI} \quad \text{Ci/MW lb} \tag{40}$$

3. Release Rates

(a) Noble Gases

(1) Leaks to the Containment

Noble gases are released from the primary coolant system in a variety of ways, however since it is assumed that all of these nuclides are carried off by the steam, and since the leak into the containment building is assumed to consist of primary water, it is further assumed that only a negligible amount of noble gas is released by this pathway.

(2) Leaks to the Turbine Building

Noble gas activity may escape into the turbine building by means of various steam and water leaks in valves and piping. This activity receives no treatment or decay; thus the rate of leakage by this pathway is just

$$R'_{G2} = g_{t1}\,\chi_{1G} = g_{t1}\chi_{oG} \qquad \text{Ci/MW hr}$$

or

$$R_{G2} = 8766\; g_{t1}\,\chi_{oG} \qquad \text{Ci/MW yr} \tag{41}$$

(3) Gland Seal Leak

Steam used to seal the shafts is sometimes supplied from the main steam supply, is sometimes cleaned up condensate, and in some cases is supplied from an external source. Only in the first case will any appreciable amount of activity be released. The release rate is

$$R_{G3} = 8766\; g_{t2}\,\chi_{oG} \qquad \text{Ci/MW yr} \tag{42}$$

(4) Release through the Air Ejectors

This is the principal source of noble gas release from the reactor coolant. In earlier models of the BWR this gas was given a 30 minute delay to permit radioactive decay of the short-lived radionuclides. Current practice is to discharge the gas through some treatment facility such as a low temperature charcoal bed in order to delay the release for several hours in the case of the kryptons and several days in the case of the xenons. The release rate by this pathway is

$$R_{G4} = 8766\;(G-g)\;X_{oG}e^{-\lambda'\tau_4} \qquad \text{Ci/MW yr} \tag{43}$$

where here τ_4 (hr) is the delay time.

(b) Iodines

(1) Leaks to the Containment

Water leaking into the containment envelope is presumed to originate from the valves, pipes, and pumps associated with the recirculation system and the reactor cleanup system. The concentration of iodine in the leaking fluid will depend upon

whether the leak occurs upstream or downstream of the system demineralizers, however to be conservative it is here assumed that the leak occurs upstream.

Iodine is introduced into the containment continuously at the rate $g_r X_{oI}$ Ci/hr. Here it is collected for a period of time t_1 (hr) and then purged from the building, possibly through a charcoal filter which permits a fraction C, of the iodine to pass through. Moreover, it is assumed that only a fraction f_1 of the iodine becomes airborne, and thus eligible for release. The building is purged $M_1 = 8766/t_1$ times per year. Hence the annual rate of release by this pathway is

$$R_{11} = \frac{CM_1 f_1 g_r X_{oI}}{\lambda} (1-e^{-\lambda' t_1}) \qquad \text{Ci/MW yr} \tag{44}$$

NOTE: If the leakage occurs downstream of the cleanup demineralizer, this fact can be handled by an appropriate adjustment to the constant C.

---

(2) Leaks to the Turbine Building

Leaks from this source are assumed to be continuous, although the iodine may be routed through a charcoal filter before release to the atmosphere. The fraction of iodine which becomes airborne is designated by f_2 and the fraction which escapes the charcoal is denoted by C_2. Hence the annual release by this pathway is

$$R_{I2} = 8766\ g_{t1} f_2 C_2 X_{1I} \qquad \text{Ci/MW yr} \tag{45}$$

(3) Gland Seal Leaks

Here again the release is assumed to be continuous. The fraction of iodine which is removed in the gaseous effluent from the gland seal condenser is designated by f_3 and if a charcoal filter or other treatment is provided, the fraction escaping this treatment is denoted by C_3. Hence the release rate by this pathway is

$$R_{I3} = 8766\ g_{t2} f_3 C_3 X_{1I} \qquad \text{Ci/MW yr} \tag{46}$$

NOTE: If "clean" steam is used for the gland seals, this source becomes negligible.

---

(4) The Condenser Air Ejector

Release of activity through the condenser air ejector is usually the largest source of activity. The amount of iodine activity emitted by this source is

$$R'_{I4} = 8766\ (G-g) f_e X_1 \qquad \text{Ci/MW yr} \tag{47}$$

where f_e is the fraction of the iodine removed by the ejector. Early designs provided for a 30 minute delay and then direct discharge of the activity, usually through a high stack. Modern designs generally provide for some method of reducing the activity release. Basically, these methods include either charcoal filtration and delay to permit decay or cryogenic concentration. Hence if C_4 is the fraction of iodine which escapes filtration, and τ_4 is the decay time, the annual rate of release of iodine by this pathway becomes

$$R_{I4} = 8766\ (G-g) f_e C_4 X_1 e^{-\lambda' \tau_4} \qquad \text{Ci/MW yr} \qquad (48)$$

C. Numerical Values of the Parameters

1. Introduction

The task of assigning numerical values to the various parameters employed in the foregoing analysis is a formidable one. For the purpose at hand, assessment of the environmental impact of the normal radioactive gaseous effluents, it is necessary to use realistic expected average values of the parameters. This differs from the approach taken in accident analyses where conservative values are frequently employed.

The choice of these expected values must be based upon a detailed examination of each plant for the purpose of determining what equipment is available and how it will be operated. For simplicity certain standard values have been assigned to each piece of equipment (i.e. demineralizers, charcoal adsorbers, etc.), and certain standard values have been assigned to describe the partition of iodine between water and air, and between water and steam. These values are based partly upon experience gained by the AEC Directorate of Licensing, partly upon experimental results, and partly upon theory. Unless there is positive evidence to the contrary, the standard values are used in the evaluation of the magnitude of the radioactive gaseous effluent release.

In all cases the fission rate and the fission product yields are based upon a fissile mixture in which 43% of the fissions are of ^{239}Pu and 57% or of ^{235}U. The reactor thermal neutron flux is assumed to be 2.9×10^{13} n/cm^{2}sec. These values correspond to a 3.3% enriched core which has operated at a power density of 30 MW/tonne for a period of 550 days. Only cumulative yields are used.

Each system is evaluated at stretch nuclear power multiplied by an assumed plant factor of 0.8. Hereinafter this power level is referred to as the reactor thermal power.

2. Pressurized Water Reactors

(a) Release of Activity from the Fuel

The escape rate coefficients currently in use are 6.5×10^{-8} sec^{-1} for noble gases (Kr, Xe) and 1.3×10^{-8} sec^{-1} for iodines. These values are used together with an assumed failed fuel fraction of 0.0025; that is 0.25% of the reactor thermal power is being generated by defective fuel. It should be noted that the effluent release results obtained in Section A are given in terms of Ci/MW year. Thus to obtain the total release from the various pathways, it is necessary to multiply the results of the calculations in Section A by 0.25% of the reactor thermal power

(expressed in MW).

(b) System Weights and Flow Rates

The weight of fluid in the various parts of the primary and secondary systems, as well as the flow rates must be obtained on an individual basis for each plant. When converting between volume and weight care must be taken to correct for temperature and phase.

(c) Leak Rates from the Primary System

Although each plant has its own individual characteristics a set of standard leak rates has been selected, based upon experience. These are used unless there is sufficient positive evidence to justify different values.

The leak rate from the primary to the secondary system (steam generator leak) is assumed to be 20 gallons/day total of hot water ($\sim$ 5 lb/hr).

The leak rate into the containment building is assumed to be 40 gallons/day of hot water ($\sim$ 10 lb/hr).

The leak rate into the auxiliary building is assumed to be 20 gallons/day of cold water ($\sim$ 7 lb/hr) and 1 gallon/day of hot water ($\sim$ 0.25 lb/hr).

The distinction between hot and cold is made here because in the former case the specific gravity of the water is about 0.7, whereas in the latter it is 1.0. Moreover the partition factor for iodine (which defines the fraction that becomes airborne) will be higher for hot water than it will be for cold water.

Given these values, together with the weight of primary coolant in the system, it is easy to compute the values of the fractional leak rates, α, β_1 and β_2.

(d) Letdown Flow

The total letdown flow must be obtained from data on the individual plant under consideration. The fractional rate of letdown flow, γ, is just the ratio of the total letdown flow expressed in lb/hr to the total weight of coolant in the primary system. The fraction of this which is stripped of noble gas, f_e, must also be determined on an individual basis.

(e) Frequency of Containment Purge

In general this is assumed to occur 4 times per year unless a different figure, based upon plant design and operating procedure, can be supported.

(f) Steam Generator Blowdown Rate

This is assumed to average 10 gpm continuously for each reactor. Some manufacturers provide a "full flow" condensate demineralizer, in which case there is usually no blowdown. In the latter case care must be taken to establish how much extraction steam is removed at, or ahead of, the turbine (for use in feedwater heaters, etc.) and to determine whether the condensate from this source is returned to the feedwater upstream or downstream of the condensate demineralizer.

For the case of blowdown g has a finite value (10 gpm hot) and d_b is set equal to zero; since there is no condensate demineralizer, d_m is set equal to unity (i.e.,

100% of the iodine passes through it). For the case of a condensate demineralizer g is set equal to zero and d_m has a finite value, less than unity, based upon the fraction of the total secondary flow that actually passes through it, and its efficiency in removing iodine.

(g) Decontamination Factors for Iodine

Steam generator internal partition generators	$K = 1 \times 10^{-2}$ (recirculating generators)
	$K = 1.0$ (straight through generators)
Steam generator blowdown vent	$f_v = 5 \times 10^{-2}$
Blowdown vent with heat exchanger	$f_v \times 10^{-1}$
Blowdown vent with heat exchanger and charcoal filter	$f_v \times 10^{-2}$
Condenser air ejector	$f_e = 5 \times 10^{-4}$
Condenser air ejector plus condenser and charcoal	$f_e = 5 \times 10^{-6}$
Charcoal filters in vents and kidney filters	$C = 10^{-1}$
Coolant leakage hot	$f = 10^{-1}$
Coolant leakage cold	$f = 10^{-4}$

(h) Periodic Degassing

Unless a different value can be supported, it is assumed that the entire noble gas inventory is stripped from the system twice a year.

(i) Noble Gas Decay

The collection time, and release rate of noble gases accumulated from the shim bleed and from the periodic shutdowns must be determined on an individual basis.

3. Boiling Water Reactors

(a) Release of Activity from the Fuel

It has been found that the escape rate coefficients used to estimate the rate of escape of gaseous fission products from PWR fuel produce results in BWR's which differ significantly from observed values. Consequently, a diffusion model has been used to estimate these release rates in BWR's. In this treatment the release rates are given by

$$q_G = 2.18 \times 10^4 \, Y_G \lambda'^{0.4}_G \quad \text{Ci/MW hr}$$

$$q_I = 2.02 \times 10^4 \, Y_I \lambda'^{0.5}_I \quad \text{Ci/MW hr}$$

Here the values of the numerical constants have been adjusted to produce a concentration of about 0.005 μ Ci/m^2 of ^{131}I in a typical 3400 MW thermal BWR, and have been normalized to 1 MW of thermal reactor power. The results are in reasonable agreement with the observed concentrations in operating reactors. Hence the results of Section B must be multiplied by the reactor thermal power.

(b) System Weights and Flow Rates

As in the case of PWR's these must be determined for each plant under consideration.

(c) Reactor Building Leakage

The reactor building leakage rate g_r is taken to be 1 gpm of hot water ($\sim$ 6 lb/min). The fraction of iodine which becomes airborne is 10^{-3}.

(d) Turbine Building Leaks

The leakage rate into the turbine building is 1700 lb/hr of primary steam with airborne iodine fraction (f_2) of unity for iodine. If clean steam is used for valve packings, this number is reduced to 340 lb/hr.

(e) Turbine Gland Seals

If primary steam is used for the gland seals, the total flow involved is assumed to be 0.1% of primary steam flow; a factor $f_3 = 10^{-2}$ is used to account for the presence of a gland seal condenser. If other treatment is provided f_3 is reduced accordingly.

If clean steam is used the release from this source is assumed to be negligible

(f) Condenser Air Ejector

The airborne fraction of iodine from the condenser air ejector is assumed to be $f_e = 5 \times 10^{-3}$ where a factor of 2 has been assumed for plate out.

(g) Decontamination Factors for Iodine

Internal partition between steam and water	$K = 1.2 \times 10^{-2}$
Charcoal filters	$C = 10^{-1}$

For special equipment such as deep bed charcoal filters, cryogenic distillation, holdup, etc. the decontamination factors are evaluated on an individual basis.

(h) Decontamination Factors for Noble Gas

Where specialized equipment such as that mentioned above is installed, it is evaluated on an individual basis. In all cases the effect of such equipment can be treated as a combination of decay and filtration.

D. Program for Calculating Gaseous Source Terms, STEFEG

Program STEFEG consists of two sections:

1. The main section computes the gaseous releases through various paths from BWR's and/or PWR's.

2. The BLOCK DATA sections contain the constants of the various isotopes being considered.

   The program is listed on the following pages.

The input data required is listed in the program as comments. As can be seen, the data deck is also used as a reference deck on each reactor since a description of the value found in columns 72-80 is on each card. Typical examples of input data for a PWR and a BWR along with the output for this data is shown.

LISTING OF PROGRAM STEFEG

Twelve pages of Computer printout follows.

```
      DIMENSION A(20)
      DIMENSION ACONT(20)
      DIMENSION ACOOL(20)
      DIMENSION ASHIM(20)
      DIMENSION AVCOOL(20)
      DIMENSION AUX(20)
      DIMENSION B(20)
      DIMENSION C1(20)
      DIMENSION C2(20)
      DIMENSION C3(20)
      DIMENSION CONCL(20)
      DIMENSION CONCP(20)
      DIMENSION CONCS(20)
      DIMENSION DECOH(20)
      DIMENSION DECON(20)
      DIMENSION EFDEC(20)
      DIMENSION EFDEH(20)
      DIMENSION ELB(20)
      DIMENSION ELSB(20)
      DIMENSION ELSV(20)
      DIMENSION FLV(20)
      DIMENSION ESCAH(20)
      DIMENSION ESCAP(20)
      DIMENSION EJT(20)
      DIMENSION EL1(20)
      DIMENSION EL2(20)
      DIMENSION EL3(20)
      DIMENSION EL4(20)
      DIMENSION ELS1(20)
      DIMENSION ELS2(20)
      DIMENSION ELS3(20)
      DIMENSION ELS4(20)
      DIMENSION EX1(20)
      DIMENSION EX2(20)
      DIMENSION EX3(20)
      DIMENSION EX4(20)
      DIMENSION EXC(20)
      DIMENSION EXX(20)
      DIMENSION FAA(20)
      DIMENSION FAB(20)
      DIMENSION NAME(20)
      DIMENSION PYIEL(20)
      DIMENSION Q1(20)
      DIMENSION Q2(20)
      DIMENSION Q3(20)
      DIMENSION Q4(20)
      DIMENSION RAAD(20)
      DIMENSION RBL(20)
      DIMENSION S(20)
      DIMENSION SGL(20)
      DIMENSION TBL(20)
      DIMENSION TOT(20)
      DIMENSION TOTS(20)
      DIMENSION UYIEL(20)
```

```
      DIMENSION X0(20)
      DIMENSION X1(20)
      DIMENSION X2(20)
      DIMENSION X3(20)
      DIMENSION X4(20)
      DIMENSION X5(20)
      DIMENSION X1L(20)
      DIMENSION X2L(20)
      DIMENSION X3L(20)
      DIMENSION X4L(20)
      DIMENSION XR(20)
      DIMENSION XX1(20)
      DIMENSION YIELD(20)
      COMMON/NAM4/UYIEL,PYIEL,DECON,EFDFC,ESCAP
   80 READ(50,50)NAME
   50 FORMAT(20A4)
      READ(50,51)KIND
   51 FORMAT(79X,I1)
      IF(KIND.EQ.1)GO TO 1003
      READ(50,201)POWTH
  201 FORMAT(70X,E10.3)
      READ(50,201)GTO
      READ(50,201)PER
      READ(50,201)GDE
      READ(50,201)OPFRA
      READ(50,201)GTB
      READ(50,201)GGS
      READ(50,201)GRB
      READ(50,201)WLIQ
      READ(50,201)WSTE
      READ(50,201)CON
      READ(50,201)FEJ
      READ(50,201)P1
      READ(50,201)P2
      READ(50,201)P3
      READ(50,201)DCN
      READ(50,201)DCU
      READ(50,201)EN
      READ(50,201)TIM1
      READ(50,201)TIM2
      READ(50,201)TIM3
      READ(50,201)TIM4
      READ(50,201)FIL1
      READ(50,201)FIL2
      READ(50,201)FIL3
      READ(50,201)FIL4
      READ(50,51)KCHAR
      READ(50,201)CHTI1
      READ(50,201)CHTI2
C
CARD  1  NAME      NAME OF REACTOR
CARD  2  KIND   1 FOR PWR, 2 FOR BWR                                        X
CARD  3  POWTH  DESIGN THERMAL POWER          (MEGAWATTS)      X.XXXE-XX
CARD  4  GTO    TOTAL STEAM FLOW              (LBS/HOUR)       X.XXXE-XX
CARD  5 *PER    FAILED FUEL                   (PERCENT)        X.XXXE-XX
```

```
CARD  6  GDE     CLEAN-UP DEMIN FLOW                              (LBS/HOUR)      X.XXXE-XX
CARD  7 *OPFRA   PLANT FACTOR                                                     X.XXXE-XX
CARD  8 *GTB     LEAK TO TURBINE BLDG.                            (GAL/MIN)       X.XXXE-XX
CARD  9 *GGS     GLAND SEAL LEAK                                  (LBS/HOUR)      X.XXXE-XX
CARD 10 *GRB     LEAK TO REACTOR BLDG                             (GAL/DAY)       X.XXXE-XX
CARD 11  WLIQ    MASS OF WATER IN THE VESSEL                      (POUNDS)        X.XXXE-XX
CARD 12  WSTR    MASS OF STEAM IN THE VESSEL                      (POUNDS)        X.XXXE-XX
CARD 13 *CON     PARTITION COEFFICIENT - STEAM/LIQUID (IODINE)                    X.XXXE-XX
CARD 14 *FEJ     PARTITION COEFFICIENT - AIR EJECTOR (IODINE)                     X.XXXE-XX
CARD 15 *P1      PARTITION COEFFICIENT - REACTOR BLDG (IODINE)                    X.XXXE-XX
CARD 16 *P2      PARTITION COEFFICIENT - TURBINE BLDG (IODINE)                    X.XXXE-XX
CARD 17 *P3      PARTITION COEFFICIENT - GLAND SEAL (IODINE)                      X.XXXE-XX
CARD 18 *DCN     FRACTION PASSING CONDENSATE DEMIN (IODINE)                       X.XXXE-XX
CARD 19 *DCU     FRACTION PASSING CLEAN-UP DEMIN (IODINE)                         X.XXXE-XX
CARD 20 *EN      TIMES PER YEAR REACTOR BLDG. IS PURGED                           X.XXXE-XX
CARD 21 *TIM1    HOLD-UP TIME - REACTOR BLDG. GAS                 (HOURS)         X.XXXE-XX
CARD 22 *TIM2    HOLD-UP TIME - TURBINE BLDG. GAS                 (HOURS)         X.XXXE-XX
CARD 23 *TIM3    HOLD-UP TIME - GLAND SEAL GAS                    (HOURS)         X.XXXE-XX
CARD 24 *TIM4    HOLD-UP TIME - AIR EJECTOR GAS                   (HOURS)         X.XXXE-XX
CARD 25  FIL1    FRACTION ESCAPING FILTER - REACTOR BLDG. (IODINE)                 X.XXXE-XX
CARD 26  FIL2    FRACTION ESCAPING FILTER - TURBINE BLDG. (IODINE)                 X.XXXE-XX
CARD 27  FIL3    FRACTION ESCAPING FILTER - GLAND SEAL (IODINE)                    X.XXXE-XX
CARD 28  FIL4    FRACTION ESCAPING FILTER - AIR EJECTOR (IODINE)                   X.XXXE-XX
CARD 29  KCHAR   DOES FACILITY HAVE CHARCOAL BED  1=YES ,0=NO                                X
CARD 30  CHTI1   HOLD-UP TIME FOR KRYPTON                         (DAYS)          X.XXXE-XX
CARD 31  CHTI2   HOLD-UP TIME FOR XENON                           (DAYS)          X.XXXE-XX
      ICOP=6
      POWFR=POWTH*0.01*PER*OPFRA
      P4=FEJ
      DO5I=1,15
      YIELD(I)=0.571*UYIEL(I)+0.429*PYIEL(I)
      IF(I.EQ.3) YIELD(I)=0.662*UYIEL(I)+0.338*PYIEL(I)
      DECOH(I)=DECON(I)*3600.
      EFDEH(I)=EFDEC(I)*3600.
      ESCAH(I)=ESCAP(I)*3600.
      RAAD(I)=(8.064E+14)*YIELD(I)/(DECON(I)**0.6)
      IF(I.GT.13) RAAD(I)=(2.484E+14)*YIELD(I)/(DECON(I)**0.5)
      EX1(I)=DECOH(I)*TIM1
      IF(EX1(I).GT.75.)EX1(I)=75.
      EX2(I)=DECOH(I)*TIM2
      IF(EX2(I).GT.75.)EX2(I)=75.
      EX3(I)=DECOH(I)*TIM3
      IF(EX3(I).GT.75.)EX3(I)=75.
      EX4(I)=DECOH(I)*TIM4
      IF(EX4(I).GT.75.)EX4(I)=75.
      IF(I.GT.13)GO TO 2000
      X0(I)=RAAD(I)/(GTO+GDE+EFDEH(I)*(WLIQ+WSTR)/3.)
      X1(I)=X0(I)
      PBL(I)=0.0
      EXC(I)=DECOH(I)*CHTI1*24.
      IF(I.GT.6)EXC(I)=DECOH(I)*CHTI2*24.
      IF(EXC(I).GT.75.)EXC(I)=75.
      TBL(I)=GTB*X1(I)*EXP(-EX2(I))
      SGL(I)=GGS*X1(I)*EXP(-EX3(I))
      EJT(I)=GTO*X1(I)*EXP(-EX4(I))*EXP(-EXC(I))
```

```
      GO TO 2001
2000  EXX(I)=EFDEH(I)*8765.8/EN
      IF(EXX(I).GT.75.) EXX(I)=75.
      XO(I)=RAAD(I)/(GTO*CON*(1.-(1.-FEJ)*DCN)+GDE*(1.-DCU)+EFDEH(I)*
     1      (WLIQ+WSTE))
      X1(I)=CON*XO(I)
      RBL(I)=(GRB*XO(I)/EFDEH(I))*P1*(1-EXP(-EXX(I)))*EN*FIL1*
     1       EXP(-EX1(I))*1.141E-04
      TBL(I)=GTB*X1(I)*P2*FIL2*EXP(-EX2(I))
      SGL(I)=GGS*X1(I)*P3*FIL3*EXP(-EX3(I))
      EXC(I)=0.
      IF(KCHAR.EQ.2) EXC(I)=DECOH(I)*CHTI1*24.
      IF(EXC(I).GT.75.) EXC(I)=75.
      EJT(I)=GTO*X1(I)*P4*FIL4*EXP(-EX4(I))*EXP(-EXC(I))
2001  EL1(I)=RBL(I)*POWER*DECOH(I)*6.581E-11
      IF(EL1(I).LE.1.000E-20) EL1(I)=0.0
      EL2(I)=TBL(I)*POWER*DECOH(I)*6.581E-11
      IF(EL2(I).LE.1.000E-20) EL2(I)=0.0
      EL3(I)=SGL(I)*POWER*DECOH(I)*6.581E-11
      IF(EL3(I).LE.1.000E-20) EL3(I)=0.0
      EL4(I)=EJT(I)*POWER*DECOH(I)*6.581E-11
      IF(EL4(I).LE.1.000E-20) EL4(I)=0.0
      TOT(I)=EL1(I)+EL2(I)+EL3(I)+EL4(I)
      ELS1(I)=EL1(I)*3.1688E-08
      ELS2(I)=EL2(I)*3.1688E-08
      ELS3(I)=EL3(I)*3.1688E-08
      ELS4(I)=EL4(I)*3.1688E-08
      TOTS(I)=TOT(I)*3.1688E-08
      CONCL(I)=XO(I)*DECON(I)*POWER*3.818E-08
      CONCS(I)=X1(I)*DECON(I)*POWER*4.772E-10
    5 CONTINUE
      DO 6 K=1,ICOP
      WRITE(51,210) NAME
  210 FORMAT(1H1,20A4)
      WRITE(51,211) POWTH,GTO,OPFRA,WLIQ,WSTE,GDE,PER,GRB,GTB,GGS
  211 FORMAT(1HO,'DESIGN THERMAL POWER',22X,1PE9.3,' MEGAWATTS'/1H ,'TOT
     1AL STEAM FLOW',26X,1PE9.3,' POUNDS/HOUR'/1H ,'PLANT FACTOR',30X,1P
     2E9.3/1H ,'WEIGHT OF LIQUID IN THE SYSTEM',12X,1PE9.3,' POUNDS'/1H
     3,'WEIGHT OF STEAM IN THE SYSTEM',13X,1PE9.3,' POUNDS'/1H ,'CLEAN-U
     4P DEMIN. FLOW',22X,1PE9.3,' POUNDS/HOUR'/1HO,'FAILED FUEL',31X,1PE
     59.3,' PERCENT'/1HO,'LEAKS'/1HO,4X,'REACTOR BLDG.',25X,1PE9.3,' POU
     6NDS/HOUR'/1H ,4X,'TURBINE BLDG.',25X,1PE9.3,' POUNDS/HOUR'/1H ,
     74X,'GLAND SEAL',28X,1PE9.3,' POUNDS/HOUR')
      WRITE(51,212) CON,P1,P2,P3,P4,DCN,DCU,FIL1,FIL2,FIL3,FIL4
  212 FORMAT(1HO,'PARTITION COEFFICIENTS (IODINE)'/1HO,4X,'STEAM/LIQUID'
     1,26X,1PE9.3/1H ,4X,'REACTOR BLDG.',25X,1PE9.3/1H ,4X,'TURBINE BLDG
     2.',25X,1PE9.3/1H ,4X,'GLAND SEAL',28X,1PE9.3/1H ,4X,'AIR EJECTOR',
     327X,1PE9.3/1HO,'FRACTION OF IODINE GETTING THROUGH THE'/1HO,4X,
     4'CONDENSATE DEMIN.',21X,1PE9.3/1H ,4X,'CLEAN-UP DEMIN.',23X,1PE9.3
     5/1H ,4X,'REACTOR BLDG. FILTER',18X,1PE9.3/1H ,4X,'TURBINE BLDG. FI
     6LTER',18X,1PE9.3/1H ,4X,'GLAND SEAL FILTER',21X,1PE9.3/1H ,4X,'AIR
     7 EJECTOR FILTER',20X,1PE9.3)
      WRITE(51,213) TIM1,TIM2,TIM3,TIM4,CHTI1,CHTI2
  213 FORMAT(1HO,'HOLD-UP TIMES'/1HO,4X,'REACTOR BLDG. GAS',21X,1PE9.3,
     1' HOURS'/1H ,4X,'TURBINE BLDG. GAS',21X,1PE9.3,' HOURS'/1H ,4X,
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     2'GLAND SEAL GAS',24X,1PE9.3,' HOURS'/1H ,4X,'AIR EJECTOR GAS',
     323X,1PE9.3,' HOURS'/1H0,'CHARCOAL BED HOLD-UP TIME FOR'/1H0,
     44X,'KRYPTONS',30X,1PE9.3,' DAYS'/1H ,4X,'XENONS',32X,1PE9.3,
     5' DAYS')
      WRITE(51,210) NAME
      WRITE(51,214)
214   FORMAT(1H0,131H----------------------------------------------------
     1----------------------------------------------------------------
     2--------------)
      WRITE(51,235)
235   FORMAT(1H0,65X,'RELEASE RATE'/1H0,63X,'(CURIES PER YEAR)',31X,'(CU
     1RIES PER SECOND)'/1H0,16X,'COOLANT CONC.',9X,'REACTOR',7X,'TURBINE
     2',8X,'GLAND',10X,'AIR'/1H ,4X,'NUCLIDE',3X,'(MICROCURIES/ML)',9X,
     3'BLDG.',9X,'BLDG.',9X,'SEAL',9X,'EJECTOR',12X,'TOTAL',14X,'TOTAL')
      WRITE(51,214)
      WRITE(51,215)
215   FORMAT(1H0,4X,'KR-83M ')
      WRITE(51,230) CONCL(1),EL1(1),EL2(1),EL3(1),EL4(1),TOT(1),TOTS(1)
230   FORMAT(1H+,17X,1PE9.3,5X,1P4E14.3,9X,1PE9.3,10X,1PE9.3)
      WRITE(51,216)
216   FORMAT(1H0,4X,'KR-85M ')
      WRITE(51,230) CONCL(2),EL1(2),EL2(2),EL3(2),EL4(2),TOT(2),TOTS(2)
      WRITE(51,217)
217   FORMAT(1H0,4X,'KR-85  ')
      WRITE(51,230) CONCL(3),EL1(3),EL2(3),EL3(3),EL4(3),TOT(3),TOTS(3)
      WRITE(51,218)
218   FORMAT(1H0,4X,'KR-87  ')
      WRITE(51,230) CONCL(4),EL1(4),EL2(4),EL3(4),EL4(4),TOT(4),TOTS(4)
      WRITE(51,219)
219   FORMAT(1H0,4X,'KR-88  ')
      WRITE(51,230) CONCL(5),EL1(5),EL2(5),EL3(5),EL4(5),TOT(5),TOTS(5)
      WRITE(51,220)
220   FORMAT(1H0,4X,'KR-89  ')
      WRITE(51,230) CONCL(6),EL1(6),EL2(6),EL3(6),EL4(6),TOT(6),TOTS(6)
      WRITE(51,221)
221   FORMAT(1H0,4X,'XE-131M')
      WRITE(51,230) CONCL(7),EL1(7),EL2(7),EL3(7),EL4(7),TOT(7),TOTS(7)
      WRITE(51,222)
222   FORMAT(1H0,4X,'XE-133M')
      WRITE(51,230) CONCL(8),EL1(8),EL2(8),EL3(8),EL4(8),TOT(8),TOTS(8)
      WRITE(51,223)
223   FORMAT(1H0,4X,'XE-133 ')
      WRITE(51,230) CONCL(9),EL1(9),EL2(9),EL3(9),EL4(9),TOT(9),TOTS(9)
      WRITE(51,224)
224   FORMAT(1H0,4X,'XE-135M')
      WRITE(51,230) CONCL(10),EL1(10),EL2(10),EL3(10),EL4(10),TOT(10),
     1              TOTS(10)
      WRITE(51,225)
225   FORMAT(1H0,4X,'XE-135 ')
      WRITE(51,230) CONCL(11),EL1(11),EL2(11),EL3(11),EL4(11),TOT(11),
     1              TOTS(11)
      WRITE(51,226)
226   FORMAT(1H0,4X,'XE-137 ')
      WRITE(51,230) CONCL(12),EL1(12),EL2(12),EL3(12),EL4(12),TOT(12),
     1              TOTS(12)
```

```
      WRITE(51,227)
  227 FORMAT(1H0,4X,'XE-138  ')
      WRITE(51,230)CONCL(13),EL1(13),EL2(13),EL3(13),EL4(13),TOT(13),
     1             TOTS(13)
      WRITE(51,228)
  228 FORMAT(1H0,4X,' I-131 ')
      WRITE(51,230)CONCL(14),EL1(14),EL2(14),EL3(14),EL4(14),TOT(14),
     1             TOTS(14)
      WRITE(51,229)
  229 FORMAT(1H0,4X,' I-133 ')
      WRITE(51,230)CONCL(15),EL1(15),EL2(15),EL3(15),EL4(15),TOT(15),
     1             TOTS(15)
      WRITE(51,214)
      WRITE(51,231)
  231 FORMAT(1H0,'0.0 APPEARING IN THE TABLE SHOULD BE INTERPRETED AS IN
     1SIGNIFICANT')
    6 CONTINUE
      GO TO 80
 1003 READ(50,100)POWTH
      READ(50,100)OPFRA
  100 FORMAT(70X,E10.3)
      READ(50,100)TOSTFL
      READ(50,100)GEN
      READ(50,100)WST
      READ(50,100)WLI
      READ(50,100)PRIVOL
      READ(50,100)DEM1FL
      READ(50,100)SFB
      READ(50,100)CONVOL
      READ(50,51)KID
      READ(50,100)TAU1
      READ(50,100)TAU2
      READ(50,100)TAU3
      READ(50,100)EN
      READ(50,100)EM
      READ(50,100)PER
      READ(50,100)GEN1L
      READ(50,100)CONLR
      READ(50,100)DEM2
      READ(50,100)TBD
      READ(50,51)KDEM
      READ(50,100)FPF
      READ(50,100)FVN
      READ(50,100)FEJ
      READ(50,100)CON
      READ(50,100)CFM
      READ(50,100)PURTIM
      READ(50,100)AUXLK
      READ(50,100)FAUX
```

CARD	3	POWTH	DESIGN THERMAL POWER LEVEL	MW THERMAL
CARD	4	OPFRA	PLANT OPERATING FACTOR	
CARD	5	TOSTFL	TOTAL STEAM FLOW	LBS/HR
CARD	6	GEN	NUMBER OF STEAM GENERATORS	
CARD	7	WST	WT. OF STEAM IN EACH GENERATOR	LBS
CARD	8	WLI	WT. OF LIQUID IN EACH GENERATOR	LBS

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CARD  9   PRIVOL    VOLUME OF PRIMARY SYSTEM                    CU.FT.
CARD 10   DEM1FL    PURIFICATION DEMIN. FLOW                    GPM
CARD 11   SRB       RATE OF SHIM BLEED                          GPM
CARD 12   CONVOL    CONTAINMENT VOLUME                          CU.FT.
CARD 13   KID       KIDNEY FILTER  0 OR 1  (NO OR YES)
CARD 14   TAU1      PRI. COOL. GAS - DECAY TIME                 DAYS
CARD 15   TAU2      SHIM BLEED GAS - DECAY TIME                 DAYS
CARD 16   TAU3      FILL TIME - DECAY TANKS                     DAYS
CARD 17   EN        CONTAINMENT PURGE                           TIMES/YR
CARD 18   EM        PRIMARY COOL. DEGAS                         TIMES/YR
CARD 19   PER       PERCENT FAILED FUEL
CARD 20   GEN1L     GENERATOR LEAK RATE                         GPD
CARD 21   CONLR     CONTAINMENT LEAKRATE                        GPD
CARD 22   DEM2      FRACT. I ESCAPING CLEAN-UP DEMIN
CARD 23   TBD       TOTAL BLOWDOWN                              LBS/HR
CARD 24   KDEM      CONDENSATE DEMIN.  0 OR 1  (NO OR YES)
CARD 25   FPF       FRACT. I PURGED FROM CONT
CARD 26   FVN       FRACT. I REMOVED BY VENT
CARD 27   FEJ       FRACT. I REMOVED BY EJT.
CARD 28   CON       PF  GAS/LIQUID
CARD 29   CFM       FLOWRATE OF KIDNEY FILTER                   CFM
CARD 30   PURTIM    PURGE TIME OF KIDNEY SYSTEM                 HOURS
CARD 31   AUXLK     LEAK TO AUX. BLDG.                          GAL/DAY
CARD 32   FAUX      PARTITION FACTOR - AUX. BLDG. IODINE
      ICOP=6
      GEN2L=0.
      GEN3L=0.
      GEN4L=0.
      DEM1=0.14
      IF(KDEM.NE.1)DEM1=1.
 1004 GBD=TBD/GEN
      GFR=TOSTFL/GEN
      ALPH1=GEN1L*1.562E-06/PRIVOL
      ALPH2=GEN2L*1.562E-06/PRIVOL
      ALPH3=GEN3L*1.562E-06/PRIVOL
      ALPH4=GEN4L*1.562E-06/PRIVOL
      ALPHA=ALPH1+ALPH2+ALPH3+ALPH4
      BETA=CONLR*1.562E-06/PRIVOL
      GAMMA=SRB*.002228/PRIVOL
      IF(SRB.EQ.0.)GAMMA=6.338E-08
      DELTA=DEM1FL*2.228E-03/PRIVOL
      IF(TAU3.EQ.0.)TAU3=.01
      PE=360./TAU3
      POWER=POWTH*.01*PER*OPFRA
      T1=3.1557E+07/EN
      T2=3.1557E+07/EM
      T3=3.1557E+07/PE
      T4=TAU1*86400.
      T5=TAU2*86400.
C
      DO7I=1,15
      YIELD(I) = 0.571 * UYIEL(I) + 0.429 * PYIEL(I)
      IF(I.EQ.3) YIELD(I) = 0.662 * UYIEL(I) + 0.338 * PYIEL(I)
      S(I) = (3.050E+16) * YIELD(I)
      C1(I) = EFDEC(I) + ESCAP(I)
```

```
      C2(I) = DECON(I) + ALPHA + BETA + GAMMA
      C3(I) = C2(I) + DELTA
C
      X1(I) = C2(I) * T2
      IF(X1(I).GT.75.) X1(I) = 75.
C
      XX1(I) = C3(I) * T2
      IF(XX1(I).GT.75.) XX1(I) = 75.
C
      X2(I) = DECON(I) * T1
      IF(X2(I).GT.75.) X2(I) = 75.
C
      X3(I) = DECON(I) * T3
      IF(X3(I).GT.75.) X3(I) = 75.
C
      X4(I) = DECON(I) * T4
      IF(X4(I).GT.75.) X4(I) = 75.
C
      X5(I) = DECON(I) * T5
      IF(X5(I).GT.75.) X5(I) = 75.
C
      IF(I.GT.13)GO TO 1030
C
      ACOOL(I) = (ESCAP(I) * S(I) / (C1(I) * C2(I))) * (1. -
     1           EXP(-X1(I)))
C
      AVCOOL(I) = (ESCAP(I) * S(I) / (C1(I) * C2(I))) * (1. - (1. -
     1           EXP(-X1(I))) / (T2 * C2(I)))
C
      ACONT(I) = (BETA * AVCOOL(I) / DECON(I)) * (1. - EXP(-X2(I)))
C
      ASHIM(I) = (GAMMA * AVCOOL(I) / DECON(I)) * (1. - EXP(-X3(I)))
      CONCP(I)=AVCOOL(I)*POWER*DECON(I)*9.544E-10/PRIVOL
      AUX(I)=AUXLK*CONCP(I)*1.3817
C
      EL1(I) = EN * ACONT(I) * DECON(I) * POWER * (0.2702703E-10)
      IF(EL1(I).LT.1.0E-20)EL1(I)=0.0
      EL2(I) = EM * ACOOL(I) * DECON(I) * POWER * (0.2702703E-10) *
     1         EXP(-X4(I))
      IF(EL2(I).LT.1.0E-20)EL2(I)=0.0
      EL3(I) = PE * ASHIM(I) * DECON(I) * POWER * (0.2702703E-10) *
     1         EXP(-X5(I))
      IF(EL3(I).LT.1.0E-20)EL3(I)=0.0
      EL4(I) = ALPHA * AVCOOL(I) * DECON(I) * POWER * (0.952892E-03)
      IF(EL4(I).LT.1.0E-20)EL4(I)=0.0
      ELB(I) = EL4(I)
      ELV(I) = 0.0
      TOT(I) = EL1(I) + EL2(I) + EL3(I) + EL4(I) + AUX(I)
C
      GO TO 1031
C
 1030 ACOOL(I) = (ESCAP(I) * S(I) / (C1(I) * C3(I))) * (1. -
     1           EXP(-XX1(I)))
      AVCOOL(I) = (FSCAP(I) * S(I) / (C1(I) * C3(I))) * (1. - (1. -
     1            EXP(-XX1(I))) / (T2 * C3(I)))
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```
      ACONT(I) = (BETA * AVCOOL(I) / DECON(I)) * (1. - EXP(-X2(I)))
      ASHIM(I) = (GAMMA * AVCOOL(I) / DECON(I)) * (1. - EXP(-X3(I)))
      CONCP(I)=AVCOOL(I)*POWER*DECON(I)*9.544E-10/PRIVOL
      AUX(I)=AUXLK*CONCP(I)*1.3817*FAUX
C
      Q1(I) = ALPH1 * AVCOOL(I) * POWER * (0.852892E-03) * DECON(I)
      Q2(I) = ALPH2 * AVCOOL(I) * POWER * (0.852892E-03) * DECON(I)
      Q3(I) = ALPH3 * AVCOOL(I) * POWER * (0.852892E-03) * DECON(I)
      Q4(I) = ALPH4 * AVCOOL(I) * POWER * (0.852892E-03) * DECON(I)
C
      A(I) = CON * GFR + (1. - CON) * GBD + DECON(I) * (WLI + CON * WST)
     1*3600.
      B(I) = CON * (GFR - GBD) * (1. - FFJ) * DEM1 + GBD * (1. - FVN) *
     1       DEM2
      FAA(I) = GEN * A(I) - (GFN - 1.) * B(I)
      FAB(I) = GEN * A(I) * (A(I) - B(I))
C
      X1L(I) = FAA(I) * Q1(I) / FAB(I)
      X2L(I) = B(I) * Q1(I) / FAB(I)
      X3L(I) = 0.0
      X4L(I) = 0.0
      IF(GEN.EQ.2.)GO TO 4001
      X3L(I) = X2L(I)
      IF(GEN.EQ.3.)GO TO 4001
      X4L(I) = X2L(I)
 4001 XR(I) = B(I) * (Q1(I) + Q2(I) + Q3(I) + Q4(I)) / ((FAB(I) * GFR) /
     1        A(I))
C
      EL1(I) = FPF * EN * ACONT(I) * DECON(I) * POWER * (0.2702703E-10)
      IF(KID.EQ.1)EXX2=((CFM*37./CONVOL)+3600.*DECON(I))*PURTIM
      IF(EXX2.GT.75.)EXX2=75.
      IF(KID.EQ.1)EL1(I)=EL1(I)*EXP(-EXX2)
      IF(KID.EQ.1.AND.CFM.EQ.0.)EL1(I)=CONVOL*EN*2.548E-09
      IF(EL1(I).LT.1.0E-20)EL1(I)=0.0
      EL2(I) = 0.0
      EL3(I) = 0.0
      CONCS(I)=XR(I)*1.34E-01
      SUMX = X1L(I) + X2L(I) + X3L(I) + X4L(I)
      ELB(I) = CON * (GFR - GBD) * FFJ * SUMX
      ELV(I) =       GBD * FVN * SUMX
      EL4(I) = ELB(I) + ELV(I)
      IF(ELB(I).LT.1.0E-20)ELB(I)=0.0
      IF(ELV(I).LT.1.0E-20)ELV(I)=0.0
      IF(EL4(I).LT.1.0E-20)EL4(I)=0.0
      TOT(I) = EL1(I) + EL2(I) + EL3(I) + EL4(I) + AUX(I)
C
 1031 ELS1(I) = EL1(I) * (3.1688E-08)
      ELS2(I) = EL2(I) * (3.1688E-08)
      ELS3(I) = EL3(I) * (3.1688E-08)
      ELS4(I) = EL4(I) * (3.1688E-08)
      ELSB(I) = ELB(I) * (3.1688E-08)
      ELSV(I) = ELV(I) * (3.1688E-08)
      TOTS(I) = TOT(I) * (3.1688E-08)
C
    7 CONTINUE
```

```
C    PUT DO LOOP HERE
       DO 8K=1,ICOP
       WRITE(51,1011)NAME
 1011 FORMAT(1H1,20A4)
       WRITE(51,1012)POWTH,OPFRA,TOSTFL,GEN,WST,WLI,PRIVOL
 1012 FORMAT(1H0,'DESIGN THERMAL POWER',43X,1PE9.3,' THERMAL MEGAWATTS'/
     11H0,'PLANT FACTOR',51X,1PE9.3/1H0,'TOTAL STEAM FLOW',47X,1PE9.3,'
     2POUNDS PER HOUR'/1H0,'NUMBER OF STEAM GENERATORS',37X,1PE9.3/1H0,'
     3WEIGHT OF STEAM IN EACH GENERATOR',30X,1PE9.3,' POUNDS'/1H0,'WEIGH
     4T OF LIQUID IN EACH GENERATOR',29X,1PE9.3,' POUNDS'/1H0,'VOLUME OF
     5 PRIMARY SYSTEM',39X,1PE9.3,' CUBIC FEET')
       WRITE(51,1013)PER,GEN1L,TBD
 1013 FORMAT(1H0,'FAILED FUEL',52X,1PE9.3,' PERCENT'/1H0,'STEAM GENERATO
     1R LEAK RATE',38X,1PE9.3,' GALLONS PER DAY'/1H0,'STEAM GENERATOR BL
     2OWDOWN RATE',34X,1PE9.3,' POUNDS PER HOUR')
       IF(SRB.NE.0.)GO TO 1015
       WRITE(51,1014)SRB
 1014 FORMAT(1H0,'RATE OF SHIMROD BLEED',42X,'TWO PRIMARY VOLUMES PER YE
     1AR')
       GO TO 1017
 1015 WRITE(51,1016)SRB
 1016 FORMAT(1H0,'RATE OF SHIMROD BLEED',42X,1PE9.3,' GALLONS PER MINUTE
     1')
 1017 WRITE(51,1018)TAU2,EN,EM,TAU1,CONVOL
 1018 FORMAT(1H0,'SHIMROD BLEED GAS DECAY TIME',35X,1PE9.3,' DAYS'/1H0,
     1'CONTAINMENT PURGE',46X,1PE9.3,' TIMES PER YEAR'/1H0,'PRIMARY COOL
     2ANT DEGASSED',39X,1PE9.3,' TIMES PER YEAR'/1H0,'PRIMARY COOLANT GA
     3S DECAY TIME',33X,1PE9.3,' DAYS'/1H0,'CONTAINMENT VOLUME',45X,1PE9
     4.3,' CUBIC FEET')
       IF(KID.NE.1)GO TO 1020
       WRITE(51,1019)
 1019 FORMAT(1H0,'THERE IS A KIDNEY FILTER')
       GO TO 1022
 1020 WRITE(51,1021)
 1021 FORMAT(1H0,'THERE IS NOT A KIDNEY FILTER')
 1022 IF(KDEM.NE.1)GO TO 1024
       WRITE(51,1023)DEM1
 1023 FORMAT(1H0,'CONDENSATE DEMINERALIZER IODINE REMAINING FRACTION',13
     1X,1PE9.3)
       GO TO 1026
 1024 WRITE(51,1025)
 1025 FORMAT(1H0,'THERE IS NO CONDENSATE DEMINERALIZER')
 1026 WRITE(51,1027)CONLP
 1027 FORMAT(1H0,'CONTAINMENT LEAK RATE',42X,1PE9.3,' GALLONS PER DAY')
       WRITE(51,1029)AUXLK
 1029 FORMAT(1H0,'AUXILIARY BUILDING LEAK RATE',35X,1PE9.3,' GALLONS PER
     1 DAY')
       WRITE(51,1028)CON,FVN,FEJ,FPF
 1028 FORMAT(1H0,'PARTITION COEFFICIENTS FOR IODINE (GAS/LIQUID)'/1H0,
     15X,'STEAM GENERATOR INTERNAL PARTITION',24X,1PE9.3/1H0,5X,'STEAM G
     2ENERATOR BLOWDOWN VENT',29X,1PE9.3/1H0,5X,'CONDENSER AIR EJECTOR',
     337X,1PE9.3/1H0,5X,'PRIMARY COOLANT LEAKAGE TO CONTAINMENT',20X,
     41PE9.3)
       WRITE(51,1034)FAUX
 1034 FORMAT(1H0,5X,'PRIMARY COOLANT LEAKAGE TO AUXILIARY BUILDING',13X,
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     11PE9.3)
      WRITE(51,1050)NAME
1050  FORMAT(1H1,20A4)
      WRITE(51,1051)
1051  FORMAT(1H0,75X,'RELEASE RATE - CURIES PER YEAR')
      WRITE(51,1052)
1052  FORMAT(1H0,19X,'COOLANT CONC',10X,'AUXILIARY',1X,' CONTAINMENT
     1DEGASIFICATION       STEAM GENERATOR LEAK'/1H0,'  NUCLIDE        (
     2MICROCURIES/ML)',9X,'BLDG',9X,'PURGE      PRIMARY    SHIMBLEED
     3  VENT    AIR EJECTOR',9X,'TOTAL')
      WRITE(51,1053)
1053  FORMAT(1H0,'-------------------------------------------------------
     1-------------------------------------------------------------
     2----------')
      WRITE(51,1054)CONCP(1),AUX(1),EL1(1),EL2(1),EL3(1),ELV(1),ELB(1),
     1TOT(1)
1054  FORMAT(1H0,'  KR-83M ',11X,1PE9.3,9X,1P6E12.3,8X,1PE9.3)
      WRITE(51,1055)CONCP(2),AUX(2),EL1(2),EL2(2),EL3(2),ELV(2),ELB(2),
     1TOT(2)
1055  FORMAT(1H0,'  KR-85M ',11X,1PE9.3,9X,1P6E12.3,8X,1PE9.3)
      WRITE(51,1056)CONCP(3),AUX(3),EL1(3),EL2(3),EL3(3),ELV(3),ELB(3),
     1TOT(3)
1056  FORMAT(1H0,'  KR-85  ',11X,1PE9.3,9X,1P6E12.3,8X,1PE9.3)
      WRITE(51,1057)CONCP(4),AUX(4),EL1(4),EL2(4),EL3(4),ELV(4),ELB(4),
     1TOT(4)
1057  FORMAT(1H0,'  KR-87  ',11X,1PE9.3,9X,1P6E12.3,8X,1PE9.3)
      WRITE(51,1058)CONCP(5),AUX(5),EL1(5),EL2(5),EL3(5),ELV(5),ELB(5),
     1TOT(5)
1058  FORMAT(1H0,'  KR-88  ',11X,1PE9.3,9X,1P6E12.3,8X,1PE9.3)
      WRITE(51,1059)CONCP(6),AUX(6),EL1(6),EL2(6),EL3(6),ELV(6),ELB(6),
     1TOT(6)
1059  FORMAT(1H0,'  KR-89  ',11X,1PE9.3,9X,1P6E12.3,8X,1PE9.3)
      WRITE(51,1060)CONCP(7),AUX(7),EL1(7),EL2(7),EL3(7),ELV(7),ELB(7),
     1TOT(7)
1060  FORMAT(1H0,'  XE-131M',11X,1PE9.3,9X,1P6E12.3,8X,1PE9.3)
      WRITE(51,1061)CONCP(8),AUX(8),EL1(8),EL2(8),EL3(8),ELV(8),ELB(8),
     1TOT(8)
1061  FORMAT(1H0,'  XE-133M',11X,1PE9.3,9X,1P6E12.3,8X,1PE9.3)
      WRITE(51,1062)CONCP(9),AUX(9),EL1(9),EL2(9),EL3(9),ELV(9),ELB(9),
     1TOT(9)
1062  FORMAT(1H0,'  XE-133 ',11X,1PE9.3,9X,1P6E12.3,8X,1PE9.3)
      WRITE(51,1063)CONCP(10),AUX(10),EL1(10),EL2(10),EL3(10),ELV(10),
     1ELB(10),TOT(10)
1063  FORMAT(1H0,'  XE-135M',11X,1PE9.3,9X,1P6E12.3,8X,1PE9.3)
      WRITE(51,1064)CONCP(11),AUX(11),EL1(11),EL2(11),EL3(11),ELV(11),
     1ELB(11),TOT(11)
1064  FORMAT(1H0,'  XE-135 ',11X,1PE9.3,9X,1P6E12.3,8X,1PE9.3)
      WRITE(51,1065)CONCP(12),AUX(12),EL1(12),EL2(12),EL3(12),ELV(12),
     1ELB(12),TOT(12)
1065  FORMAT(1H0,'  XE-137 ',11X,1PE9.3,9X,1P6E12.3,8X,1PE9.3)
      WRITE(51,1066)CONCP(13),AUX(13),EL1(13),EL2(13),EL3(13),ELV(13),
     1ELB(13),TOT(13)
1066  FORMAT(1H0,'  XE-138 ',11X,1PE9.3,9X,1P6E12.3,8X,1PE9.3)
      WRITE(51,1067)CONCP(14),AUX(14),EL1(14),EL2(14),EL3(14),ELV(14),
     1ELB(14),TOT(14)
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 1067 FORMAT(1H0,'   I-131 ',11X,1PE9.3,9X,1P6E12.3,8X,1PE9.3)
      WRITE(51,1068)CONCP(15),AUX(15),EL1(15),EL2(15),EL3(15),ELV(15),
     1ELB(15),TOT(15)
 1068 FORMAT(1H0,'   I-133 ',11X,1PE9.3,9X,1P6E12.3,8X,1PE9.3)
      WRITE(51,1053)
      WRITE(51,231)
    8 CONTINUE
      GO TO 80
      END
      BLOCK DATA
      COMMON/NAM4/UYIEL,PYIEL,DECON,EFDEC,ESCAP
      DIMENSION UYIEL(20),PYIEL(20),DECON(20),EFDEC(20),ESCAP(20)
C
C     ORDER OF ISOTOPES
C
C     ORDER      /   KR-83M,    KR-85M,     KR-85,     KR-87,     KR-88,
C                     KR-89,   XE-131M,   XE-133M,    XE-133,   XE-135M,
C                    XE-135,    XE-137,    XE-138,     I-131,     I-133,
C                    ------,    ------,    ------,     -----,     -----/
C
      DATA UYIEL/5.200E-03,1.310E-02,3.367E-03,2.490E-02,3.570E-02,
     1           4.590E-02,2.051E-04,1.700E-03,6.610E-02,1.800E-02,
     2           6.410E-02,6.000E-02,5.740E-02,2.930E-02,6.610E-02,
     3           0.000E-00,0.000E-00,0.000E-00,0.000E-00,0.000E-00/
C
      DATA PYIEL/3.000E-03,5.300E-03,1.400E-03,9.200E-03,1.420E-02,
     1           1.540E-02,2.646E-04,1.640E-03,6.533E-02,1.947E-02,
     2           7.170E-02,5.100E-02,6.310E-02,3.780E-02,6.533E-02,
     3           0.000E-00,0.000E-00,0.000E-00,0.000E-00,0.000E-00/
C
      DATA DECON/1.035E-04,4.375E-05,2.040E-09,1.520E-04,6.880E-05,
     1           3.632E-03,6.800E-07,3.548E-06,1.520E-06,7.357E-04,
     2           2.090E-05,3.024E-03,6.800E-04,9.970E-07,9.170E-06,
     3           0.000E-00,0.000E-00,0.000E-00,0.000E-00,0.000E-00/
C
      DATA EFDEC/1.035E-04,4.375E-05,2.040E-09,1.520E-04,6.880E-05,
     1           3.632E-03,6.800E-07,3.548E-06,1.520E-06,7.357E-04,
     2           1.030E-04,3.024E-03,6.800E-04,9.970E-07,9.170E-06,
     3           0.000E-00,0.000E-00,0.000E-00,0.000E-00,0.000E-00/
C
      DATA ESCAP/6.500E-08,6.500E-08,6.500E-08,6.500E-08,6.500E-08,
     1           6.500E-08,6.500E-08,6.500E-08,6.500E-08,6.500E-08,
     2           6.500E-08,6.500E-08,6.500E-08,1.300E-08,1.300E-08,
     3           0.000E-00,0.000E-00,0.000E-00,0.000E-00,0.000E-00/
C
      END
```

DISCUSSION

BURNS: I notice from your slide on the computer input for a PWR that you assumed a quarter percent failed fuel. I was wondering if you considered that a standard value.

BINFORD: That is a standard value that we have settled on at the moment. It seems to reflect the average of the experience that one can find on failed fuel. A quarter of one percent is about the average, but don't ask me what the standard deviation is.

BURNS: Have you been using that for BWR's, also?

BINFORD: The information for BWR's is extremely difficult to come by, and I would say that while we do tie it in to a failed fuel number, it is a synthetic number. The result that we get pretty well matches the experience. It is just that the computer program uses it that way.

PHILLIPS: I was wondering if it is presently a requirement to obtain a license that the air from the turbine building be passed through a charcoal filter. If it isn't a requirement yet, do you expect it to be one in the near future?

BINFORD: I would prefer to have somebody from the AEC answer that question. I don't think that any single piece of equipment is required for licensing. You meet the requirements of Appendix I; and you can do that in a lot of ways. Whether you do it with charcoal or something else, I don't think makes any difference.

ESTAREICH: Does your model consider daughter decay products and what contribution do you think they are likely to have?

BINFORD: Are you talking about the daughters of the noble gases?

ESTAREICH: The daughters of any of the originals.

BINFORD: No, this model does not. The model is aimed only at the noble gases themselves and at iodine. This could be put in, but, as I said, with the uncertainty of the input data, I don't think the additional complexity is worth it right now.

ABBY: Are your various input parameters based on experimental data or theoretical considerations?

BINFORD: Are you talking about the partition coefficients or the leak rates?

ABBY: Either one.

BINFORD: The leak rates are based primarily on experience, most of which has been gained by the Division of Compliance. For the partition coefficients, I guess it is a combination of experience, theory, and experiment. I think George Parker, if he is here, probably could answer that question better than I can.

PARKER, G: I have to repeat Frank's answer, partly in the light that we've done the best we can. Of course, we compare notes with the vendors and take a lot of cognizance of the current observations that are going on, like the ones that Ned Horton referred to on the BWR's and some similar ones at Ginna for PWR's. We go back, occasionally, to AEC's own "Moses" of the partition-coefficients, Gordon Burley, who has changed hats now. Gordon did a good job of establishing the precedents on these numbers.

FRANZEN: I have two questions. The first relates to the iodine concentration you gave in your example for boiling water reactors. The figure there was 0.005 μCi/ml. Is this an average value?

BINFORD: That is an average number. With the experience we've had, 0.005 μCi/ml is what you would expect with the typical boiling reactor. If you have a high percentage of fractured fuel, it would go up. But, again, this is what we think you would expect, on the average, with a 30- or 40-year lifetime system, assuming no tremendous improvements or no tremendous changes in the other direction.

FRANZEN: My second question concerns the leakage rates from activity-containing systems and components. Can you only calculate back from the values of released activity?

BINFORD: It's possible, I think, to measure the amount of water, for example, that leaks out of a recirculating pump. One has some idea of leakage rates in equipment, and this is more or less what it is based on. Sure, you can have a situation where one of the glands goes out on a particular pump and for maybe an hour or two it is leaking very badly. On the other hand, after you go in and repair it, perhaps it won't leak again for two months. I think the minimum that you can detect is something like 50 drops a minute. The numbers we've come up with are what we would expect if you averaged it out over the lifetime of the system. I must say that they are probably not completely defensible. They are the best numbers we've been able to come up with.