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THE SPACE DEPENDENT TREATMENT OF PEBBLE BED REACTOR FUEL MANAGEMENT USING THE BURNUP CODE FRIZLE

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ABSTRACT

An outline is given of the model used in the FRIZLE code complex in order to treat the two dimensional space dependent fuel management problem. The model is an extension of the zero dimensional burnup model, which allows the linking up of some existing codes. The code complex is capable of determining, for all envisaged pebble bed reactor fuel management schemes, the core power distribution based on the calculated average composition and temperature in specified core zones.

The code is used for assessing several practicable management schemes applicable to a pebble bed reactor. These show that the same achievable burnup is obtained as with the zero dimensional method, based on the assumption of infinite recirculation. However, because of the markedly different core power distributions produced by various schemes, it is more important to arrange the management to reduce the core size and capital cost, than to increase burnup.

Details are given of the code complex and data requirements.

CONTENTS

1. INTRODUCTION

Burnup predictions for a pebble bed reactor operating at equilibrium conditions have been made using the zero dimensional constant flux model (Bicevskis and Hesse 1966) which assumes that the neutron flux which the pebble sees during burnup is constant throughout its lifetime. This model is easy to calculate and fairly realistic, provided the core is large, (to reduce effects of reflectors) and the number of passes of randomly loaded fuel pebbles is large (to average out flux and temperature variations). However, any deliberate fuel management scheme will try to alter these conditions. For example, in an effort to reduce fuel handling costs, the number of pebble passes through the core may be reduced. This, however, will upset the condition of the average mixture of fuel being evenly distributed throughout the core, and make the variation of flux and temperature down and across the core more pronounced. Again, the average will not be representative of the actual conditions, in a scheme which gives a radial bias to the fuel loading in order to flatten the power distribution or to improve neutron economy.

Economic considerations will have the main influence in determining the best fuel management scheme. The main factors having a bearing on the power production costs are the achievable burnup and core power density. These two conflict with one another; increase in one brings about a reduction in the other, limiting the possible overall gains. In the Pebble Bed Reactor (P.B.R.), high core power density is limited by the maximum power obtainable from a fuel pebble without exceeding its permissible thermal stress. As the thermal stress is a function of power density, temperature, and irradiation dose, it is necessary to obtain the history of these factors in the pebble lifetime for assessing a feasible management scheme.

Although it is not possible to examine each pebble, the FRIZLE code has been written to calculate the equilibrium spatial flux, power, and temperature distributions in order to examine a number of representative pebbles undergoing most practicable P.B.R. fuel management schemes. In addition, by calculating the space dependent burnup, it is possible to check on the accuracy of predictions made by the zero dimensional burnup methods used for survey purposes.

2. MODEL CHOSEN FOR TREATING SPACE DEPENDENT P.B.R. BURNUP AND FUEL MANAGEMENT

The model for treating P.B.R. management was chosen because it is an extension of the constant flux zero dimensional model and also allows the use of two available large codes.

In the zero dimensional model the reaction rates per atom are based on the neutron flux spectrum produced by the average fuel mixture and temperature of a complete infinite core. The average fuel mixture is thus simply the time averaged composition of one fuel pebble. In the FRIZLE model the reaction rates per atom are based on the neutron flux spectrum of a small region of the core; the flux spectrum is dependent on the average fuel mixture and temperature within the region, as well as on the effects of surrounding regions. The average fuel mixture of a region is then made up of the average composition over the dwell time, within the region, of a number of different fuel pebbles.

The calculational procedure for the zero dimensional model is to find the average composition of a pebble for a set burnup time and flux level, in an assumed environment composition (and therefore neutron flux spectrum). By an iterative procedure the environment composition is changed to converge to the calculated average composition of a pebble. In FRIZLE a similar technique is used to find the average composition in each region. However, in this case the code calculates the flux level and dwell time in each region to satisfy the required core power and excess reactivity. It also estimates the temperature in each region to allow for temperature effects. Hence finally, on convergence, the calculated average composition and flux in each region is the same as was initially used to set the neutron spectrum for calculation of the pebble reaction rates.

The user splits up the core into many regions or zones, in each of which the energy dependent flux spectrum is determined by the average composition and average temperature of the zone. This spectrum, which is calculated from a multigroup cross section library incorporating a resonance treatment, is used to obtain a set of few group cross sections. These are used to link the zones together by means of a two dimensional (or one dimensional) multigroup flux calculation, to obtain the spatial multigroup fluxes in each zone. The isotopic reaction rates per atom for determining the burnup in each zone are then calculated from the space and energy dependent fluxes and energy dependent cross sections.

ay be preferable [illegible]

The achievable burnup and power distribution of several practical management schemes were [illegible]. In addition the calculated burnup served to check on the validity of the values of [illegible], obtained with the zero dimensional constant flux model.

Figure 3 details the core geometry and properties used in these calculations to simulate a 200 MWe pebble bed reactor design. A fuel mixture of 3 parts of plutonium to 20 parts of thorium (see definitions of Bicevskis 1966) was used as the standard reference fuel mixture. The four groups used in the CRAM calculation were based on those used in previous work (Hesse 1966). A 40 group, 23 nuclide, condensed GYMEA library, with 4 scattering matrix temperatures, was used to calculate the four group microscopic cross sections. This library was compared with the normal full GYMEA library, as used in the fuel survey (Bicevskis 1966) and was shown to give slightly optimistic values of F.I.F.A. (a library having a better fission product treatment, has been prepared from more recent work, see Appendix 3, though the present one is quite adequate for comparison). Two per cent. excess reactivity at equilibrium was allowed for control and other losses.

For the temperature calculations, it was assumed that the core had upflow cooling with an inlet temperature of 320 °C, and that the average rise in gas temperature across the core was 49 °C per watt/cm^3 of average core power. The pebble to gas temperature difference was 8 °C per watt/cm^3 of average core power. These values were based on detailed design calculations.

4.1 Seven Pass Recirculation Scheme with Random Radial Loading

A practicable scheme of seven recirculations of a standard fuel, was calculated in order to compare the achievable value of F.I.F.A. with that produced by the zero dimensional model which, in effect, assumes an infinite recirculation rate. The active core was divided into six equal axial zones to allow for variation in temperature and fuel composition with its associated variation of flux spectrum down the core (see Figure 3). It also allowed for any effects created by realistic axial and radial reflectors. For this scheme, it was assumed that the mixing during the seven passes would even out the fuel composition radially.

4.2 One Pass Scheme

There is a justification for installing fuel recirculation equipment if it can be demonstrated that a significant improvement in burnup or power density can be obtained, beyond that of a one pass fuel management scheme. A management scheme having only one pass was compared with the above reference case by treating a core subdivided into two radial and six axial zones (see Figure 3). Splitting the core radially allowed for the effect of slower burning of the fuel away from the centre. Two radial regions, although not adequate, served to give preliminary results for comparison with other schemes.

4.3 Controlled Seven Pass Recirculation Scheme

As a compromise between the previous schemes, one was considered where the first pass of the fuel pebble would be down the centre region of the core and the six subsequent passes would be down the outer region. This would be practicable for the P.B.R. reference design, which has one central and six equally spaced radial inlet and discharge ports. The six subsequent passes of fuel pebbles down the outer zones would be arranged to achieve angular flux symmetry. The scheme has the advantage that since all fuel from the outlet of the centre zone would be returned to the top, no detection equipment would be necessary. Also it would allow the full utilization of the creep properties of the pebble in the hottest part of the core while it was producing its maximum power. Creep would reduce the thermal stress produced in the pebble. In the first instance, a fuel composition of "extra plutonium" than the reference mixture (that is, 5 parts of plutonium to 20 of thorium) was tried, but was found to give an unacceptable power peak. A fuel composition of "extra thorium" than the reference mixture (that is, 3 parts of plutonium to 30 parts of thorium) was found to give a more acceptable power distribution.

5. RESULTS

The results produced by the FRIZLE code for these preliminary cases are now discussed in two parts: effect on achievable burnup and effect on power distribution.

5.1 Effect of Fuel Management on Burnup

To study the effect of management on burnup, the achievable value for F.I.F.A., calculated by the zero dimensional burnup method using the same cross section library, was compared with those obtained by the FRIZLE code. For the cases considered (see Table 1), the same value was achieved regardless of the type of fuel management, or type of calculation. The case of "extra plutonium" was not completed because of the excess power being produced in the middle top zone (zone temperature > 1500 °C) and the corresponding estimated value of F.I.F.A., even if correct, is not realistic.

TABLE 1

MAXIMUM POWER DENSITIES AND COMPARISON OF VALUE FOR F.I.F.A.

AS PREDICTED BY FRIZLE CODE AND ZERO DIMENSION METHOD

Fuel Type	Passes	Maximum Power, W/cm^3		F.I.F.A. Predicted	
		In Zone	In Pebble	FRIZLE Code	Zero Dimension Method
Reference	7	25	69	1.4)	1.41
Reference	1	26	32	1.4)	
Extra Plutonium	1 + 6	50	50	1.6 *	1.45
Extra Thorium	1 + 6	19	29	1.0	1.05

* Case not converged owing to its non–feasible, high temperatures.

The results demonstrate that the zero dimensional calculations give just as accurate predictions of obtainable F.I.F.A. as the two dimensional calculations. This also applies in fuel burnup conditions quite different to those assumed in the zero dimensional model.

As shown in other work (Hesse 1966) the reference 200 MWe core has only 5 per cent. leakage through the reflectors and therefore little gain in reactivity can be achieved by any management scheme attempting to increase burnup. In attempting to gain this reactivity the power form factor will become much worse than the cosine is already (by conventional reactor standards). As shown in the next section, if one is to achieve any acceptable temperatures and power distributions by flattening, there must be an increase in leakage (more neutrons near the reflector), which will reduce F.I.F.A.

5.2 Effect of Fuel Management on Power Density

Although fuel management appears not to improve the achievable burnup, it can have a significant effect on the power distribution and feasibility of operation, as Figures 4 to 11 show. In each figure the thin, stepped lines are produced by the code because of the use of discrete zones and stepwise movement of the fuel. The thick lines are drawn to approximate the true condition.

Figure 4 compares the axial power distribution at the centre of the core, obtained by the FRIZLE code for the reference seven–pass recirculation scheme, with that of an infinite recirculation. This shows that the seven–pass case is very close to that of the infinite case, with only a slight movement of the maximum point towards the newer fuel in the upper part of the core.

A time history of the power density, approximate temperature, total power, and irradiation dose is given in Figure 5, for the representative pebble travelling at the average pebble speed in the average flux of each zone. The temperatures, as previously stated, are those of the zones. The power density for this scheme shows the effect of the plutonium being quickly depleted on the first pass, leaving virtually only U233. In this case, the maximum pebble power density is approximately 69 W/cm^3.

Figure 6 and 7 show the radial and axial power distribution for the one pass scheme. Despite the poor axial distribution, the improvement in the radial distribution leads to a low maximum pebble power density (see Table 1 above), which results from the outer fuel initially burning more slowly than the centre fuel. Further down the core the outer zone has more fissile material than the centre and is thus able to keep the flux level and power high. This effect of reducing the power demands from the centre region is shown clearly in Figure 8 where the outer pebble total power is nearly equal to that at the centre. Although the axial distribution is very peaked, it may be turned to advantage in that a steel supporting grid can be used with little loss in neutron economy.

Although to examine the scheme in detail, additional radial zones should be used, the results indicate that an approximate improvement of 2 can be expected on the maximum pebble power over that of the seven-pass scheme. Provided that the limit of maximum pebble power is the only limitation and the reference case of seven passes is acceptable, then the core could be reduced in volume by this factor. Although the reduction in core volume would slightly reduce the achievable burnup, the reduction of fissile investment and core capital cost would easily outweigh this loss.

Figures 9 and 10 show the radial and axial power distribution for the controlled seven-pass recirculation scheme using "extra thorium". As pointed out above, in order to obtain acceptable temperature at the top of the centre zone, additional thorium had to be added to the fuel pebble to improve its fuel breeding for subsequent passes. This had the effect of improving the radial form factor and reducing the maximum pebble power, which then occurred on the second pass where the benefit of creep could not be used, owing to the lower gas temperatures (see Figure 11). Thus, if not striving to utilize the creep properties to allow an increase in the pebble output power, it is possible with this scheme, and by a careful choice of fuel, to reduce the maximum pebble power. However, the one pass scheme gave approximately the same results as this scheme.

6. CONCLUSIONS

(a) The zero dimensional, constant flux model, as used for burnup survey work, gives similar results to the spatially dependent model used in the code FRIZLE and thus is completely adequate for predicting the burnup of the reference design of pebble bed reactor.

(b) Little gain in fissions per initial fissile atom can be expected from any feasible management scheme.

(c) However it appears that large gains in form factor and pebble maximum power can be achieved by either skilful choice of fuel composition and selected radial loading or adopting a one pass fuel management scheme.

(d) These improvements in core power density would allow large reductions in core volume (possibly by a factor of 2), leading to reduced fissile investment, core capital cost, and pebble handling cost, with only a slight reduction in fissions per initial fissile atom.

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APPENDIX 1

DETAILS OF EACH CODE WITHIN THE FRIZLE COMPLEX

1. General

The three codes are all separate and have been written to read card input and to produce card output data. When coupled together in the complex, the card image data is written onto a scratch tape for the next stage to read in. The code complex was written for an IBM 7040 computer with 7 tape units.

2. GYMEA

For details of this code, reference should be made to the GYMEA report (Pollard and Robinson 1966). The function of the GYMEA code in the complex is to calculate the multigroup flux spectrum for the average zone nuclide concentration and temperature, to produce few group ($\leqslant 6$) microscopic and macroscopic cross sections. As the GYMEA input control data are read in at execution time, it is entirely the user's prerogative to decide how the spectrum calculation or condensation is to be carried out. Thus, the user may change the group structure, libraries, add self-shielding factors (to simulate fuel rods), etc. The only necessary conditions are:

(1) The nuclides used in the GYMEA calculation may not exceed twenty-five.

(2) The GYMEA job must be capable of:

  (a) Reading a temperature card for each burnup zone, followed by one title card, then cards containing the nuclide concentrations. (It is not necessary for the code to use the first two cards, as would be the case for a temperature independent library. This is required because of the manner in which output from the FRIZLE code is produced).

  (b) Calling exit on reading a temperature card equal to zero, which signals the end of data.

  (c) Producing zone microscopic cross sections on tape unit 4 (X(50) = -1, and MATS (1,25) see example) and macroscopic data in CRAMbb2 form.

(3) In addition to the above requirements a few control cards which are not supplied by the user are produced by the BOSS code, namely the JOB, HEAD, USE-,--,- ,DATA and CEASE cards. Details of loading data are given in Appendix 2.

3. CRAM

For details of this code reference should be made to the CRAM report (Hassitt 1962).

The function of the CRAM code in the complex is to calculate the k_{eff} and the flux distribution in the core. A special "routine 5" has been written and added to this 7040 CRAM version, which will produce the power distribution in the core, in addition to calculating:

(1) Average group fluxes, reaction rates, and power of each active burnup zone.

(2) Effective core excess neutron production (CENP) for the specified excess reactivity (SEC). This is required for the FRIZLE code and is obtained from the following:

$$\text{CENP} = (\text{SEC}-(k_{eff}-1)) + \frac{\nu\bar{\Sigma}_f-\bar{\Sigma}_a}{\bar{\Sigma}_a} ,$$

where k_{eff} = CRAM k_{eff}

$$\bar{\Sigma} = \sum_{i=1}^{NEZ} (\phi\Sigma)_i{}^* \phi_i {}^*\text{Vol}_i$$

$(\phi\Sigma)_i$ = Average macroscopic reaction rate in zone i

Vol_i = Volume of zone i

NEZ = Number of active zones

This processed data are written on tape unit 4 as the third CRAM dump file.

Data are supplied in the normal manner to CRAM with the following modifications:

(1) Burnup zones must be numbered consecutively from one to NEZ (the number of burnup zones used in the FRIZLE burnup calculation) The zones must be numbered down the core and from the centre outwards

(2) Non-burnup zones such as reflectors must obviously have zone numbers greater than NEZ.

(3) As the BOSS code will only supply "isotopic" data (I1 etc.) for the burnup zones, which are macroscopic data, the user must supply the required M and Z data cards.

(4) For slug flow the axial heights of each zone should be the same. The zone volumes should be constructed with the desired fuel management scheme.

(5) In addition to the above requirements the title and the cards following the SP data are not supplied.

Details of loading this data are given in Appendix 2.

4. FRIZLE

The function of the FRIZLE code in the complex is to calculate the burnup of various fuel pebble streams for a residence time and a flux level which achieves the required core reactivity, and power output. From this it produces the average isotopic composition and temperature in each zone to be fed back into the GYMEA code for a further "outer" iteration.

The outline of the FRIZLE code may be obtained from Figure 2. As can be deduced from this figure, the major part of the code is concerned with the necessary interpreting, handling, storing, and updating of data, rather than with calculation of the burnup. The burnup is calculated by a modified version of a GYMEA burnup subroutine, which calculates "After" and "Average" fuel composition for a given burnup time, having been given the required "Before" composition, reaction rates, decay constants, and fission yields. The required zone reaction rates and fuel composition are supplied by the mainline in their correct order and the decay constants and fission yields are read in, initially, from a burnup table which is similar to that of the GYMEA library (see Appendix 2).

The code treats the management burnup problem as a series of separate burnup calculations, each representing the burnup in a reactor zone through which a pebble stream passes. These reactor zones have been previously specified in the CRAM input data. The number of burnup calculations for one inner iteration is limited to $\leqslant 50$ in the present version of the code. In the input schedule data, only the top zone of the CRAM calculation is given to specify a complete pass. The code will treat up to five separate streams of pebbles, each representing different numbers of similar pebbles. This makes it possible to treat a fuel management such as a stream consisting of four plutonium pebbles and a stream consisting of one thorium pebble entering a zone, by only two burnup calculations rather than five. A new pass introducing a new pebble stream is specified by a negative top zone number and the number (or weight) of pebbles in the stream is given with the fuel composition specification. To treat the case of delay of fuel outside the core before re-entering, the pebble is made to pass through a zone numbered zero.

The following are the methods employed by the code to produce zone, core, and convergence data:

(a) The average zone power $(POW)_i$ is obtained from:

$$(POW)_i = \frac{\sum\limits_{M=1}^{Passes}\ \sum\limits_{j=1}^{NN}\left(N_{jl}\,(\phi\sigma_f)_{ij}\,/\,3.121*10^{+10}\right)*WT_l}{\sum\limits_{M=1}^{Passes} WT_l},$$

where N_{jl} = Average isotopic composition j of pebble stream l during time in zone i.

WT_l = Number of pebbles this stream l represents.

Passes = Total number of passes of all streams through zone i.

$(\phi\sigma_f)_{ij}$ = Average zone reaction rate for isotope j in zone i calculated from the GYMEA group cross sections and CRAM fluxes.

(b) The core power (POWREA) is obtained from:

$$POWREA = \sum_{i=1}^{NEZ} (POW)_i * Vol\ i,$$

where Vol_i = Volume of zone i obtained from the CRAM calculation.

(c) The approximate average zone temperature $(TEMP)_i$ is obtained from

$$(TEMP)_i = TIN_i + (POW)_i\left(\frac{1}{2}\,\frac{\Delta TG}{NAX} + TM\right),$$

where TM = Average temperature difference between gas and material per average core power density.

ΔTG = Average core temperature rise per average core power density.

NAX = Number of axial zones.

TIN_i = Zone i inlet temperature

$= TIN_{i-1} + (POW)_{i-1} * \Delta TG/NAX.$

(d) The FRIZLE calculated excess neutron production (FENP) is obtained in a similar "flux squared" manner as in the ROUTINE 5 stage.

(e) The relationship found to be reliable for obtaining the correct flux level and dwell-time which satisfies the reactivity and power requirements is:

ϕ_3 = ϕ_2 x Power required/power calculated

t_3 = $t \times \phi_2/\phi_3$

and t = $$\frac{1}{\phi_3}\left[\phi_2 \times t_2 + \frac{(CENP - (FENP)_2) \times (\phi_2 \times t_2 - \phi_1 \times t_1)}{(FENP)_1 - (FENP)_2}\right],$$

where subscripts 1 = Previous iteration

2 = Current iteration

3 = Next iteration.

For the second iteration the equations used are:

$$\phi_3 = \left[\phi_2 \times (1 + AM)/2\right] \text{ or } = \left[\phi_2 \times 2/(1 + AM)\right]$$

and $t_3 = \left[t_2 \times AM \right]$ or $= \left[t_2/AM \right]$,

depending on the value of FENP.

AM = step length.

(f) The average core F.I.F.A. is obtained from the summation of all the pebble fissions divided by the total pebble fissile content.

(g) The fast flux dose experienced by a pebble is calculated simply by integrating the flux in group 1 of each zone through which the pebble travels, over time, and multiplying this by the fraction of flux above 1 MeV in this group. This factor is supplied as input data.

(h) The conversion rate is defined as the percentage absorptions in materials labelled as fertile in the input burnup table, to the total absorptions in all materials in the zone.

5. BOSS

The function of the BOSS code is to supervise the three codes. As well as attending to all the necessary preparation of card data and binary tapes for the separate stages it takes care of updating all output card and binary data.

The role of the BOSS code in the code complex is shown in Figure 1.

All the latest output information from any of the codes, together with the two GYMEA libraries and the BOSS common, is held on the BOSS dump tape for future restarts. Most of the input data sections may be altered at the beginning of a restart calculation which can take place at any stage of the complex.

The preparation and reading of card output data to and from the codes is achieved by switching the card reader and punch to tape units 2 and 3 at the required times by means of a MAP subroutine called SWITCH. Copying or skipping binary files such as the GYMEA cross section library, CRAM, and GYMEA dump information for updating the BOSS tape, is also achieved by MAP subroutines, COPY and SKIP, made available by the Computer Section of the A.A.E.C. The calling of the codes is achieved by the use of NXPROG, which is on the system library tape.

In addition, the BOSS code checks on the convergence of the complete cycle, as well as the number of allowable "outer" iterations. It also determines whether there is sufficient time available for another "outer" iteration.

APPENDIX 2

CODE DATA SPECIFICATION

1. General

Data are loaded in sections headed by one of the following cards; CONTROL, *GYM1*, *GYM2*, *CRM1*, *CRM3*, or *FRIZ* (columns one to six). Data following * cards may be loaded in any order and hold information read in by one of the three codes. The final card, DATEND, signals the end of data.

For a restart or continuation of a job any or none of the above data may be inserted after the card

RESTAR*-----*bYY

where YY = NFILE

NFILE = Number of files on the BOSS dump tape. This is given as output and equals (NSCAT + (NN+1) + 3 + NEZ), which is explained later.

---- = Any of the * names above. These indicate the point at which the code should restart.

2. CONTRL data

This section, consisting of four cards, contains the information used by the BOSS code. Some of the data on card number 4 (marked 1 to 4) are required by, or have bearing on, data in other sections.

CARD 1 FORMAT (11A6,3X,I3)

Title .... Time

Identical to the CRAM title card, with the maximum CRAM running time before the dump should occur. (If left blank the code will insert thirty minutes).

CARD 2 FORMAT (7I5)

Maximum number of iterations; Estimated running time of "outer" iteration minus time of CRAM calculations; Successive allowable time for CRAM calculations. (If left blank the code will insert title time for each iteration).

CARD 3 FORMAT (4E10.3)

Percentage convergence criteria for successive CRAM k_{eff}; FRIZLE FIFA; Zone 1 temperature; Zone 1 power.

CARD 4 FORMAT (8I5)

Number of burnup zones (NEZ)[1]; Number of zone compositions supplied for first GYMEA calculation (NEZST)[2]; Number of neutron groups ($NG \leqslant 6$)[3]; Number of burnup nuclides ($NN \leqslant 25$)[4]; Number of files in GYMEA scattering library (NSCAT): Whether flux supplied (YES = 1); Whether CRAM output in PRINT 2 or PRINT 3 form (if not equal to 2, assumed to be 3).

1 See *CRM3*

2 See *CYM2*

3 See *GYM2* (Number of condensed groups) and *CRM1* (GC card)

4 See *GYM1* and *GYM2* (Number of concentrations read in).

For a restart, card 4 is not required, if CONTRL data is loaded. If the card is left in, the code will ignore it.

3. GYMEA data

This is divided into two parts.

3.1 *GYM1* Section

This data is like a normal GYMEA job specification in GYMEA, Fortran-like cards, with some modifications (see Appendix 1).

3.2 *GYM2* Section

This is normal free format data for a GYMEA job, consisting of NEZST sets of zone data:

CARD 1 Temperature (°C) of zone

CARD 2 Title card of zone

CARD 3 NN nuclide concentrations of zone.

If the user has no knowledge of the distribution of the nuclide concentration of the reactor at equilibrium he may put NEZST equal to one, and supply only one set. This will mean that the CRAM calculation will have a basically cosine shape. The user may also use the 6*2=6 GYMEA convention for this data.

4. CRAM data

The CRAM data is divided into three parts. The middle part (*CRM2*) consists of the I data of the burnup zones, which is supplied by the BOSS code.

4.1 *CRM1* Section

This is the normal first part of CRAM data, up to but not including the I1 card and without the title card, which is inserted by the BOSS code with the appropriate dump time. The GC card must have the correct number of neutron groups.

4.2 *CRM3* Section

This is the normal CRAM data starting from the I data of the non-burnup zones, through to the SP data, with some modifications (see Appendix 1).

5. FRIZLE data

The FRIZLE data consists of 7 types of card data as follows:

CARD 1 FORMAT (3I5)-----Fuel management details.

Total number of pebble stream axial passes down the core (IPASS); Number of core axial burnup zones (NEZ); Reduced print out of microscopic cross sections (=1) of full print out (=0).

CARD 2 FREE FORMAT-----Route of fuel pebble streams.

Inlet top zone numbers are specified only for each successive pebble pass. If new fuel is to go in at a given pass, the zone number is put negative, otherwise the rejected fuel from the previous pass is inserted. (The code will assume that the first number should be negative). If the fuel is to be delayed, it is treated as passing through zone zero.

CARD 3 FORMAT (4F10)-----Core temperature and dose details.

Gas inlet temperature °C (put negative if downflow cooling is required); Gas temperature rise per average core power density ($^{\circ}C/W/cm^3$); Temperature difference between pebble and gas per average core power density ($^{\circ}C/W/cm^3$); Average fraction of neutrons above 1 MeV in the first neutron group of CRAM.

CARD 4 FORMAT (4F10.)-----Convergence and time data.

First time guess for average pebble core residence time (days): Step length as fraction of first guess; Percentage convergence criteria on excess leakage and specified power; Time of delay outside core (days).

CARD 5 (or cards of type 5) FORMAT (A5, 3(2X, I3), 5E10.)----- Nuclide burnup table and constants.

This table is similar but not identical to the GYMEA library table and consists of NN cards of:

Nuclide name; Type; Nuclide decays to; Nuclide capture to; Decay constant ($1/10^{24}$ SEC); Yields from fuel type 1,2,3,4.

The type of nuclide is given by a fixed point number having the following meaning.

1 to 4 = Fission material giving fission products with yields of type 1 to 4.

> 4 = Designated as a "fertile" material for use for obtaining percentage absorptions in these designated materials.

Negative = Fission product.

The "Decays to", and "Capture to", are in absolute position and only downwards, that is, 11 (Pu240) goes to 12 (Pu241) via capture in example given in the appendix.

CARDS 6 and 7

New fuel composition of pebble stream, one set for each negative number in card 2.

CARD 6 FORMAT (1F5., A5, 6 (5X,A5) I2)

Weight fraction; Nuclide names (as in burnup table)

Continuation (see note below).

CARD 7 FORMAT (7E10)

Nuclide concentration (atoms/barn cm) of pebble within stream.

Note – If composition of fuel read is continued onto the next cards, insert a positive number in column 72 on card 6 and follow by additional sets of cards 6 and 7. If the nuclide concentration is to represent more than one pebble, put weight fraction in columns 1 to 5 (F format) on card 6.

6. Computer Job Layout

	Comments
$IBSYS	
$JOB	
$EXECUTE AEIOCP	To make sure 1401 is available for 2 (via 1401) .
$*	Dummy card.
$PAUSE REPLACE MONITOR LIBRARY WITH FILE PROTECTED TAPE 146	BOSS monitor library tape.
$SWITCH S.SLB1, S.SLB1	To reposition library tape.
$PAUSE LOAD TAPE...ON 1 AND TAPE... ON 2(VIA 1401)	Must have a library or BOSS tape on unit 1.
$TIME	
$EXECUTE BOSS	
CONTRL (or RESTAR*....*b)	Must be either one to start, then any order under headings of CONTRL,*GYM1* *GYM3*, *CRM1* *CRM3*,*FRIZ* .
DATEND	Final card of data.
$IBSYS	
$* SAVE TAPE ON 2(VIA 1401)	If tape on 2 is to be saved.
$PAUSE RELOAD MONITOR LIBRARY ON 9)) $SWITCH S.SLB1, S.SLB1)	This may be left until later if there are more jobs to follow.
$IBSYS	

7. Tape Specification

(A) For a New Job

(a) On unit 1	A tape (file protected), which must have a GYMEA scattering library of NSCAT files, followed by a GYMEA cross section library of NN+1 files. The tape may have, in addition two more files holding a CRAM flux dump from a previous suitable job.
(b) On unit 2 (via 1401)	A scratch tape, or preferably a tape (with ring in), which can be saved from later restarts. Once the job starts this tape will hold all necessary information, including files copied from tape on unit 1.

(B) For Restart or Continuation Jobs

(a) On unit 1	A previous BOSS job tape from unit 2. This should have NFILE files of information, followed by a file holding the BOSS common information.
(b) On unit 2 (via 1401)	As with new job.

APPENDIX 3

SAMPLE INPUT AND OUTPUT DATA

The following example is for a more recent investigation of a two zone, one pass fuel management scheme. The inner zone has a fuel composition of 30 parts thorium to three parts plutonium, and the outer zone has a fuel composition of 20 parts thorium to 3.5 parts plutonium. The outer zone is split into two, to treat the slower burnup of the outer pebbles more correctly. This is simulated by having two similar pebbles. The core is split up into six axial regions. The pebbles are delayed for a hundred days after rejection to get an idea of the pebble makeup for reprocessing purposes. The bottom reflector has been replaced by a steel grid. The CRAM calculation is carried out now in five groups.

The system library containing the complex of codes is on tape 146 on unit 9.

The tape 147 on unit 1 contains the GYMEA reduced 30 groups libraries of 30SE and 30FE (Pollard and Robertson 1967). The scattering library contains only BeO at 4 temperatures and the cross section library contains only the first 24 nuclides which are used in the calculation.

The tape 5 on unit 2 (Via 1401) will contain these libraries plus the CRAM flux dump and 18 sets of GYMEA 5 group microscopic cross sections as well as the BOSS common data, which can be used for future restarts.

Input Card Data	pages 17 – 19
Output Printed Data	pages 20 – 29

```
$IBSYS
$JOB           2302 E.HESSE      'BOSS'
$EXECUTE       AEIOCP
$*
$PAUSE         PLEASE LOAD FILE PROTECTED TAPE 146 ON UNIT 9.  THANKS.
$SWITCH        S.SLB1,S.SLB1
$*             PLEASE LOAD TAPES ------
$*             FILE PROTECTED TAPE 147 ON UNIT 1,173 WITH RING IN ON
$*           2 (VIA 1401) AND SCRATCH TAPES ON UNITS 0,2,3 AND 4. PLEASE
$PAUSE         NOTE - THIS JOB NEEDS ALL UNITS.  THANK YOU.
$TIME          20
$EXECUTE       BOSS
CONTRL
 1 PASS, 2 FUELS (3X30 + 3.5X20), 3 RADL ZONES WITH ABSORBING GRID    30
    4   40   10   15   20
  10.       0.01       1.0        1.0
   18    1    5   24    5    0    0
*GYM1*
     'BEO'=1.BE9,1.016,0.''
     'CRAM'=0.'BEO'T-467016,0.(3,25),0.''
*  TO OBTAIN MICROSCOPIC DATA (1,25) AND CRAM OUTPUT (IN THIS ORDER)
     MATS (1,25) 'CRAM' ''
     OUTPUT 1 CRAM  2
*  FIX MICRO. OUTPUT TO GO ON TAPE
     X(50)= -1
*  DEPENDENT ON NO. OF GROUPS USED
     GROUPS   5,1,6,14,20,25,30
*  READ FRIZLE OUTPUT --TEMP.,TITLE,COMP.(DEPENDENT ON NO.NUCLIDES USED)
/   1 RZS 1,450
*    CHECK FOR EXIT
     IF(Z(450)) 3,3,2
/   2 RXS 0
*  DEPENDENT ON NO. OF NUCLIDES USED
     RX 51 74 1
     Z(467) = X(52)-X(51)
*    FIX TEMPERATURE TO KELVIN + 150 AND FIND NEAREST SCAT. LIB.
     Z(450) = Z(450)+423.
     J(0) = Z(450)/300.
*  CHECK IF OUT OF RANGE
     J(1) = J(0)-4
     IF(J(1)) 4,4,5
/   4 J(0) = J(0)*2
     GO TO 0
     CONTINUE
     SCAT 300. 'BEO' CRY   ''
     GO TO 6
     SCAT 600. 'BEO' CRY   ''
     GO TO 6
     SCAT 900. 'BEO' CRY   ''
     GO TO 6
/   5 SCAT 1200. 'BEO' CRY   ''
*    PUT IN RESONANCE TEMP.
/   6 X(40) = Z(450)-150
*  CHECK IF PREVIOUS FLUX IS ACCEPTABLE (SAME SCAT. LIB.)
     J(1) = J(2)-J(0)
     J(2) = J(0)
/   7 T = 0.,20,0
*    WRITE OUT ZONE TITLE
/   9 WXS 0
```

```
* SKIP FILE ON TAPE
      X(49)=X(49)+1.
      GO TO 1
/   3 CALL EXIT
      END
      SUBROUTINE SEND
      CALL EXIT
      END
*GYM2*
 900.
 GUESS COMPOSITION
  4.000E-02  4.100E-02  7.806E-07  2.414E-04  8.101E-07  5.121E-06
  5.697E-07  8.985E-08  4.076E-09  5.655E-06  2.845E-06  3.168E-06
  5.393E-07  4.585E-10  1.380E-07  2.106E-09  1.028E-09  7.289E-09
  1.333E-07  3.547E-08  6.853E-08  4.041E-08  3.071E-06  1.739E-05
*CRM1*
GC  5 0 1 1 1.0
ACCURACY      0.0005  0.0005 0.001  0.0001  0.05
RM 0(12)6(8)10(12)15U8)19(12)21(8)23(5)25(7.5)27(10)30
ZM 0(20)1(10)4(9)5(12)8(15)23(10)24(15)25
BC 0(1E9)25
*CRM3*
 I20
  3.74783E+00  4.44800E+00  4.44872E+00  4.45000E+00  4.45079E+00
  7.95559E-02  1.51405E-01  7.59325E-01  1.24911E+00  7.49070E-01
  0.           0.           0.           0.           0.
  0.           7.85539E-02  0.           0.           0.
  0.           0.           1.50405E-01  0.           0.
  0.           1.80597E-02  0.           7.28266E-01  1.19454E-02
  0.           0.           2.79120E-01  0.           9.68380E-01
  0.           0.           3.64723E-03  7.42465E-01  0.
  1.00203E-03  1.00001E-03  1.05457E-03  1.60873E-03  2.95763E-03
  0.           0.           0.           0.           0.
 I21
  2.64860E-03  5.94346E-02  2.51266E-01  4.30395E-01  7.86542E-01
  2.94608E-03  5.95067E-02  2.51030E-01  4.30752E-01  7.94117E-01
  0.           0.           0.           0.           0.
  0.           0.           0.           0.           0.
  0.           0.           0.           0.           0.
  0.           0.           0.           0.           0.
  0.           0.           0.           0.           0.
  0.           0.           0.           0.           0.
  2.94608E-03  5.95067E-02  2.51030E-01  4.30752E-01  7.94117E-01
  0.           0.           0.           0.           0.
M 1 I 1 1.0 M 2 I 2 1.0 M 3 I 3 1.0 M 4 I 4 1.0 M 5 I 5 1.0 M 6 I 6 1.0
M 7 I 7 1.0 M 8 I 8 1.0 M 9 I 9 1.0 M10 I10 1.0 M11 I11 1.0 M12 I12 1.0
M13 I13 1.0 M14 I14 1.0 M15 I15 1.0 M16 I16 1.0 M17 I17 1.0 M18 I18 1.0
M20 I20 0.06 I21 0.01 M21 I21 0.18 M22 I20 0.08
Z 1 M 1 1.0 Z 2 M 2 1.0 Z 3 M 3 1.0 Z 4 M 4 1.0 Z 5 M 5 1.0 Z 6 M 6 1.0
Z 7 M 7 1.0 Z 8 M 8 1.0 Z 9 M 9 1.0 Z10 M10 1.0 Z11 M11 1.0 Z12 M12 1.0
Z13 M13 1.0 Z14 M14 1.0 Z15 M15 1.0 Z16 M16 1.0 Z17 M17 1.0 Z18 M18 1.0
Z20 M20 1.0 Z21 M21 1.0 Z22 M22 1.0
C1 0 Z20 4 Z1 8 Z2 11 Z3 14 Z4 17 Z5 20 Z6 23 Z21 25 1E9 1E9
C2 0 Z20 4 Z7 8 Z8 11 Z9 14 Z10 17 Z11 20 Z12 23 Z21 25 1E9 1E9
C3 0 Z20 4 Z13 8 Z14 11 Z15 14 Z16 17 Z17 20 Z18 23 Z21 25 1E9 1E9
C4 0 Z22 25 1E9 1E9
CA 0 C1 8 C2 17 C3 24 C4 30
SP
  1.00000E+00  0.           0.           0.           0.
```

```
 0.0  500.
*FRIZ*
    6    6    1
  -1  0  -7  0  -13  0
   322.      48.       8.        .14
 1200.      .9       1.0       0.10      100.
BE   9     0    0    3 0.        0.        0.        0.        0.
O   16     0    0    0 0.        0.        0.        0.        0.
LI   6     0    0   -1 0.        0.        0.        0.        0.
TH232      9    0    5 0.        0.        0.        0.        0.
PA233      0    6    7 2.928E+17 0.        0.        0.        0.
U 233      1    0    7 0.        0.        0.        0.        0.
U 234      0    0    8 0.        0.        0.        0.        0.
U 235      2    0    9 0.        0.        0.        0.        0.
U 236      0    0   -1 0.        0.        0.        0.        0.
PU239      3    0   11 0.        0.        0.        0.        0.
PU240      9    0   12 0.        0.        0.        0.        0.
PU241      4   -1   13 1.690E+15 0.        0.        0.        0.
PU242      0    0   -1 0.        0.        0.        0.        0.
XE135     -1   -1   -1 2.093E+19 6.000E-02 6.410E-02 7.400E-02 6.500E-02
PM147     -1    0   17 0.        2.000E-02 2.150E-02 2.050E-02 2.200E-02
PM148     -1   -1   18 1.488E+18 1.0   E-02 1.0   E-02 1.0   E-02 1.0   E-02
'PM8M     -1   -1   18 1.976E+17 0.        0.        0.        0.
SM149     -1    0   19 0.        7.900E-03 1.020E-02 1.320E-02 1.200E-02
SM150     -1    0   20 0.        0.        0.        0.        0.
SM151     -1    0   21 0.        3.300E-03 4.000E-03 8.000E-03 5.000E-03
SM152     -1    0   22 0.        2.200E-03 2.600E-03 6.000E-03 3.000E-03
EU153     -1    0   -1 0.        1.100E-03 1.500E-03 3.400E-03 2.000E-03
'P1 '     -1   -1   -1 8.487E+12 2.221E-01 2.741E-01 3.708E-01 4.150E-01
'P2 '     -1   -1   -1 3.453E+15 2.055E+00 1.986E+00 1.874E+00 1.763E+00
  1. BE   9      O  16     TH232     PU239     PU240     PU241
  4.00E-02  4.10E-02  3.00E-04  2.34E-05  5.10E-06  1.50E-06
  1. BE   9      O  16     TH232     PU239     PU240     PU241
  4.00E-02  4.10E-02  2.00E-04  2.80E-05  6.12E-06  1.80E-06
  1. BE   9      O  16     TH232     PU239     PU240     PU241
  4.00E-02  4.10E-02  2.00E-04  2.80E-05  6.12E-06  1.80E-06
DATEND
$IBSYS
$IBSYS
$*             PLEASE UNLOAD AND SAVE THE TAPE ON UNIT 2 AND
$PAUSE         PLEASE REPLACE THE SYSTEM MONITOR LIBRARY ON 9
$PAUSE         IF READY PUSH START
$SWITCH        S.SLB1,S.SLB1
$IBSYS
```

```
                                        BOSS CONTROL DATA

                        1 PASS, 2 FUELS (3X30 + 3.5X20), 3 RADL ZONES WITH ABSORBING GRID

STARTING ITERATION NO.          ITERATIONS TO GO          ESTIMATED CYCLE TIME          ESTIMATED CRAM TIMES
        5                               4                          40                 20  25  30  30  30  30

                                            PERCENTAGE CONVERGENCE CRITERIA ON -
     CRAM KEFF                      FRIZLE FIFA                        ZONE TEMPERATURE                AND POWER
      10.00                            0.01                               1.00                           1.00

NO OF ---BURN UP ZONES    ZONE COMPOSITIONS SUPPLIED        GROUPS              NUCLIDES              SCAT. FILES
          18                          18                       5                   24                       5

                                            EQUILIBRIUM CONSTANT FLUX RUN
      FLUX GUESS AVAILABLE                                                         PRINT 3

                                                RESTART SEQUENCE

                                            DATA MODIFICATION CONCLUDED
                                                RESTART AT *GYM1*

                                            FOR RESTART USE NFILE EQUAL TO    51


BOSS      PART 1 COMPLETED.     TIME LEFT  96 MINS.
          STARTING AT SECTION    2
          DATA HANDLING STARTS
          GYMEA DATA PREPARED
          ENTERING GYMEA


                 GYMEA DATA LIST          * 04/11/66 *
                                            --------
ISN          SOURCE STATEMENT

 1     *GYMEA
 1           ,BOSS  1 PASS, 2 FUELS (3X30 + 3.5X20), 3 RADL ZONES WITH ABIT.  6
 2           HEAD   1 PASS, 2 FUELS (3X30 + 3.5X20), 3 RADL ZONES WITH ABSORBIN
 3           USE 1,24,2
 4           'BEO'=1.BE9,1.016,0.''
 5           'CRAM'=0.'BEO',-467016,0.(3,25),0.''
 6     *  TO OBTAIN MICROSCOPIC DATA (1,25) AND CRAM OUTPUT (IN THIS ORDER)
 6           MATS (1,25) 'CRAM' ''
 7           OUTPUT 1 CRAM  2
```

(ETC. AS PER INPUT DATA)

```
GYMEA JOB BOSS X-SEC LIB. 30FE ( 30, 24,     0.K) ON 1    * 04/11/66 *          OUTPUT NO.  1     RESONANCE TEMP= 1144.K
          ---- SCATT  ''  EHJF           ( 1200.K) '' 2    --------  [SN  32              ---
                                           UNIT SCE
T(DAYS)   _FLUX-T     POWER-T     FIFA       FLUX     POWER              /   7 T = 0.,20,0
    0.    0.          0.          0.       2.388E+02 0.          (AFTER )
                                                     0.          (AVERGE)
                                                     0.          (BEFORE)
                                                     0.          (SPEC. )
(AFT.N)      K           B2         B2AV    CRIT.R-EXTRAP.D(CM)    A/S
(EFF. )   1.0294      1.168E-04                                  1.0000134E+00      4   1   1    11
(INF. )   1.0294      1.168E-04 1.168E-04 2.880E+02 2.662E+00                    IT-FLUX,EIGEN.XS-OT

                  SCAT BY       4.000E-02 'BEO'  CRY

OUTPUT NO.  1  BOSS   1 PASS, 2 FUELS (3X30 + 3.5X20), 3 RADL Z       AFT.N*SIGMA*FLUX/SOURCE NEUTRON

 T(RANGE)=      0.      -DAYS-       0.
  NUCLIDE     AFT.N      AVE.N      BEF.N       BURN       CAP1       FISS        ABS      NU-FISS     TRANS      CAP2       DECAY
  C LEAK                                                                        2.520E-13
  1 BE9     4.000E-02 4.000E-02 0.                0     3.340E-02 0.         -4.538E-02 0.         4.260E+01 8.271E-02 0.
  2 O16     4.100E-02 4.100E-02 0.                0     0.         0.         8.171E-03 0.         3.134E+01 0.         0.          2
  3 LI6     2.689E-07 2.689E-07 0.                0     2.521E-03 0.         2.521E-03 0.         2.060E-03 0.         0.          3
  4 TH232   2.980E-04 2.980E-04 0.                0     2.321E-01 5.887E-04 2.326E-01 1.342E-03 8.603E-01 7.861E-05 0.          4
  5 PA233   5.959E-07 5.959E-07 0.                0     6.368E-03 9.847E-06 6.378E-03 2.378E-05 6.667E-03 0.         1.745E+11   5
  6 U233    1.252E-06 1.252E-06 0.                0     2.507E-03 1.471E-02 1.722E-02 3.681E-02 1.675E-02 0.         0.          6
  7 U234    5.747E-08 5.747E-08 0.                0     4.636E-04 2.614E-06 4.663E-04 5.887E-06 5.028E-04 0.         0.          7
  8 U235    2.161E-09 2.161E-09 0.                0     4.675E-06 1.152E-05 1.619E-05 2.812E-05 1.819E-05 0.         0.          8
  9 U236    1.614E-11 1.614E-11 0.                0     6.233E-08 2.667E-10 6.260E-08 6.442E-10 8.309E-08 0.         0.          9
 10 PU239   1.886E-05 1.886E-05 0.                0     1.840E-01 2.937E-01 4.777E-01 8.521E-01 4.061E-01 0.         0.         10
 11 PU240   5.059E-06 5.059E-06 0.                0     2.069E-01 4.212E-05 2.070E-01 1.235E-04 1.072E-01 0.         0.         11
 12 PU241   2.770E-06 2.770E-06 0.                0     1.714E-02 4.567E-02 6.280E-02 1.398E-01 5.552E-02 0.         4.681E+09  12
 13 PU242   1.268E-07 1.268E-07 0.                0     7.499E-04 0.         7.499E-04 0.         9.611E-04 0.         0.         13
 14 XE135   7.087E-10 7.087E-10 0.                0     9.765E-03 0.         9.765E-03 0.         1.017E-02 0.         1.483E+10  14
 15 PM147   5.743E-08 5.743E-08 0.                0     7.179E-04 0.         1.521E-03 0.         1.731E-03 7.994E-04 0.         15
 16 PM148   1.902E-09 1.902E-09 0.                0     5.988E-04 0.         5.988E-04 0.         8.599E-04 0.         2.830E+09  16
 17 'PM8M'  5.682E-10 5.682E-10 0.                0     5.104E-04 0.         5.104E-04 0.         4.341E-04 0.         1.123E+08  17
 18 SM149   1.187E-08 1.187E-08 0.                0     4.554E-03 0.         4.554E-03 0.         3.696E-03 0.         0.         18
 19 SM150   3.598E-08 3.598E-08 0.                0     3.818E-04 0.         3.818E-04 0.         6.112E-04 0.         0.         19
 20 SM151   2.041E-08 2.041E-08 0.                0     9.200E-04 0.         9.200E-04 0.         9.799E-04 0.         0.         20
 21 SM152   2.235E-08 2.235E-08 0.                0     5.914E-04 0.         5.914E-04 0.         6.452E-04 0.         0.         21
 22 EU153   0.        0.        0.                0     0.         0.         0.         0.         0.         0.         0.         22
 23 'P1'    1.159E-06 1.159E-06 0.                0     6.754E-03 0.         6.754E-03 0.         7.955E-03 0.         9.836E+06  23
 24 'P2'    5.860E-06 5.860E-06 0.                0     4.753E-03 0.         4.753E-03 0.         1.770E-02 0.         2.024E+10  24
==========
 ISOTOPIC COMPOSITION FOR ZONE     1 1 PASS, 2 FUELS (3X30 + 3.5X20), 3
```

(ETC. OUTPUT FOR ZONES 2 TO 18 AS ABOVE)

```
   BOSS      PART 2 COMPLETED.     TIME LEFT  76 MINS.
             COMMON RETREIVED
             DATA HANDLING STARTS
             GYMEA DATA RETREIVED
             CRAM DATA PREPARED
             ENTERING CRAM
```

```
PROBLEM     1

                        4 NOV 1966
 1 PASS, 2 FUELS (3X30 + 3.5X20), 3 RADL ZONES WITH ABSORBIN     6IT. 20
GC  5 0 1 1 1.0
ACCURACY      0.0005  0.0005 0.001  0.0001  0.05
RM 0(12)6(8)10(12)15(8)19(12)21(8)23(5)25(7.5)27(10)30
ZM 0(20)1(10)4(9)5(12)8(15)23(10)24(15)25
BC 0(1E9)25
  I  1
     2.90976E-01   3.80574E-01   3.94004E-01   4.01558E-01   4.08254E-01
     6.19481E-03   1.75894E-02   4.92915E-02   6.35890E-02   6.16990E-02
     3.12838E-04   2.89662E-03   3.68352E-02   4.52934E-02   3.97985E-02
     0.            5.68737E-03   0.            0.            0.
     0.            0.            9.98851E-03   8.19103E-07   1.23286E-09
     0.            5.11690E-03   0.            1.82060E-02   4.08050E-03
     0.            9.24004E-07   2.43590E-02   0.            1.20790E-02
     0.            2.11614E-07   1.34146E-02   2.25424E-02   0.
     8.59801E-04   6.56289E-03   9.11395E-03   1.14651E-02   1.17833E-02
     1.08303E-04   1.00311E-03   1.26849E-02   1.55261E-02   1.36733E-02
  I  2
     2.91101E-01   3.81431E-01   3.89725E-01   3.95929E-01   4.05451E-01
     6.19509E-03   1.79592E-02   4.54517E-02   5.78626E-02   5.88086E-02
     3.24535E-04   3.69616E-03   2.80217E-02   3.47323E-02   3.24046E-02
     0.            5.67692E-03   0.            0.            0.
     0.            0.            9.84260E-03   8.32016E-07   1.32037E-09
     0.            4.69271E-03   0.            1.93443E-02   4.56713E-03
     0.            9.24759E-07   2.43725E-02   0.            1.20888E-02
     0.            2.11306E-07   1.34033E-02   2.25395E-02   0.
     8.62610E-04   6.73993E-03   7.07955E-03   9.33939E-03   1.13522E-02
     1.15773E-04   1.32093E-03   9.67457E-03   1.18974E-02   1.12188E-02
  I  3
     2.91257E-01   3.81897E-01   3.84642E-01   3.89241E-01   4.00602E-01
     6.19086E-03   1.78624E-02   4.50824E-02   5.39512E-02   4.98139E-02
     3.14714E-04   3.93682E-03   1.87826E-02   2.30409E-02   2.44283E-02
     0.            5.67872E-03   0.            0.            0.
     0.            0.            9.89985E-03   1.96019E-07   0.
     0.            3.20494E-03   0.            2.57663E-02   4.64854E-03
     0.            1.31831E-08   2.02070E-02   0.            1.90541E-02
     0.            0.            5.76676E-03   2.60279E-02   0.
     8.55578E-04   6.44414E-03   4.82615E-03   6.54987E-03   9.07716E-03
     1.16213E-04   1.45071E-03   6.53811E-03   7.97118E-03   8.63737E-03
  I  4
     2.91382E-01   3.81694E-01   3.80509E-01   3.84627E-01   3.96647E-01
     6.18436E-03   1.79387E-02   4.35243E-02   4.92505E-02   4.58950E-02
     2.87780E-04   3.66683E-03   1.14859E-02   1.47737E-02   1.78708E-02
     0.            5.68932E-03   0.            0.            0.
     0.            0.            1.06492E-02   2.31737E-07   0.
     0.            2.83830E-03   0.            2.80537E-02   5.28986E-03
     0.            1.28809E-08   2.00744E-02   0.            1.90389E-02
     0.            0.            5.74862E-03   2.60094E-02   0.
     8.44534E-04   5.82529E-03   3.15030E-03   4.71749E-03   7.28955E-03
     1.09672E-04   1.39301E-03   4.09076E-03   5.24892E-03   6.53994E-03
  I  5
     2.91438E-01   3.81184E-01   3.78475E-01   3.82426E-01   3.95057E-01
     6.17979E-03   1.72973E-02   4.66224E-02   5.08854E-02   3.74382E-02
     2.69070E-04   3.38082E-03   7.86317E-03   1.06609E-02   1.50310E-02
     0.            5.69939E-03   0.            0.            0.
```

(ETC. AS PER NORMAL CRAM INPUT)

```
    1 PASS, 2 FUELS (3X30 + 3.5X20), 3 RADL ZONES WITH ABSORBIN      6IT. 20
X= 25205 TO 32767

     ROUTINE 5
      0.0  500.

   ZONE NO.   ABSOLUTE 5 GROUP FLUXES                VOLUMES(CC), POWER(W/CC) ,USIGMA F , SIGMA A

       1      1.503E+14 5.233E+13 1.354E+13 4.781E+12 2.051E+12 1.095E+06 1.098E+01 9.954E+11 9.529E+11
       2      2.318E+14 7.915E+13 2.308E+13 9.214E+12 3.736E+12 1.095E+06 1.622E+01 1.456E+12 1.434E+12
       3      2.281E+14 7.705E+13 2.525E+13 1.609E+13 8.466E+12 1.095E+06 1.617E+01 1.427E+12 1.409E+12
       4      1.644E+14 5.622E+13 2.377E+13 1.905E+13 1.066E+13 1.095E+06 1.164E+01 9.986E+11 1.010E+12
       5      7.975E+13 2.734E+13 9.940E+12 1.198E+13 1.082E+13 1.095E+06 1.160E+01 9.650E+11 9.949E+11
       6      2.057E+13 7.104E+12 2.723E+12 3.549E+12 3.306E+12 1.095E+06 1.546E+00 1.268E+11 1.294E+11
       7      1.706E+14 6.019E+13 1.420E+13 4.495E+12 1.891E+12 3.486E+06 1.295E+01 1.176E+12 1.059E+12
       8      2.564E+14 8.922E+13 2.385E+13 8.693E+12 3.461E+12 3.486E+06 1.843E+01 1.665E+12 1.552E+12
       9      2.401E+14 8.337E+13 2.580E+13 1.540E+13 8.006E+12 3.486E+06 1.716E+01 1.535E+12 1.448E+12
      10      1.603E+14 5.684E+13 2.344E+13 1.849E+13 1.044E+13 3.486E+06 1.113E+01 9.740E+11 9.532E+11
      11      8.086E+13 2.911E+13 1.072E+13 1.317E+13 1.204E+13 3.486E+06 5.552E+00 4.717E+11 4.832E+11
      12      2.382E+13 8.666E+12 3.401E+12 4.667E+12 4.470E+12 3.486E+06 1.656E+00 1.383E+11 1.431E+11
      13      1.220E+14 4.293E+13 1.058E+13 3.903E+12 2.057E+12 3.631E+06 1.031E+01 9.365E+11 8.089E+11
      14      1.802E+14 6.252E+13 1.524E+13 7.214E+12 4.108E+12 3.631E+06 1.435E+01 1.300E+12 1.167E+12
      15      1.661E+14 5.768E+13 1.656E+13 9.863E+12 5.738E+12 3.631E+06 1.304E+01 1.174E+12 1.078E+12
      16      1.146E+14 4.017E+13 1.394E+13 1.018E+13 6.122E+12 3.631E+06 8.897E+00 7.940E+11 7.450E+11
      17      6.178E+13 2.172E+13 6.852E+12 7.281E+12 6.608E+12 3.631E+06 4.807E+00 4.238E+11 4.034E+11
      18      1.949E+13 6.888E+12 2.313E+12 2.736E+12 2.591E+12 3.631E+06 1.551E+00 1.357E+11 1.284E+11

      FRIZLE DB=  6.748E-02 NORMAL DB=  6.645E-02


       POWER-WATTS/CC, TOTAL POWER IS  0.500E+03 M.W.

PRINT OF  30  COLUMNS BY   25  ROWS.   10  COLUMNS PER ROW.


COLUMNS   1  TO  10
  1.52474E-02  1.53572E-02  1.55727E-02  1.58898E-02  1.62980E-02  1.67741E-02  1.71927E-02  1.75169E-02  1.78083E-02  1.80465E-02
  3.97822E-02  4.00719E-02  4.06437E-02  4.14915E-02  4.25948E-02  4.39016E-02  4.50687E-02  4.59763E-02  4.67946E-02  4.74712E-02
  5.41077E-02  5.45037E-02  5.52879E-02  5.64560E-02  5.79873E-02  5.98192E-02  6.14673E-02  6.27390E-02  6.38665E-02  6.48194E-02
  6.01618E-02  6.06038E-02  6.14825E-02  6.27984E-02  6.45387E-02  6.66470E-02  6.85534E-02  6.99641E-02  7.10626E-02  7.21163E-02
  7.72440E+00  7.78126E+00  7.89496E+00  8.06670E+00  8.29742E+00  8.58483E+00  8.85020E+00  9.00313E+00  1.00517E+01  1.01704E+01
  8.61851E+00  8.68168E+00  8.80871E+00  9.00184E+00  9.26422E+00  9.59755E+00  9.91430E+00  1.01005E+01  1.12244E+01  1.13710E+01
  1.05959E+01  1.06725E+01  1.08271E+01  1.10630E+01  1.13847E+01  1.17959E+01  1.21908E+01  1.24278E+01  1.38216E+01  1.40091E+01
  1.25821E+01  1.26710E+01  1.28511E+01  1.31259E+01  1.35010E+01  1.39802E+01  1.44391E+01  1.47119E+01  1.63592E+01  1.65717E+01
  1.36163E+01  1.37093E+01  1.38981E+01  1.41863E+01  1.45790E+01  1.50793E+01  1.55591E+01  1.58672E+01  1.73269E+01  1.75604E+01
  1.50507E+01  1.51483E+01  1.53468E+01  1.56497E+01  1.60618E+01  1.65852E+01  1.70834E+01  1.73949E+01  1.89729E+01  1.92003E+01
  1.61671E+01  1.62650E+01  1.64648E+01  1.67692E+01  1.71822E+01  1.77051E+01  1.81993E+01  1.85002E+01  2.01671E+01  2.03761E+01
  1.52106E+01  1.52955E+01  1.54691E+01  1.57332E+01  1.60904E+01  1.65411E+01  1.69731E+01  1.72782E+01  1.81785E+01  1.83864E+01
  1.52769E+01  1.53542E+01  1.55128E+01  1.57537E+01  1.60783E+01  1.64862E+01  1.68748E+01  1.71442E+01  1.80264E+01  1.81990E+01
  1.49692E+01  1.50363E+01  1.51747E+01  1.53842E+01  1.56647E+01  1.60155E+01  1.63496E+01  1.65800E+01  1.74373E+01  1.75741E+01
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(ETC.)

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     BCSS      PART 3 COMPLETED.    TIME LEFT  52 MINS.
               COMMON RETREIVED
               DATA HANDLING STARTS
               CRAM DATA RETREIVED
               FRIZLE DATA PREPARED
               ENTERING FRIZLE
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                                        1 PASS, 2 FUELS (3X30 + 3.5X20), 3 RADL ZONES WITH ABSORBIN      6IT. 20

                                          INPUT DATA IS AS FOLLOWS

NUMBER OF CORE ZONES 18     NUMBER OF AXIAL ZONES  6     CRAM KEFF. WAS  0.99897

NUMBER OF NEUTRON GROUPS  5     NUMBER OF ISOTOPES 24      DESIRED LEAKAGE 6.748E-02 AND REACTOR POWER(MW)  5.000E+02

CONVERGENCE CRITERIA---ON LEAKAGE,   1.0000   ON POWER    0.1000      MAX. DAY STEP FRACTION  0.9000

GAS TEMPERATURE RISE PER W/CC  4.800E+01  GAS INLET TEMPERATURE  3.220E+02  TEMP. DIFF. GAS TO BALL PER W/CC  8.000E+00

FRACTION OF NEUTRONS ABOVE 1 MEV IN GROUP 1    0.140          FUEL DELAY OUTSIDE CORE 100.0 DAYS

                                    NUCLEAR BURN-UP TABLE

          NUCLIDE TYPE,DECAY,CAP,DECAY CONST.,YIELD 1, 2, 3, 4.

  1       BE  9     0    0     3 0.         0.         0.         0.         0.
  2       O  16     0    0     0 0.         0.         0.         0.         0.
  3       LI  6     0    0    -1 0.         0.         0.         0.         0.
  4       TH232     9    0     5 0.         0.         0.         0.         0.
  5       PA233     0    6     7 2.928E+17 0.         0.         0.         0.
  6       U 233     1    0     7 0.         0.         0.         0.         0.
  7       U 234     0    0     8 0.         0.         0.         0.         0.
  8       U 235     2    0     9 0.         0.         0.         0.         0.
  9       U 236     0    0    -1 0.         0.         0.         0.         0.
 10       PU239     3    0    11 0.         0.         0.         0.         0.
 11       PU240     9    0    12 0.         0.         0.         0.         0.
 12       PU241     4   -1    13 1.690E+15 0.         0.         0.         0.
 13       PU242     0    0    -1 0.         0.         0.         0.         0.
 14       XE135    -1   -1    -1 2.093E+19 6.000E-02 6.410E-02 7.400E-02 6.500E-02
 15       PM147    -1    0    17 0.         2.000E-02 2.150E-02 2.050E-02 2.200E-02
 16       PM148    -1   -1    18 1.488E+18 1.000E-02 1.000E-02 1.000E-02 1.000E-02
 17       'PM8M    -1   -1    18 1.976E+17 0.         0.         0.         0.
 18       SM149    -1    0    19 0.         7.900E-03 1.020E-02 1.320E-02 1.200E-02
 19       SM150    -1    0    20 0.         0.         0.         0.         0.
 20       SM151    -1    0    21 0.         3.300E-03 4.000E-03 8.000E-03 5.000E-03
 21       SM152    -1    0    22 0.         2.200E-03 2.600E-03 6.000E-03 3.000E-03
 22       EU153    -1    0    -1 0.         1.100E-03 1.500E-03 3.400E-03 2.000E-03
 23       'P1 '    -1   -1    -1 8.487E+12 2.221E-01 2.741E-01 3.708E-01 4.150E-01
 24       'P2 '    -1   -1    -1 3.453E+15 2.055E+00 1.986E+00 1.874E+00 1.763E+00

                                       NEW BALL  1 COMPOSITION IS

 BE  9     O  16     LI  6      TH232     PA233     U 233     U 234     U 235     U 236     PU239     PU240     PU241     PU242
4.000E-02 4.100E-02 0.         3.000E-04 0.         0.        0.        0.        0.        2.340E-05 5.100E-06 1.500E-06 0.

 XE135     PM147     PM148     'PM8M     SM149     SM150     SM151     SM152     EU153     'P1 '     'P2 '
0.        0.        0.        0.        0.        0.        0.        0.        0.        0.        0.

                                       NEW BALL  2 COMPOSITION IS

 BE  9     O  16     LI  6      TH232     PA233     U 233     U 234     U 235     U 236     PU239     PU240     PU241     PU242
4.000E-02 4.100E-02 0.         2.000E-04 0.         0.        0.        0.        0.        2.800E-05 6.120E-06 1.800E-06 0.
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   XE135     PM147     PM148     'PM8M     SM149     SM150     SM151     SM152     EU153     'P1 '     'P2 '
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                                          NEW BALL  3 COMPOSITION IS

   BE  9     O  16     LI  6     TH232     PA233     U 233     U 234     U 235     U 236     PU239     PU240     PU241     PU242
 4.000E-02 4.100E-02 0.        2.000E-04 0.        0.        0.        0.        0.        2.800E-05 6.120E-06 1.800E-06 0.

   XE135     PM147     PM148     'PM8M     SM149     SM150     SM151     SM152     EU153     'P1 '     'P2 '
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                                       ZONE CROSS SECTION DATA FROM 1 TO 18

GROUP CROSS-SECTIONS----GROUP 1 CAP,FIS,ABS,UFIS,GROUP 2 CAP,FIS,ETC.     REACTION RATES CAP,FIS,ABS,UFIS

                    REACTION RATES LOADED IN ZONE  1 FLUX  2.230E+14 VOLUME  1.095E+06

                    REACTION RATES LOADED IN ZONE  2 FLUX  3.470E+14 VOLUME  1.095E+06

                    REACTION RATES LOADED IN ZONE  3 FLUX  3.549E+14 VOLUME  1.095E+06

                                      (ETC.  UP TO ZONE 18)

                    ALL ZONES LOADED

                             ITERATION NO.   1

                             ZONE BURN-UP TIME   207.300 DAYS    TOTAL FUEL FIFA  1.21

                             APPROX. LEAKAGE  7.238E-02      CORE POWER(MW) 4.964E+02

                             ITERATION NO.   2

                             ZONE BURN-UP TIME   230.333 DAYS    TOTAL FUEL FIFA  1.32

                             APPROX. LEAKAGE  5.190E-02      CORE POWER(MW) 4.857E+02

                             ITERATION NO.   3

                             ZONE BURN-UP TIME   207.300 DAYS    TOTAL FUEL FIFA  1.21

                             APPROX. LEAKAGE  7.233E-02      CORE POWER(MW) 4.964E+02

                             ITERATION NO.   4

                             ZONE BURN-UP TIME   214.097 DAYS    TOTAL FUEL FIFA  1.24

                             APPROX. LEAKAGE  6.757E-02      CORE POWER(MW) 4.910E+02
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ITERATION NO.   5   FINAL PRINT

FUEL MANAGEMENT CYCLE. BALL IN AT ZONES ( NEW FUEL IF NEGATIVE )

 -1   0  -7   0 -13   0

FUEL DELAY OUTSIDE CORE 100.0 DAYS

ZONE BURN-UP TIME   210.391 DAYS.   TOTAL FUEL FIFA  1.24

APPROX. LEAKAGE  6.707E-02      CORE POWER(MW) 4.998E+02


AVERAGE REACTOR ZONE DATA


                      * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

                                                               TOP REFLECTOR

                      * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                      *                                  *                                  *                                  * REF *
                      *        CENTRE ZONE   1           *        MID   ZONE   7            *        OUTER ZONE 13             * REF *
                      *                                  *                                  *                                  * REF *
AVE,MIN,MAX POW W/CC  *   11.253     10.445    12.389    *   13.278     12.202    14.678    *   10.554      9.773    11.526    * REF *
                      *                                  *                                  *                                  * REF *
FLUX TEMP(C) CON.RAT. *  2.29E+14    868.66    43.027    *  2.58E+14    913.98    39.096    *  1.86E+14    796.81    37.031    * REF *
                      *                                  *                                  *                                  * REF *
AVERAGE COMP. (A/B)   *        FOR  1.00 BALLS           *        FOR  1.00 BALLS           *        FOR  1.00 BALLS           * REF *
LI  6 TH232 PA233     *  2.74E-07  2.98E-04  6.01E-07    *  3.08E-07  1.98E-04  4.92E-07    *  2.23E-07  1.99E-04  3.54E-07    * REF *
U 233 U 234 U 235     *  1.28E-06  5.92E-08  2.26E-09    *  1.04E-06  5.33E-08  2.33E-09    *  7.63E-07  2.84E-08  9.02E-10    * REF *
U 236 PU239 PU240     *  2.07E-11  1.88E-05  5.05E-06    *  2.16E-11  2.25E-05  5.99E-06    *  3.87E-12  2.36E-05  6.19E-06    * REF *
PU241 PU242 XE135     *  2.79E-06  1.30E-07  7.09E-10    *  3.37E-06  1.60E-07  8.62E-10    *  2.94E-06  1.14E-07  6.96E-10    * REF *
PM147 PM148 'PM8M     *  5.82E-08  1.90E-09  5.78E-10    *  6.75E-08  2.20E-09  7.60E-10    *  5.60E-08  1.84E-09  5.28E-10    * REF *
SM149 SM150 SM151     *  1.19E-08  3.67E-08  2.07E-08    *  1.51E-08  4.35E-08  2.47E-08    *  1.20E-08  3.29E-08  1.98E-08    * REF *
SM152 EU153 'P1 '     *  7.45E-09  0.        1.18E-06    *  2.46E-08  1.48E-08  1.39E-06    *  1.86E-08  1.12E-08  1.11E-06    * REF *
'P2 ' 000000000000    *  5.95E-06  0.        0.          *  7.04E-06  0.        0.          *  5.59E-06  0.        0.          * REF *
                      *                                  *                                  *                                  * REF *
                      * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                      *                                  *                                  *                                  * REF *
                      *        CENTRE ZONE   2           *        MID   ZONE   8            *        OUTER ZONE 14             * REF *
                      *                                  *                                  *                                  * REF *
AVE,MIN,MAX POW W/CC  *   16.537     14.487    19.319    *   18.822     16.036    22.397    *   14.684     12.946    16.833    * REF *
                      *                                  *                                  *                                  * REF *
FLUX TEMP(C) CON.RAT. *  3.56E+14    799.78    41.263    *  3.91E+14    829.93    37.085    *  2.76E+14    728.90    36.372    * REF *
                      *                                  *                                  *                                  * REF *
AVERAGE COMP. (A/B)   *        FOR  1.00 BALLS           *        FOR  1.00 BALLS           *        FOR  1.00 BALLS           * REF *
LI  6 TH232 PA233     *  8.69E-07  2.93E-04  1.03E-06    *  9.64E-07  1.94E-04  8.21E-07    *  7.09E-07  1.96E-04  5.92E-07    * REF *
U 233 U 234 U 235     *  4.72E-06  3.79E-07  3.67E-08    *  3.76E-06  3.30E-07  3.61E-08    *  2.87E-06  1.77E-07  1.41E-08    * REF *
U 236 PU239 PU240     *  8.27E-10  9.90E-06  4.14E-06    *  8.76E-10  1.20E-05  4.82E-06    *  2.59E-10  1.47E-05  5.70E-06    * REF *
PU241 PU242 XE135     *  4.71E-06  7.08E-07  7.34E-10    *  5.66E-06  8.55E-07  8.73E-10    *  4.85E-06  5.81E-07  6.88E-10    * REF *
PM147 PM148 'PM8M     *  1.57E-07  2.64E-09  1.57E-09    *  1.74E-07  2.92E-09  1.96E-09    *  1.54E-07  2.47E-09  1.50E-09    * REF *
SM149 SM150 SM151     *  1.32E-08  1.54E-07  5.30E-08    *  1.67E-08  1.82E-07  6.44E-08    *  1.25E-08  1.40E-07  4.97E-08    * REF *
SM152 EU153 'P1 '     *  8.14E-08  3.24E-08  3.75E-06    *  8.82E-08  6.17E-08  4.37E-06    *  7.35E-08  4.70E-08  3.54E-06    * REF *
'P2 ' 000000000000    *  1.99E-05  0.        0.          *  2.31E-05  0.        0.          *  1.82E-05  0.        0.          * REF *
                      *                                  *                                  *                                  * REF *
                      * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                      *                                  *                                  *                                  * REF *
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                       *      CENTRE ZONE   3        *       MID   ZONE   9        *       OUTER ZONE 15        * REF *
                       *                             *                             *                            * REF *
AVE,MIN,MAX POW W/CC   *   16.292    13.575   19.938 *   17.310    13.719   22.022 *   13.341    11.401   15.712 * REF *
                       *                             *                             *                            * REF *
FLUX TEMP(C) CON.RAT.* 3.64E+14    666.50    36.998 * 3.82E+14    673.31    32.676 * 2.63E+14    606.05    34.117 * REF *
                       *                             *                             *                            * REF *
AVERAGE COMP. (A/B)    *      FOR  1.00 BALLS        *      FOR  1.00 BALLS        *      FOR  1.00 BALLS       * REF *
LI  6 TH232 PA233      * 1.35E-06  2.87E-04 1.09E-06 * 1.47E-06  1.89E-04 8.29E-07 * 1.13E-06  1.93E-04 5.88E-07 * REF *
U 233 U 234 U 235      * 7.75E-06  9.47E-07 1.52E-07 * 6.01E-06  7.90E-07 1.42E-07 * 4.85E-06  4.34E-07 5.69E-08 * REF *
U 236 PU239 PU240      * 6.77E-09  3.53E-06 2.41E-06 * 6.72E-09  4.35E-06 2.79E-06 * 1.89E-09  7.43E-06 4.44E-06 * REF *
PU241 PU242 XE135      * 4.49E-06  1.71E-06 4.36E-10 * 5.36E-06  2.03E-06 4.86E-10 * 5.44E-06  1.37E-06 4.98E-10 * REF *
PM147 PM148 'PM8M      * 2.18E-07  2.63E-09 1.56E-09 * 2.31E-07  2.75E-09 1.81E-09 * 2.18E-07  2.29E-09 1.73E-09 * REF *
SM149 SM150 SM151      * 7.41E-09  2.84E-07 5.81E-08 * 8.73E-09  3.26E-07 7.10E-08 * 9.10E-09  2.54E-07 6.11E-08 * REF *
SM152 EU153 'P1 '      * 1.50E-07  9.91E-08 6.18E-06 * 1.68E-07  1.29E-07 7.04E-06 * 1.36E-07  9.52E-08 5.85E-06 * REF *
'P2 ' 000000000000     * 3.52E-05  0.       0.       * 3.96E-05  0.       0.       * 3.11E-05  0.       0.       * REF *
                       *                             *                             *                            * REF *
                       * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                       *                             *                             *                            * REF *
                       *      CENTRE ZONE   4        *       MID   ZONE  10        *       OUTER ZONE 16        * REF *
                       *                             *                             *                            * REF *
AVE,MIN,MAX POW W/CC   *   11.473     9.767   13.655 *   10.977     8.822   13.752 *    9.058     7.847   10.470 * REF *
                       *                             *                             *                            * REF *
FLUX TEMP(C) CON.RAT.* 2.81E+14    516.89    33.108 * 2.76E+14    509.50    28.547 * 1.90E+14    482.20    31.846 * REF *
                       *                             *                             *                            * REF *
AVERAGE COMP. (A/B)    *      FOR  1.00 BALLS        *      FOR  1.00 BALLS        *      FOR  1.00 BALLS       * REF *
LI  6 TH232 PA233      * 1.49E-06  2.81E-04 8.68E-07 * 1.58E-06  1.85E-04 6.21E-07 * 1.34E-06  1.90E-04 4.42E-07 * REF *
U 233 U 234 U 235      * 9.25E-06  1.50E-06 3.14E-07 * 7.00E-06  1.20E-06 2.75E-07 * 6.04E-06  6.77E-07 1.16E-07 * REF *
U 236 PU239 PU240      * 2.24E-08  9.53E-07 1.06E-06 * 2.08E-08  1.21E-06 1.26E-06 * 5.73E-09  3.47E-06 3.15E-06 * REF *
PU241 PU242 XE135      * 2.78E-06  2.54E-06 2.53E-10 * 3.33E-06  2.98E-06 2.51E-10 * 4.72E-06  2.14E-06 3.18E-10 * REF *
PM147 PM148 'PM8M      * 2.36E-07  1.97E-09 1.21E-09 * 2.40E-07  1.89E-09 1.27E-09 * 2.44E-07  1.65E-09 1.47E-09 * REF *
SM149 SM150 SM151      * 4.27E-09  3.64E-07 4.59E-08 * 4.46E-09  4.03E-07 5.30E-08 * 6.02E-09  3.30E-07 5.65E-08 * REF *
SM152 EU153 'P1 '      * 1.97E-07  1.56E-07 7.60E-06 * 2.21E-07  1.86E-07 8.47E-06 * 1.82E-07  1.39E-07 7.36E-06 * REF *
'P2 ' 000000000000     * 4.66E-05  0.       0.       * 5.06E-05  0.       0.       * 4.00E-05  0.       0.       * REF *
                       *                             *                             *                            * REF *
                       * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                       *                             *                             *                            * REF *
                       *      CENTRE ZONE   5        *       MID   ZONE  11        *       OUTER ZONE 17        * REF *
                       *                             *                             *                            * REF *
AVE,MIN,MAX POW W/CC   *    5.647     5.256    6.016 *    5.373     4.783    6.018 *    4.870     4.457    5.304 * REF *
                       *                             *                             *                            * REF *
FLUX TEMP(C) CON.RAT.* 1.43E+14    401.80    30.747 * 1.50E+14    399.27    25.910 * 1.07E+14    392.99    29.948 * REF *
                       *                             *                             *                            * REF *
AVERAGE COMP. (A/B)    *      FOR  1.00 BALLS        *      FOR  1.00 BALLS        *      FOR  1.00 BALLS       * REF *
LI  6 TH232 PA233      * 1.42E-06  2.78E-04 5.07E-07 * 1.46E-06  1.83E-04 3.71E-07 * 1.37E-06  1.88E-04 2.70E-07 * REF *
U 233 U 234 U 235      * 9.73E-06  1.84E-06 4.31E-07 * 7.16E-06  1.44E-06 3.65E-07 * 6.56E-06  8.35E-07 1.64E-07 * REF *
U 236 PU239 PU240      * 4.18E-08  3.11E-07 4.96E-07 * 3.80E-08  3.90E-07 5.98E-07 * 1.05E-08  1.86E-06 2.30E-06 * REF *
PU241 PU242 XE135      * 1.56E-06  2.86E-06 1.36E-10 * 1.84E-06  3.38E-06 1.21E-10 * 3.76E-06  2.64E-06 1.73E-10 * REF *
PM147 PM148 'PM8M      * 2.34E-07  1.08E-09 9.61E-10 * 2.31E-07  1.02E-09 9.41E-10 * 2.51E-07  9.56E-10 1.18E-09 * REF *
SM149 SM150 SM151      * 2.40E-09  3.95E-07 3.08E-08 * 2.25E-09  4.29E-07 3.22E-08 * 3.51E-09  3.67E-07 4.24E-08 * REF *
SM152 EU153 'P1 '      * 2.21E-07  1.85E-07 8.11E-06 * 2.46E-07  2.16E-07 8.88E-06 * 2.13E-07  1.66E-07 8.10E-06 * REF *
'P2 ' 000000000000     * 5.19E-05  0.       0.       * 5.51E-05  0.       0.       * 4.42E-05  0.       0.       * REF *
                       *                             *                             *                            * REF *
                       * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                       *                             *                             *                            * REF *
                       *      CENTRE ZONE   6        *       MID   ZONE  12        *       OUTER ZONE 18        * REF *
                       *                             *                             *                            * REF *
AVE,MIN,MAX POW W/CC   *    1.505     1.478    1.510 *    1.598     1.542    1.638 *    1.568     1.515    1.613 * REF *
                       *                             *                             *                            * REF *
FLUX TEMP(C) CON.RAT.* 3.82E+13    340.06    30.088 * 4.62E+13    341.18    25.172 * 3.49E+13    340.81    29.105 * REF *
                       *                             *                             *                            * REF *
AVERAGE COMP. (A/B)    *      FOR  1.00 BALLS        *      FOR  1.00 BALLS        *      FOR  1.00 BALLS       * REF *
LI  6 TH232 PA233      * 1.34E-06  2.76E-04 1.77E-07 * 1.34E-06  1.82E-04 1.43E-07 * 1.35E-06  1.87E-04 1.08E-07 * REF *
U 233 U 234 U 235      * 9.91E-06  1.96E-06 4.77E-07 * 7.17E-06  1.53E-06 4.00E-07 * 6.77E-06  9.07E-07 1.87E-07 * REF *
U 236 PU239 PU240      * 5.35E-08  1.88E-07 3.43E-07 * 4.92E-08  2.19E-07 4.02E-07 * 1.38E-08  1.34E-06 1.92E-06 * REF *
PU241 PU242 XE135      * 1.11E-06  2.93E-06 7.42E-11 * 1.25E-06  3.47E-06 6.87E-11 * 3.18E-06  2.85E-06 9.04E-11 * REF *
PM147 PM148 'PM8M      * 2.32E-07  3.30E-10 7.10E-10 * 2.24E-07  3.43E-10 6.97E-10 * 2.52E-07  3.39E-10 8.48E-10 * REF *
SM149 SM150 SM151      * 1.84E-09  4.03E-07 2.47E-08 * 1.63E-09  4.32E-07 2.43E-08 * 2.63E-09  3.80E-07 3.36E-08 * REF *
SM152 EU153 'P1 '      * 2.28E-07  1.96E-07 8.23E-06 * 2.51E-07  2.26E-07 8.92E-06 * 2.26E-07  1.79E-07 8.38E-06 * REF *
'P2 ' 00000000C000     * 5.23E-05  0.       0.       * 5.50E-05  0.       0.       * 4.46E-05  0.       0.       * REF *
                       *                             *                             *                            * REF *
                       * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

                                                       BOTTOM REFLECTOR

                       * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
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 ITERATION  5   BALL HISTORY

AVERAGE BALL COMPOSITION DURING BURN-UP IN ZONE  1          BALL  1

  BE  9     O  16      LI  6     TH232     PA233     U 233     U 234     U 235     U 236     PU239     PU240     PU241     PU242
4.000E-02 4.100E-02 2.742E-07 2.980E-04 6.009E-07 1.281E-06 5.925E-08 2.261E-09 2.069E-11 1.879E-05 5.055E-06 2.788E-06 1.297E-07

  XE135     PM147     PM148     'PM8M     SM149     SM150     SM151     SM152     EU153     'P1 '     'P2 '
7.088E-10 5.819E-08 1.904E-09 5.782E-10 1.191E-08 3.675E-08 2.067E-08 7.451E-09 0.        1.177E-06 5.954E-06

BALL COMPOSITION ON LEAVING ZONE  1

  BE  9     O  16      LI  6     TH232     PA233     U 233     U 234     U 235     U 236     PU239     PU240     PU241     PU242
4.000E-02 4.100E-02 5.332E-07 2.960E-04 7.267E-07 2.887E-06 1.488E-07 8.014E-09 8.504E-11 1.483E-05 4.799E-06 3.864E-06 2.984E-07

  XE135     PM147     PM148     'PM8M     SM149     SM150     SM151     SM152     EU153     'P1 '     'P2 '
6.460E-10 1.050E-07 1.826E-09 1.100E-09 1.378E-08 8.101E-08 3.673E-08 4.843E-08 0.        2.240E-06 1.144E-05

BALL POWER (W/CC)   ENTRY=  12.39   AVERAGE=  11.25   EXIT=  10.45   TOTAL POWER FOR  210.39 DAYS IS 2.367E-03 MWDAYS/CC

INTERGRATED FIFA 0.256  FISSION RELEASE 6.38E+18 AND DOSE 3.92E+20 NVT.   PERCENT ABSORBS IN 'FERTILE' MATERIAL   43.03

                                                     *----*----*

AVERAGE BALL COMPOSITION DURING BURN-UP IN ZONE  2          BALL  1

  BE  9     O  16      LI  6     TH232     PA233     U 233     U 234     U 235     U 236     PU239     PU240     PU241     PU242
4.000E-02 4.100E-02 8.694E-07 2.929E-04 1.029E-06 4.723E-06 3.789E-07 3.671E-08 8.272E-10 9.904E-06 4.138E-06 4.712E-06 7.079E-07

  XE135     PM147     PM148     'PM8M     SM149     SM150     SM151     SM152     EU153     'P1 '     'P2 '
7.342E-10 1.568E-07 2.639E-09 1.571E-09 1.324E-08 1.544E-07 5.300E-08 8.135E-08 3.242E-08 3.748E-06 1.989E-05

BALL COMPOSITION ON LEAVING ZONE  2

  BE  9     O  16      LI  6     TH232     PA233     U 233     U 234     U 235     U 236     PU239     PU240     PU241     PU242
4.000E-02 4.100E-02 1.175E-06 2.898E-04 1.084E-06 6.531E-06 6.381E-07 8.028E-08 2.280E-09 6.210E-06 3.304E-06 5.104E-06 1.137E-06

  XE135     PM147     PM148     'PM8M     SM149     SM150     SM151     SM152     EU153     'P1 '     'P2 '
6.252E-10 1.900E-07 2.339E-09 1.921E-09 1.244E-08 2.179E-07 6.446E-08 1.097E-07 6.421E-08 4.993E-06 2.732E-05

BALL POWER (W/CC)   ENTRY=  19.32   AVERAGE=  16.54   EXIT=  14.49   TOTAL POWER FOR  420.78 DAYS IS 5.847E-03 MWDAYS/CC

INTERGRATED FIFA 0.633  FISSION RELEASE 1.58E+19 AND DOSE 9.98E+20 NVT.   PERCENT ABSORBS IN 'FERTILE' MATERIAL   41.26

                                                     *----*----*
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(ETC. BALL 1 THROUGH ZONES 3 TO 6, BALL 2 THROUGH ZONES 7 TO 12 AND BALL 3 THROUGH ZONES 13 TO 17)

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BALL POWER (W/CC)   ENTRY=   5.30   AVERAGE=   4.87   EXIT=   4.46   TOTAL POWER FOR 1051.95 DAYS IS 1.105E-02 MWDAYS/CC

INTERGRATED FIFA 1.000  FISSION RELEASE 2.98E+19 AND DOSE 1.68E+21 NVT.   PERCENT ABSORBS IN 'FERTILE' MATERIAL   29.95

                                                  *----*----*


AVERAGE BALL COMPOSITION DURING BURN-UP IN ZONE 18           BALL  3

  BE  9      O  16      LI  6      TH232      PA233      U 233      U 234      U 235      U 236      PU239      PU240      PU241      PU242
4.000E-02 4.100E-02 1.348E-06 1.872E-04 1.078E-07 6.770E-06 9.067E-07 1.867E-07 1.376E-08 1.337E-06 1.922E-06 3.178E-06 2.851E-06

  XE135      PM147      PM148      'PM8M      SM149      SM150      SM151      SM152      EU153      'P1 '      'P2 '
9.035E-11 2.520E-07 3.390E-10 8.484E-10 2.630E-09 3.802E-07 3.364E-08 2.258E-07 1.788E-07 8.379E-06 4.461E-05

BALL COMPOSITION ON LEAVING ZONE 18

  BE  9      O  16      LI  6      TH232      PA233      U 233      U 234      U 235      U 236      PU239      PU240      PU241      PU242
4.000E-02 4.100E-02 1.337E-06 1.869E-04 7.873E-08 6.796E-06 9.233E-07 1.923E-07 1.469E-08 1.226E-06 1.834E-06 3.009E-06 2.901E-06

  XE135      PM147      PM148      'PM8M      SM149      SM150      SM151      SM152      EU153      'P1 '      'P2 '
8.700E-11 2.521E-07 3.092E-10 8.155E-10 2.429E-09 3.824E-07 3.184E-08 2.284E-07 1.817E-07 8.439E-06 4.400E-05

BALL POWER (W/CC)   ENTRY=   1.61   AVERAGE=   1.57   EXIT=   1.51   TOTAL POWER FOR 1262.34 DAYS IS 1.138E-02 MWDAYS/CC

INTERGRATED FIFA 1.029  FISSION RELEASE 3.07E+19 AND DOSE 1.73E+21 NVT.   PERCENT ABSORBS IN 'FERTILE' MATERIAL   29.10

                                                  *----*----*



BALL COMPOSITION AFTER DELAY OUTSIDE CORE FOR  100.000 DAYS     BALL  3

  BE  9      O  16      LI  6      TH232      PA233      U 233      U 234      U 235      U 236      PU239      PU240      PU241      PU242
4.000E-02 4.100E-02 1.337E-06 1.869E-04 6.273E-09 6.868E-06 9.233E-07 1.923E-07 1.469E-08 1.226E-06 1.834E-06 2.966E-06 2.901E-06

  XE135      PM147      PM148      'PM8M      SM149      SM150      SM151      SM152      EU153      'P1 '      'P2 '
0.        2.521E-07 8.068E-16 1.479E-10 2.429E-09 3.824E-07 3.184E-08 2.284E-07 1.817E-07 8.439E-06 4.271E-05

                                                  *----*----*


   BOSS      PART 4 COMPLETED.     TIME LEFT  46 MINS.
             COMMON RETREIVED
             DATA HANDLING STARTS
CASE CONVERGED
             ITERATION  6 COMPLETED
             TAPE UPDATED, FOR RESTART USE NFILE= 51
```

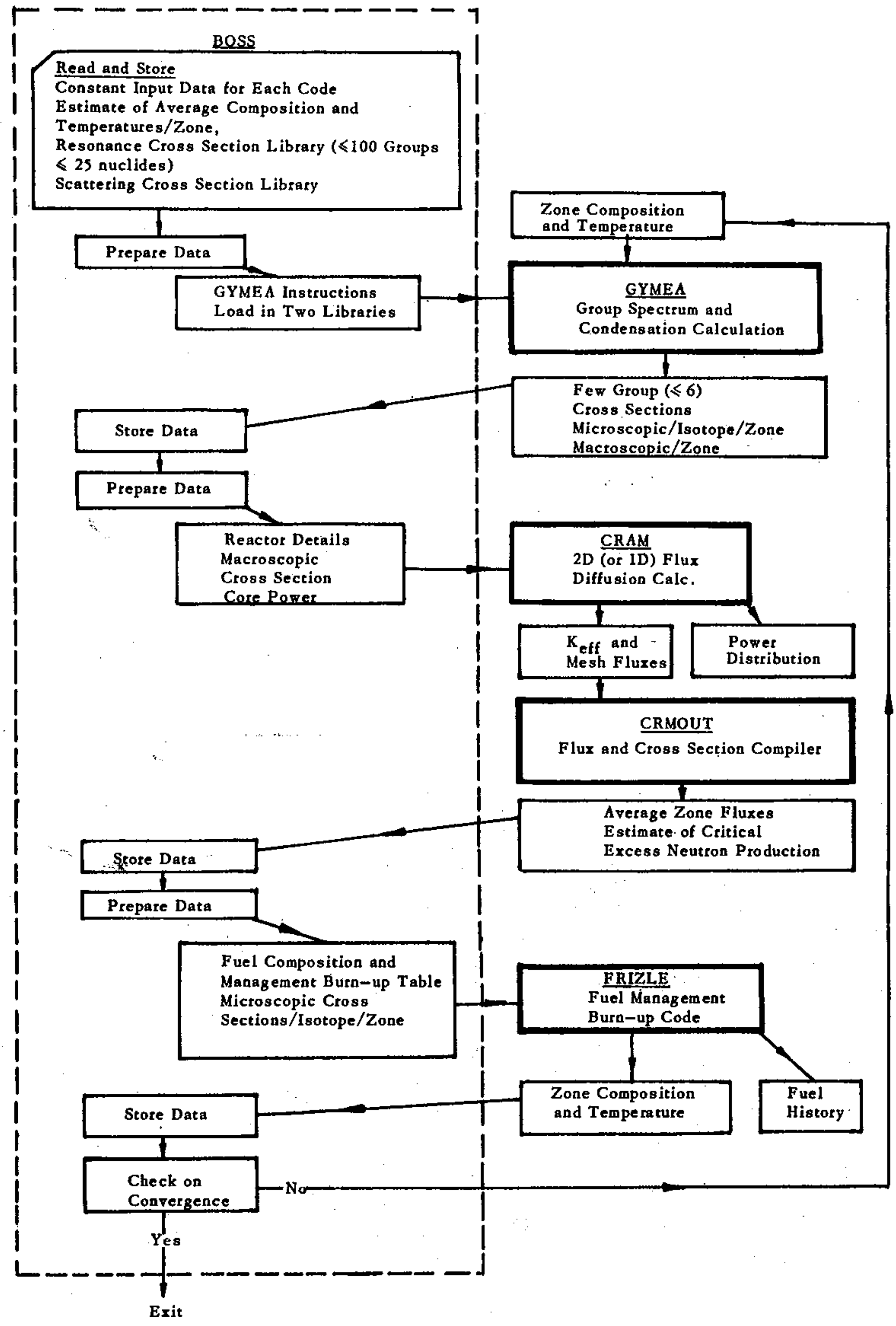

FIGURE 1. FRIZLE CODE COMPLEX – FUNCTIONAL BLOCK DIAGRAM

P929

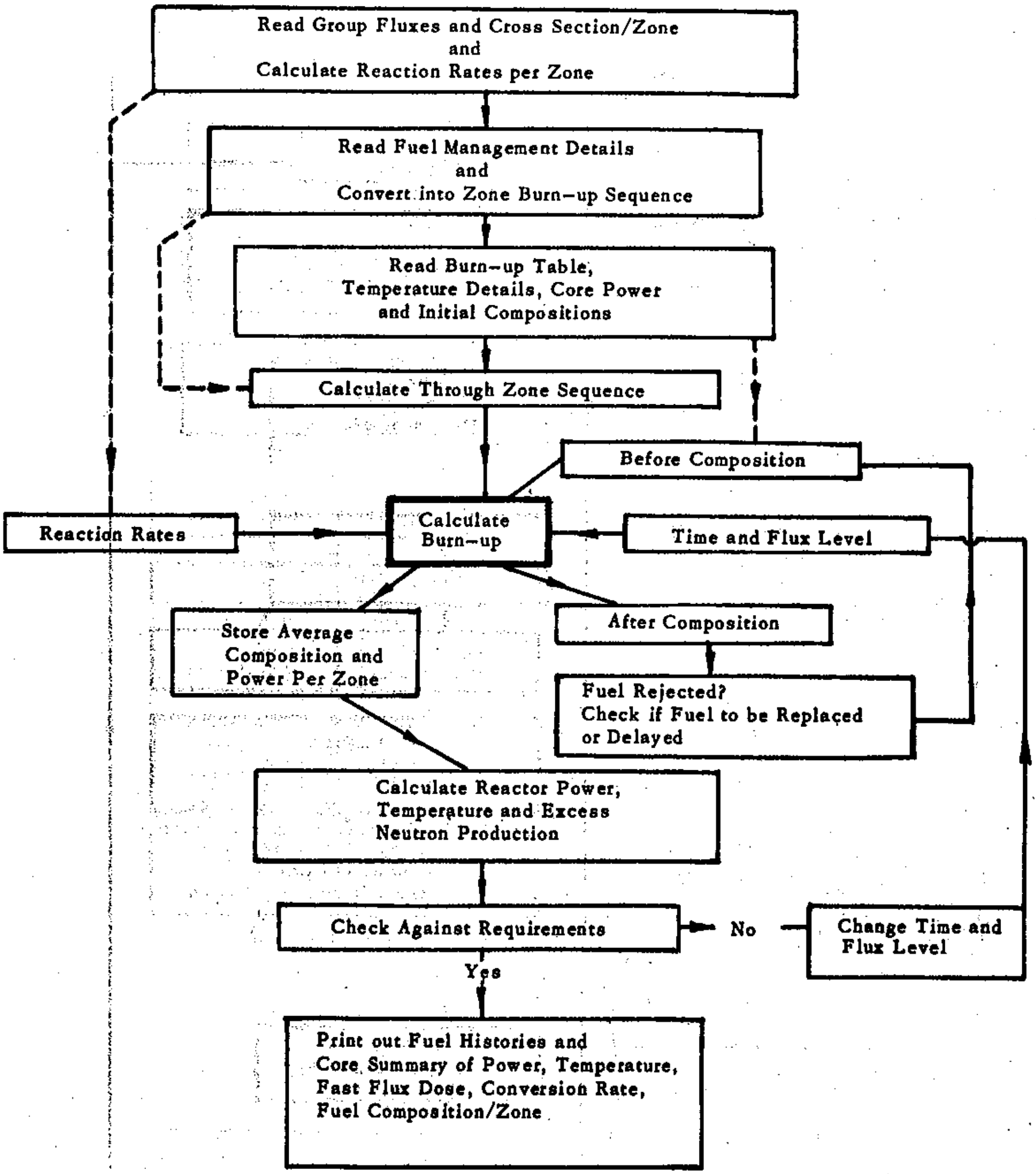

FIGURE 2. FRIZLE FUEL MANAGEMENT AND BURNUP CODE – FUNCTIONAL BLOCK DIAGRAM

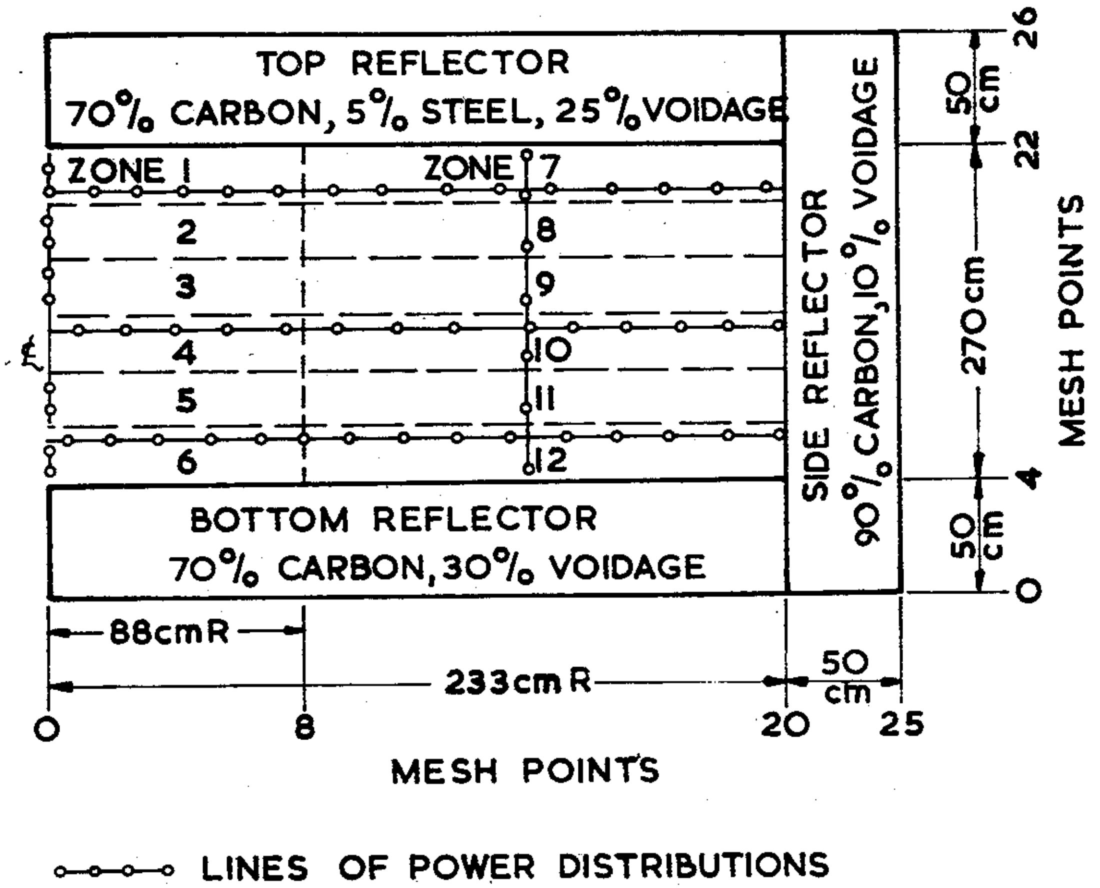

FIGURE 3. LAYOUT OF REACTOR CORE AS USED IN PRELIMINARY FRIZLE CALCULATIONS

P1090

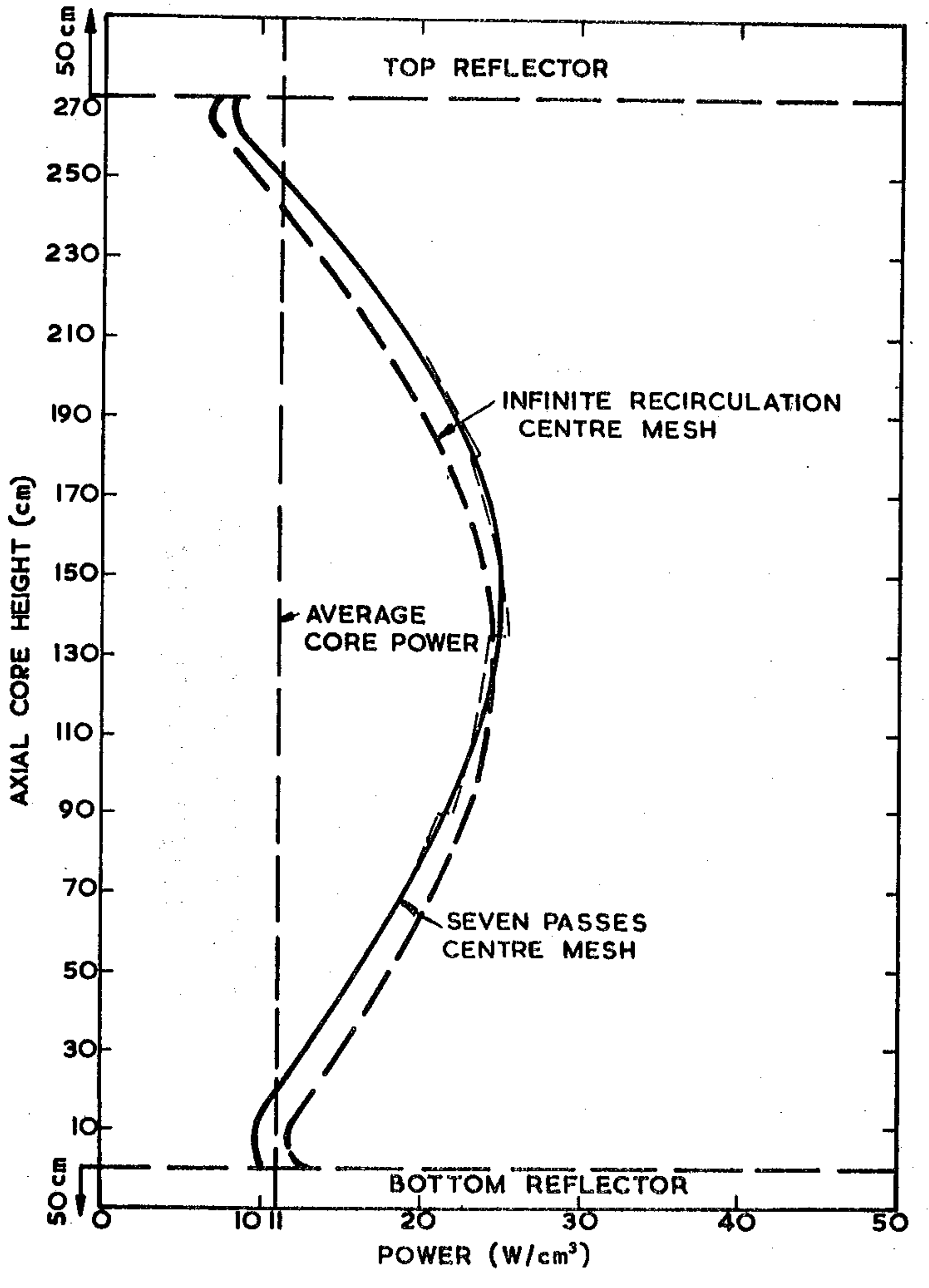

FIGURE 4. AXIAL POWER DISTRIBUTION FOR A SEVEN PASS CORE WITH RANDOM RADIAL LOADING AND AN INFINITE RECIRCULATION FUEL MANAGEMENT SCHEME

P1090

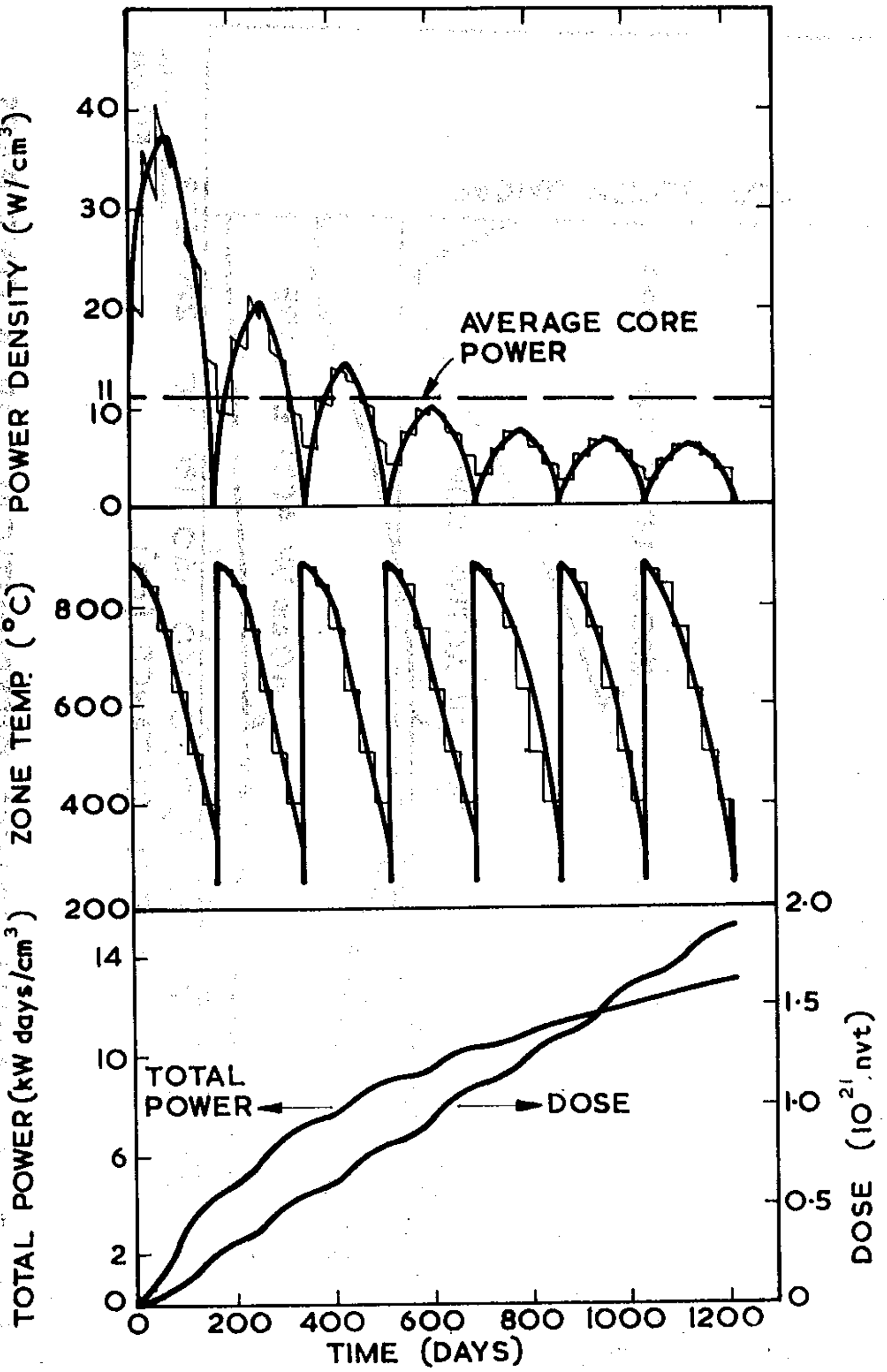

FIGURE 5. AVERAGE PEBBLE HISTORY FOR A SEVEN PASS RECIRCULATION SCHEME WITH RANDOM RADIAL LOADING

P1090

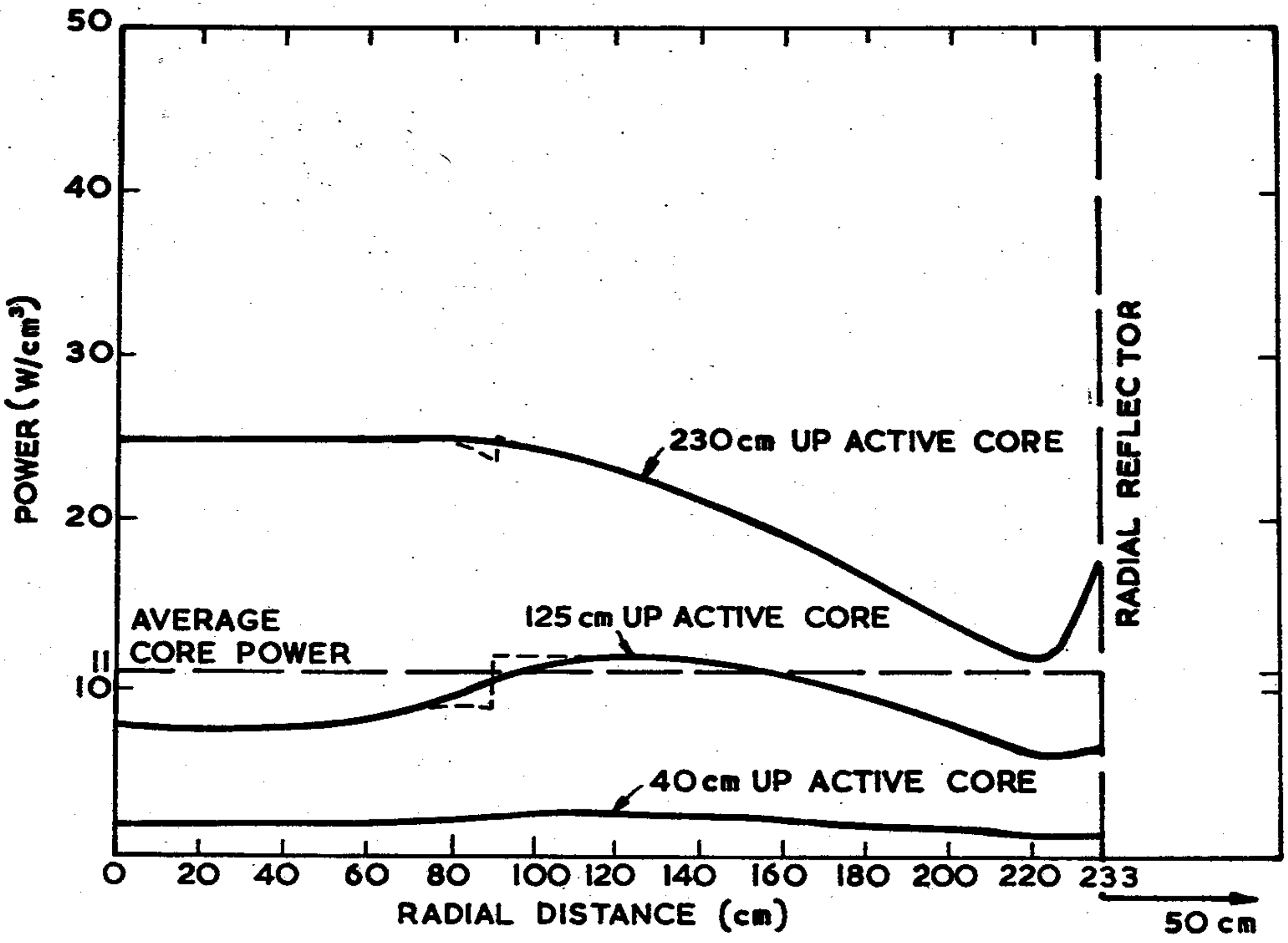

FIGURE 6. RADIAL POWER DISTRIBUTION FOR A ONE PASS FUEL MANAGEMENT SCHEME

P1090

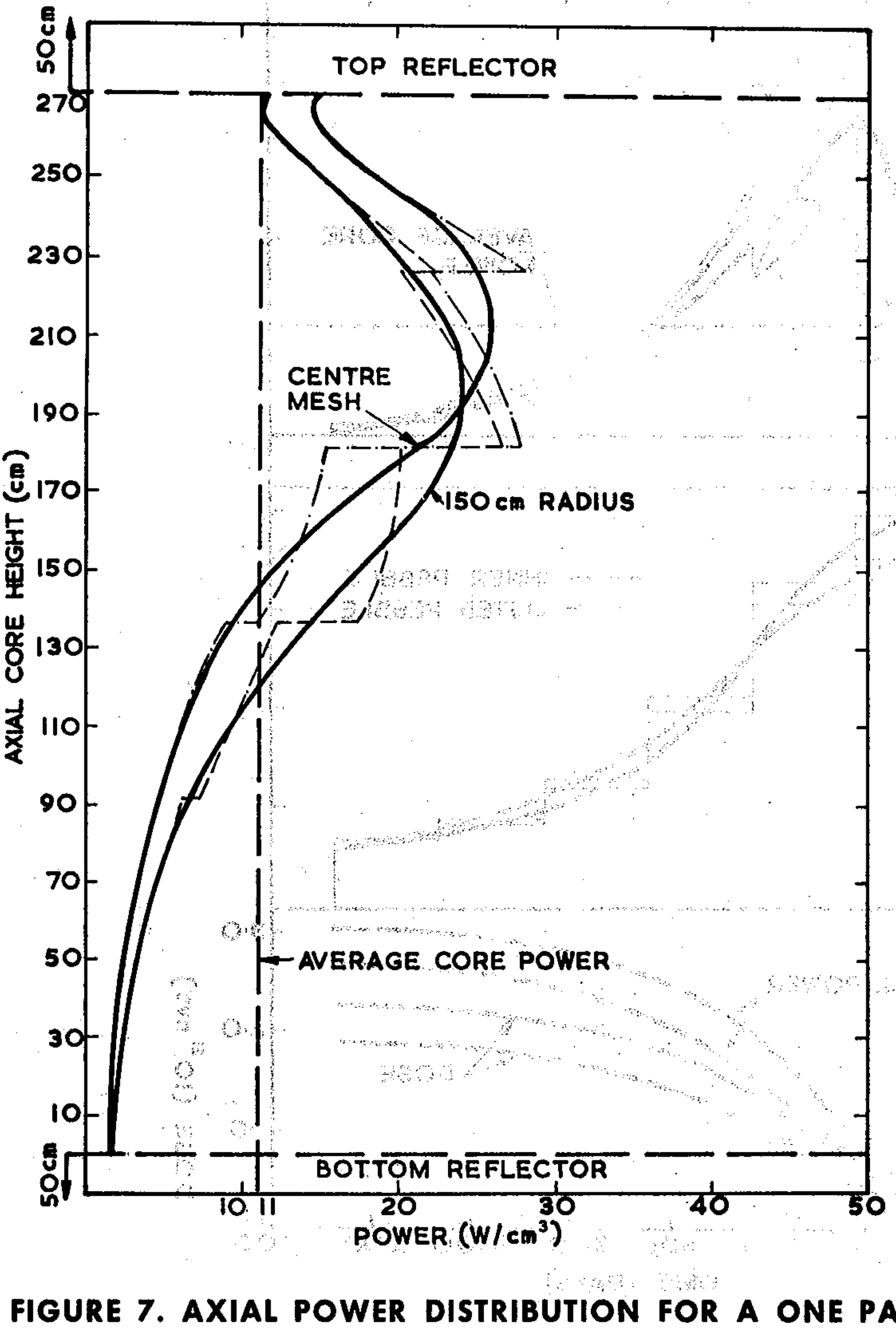

FIGURE 7. AXIAL POWER DISTRIBUTION FOR A ONE PASS FUEL MANAGEMENT SCHEME

P1090

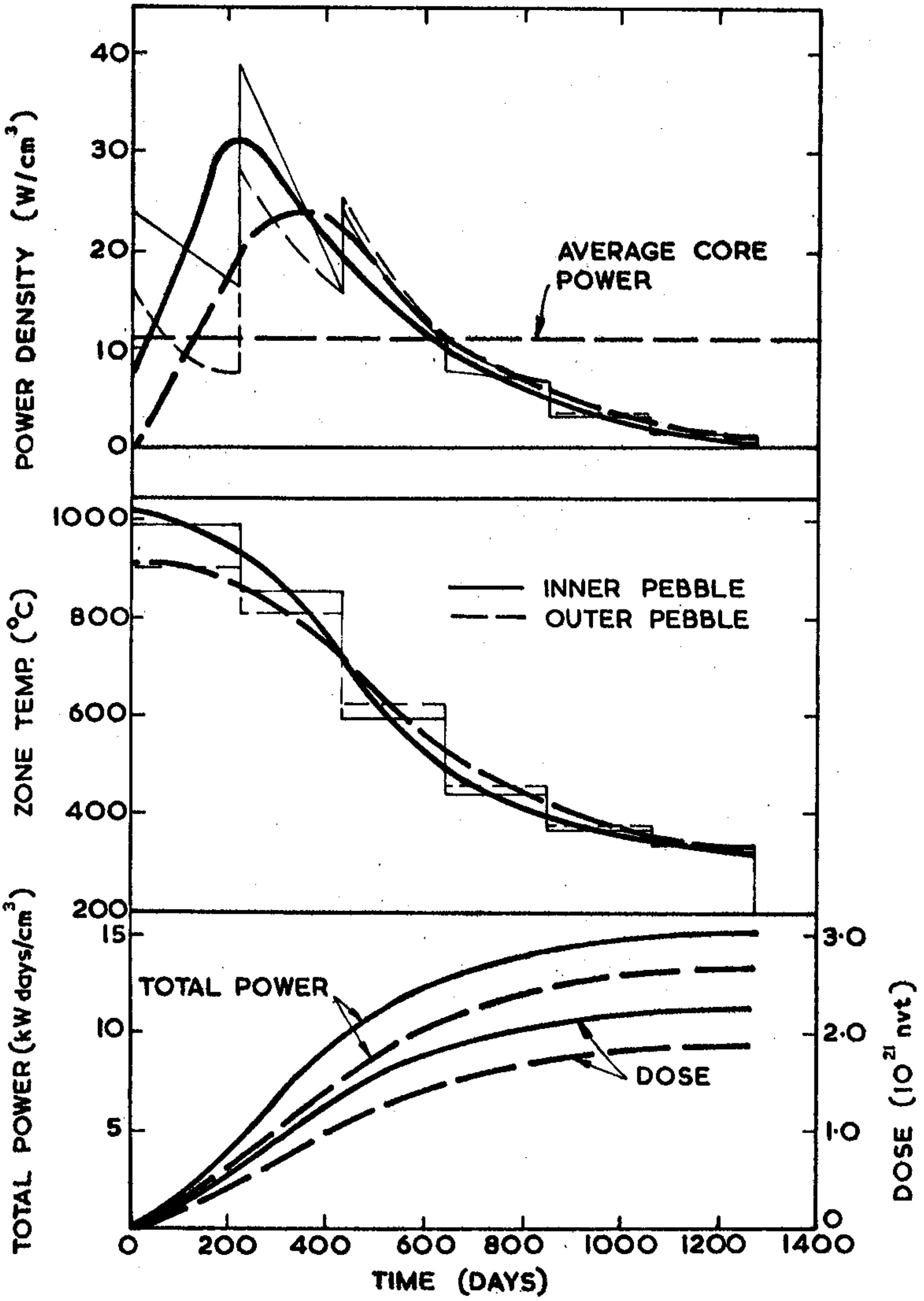

FIGURE 8. AVERAGE PEBBLE HISTORIES FOR INNER AND OUTER ZONES OF A ONE PASS SCHEME

P1090

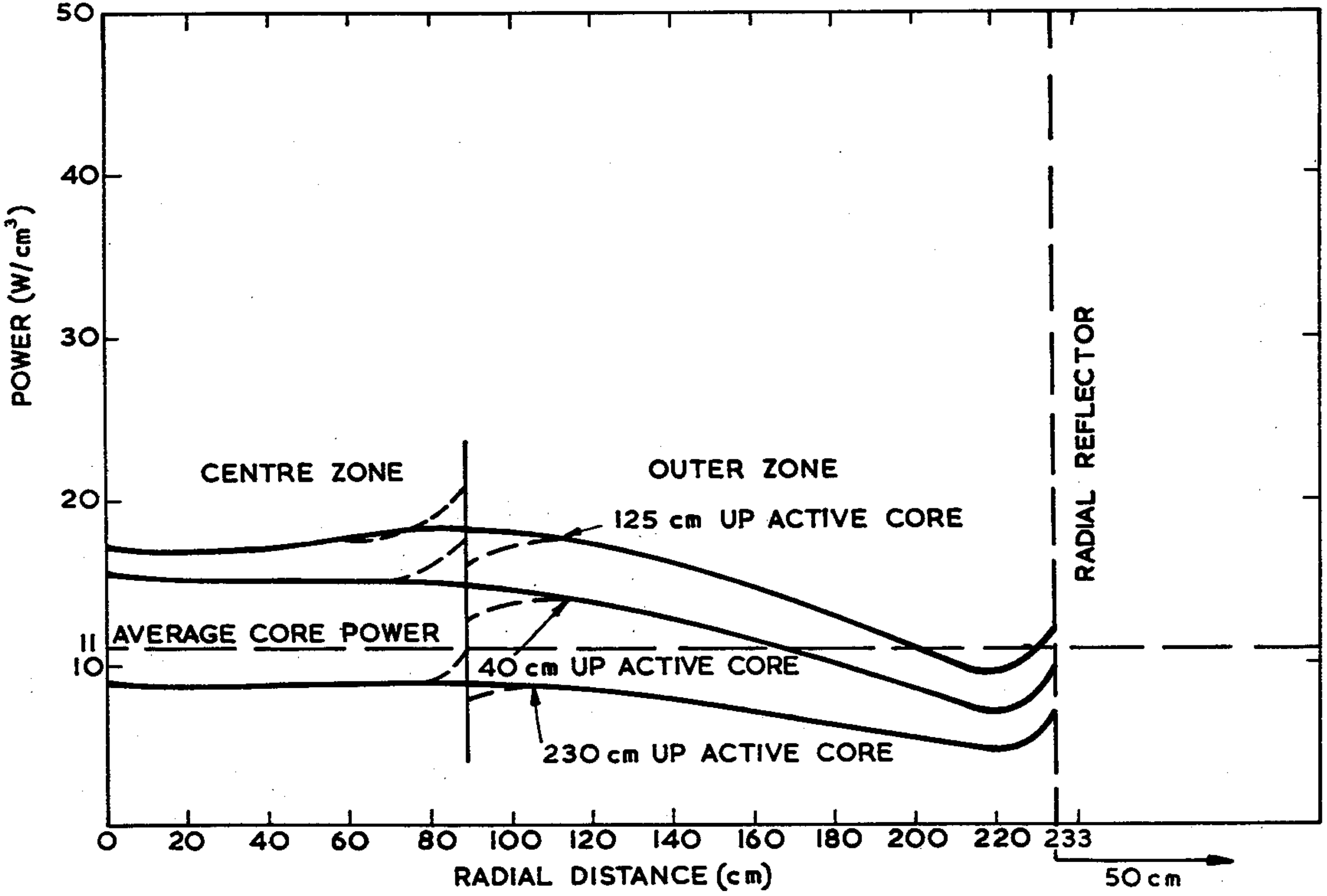

FIGURE 9. RADIAL POWER DISTRIBUTION FOR A CONTROLLED SEVEN PASS RECIRCULATION SCHEME USING 'EXTRA THORIUM'

P1090

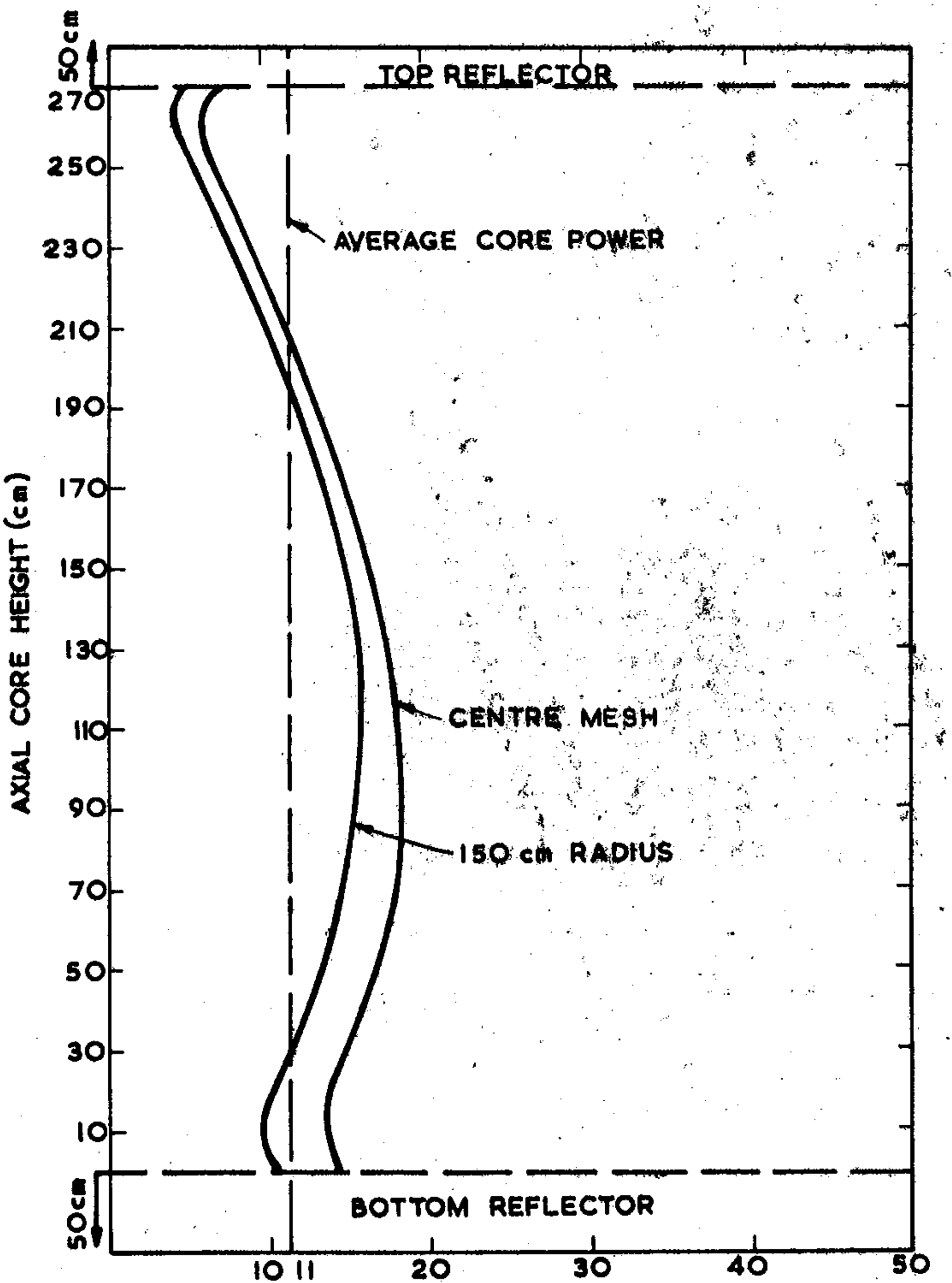

FIGURE 10. AXIAL POWER DISTRIBUTION FOR A CONTROLLED SEVEN PASS RECIRCULATION SCHEME USING 'EXTRA THORIUM'

P1090

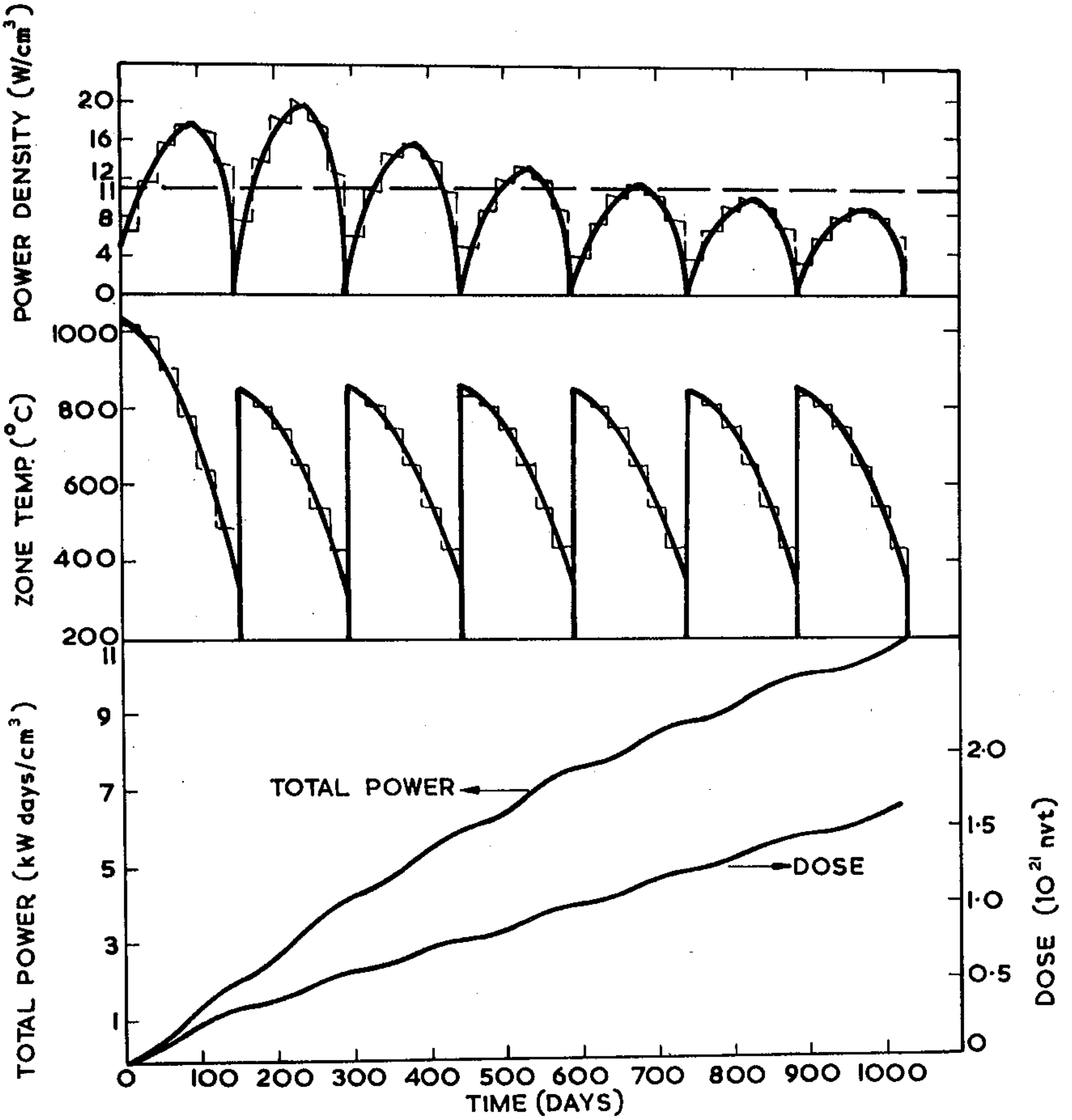

FIGURE 11. AVERAGE PEBBLE HISTORY FOR A CONTROLLED SEVEN PASS RECIRCULATION SCHEME USING 'EXTRA THORIUM'

P1090