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ADDENDUM-SAFETY ANALYSIS REPORT FOR THE ICPP ELECTROLYTIC DISSOLUTION PROCESS

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IDAHO OPERATIONS OFFICE

By

R. D. DENNEY

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ALLIED CHEMICAL CORPORATION
IDAHO CHEMICAL PROGRAMS - OPERATIONS OFFICE
NATIONAL REACTOR TESTING STATION

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FORWARD

This document was prepared as an addendum to the safety analysis report (SAR) for the ICPP electrolytic dissolution process, ICP-1009(1). No attempt was made to reproduce in the addendum the basic descriptive and analytical data presented in the SAR although the material presented in the addendum is arranged in the same format as that presented in the basic document. Because of this the user may find it desirable and at times necessary to consult the basic information given in the SAR in connection with new information given in the addendum.

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I. INTRODUCTION

An electrolytic dissolution process has been installed at ICPP for dissolving stainless steel clad fuels in nitric acid. The final safety analysis report for this process was issued in October 1972 and actual fuel reprocessing started in January 1973. In the intervening period several additional safety related questions were analyzed and satisfactorily answered. In no case was the basic safety of the process found to be in doubt. It is the purpose of this addendum to the SAR (ICP-1009)⁽¹⁾ to record these additional analyses and conclusions.

II. PROCESS AND EQUIPMENT CHANGES

1. HEADEND MODIFICATION

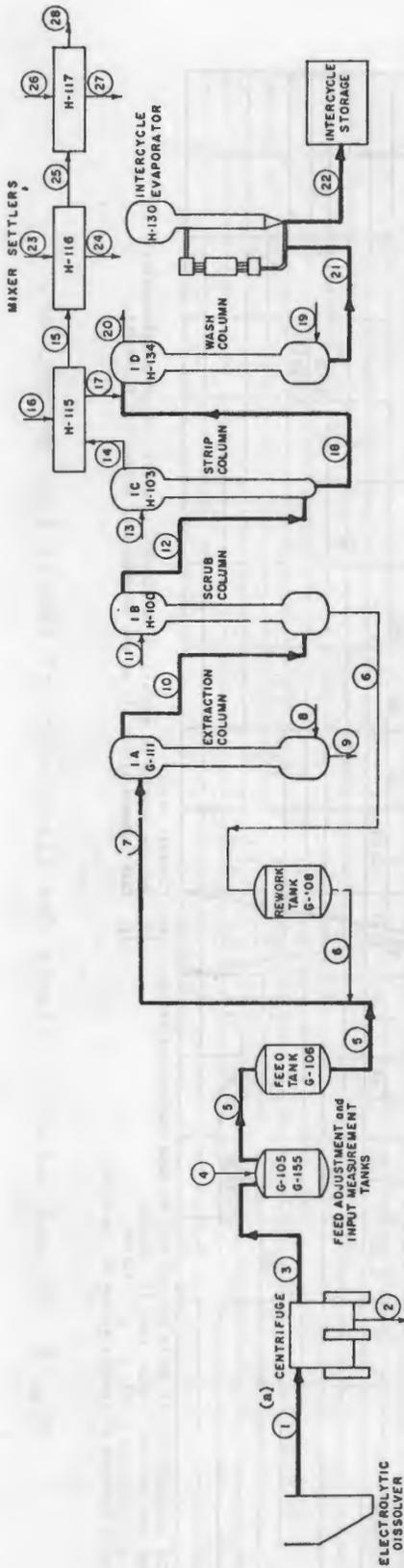
Some process and equipment changes have been incorporated into the electrolytic dissolver system since the SAR was published. These changes were brought about as improvements were made and as dictated by actual operating performance. They are summarized below with the corresponding SAR references.

The settling tanks, which were anticipated to remove approximately one ft³ of solids during the first enriched fuel processing campaign from the dissolver product, removed less than 0.2 ft³ in 45 days of dissolution and have been eliminated from the system. The solids are now all removed in the process centrifuge on which a safety analysis has been made.⁽²⁾ This eliminated several remotely operated valves which can potentially leak. The high-load charging cask which was reported to weigh 17 tons (SAR p.6) actually weighs 13.5 tons; the floor loading is correct at 1400 lb/ft².

The system volume, reported to be ~700 liters, has been more accurately determined to be ~750 liters. Updated material balances showing minor additional changes to those in SAR (pp.10-17) are shown in Figures 1, 3, 5, and 7. As shown in the flowsheets for canned fuel, mercury to catalyze the aluminum dissolution is added as an option.

Six-inch diameter York-mesh demisters have been added to both the VOG and DOG lines in CPP-640 Cell 5. Each demister has a spray nozzle located above the mesh for decontamination purposes. These were installed as a purely precautionary measure based on experience elsewhere in the plant in that removal of mist at these points might be valuable in reducing activity in the downstream off-gas systems.

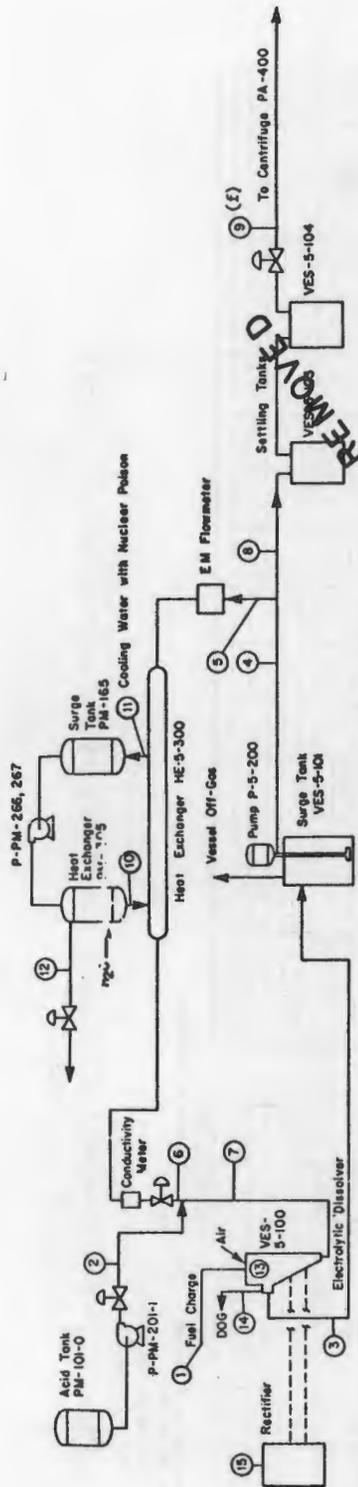
New alarms on the electrolytic panel in addition to those listed in the SAR (p.39), are (1) low gadolinium in PM-101-0 (each channel), (2) PM-165 level (high and low), (3) rectifier off, (4) pump P-5-200 vibration, (5) loss of signal to the nuclear poison detector, and (6) low VOG pressure.



STREAM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19 & 20	21	22	23	24	25	26 & 27	28	
DESCRIPTION	DISOLVER (a)	SOLIDS TO CENTRIFUGE	DISOLVER PRODUCT	ADJUSTED SOLUTION	ADJUSTED SOLUTION	FEED SOLUTION	FEED SOLUTION	ADJUSTED SOLUTION																			
Flow, g/hr	21	79	100	50	150	300	150	300	50	300	200	300	300	50	50	200	10 (e)	250	6.9	30	300	30	300	30	300	300	
U ₂ N ₂	4.2	3.2	3.2	2.4	2.5	2.5	2.2	2.2	0.2	0.2	0.2	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.4	0.01	0.01	0.01	0.01	0.01	0.01	0.01
NO ₂ , M	8.0	3.2	3.2	2.4	2.6	2.6	3.2	3.2	0.2	0.2	0.2	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
SS, g/l	48.5 (b)	48.5	48.5	48.5	48.5	48.5	48.5	48.5	0.1	0.1	0.1	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Na ₂ CO ₃ , g/l	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	0.4	0.4	0.4	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Ca, g/l	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	0.4	0.4	0.4	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Fissium, g/l	5.3 (c)	5.3	5.3	5.3	5.3	5.3	5.3	5.3	0.4	0.4	0.4	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
U ₂ g/l	100	100	100	100	100	100	100	100	0.4	0.4	0.4	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
U-235, g/l	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	0.2	0.2	0.2	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Solids, g/hr ave	65	65	65	65	65	65	65	65	0.2	0.2	0.2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Al, M									0.5	0.5	0.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
NH ₄ , M									0.2	0.2	0.2	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
TBP, %									10 (d)	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Na ₂ CO ₃ , M									0.2	0.2	0.2	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
SP.GR. @ 25°C									1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15

(a) Stream (9) on the dissolution flowsheet.
 (b) 0.5 g/l SS solids present.
 (c) Fifty percent of the fissium is insoluble in the dissolver.
 (d) 10% TBP in NPH.
 (e) Acid deficient with NH₄OH.
 (f) ANSCO

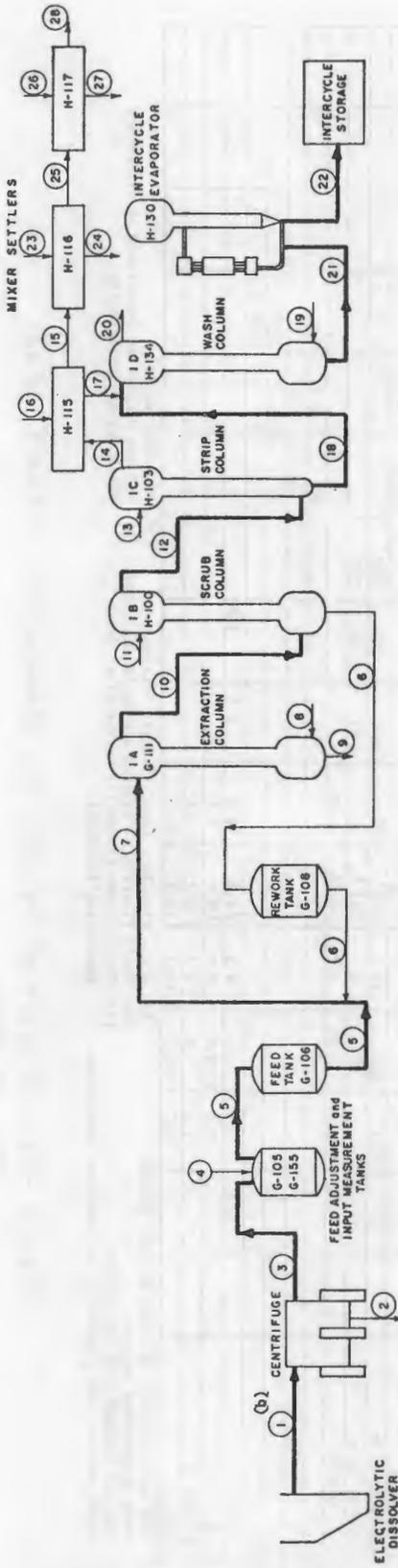
Fig. 2 Typical material balance for first-cycle extraction of EBR-II fuel assemblies.



Stream	Description	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Flow, l/hr	41	4500	4500	4500	4500	41	41	41	3.6x10 ⁴									
	Litrium																		
	Stainless Steel, g/hr	2085																	
	Sodium, g/hr	492																	
	Fission, g/hr	23																	
	Aluminum, g/hr	110																	
	Uranium, g/l	1240																	
	Stainless Steel, g/l (a)		50.8	50.8	50.8	50.8	50.8	50.8	50.8	50.8	50.8	50.8	50.8	50.8	50.8	50.8	50.8	50.8	50.8
	Fission, g/l (a)		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
	Undissolved solids, g/l		2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
	H ₂ , M		2.3(d)	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
	Flow, scfm		9.0	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
	Temperature, °F		70	130	125	115	125	120	104	107	107	107	107	107	107	107	107	107	107
	Pressure, psig		55	55	1	55	5	85	80	100	100	100	100	100	100	100	100	100	100
	SP.Gr. @ 25°C		1.28	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36
	H ₂ , %																		
	Amps																		
	Volts																		
	Gd, g/l		4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
	Na, g/l		0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
	Aluminum, M		1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
	U-235, g/l		26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7

(a) The concentration of these streams include some undissolved solids.
 (b) One can charged each 164 minutes.
 (c) Acid contains .01 M Hg(NO₃)₂ for aluminum dissolution, extraction flowsheet.
 (d) 1 g/l stainless steel, 1.3 g/l fission.
 (e) Small flowrate of product stream is neglected.
 (f) This becomes stream (1) on the first cycle.
 (g) Flowrate varies.
 (h) Voltage depends on resistance in dissolver, which varies continuously.

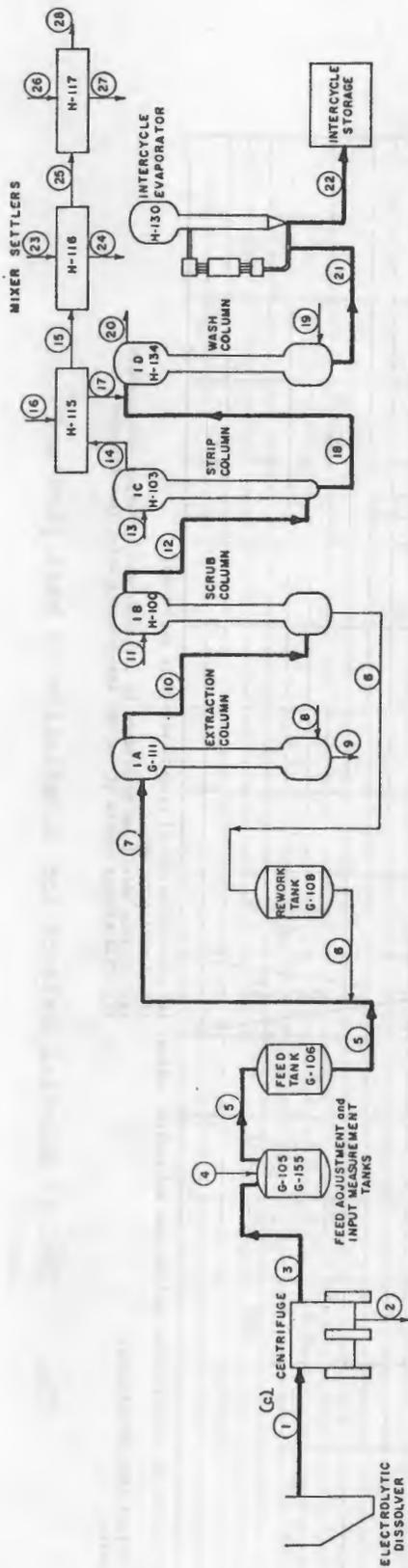
Fig. 3 Typical material balance for dissolution of EBR-II clad pins in cans.



STREAM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
DESCRIPTION	DISSOLVER PRODUCT	SOLIDS TO CENTRIFUGE	CENTRIFUGED DISSOLVER PRODUCT	FEED ADJUSTMENT SOLUTION	ADJUSTED DISSOLVER PRODUCT	DISSOLVER PRODUCT	IAI	IAJ	IAP	IAP	IAK	IAP	ICX	ICX	ICN	ICN	ICM	ICM	ICP	ICP	ICQ	ICQ	ICR	ICR	ICR	ICR	ICR	ICR	ICR
Flow, l/hr	41	59	100	50	150	300	150	300	50	300	200	300	300	300	50	200	10(2)	250	6.9	30	30	300	30	300	30	300	300	300	
H ₂ N	3.5	3.3	3.4	0.7	2.5	2.2	0.1	0.2	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
NO ₃ -M	7.4	7.4	3.3	5.0	2.4	4.1	3.6	0.2	1.5	0.1	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	
Al ₂ O ₃ -M	1.1	1.1	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
SS, g/l	11.5(c)	11.5	4.5	4.5	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	
Na ₂ CO ₃ , g/l	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	
Gd, g/l	4.3	4.3	1.8	1.8	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	
Fissium, g/l	2.7(d)	2.7	1.4	1.4	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	
U, g/l	50.8	50.8	20.8	20.8	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	
U-235, g/l	26.7	26.7	10.9	10.9	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	
Solids, g/hr	74	74	26.7	26.7	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	
NH ₃ -M																													
TEMP, °M																													
Na ₂ CO ₃ , M																													
SP. GR. @ 25°C																													
Hg(NO ₃) ₂ M (a)	0.01	0.01	0.004	0.004	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	

(a) Optional
 (b) Stream (9) on the dissolution flow sheet.
 (c) Approximately 0.5 g/l SS solids.
 (d) Fifty percent of the fissium is insoluble.
 (e) 10% TSP in NPH.
 (f) Acid deficient with NH₄OH.
 (g) AMSCO

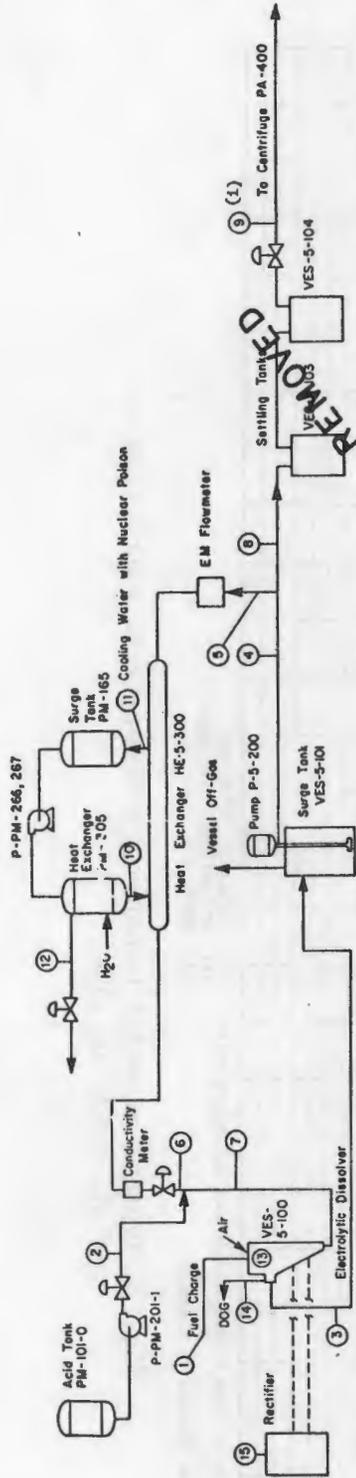
Fig. 4 Typical material balance for first-cycle extraction of EBR-II clad pins in cans.



STREAM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19 & 20	21	22	23	24	25	26 & 27	28		
DESCRIPTION	DISSOLVER PRODUCT	SOLIDS TO CENTRIFUGE	CENTRIFUGED DISSOLVER PRODUCT	FEED ADJUSTMENT SOLUTION	ADJUSTED DISSOLVER PRODUCT	ADJUSTED DISSOLVER PRODUCT	FEED ADJUSTMENT AND INPUT MEASUREMENT TANKS	FEED ADJUSTMENT AND INPUT MEASUREMENT TANKS	EXTRACTION COLUMN	EXTRACTION COLUMN	EXTRACTION COLUMN	EXTRACTION COLUMN	EXTRACTION COLUMN	EXTRACTION COLUMN	EXTRACTION COLUMN	EXTRACTION COLUMN	EXTRACTION COLUMN	EXTRACTION COLUMN	EXTRACTION COLUMN	EXTRACTION COLUMN	EXTRACTION COLUMN	EXTRACTION COLUMN	EXTRACTION COLUMN	EXTRACTION COLUMN	EXTRACTION COLUMN	EXTRACTION COLUMN	EXTRACTION COLUMN	
Flow, 2/hr	41	59	100	50	300	150	300	150	300	50	300	200	300	300	50	50	50	50	200	10 (E)	250	6.9	30	30	300	300	300	
H ⁺ , M	4.1	4.1	2.9	1.4	0.7	2.5	2.2	0.2	-0.2 (e)	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
NO ₃ ⁻ , M	7.5	7.5	4.8	2.4	4.0	3.5	0.2	1.5	0.6	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Al ³⁺ , M	1.1	1.1	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Cd, g/l	4.3	4.3	1.8	1.2	1.2	1.2	1.2	1.2	1.2	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Fissium, g/l (a)	2.7	2.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
U, g/l	50.8	50.8	20.8	0.4	14	1.830	7.0	6.9	6.9	2.2x10 ⁻³	1.2x10 ⁻⁴	1.2x10 ⁻⁵																
U, g/l	26.7	26.7	10.9	0.2	7.4	0.9x10 ⁻³	3.7	3.6	3.6	0.01	10.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4
Solids, g/hr	55	55	0.2	0.1	10 (d)	0.1	10	0.2	0.2	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
NH ₄ ⁺ , M																												
TEMP, °F																												
NH ₂ CO ₃																												
SP. GR. @ 25°C																												
H ₂ (NO ₃) ₂ (b)																												

(a) The concentration of these streams include some undissolved solids.
 (b) Optional.
 (c) Stream (9) on the dissolution flowsheet.
 (d) Ten percent TBP in NH₃.
 (e) Acid deficient with NH₄OH.
 (f) AMSCO.

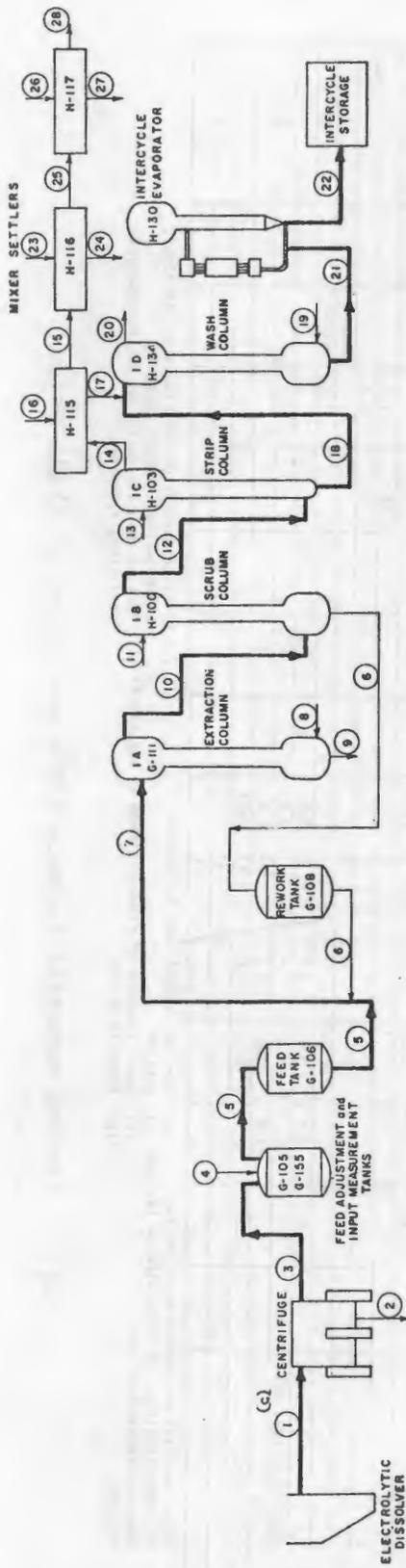
Fig. 6 Typical material balance for first-cycle extraction of bare pins and ingots in cans.



Stream	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Description	Fuel Charge (d)	Acid Dissolvent	Leakage to Surge Tank	Recirculation Solution to Heat Exchanger	Recirculation Solution from Heat Exchanger	Product Steam to Settling Tanks	Product Steam to Centrifuge (1)	Cooling Water to Heat Exchanger	Cooling Water from Heat Exchanger	Secondary Cooling Water	Dissolver Off-Gas	Diluted Off-Gas	Rectifier					
Flow, l/hr	57	4500	4500 (E)	4500 (E)	4500 (E)	57	57	3.6x10 ⁴	3.6x10 ⁴	3.6x10 ⁴	(g)							
Uranium, g/hr	1370																	
Fissium, g/hr	70																	
Aluminum, g/hr	1710																	
Solids, g/hr(a)	84																	
Uranium, g/l		24	24	24	24	24	24											
Fissium, g/l(b)		1.2	1.2	1.2	1.2	1.2	1.2											
H ⁺ , M	9.0	5.4	5.4	5.4	5.4	5.4	5.4											
NO ₃ , M	9.0	7.9	7.9	7.9	7.9	7.9	7.9											
Aluminum, M		1.1	1.1	1.1	1.1	1.1	1.1											
Flow, scfm																		
Temperature, °F	70	130	125	115	125	120	104	107	107									
Pressure, psig	55		55	1	55	5	85	80	100									
SP.GR. @ 25°C	1.28	1.34	1.34	1.34	1.34	1.34	1.34											
NO ₂ , %																		
H ₂ , %																		
Amps																		
Volts																		
CD, g/l	3.9	3.9	3.9	3.9	3.9	3.9	3.9	2.6	2.6									
Undissolved solids, g/l																		
U-235, g/l	0.01	12.6	12.6	12.6	12.6	12.6	12.6											
Hg(NO ₃) ₂ , M(c)		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01									

(a) Solid material associated with the fuel. (d) One can charged each 67 minutes.
 (b) The concentrations of these streams include (e) Fissium, which is continuously changing.
 (c) Optional. (f) Small flowrate of product stream is neglected. (1) This becomes stream (1) on the accompanying extraction flowsheet.
 (g) Flowrate varies.

Fig. 7 Typical material balance for dissolution of skull oxide in cans.



DESCRIPTION	STREAM																											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Flow, g/hr	57	43	100	50	150	300	150	300	50	300	200	300	300	50	50	200	10	250	4.6	30	300	30	300	30	300	30	300	
H ⁺ , M	5.4	0.7	3.4	0.7	2.5	2.2	0.1	0.2	0	0.01	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
NO ₃ ⁻ , M	7.9	0.7	4.8	2.4	4	3.6	0.2	1.5	0.1	0.01	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Al ³⁺ , M	1.1	0.6	0.6	0.5	0.6	0.6	0.2	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LiCl, g/l	3.9	2.2	2.2	0.4	1.5	1.5	0.2	0.2	0.2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Fissium, g/l(a)	2.4	0.6	13.7	0.3	9.2	1.5x10 ⁻³	4.6	4.6	4.6	8x10 ⁻⁴	1x10 ⁻⁴	4x10 ⁻³	4x10 ⁻³	5x10 ⁻³	6.8	2.9	1.58	5.5	300	6x10 ⁻⁴	5.5	300	6x10 ⁻⁴	5.5	300	6x10 ⁻⁴	5.5	300
U, g/l	24	0.6	13.7	0.3	9.2	1.5x10 ⁻³	4.6	4.6	4.6	8x10 ⁻⁴	1x10 ⁻⁴	4x10 ⁻³	4x10 ⁻³	5x10 ⁻³	6.8	2.9	1.58	5.5	300	6x10 ⁻⁴	5.5	300	6x10 ⁻⁴	5.5	300	6x10 ⁻⁴	5.5	300
U-235, g/l	12.6	0.3	6.8	0.15	4.6	7x10 ⁻⁴	2.4	2.4	2.4	4x10 ⁻³	5x10 ⁻³	2x10 ⁻³	2x10 ⁻³	2x10 ⁻³	3.6	1.58	2.9	1.58	2.9	1.58	2.9	1.58	2.9	1.58	2.9	1.58	2.9	1.58
Solids, g/l	34	0.2	0.2	0.1	10	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
NH ₄ ⁺ , M																												
TBP, %																												
Na ₂ CO ₃ , M																												
SP GR @ 25°C																												
H ₂ (NO ₃) ₂ , M(b)	0.01		0.006		0.004	0.004		0.004																				

(a) The concentration of these streams include some undissolved solids. (d) Ten percent TBP in NPH.
 (b) Optional. (e) Acid deficient with NH₄OH.
 (c) Stream (9) on the dissolution flowsheet. (f) ANSCO.

Fig. 8 Typical material balance for first-cycle extraction of skull oxide in cans.

A piece of new equipment installed in the cell is a remote radiation monitor (ranged to $\sim 10^4$ R/hr). Readout equipment located on the instrument panel utilizes a Fluke high-voltage power supply and a Keithley 610 BR Electrometer.

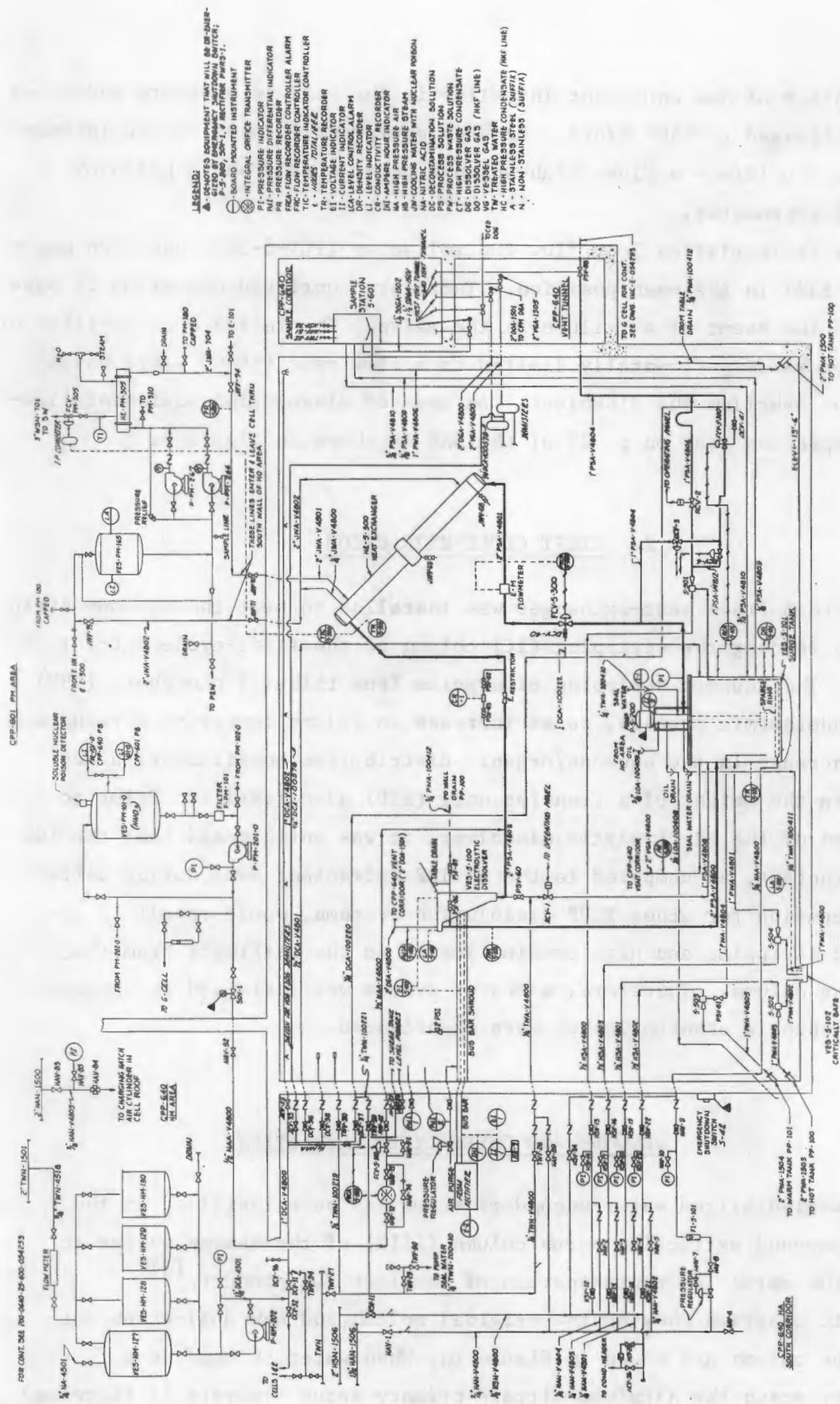
The recirculation loop flow control valve (FCV-5-300) has been modified to fail in the open position. Therefore continued operation is possible in the event of a failure in the valve. The failed open position of the valve was experimentally limited to a flow rate (~ 6000 l/hr) which would not overflow the dissolver. An updated dissolution equipment flow-sheet replacing that on p. 29 of the SAR is shown in Figure 9.

2. FIRST CYCLE EXTRACTION

A steam-trace heat-exchanger was installed to heat the aqueous stripping solution feeding the stripping (IC) column of the first-cycle extraction system. The aqueous stripping of uranium from tributyl phosphate (TBP) is an endothermic process, so an increase in column temperature results in an increase in the aqueous/organic distribution coefficient; a decrease in the height of a transfer unit (HTU) also results. Prior to operation of the electrolytic dissolver, it was anticipated that the 10% TBP extractant, as compared to the 5% TBP extractant used during extraction operation for other ICPP dissolution systems, would result in incomplete stripping and high uranium losses in the raffinate from the stripping column. Therefore, a heater system was installed to be used if unacceptable uranium losses were experienced.

3. SECOND- AND THIRD-CYCLE EXTRACTION

A demineralized water secondary scrub has been installed in the final compound extraction-scrub column (IIIA) of the hexone system to reduce the metal ion contamination of the ICPP UO_3 product.⁽³⁾ Schematic diagrams showing the original column and new dual-scrub set-up on the column are shown in Figure 10. When water is used as a secondary scrub the aluminum nitrate primary scrub flowrate is increased to maintain an adequate salting strength in the extraction section of



- LEGEND:**
- ▲ - DENOTES EQUIPMENT THAT WILL BE DE-MAINTAINED BY THE CONTRACTOR (SEE INSTRUMENT LIST)
 - - BOARD MOUNTED INSTRUMENT
 - ⊗ - INTEGRAL ORifice TRANSMITTER
 - PI - PRESSURE INDICATOR
 - PD - PRESSURE DIFFERENTIAL INDICATOR
 - PR - PRESSURE RECORDER/CONTROLLER ALARM
 - FAC - FLOW RECORDER/CONTROLLER ALARM
 - TIC - TEMPERATURE INDICATOR/CONTROLLER
 - TR - TEMPERATURE RECORDER
 - EI - VOLTAGE INDICATOR
 - LI - LEVEL INDICATOR
 - LC - LEVEL CONTROLLER
 - DR - DENSITY RECORDER
 - MI - HIGH PRESSURE AIR INDICATOR
 - MI - AMPERE HOUR INDICATOR
 - MI - COOLING WATER WITH NUCLEAR POISON
 - NA - NITRIC ACID
 - DC - DECONTAMINATION SOLUTION
 - PP - PROCESS WASTE SOLUTION
 - CT - HIGH PRESSURE CONDENSATE
 - DO - DISSOLVER GAS (HFK LINE)
 - VS - VESSEL GAS (HFK LINE)
 - TR - TREATED WATER CONDENSATE (HFK LINE)
 - ST - STEEL
 - A - STAINLESS STEEL (SUFFIX)
 - N - NON-STAINLESS (SUFFIX)

Fig. 2 Dissolution equipment flowsheet.

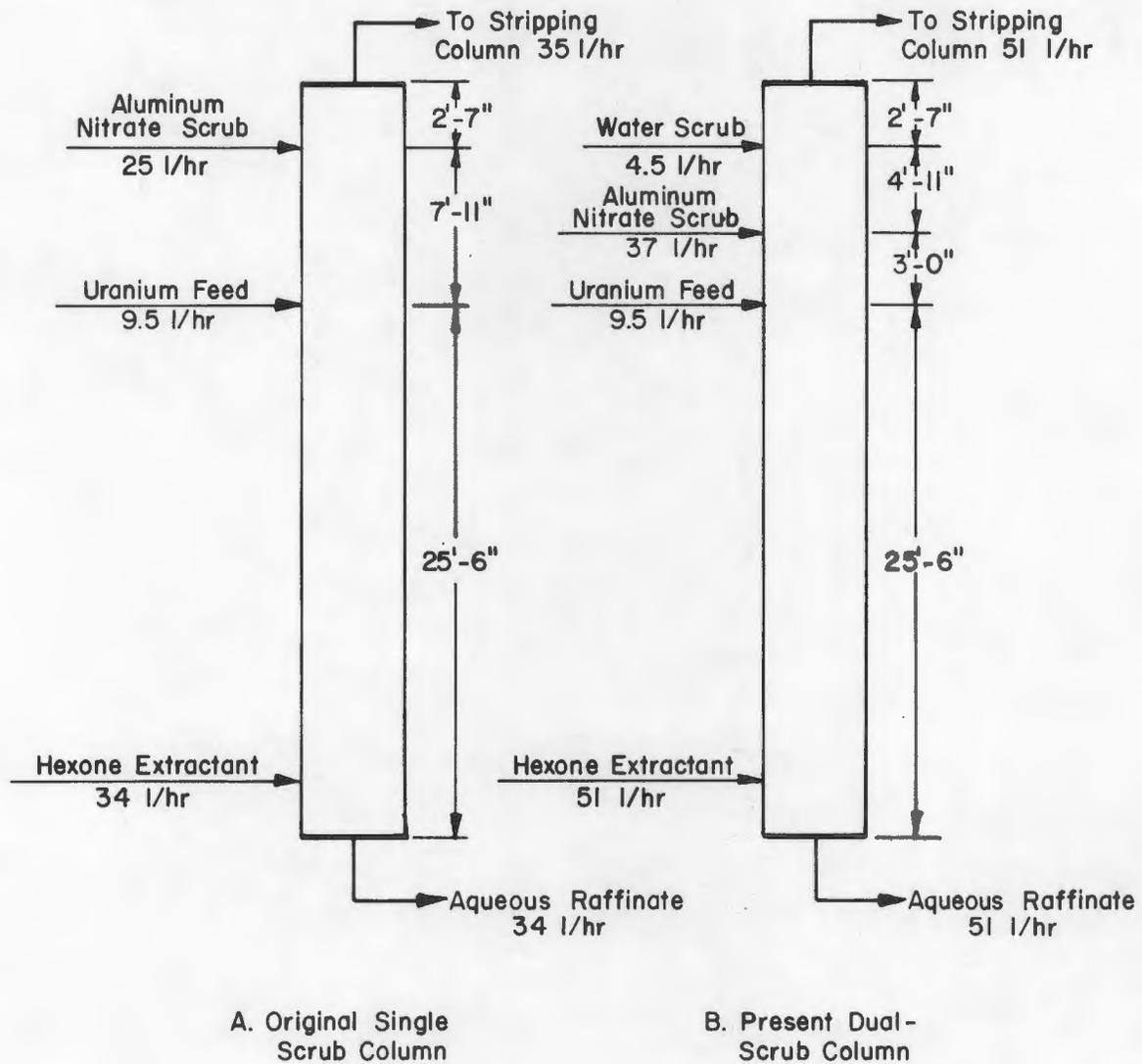


Fig. 10 Schematic diagrams showing original single-scrub (IIIA) column and present dual-scrub column used in the final hexone cycle.

the column. Dual scrub operation made practical the use of ferrous reductant in the IIIA scrub stream for an additional cycle of plutonium decontamination.

A material balance and flowsheet replacing that in the SAR (p.27) is shown in Figure 11.

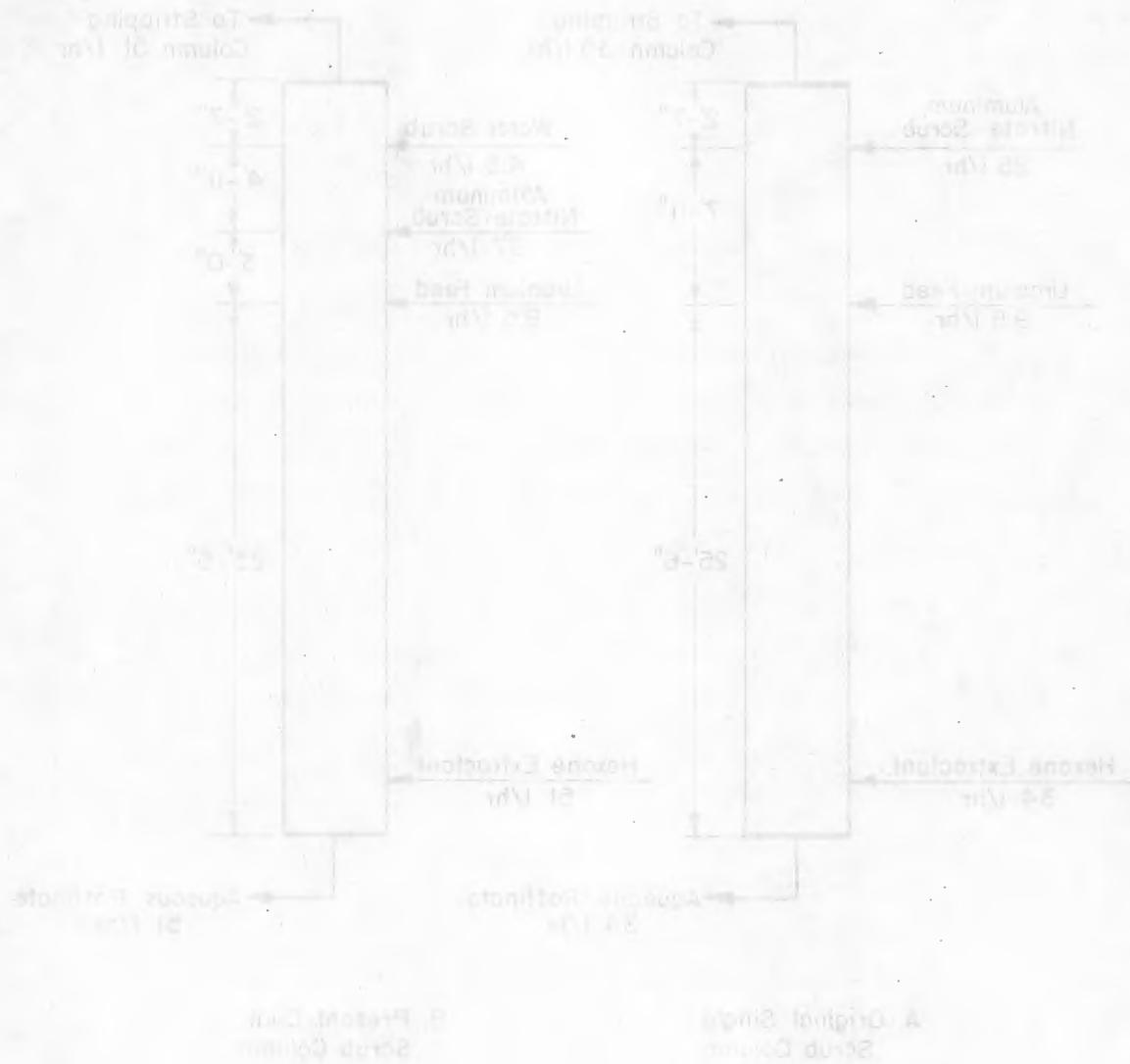
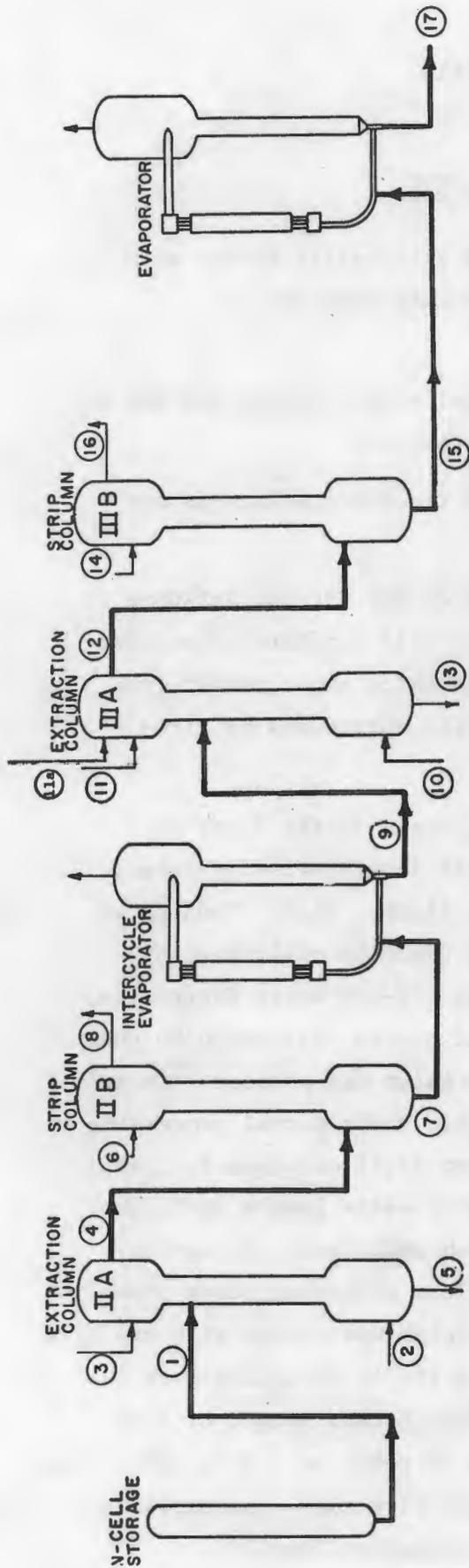


Fig. 11. Material balance and flowsheet for the dual scrub column. The original single scrub column is shown in parentheses.



STREAM	1	2	3	4	5	6	7	8	9	10	11	11a	12	13	14	15	16	17
DESCRIPTION	II AF	II AX	II AS	II AP	II AR	II BX	II BP	II BR	SECOND CYCLE PREDUCT	III AX	IIIAS ¹	IIIAS ²	III AP	III AR	III BX	III BP	III BR	PRODUCT
FLOW, l/hr	50	40	51	50	30	31	50	9.5	51	37	4.5	51	51	25	25	51	9.5	
SP GR	1.43	0.80	1.31	0.89	1.25	1.15	0.80	1.48	0.80	1.31	1.04	0.89	1.23	1.18	1.00	0.80	1.48	
EXTRACTANT	Hexone	Hexone	Hexone	Hexone	Hexone	Hexone	Hexone	Hexone	Hexone	Hexone	Hexone	Hexone	Hexone	Hexone	Hexone	Hexone	Hexone	
Al(NO ₃) ₃ , M	2.00			1.60					2.00				1.45					
HNO ₃ , M	1.0			0.22				0.13					0.20					
NH ₄ OH, M	0.55			0.22					0.32				0.04					
NH ₄ NO ₃ , M				5x10 ⁻³									5x10 ⁻³					
U, g/l	300			65		110		350				65	5x10 ⁻³		132			350
Fe(NH ₂ SO ₃) ₂ , M		0.08		0.06					0.08				0.06					
Gd, g/l	1.45			0.32														

Fig. 11 Material balance and flowsheet for second- and third-cycle extraction.

III. SAFETY ANALYSIS

1. CRITICALITY SAFETY

Several additional questions regarding criticality safety were analyzed with the results given in the following sections.

1.1 Cell Flooding

Flooding of CPP-640 Cell 5 was not considered credible and was not covered in the basic SAR for the following reasons:

- (1) The hydrology of the CPP area and the surroundings is not suggestive of flooding at CPP.
- (2) The large volume (over 7,000 ft³) of the CPP-640 building at elevations lower than the floor of Cell 5 offers a considerable reservoir for man-made floods which might result from ruptured water lines, automatic fire sprinklers or fire-fighting.
- (3) Although there is no free running drain in the floor of CPP-640 Cell 5 (a safeguard against loss of fissile material), there is a sump which has a level alarm. Minor flooding of the cell floor would be noted and could be dealt with by transfer of the flood water to the CPP-640 Waste System via an existing jet from the sump. Of course this would be done only after verification that no uranium was present. Calculations⁽⁴⁾ (Appendix A) indicate that under normal processing conditions a dissolver operating on 52.6% enriched fuel would have a k_{eff} of 0.95 or less at flood water levels up to the product overflow level. To furnish additional protection against flooding from fire sprinklers or broken water mains in the HM area the edge of the cell hatch was sealed with caulking compound and covered with tape. A lid is installed over the the charging chute. There is a significant length of time (~35 min) available for personnel to react to a fire water line failure hence stoppage of the water flow can be accomplished long before the water rises to a hazardous level.⁽⁵⁾

- (4) Flow in any part of the fire-protection sprinkling system adjacent to CPP-640 Cell 5 initiates a coded alarm over the CPP fire alarm system and at the CFA fire station in less than one minute. Thus, the alarm alerts the operators to a potential source of flood water.

1.2 Soluble Nuclear Poison in the Fresh Acid

The precautions to be taken to insure the presence of gadolinium, the soluble nuclear poison, in the fresh acid and dissolver solutions were described in the SAR. (p.56) The actual conditions imposed upon the process are summarized in Figure 12 and described in greater detail in the following paragraphs.

1.21 Reagent Makeup. Gadolinium oxide to be used as a soluble poison is purchased as a relatively high purity solid chemical of stated gadolinium content. The gadolinium content is rechecked by quantitative chemical analysis and the isotopic distribution verified by mass spectrometer analysis, both at ICPP. The quantitative chemical analysis method, which was not specifically designed for gadolinium, is standardized using mercury as an independent standard.

The reagent make-up vessel is isolated from all interconnections not required for this specific function. The weight of gadolinium oxide required is specified in the SOP's. For solution makeup the operator adding the gadolinium oxide certifies the weight added and takes a sample for quantitative and qualitative analysis for gadolinium and for acid. The Shift Supervisor or Foreman evaluates the analytical results and certifies that the concentration of gadolinium is correct for the particular process and that the solution can be transferred to the reagent feed tank. When a transfer between the reagent makeup tank and the reagent feed tank is to be made a valve in the transfer line between the two tanks will be unlocked and opened; the circuit breaker on the transfer pump will be unlocked and closed. Except during a transfer the valve is locked closed and the circuit breaker is locked open insuring isolation of the reagent feed tank from the reagent make-up tank. Reanalysis of the gadolinium is then performed to insure no dilution has occurred and isolation of the tank from cell systems is completed.

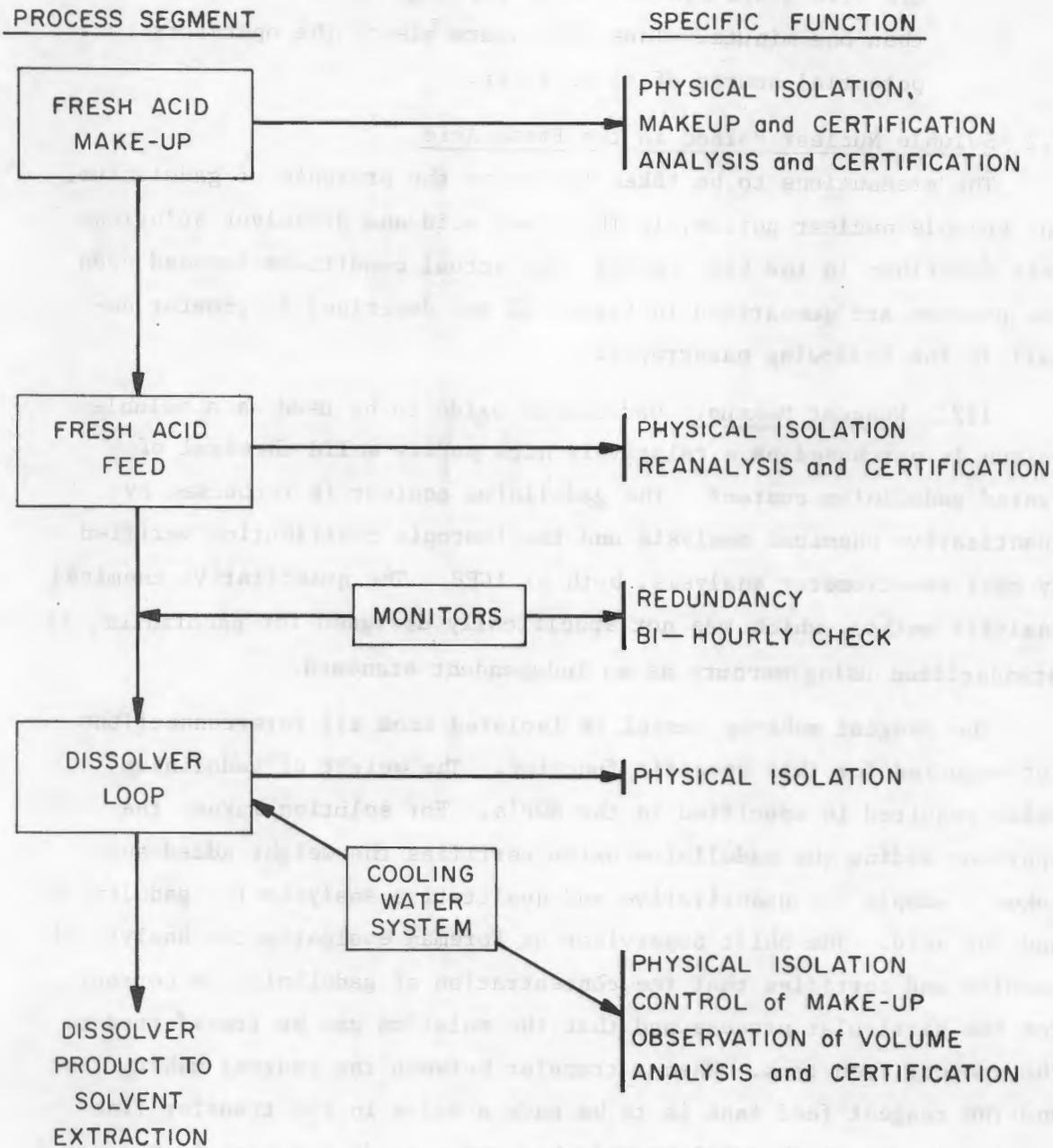


Fig. 12 Soluble nuclear poison in the acid feed and dissolver product - summary of safety controls.

1.22 Loss of Gadolinium Flow to Dissolver. The time required to dilute the nuclear poison in the dissolver system from the operating value to the safety limit as specified in the SL's and SR's determines the testing frequency while under single channel operation. Calculations of this dilution time were performed (see Appendix B for model) for each fuel type as per the material balances shown in Figures 1, 3, 5, and 7. Results of these calculations are shown in Table I.

TABLE I
DILUTION TIMES FOR GADOLINIUM IN THE ELECTROLYTIC DISSOLVER

<u>Assemblies</u>		<u>EBR-II Fuel Type Clad Pins, Bare Pins, Ingots</u>		<u>Skull Oxide</u>	
<u>t, hrs.</u>	<u>Gd, g/l</u>	<u>t, hrs.</u>	<u>Gd, g/l</u>	<u>t, hrs.</u>	<u>Gd, g/l</u>
0	2.60	0	2.60*	0	2.60*
1	2.53	1	2.46	1	2.41
2	2.46	2	2.33	2	2.23
4	2.32	4	2.09	4	1.92
6	2.20	6	1.87	5	1.78
8	2.08	7	1.77		
10	1.96				
12	1.86				
14	1.76				

* Assumes cans are full of water which dilutes Gd from flowsheet value to 2.6 g/l.

1.3 Soluble Nuclear Poison in the Cooling Loop

The requirements for nuclear poison in the cooling loop are discussed in the SAR (p.58). The actual conditions imposed on the process are discussed in further detail below.

The gadolinium is dissolved in small volumes of nitric acid and added to the cooling loop (~900 l volume). When consecutive sample analyses for gadolinium in the cooling loop agree within SOP specified limits and the concentration is above the required value, the coolant loop is ready for use. The system is isolated from other interacting systems by tagging out appropriate valves. The level is checked every two hours to insure that dilution or leaks have not occurred.

1.4 First-Cycle Extraction

Safety aspects of the first cycle extraction column (G-111) are covered in the SAR (p.60). The remaining equipment is discussed below.

After the extraction column, the stripping column is the most sensitive piece of equipment.⁽⁶⁾ The stripping solution would have to stop and stay stopped for more than four hours with the solvent flowing at normal rates together with total uranium transfer to the stagnant stripping solution before critical uranium concentrations would be encountered. This possibility will be prevented by hourly flowrate checks on the stripping solution stream. A criticality could only occur in the scrubbing column (H-100) after one had already occurred in the extraction column (G-111). Likewise, a criticality in the mixer settlers (H-115, -116, and -117) would have to follow a criticality in H-103. This is discussed in the following paragraphs.

The possibility of feeding water into the H-100 (scrubbing) column instead of the IBS aluminum nitrate scrub has been identified as a potential problem. However, calculations performed indicate that the distribution coefficients in the column under these conditions are so low that it is impossible for a criticality to occur with uranium concentrations in the designated flowsheet.⁽⁷⁾ The only possible way for a criticality in H-100 to occur would be to have a surge of a critical mass of uranium from a criticality in G-111.

The stripping column H-103 is a 9-inch diameter column with a 24-inch diameter head. The critical concentration of U-235 in the 9-inch section was calculated to be 153 g/l.⁽⁸⁾ The flowsheets (Figures 2, 4, 6, and 8) show the following flowrates and compositions for the pertinent streams: IBP = 300 l/hr @ 3.6 g/l U-235, ICP = 200 l/hr @ 5.4 g/l U-235. Since the IBP enters the stripping column at the bottom and the column is aqueous

continuous, there is a concentration gradient of uranium in the column from bottom to top. If it is assumed that the gradient would be linear in the 9-inch section (153 g/l U-235 at the bottom and 5.4 g/l U-235, the U-235 concentration in the inlet organic stream, at the top) the average concentration would be about 79 g/l U-235. The column would still be subcritical ($k_{eff} = .92$) because the critical concentration of 153 g/l U-235 was calculated for an infinitely long cylinder. The volume of the 9-inch section of the column is about 170 liters. Therefore, over 11.6 hours would be required for the IBP to introduce enough U-235, at flowsheet rate and concentration, into the stagnant aqueous phase to approach criticality.

If it is assumed that the contents of the column are well mixed (no concentration gradient) the worst possible case results.⁽⁶⁾ Then the 24-inch diameter head becomes the most sensitive part of the column. Calculations have been made for the head of the extraction column (G-111) which is the same diameter as the head of H-103. It was calculated that 27.2 g/l U-235 was the critical concentration for an eight-inch thick layer of solvent in the head. It was also calculated that with the head completely full of solvent (25-inch layer) the critical concentration was 18 g/l U-235. Therefore, it can be correctly assumed that at least 18 g/l U-235 would be required for criticality in H-103. The normal operating volume of H-103 is 344 liters. At least four hours would be required for the IBP, at flowsheet rate and concentration, to introduce this amount of U-235 into the stagnant column. Hence, hourly flowrate checks on the stripping solution to guarantee flow will be more than adequate to guarantee nuclear safety.

The first solvent wash mixer-settler (H-115) was also reviewed for criticality.⁽⁶⁾ Its aqueous operating volume is 455 liters. It was calculated that 19.3 g/l of 93.2% enriched uranium was the critical concentration in H-115. This is equivalent to 18 g/l of U-235. If the IBP at 300 l/hr and 3.6 g/l U-235 flowed through a stagnant H-103 to a stagnant H-115, at least 7.5 hours would be required to build up to a critical concentration. Of course, this could only happen after the stripping solution to H-103 had been stopped long enough for the stripping solution to become saturated with uranium. In other words, a criticality

would have already occurred in H-103. Criticality in the downstream mixer settlers (H-116 and H-117) is even more incredible.

1.5 High Load Charging Cask

Calculations have been performed (see Appendix C) to determine the safe-loading conditions for the High-Load Charging cask when hauling various EBR-II fuel types.⁽⁹⁾

The results were:

- (1) A total of nine EBR-II fuel assemblies or control rods can be safely loaded into the cask in any configuration.
- (2) For cans containing clad pins, bare pins or ingots up to 70% enrichment, the three diagonal positions of the nine position cask insert must be blanked off. Two cans can then be placed in each of the six remaining position for a total of twelve.
- (3) The same arrangement as in (2) above will apply to skull oxide fuel since it is lower in U-235 content.

1.6 Table Limits

The amount of U-235 which can safely be loaded on the electrolytic cell charging table as EBR-II fuel assemblies is shown in Figure 13. The model used assumed an array of 80 clad pins deep, 80 clad pins wide and two clad pins long from 52.6% enriched assemblies. With the model used a $k_{eff} = 1.0$ is reached when 503 kg U-235 are loaded on the table.

The number of EBR-II fuel cans that can safely be loaded on the table is shown on Figure 14. As can be seen for skull oxide fuel 51 cans (40.8 kg U-235) would be necessary to reach a $k_{eff} = 1.0$. For the remaining canned fuel, of which 70% enriched uranium bare pins in water filled cans is the worst case, 17 cans (51 kgs U-235) would be needed to reach a $k_{eff} = 1.00$.

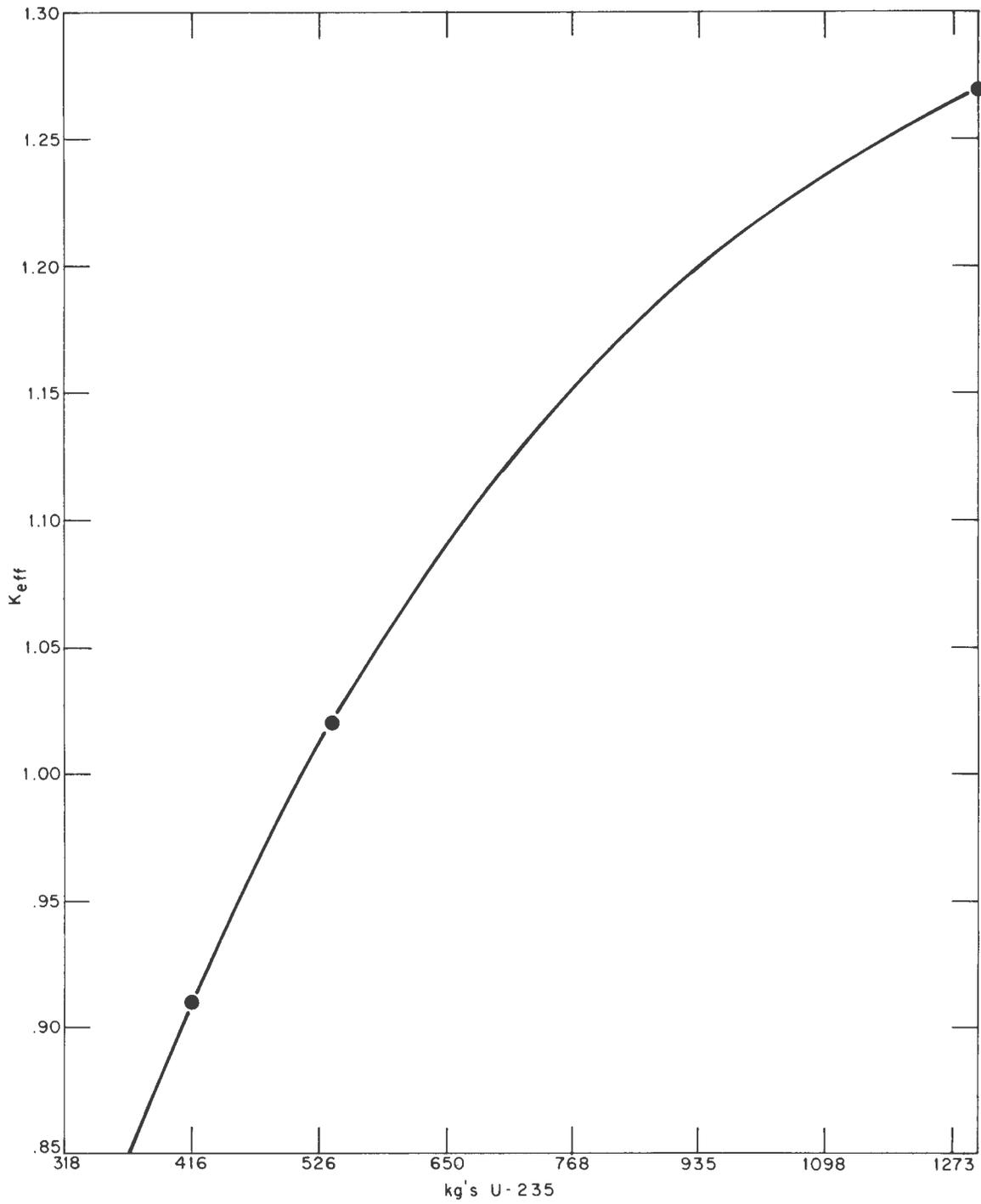


Fig. 13 k_{eff} versus kgs U-235 in 52.6% fuel assemblies for table limit calculations.

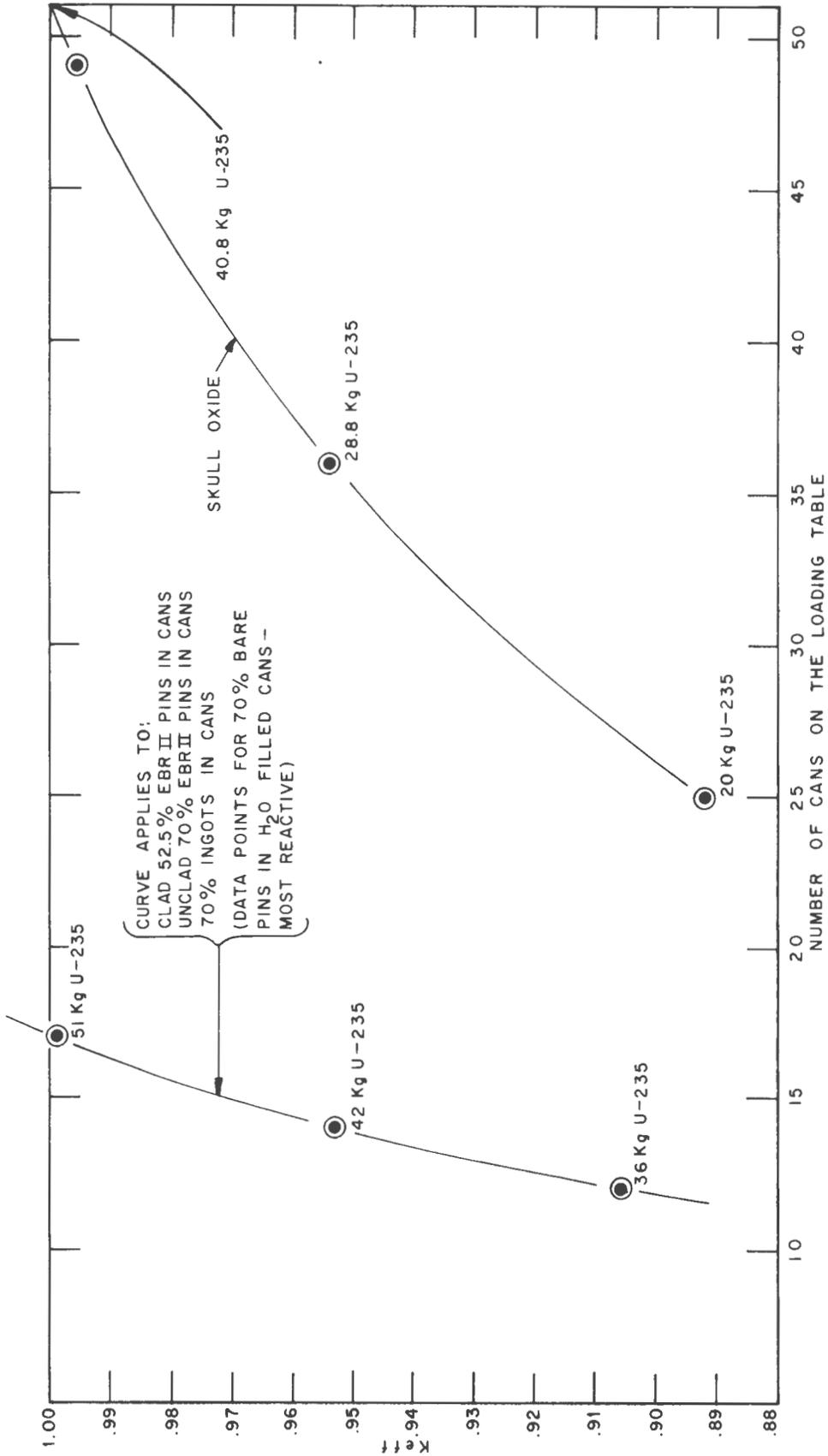


Fig. 14 k_{eff} versus number of fuel cans for electrolytic table limits,

1.7 Product Collection Vessels (Infinite Volume)

The average concentration of U-235 in solution sent to product collection vessels is about 50 g/l. Shown in Figure 15 are the results of criticality calculations made for an infinite volume of product solution. For a solution containing 2.6 g/l Gd, over 160 g/l U-235 would be necessary for a criticality to occur.

2. NUCLEAR POISON DETECTION SYSTEM

During dissolution of nuclear fuel in the electrolytic dissolution headend, soluble nuclear poison is added to the dissolvent acid to avoid the possibility of forming a critical mass with a resulting uncontrolled release of energy. The Nuclear Poison Detection System (NPDS) was designed to monitor the poison concentration in the acid feed solution to the electrolytic dissolver and to generate an alarm and stop the acid feed when the concentration is reduced below a predetermined minimum.

Because the NPDS is involved with criticality safety, its functional reliability is of the utmost importance. To the greatest extent practical, therefore, it was designed to meet modern standards of reliability through the use of two redundant, independent instrument channels. Great care was taken to retain the physical and electrical separation necessary to achieve independence.

The Reliability Analysis⁽¹⁰⁾ of the NPDS is documented here to demonstrate that the reliability of the system is consistent with modern standards. The analysis covered all the components readily identifiable as part of the NPDS. It included all environmental influences and all other interfaces between the NPDS and the rest of the plant.

Drawings used for the analysis are:

1230-CPP-640-T-1	1230-CPP-640-E-6	ACC-055104
T-12	E-7	ACC-055060
T-15	E-35	ACC-055454
T-18	P-5	ACC-055455
T-20		4272-710-112

NOTE: This Figure also Shows the Gd Concentration Required to Prevent Criticality During normal Operation. With a Normal U-235 Concentration of 52.6 g/l a Gd Concentration of About 0.45 g/l Would Correspond to a Keff of 1.0 for Infinite Volume. Therefore, When Operating at 2.6 g/lGd as Proposed, the System Should be Extremely Safe.

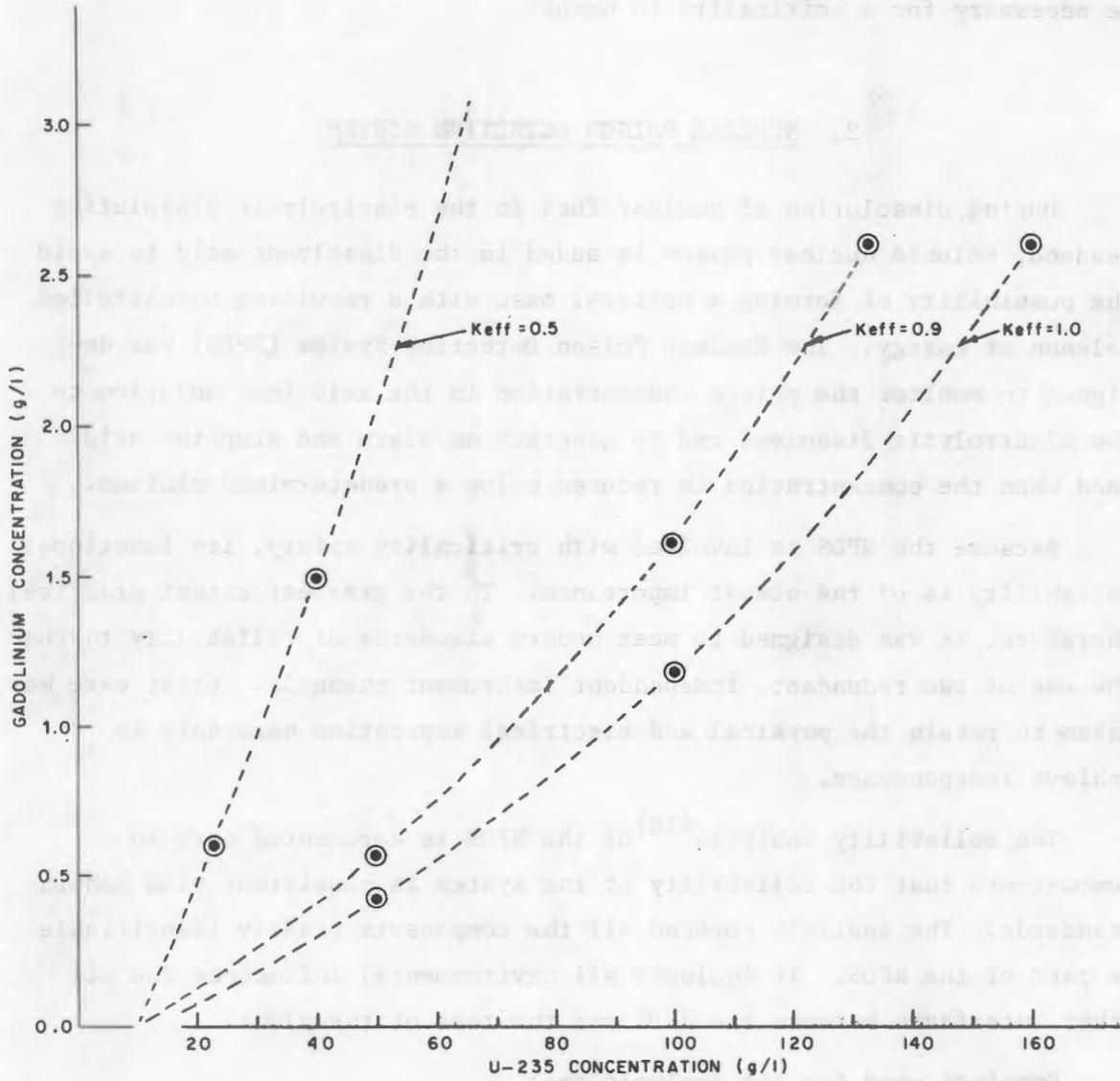


Fig. 15 k_{eff} for infinite volume of solution as a function of U-235 and Gd concentration.

After completing the reliability analysis, the following conclusions were reached.

- (1) The Nuclear Poison Detection System is a well designed, highly reliable system that is more than capable of meeting its Essential Performance Requirements.
- (2) Physical and electrical separation have successfully eliminated all sources of common mode failures.
- (3) Faithful execution of the test and calibration procedures will assure reliability and accuracy that are consistent with the demands imposed by safe nuclear fuel reprocessing.
- (4) Specified administrative controls provide adequate assurance against system failure due to human actions.

2.1 Essential Performance Requirements

The Essential Performance Requirements (EPRs) were determined by Allied Chemical Corporation personnel after a thorough evaluation of the potential for nuclear hazard. They are as follows:

- (1) The NPDS must prevent the flow of fresh acid to the dissolution system in less than 5 to 14 hours depending upon the type of fuel being processed (see Table I, Section 1.22) if the nuclear poison concentration is below a predetermined minimum.
- (2) The NPDS must prevent the flow of fresh acid to the dissolution system within 5 to 14 hours (see reference in EPR #1) when the solution level in the makeup tank decreases below a level 4 inches above the top of the active region of the neutron detectors.
- (3) At true poison concentrations between 1.5 and 5 g/l of gadolinium or its equivalent, system accuracy must be within $\pm .20$ g/l.
- (4) The system shall meet the preceding EPRs within the following ranges of environmental conditions:
 - (a) Temperature 10 to 50°C
 - (b) AC Power Frequency 60 Hz \pm .2%
 - (c) AC Power Voltage 115 VAC \pm 5%
 - (d) Humidity 5 to 90%

- (e) Pressure 20 to 30 in. Hg
- (f) Vibration \pm 2 g
- (g) Radiation 0 to 50 mr/hr

2.2 System Description

The NPDS can be broken down into three functional subsystems, namely detection, signal conditioning, and response. With the exception of the single neutron source, the following description applies to each independent instrument channel.

2.21 Detection Subsystem. A PuBe neutron source and a neutron detector are installed in a rigid jig and immersed in the acid/poison solution. Neutrons from the source are thermalized by the water, some are absorbed by the poison, and some are absorbed by the neutron detector. As the poison concentration is increased, more neutrons will be absorbed by the poison and fewer neutrons will reach the detector. Thus, with a constant source strength, the average neutron detection rate at the detector is an inverse function of poison concentration. This is the mechanism by which poison concentration is determined. The neutron detector delivers an electrical pulse to the signal conditioning subsystem for each neutron the detector absorbs. The neutron detectors are the BF₃ type, Reuter-Stokes Model RSN-7A.

2.22 Signal Conditioning Subsystem. The signal conditioning subsystem provides high voltage to the neutron detector and amplifies, conditions, and counts the electrical pulses delivered to it by the neutron detector. It compares the average pulse rate to a preset reference and activates the Response Subsystem if the pulse rate indicates too low a concentration.

A wall-mounted, charge-sensitive preamplifier is located near the acid vessel PM-101-0 in the PM area. The remainder of the subsystem is located in the control panel, in the Access Corridor, two floors below the PM area. It consists of a voltage amplifier, level discriminator, pulse-counting circuitry, logic, and the power supplies necessary to operate these electronics and the neutron detector.

The preamplifier receives pulses of electrical charge from the neutron detector, converts them to voltage pulses, amplifies them, and

delivers them via coaxial cable to the voltage amplifier in the control panel. This variable gain amplifier provides further amplification, pulse shaping, and the drive capability required by the level discriminator.

The level discriminator is a threshold device which rejects pulses below a preset voltage level and passes all pulses above that level. Its output is a series of rectangular pulses whose two voltage levels are compatible with digital logic requirements. The purpose of the level discriminator is to reject low-level pulses due to electronic noise, thus improving the signal-to-noise ratio and increasing the accuracy of the measurement.

Laboratory experiments have shown that voltage gain and threshold setting are not critical to the measurement. Voltage gains implemented are good compromises between saturation and baseline buildup. Threshold settings implemented give good noise rejection without losing a significant number of valid pulses.

The pulse counting circuitry receives pulses from the level discriminator and counts them for 400 seconds. This time interval is established by a built-in timer. The accumulated count is continuously compared to a preset number (setpoint) in a digital comparator. If the accumulated count is less than the setpoint, indicating a sufficient poison concentration, the counting circuitry is reset, and the process begins again. If the accumulated count is greater than the setpoint, the comparator output opens a solid state relay. The relay contacts activate the Response Subsystem.

The counting circuitry also converts the accumulated count to an analog voltage which is displayed on a Digital Voltmeter and is recorded on a strip chart recorder. The strip chart recorder includes an adjustable setpoint which activates the Response Subsystem if the count decreases below a preset value. Such an event would indicate either a failure of the instrument channel or that the acid level in Tank PM 101-0 had decreased below the level required for a valid measurement.

The Signal Conditioning Subsystem also includes various switches for establishing test conditions and for manual shutdown of the acid flow.

2.23 Response Subsystem. The function of the Response Subsystem is to alert the operator to the existence of a problem and to stop the flow of acid to the dissolver vessel.

When the solid state relays in the Signal Conditioning Subsystem opens, three events occur in the Response Subsystem: (1) a solenoid-operated vent valve opens and removes the air pressure from an air-to-open, pneumatically operated valve in the acid feed line to the dissolver vessel; (2) the pneumatic valve closes, stopping flow, (3) an audible and a visual alarm (annunciator) are activated to alert the operator to the flow shutdown; and (4) a "Normal Operation" indicator lamp is turned off. Through these events, the two major objectives of this subsystem are achieved.

When the "Loss of Signal" setpoint is exceeded, contacts in the strip chart recorder open and de-energize the solid state relay in the Signal Conditioning Subsystem. Subsequent events are as described above.

2.3 Common Mode Failure Analysis

The NPDS was designed and constructed to eliminate all common mode failures. A one-out-of-two logic configuration was chosen which utilizes two independent, redundant instrument channels. Physical separation of hardware was emphasized to assure independence, and provisions for testing were made to assure that no component failure could go undetected.

2.31 Physical Separation. Separation between channels has been maintained from the neutron detectors to the alarms and shutoff valves.

Each detector is housed in a separate dry tube immersed in the acid tank. The cables to each detector emerge from the dry tube and enter separate conduits carrying them to the adjacent wall-mounted preamplifier cabinets. Between the dry tubes and the conduits, the cables are enclosed by a metal enclosure and are separated by a solid divider.

Each preamplifier is completely enclosed in a separate cabinet. Cables are run in separate conduits to the Access Corridor. Access Corridor electronics are housed in a completely enclosed cabinet with a solid divider separating the two channels. All leads emanating from this cabinet are enclosed in separate conduits.

2.32 Potential Common Mode Failures. The physical separation described above is the primary defense against common failures. No realistic vulnerability to common hazards was found during this analysis, although several highly improbable events were considered.

(1) High Temperature in or Near PM 101-0. The detectors, their cables, and the preamplifiers are generally subject to the same temperatures. However, there is no heat source located in this area and the extreme ambient temperatures, including the acid temperature, are well within the design limits of the instrumentation. A local fire could destroy both instrument channels, but they would necessarily fail safe. Either open or shorted cables would activate the Response Sub-system. Furthermore, such a fire could not go undetected for long and would be followed by recalibration of the instrumentation.

(2) High Temperature in the Access Corridor. The statements of Item 2.1 above apply equally well to this consideration.

(3) AC Power Effects. Both instrumentation channels are necessarily powered from the same power source. Complete power failure would release the solenoid valves which would vent the air from the pneumatic valves and stop the acid flow. This event is a safe failure.

Low AC line voltage could reduce voltage to the neutron detectors to the point where it caused a reduced count rate in both channels. This occurs at less than 50 volts. This would indicate a high poison concentration and would constitute a common mode failure. However before this happens, undervoltage relays trip at 90 volts stopping acid flow. This event is a safe failure.

Operating procedures require proper calibration of the undervoltage relays.

High AC line voltage would cause a high count rate and activate the normal alarm and shutdown mechanism. The separate isolation transformer in the power line to each channel provides good protection against fast transients. Careful analysis has not yielded any credible failure modes which would disable both channels without initiating a shutdown.

Because the timer in each channel derives its timing reference from the power line frequency, a high power line frequency would result in a short counting period. Thus, both channels would indicate too high a poison concentration. This event would be a common mode failure.

With this possibility in mind, the stability of the power line frequency was investigated. The contract with the power company requires that "the power frequency shall be maintained within limits established by good modern practice". Personnel of Aerojet Nuclear Company who monitor the AC power say that the frequency is held within $\pm 0.2\%$ of 60 Hz. Exceptions only occur during infrequent power fluctuations, are only a few seconds in duration, and do not exceed 30%.

The 0.2% normal frequency deviation would cause an 0.4% error in the indicated poison concentration. A four-second excursion of 33% would cause an error of 0.6%. This potential error contribution of 1.0% leaves the total calculated error of the NPDS less than the $\pm 7\%$ allowed by the EPRs.

Based on the above considerations, a sustained power frequency excursion with a magnitude sufficient to produce an error in excess of that allowed by the EPRs is considered to be an incredible event.

(4) Low Acid Level in PM 101-0. Laboratory data (shown in Figure 16) show that if the acid level in PM 101-0 decreases to a level less than four inches above the active regions of the neutron detectors, decreased neutron moderation will result in a decreased count rate. Since this indicates a high poison concentration, this event, if undetected, would constitute a common mode failure. The NPDS has been designed to detect this event and to stop the acid flow when it occurs.

The analog strip chart recorders each have a set of contacts which open when the count rate decreases below a predetermined value. These contacts are connected in series with the solid state relay and will de-energize the solenoid vent valve when they open. Thus, when this setpoint is properly adjusted, the acid flow will stop when the level in PM 101-0 decreases below the minimum permissible level.

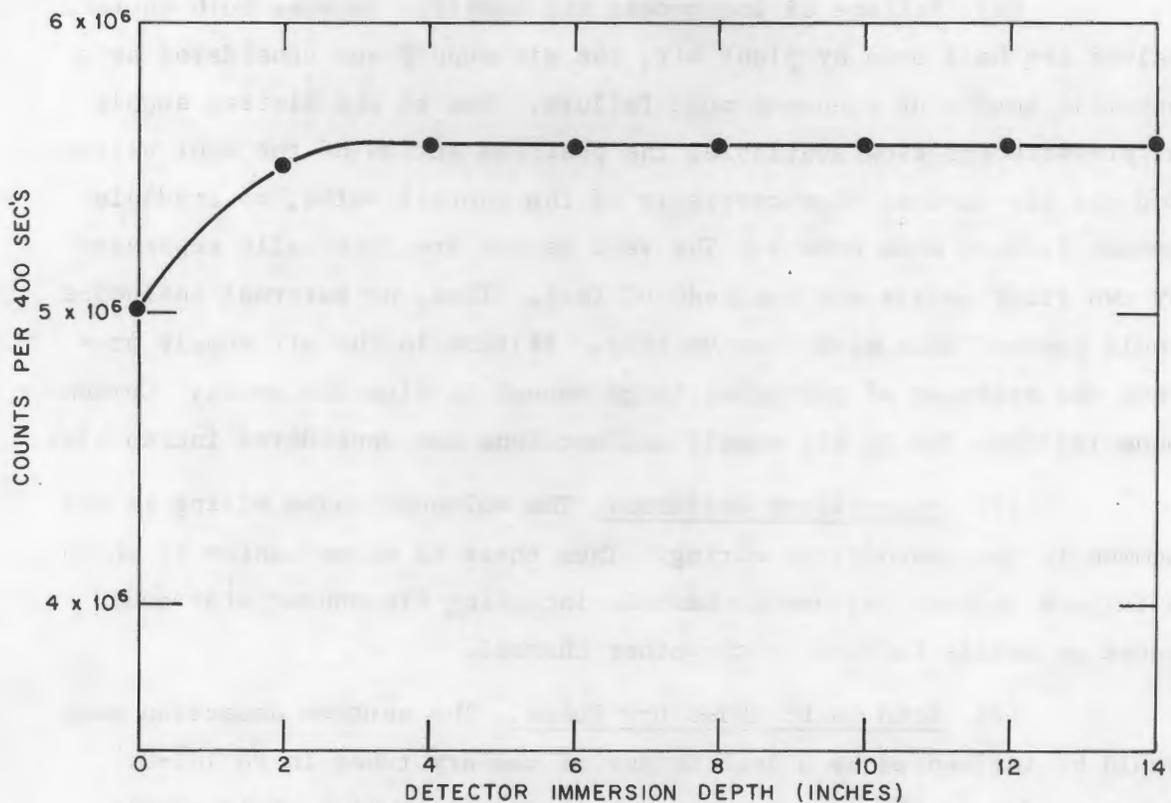


Fig. 16 Effect of immersion depth on neutron detector count rate.

Operating Procedures require that this setpoint be adjusted to actuate at a poison concentration of 3.0 g/l. This value allows for variance in the concentration due to makeup uncertainty while still providing protection against decreased accuracy due to low acid level.

(5) Temperature Sensitivity of Neutron Detectors. The possibility was considered that the neutron detectors are temperature sensitive and that large temperature changes in the PM 101-0 acid will cause the accuracy requirements to be violated. It was concluded that there is no heat source available that could cause a detectable temperature change after the solution is made up. Operating procedures require that the NPDS indication correspond to within 5% of the chemical analysis before starting the acid flow. Thus, there is no possibility of an initial temperature causing excessive error. Failure of the NPDS due to acid temperature considerations is therefore considered an incredible event.

(6) Failure of Instrument Air Supply. Because both shutoff valves are held open by plant air, the air supply was considered as a possible source of a common mode failure. Due to the limited supply of pressure and flow available, the positive action of the vent valves, and the air-to-open characteristic of the shutoff valve, no credible common failure mode exists. The vent valves are physically separated by two floor levels and hundreds of feet. Thus, no external influence could prevent them both from venting. Filters in the air supply prevent the entrance of particles large enough to plug the vents. Common mode failures due to air supply malfunctions are considered incredible.

(7) Annunciator Failures. The solenoid valve wiring is not common in the annunciator wiring. Thus there is no mechanism by which a failure in one instrument channel, including its annunciator could cause an unsafe failure in the other channel.

(8) Acid in PM 101-0 Dry Tubes. The neutron detection rate would be influenced by a leak in any of the dry tubes in PM 101-0. However, due to the increased neutron moderation which would result, the count rate could be increased, indicating a low poison concentration. Such an event constitutes a safe failure.

It is felt that the thorough investigation described above has left no unresolved sources of common mode failures and that no credible source of common mode failures exists in the NPDS.

2.4 Failure Detectability

In considering potential failures of the NPDS, two major classifications are useful. These classifications are safe and unsafe failures. By definition, safe failures are those which result in shutdown of the acid feed to the dissolver and are, therefore, detectable. Since these failures have no undesirable safety implications, they need not be considered beyond identifying them as such. Unsafe failures are those which prevent the NPDS from meeting its EPRs. Test and calibration procedures have been designed to eliminate all undetectable failures from the NPDS.

Unsafe failures can be further classified as (1) those which result in decreased system accuracy and (2) those which prevent the NPDS from

stopping the acid flow when the poison concentration or acid level in PM 101-0 is too low. Since the Common Mode Failure Analysis did not reveal any credible mechanism by which both channels would suffer a commonly caused unsafe failure, only single-channel failures need be considered further.

2.41 Reduced Channel Accuracy. This single channel failure is detectable by cross-checking between channel indicators.

2.42 Total Channel Failure. Cross-checking between channel indicators will also verify, with a few exceptions, that a channel has not suffered a total failure. These exceptions require special testing to assure that they are functioning properly. Operating procedures require such periodic testing to check the operation of the digital comparator, the solid-state relay, the annunciators and the setpoint contacts on the strip chart recorder.

The tests involve resetting the counter to zero, which will drive the strip chart recorder off scale and open the setpoint contacts. The corresponding annunciator will alarm. This response verifies the operation of the recorder setpoint contacts, its annunciator and the associated wiring.

The counter is then driven by pulses from a built-in oscillator. The accumulated count eventually exceeds the setting of the comparator and the corresponding annunciator alarms. This response verifies the correct operation of the comparator and the solid state relay. Careful circuit analysis has not revealed any possible channel failures which would not be detected by the above tests.

2.43 Shutoff Valve Leaking. Manual drain valves have been installed in the feed line downstream of each of the shutoff valves. Operating procedures require that, with first one shutoff valve open and then the other, the drain valve associated with closed shutoff valve be opened. If any flow is detected, it indicates that the closed shutoff valve is leaking. Procedures require that the leak be stopped before proceeding with dissolution. The frequency of this periodic test is based on reliability calculations. This test will also verify the correct operation of the solenoid valves.

The possibility of either drain valve becoming plugged by solid debris was considered. Operating procedures require that, after performing the above tests, both shutoff valves be opened with each drain valves slightly opened in succession. Flow will verify that the drain valve was not plugged during the test of the shutoff valve.

2.5 Test Intervals

In a system whose reliability depends on periodic testing, the reliability is a strong function of the time interval between tests. Ideally, the minimum acceptable system reliability is defined and reliability calculations using component failure rate data are performed. A test interval is then specified which will keep the calculated reliability above the required minimum.

For the NPDS, however, a specific reliability requirement has not been defined, and valid failure rate data for the current generation of solid state electronics are not available. The classical, definitive approach cannot, therefore, be taken. Where available, failure rate data was used and reliability calculations performed. Elsewhere, a more heuristic approach was used in an effort to obtain a conservative estimate of the fundamental reliability of the NPDS. Given this conservative estimate, test intervals were specified which represent a balance between plant availability and reliability..

2.51 Tests for Leaking Valves. Authoritative failure rate data are available⁽¹¹⁾ for pneumatic and solenoid valves. Published failure rates are:

Pneumatic valves (open): 10^{-6} failures/hr

Solenoid valves (closed): 10^{-6} failures/hr

These are the unsafe failure modes for the NPDS.

Because the tests for leaking valves involve possible operator involvement with nitric acid, it is desirable to minimize their frequency. A processing campaign does not exceed three months in duration. A similar test interval would permit tests for leak detection during cold runs at the beginning of each processing campaign.

Under the usual assumption of constant failure rate, the reliability of a single component is

$$R(t) = e^{-\lambda t}$$

where

$R(t)$ is the time varying probability that the component has not failed.

e is the base of the Napierian logarithm system.

λ is the component failure rate in failures/hr.

t is the elapsed time in hours.

For a pneumatic valve, the reliability at 90 days (2160 hr):

$$R(2160) = e^{-.00216} = .9978$$

The probability that at least one valve is not leaking after 90 days is, according to probability theory,

$$P(1) = 2R(2160) - R^2(2160).$$

For the NPDS,

$$P(1) = 2(.9978) - (.9978)^2$$

$$P(1) = .999995$$

This is the probability that, after 90 days of operation, the cascaded shutoff valves will not permit acid to leak into the dissolver when the NPDS requires shutdown. It is judged to be an entirely sufficient reliability. Operating Procedures specify that the leak tests be performed every 90 days of operation.

The identical conclusion is reached about test requirements for the solenoid valves because they have the same published failure rate. Thus, no additional tests for solenoid valve operation are required.

2.52 Tests for Electronic Failures. Because failure rate data do not exist for the electronic circuitry, detailed reliability calculations could not be performed with this system. The electronics have operated for three months without suffering an unsafe failure; thus, the electronics are sufficiently reliable to depend on a test interval once per seventy two hours.

While this specification lacks a mathematical basis, credence is lent by the channel redundancy and by the fact that failure of the system does not imply a nuclear incident. Built-in safeguards against low poison concentration yield a joint probability of low poison concentration and NPDS failure which must be vanishingly small. Furthermore, such a test interval will have a minimal impact on system availability. Procedures specify that the periodic tests be conducted each 72-hours of operation.

Cross checks between channels will be made every two hours during normal data logging.

2.6 Miscellaneous Reliability Considerations

Various other aspects of the design and use of the NPDS relate to the reliability of the system.

2.61 Calibration. Calibration of the NPDS is based on a chemical analysis of the acid/poison solution. Detailed procedures specify the method for generating a calibration curve relating accumulated counts to actual poison concentration. A new curve is generated at the start of each processing campaign. A daily check after acid makeup requires correspondence within 5% between NPDS indication and the actual poison concentration as determined by chemical analysis. Acid feed cannot commence until such correspondence is obtained.

2.62 NPDS/Control System Interface. Under normal conditions, the pneumatic valve in the NPDS Channel 2 is part of the control system which regulates the acid feed rate to the dissolver. While this configuration sometimes has reliability implications, such is not the case in the NPDS. The positive action of the solenoid vent valve necessarily overrides any concurrent control signal. Furthermore, until such action by the solenoid valve, there is no way in which the NPDS can affect the control system. Thus, there can be no actual interaction between the two systems.

2.63 Control of Setpoint Adjustments. Administrative control of setpoint adjustments is maintained through the use of seal locks. The two setpoints per channel, strip chart recorder contacts and digital

comparator setting are accessible from the front of the control panel. They are protected with seal locks. Shift supervisor approval is required to break these seals.

The other two channel adjustments, amplifier gain and discriminator settings, are totally enclosed in the instrument cabinet and have key locks on the doors which also require shift supervisor approval for unlocking.

2.64 System Accuracy. The accuracy of the NPDS is determined by errors from three major sources. These are counting statistics, instrument drift, and chemical analysis techniques. Analysis of the variance⁽¹²⁾ in the counting of the Poisson-distributed neutrons, given a 400-second counting interval and a two-Curie source at 2.0 grams of poison per liter, yielded a .4% uncertainty at the three-standard deviation confidence level. Instrument drift, due primarily to temperature effects, is on the order of 1.0%. Uncertainty in the results of the chemical analysis is reported to be approximately 0.5%.

Thus, a nominal estimate of the total error is on the order of + 1.9%. This uncertainty at 2.0 g/l is .04 g/l is well within the .2 g/l accuracy EPR.

2.65 Channel Bypass. No provisions are made for bypassing a channel during operation.

2.66 Manual Initiation of Shutdown. A separate switch is provided in each channel for manual initiation of shutdown.

3. HYDROGEN FLAMMABILITY

The question of flammability and/or explosibility of the off-gas mixture from the electrolytic dissolution of EBR-II fuel is of great importance in view of possible equipment damage and spread of contamination. More detailed estimates⁽¹³⁾ of the off-gas composition have been made since the SAR was published and are reported here. It should be noted that samples taken during hot operation indicate these estimates are quite conservative.⁽¹⁴⁾

The dissolution of EBR-II fuel elements in the electrolytic dissolver at ICPP is accompanied by the evolution of a gaseous mixture of hydrogen, oxygen, nitrogen, nitrous oxide (N₂O), nitric oxide (NO), and nitrogen dioxide (NO₂). It must be assumed that during operation of the dissolver, sources of ignition will always be present; e.g., sparks from fuel elements striking parts of the dissolver, small pieces of hot sodium metal being carried to the liquid surface by gas bubbles, etc. Thus, in order to identify any fire or explosion hazards from off-gases, reasonably accurate estimates of the off-gas compositions must be made for various possible operating conditions of the dissolver. The gases generated during the process will arise from three sources: (1) electrolysis of nitric acid produces a mixture of all of the gases mentioned above, (2) dissolution of uranium metal in nitric acid causes evolution of NO and NO₂, and (3) sodium (used as bonding agent between the fuel meat and the stainless steel cladding) reacts with the acid to produce hydrogen. Air entering the dissolver through holes in the lid and around the edges of the lid will then dilute these gases to about 50 cfm (38 scfm) as it sweeps across the liquid surface and exits through the dissolver off-gas line.

Case 1: Stainless Steel Dissolution

The average composition of off-gas samples obtained during electrolytic dissolution of stainless steel in pilot plant studies is shown in Table II as Case 1, along with the ranges of variance. The average gas production rate noted in these experiments was 8×10^{-3} scf/amp-hr, or 0.80 scfm for a current of 6000 amperes, the maximum to be used during EBR-II fuel dissolution.

Case 2: EBR-II Fuel Dissolution

The maximum steady-state dissolution rate expected during EBR-II fuel processing will be 6.56 kg/hr, corresponding to 4.2 kg U/hr, 2.1 kg ss/hr, and 48. g Na/hr. An off-gas mixture of composition calculated from these dissolution rates, and assuming a current of 6000 amperes, is shown in Table II as Case 2. The gas composition after air dilution to 38 scfm is also listed.

Case 3: Dissolution of EBR-II Fuel Pins in Aluminum Cans

EBR-II fuel pins contained in aluminum cans will also be dissolved in the electrolytic dissolver. The use of mercuric nitrate catalyst during dissolution of these aluminum cans is optional, and since use of the catalyst would result in greater off-gas volumes, the presence of mercury was assumed. This off-gas mixture would then contain the electrolysis gases (as for ss dissolution), the gases evolved during Hg - catalyzed Al dissolution, and the gases from Na and U dissolution. The composition of this mixture was calculated from the maximum expected dissolution rate (2.1 kg U/hr, 1.24 kg Al/hr, 0.49 kg ss/hr, and 24. g Na/hr), assuming a current of 6000 amperes, and is listed as Case 3 in Table II. The composition after air-dilution to 38 scfm is also listed. Off-gases during the dissolution of aluminum cans containing unclad fuel pins, fuel ingots, and skull oxides would be similar to Case 3 but lower in hydrogen because of a lack of sodium.

The lower limit of hydrogen flammability in air is 4.1%. Figure 17 shows how this limit varies with composition in air-NO mixtures, and Figure 18 shows the H₂-flammability limit in Air-NO-N₂O mixtures.⁽¹⁵⁾ These mixtures would also contain NO₂ from reaction of NO and O₂. It can be seen that NO and NO₂ inhibit the flammability of H₂ at the lower limit. All of the undiluted off-gas mixtures in Table III are approximately equivalent in flammability to mixtures of 30-40% air and 60-70% nitrogen oxides, in which the lower limit of H₂ flammability is between 6.5 and 7%. Thus, none of the undiluted off-gas mixtures listed in Table II would be flammable.

The lower explosion or detonation limit is defined as the concentration above which the flame front rapidly accelerates to the detonation wave velocity, which is much more damaging than the very slow flame front in mixtures near the flammable limit. The H₂ explosion limit is 20% in air, 22% in N₂O, and 30% in NO₂. Thus, none of the mixtures listed in Table II would be explosive.

In order for the atmosphere inside the dissolver to approach a flammable or explosive composition, two abnormal conditions would have to occur simultaneously. First, the dissolver off-gas (DOG) line would

TABLE II

MAXIMUM EXPECTED HYDROGEN CONCENTRATIONS IN OFF-GAS FROM ELECTROLYTIC DISSOLUTION OF EBR-II FUEL

Situation	Concentration, %						Rate Scfm
	H ₂	O ₂	N ₂	N ₂ O	NO	NO ₂	
<u>Case 1:</u> Stainless steel dissolution (I = 6000 amps) Undiluted	3.4 ± 1.6	17 ± 7	22 ± 7	22 ± 5	18 ± 8	18 ± 8	0.80
<u>Case 2:</u> Maximum EBR-II Fuel Dissolution Rate (6.56 kg/hr) (I = 6000 amps) Undiluted	2.5	8.3	10.8	10.8	26.7	41.0	1.64
Diluted to 38 scfm	0.11	20.4	75.0	0.46	1.1	1.8	38.0
<u>Case 3:</u> Steady State Dissolution of EBR-II Pins in Aluminum Cans (2.1 kg U/hr, 1.24 kg Al/hr) (I = 6000 amps) Undiluted	3.0	9.2	11.9	14.7	26.6	34.6	1.48
Diluted to 38 scfm	0.12	20.5	75.5	0.57	1.0	1.3	38

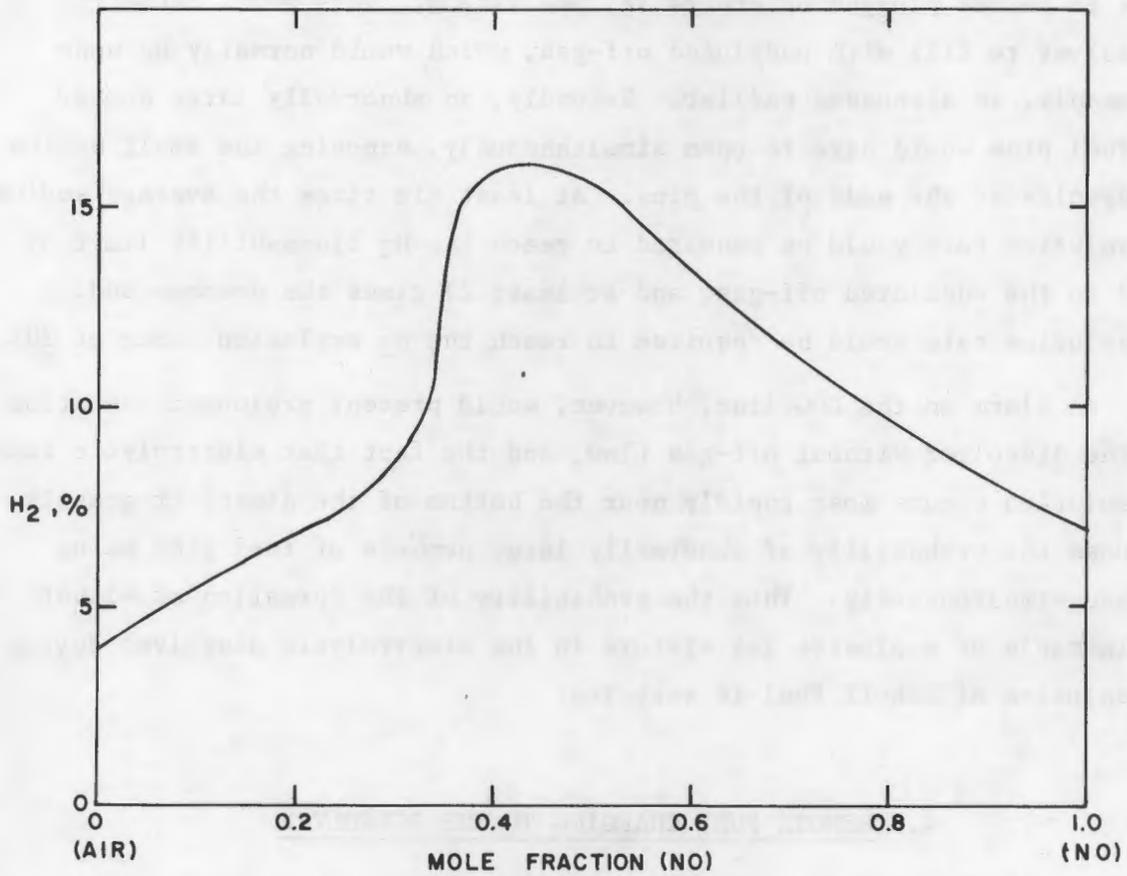


Fig. 17 H₂ flammability limit in air - NO mixtures.

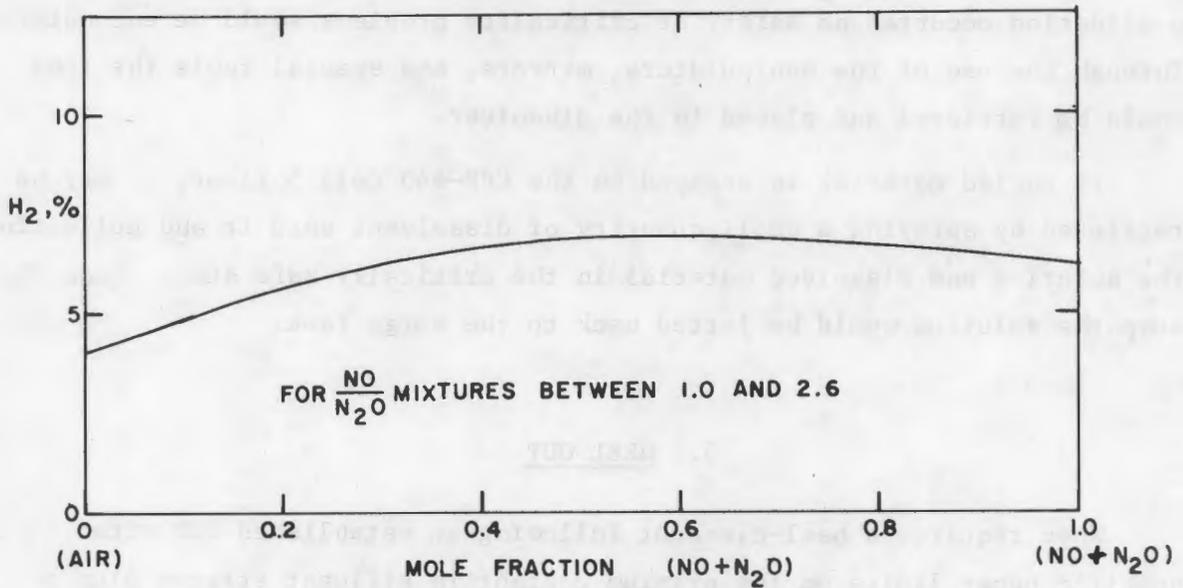


Fig. 18 H₂ flammability limit in air - NO - N₂O mixtures,

have to become plugged or otherwise lose vacuum. This would cause the dissolver to fill with undiluted off-gas, which would normally be non-flammable, as discussed earlier. Secondly, an abnormally large number of fuel pins would have to open simultaneously, exposing the small sodium reservoirs at the ends of the pins. At least six times the average sodium dissolution rate would be required to reach the H₂ flammability limit of 6.5% in the undiluted off-gas, and at least 27 times the average sodium dissolution rate would be required to reach the H₂ explosion limit of 20%.

An alarm on the DOG line, however, would prevent prolonged operation of the dissolver without off-gas flow, and the fact that electrolytic fuel dissolution occurs most rapidly near the bottom of the dissolver greatly reduces the probability of abnormally large numbers of fuel pins being opened simultaneously. Thus the probability of the formation of either a flammable or explosive gas mixture in the electrolytic dissolver during dissolution of EBR-II fuel is very low.

4. REMOTE FUEL CHARGING TO THE DISSOLVER

Fuel is charged to the electrolytic dissolver using master-slave or bridge mounted manipulators. There is a possibility, although very unlikely, that fuel could be dropped to the floor during charging. If such a situation occurred no safety or criticality problems would be encountered. Through the use of the manipulators, mirrors, and special tools the fuel could be retrieved and placed in the dissolver.

If unclad material is dropped on the CPP-640 Cell 5 floor, it may be retrieved by spraying a small quantity of dissolvent onto it and collecting the solution and dissolved material in the critically safe sump. From the sump the solution would be jetted back to the surge tank.

5. HEEL OUT

When required a heel-cleanout following an established SOP with specific upper limits on the uranium content in effluent streams plus a visual inspection of the dissolver will be made to establish that the uranium content of CPP-640 Cell-5 equipment is negligible.

IV. CONCLUSIONS

- (1) Equipment modifications and additions have improved the safety considerations of the Electrolytic Dissolver Facility.
- (2) Flooding of CPP-640 Cell 5 is considered very remote.
- (3) Nuclear poison can be guaranteed in all required streams.
- (4) The first cycle extraction system under normal operating surveillance is safe.
- (5) The possibility of an hydrogen explosion in CPP-640 Cell 5 is remote.

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- (3) Letter M. W. Andrews to S. L. Goren, MWA-3-73, "AIChE Paper on Use of Dual Scrub", dated March 5, 1973.
- (4) Letter W. R. Carpenter to G. F. Offutt (Carp-1-73), "Reactivity Effect of Immersing Electrolytic Dissolver in Water During Processing of Clad 52.6% EBR-II Fuel", dated January 11, 1973.
- (5) Letter J. A. Buckham to C. W. Bills, Buc-80-73, "Electrolytic Dissolver Criticality Control", dated March 13, 1973.
- (6) Letter R. E. Commander to K. L. Rohde, Com-31-72, "Safety in the First Cycle Extraction System During Electrolytic Processing", dated September 12, 1972.
- (7) C. L. Bendixsen, Allied Chemical Corporation, private communication (May 1973).
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- (12) Letter M. W. Andrews to G. F. Offutt, MWA-5-72, "Soluble Nuclear Poison Detection Systems - Gadolinium", dated June 20, 1972.
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- (14) Letter W. J. Bjorklund to K. L. Rohde, Bjor-3-73, "Electrolytic Off-Gas Study", dated April 20, 1973.
- (15) F. E. Scott, R. W. VanDolah, and M. G. Zabetakis, "The Flammability Characteristics of the System H_2 -NO- N_2O -Air". Sixth International Symposium on Combustion, Yale University, 1956, Pub. 1957 pp. 540-45.

APPENDIX A

REACTIVITY EFFECT OF IMMERSING ELECTROLYTIC DISSOLVER IN WATER DURING PROCESSING OF CLAD 52.6% EBR-II FUEL

General Notes

Also see Section 2.1, with its own legend and flow diagram.

Calculation Parameters

Parameters of the electrolytic dissolver vessel are given below in Table 1.

Procedure

The electrolytic dissolver was filled with water up to the overflow point. The dissolved fuel was collected in a beaker.

APPENDIX A

REACTIVITY EFFECT OF IMMERSING ELECTROLYTIC DISSOLVER IN WATER DURING PROCESSING OF CLAD 52.6% EBR-II FUEL

The experiment was conducted in a reactor vessel of the EBR-II.

Procedure

- (1) The dissolver is filled along the length and to the top with water.
- (2) The reactor adjusted overflow level is 2.5 in. above the bottom of the fuel.
- (3) The dissolver is reflected by a horizontal surface of stainless steel, and a 50 volt source, 50 amp current is applied. The reactor distance was 0.15 in. on the right side and 1.15 in. on the left side.
- (4) The dissolved product radionuclide concentration is 1.5 g/l.
- (5) The dissolver product U-235 concentration is 2.5 g/l.
- (6) Water collection was provided by direct water (DWS) and (DWS) cross section—see water albedo.

APPENDIX A

REACTIVITY EFFECT OF IMMERSING ELECTROLYTIC DISSOLVER IN WATER DURING PROCESSING OF CLAD 52.6% EBR-II FUEL

Computer Codes:

KENO II, Version WRC 5, with 16-Group Hansen and Roach Cross sections.

Calculations Performed:

Determined the k_{eff} of the Electrolytic Dissolver vessel at various levels of water flooding in CPP-640 Cell 5.

Conclusions:

Immersing the Electrolytic Dissolver into water up to the product overflow point will increase the dissolver's reactivity by about 10% $\Delta k/k$. For the particular case of processing 52.6% enriched clad pins, the dissolver would remain subcritical during a cell flooding up to the dissolver product overflow level (about 3'7" of water in the cell), provided no other abnormal condition occurred, such as a product U-235 concentration increase or gadolinium concentration decrease.

Assumptions:

- (1) The dissolver is filled along the length and to the top with clad 52.6% enriched fuel pins.
- (2) The product solution overflow level is 24.3 in. up from the bottom of the fuel.
- (3) The dissolver is reflected by a homogenized mixture of niobium, titanium, and product (50 vol% metal, 50 vol% product). The reflector thickness was 0.75 in. on the cathode side and 1.25 in. on the anode side.
- (4) The dissolver product gadolinium concentration is 2.6 g/l.
- (5) The dissolver product U-235 concentration is 52.6 g/l.
- (6) Water reflection was provided by discrete water (hydrogen and oxygen) cross sections—not water albedos.

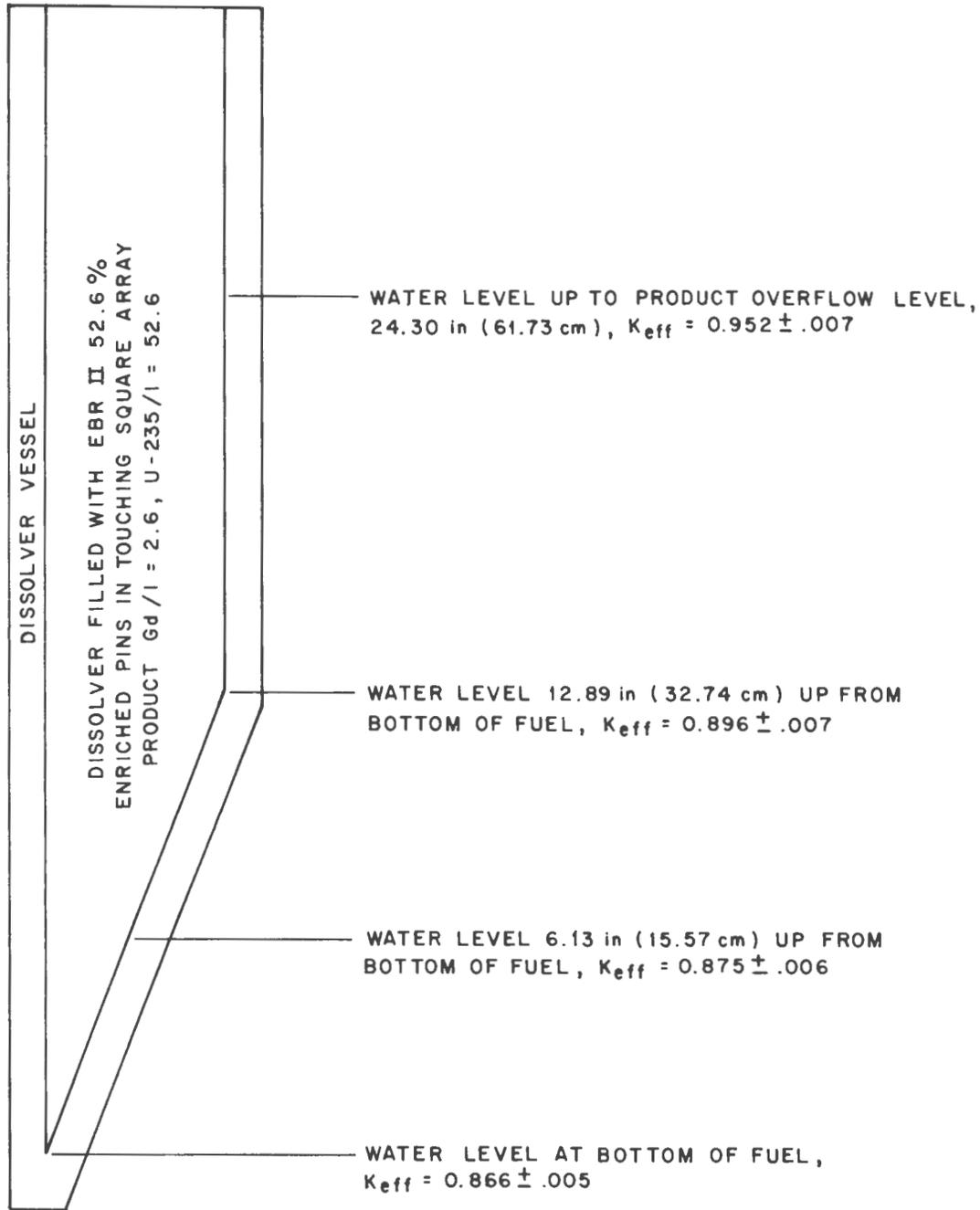


Fig. A-1 k_{eff} in electrolytic dissolver full of EBR-II 52.6% enriched pins for four levels of water immersion.

NUCLEAR POISON DILUTION MODEL FOR THE
ELECTROLYTIC DISSOLVER SYSTEM

Dissolver Cadmium Balance

The poison dilution model for the electrolytic dissolver is based on the following cadmium balance.

(1)
$$\frac{dC_1}{dt} = \frac{I}{V} - \lambda C_1$$

APPENDIX B

NUCLEAR POISON DILUTION MODEL FOR THE
ELECTROLYTIC DISSOLVER SYSTEM

For the case when there is no cadmium in the lead, equation (1)

(2)
$$\frac{dC_1}{dt} = \frac{I}{V} - \lambda C_1$$

Integrating and solving for C_1 gives

(3)
$$C_1 = \frac{I}{\lambda V} (1 - e^{-\lambda t})$$

where C_1 is the initial cadmium concentration in the dissolver at the time the cadmium is the lead is dissolved.

APPENDIX B

DISSOLVER POISON DILUTION MODEL FOR THE
ELECTROLYTIC DISSOLVER SYSTEM

Dissolver Gadolinium Balance

The poison dilution model for the electrolytic dissolver is based on the following gadolinium balance.

$$F_0 C_0 - F_1 C_1 = \frac{d(V C_1)}{dt} \quad (1)$$

where

F_0 = Feed rate of fresh acid in, l/hr.

F_1 = Dissolver product out, l/hr

C_0 = Nuclear poison concentration in, g Gd/l

C_1 = Nuclear poison concentration out, g Gd/l

V = Volume of recirculation loops, 750 l

t = time, hrs

For the case when there is no gadolinium in the feed, equation (1) becomes

$$\frac{-F_1}{V} = \frac{1}{C_1} \frac{d(C_1)}{dt} \quad (2)$$

Integrating and solving for C_1 gives

$$C_1 = C_{11} e^{\frac{-F_1}{V} t} \quad (3)$$

where C_{11} is the initial gadolinium concentration in the dissolver at the time the gadolinium in the feed is shut off.

APPENDIX C

HIGH LOAD CHARGER - CRITICALITY CALCULATIONS

Computer Code Level:

1970-11 study is group number four cross-section.

Assumptions and Conditions:

- (1) Fuel elements in positions that are normally loading.
- (2) Fuel elements in positions that are normally loading.
- (3) Fuel elements in positions that are normally loading.
- (4) Fuel elements in positions that are normally loading.
- (5) Fuel elements in positions that are normally loading.
- (6) Fuel elements in positions that are normally loading.
- (7) Fuel elements in positions that are normally loading.
- (8) Fuel elements in positions that are normally loading.

APPENDIX C

HIGH LOAD CHARGER - CRITICALITY CALCULATIONS

The case loaded with complete elements was the most severe configuration. The elements were each loaded to 1.15 kg of ^{235}U . The configuration had two elements in each of the positions. The two elements in each position were converted into a cylinder on an equal area basis. This gave a half of 0.58 kg. Another configuration was run in which only one element per position was used. This gave a half of 0.29 kg.

Two more configurations were run in an effort to determine the most reactive configuration for a total loading of nine elements. In one of these, a two tier partial loading was used as shown in Figure 3-1. Case 1. Five positions had one element each in the first tier and two in the second tier as shown in the figure. Other positions were water filled. This gave a half of 0.58 + 0.08 in a two tier configuration, only one tier was used, but two elements were put into each of four positions as shown in Figure 3-1. Case 2. The ninth element was put into an adjacent position. This gave a half of 0.58 + 0.11.

APPENDIX C

HIGH LOAD CHARGER - CRITICALITY CALCULATIONS

Computer Code Used:

KENO-II with 16 group Hansen-Roach cross-sections.

Assumptions and Conditions:

- (1) Fuel corresponds to preburnup fuel in uranium loading.
- (2) Fuel contains no boron.
- (3) Cask is water flooded and reflected.
- (4) Fuel box is water-filled.
- (5) EBR-II fuel cans were full of water.
- (6) Cask materials and dimensions are as per Dwg Nos. CPP-E-054273 to --054279, latest revisions.
- (7) Boron content of stainless steel dividers was 1.36 w/o.
- (8) EBR-II fuel elements were 52% enriched, and canned scrap or oxide were 70% enriched.

A. EBR-II Fuel Elements

The cask loaded with complete elements was run using several configurations. The elements were each loaded to 3.12 kg of U-235. One configuration had two elements in each of the nine positions. The two elements in each position were converted into a cylinder on an equal area basis. This gave a k_{eff} of $0.98 \pm .01$. Another configuration was run in which only one element per position was used. This gave a k_{eff} of $0.75 \pm .01$.

Two more configurations were run in an effort to determine the most reactive configuration for a total loading of nine elements. In one of these, a two tier partial loading was used as shown in Figure C-1. Case 1. Five positions had one element each in the first tier and four in the second tier as shown in the figure. Other positions were water filled. This gave a k_{eff} of $0.69 \pm .009$. In the second configuration, only one tier was used, but two elements were put into each of four positions as shown in Figure C-1. Case 2. The ninth element was put into an adjacent position. This gave a k_{eff} of $0.855 \pm .011$.

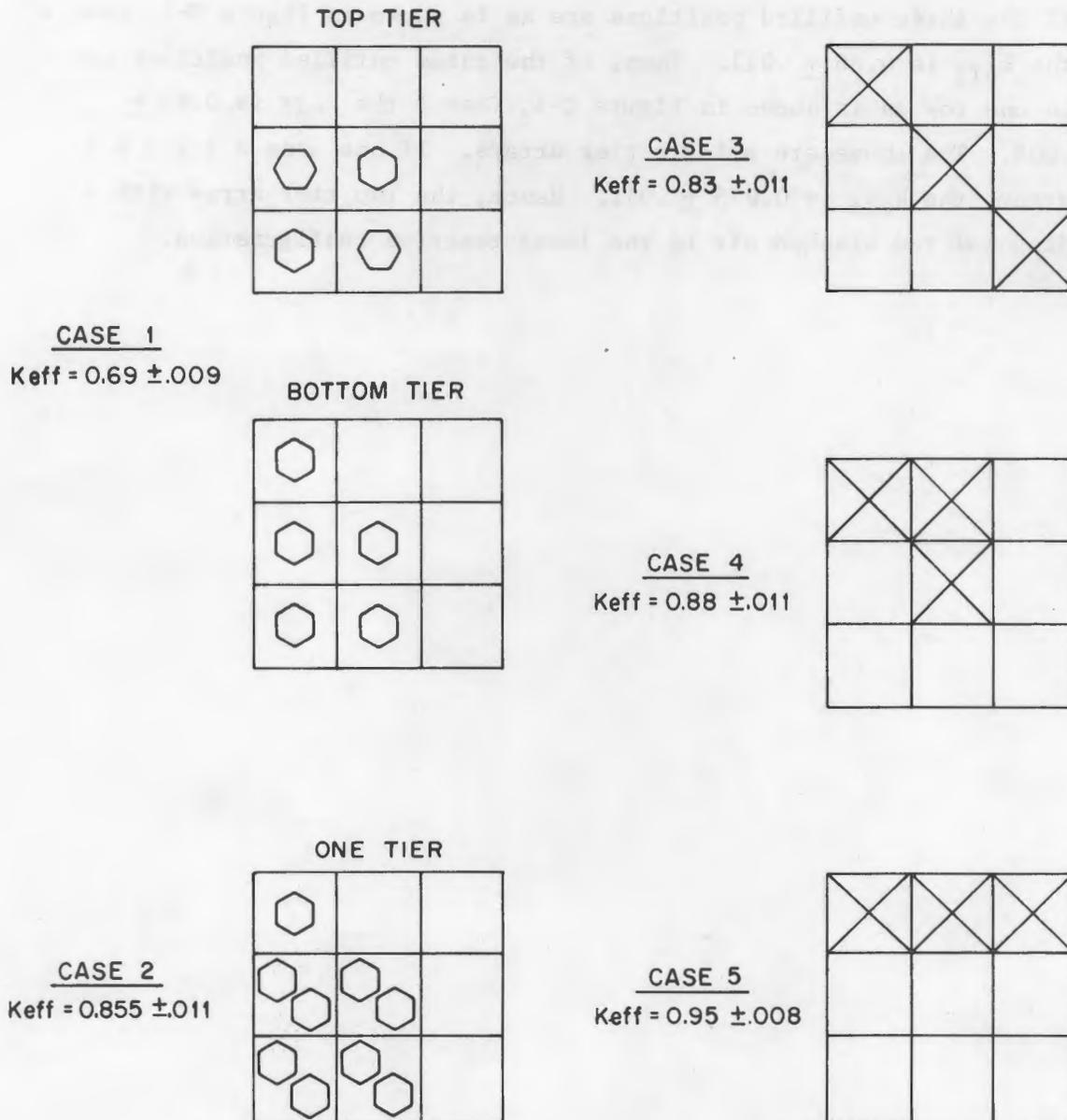


Fig. C-1 Loading of the high-load charger with EBR-II fuel.

B. EBR-II Fuel Scrap in Cans

Each fuel scrap can was assumed to be loaded to 3.0 kg in U-235. The fuel was homogenized with the water in a full can. If each position in the cask has two cans in two tiers with no water gap between fuel, the k_{eff} is $1.036 \pm .009$. If three positions are blanked off as shown in Figure C-1, Case 3 the k_{eff} is reduced to $0.83 \pm .011$. If the three unfilled positions are as is shown in Figure C-1, Case 4 the k_{eff} is $0.88 \pm .011$. Then, if the three unfilled positions are in one row as is shown in Figure C-1, Case 5 the k_{eff} is $0.95 \pm .008$. The above are all two tier arrays. If one uses a $3 \times 3 \times 1$ array, the k_{eff} is $0.975 \pm .011$. Hence, the two tier array with a diagonal row blanked off is the least reactive configuration.

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