START-UP OF THE PHW 600 REACTOR WITH A REDUCED INITIAL CORE LOADING

by

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ABSTRACT

Savings, in terms of increased first charge burnup and lower fuel inventory costs, are made when a CANDU reactor is started up with a reduced initial core loading. Enough fuel is loaded to make the reactor critical and then progressively added to the outer channels to maintain criticality during operation over the intial transient. As more fuel is loaded, the form factor improves permitting the reactor power to be increased. When the last channel is loaded, full power can be achieved.

The trade off between decreased fuel costs and energy loss has been investigated by simulating operation to 300 full power days (FPD) with a two dimensional fuel management program for various initial loadings of the PHW 600 reactor. The results for the reference case (fully loaded initial core producing full power from start-up) were available from a previous study (2). It was found that the optimum trade off occurred for an initial loading of about 95%. A 3% improvement in first charge burnup was obtained which was offset by an energy loss of 8 FPD over the initial transient. The maximum burnup improvement, for 34% initial loading, was about 13% with an energy loss of 73 FPD.

It was concluded that the reduced core concept can be used to advantage only by a utility which does not require full power immediately. If, however, the lost energy has to be replaced from another source, utility operating costs are minimized by starting up under normal conditions owing to relatively high replacement energy costs.

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I PROJECT DESCRIPTION

1.0 INTRODUCTION

The purpose of this study was to examine the operation of the PHW 600 reactor from initial start-up with a reduced core loading to equilibrium, and to compare the results with the normal start-up in which the core is fully loaded with fresh fuel and full power is produced immediately. Although in the former case the maximum reactor power is at first low and builds up gradually, savings are made in terms of lower fuel inventory costs and increased first charge burnup. It might be more economical for a utility with a new reactor to start-up with a reduced core replacing the lost energy during the initial transient from another source. Note that this study deals only with fresh fuel start-ups.

The reactor is of standard CANDU-PHW design consisting of a cylindrical calandria lying on its side containing 380 horizontal pressurized fuel channel assemblies. Each channel is normally loaded with 12 natural uranium oxide fuel bundles and the system is cooled and moderated with heavy water. The total design power is limited to 2,061 MWT by maximum permissible bundle and channel powers. At equilibrium, radial flattening is achieved by a combination of differential burnup and adjuster rods. The adjusters can be withdrawn after a shut-down for xenon override. Fuelling is by the on power, bydirectional, pushthrough method at an average equilibrium rate of about 16 bundles per day in two, eight bundle shifts.

1.1 REACTOR START-UP WITH A FULLY LOADED INITIAL CORE

The reactor is normally started up with a fully loaded core producing full power as soon as low power testing is completed. During the initial transient, the central region power would be unacceptably high without some means of flattening to replace differential burnup. This is provided by depleted UO_2 bundles located stategically in the inner fuel region. At start-up, there is far more fuel than required for criticality resulting in a considerable excess reactivity. This is taken up by soluble boron poison in the moderator which is at first added during operation until the plutonium peak is reached and then removed as the first charge is further burnt. Refuelling begins after 120 FPD when the excess reactivity has fallen to zero. Fig 1.1 shows the initial transient excess reactivity for normal operation.

1.2 REACTOR START-UP WITH A REDUCED INITIAL CORE LOADING

Enough fuel is charged to make the reactor critical and the remaining channels are filled with dummy bundles in order to provide an even resistance to coolant flow throughout the core. New fuel is progressively added to the outer channels replacing the dummy fuel in order to maintain criticality over the initial transient. As more fuel is added, the form factor (average radial flux/maximum radial flux) improves permitting the reactor power to be increased and when the last channel is loaded, full power can be achieved. At this point normal refuelling begins. The burnup obtained from the first charge is higher than when a full charge is loaded initially because of a lower poison load over the initial transient resulting in better neutron economy.

1.3 METHOD OF ANALYSIS

The reactor was simulated from start-up with fresh fuel to 300 FPD with STOKE for various initial loadings. A model had been prepared in earlier design work (1,2) and the results for the reference case (fully loaded initial core producing full power from start-up) were available from a previous study (2). For each case, the total fuel cost for the first 300 days of operation was determined using the following equation:

$$\text{TOTAL FUEL COST} = \text{CAPITAL COST OF CHARGED FUEL} + \text{INTEREST COST OF FUEL} - \text{VALUE OF FUEL IN CORE AFTER 300 DAYS} \qquad \text{Eq.1.3.1}$$

Compound interest should be charged at a rate of about 10/12% per month on the dollar value of the fuel in the core at each time interval. The number of bundles in the normal core is constant but the value of the fuel in terms of producing energy at first rises until the Pu peak is reached and then decreases as the fission products build up. However, for the purpose of interest calculation, it is reasonable to assume that the dollar value steadily decreases to zero at discharge.

For start-up with a reduced core loading, the dollar investment decreases with increasing burnup as before, but increases as more fuel is added to the outer channels during the initial transient.

At equilibrium, fuel interest costs are constant.

The final term in the Eq.1.3.1 was determined for each case after finding the average burnup of bundles in the core after 300 days. It permits cost comparison even though the distance from equilibrium after 300 days depends upon the initial core loading.

A small program, developed and listed in Appendix C, was written to calculate the total fuel costs according to Eq. 1.3.1 using the output data from the main program.

The trade off between decreased fuel costs and energy loss wasdetermined by calculating the indifference value of the replacement energy cost for each case. This is the replacement energy cost at which the benefit derived from operating with a reduced core is exactly balanced by the cost of the replacement energy. The value is best illustrated by taking a hypothetical example. Consider a utility with two generating units - a new CANDU reactor and a coal fired plant which must together produce Qkwh over a period of T days. The reactor is always loaded to power first since CANDU fuel is much cheaper than coal and capital payments on both plants are fixed. However, over the initial transient to equilibrium, the total operating costs of the utility might be decreased if the reactor is operated with a reduced core with the lost nuclear power being replaced by the coal fired plant. During this period the average nuclear energy cost, in mills/kwh, depends upon the initial loading, while the coal cost per kwh can be assumed constant.

TABLE 1.3.1 UTILITY OPERATING COSTS FOR NORMAL START-UP AND FOR START-UP WITH A REDUCED INITIAL CORE

	REACTOR		COAL FIRED PLANT	
	NORMAL OPERATION	RED. INIT. CORE		
ENERGY GENERATED KWH	a	x	$Q-a$	$Q-x$
AVERAGE FUEL COST mills/KWH	$f(x)\|_a$	$f(x)$	K	K
TOTAL FUEL COST mills	$af(x)\|_a$	$xf(x)$	$K(Q-a)$	$K(Q-x)$

Utility operating cost for normal operation $= af(x)\big|_a + K(Q-a)$ Eq. 1.3.2.

Utility operating cost for operation with a reduced initial core $= xf(x) + K(Q-x)$ Eq. 1.3.3.

For operation with a reduced core to be more economical,

Eq. 1.3.2. - Eq. 1.3.3 > 0 , ie $\dfrac{af(x)\big|_a - xf(x)}{a - x} > K$

$$\frac{TFC_{\text{reference}} - TFC_{\text{reduced core}}}{\text{Nuclear energy lost}} > \text{Replacement energy cost}$$

The expression on the left was determined for four reduced core loadings with normal start-up as reference. An additional case was run with a fully loaded initial core but without depleted fuel bundles for radial flattening.

1.4 METHOD OF SIMULATION

Details of STOKE and the STOKE model of the PHW 600 reactor are given in Appendix A. The simulations were performed in two parts. For the first part, STOKE was in the semiautomatic mode so that the simulation terminated at onset of normal fuelling. In this mode, the unfuelled channels were fuelled using external control cards. The innermost ring containing dummy fuel was completely recharged with natural UO_2 fuel so that the outer ring was the last fuelled in this manner. The simulations were completed to 300 FPD with STOKE in the automatic mode in which selection of rings for refuelling is carried out automatically. The coolest ring is selected and 8 bundles per channel are loaded in each shift.

Three auxillary programs, previously developed by A.L. Wight, were used. STOSUM selects important information from the STOKE output and normalizes flux and power distributions if bundle or channel power limits are exceeded. STOCNV converts the fuel array table output fromPOWDERPUFFS to an array suitable for STOKE input. Merging of output from one program into the input of another was accomplished using FTOF. A flow chart for the simulation of a fully loaded initial core to onset of normal fuelling is given in Appendix B.

The limiting bundle and channels powers were 954 kw and 7.5 MW respectively. These were the values used in the early design work on Gentilly-2 (2).

1.5 REFERENCE CASE

U. Nurmsoo has simulated the reactor operation from start-up with a fully loaded fresh core to 1,000 FPD (2). Depleted UO_2 (0.52 atom% U235) in bundle positions #8 and #9 in the inner 148 channels produced the most satisfactory operating conditions for full power operation over the initial transient. The data from this run are used in the present study for the reference case, and are presented in Table 2.1.

2 DISCUSSION OF RESULTS

The simulation results, including the data for the reference case discussed in section 1.5, are presented in Table 2.1.

In Fig. 2.1, the initial excess reactivity is plotted against the initial core loading. Extrapolation to zero excess reactivity gives a minimum critical loading of 34%.

Figs. 2.2 show the maximum power over the initial transient as a function of core burnup and were used to determine the energy loss for each case. For example, Fig.2.3, showing the maximum power output as a function of time for a 50.5% initial loading, was constructed from Fig. 2.2.2. The area under the curve is 300 FPD and the area above gives an energy loss of 59.7 FPD. In every case, power cutback was necessary to prevent the channel power limit (7.5 MW) from being exceeded.

Fig. 2.4 shows that higher first charge burnups are obtained by starting up with smaller reduced cores. The maximum improvement of about 13% is obtained by starting up with the minimum critical loading resulting in a minimum average fuel cost of 1.92 mills per kwh (e) (Fig. 2.6). However this was offset by a maximum energy loss of 73 FPD (Fig. 2.5) which, for our hypothetical utility, would have to be replaced by burning coal costing about 5 mills per kwh (e). Note that the bracketed percentage beside each point in Fig. 2.4 refers to the fraction of total first charge (4560 bundles) which was discharged after 300 days and over which the burnup average was taken. Note also that higher burnup values were obtained when the average was taken over a longer interval (ie 300 FPD). This is to be expected as at start-up, the neutron economy is relatively poor and improves until all of the boron is removed from the moderator. The first bundles discharged, especially the first four from each channel, have a relatively low burnup.

Fig. 2.7 was constructed from Figs. 2.5 and 2.6. It shows the indifference value of replacement energy cost as a function of initial core loading. The optimum trade-off between increased first charge burnup and energy loss occurs for an initial loading of about 95%. The replacement energy cost would have to be less than 4.5 mills per kwh (e) for a lower utility operating cost with this initial loading for the first 300 days of operation. The burnup improvement would be about 3% with 8 FPD energy loss. With replacement energy cost below 3 mills per kwh (e), the smallest loading is economical.

3. CONCLUSIONS

For our hypothetical utility, the reactor should be operated over the initial transient to equilibrium according to the reference case - that is with a fully loaded initial core producing full power from start-up. If the price of coal falls below 4.5 mills per kwh (e), it would be economical to start up with a 95% initial loading.

The reduced core concept can be used to advantage by a utility which does not require full power immediately. The initial loading can be chosen after comparing the demand curve expected for the first six months with the maximum power vs. time curves. The average energy cost can then be predicted from Fig. 2.6. Note that for a fully loaded initial core, even with the power cut back, the average fuel cost is about 2.18 mills per kwh (e) for the first 300 days of operation.

4 REFERENCES

1. Wight, A.L.: Private Communication.
2. Nurmsoo, U.: Private Communication.
3. Segal, A.W.: Estimating CANDU Fuel Costs. AECL Sept, 1972.

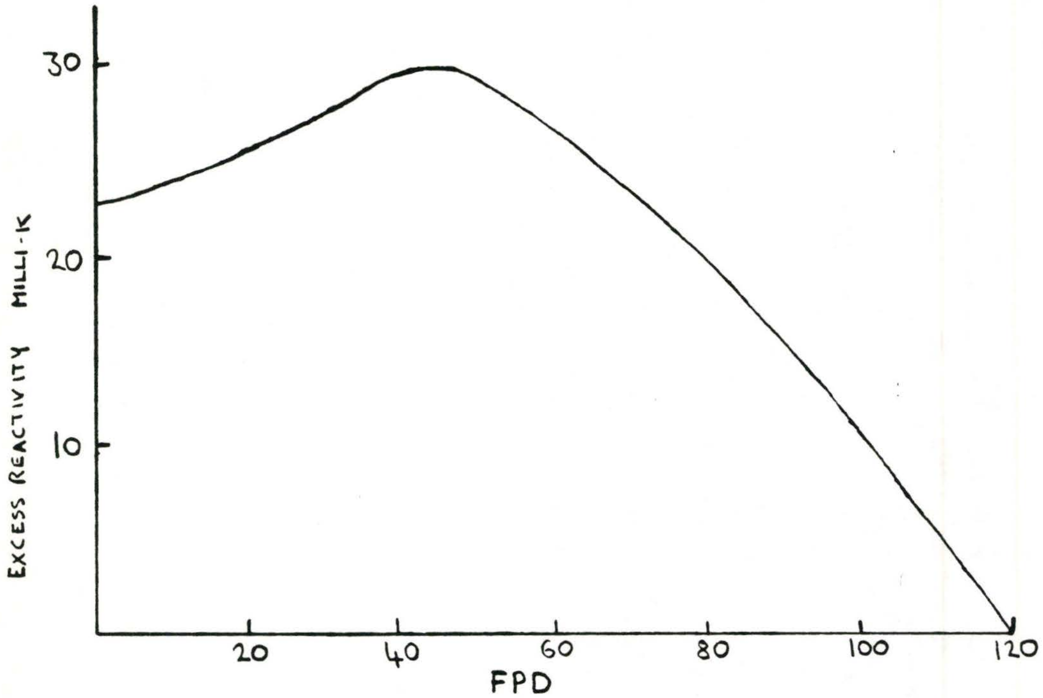


FIG. 1.1 INITIAL TRANSIENT EXCESS REACTIVITY FOR NORMAL STARTUP

TABLE 2.1: SIMULATION RESULTS

CASE	ONSET OF NORMAL FUELLING		ENERGY LOST AFTER 300 DAYS	FUEL BUNDLES DISCHARGED AFTER 300 DAYS	AVERAGE DISCHARGE BURNUP		EXCESS REACTIVITY		ADJUSTED VALUE FOR FUEL BUNDLES DISCHARGED AFTER 300 DAYS ǂ
	FPD	DAYS	FPD		MWD/BUNDLE		Milli-k		
					AFTER 300 DAYS	AFTER 300FPD	0 DAYS	300 DAYS	
REFERENCE FULLY LOADED INITIAL CORE WITH DEPLETED BUNDLES AT POSITIONS #8 and 9 in INNER 148 CHANNELS	111	111	0	3352 TYPE 1* 296 TYPE 2†	95 TYPE 1 86 TYPE 2		22.8	~5	3352 TYPE 1 296 TYPE 2
CG01-14 INNER 148 CHANNELS LOADED (39%)	113	182	69.1	2016	107	109	10.3	8.2	1900
CG01-17 INNER 192 CHANNELS LOADED (50.5%)	110	170	59.7	2240	106	108	21.1	6.6	2181
CG01-20 INNER 240 CHANNELS LOADED (63%)	107	151	43.9	2720	104	107	27.2	6.8	2656
CG01-24 INNER 300 CHANNELS LOADED (79%)	109	132	22.9	3040	104	106	33.1	7.4	2955
CG01-28 FULLY LOADED INITIAL CORE WITH NAT UO_2 FUEL (380 CHANNELS)	122	125	2.79	3552	98	98	37.4	6.9	3484

* - NATURAL UO_2 WHEN FRESH
† - DEPLETED UO_2 WHEN FRESH
ǂ SEE APPENDIX E

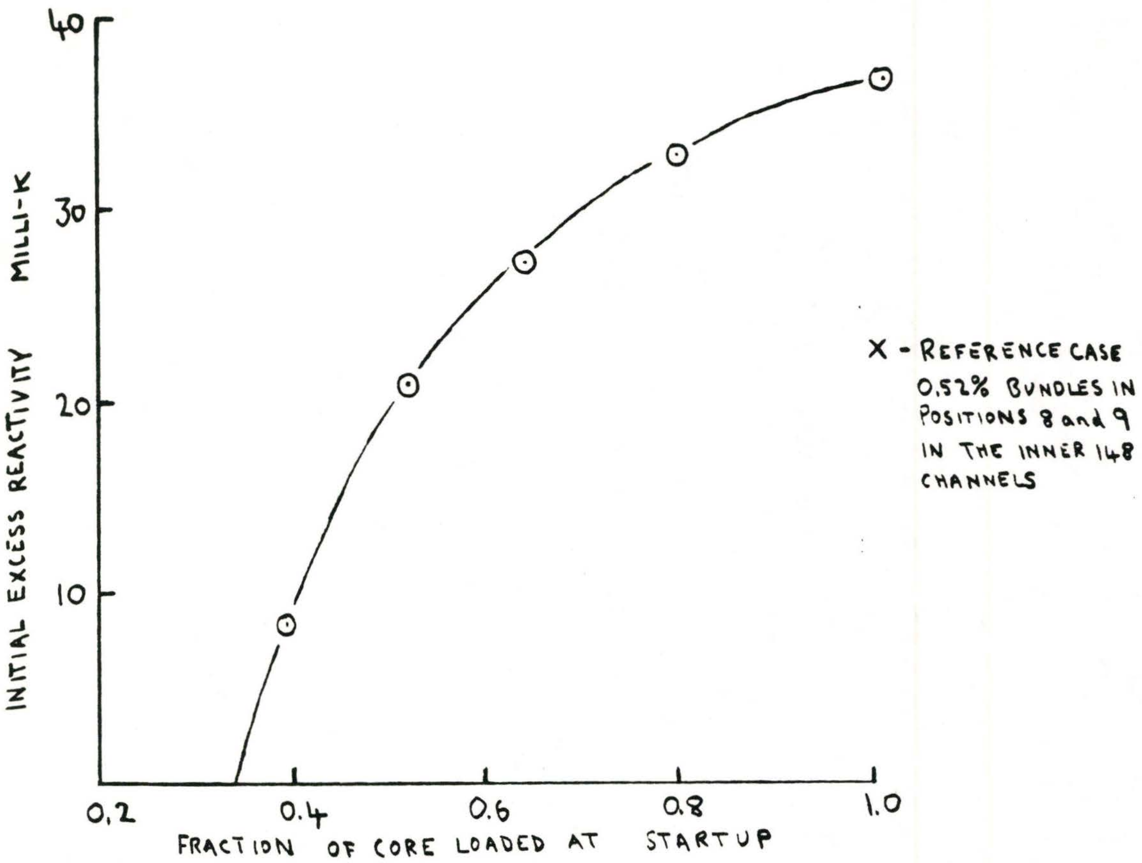


FIG. 2.1 INITIAL EXCESS REACTIVITY VS. INITIAL CORE LOADING

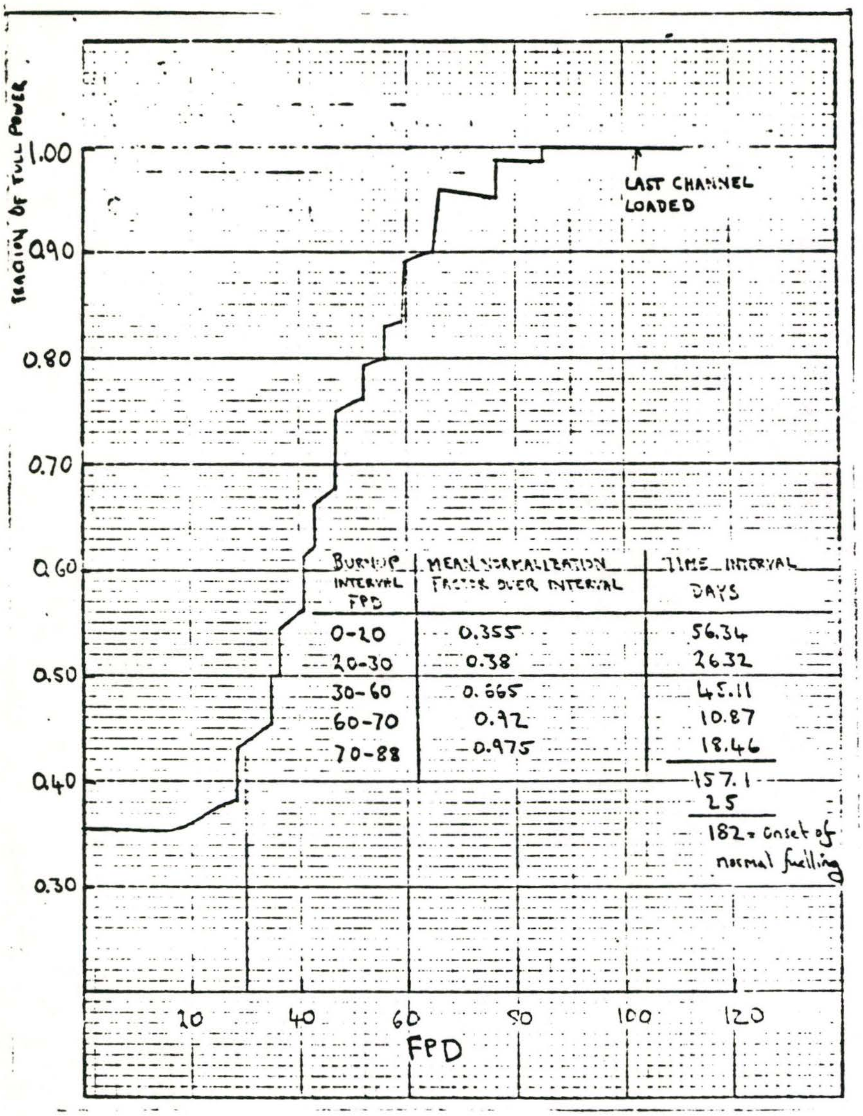
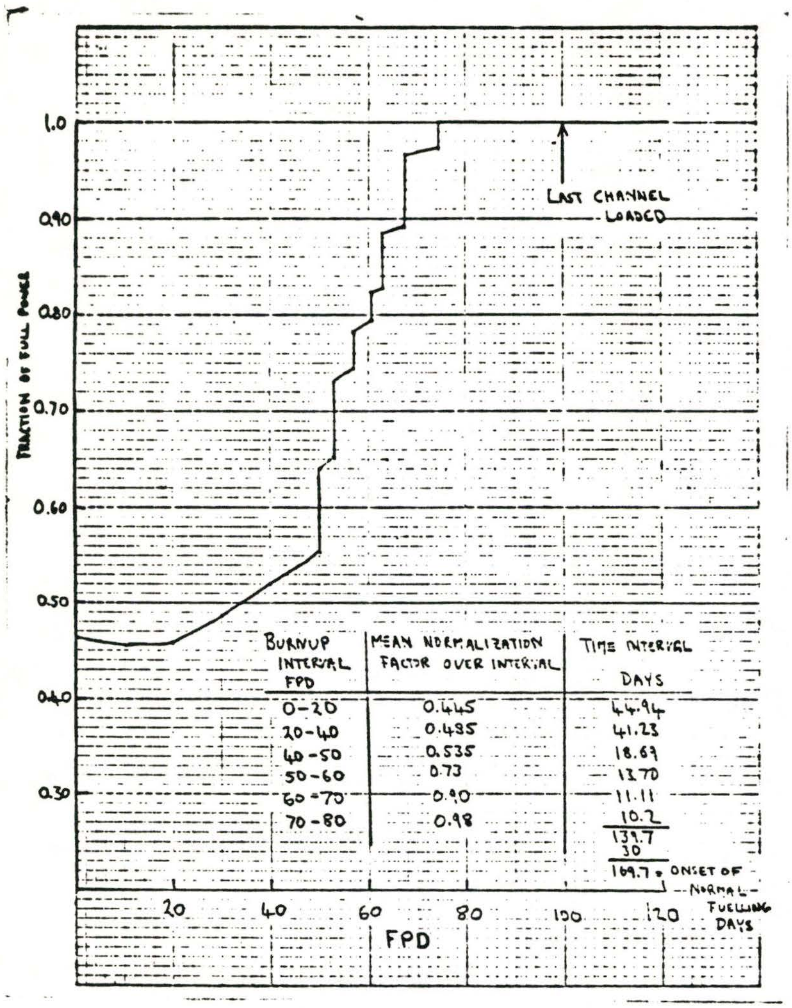


Fig. 2.2.1 Maximum power output with reduced initial core loading. Case CGO 1-14.



BURNUP INTERVAL FPD	MEAN NORMALIZATION FACTOR OVER INTERVAL	TIME INTERVAL DAYS
0-20	0.445	44.94
20-40	0.435	41.23
40-50	0.535	18.67
50-60	0.73	13.70
60-70	0.90	11.11
70-80	0.98	10.2
		139.7
		30
		169.7 = ONSET OF NORMAL FUELLING DAYS

Fig. 2.2.2 Maximum power output with reduced initial core loading. Case CGO 1-17.

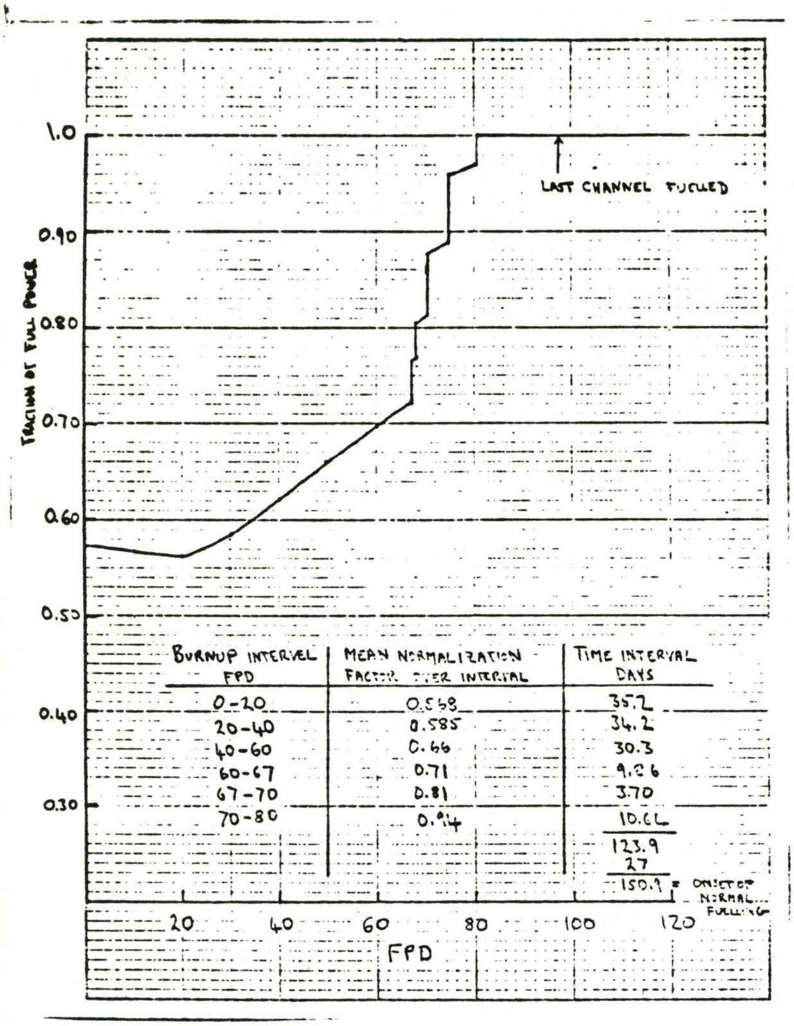


Fig. 2.2.3 Maximum power output with reduced initial core loading. Case CGO 1-20.

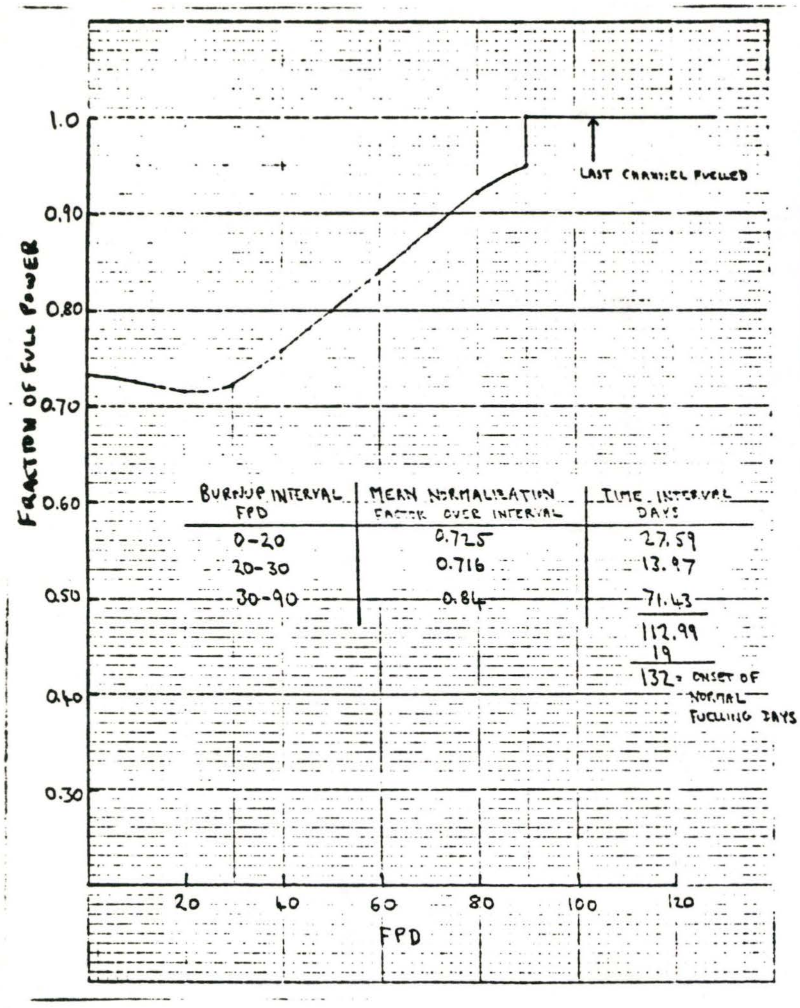


Fig. 2.2.4 Maximum power output with reduced initial core loading. Case CGO 1-24.

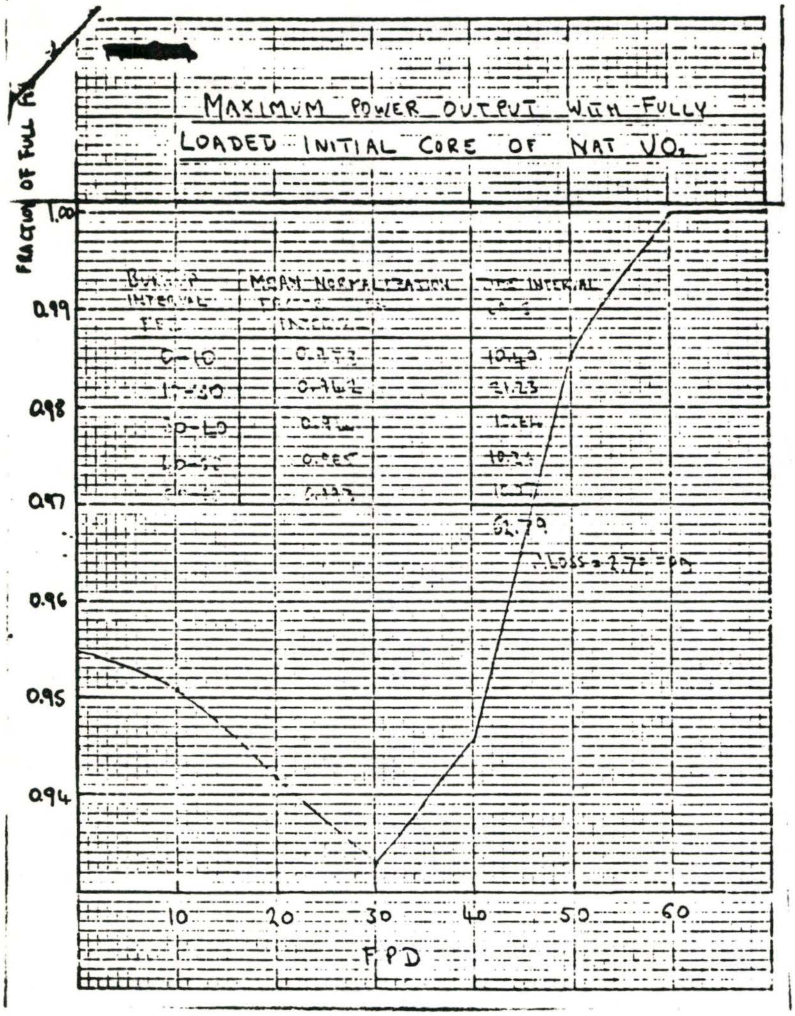


Fig. 2.2.5 Maximum power output with reduced initial core loading. Case CGO 1-28.

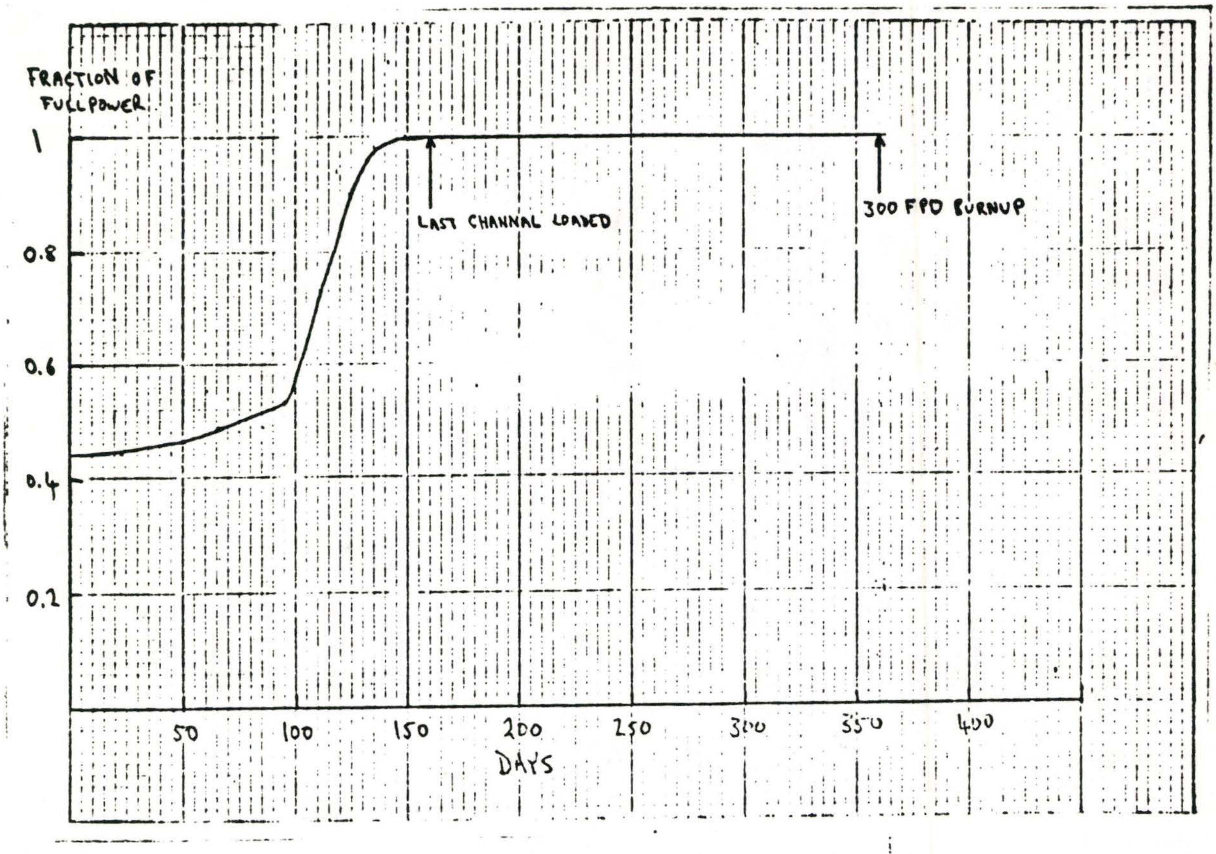


Fig. 2.3 Maximum reactor power vs. time for operation with a 50.5% initial core loading.

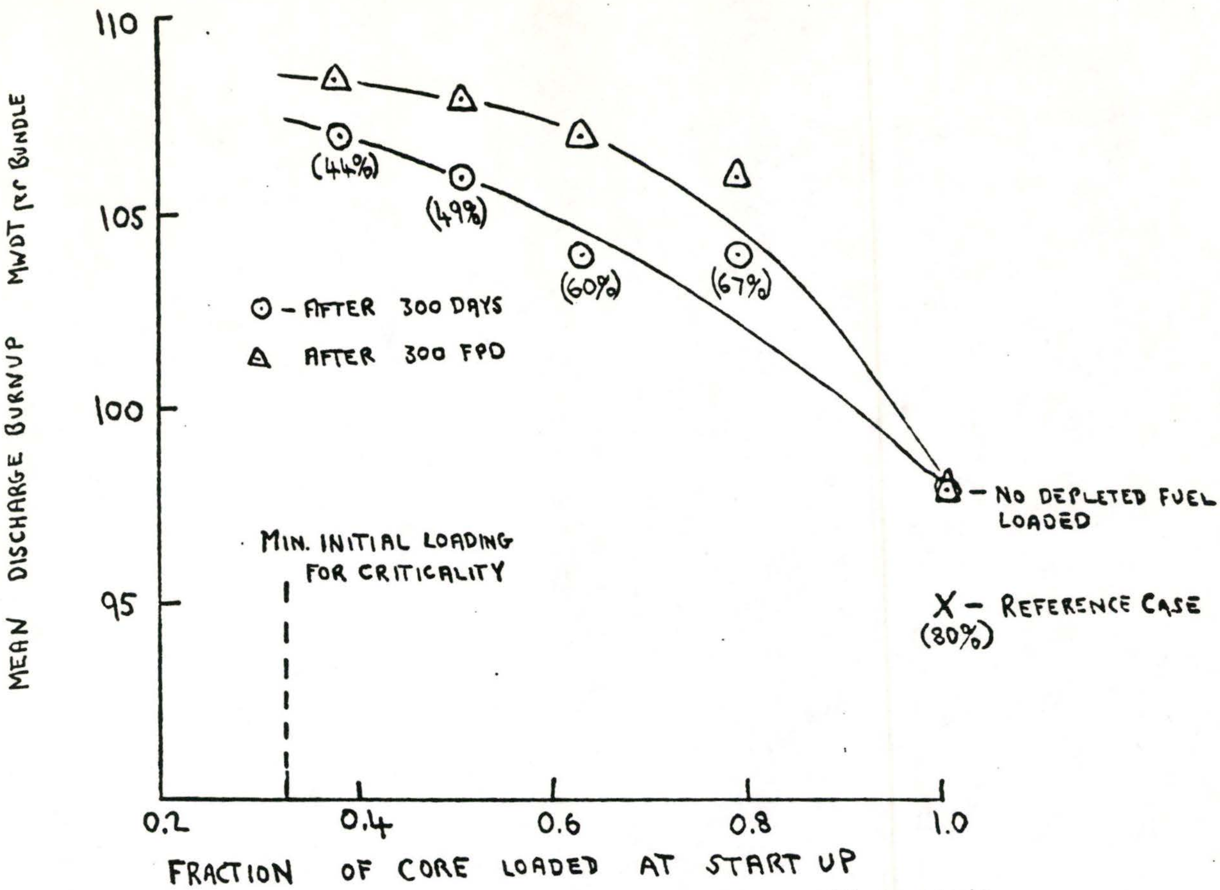


Fig.2.4 MEAN DISCHARGE BURNUP vs. INITIAL CORE LOADING

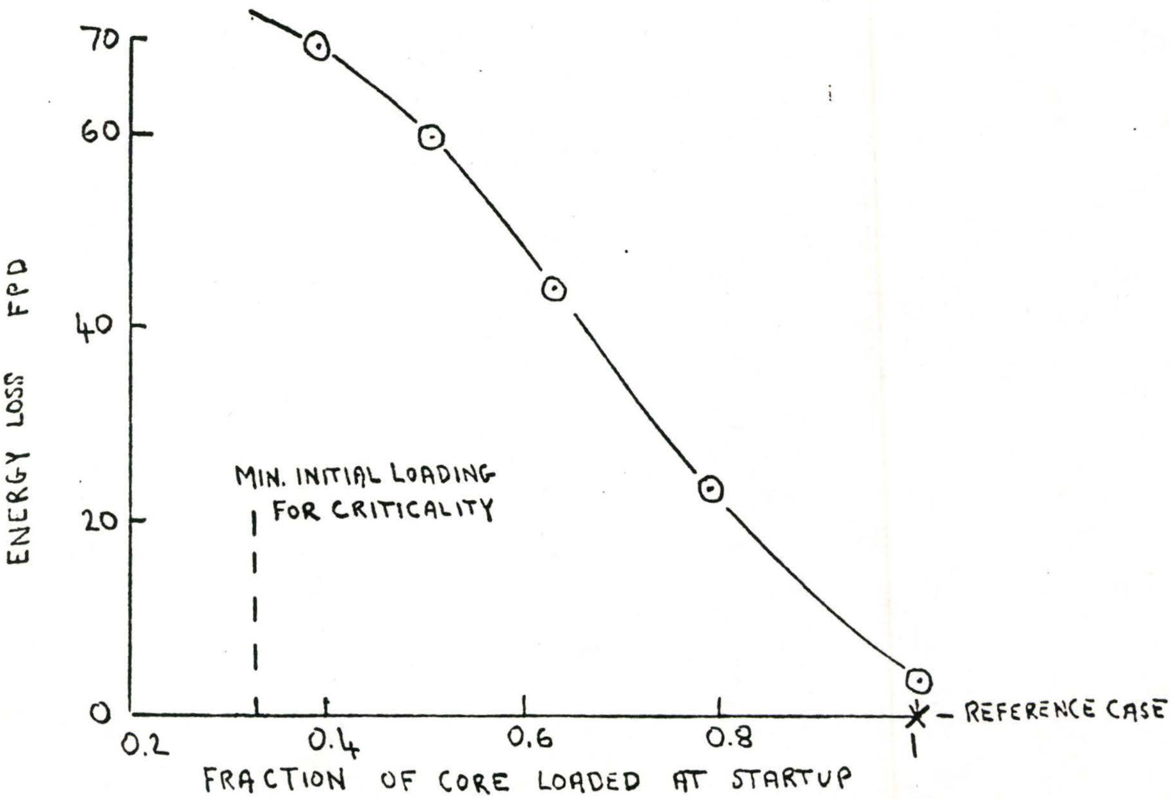


Fig.2.5 ENERGY LOSS vs INITIAL CORE LOADING

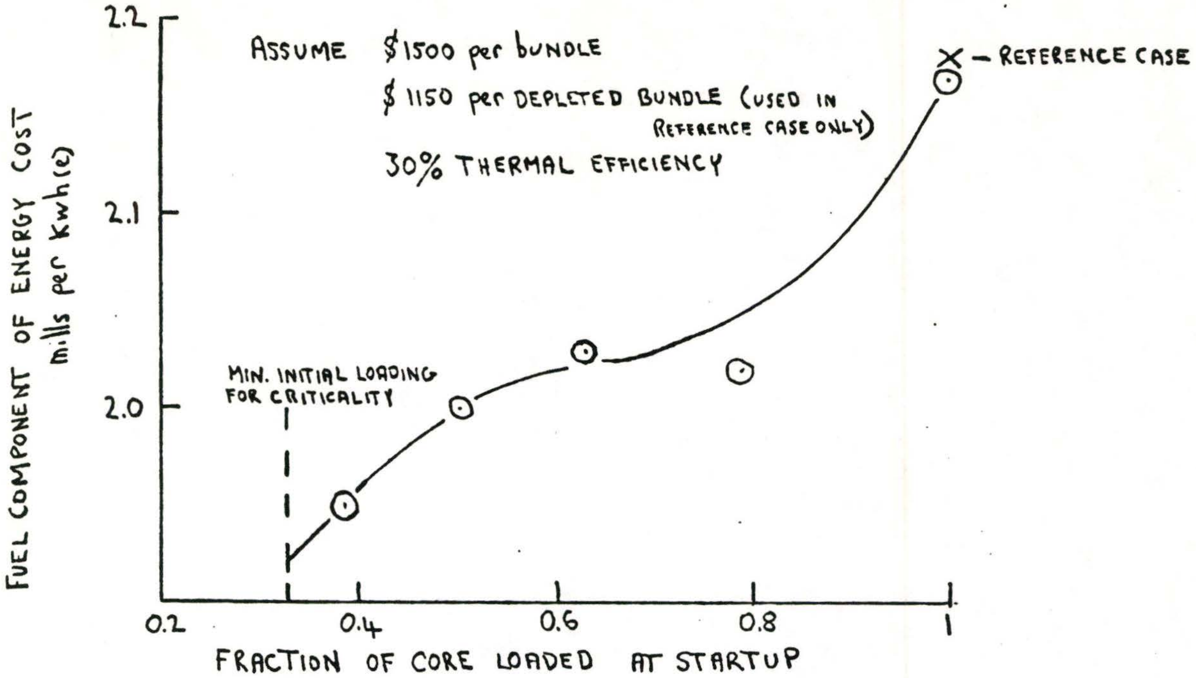


Fig. 2.6 AVERAGE ENERGY COST FOR FIRST 300 DAYS OF OPERATION

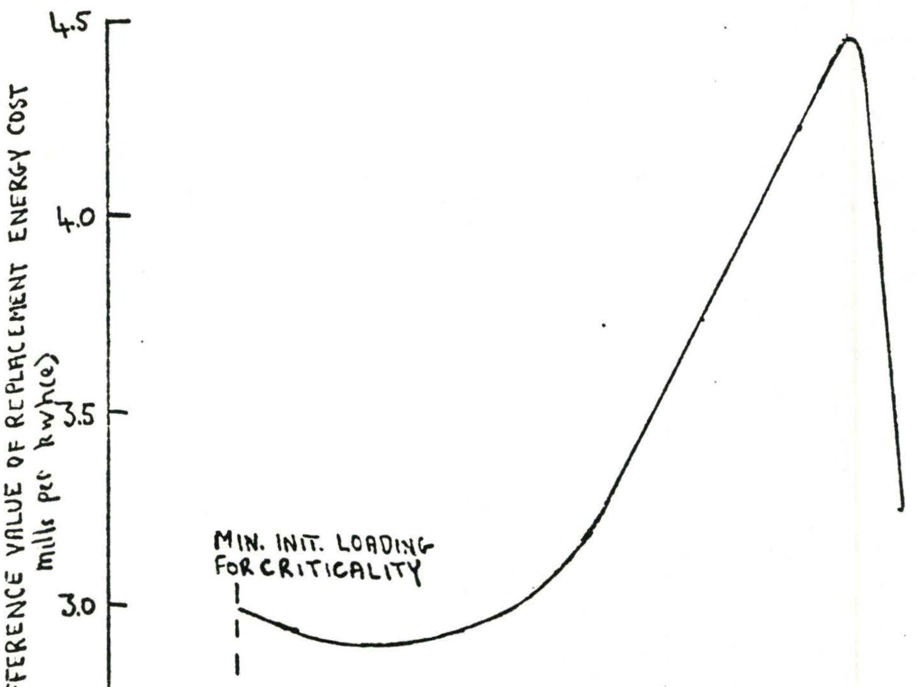


Fig. 2.7 INDIFFERENCE VALUE OF REPLACEMENT ENERGY COST VS INITIAL CORE LOADING

APPENDIX A*

THE STOKE MODEL USED IN STUDY

The Gentilly-2 reactor is represented in STOKE as a right circular cylinder with a notch in the reflector at either end of the core. The reactor was divided radially into three core regions plus a reflector. The inner two regions are the flattened region of the core, which have a higher average burnup at equilibrium, and a depleted fuel load at startup.

The core has 12 bundles per channel. STOKE assigns one mesh point axially in the centre of each bundle. Physics parameters are obtained by averaging symmetrically opposite bundles to simulate bidirectional fuelling. The flux is calculated assuming symmetry about the transverse midplane, and is unfolded for the subsequent calculation of power and irradiation. Each region of the core is divided into rings, each ring representing several channels. The outer radius and the number of channels represented by each ring are shown in Table A.1. The radii are selected to produce a constant area per channel for each ring. Channels are grouped into rings so that channels at approximately the same radius are in the same ring.

The equilibrium channel powers in each ring were obtained from STOKE by varying irradiation in the inner and outer regions until the desired form factor and excess reactivity were obtained.

The adjuster rods were modelled as discs of absorber between planes 6 and 7, and at planes 5 and 8. A heavily loaded region extended from rings 1 to 8, the more lightly absorbing region from ring 9 to 14. The amount of absorption was adjusted to give the required amount of xenon override.

* This appendix has been reproduced from an earlier design study on Gentilly-2 (1)

APPENDIX B

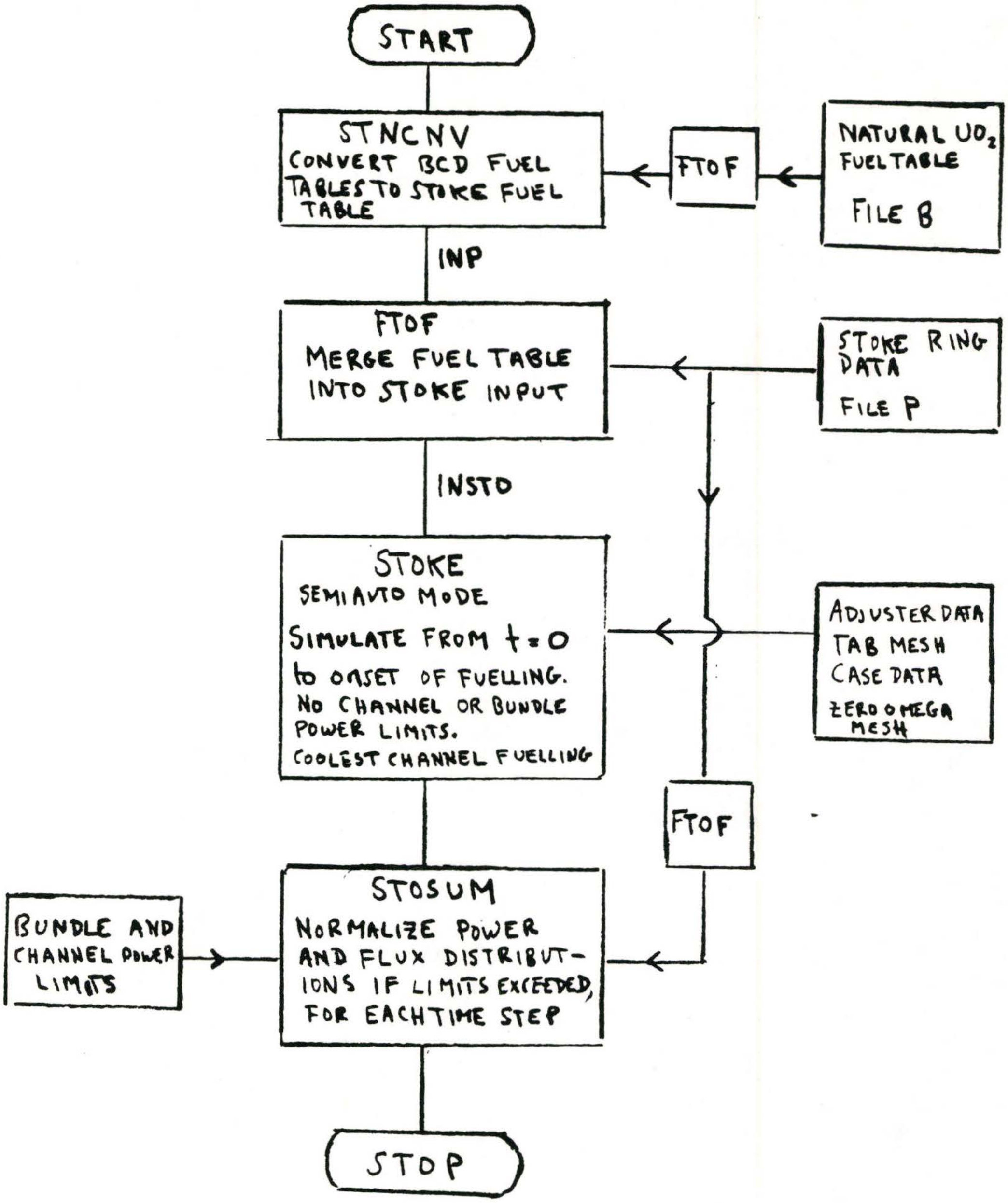


Fig.B.1 Simulation from start-up to onset of fuelling for normal operation

APPENDIX C: Development of program to calculate fuel costs

Value of fuel bundle at zero burnup = \$1500

Value of fuel at average discharge burnup (ADB after 300 days) = \$0

Assume \$ value decreases linearly with burnup

Average core bundle burnup at time T = (Cummulative energy Produced − Cummulative discharge burnup) / No. of bundles in core
ACBB(T) MWDT/bundle

$$= \frac{CEP(T) - CDB(T)}{NBC(T)}$$

Average value of core bundles at time T ($)

$$= \frac{ADB - ACBB(T)}{ADB} \times 1500$$

Value of core at time T, ($)

$$VOC(T) = \left[\frac{ADB - \frac{CEP(T) - CDB(T)}{NBC(T)}}{ADB} \right] 1500 \times NCB(T)$$

Interest for each step ICF $= \frac{10}{1200} \times VOC(T)$

Eq. 1.3.1 $\quad TFC = CCCF + ICF(T) - VOC(T_{end})$

where $VOC(T_{end}) = ICF(T_{end}) - ICF(T_{end}-1) \quad \times \frac{1200}{10}$

FUEL COSTS

C. CALCULATION OF TOTAL FUEL COSTS FOR 300 DAYS

```
INTEGER T
REAL ICF
DIMENSION CEP(10), NBC(10), CDB(10)
READ*, CEP, NBC, CDB, ADB, CCCF
ICF = 0.0
DO 30 T=1,10
IF(T.EQ.10)X=ICF
```

```
      ICF = ICF + (10.0/12.0)*1500.0*NBC(T)*(ADB-(CEP(T)-CDB(T))
     1 /NBC(T)/ADB/100.0
      PRINT*, T, ICF
   30 CØNTINUE
      VØC = (ICF-X)*1200.0/10.0
      TFC = ICF + CCCF - VØC
      PRINT*, TFC, VØC
      END
```

Each time interval is 30 days

Assume $1500 per bundle

$1150 per depleted bundle (see Appendix D)

A cost breakdown for each case is given in Table C.1 and a sample input to FUEL COSTS is given in Appendix E.

TABLE C.1 COSTS OVER 300 DAYS

ASSUME \$1500 per bundle
\$1125 per depleted bundle

$\frac{10}{12}$ % interest per 30 days on fuel in core. 30% thermal efficiency

CASE	FUEL CAPITAL COSTS CCCF – VOC \$	FUEL INTEREST COSTS ΣICF \$	FUEL COMPONENT OF ENERGY COST mills per kwh(e)
REFERENCE	9,390,000	~301,000	2.18
CGO 1-14	6,420,000	257,000	1.95
CGO 1-17	6,850,000	271,000	2.00
CGO 1-20	7,430,000	288,000	2.03
CGO 1-24	8,000,000	298,000	2.02
CGO 1-28	9,260,000	301,000	2.17

APPENDIX D Calculation of depleted bundle cost (0.52% U235)

Component	Calculation	1.5%	Cost: $/kg U	(1972 CAN $) 0.52%
Enriched UF_6	U_3O_8 cost is $15.75/kg U. From USAEC data (Appendix I), feed component is 2.544. Subsequent loss allowances are 0.5, 0.5 and 0.2%. (↑ SEE TABLE D.2) 1.5 Cost is (15.75)(2.544)(1.005)(1.005)(1.002) 0.52 " " $(15.75)(0.628)(1.005)^2(1.002)$	= 40.55		9.98
	Convert U_3O_8 to UF_6 costs $2.61/kg U(4). Increment by feed component and subsequent losses of 0.5 and 0.2%	= 6.69		1.65
	Toll enrichment. Cost is $32.00 (1972 US) per SWU; 1.227 SWU for 1.5%, subsequent losses of 0.5 and 0.2%	= 39.54[a]		−5.22
	Withdrawal, insurance, ship to PP (approximate)	= 0.89	87.67	0.6 7.0
PP (convert UF_6 to UO_2)	Building charge is 21% of $1,930,000 (V) Equipment charge is 27% of $4,500,000 (V) Operating plus working capital charge is 103% of $1,235,000 (V) Adding overhead and dividing by production of 2.5 $(10)^5$ kg U		13.75	—*
Zircaloy-4 Material Supply	No change from table 10		12.92	12.92
PEA	Building charge is 21% of $950,000 (V) Equipment charge is 27% of $2,020,000 (V) Operating plus working capital charge is 106% of $2,280,000 (90% F, 10% V) Apply overhead and total production		15.06	15.06
Interest	7% on $40.55 for 6 weeks, $47.24 for 13 weeks, $87.67 for 10 weeks and $101.45 for 12 weeks		3.98	~0.3
Shipping	Based on Canadian experience for distances up to 500 km		0.17	~0.1
Total			133.55	35.4

Table D.1 1.5% (example reproduced from Ref. 3) and 0.52% UO_2 fuel costs.

Nat UO_2 fuel cost = 45.71 $ per kg (1972 Canadian $)
Fractional capital cost of a 0.52% depleted bundle

*Note that no cost was charged for converting the 0.52% UF_6 to UO_2. Equal weights of lean and enriched UF_6 are produced from the diffusion plant and most of the depleted uranium goes to waste. However it must still be converted to the chemically safe oxide before dumping.

TABLE D.2* STANDARD TABLE OF ENRICHING SERVICES[a]

Product Enrichment wt% U^{235}	Feed Component Factor, C_F kg U natural / kg U product	Separative Work Units SWU/kg U product
0.20	0	0
0.25	0.098	-0.100
0.30	0.196	-0.158
0.35	0.294	-0.189
0.38	0.352	-0.197
0.40	0.391	-0.198
0.42	0.431	-0.197
0.44	0.470	-0.194
0.46	0.509	-0.189
0.48	0.548	-0.182
0.50	0.587	-0.173
0.52	0.626	-0.163
0.54	0.665	-0.151
0.56	0.705	-0.137
0.58	0.744	-0.123
0.60	0.783	-0.107
0.65	0.881	-0.062
0.70	0.978	-0.012
0.711	1.000	0.000
0.75	1.076	0.044
0.80	1.174	0.104
0.85	1.272	0.168
0.90	1.370	0.236
0.95	1.468	0.307
1.00	1.566	0.380
1.10	1.761	0.535
1.20	1.957	0.698
1.30	2.153	0.868
1.40	2.348	1.045
1.50	2.544	1.227
1.60	2.740	1.413
1.70	2.935	1.603
1.80	3.131	1.797
1.90	3.327	1.994
2.00	3.523	2.194
2.20	3.914	2.602
2.40	4.305	3.018

* Reproduced from Ref. 3.

APPENDIX E SAMPLE CALCULATIONS

CASE CGO 1-14 (39% initial loading)

No. of fuel bundles initially loaded = 148 X 12 = 1776

No. of dummy " " " = 232 X 12 = 2784

The STOKE output shows only 8 dummy bundles per channel being replaced as the core is loaded over the initial period before normal fuelling although the OMEGA and PAB meshes show that the fuelling is carried out correctly (i.e.12 bundles per channel). STOKE shows only 5184 bundles (both types) discharged after 300 FPD for case CGO 1-14 when, in fact, (5184 + 4 X 232) bundles were discharged.

No. of UO_2 bundles discharged after 300 FPD = 5184 - (232 X 8)

= 3328

No. of UO_2 bundles discharged after 300 days (230.9 FPD)

= (3872 - 232 X 8)

= 20176

Excess reactivity after 230.7 FPD = 8.269 milli-k

" " " 230.9 FPD (300 days)

$$= 8.269 - \left(0.44 \frac{\text{milli-k decrease}}{\text{FPD}} \times 0.2 \text{ FPD}\right)$$

= 8.18 milli-k

The number of uranium bundles discharged was adjusted to allow for the different excess reactivity at 300 days obtained in each case. An average reactivity value of 0.0275 mk per bundle was used and the reference end reactivity was 5 mk.

Adjusted number of uranium bundles discharged after 300 days

$$= 2016 - \frac{8.18-5}{0.0275} = 1900$$

TABLE E.1 SAMPLE INPUT TO FUEL COSTS FOR CASE CG01-14

DAYS	FPD	CEP(T) MWDT	NBC(T)	CDB(T) MWDT
30	10.6	21950.0	1776	0.0
60	22	44100.0	1776	0.0
90	35	71400.0	1968	0.0
120	55	112500.0	2976	0.0
150	81	166400.0	3792	0.0
180	111	228600.0	4560	0.0
210	141	290400.0	4560	85,500.0
240	171	352200.0	4560	121,000.0
270	201	414100.0	4560	165,000.0
300	231	475900.0	4560	216,000.0

ADB = 109 MWDT per bundle

CCCF = (4560+1900)*1500.0 = 9,694,000.0

CALCULATION OF ENERGY INDIFFERENCE VALUE

$$EIV = \frac{af(x)|_a - xf(x)}{a-x}$$

$$a = \overbrace{300\ FPD\left[2061 \times 0.3\ \frac{MWD(e)}{FPD}\right] \times 24\ \frac{hrs}{DAY} \times 10^3\ \frac{KW}{MW}}^{K'} = 4.45 \times 10^9\ kwh$$

$$\therefore af(x)|_a = 4.45 \times 10^9 \times 2.18 = 9.705 \times 10^9\ mills$$

$$x = (300 - 69.1)K'\ kwh = 3.43\ Kwh$$

$$\therefore xf(x) = 3.43 \times 10^9 \times 1.95 = 6.681 \times 10^9\ mills$$

$$\therefore EIV = \frac{(9.705 - 6.681) \times 10^9}{1.026}$$

$$= \underline{2.95\ mills\ per\ kwh}$$