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U. S. Atomic Energy Commission
Docket 50-3
Exhibit K-5A14

BAW-142, Rev. 1

**CORROSION PRODUCT ACTIVITY DISTRIBUTION
ACROSS THE CHEMICAL PROCESS SYSTEM
IN THE CONSOLIDATED EDISON THORIUM
REACTOR PLANT**

Prepared September 1958

Revised August 1960

This document is
PUBLICLY RELEASABLE
Angelo Cruise
Authorizing Official
Date: *8/8/02*

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THE BABCOCK & WILCOX COMPANY
ATOMIC ENERGY DIVISION

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CORROSION PRODUCT ACTIVITY DISTRIBUTION
ACROSS THE CHEMICAL PROCESS SYSTEM
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REACTOR PLANT

Prepared September 1958
Revised August 1960

PREPARED FOR
THE CONSOLIDATED EDISON COMPANY OF NEW YORK

By
THE BABCOCK & WILCOX COMPANY
ATOMIC ENERGY DIVISION

AND
THE VITRO ENGINEERING COMPANY

CROSS REFERENCE INDEX

This Cross Reference Index has been prepared to key the supplementary material to the information which is contained in the Hazards Summary Report dated January, 1960, Exhibit K-5 (Rev-1) filed with Amendment No. 10 to Consolidated Edison's Application for Licenses.

SECTION 2 - REACTOR DESIGN

<u>2.1 - REACTOR DESCRIPTION</u>	<u>EXHIBIT NO.</u>
<u>2.1.1 Reactor Vessel and Its Internal Structure</u>	
Consolidated Edison Thorium Reactor Reactor Vessel Internal Components Design (Report BAW-136)	K-5A1
<u>2.1.2 Fuel Element Design</u>	
Fuel Element Structural Design and Manufacture for the Consolidated Edison Thorium Reactor Plant (Report BAW-133)	K-5A2
<u>2.1.3 Control Rods, Fixed Shim Rods and Flux Depressors</u>	
Design of the Movable and Fixed Control Components for the Consolidated Edison Thorium Reactor (Report BAW-147)	K-5A3
<u>2.2 - THERMAL AND HYDRAULIC DESIGN</u>	
<u>2.2.1 General Design Data</u>	
Thermal and Hydraulic Design of the Consolidated Edison Thorium Reactor (Report BAW-132)	K-5A4
<u>2.2.2 Design Methods and Correlations</u>	
Thermal and Hydraulic Design of the Consolidated Edison Thorium Reactor (Report BAW-132)	K-5A4
Irradiation Test Program for the Consolidated Edison Thorium Reactor (Report BAW-134)	K-5A5

EXHIBIT NO.

2.2.3 Maximum Safe Reactor Power

Thermal and Hydraulic Design of the
Consolidated Edison Thorium Reactor
(Report BAW-132)

K-5A4

2.3 - NUCLEAR DESIGN

2.3.1 Introduction

Consolidated Edison Thorium Reactor
Physics Design (Report BAW-120 Rev. 1)

K-5A6

2.3.2 Reactivity and Lifetime

Consolidated Edison Thorium Reactor
Physics Design (Report BAW-120 Rev. 1)

K-5A6

Consolidated Edison Thorium Reactor
Critical Experiments with Oxide Fuel Pins
(Report BAW-119 Rev. 1)

K-5A7

Consolidated Edison Thorium Reactor
Hot Exponential Experiment (Report
BAW-116 Rev. 1)

K-5A8

Geometric and Temperature Effects in
Thorium Resonance Capture for the
Consolidated Edison Thorium Reactor
(Report BAW-144)

K-5A9

2.3.3 Control Rod Worth

Consolidated Edison Thorium Reactor
Physics Design (Report BAW-120 Rev. 1)

K-5A6

Consolidated Edison Thorium Reactor
Critical Experiments with Oxide Fuel Pins
(Report BAW-119 Rev. 1)

K-5A7

Consolidated Edison Thorium Reactor
Hot Exponential Experiment (Report
BAW-116 Rev. 1)

K-5A8

Geometric and Temperature Effects in
Thorium Resonance Capture for the
Consolidated Edison Thorium Reactor
(Report BAW-144)

K-5A9

2.3.4 Reactivity Control

Consolidated Edison Thorium Reactor
Physics Design (Report BAW-120 Rev. 1)

K-5A6

EXHIBIT NO.

2.3.5 Reactivity Coefficients

Consolidated Edison Thorium Reactor
Physics Design (Report BAW-120 Rev. 1) K-5A6

Consolidated Edison Thorium Reactor
Critical Experiments with Oxide Fuel Pins
(Report BAW-119 Rev. 1) K-5A7

Consolidated Edison Thorium Reactor
Hot Exponential Experiment (Report
BAW-116 Rev. 1) K-5A8

Geometric and Temperature Effects in
Thorium Resonance Capture for the
Consolidated Edison Thorium Reactor
(Report BAW-144) K-5A9

2.3.6 Delayed Neutron Fraction

Consolidated Edison Thorium Reactor
Physics Design (Report BAW-120 Rev. 1) K-5A6

2.3.7 Power Distribution

Consolidated Edison Thorium Reactor
Physics Design (Report BAW-120 Rev. 1) K-5A6

Consolidated Edison Thorium Reactor
Critical Experiments with Oxide Fuel Pins
(Report BAW-119 Rev. 1) K-5A7

Consolidated Edison Thorium Reactor
Hot Exponential Experiment (Report
BAW-116 Rev. 1) K-5A8

2.4 - CONTROL ROD DRIVE MECHANISMS

Consolidated Edison Thorium Reactor
Control Rod Drive Line Testing
(Report BAW-137) K-5A10

SECTION 3 - PLANT DESIGN

3.1 - PRIMARY SYSTEMS

3.1.1 Primary Coolant System

Supplementary Information on Plant
Design of Consolidated Edison Nuclear
Steam Generating Station K-5A11

3.1.2 Pressurizer System

Functional Design Analysis of the
Pressurizer for the Consolidated Edison
Thorium Reactor Plant (Report BAW-41
Rev. 1) K-5A12

EXHIBIT NO.

3.1.3 Seal Water and Primary Makeup System

Supplementary Information on Plant
Design of Consolidated Edison Nuclear
Steam Generating Station

K-5A11

3.1.4 Primary Relief System

Supplementary Information on Plant
Design of Consolidated Edison Nuclear
Steam Generating Station

K-5A11

3.1.5 Primary Vent System

Supplementary Information on Plant
Design of Consolidated Edison Nuclear
Steam Generating Station

K-5A11

3.2 - SECONDARY SYSTEMS

Exhibit K-5A11 contains an introductory section entitled, "Conventional Plant Features Contributing to Nuclear Plant Safety." In addition, this exhibit contains supplementary data on the following systems:

3.2.1 Steam Piping System

3.2.2 Secondary Relief System

3.2.3 Boiler Feed System

3.2.4 Boiler Blowdown System

3.3 - SUPPORTING SYSTEMS

3.3.1 Chemical Processing Systems

Supplementary Information on Plant
Design of Consolidated Edison Nuclear
Steam Generating Station

K-5A11

The Effects of Fuel Rod Fission Product
Leakage on the Consolidated Edison Thorium
Reactor Plant (Report BAW-85 Rev. 1)

K-5A13

Corrosion Product Activity Distribution
Across the Chemical Process System
for the Consolidated Edison Thorium Reactor
(Report BAW-142 Rev. 1)

K-5A14

3.3.2 Boron Addition System

3.3.3 Decay Heat Cooling System

3.3.4 Component Drain System

3.3.5 Sampling System

3.3.6 Fresh Water Cooling System

3.3.7 Electrical System

Additional data on these six supporting
systems described in the Hazards Summary
Report is contained in the report, "Supplementary
Information on Plant Design of Consolidated
Edison Nuclear Steam Generating Station"

K-5A11

EXHIBIT NO.

3.4 - INSTRUMENTATION AND CONTROL

3.4.1 Nuclear Instrumentation

Supplementary Information on Plant
Design of Consolidated Edison Nuclear
Steam Generating Station

K-5A11

3.4.3 Reactor Control System

Consolidated Edison Thorium Reactor
Control System Design (Report BAW-138)

K-5A15

3.4.5 Radiation Monitoring

Supplementary Information on Plant
Design of Consolidated Edison Nuclear
Steam Generating Station

K-5A11

3.7 - HANDLING SYSTEMS

Supplementary Information on Plant
Design of Consolidated Edison Nuclear
Steam Generating Station

K-5A11

SECTION 4 - INCIDENT ANALYSIS

4.4 - MECHANICAL INCIDENTS

4.4.2 Incidents Involving Reduction or
Loss of Forced Coolant Flow

Thermal and Hydraulic Design of the
Consolidated Edison Thorium Reactor
(Report BAW-132)

K-5A4

CONTENTS

	Page
List of Tables	iii
Abstract	v
I. INTRODUCTION	1
II. ASSUMPTIONS AND BASIC EQUATIONS	3
A. Sodium-24 Concentration	3
B. Corrosion Products	4
III. GENERAL SOLUTIONS OF EQUATIONS AND ADDITIONAL INPUT DATA	7
IV. ACTIVITY ON THE PURIFICATION FILTERS AND ION EXCHANGERS	15
V. CORROSION PRODUCT ACTIVITY ON THE SPENT FUEL AND TRANSFER ION EXCHANGER RESIN BEDS	17

LIST OF TABLES

Table	Page
I. Corrosion Product Activities in Primary Loop Water	8
II. Corrosion Product Activities on the Purification Filters and Ion Exchanger Resins	12
III. Corrosion Product Input Data	13
IV. Activities Accumulated on Filters and Ion Exchangers During Final Six Months of Purification	16

ABSTRACT

A study has been performed to determine the corrosion product and water impurity activities in the CETR Chemical Process System. These activities have been calculated as functions of the following parameters:

1. Reactor operating time
2. Primary loop blowdown purification rate
3. Decay time following removal from the primary loop.

For the design blowdown purification rate chosen, only five isotopes are important to the design of radiation shielding. They are as follows:

Cobalt	Co-60 and Co-58
Iron	Fe-55
Chromium	Cr-51
Manganese	Mn-56

Where corrosion products accumulate on equipment, such as filters and ion exchangers, only four isotopes are important - Co-60, Co-58, Fe-55, Cr-51.

A simplified mathematical model is used to represent the physical situation; however, the magnitude of the activities, taken at the end of core life to represent the most conservative case, is considered sufficiently accurate for engineering calculations.

I. INTRODUCTION

Corrosion product activities in the Consolidated Edison Thorium Reactor (CETR) Plant Chemical Process System are important from a shielding and operational standpoint. Short of a major fuel element failure, the corrosion product activities overshadow any other non-volatile activities in effects on shielding requirements. It is, therefore, important not only to determine the approximate activities, but also to know the points of concentration in the system where they are expected to appear.

Corrosion product activities have been calculated using a simplified mathematical model. The model did not include such factors as exchange reactions on the primary loop surfaces, the effect of hide-out in valve seats, the effect of alloys other than Type 304 stainless steel, or the difference between the corrosion rate and the actual release rate to the primary fluid; and all of these would tend to reduce the activities at points of interest.

Sufficient experimental data are not available at present to devise an absolutely correct mathematical model. Most of the present data are from plants with zirconium (Zr) cores. The only stainless steel corrosion product data from an operating reactor approximating the CETR are those obtained from the Army Package Power Reactor (APPR). Even if these data were complete, there is no assurance of any great degree of correlation between them and similar data for the operating CETR because of the differences in design, operating conditions, and the presence of large cobalt concentrations in the APPR core.

Despite these limitations, the magnitude of the activities is considered conservative and sufficiently precise for present applications. This is especially true since all calculations are based on activities at the end of core life.

II. ASSUMPTIONS AND BASIC EQUATIONS

A. SODIUM-24 CONCENTRATION

The equations governing the concentration of Na-24 are:

1. In the Primary Loop

$$\frac{dn}{dt} = \frac{V_c}{V} \phi_c \sigma N + \frac{V_r}{V} \phi_r \sigma N - \lambda n - g \frac{B}{V} n$$

2. In the Ion Exchanger

It is assumed that all Na-24 is removed in the ion exchanger and none is removed in the filter of the chemical process system.

$$\frac{dn_1}{dt} = gBn - \lambda n_1$$

where

- n = concentration of Na-24 in the primary loop, atoms/cm³
- n_1 = total number of atoms of Na-24 on the ion exchanger
- t = reactor operating time
- V = primary loop volume, cm³
- V_c = water volume in core, cm³
- V_r = water volume in reflector, cm³
- ϕ_c = average core thermal flux, n/cm²-sec
- ϕ_r = average reflector thermal flux, n/cm²-sec
- σ = thermal neutron activation cross section for Na-23, cm²
- N = initial concentration of Na-23 in the water of the primary loop, atoms/cm³
- λ = decay constant for Na-24, sec⁻¹
- g = efficiency of the ion exchanger for removal of sodium
- B = blowdown rate in cm³/sec

Because of the short half life of Na-24 these equations need only be considered at equilibrium. In this case the activities of concern will be

$$A \equiv \frac{\lambda n}{3.7 \times 10^4} = \frac{\lambda \left(\frac{V_c}{V} \phi_c + \frac{V_r}{V} \phi_r \right) \sigma N}{3.7 \times 10^4} \mu\text{c/cm}^3 \text{ in the primary loop}$$

$$A_1 \equiv \frac{\lambda n_1}{3.7 \times 10^{10}} = \frac{g B n}{3.7 \times 10^{10}} \text{ curies on the ion exchanger}$$

For the CETR the parameters in these equations have the values:

$$\begin{aligned} V &= 1.33 \times 10^8 \text{ cm}^3 \\ V_c &= 3.76 \times 10^6 \text{ cm}^3 \\ V_r &= 9.2 \times 10^5 \text{ cm}^3 \\ \phi_c &= 1.6 \times 10^{13} \text{ n/cm}^2\text{-sec} \\ \phi_r &= 1.8 \times 10^{13} \text{ n/cm}^2\text{-sec} \\ \sigma &= 5.3 \times 10^{-25} \text{ cm}^2 \\ \lambda &= 1.28 \times 10^{-5} \text{ sec}^{-1} \\ g &= 0.75 \\ N &= 2.1 \times 10^{16} \text{ p, where p is the initial sodium-23 concentration in ppm. In the calculations that follow, p was taken to be 0.01 ppm. This value is considerably higher than the sodium concentration to be expected in the primary loop.} \end{aligned}$$

B. CORROSION PRODUCTS

The mathematical model assumes that the activity due to corrosion products arises in essentially two ways. Either the active nuclei are produced in the fuel rod cladding or thermal shield before they enter the coolant stream, or else the active nuclei are produced in flowing through the core and shield after they have entered the coolant stream from any part of the primary loop surface area. For this reason four equations are required to describe the buildup of each particular active species.

1. Concentration of parent corrosion product in primary loop

$$\frac{dn}{dt} = \frac{LAf}{V} - \frac{gB}{V} n$$

2. Relative number of active atoms in core and thermal shields

$$\frac{df_c}{dt} = \phi_c \sigma f - \lambda f_c; \quad \frac{df_s}{dt} = \phi_s \sigma f - \lambda f_s$$

3. Activity in the primary coolant loop

$$\frac{dn}{dt} = \frac{LA_c f_c}{V} + \frac{LA_s f_s}{V} + \frac{\phi_c V_c \sigma}{V} n + \frac{\phi_s V_s \sigma}{V} n - \frac{gB}{V} n - \lambda n$$

4. Activity on the filter plus ion exchanger

$$\frac{dn_1}{dt} = gBn - \lambda n_1$$

The symbols in these equations have the following meanings:

- n = concentration of the corrosion product parent in the primary loop, atoms/cm³
- t = reactor operating time, sec
- L = corrosion rate, atoms/sec/ft²
- A = total primary loop area, ft²
- f = fraction of atoms in the steel which are parent atoms
- V = primary loop volume, cm³
- g = efficiency of filter for removal of corrosion products
- B = blowdown purification rate, cm³/sec
- f_c = fraction of active atoms out of all atoms in the steel cladding of the core
- f_s = fraction of active atoms out of all atoms in the steel of the thermal shields
- ϕ_c = average thermal core flux, n/cm²-sec
- ϕ_s = average thermal flux in the thermal shields, n/cm²-sec
- σ = activation cross section, cm²
- λ = radioactive decay constant for active nuclei, sec⁻¹
- n = concentration of active nuclei in the primary coolant loop, atoms/cm³
- A_c = area of pin surface in core, ft²

A_s = area of thermal shield surface, ft^2
 V_c = volume of water in core, cm^3
 V_s = volume of water in thermal shield, cm^3
 n_1 = number of active atoms on filter

The system parameters for the CETR have the following values:

A = 75,000 ft^2
 V = $1.33 \times 10^8 \text{ cm}^3$
 g = 1.0
 ϕ_c = $1.6 \times 10^{13} \text{ n/cm}^2\text{-sec}$
 ϕ_s = $2.0 \times 10^{12} \text{ n/cm}^2\text{-sec}$
 A_c = 16,000 ft^2
 A_s = 2,700 ft^2
 V_c = $3.8 \times 10^6 \text{ cm}^3$
 V_s = $9.5 \times 10^6 \text{ cm}^3$

III. GENERAL SOLUTIONS OF EQUATIONS AND ADDITIONAL INPUT DATA

The equations of the preceding section were solved for various operating times and various blowdown rates. Table I gives the concentrations found in the primary loop. On the basis of these results, a design blowdown purification rate of 36,000 lb/hr (90 gpm) has been chosen for the CETR Chemical Process System. Table II presents the sodium and corrosion product activities on the filters plus ion exchangers for this design blowdown rate.

In obtaining these activities, it was assumed that all primary loop surface area was composed of Type 304 stainless steel and that a uniform corrosion rate of 10 mg/dm²-mo occurred. The isotopes of interest and their pertinent parameters are given in Table III.

The corrosion rate, L , in atoms/sec/ft² is related to the corrosion rate, r , in mg/dm²-mo and the total number of atoms per gram of steel, N , by the formula

$$L = 3.6 \times 10^{-9} rN$$

Using

$$r = 10 \text{ mg/dm}^2\text{-mo}$$

$$N = 1.1 \times 10^{22} \text{ atoms per gram of 304 SS}$$

then

$$L = 3.9 \times 10^{14} \text{ atoms/sec-ft}^2$$

TABLE I
CORROSION PRODUCT ACTIVITIES IN PRIMARY LOOP WATER

Purification Rate lb/hr	Isotope	Days				
		30	100	200	400	600
		Activity, $\mu\text{c/ml}$				
None	Co-60	3.67×10^{-3}	3.93×10^{-2}	1.53×10^{-1}	5.83×10^{-1}	1.24×10^0
	Co-60m	5.02×10^{-3}	5.02×10^{-3}	5.02×10^{-3}	5.02×10^{-3}	5.02×10^{-3}
	Fe-59	1.31×10^{-2}	7.50×10^{-2}	1.34×10^{-1}	1.63×10^{-1}	1.64×10^{-1}
	Cr-51	1.63×10^0	4.90×10^0	6.50×10^0	6.75×10^0	6.75×10^0
	Ni-65	6.34×10^{-4}	6.34×10^{-4}	6.34×10^{-4}	6.34×10^{-4}	6.34×10^{-4}
	Mn-56	7.19×10^{-2}	7.19×10^{-2}	7.19×10^{-2}	7.19×10^{-2}	7.19×10^{-2}
	Fe-55	3.79×10^{-2}	4.05×10^{-1}	1.55×10^0	5.70×10^0	1.17×10^1
	Co-58	3.25×10^{-2}	2.35×10^{-1}	5.55×10^{-1}	8.90×10^{-1}	9.81×10^{-1}
	Na-24	<u>1.81×10^{-3}</u>	<u>1.81×10^{-3}</u>	<u>1.81×10^{-3}</u>	<u>1.81×10^{-3}</u>	<u>1.81×10^{-3}</u>
TOTALS		2.15	6.08	9.31	14.6	21.3

TABLE I (CONT'D)

Purification Rate lb/hr	Isotope	Days				
		30	100	200	400	600
		Activity, $\mu\text{c/ml}$				
36,000	Co-60	6.39×10^{-5}	2.12×10^{-4}	4.17×10^{-4}	8.06×10^{-4}	1.17×10^{-3}
	Co-60m	4.83×10^{-3}	4.83×10^{-3}	4.83×10^{-3}	4.83×10^{-3}	4.83×10^{-3}
	Fe-59	2.51×10^{-4}	5.36×10^{-4}	6.51×10^{-4}	6.81×10^{-4}	6.82×10^{-4}
	Cr-51	2.49×10^{-2}	4.29×10^{-2}	4.62×10^{-2}	4.65×10^{-2}	4.65×10^{-2}
	Ni-65	4.04×10^{-4}	4.04×10^{-4}	4.04×10^{-4}	4.04×10^{-4}	4.04×10^{-4}
	Mn-56	4.59×10^{-2}	4.59×10^{-2}	4.59×10^{-2}	4.59×10^{-2}	4.59×10^{-2}
	Fe-55	6.73×10^{-4}	2.21×10^{-3}	4.29×10^{-3}	8.05×10^{-3}	1.13×10^{-2}
	Co-58	9.90×10^{-4}	2.11×10^{-3}	2.56×10^{-3}	2.68×10^{-3}	2.69×10^{-3}
	Na-24	<u>4.2×10^{-4}</u>	<u>4.2×10^{-4}</u>	<u>4.2×10^{-4}</u>	<u>4.2×10^{-4}</u>	<u>4.2×10^{-4}</u>
TOTALS		0.0819	0.103	0.109	0.114	0.117

TABLE I (CONT'D)

Purification Rate lb/hr	Isotope	Days				
		30	100	200	400	600
		Activity, $\mu\text{c/ml}$				
80,000	Co-60	2.89×10^{-5}	9.54×10^{-5}	1.88×10^{-4}	3.62×10^{-4}	5.24×10^{-4}
	Co-60m	2.13×10^{-3}	2.13×10^{-3}	2.13×10^{-3}	2.13×10^{-3}	2.13×10^{-3}
	Fe-59	1.13×10^{-4}	2.41×10^{-4}	2.93×10^{-4}	3.07×10^{-4}	3.07×10^{-4}
	Cr-51	1.12×10^{-2}	1.93×10^{-2}	2.08×10^{-2}	2.09×10^{-2}	2.09×10^{-2}
	Ni-65	1.93×10^{-4}	1.93×10^{-4}	1.93×10^{-4}	1.93×10^{-4}	1.93×10^{-4}
	Mn-56	2.20×10^{-2}	2.20×10^{-2}	2.20×10^{-2}	2.20×10^{-2}	2.20×10^{-2}
	Fe-55	3.04×10^{-4}	9.94×10^{-4}	1.93×10^{-3}	3.62×10^{-3}	5.10×10^{-3}
	Co-58	4.45×10^{-4}	9.50×10^{-4}	1.15×10^{-3}	1.21×10^{-3}	1.21×10^{-3}
	Na-24	2.27×10^{-4}	2.27×10^{-4}	2.27×10^{-4}	2.27×10^{-4}	2.27×10^{-4}
TOTALS		0.0385	0.0480	0.0510	0.0520	0.0540

TABLE 1 (CONT'D)

Purification Rate lb/hr	Isotope	Days				
		30	100	200	400	600
		Activity, $\mu\text{c/ml}$				
160,000	Co-60	1.15×10^{-5}	4.77×10^{-5}	9.39×10^{-5}	1.81×10^{-4}	2.62×10^{-4}
	Co-60m	1.03×10^{-3}	1.03×10^{-3}	1.03×10^{-3}	1.03×10^{-3}	1.03×10^{-3}
	Fe-59	5.67×10^{-5}	1.21×10^{-4}	1.47×10^{-4}	1.53×10^{-4}	1.54×10^{-4}
	Cr-51	5.62×10^{-3}	9.67×10^{-3}	1.04×10^{-3}	1.05×10^{-2}	1.05×10^{-2}
	Ni-65	1.01×10^{-4}	1.01×10^{-4}	1.01×10^{-4}	1.01×10^{-4}	1.01×10^{-4}
	Mn-56	1.15×10^{-2}	1.15×10^{-2}	1.15×10^{-2}	1.15×10^{-2}	1.15×10^{-2}
	Fe-55	1.52×10^{-4}	4.97×10^{-4}	9.64×10^{-4}	1.81×10^{-3}	2.55×10^{-3}
	Co-58	2.24×10^{-4}	4.77×10^{-4}	5.80×10^{-4}	6.03×10^{-4}	6.07×10^{-4}
	Na-24	1.21×10^{-4}	1.21×10^{-4}	1.21×10^{-4}	1.21×10^{-4}	1.21×10^{-4}
TOTALS		0.0187	0.0241	0.0259	0.0270	0.0279

TABLE II
CORROSION PRODUCT ACTIVITIES ON THE PURIFICATION FILTERS
AND ION EXCHANGER RESINS

Isotope	Days				
	30	100	200	400	600
	Activity, $\mu\text{c/ml}$				
Co-60	4.8×10^{-1}	5.2×10^0	2.03×10^1	7.74×10^1	1.65×10^2
Co-60m	2.5×10^{-2}	2.5×10^{-2}	2.5×10^{-2}	2.5×10^{-2}	2.5×10^{-2}
Fe-59	1.7×10^0	9.91×10^0	1.77×10^1	2.15×10^1	2.17×10^1
Cr-51	1.60×10^2	6.46×10^2	8.58×10^2	8.90×10^2	8.90×10^2
Ni-65	3.06×10^{-2}	3.06×10^{-2}	3.06×10^{-2}	3.06×10^{-2}	3.06×10^{-2}
Mn-56	3.46×10^0	3.46×10^0	3.46×10^0	3.46×10^0	3.46×10^0
Fe-55	4.95×10^0	5.36×10^1	2.06×10^2	7.57×10^2	1.56×10^3
Co-58	4.2×10^0	3.10×10^1	7.34×10^1	1.18×10^2	1.30×10^2
Na-24	1.85×10^{-1}	1.85×10^{-1}	1.85×10^{-1}	1.85×10^{-1}	1.85×10^{-1}
TOTALS	178	750	1179	1868	2771

TABLE III
CORROSION PRODUCT INPUT DATA

<u>Active Corrosion Product</u>	<u>Parent Nuclide</u>	<u>f, Fraction of Parent Atoms in 304 SS</u>	<u>λ, Decay Constant</u>	<u>σ, Activation Cross Section Barns*</u>
Co-60	Co-59	4.73×10^{-4}	4.16×10^{-9}	20
Co-60m	Co-59	4.73×10^{-4}	1.1×10^{-3}	16
Fe-59	Fe-58	2.18×10^{-3}	1.78×10^{-7}	0.98
Cr-51	Cr-50	8.74×10^{-3}	2.89×10^{-7}	15
Ni-65	Ni-64	9.60×10^{-4}	7.35×10^{-5}	1.6
Mn-56	Mn-55	1.22×10^{-2}	7.48×10^{-5}	13.3
Fe-55	Fe-54	4.10×10^{-2}	7.49×10^{-9}	2.3
Co-58	Ni-58	5.61×10^{-2}	1.12×10^{-7}	0.13

* All cross sections are thermal cross sections given in the "Trilinear Chart of Nuclides"¹ with the exception of the cross section for the Ni-58 (n, p) Co-58 reaction which was chosen to obtain agreement with the measured activity in the APPR.²

¹ Sullivan, William H., Trilinear Chart of Nuclides, U. S. Atomic Energy Commission, January 1957.

² Small, W. J., Zegger, J. L., Medin, A. L., Long-Lived Circulating Activity in the APPR, APAE-20, August 1957.

IV. ACTIVITY ON THE PURIFICATION FILTERS AND ION EXCHANGERS

It is assumed that the purification filters and ion exchangers in the blowdown stream catch and retain all of the corrosion products from the primary loop. The normal blowdown rate for the primary loop is 90 gpm at 485 F or 36,000 lb/hr. Two (2) filters and ion exchangers will operate in parallel for the normal blowdown rate. The filters and ion exchange resins used in this study are those removed from the purification stream at the end of core lifetime. For the sake of greater safety in the shield design it may be assumed that either the filter or the ion exchange resin in series with it could accumulate all of the activity removed during blowdown.

The activities given in Table II are integral values in the sense that they represent the total activities on all filters and ion exchange resins used in the primary purification system including those which have been replaced. To get the activity in the purification system accumulated during the final 6 months of operation it is necessary to use the formula:

Activity accumulated during final interval to time t after an initial reactor operating period of length T equals

$$n_1(t + T) - n_1(T)e^{-\lambda t},$$

where n_1 and λ have the meanings given previously.

Using this formula, Table IV has been constructed showing the activity at shutdown on the final complement of filters and ion exchangers.

V. CORROSION PRODUCT ACTIVITY ON THE SPENT FUEL AND TRANSFER ION EXCHANGER RESIN BEDS

Following a refueling, it will be necessary to remove corrosion products from the spent fuel storage water because it mixes with primary coolant water during the refueling process. For purposes of this study, it is assumed the equilibrium corrosion products in the loop at 600 days, with a purification rate of 36,000 lb/hr, are transferred to the spent fuel pool water. It will take about 15 days to process the pool water.

The total additional activity remaining with the chemical cleanup system after this operation will be 6.2 curies, made up of 4.2c of Cr-51, 1.5c of Fe-55, 0.31c of Co-58, 0.072c of Fe-59 and 0.16c of Co-60.