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PROCESS OPTIMIZATION 709 PROGRAM

AUTHOR

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4/6/60

PROCESS OPTIMIZATION 709 PROGRAM**DECLASSIFIED**INTRODUCTION

In the past two years a number of process optimization studies have been made with the aid of IBM machine programs. These programs have been designed to calculate optimum power levels and optimum goal exposures so that better insight could be gained for use in resolving plant operating plans. We feel that this approach has been highly successful.

In January of 1960, we decided to write a new program for the IBM 709 to incorporate the desirable features of the previous programs and to provide additional output data. This document is a description of the new program.

DISCUSSION

An IBM program is a tool to permit calculations, that are lengthy by other methods, to be made rapidly. The "answers" provided by an IBM program are only as good as the input data permits. In the past we have found that three types of information are desired from an optimization program for the reactors.

1. What are the optimum power levels and goal exposures?
2. What is the effect of changing power and exposure?
3. What are the loss and cost parameters for a given set of power and exposures?

For each type of problem, it is helpful to have complete information on loss terms, cost terms and operation parameters, e.g., power level, goal exposures, production.

In the new program we have provided means of obtaining the above within the single program. In addition, features have been built into the program; 1) to permit calculating results on either a total plutonium basis or a plutonium 239 basis; 2) to permit assessing a plutonium 240 penalty; 3) to permit assessing losses associated with bulk outlet temperature, production efficiency, and per cent heat generated in the enriched metal; 4) to permit storing the results from individual runs and then summing or averaging the results as appropriate to obtain results based on periods of time longer than one day, (e.g. week, month, year, etc.).

A diagram of the program is on page 3.

"Optimum" refers to the results obtained when power level, goal exposure for I & E natural, goal exposure for I & E enriched, and goal exposure for the solid slugs are varied until the combination of power level and goal exposures results in the maximum net return plus fixed cost (Z) for the given set of input data.

"Ridges" refers to the results obtained when the goal exposure of I & E natural is held constant at pre-set values, and power level and the remaining two goal exposures are allowed to vary until the maximum net return is obtained with the restraint on I & E natural goal exposure. The program calculates nine cases of

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- (1) See Appendix A, page 5.
- (2) See Appendix B, page 15.
- (3) See Appendix C, page 21.

DECLASSIFIED

HW-84654

-4-

4/6/60

the above type with I & E natural goal exposure fixed at 200 through 900 at intervals of 100 MWD/T. Eleven cases are calculated for determining the optimum goal exposures to give maximum net return when the tube power is held constant. The tube powers at which the above calculations are made are fixed at 1.0 MW to 2.0 MW varying by 0.1 MW's. With the results of the above type of calculation, effects on throughput, production, losses and costs can be evaluated for varying exposure and power conditions.

"Fixed" refers to the cases where power level, and goal exposure for the three types of metal are provided as input data. The production, loss terms and cost terms are then calculated using the equations programmed.

There are four separate paths that can be taken through each of the main paths. These are designated by Z, Z-ZL, Z240, and Z240-ZL. Which path that is taken is controlled by the value assigned to "I" and card 1 (see Appendix A). The Z path means that each time in the program that Z is calculated, the basic net return equation (1) is used. The Z-ZL path means that each time Z is calculated in the program, the basic net return equation is used and the value found is reduced by the appropriate loss term(s) before the next step in the program is carried out. The last two paths are the same as the first two paths except, the basic equation has been modified to operate on a plutonium 239 basis with the provision for assessing a penalty for plutonium 240 production.

Attached appendices give the detailed information needed by the user of the new program.

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RLT:CFP:mf

(1) HW-61579, Music, JF, et al, "Reactor Process Optimization," 8/17/59, (Secret).

* Now a member of the Atomic Power Equipment Department.

APPENDIX A

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INPUT DATA FOR "IPD-PROCESS OPTIMIZATION - PROCESS ANALYSIS UNIT"

The nomenclature for input data is as follows:

(1) Program Control

<u>Symbol</u>	<u>Definition</u>
L1	Designates the reactor, 1 for B, 2 for C, 3 for D, 4 for DR, 5 for F, 6 for H, 7 for KE, 8 for KW and 9 for NPR.
L2	If an optimum calculation is to be made, L2 = 2, if not L2 = 0.
L3	If a ridge calculation is to be made, L3 = 2, if not L3 = 0.
L4	If a fixed case is to be calculated, L4 = 2, if not L4 = 0.
I	Has the value of 1 through 4; if I = 1, the Z equation with total plutonium produced will be used, if I = 2, the Z equation minus the input auxiliary losses will be used, if I = 3, the Z equation based on Pu-239 will be used, if I = 4, the Z equation based on 239 will be used minus the input auxiliary losses.
L7	If bulk temperature loss terms have been provided, L7 = 2, if not, L7 = 0.
L8	If loss terms as a function of E have been provided (total control losses), then L8 = 2, if not L8 = 0.
L9	If loss terms as a function of production efficiency have been provided L9 = 2, if not L9 = 0.
L14	If results of the optimum cases are to be accumulated, L14 = 2, if not L14 = 0.
L15	If results of the fixed cases are to be accumulated, L14 = 2, if not L15 = D.
A16	Constant by which the daily values for the first optimum case are multiplied.

DECLASSIFIED

4/6/60

<u>Symbol</u>	<u>Definition</u>
A17	Constant by which the daily values for succeeding cases are multiplied.
A18	Constant by which the daily values for the first fixed case are multiplied.
A19	Constant by which the daily values for the succeeding fixed cases are multiplied.

(2) Conversion Ratios

IA = code number for reactor group,
4 for old reactors, 6 for C Reactor and 8 for K Reactors.

LOTI = code numbers for I & E natural

1203 - O-II-N
1003 - C-II-N
1103 - K-II-N
1804 - K-III-N

LOTE = code numbers for I & E enriched

0803 - O-II-E
0705 - C-II-E
0705 - K-II-E
1906 - K-III-E

LOTS = code number for solid natural

0101 - OSN
0101 - CSN
0101 - KSN

SPA = number of 8" spacers between the standard 120" dummy charge and the fuel elements: SPA1, I & E natural; SPA2, I & E²; SPA3, solid natural.

PCS = number of slugs in the fuel element charge: PCS1, I & E natural; PCS2, I & E²; PCS3, solid natural.

BEAT = factor for changing the heat of fission number used in conversion ratio calculations. This number will normally be zero.

(3) Heat Generated in Enriched Metal

GR = ration of heat generated in an I & E² column to that generated in an I & E natural column, when both are put at the same location.

AT = number of active tubes.

4/6/60

DECLASSIFIED

QR = number of I & E^2 columns in flattening ring.

QS = number of I & E^2 columns in spike enrichment.

RF = average tube factor for the flattening ring.

SF = average tube factor for the spike enrichment.

EMB = goal exposure of I & E natural in MWD/T at base condition.

QMI = change in number of I & E^2 columns per one MWD/T change in I & E natural goal exposure.

PB = average tube power of the ten highest powered tubes in MW's, at base conditions.

EN = number of effective central zone tubes (ECT).

QP = change in number of I & E^2 columns per MW change in power level.

Base conditions are those for which the current enrichment loading was planned. All the above numbers should be obtained from Operational Physics. Our latest contact was with R. D. Carter.

(4) Rupture Relationship

CRIT = metal performance index on a tube basis for I & E natural slugs.
Obtain from R. R. Bloomstrand.

CRET = same for I & E^2 slugs.

AI = ratio of tube metal performance index to reactor metal performance index for I & E natural.

AE = same for I & E^2 slugs.

AS = same for solid natural slugs.

ELN = hours lost to a rupture including non-equilibrium losses, for current conditions.

ELO = hours lost to a rupture including non-equilibrium losses used in calculating the tube metal performance index.

WN = factor for extent of front to rear flux peaking for current conditions and equal to 1.0 when the flux has a cosine distribution.

WO = factor for extent of flux peaking used in calculating tube metal performance index.

TIN = inlet water temperature in $^{\circ}\text{C}$.

DECLASSIFIED

HW-64654

-8-

4/6/60

FOI = I & E natural tube flow rate in gpm used in calculating tube metal performance index.

FOE = I & E² tube flow rate in gpm used in calculating tube metal performance index.

FOS = solid slug tube flow rate in gpm used in calculating tube metal performance index.

FNI = current tube flow rate in gpm, I & E natural.

FNE = current tube flow rate in gpm, I & E².

FNS = current tube flow rate in gpm, solid slugs.

S = fraction of heat generated in solid tube charges compared to heat generation of the reactor.

(5) Tube Replacement Loss

The equation programmed is as follows:

$$\text{Tube Replacement Loss} = \frac{(\text{CK})(\text{CK 1})(2)}{(\text{DM})(\text{DMR})(\text{DTR})} \frac{\left[\frac{t_i + (\text{RK})(\Delta T)}{12} \right] (\text{AT})}{12}$$

Where: The expression $\frac{t_i + (\text{RK})(\Delta T)}{12}$ is the corrosion rate expression in mils per month published by N. R. Miller.⁽²⁾

$$\Delta T = \frac{(\text{Reactor Power Level, kw})}{.2635 (\text{Reactor flow, gpm})}$$

CK = factor to adjust the corrosion rates so that calculated rates will be representative of the reactor.

CK1 = tube corrosion factor used by N. R. Miller and which is equal to 0.0008.

RK = average ratio for the tube annulus temperature ΔT to tube bulk temperature ΔT .

FR = reactor flow rate in gpm.

DM = days per month, usually 30 is used.

DMR = mils removed from tube wall before tube is replaced.

DTR = tube replacement rate in tubes per day.

(2) Letter from N. R. Miller to J. R. Young, "Proposed Basis for Predicting Process Tube Corrosion," 12/18/59.

4/6/60

(6) Charge Discharge Loss Term**DECLASSIFIED**

TTI = tubes per ton for I & E natural charges.

TTE = tubes per ton for I & E² charges.

TTS = tubes per ton for solid natural charges.

CDRI = charge-discharge rate, including set-up and button-up time, for I & E natural slugs.

CDRE = same as above for I & E².

CDRS = same as above for solid natural slugs.

CDLINE = factor for multiplying the C-D downtime loss so that non-equilibrium losses will also be represented, 1.35 is about right for I & E natural slugs.

CDLENE = same factor as above for I & E².

CDLSNE = same factor as above for solid natural.

- (7) If additional loss terms are to be considered, a table of dollar loss per day is inserted as input data with the following correlation:

a) Bulk Temperature Loss

<u>Bulk Temperature, °C</u>	<u>Table Position</u>
88 - 88.99	1
89 - 89.99	2
90 - 90.99	3
91 - 91.99	4
92 - 92.99	5
93 - 93.99	6
94 - 94.99	7
95 - 95.99	8
96 - 96.99	9
97 - 97.99	10
98 - 98.99	11
99 - 99.99	12
100 - 100.99	13
101 - 101.99	14

Each time Z (net return plus fixed cost) is calculated in the program, the value calculated will be reduced by the amount placed in the corresponding bulk temperature table position.

4/6/60

b) Losses Associated with Production Efficiency

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<u>Production Efficiency, Per Cent</u>	<u>Table Position</u>
61 - 61.99	1
62 - 62.99	2
63 - 63.99	3
64 - 64.99	4
65 - 65.99	5
66 - 66.99	6
67 - 67.99	7
68 - 68.99	8
69 - 69.99	9
70 - 70.99	10
71 - 71.99	11
72 - 72.99	12
73 - 73.99	13
74 - 74.99	14
75 - 75.99	15
76 - 76.99	16
77 - 77.99	17
78 - 78.99	18
79 - 79.99	19
80 - 80.99	20
81 - 81.99	21
82 - 82.99	22
83 - 83.99	23
84 - 84.99	24
85 - 85.99	25

Each time Z is calculated in the program, the value will be reduced by the amount placed in the corresponding production efficiency table position.

c) Losses Associated With Amount of Enrichment (Total Control Losses)

<u>% Heat Generated in E Metal</u>	<u>Table Position</u>
6 - 6.99	1
7 - 7.99	2
8 - 8.99	3
9 - 9.99	4
10 - 10.99	5
11 - 11.99	6
12 - 12.99	7
13 - 13.99	8
14 - 14.99	9
15 - 15.99	10
16 - 16.99	11
17 - 17.99	12
18 - 18.99	13
19 - 19.99	14
20 - 20.99	15

DECLASSIFIED

HW-64654

-11-

4/6/60

Each time Z is calculated in the program, the value will be reduced by multiplying the Z calculated by (1-f) where f is the fraction placed in the table corresponding to the heat generation value at the time.

Input data is punched in IBM Data Processing cards. The cards have room for 80 spaces of which only the first through the seventy-second are used for input data. Input data is put in in accordance with a format written into the program. For your convenience a list of the input data is provided which will permit punching a set of input data cards in the proper card position and in the proper form. Numbers are put into an IBM program as 1) intergers which are designated by IX where I designates the number is an interger and X is the number of spaces occupied, or, 2) as fixed point numbers designated by FX.y where F indicates they are a fixed point number, X tells the number of spaces occupied by the number including the decimal point and y is the number of digits to the right of the decimal point, or; 3) as floating point numbers that are designated by EX.y where E indicates that the number is a floating point number, X tells the number of spaces occupied by the number including decimal and y is the spaces to the right of the decimal. The input data for the conversion ratio calculations is not provided in this document.

The following is a list of the spaces occupied, the type of number and the symbol used for each input card following the binary and conversion ratio load decks.

CARD 1

<u>Space</u>	<u>Type of Number</u>	<u>Symbol</u>
1-2	I2	L1
3-4	I2	L2
5-6	I2	L3
7-8	I2	L4
9-10	I2	I
11-12	I2	L7
13-14	I2	L8
15-16	I2	L9
17-18	I2	L14
19-20	I2	L15
21-26	F6.0	A10
27-32	F6.0	A17
33-38	F6.0	A18
39-44	F6.0	A19

CARD 2

1-2	I2	IA
3-6	I4	LOTI
7-10	I4	LOTE
11-14	I4	LOTS
15-16	F2.0	SPA1
17-18	F2.0	SPA2
19-20	F2.0	SPA3
21-22	F2.0	PCS1
23-24	F2.0	PCS2
25-26	F2.0	PCS3
27-36	F10.4	BEAT

4/6/60

DECLASSIFIED

CARD 3

Space

Type of Number

Symbol

1-6
7-12
13-18
19-24
25-30
31-36
37-42
43-50
51-56
57-62
63-70

F6.3
F6.0
F6.0
F6.0
F6.3
F6.3
F6.0
F8.5
F6.3
F6.0
F8.5

GR
AT
QR
QS
RF
SF
EMB
QMI
PB
EN
QP

CARD 4

1-11
12-22
23-33
34-39
40-45
46-51
52-54
55-57
58-62
63-67
68-72

E11.4
E11.4
E11.4
F6.3
F6.3
F6.3
F3.0
F3.0
F5.2
F5.2
F5.1

CRIT
CRET
CRST
AI
AE
AS
ELN
ELO
WN
WO
TIN

CARD 5

1-7
8-14
15-21
22-28
29-35
36-42
43-49

F7.2
F7.2
F7.2
F7.2
F7.2
F7.2
F7.4

FOI
FOE
FOS
FNI
FNE
FNS
S

CARD 6

1-6
7-15
16-23
24-30
31-34
35-38
39-44

F6.3
F9.5
F8.3
F7.0
F4.0
F4.0
F6.0

CK
CK1
RK
FR
DM
DMR
DTR

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CARD 7

<u>Space</u>	<u>Type of Number</u>	<u>Symbol</u>
1-8	F8.3	PU
9-16	F8.3	BI
17-24	F8.3	BE
25-32	F8.3	BS
33-40	F8.3	EMCI
41-48	F8.3	EMCE
49-56	F8.3	EMCS
57-64	F8.3	EMLSC
65-72	F8.3	PU240

CARD 8

1-8	F8.3	TII
9-16	F8.3	TTE
17-24	F8.3	TTS
25-32	F8.3	CDRI
33-40	F8.3	CDRE
41-48	F8.3	CDRS
49-56	F8.3	CDLINE
57-64	F8.3	CDLENE
65-72	F8.3	CDLSNE

CARD 9 Only used if L7 = 2 (otherwise left out)

1-7	F7.0	DBT (1)
2-14	F7.0	DBT (2)
15-21	F7.0	DBT (3)
22-28	F7.0	DBT (4)
29-35	F7.0	DBT (5)
36-42	F7.0	DBT (6)
43-49	F7.0	DBT (7)
50-56	F7.0	DBT (8)
57-63	F7.0	DBT (9)
64-70	F7.0	DBT (10)

CARD 10 Only used if L7 = 2 (otherwise left out)

1-7	F7.0	DBT (11)
8-14	F7.0	DBT (12)
15-21	F7.0	DBT (13)
22-28	F7.0	DBT (14)

4/6/60

DECLASSIFIED

CARD 11 Only Used if L9 = 2 (otherwise left out)

<u>Space</u>	<u>Type of Number</u>	<u>Symbol</u>
1-7	F7.0	DPE (1)
8-14	F7.0	DPE (2)
15-21	F7.0	DPE (3)
22-28	F7.0	DPE (4)
29-35	F7.0	DPE (5)
36-42	F7.0	DPE (6)
43-49	F7.0	DPE (7)
50-56	F7.0	DPE (8)
57-63	F7.0	DPE (9)
64-70	F7.0	DPE (10)

CARD 12

Same as card 11 except values for DPE (11) through DPE (20) are placed on the card.

CARD 13

Same as card 11 except values for DPE (21) through DPE (25) are placed on the card.

CARD 14 Only used if L8 = 2 (otherwise left out)

<u>Space</u>	<u>Type of Number</u>	<u>Symbol</u>
1-7	F7.3	DE (1)
8-14	F7.3	DE (2)
15-21	F7.3	DE (3)
22-28	F7.3	DE (4)
29-35	F7.3	DE (5)
36-42	F7.3	DE (6)
43-49	F7.3	DE (7)
50-56	F7.3	DE (8)
57-63	F7.3	DE (9)
64-70	F7.3	DE (10)

CARD 15 Only used if L8 = 2 (otherwise left out)

1-7	F7.3	DE (11)
8-14	F7.3	DE (12)
15-21	F7.3	DE (13)
22-28	F7.3	DE (14)
29-35	F7.3	DE (15)

CARD 16 Only used if L4 = 2 (otherwise left out)

1-6	F6.3	P
7-11	F5.0	EMI
12-16	F5.0	EME
17-21	F5.0	EMS

DECLASSIFIED 4/6/60

Additional cards for each fixed case are used with the same format as card 16. When all the fixed cases are punched in, the card immediately after the fixed case cards should be blank. If, accumulation is desired, the card after the blank card must contain L14, L15, A16, A17, A18, A19 in the same card position as shown on card one. At this point a new input deck starting with card one can be added and additional cases will be calculated or another blank card may be put in which will cause the program to call EXIT and quit.

APPENDIX B
EQUATIONS USED IN PROCESS OPTIMIZATION

$$(1) \quad E = \frac{GR}{AT} \left[(QR)(RF) + (QS)(SF) + (EMB-EMI)(QMI)(SF) + (P-PB)(EN)(QP)(SF) \right]$$

Where: E = fraction of heat generated in I & E enriched load.

GR = ratio of heat generated in an enriched fuel element column compared to that generated in an I & E natural fuel element column in the same location.

AT = number of active tubes.

QR = number of E columns in flattening ring.

RF = average power factor of E columns in the flattening ring.

QS = number of E columns used in "spike" enrichment.

SF = average power factor of E columns used as "spike" enrichment.

EMB = goal exposure of I & E natural in MWD/T at base conditions.

EMI = goal exposure of I & E natural at the time of the specific calculation.

QMI = change in number of E columns per one MWD/T change in I & E natural goal exposure.

P = tube power in MW's of the ten highest powered tubes.

PB = average tube power in MW's of the ten highest powered tubes at base conditions.

EN = number of effective central zone tubes (ECT).

QP = change in number of E columns per MW change in reactor power level.

The above equation is based on the assumption that adjustment of enrichment will be made by charging or discharging "spike" enrichment.

4/6/60

$$(2) I = 1. - E - S$$

Where I = fraction of heat generated in the I & E natural loading.

E = fraction of heat generated in the I & E² loading, and

S = fraction of heat generated in the solid slug loading.

$$(3) CRI = (CRIT)(AI)(ELN/ELO)(WN/WO) \left[\frac{FOI}{FNI} + \frac{(.2635)(FOI)(TIN)}{(1000P)} \right]^{8.7}$$

Where: CRI = reactor metal performance index for I & E natural loading.

CRIT = tube metal performance index for I & E natural loading.

AI = ratio of tube metal performance index to reactor metal performance index.

ELN = hours lost to rupture removal including non-equilibrium losses, for current conditions.

ELO = hours lost to rupture removal including non-equilibrium losses used in calculating tube metal performance index.

WN = factor for extent on front to rear flux peaking for current conditions and equal to 1.0 when the flux has a front to rear cosine distribution.

WO = factor for extent of flux peaking used in calculating tube metal performance index.

TIN = inlet water temperature, °C.

FOI = I & E natural tube flow rate in gpm used in calculating tube metal performance index.

FNI = current tube flow rate in gpm, I & E natural.

Equation three also applies to I & E² and solid slugs when the appropriate constants are used for metal performance index and flows.

$$(4) PE = 1. / (1.0 + EMISC + (CK)(CKL)(AT)(2) \left[\frac{TIN + \frac{1000 P (EN)(RK)}{.2635 FR}}{12} \right] / \left\{ (DM)(DMR)(DTR) + P (EN) \left\{ (I)(TTI)(CDLINE)/(CDRI)(EMI) + E (TTE)(CDLENE)/(CDRE)(EME) + S (TTS)(CDLSNE)/(CDRS)(EMS) + P^{12} \left[(I)(CRI)(EMI)^4(TTI) + E (CRE)(EME)^4(TTE) + S (CRS)(EMS)^4(TTS) \right] \right\} \right\}$$

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Where: EMISC = miscellaneous loss in fraction of a day per equilibrium operating day.

CK = factor to adjust the tube corrosion rates so that calculated rates will be representative of the reactor.

CK1 = tube corrosion factor used by N. R. Miller and which is equal to 0.0008.

RK = average ratio for the bulk annulus temperature ΔT to tube bulk temperature ΔT .

FR = reactor flow in gpm.

DM = days per month.

DMR = mils removed from tube wall before tube is replaced.

DTR = tube replacement rate in tubes per day.

AT = number of active tubes in reactor.

TTI = tubes per ton of I & E natural slugs.

TTE = tubes per ton of I & E² slugs.

TTS = tubes per ton of solid slugs.

CDLINE = factor for multiplying the C-D downtime loss so that non-equilibrium losses will also be represented.

CDLENE = same factor for I & E² and solid slugs respectively.
CDLSNE

CDRI = charge-discharge rate, including set-up and button-up time, for I & E natural slugs, tubes/day.

CDRE = same as above for I & E² and solid slugs respectively.
CDRS

EMI = goal exposure of I & E natural slugs, MWD/T at the time of the calculation.

EME = same as above for I & E² and solid slugs respectively.
EMS

CRI = reactor metal performance index for I & E natural

CRE = same as above for I & E² and solid slugs respectively.
CRS

4/6/60

To calculate on a total plutonium basis, the following equation was used.

$$(5) \quad Z = (P)(EN)(PE) \left\{ I \left[(PU-BI)(CONVRI) - \frac{EMCI}{EMI} \right] + E \left[(PU-BE) \right. \right. \\ \left. \left. (CONVRE) - \frac{EMCE}{EME} \right] + S \left[(PU-BS)(CONVRS) - \frac{EMCS}{EMS} \right] \right\}$$

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Where: Z = net return plus fixed costs in dollars per day.

PU = dollar value of plutonium (all isotopes) per gram.

BI = burnout cost per gram of plutonium produced in I & E natural material.

BE = same as above except the plutonium is produced in I & E^2 and
 BS = solid material respectively.

$CONVRI$ = grams of PU produced per MWD in I & E material.

$CONVRE$ = same as above except refers to I & E^2 and solid material
 $CONVRS$ = respectively.

$EMCI$ = incremental metal cost/ton of I & E natural.

$EMCE$ = same as above for I & E^2 and solid slugs respectively.
 $EMCS$

To calculate on a plutonium 239 basis, the following equation was used.

$$(6) \quad Z = (P)(EN)(PE) \left\{ I \left[(PU-BI) \frac{(PU39(1))}{(EMI)} - \frac{(PU240)}{EMI} (PU40(1)) - \frac{EMCI}{EMI} \right] \right. \\ + E \left[(PU-BE) \frac{(PU39(2))}{EME} - \frac{(PU240)}{EME} (PU40(2)) - \frac{EMCE}{EME} \right] \\ \left. + S \left[(PU-BS) \frac{(PU39(3))}{EMS} - \frac{(PU240)}{EMS} (PU40(3)) - \frac{EMCS}{EMS} \right] \right\}$$

Where: $PU39(1)$ = grams of Pu-239/Ton in I & E natural

$PU39(2)$ = grams of Pu-239/Ton in I & E^2 .

$PU39(3)$ = grams of Pu-239/Ton in solids.

$PU40(1)$ = grams of Pu-240/Ton in I & E natural

$PU40(2)$ = grams of Pu-240/Ton in I & E^2 .

$PU40(3)$ = grams of Pu-240/ton solids.

$PU240$ = penalty per gram of Pu-240.

4/6/60

The nomenclature, other than the above, is the same as given for equation 5. As shown in Appendix A, it is possible to put in loss terms as a function of bulk outlet temperature, production efficiency, and/or E. When the additional loss terms are used, Z is first calculated by either equation 5 or 6, then the value calculated is modified by the appropriate loss terms.

$$(7) \quad BT = TIN + 1000 (P)(EN) / .2635 (FR)$$

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Where: BT = bulk outlet water temperature, °C.

P = average power of the ten highest power tubes, MW's.

EN = effective number of central zone (ECT)

FR = reactor flow in gpm.

A number of the parameters are calculated after the program has determined the optimum parameters. The equation used, primarily for output purposes, are as follows:

$$(8) \quad PN = P (EN)$$

Where: PN = reactor power level in MW's.

$$(9) \quad TRL = CK (CK1)(AT) \left(2 \frac{TIN + 1000 (PN)(RK)}{12 \cdot .2635 (FR)} \right) (PE)$$

Where: TRL = Tube replacement loss, fraction of total time.

$$(10) \quad CDI = PN(I)(TTI)(CDLINE) / (CDRI)(EMI)(PE) = \text{C-D loss, fraction of total time.}$$

$$CDE = PN(E)(TTE)(CDLENE) / (CDRE)(EME)(PE) = \text{" " " " " " "}$$

$$CDS = PN(S)(TTS)(CDLSNE) / (CDRS)(EMS)(PE) = \text{" " " " " " "}$$

$$CDT = CDI + CDE + CDS = \text{Total charge-discharge loss.}$$

$$(11) \quad RLI = PN(P)^{12} (I)(CRI)(EMI)^4 (TTI)(PE) = \text{Rupture loss, fraction of total time.}$$

$$RLE = PN(P)^{12} (E)(CRE)(EME)^4 (TTE)(PE) = \text{" " " " " " "}$$

$$RLS = PN(P)^{12} (S)(CRS)(EMS)^4 (TTS)(PE) = \text{" " " " " " "}$$

$$RLT = LRI + RLE + RLS = \text{Total rupture loss.}$$

$$(12) \quad RUP = RLT (24/ELN) = \text{number of ruptures/day.}$$

4/6/60

DECLASSIFIED

(13) $MWDT = PN(PE) = \text{Production in MWD's (total)/day}$

$MWDI = MWDT(I) = \text{Production in MWD's in I \& E/day}$

$MWDE = MWDT(E) = \text{Production in MWD's in I \& } E^2/\text{day}$

$MWDS = MWDT(S) = \text{Production in MWD's in solids/day}$

(14) $GRMI = MWDI(CONVRI) = \text{Grams/day produced in I \& E}$

$GRME = MWDE(CONVRE) = \text{Grams/day produced in I \& } E^2$

$GRMS = MWDS(CONVRS) = \text{Grams/day produced in solids}$

$GRMT = GRMI + GRME + GRMS = \text{total grams produced.}$

(15) $BOCI = BI(GRMI) = \text{Burnout cost for I \& E/day}$

$BOCE = BE(GRME) = \text{Burnout cost for I \& } E^2/\text{day}$

$BOCS = BS(GRMS) = \text{Burnout cost for solids/day}$

$BOCT = BOCI + BOCE + BOCS = \text{total burnout cost/day}$

(16) $TPI = MWDI/EMI = \text{Tons of I \& E throughput/day}$

$TPE = MWDE/EME = \text{Tons of I \& } E^2 \text{ throughput/day}$

$TPS = MWDS/EMS = \text{Tons of solids throughput/day}$

$TPT = TPI + TPE + TPS = \text{total metal cost/day}$

(17) $TPCI = TPI(EMCI) = \text{metal cost, I \& E/day}$

$TPCE = TPE(EMCE) = \text{metal cost, I \& } E^2/\text{day}$

$TPCS = TPS(EMCS) = \text{metal cost, solids/day}$

$TPCT = TPCI + TPCE + TPCS = \text{total metal cost/day}$

(18) $AVINI = (BOCI + TPCI)/GRMI = \text{average incremental cost/gram in I \& E}$

$AVINE = (BOCE + TPCE)/GRME = \text{average incremental cost/gram in I \& } E^2$

$AVINS = (BOCS + TPCS)/GRMS = \text{average incremental cost/gram in solids}$

$AVINT = (BOCT + TPCT)/GRMT = \text{average incremental cost/gram total}$

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HW-64654

-21-

4/6/60

The accumulation for both the optimum cases and the fixed cases is done in the same manner. There are two types of calculations made. One is a summation of the daily values for Z, MWD's, grams, burnout costs, metal costs, ruptures and throughputs. The other is an average for the goal exposures of each type of metal, the average tube replacement loss in fraction of the total time, and the average total charge-discharge loss in fraction of total time.

The first optimum case daily values are multiplied by the constant A16 put in as input while the succeeding cases are multiplied by A18. The first fixed case daily values are multiplied by the constant A18 and the succeeding cases' daily values are multiplied by A19.

APPENDIX C
PRINT OUT

The title printed out is "IPD-Process Optimization - Process Analysis Unit." Immediately below the title the input data is printed according to the following format:

Line 1 L1, L2, L3, L4, I, L7, L8, L9, L14, L15, A16, A17, A18, A19
2 GR, AT, QR, QS, RF, SF, EMB, QMI, PB, EN, QP
3 CRIT, CRET, CRST, AI, AE, AS, ELN, ELO, WN, WO, TIN
4 FOI, FOE, FOS, FNI, FNE, FNS, S
5 CK, CK1, RK, FR, DM, DMR, DTR
6 PN, BI, BE, BS, EMCI, EMCE, EMCS, EMISC, PU240
7 TTI, TTE, TTS, CDRI, CDRE, CDRS, CDLINE, CDLENE, CDLSNE
8 IA, LOTI, LOTE, LOTS, SPA(1), SPA(2), SPA(3), PCS(1), PCS(2), PCS(3), BEAT

The symbols are defined on the preceding pages.

The first form for output data will be found under the headings "Optimum Parameters," "Ridges," or "Fixed Points" and is as follows:

Z, P, ECT, PN, MI, ME, MS, I, E, S, TIN, BT, RF, CORI, CORE, CORS, PE

CRI, CRE, CRS

CDLI RLI MWDI GRMI BOCI AVCI MCI TPI

CDLE RLE MWDE GRME BOCE AVCE MCE TPE

CDLS RLS MWDS GRMS BOCS AVCS MCS TPS

CDLT RLT MWDT GRMT BOCT AVCT MCT TPT TRL RUP MISC

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HW-64654

-22-

4/6/60

*DBT(1)	DBT(2)	DPT(3)	DBT(4)	DPT(5)	DBT(6)	DBT(7)	DBT(8)	DBT(9)
DBT(10)	DBT(11)	DPT(12)	DPT(13)	DPT(14)				
DE(1)	DE(2)	DE(3)	DE(4)	DE(5)	DE(6)	DE(7)	DE(8)	DE(9)
DE(10)	DE(11)	DE(12)	DE(13)	DE(14)	DE(15)			
PEL(1)	PEL(2)	PEL(3)	PEL(4)	PEL(5)	PEL(6)	PEL(7)	PEL(8)	PEL(9)
PEL(10)	PEL(11)	PEL(12)	PEL(13)	PEL(14)	PEL(15)	PEL(16)	PEL(17)	PEL(18)
PEL(19)	PEL(20)	PEL(21)	PEL(22)	PEL(23)	PEL(24)	PEL(25)		

*If no input data is provided for additional bulk outlet temperature loss terms, the DBT (m) table will not be printed out. If just DE (m) or total control loss terms are put in as input then DE (m) and PEL (m) tables will be printed out. If only PEL (m) loss terms are used as input only PEL (m) will be printed out.

DBT = input loss term in \$ put in the respective table positions 1-14.

DE = total control loss terms in fraction of Z put in as input in table positions 1-15.

PEL = production efficiency loss terms in dollars put in as input in table positions 1-25.

Where: Z = net return plus fixed cost in \$/calender day

P = maximum tube power in MW's

ECT = number of effective central zone tubes

PN = power level in MW's

M = average goal exposure in MWD/T

I = fraction of heat generated in I & E natural slugs

E = fraction of heat generated in I & E² slugs

S = fraction of heat generated in solid slugs

TIN = inlet temperature, °C

BT = bulk outlet temperature, °C

RF = reactor flow in gpm

COR = grams/MWD

PE = production efficiency expressed as a fraction

CR = pile rupture loss constant

CDL = charge-discharge loss expressed as a fraction of total time

RL = rupture loss expressed as a fraction of total time

4/6/60

DECLASSIFIED

MWD = production in MWD per calender day

GRM = grams produced per calender day

BOC = burnout cost in \$/calender day

AVC = average cost per gram

MC = metal cost per calendar day

TP = throughput in tons per calender day

TRL = tube replacement loss expressed as a fraction of total time

RUP = number of ruptures per calender day

MISC = input miscellaneous loss term expressed as a fraction per equilibrium operating day.

The second form used for output data is found under the headings "Accumulation - Optimum" or Accumulation-Fixed. All the numbers are expressed in floating point (e.g, 1.00 E + 02 = 100).

Z T	MWDT	GRMT	TPT	RUPT
AVPN	AVMI	AVME	AVMS	AVTRL
AVCDLT	BOCT	MCT		

Where: What is summed up or averaged depends on how the input data was set-up. However, in any event the above symbols are defined as follows:

ZT = total net return plus fixed costs.

MWDT = total production in MWD

GRMT = total production in grams

TPT = total throughput in tons

RUPT = total number of ruptures

AVPN = average power level in megawatts

AVMI = average goal exposure in MWD/T; subscripts have same meaning as defined earlier.

AVTRL = average tube replacement loss in fraction of total time.

AVCDLT = average charge-discharge loss for all types of metal in fraction of total time.

4/6/60

BOCT = total burnout costs in dollars/day

MCT = total metal cost in dollars/day

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An accumulation case is set up for either fixed calculations or optimum calculations. In the optimum case, to obtain the totals, the daily values for the first case are multiplied by A-16, an input constant which is equal to the number of days you desire. The daily values for the subsequent cases are multiplied by A-17, again an input constant. The same sort of system is used to accumulate fixed power and exposure cases but the input constants used are A-18 and A-19.

END

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11 / 16 / 193