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**OAK RIDGE NATIONAL LABORATORY**

MARTIN MARIETTA

# An EBT Reactor Systems Analysis and Cost Code: Description and User's Guide (Version 1)


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MASTER


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FOR THE UNITED STATES
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## ABSTRACT

An ELMO Bumpy Torus (EBT) reactor systems analysis and cost code that incorporates the most recent advances in EBT physics has been written. The code determines a set of reactors that fall within an allowed operating window determined from the coupling of ring and core plasma properties and the self-consistent treatment of the coupled ring-core stability and power balance requirements. The essential elements of the systems analysis and cost code are described, along with the calculational sequences leading to the specification of the reactor options and their associated costs. The input parameters, the constraints imposed upon them, and the operating range over which the code provides valid results are discussed. A sample problem and the interpretation of the results are also presented.

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**NOTICE** This document contains information of a preliminary nature. It is subject to revision or correction and therefore does not represent a final report.

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## ABSTRACT

An ELMO Bumpy Torus (EBT) reactor systems analysis and cost code that incorporates the most recent advances in EBT physics has been written. The code determines a set of reactors that fall within an allowed operating window determined from the coupling of ring and core plasma properties and the self-consistent treatment of the coupled ring-core stability and power balance requirements. The essential elements of the systems analysis and cost code are described, along with the calculational sequences leading to the specification of the reactor options and their associated costs. The input parameters, the constraints imposed upon them, and the operating range over which the code provides valid results are discussed. A sample problem and the interpretation of the results are also presented.

# 1. INTRODUCTION

An essential task in any fusion reactor design is the integration of physics, engineering, and cost constraints to determine the range of acceptable reactor design options and to demonstrate the most attractive technical and economic characteristics of these reactors. In order to carry out this integration, an ELMO Bumpy Torus (EBT) reactor systems analysis and cost code has been developed that incorporates recent advances in EBT physics. A unique feature of this code, which differs from those used previously, is the coupling of ring and core plasma properties and the self-consistent treatment of the coupled ring-core stability and power balance requirements. The code establishes a reactor operating space on the basis of these requirements, along with additional limits imposed by other physics and engineering constraints.

The essential elements of the systems analysis and cost code are described in this report. The calculational sequence leading to the specification of reactor options and their associated costs and the physical processes that are incorporated into the various subroutines are described in Sect. 2. The input parameters and the constraints imposed on them and the operating range over which the code provides valid results are discussed in Sect. 3. Operating instructions and a sample problem are reviewed in Sect. 4. Additional information and program listings are included in the appendices.

## 2. PHYSICS MODELS AND CALCULATIONAL SEQUENCES

The basic EBT operation requires a toroidal array of simple mirrors with energetic electron (or ion) rings contained in each mirror for stability of the overall plasma configuration.[1] The stability of the core plasma and that of the rings are closely coupled, so a consistent analysis of EBT reactor operation requires consideration of these processes. In addition, the core-ring plasma stability criteria, profile effects, and the steady-state power requirements of the electron (and ion) rings and their coupling to one another must be taken into account. The physics models incorporated into the code are described in detail in ref. 2 and the references contained therein. In the present version of the code, some of the phenomena (e.g., profile effects) have been included in an approximate manner. The approximations used are compared with the equations that describe the actual processes.

The code was written on the basis of the core and ring stability requirements and the coupling between them. The core plasma requires energetic rings (to produce a diamagnetic well) for its stability with the maximum allowable core beta: $\beta_c \lesssim 2\Delta/R_c$, where $2\Delta$ is the ring width and $R_c$ is the magnetic radius of curvature near the ring. The stability of the ring is established by the hot electron interchange mode, which requires a sufficient amount of core plasma density (i.e., $n_{\text{cold}}/n_{\text{hot}} = n_c/n_h$).[2]

The sequence of calculations carried out in the code is shown in Fig. 1. The code is constructed in a sequence of subroutines to ensure that uncertainties introduced by the various processes are decoupled and that revisions to the various processes can be readily made in the appropriate modules. To properly consider the coupling of the stability and power balance and to determine the operating space in which the plasma parameters fall (within the bounds of constraints imposed by the physics), the physics data are input to the code. In other systems codes (e.g., see ref. 3), input parameters are selected from engineering constraints and reactor size (e.g., plasma major radius, number of coils, net electric power, etc.), which may or may not be acceptable from physics considerations.

This code is further structured, insofar as possible, so that all of the calculations are carried out for a single mirror sector. The dimensions of the sector are determined from the specification of the plasma radius under a coil $r_p$, the mirror ratio $M$, and the magnitude of the magnetic field $B$. The total number of sectors (number of coils) and, correspondingly, the major radius are determined from neoclassical confinement scaling: $n\tau \sim A^2T^{3/2}$, where $A$ is the magnetic aspect ratio and $T$ is the plasma temperature.

### 2.1 MAGNETICS CALCULATIONS (SUBROUTINE MAGNET)

The average magnetic field curvature is related to the plasma major radius $R_T$, the mirror ratio $M$, the number of sectors $N$, and the coil radius $r_c$. If the coils are approximated by a current sheet of finite length and if a large aspect ratio is assumed, the magnetic field in cylindrical coordinates $(r,\theta,z)$, as shown in Fig. 2, is given by[4]

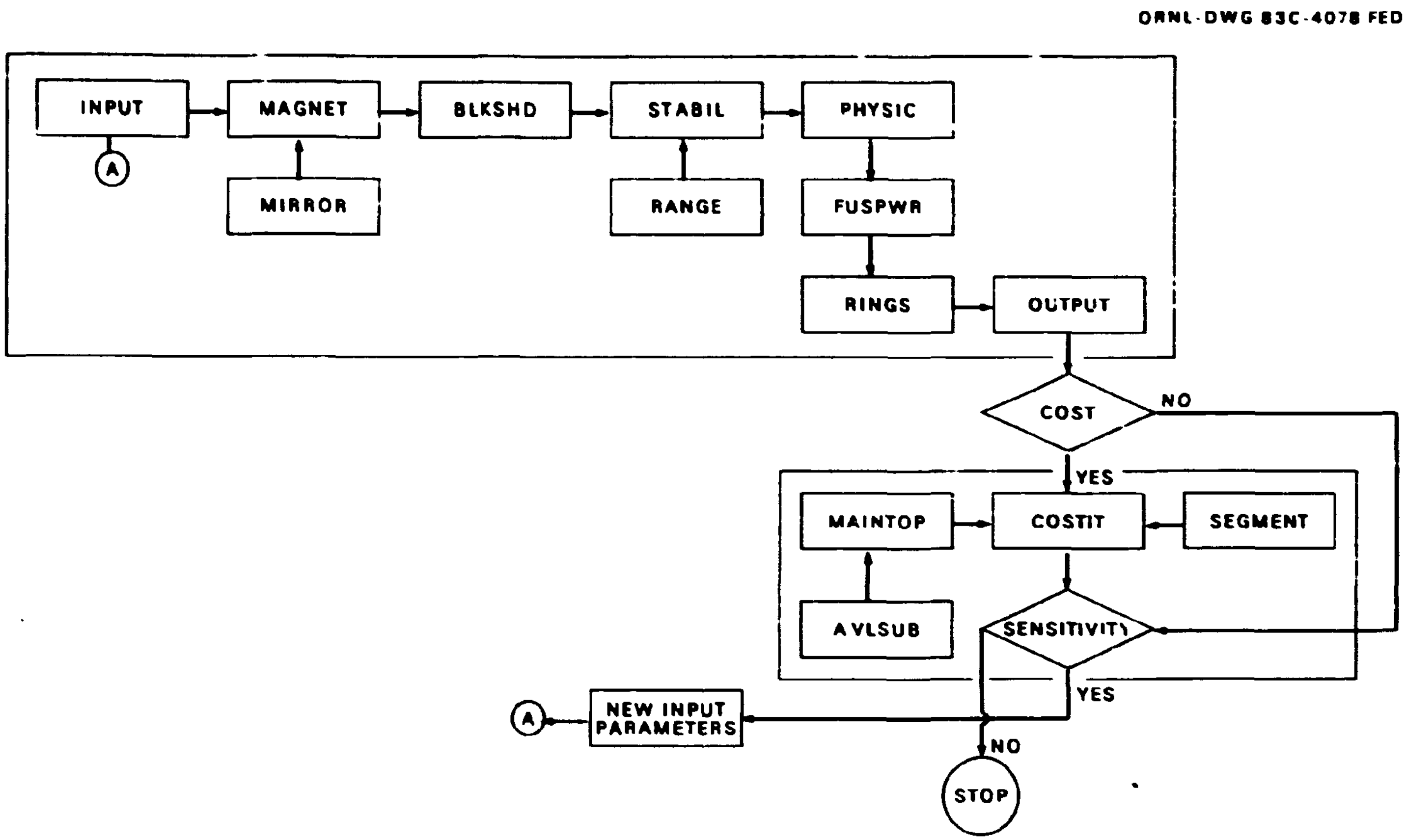


Fig. 1. Sequence of code calculations for EBT systems analysis and cost.

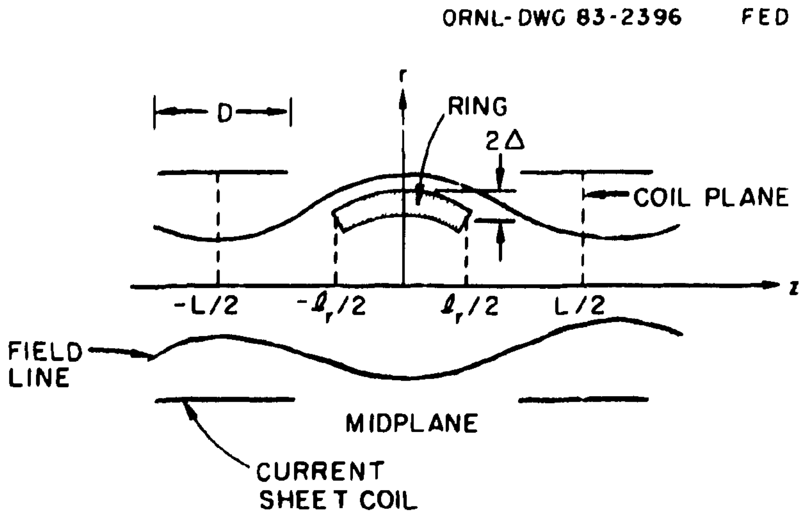


**Fig. 2. EBT sector geometry and ring dimensions.**

$$B_z(r,z) = \mu_0 \frac{I}{L}\left[1 + \sum_n (-1)^n \alpha_n(D) I_0(k_n r)\cos(k_n z)\right] \tag{1}$$

and

$$B_r(r,z) = \mu_0 \frac{I}{L}\left[\sum_n (-1)^n \alpha_n(D) I_1(k_n r)\sin(k_n z)\right] , \tag{2}$$

where

$$k_n = \frac{2\pi n}{L} = n(N/R_T) \quad \text{and} \quad \alpha_n(D) = 2\left[\frac{\sin(n\pi D/L)}{n\pi D/L}\right](k_n r_c)K_1(k_n r_c) .$$

In these equations,

$L$ = sector length = $2\pi R_T/N$,
$D$ = length of a current sheet,
$r_c$ = coil current center (radius of the current sheet),
$I$ = total coil current,
$I_0$, $I_1$, $K_1$ = modified Bessel functions.

The total magnetic field is $B = (B_z^2 + B_r^2)^{1/2} \simeq B_z$, and the mirror ratio is $M = B_{max}/B_{min} = B_z(r = 0, z = \pm L/2)/B_z(r = 0, z = 0)$, which is given by

$$M = \frac{1 + \sum_n \alpha_n(D)}{1 + \sum_n (-1)^n \alpha_n(D)} = f(Nr_c/R_T, D/L) \; . \tag{3}$$

In the limit, as $D \to 0$, the results given above reduce to the current loop approximation.

The relationship between the mirror ratio $M$ and $y = NR_T/r_c$ is plotted in Fig. 3 for values of $D/L = 0$ and 0.25. In the present version of the code, values of $y$ for $D/L = 0.25$ are stored in subroutine **MIRROR** over the range of mirror ratio values between $1.6 \leq M \leq 4.0$. Lagrangian interpolation methods are used to determine $y$ for the value of the mirror ratio specified in the input to the code and are used in subroutine **MAGNET** to determine the magnet coil and sector dimensions.

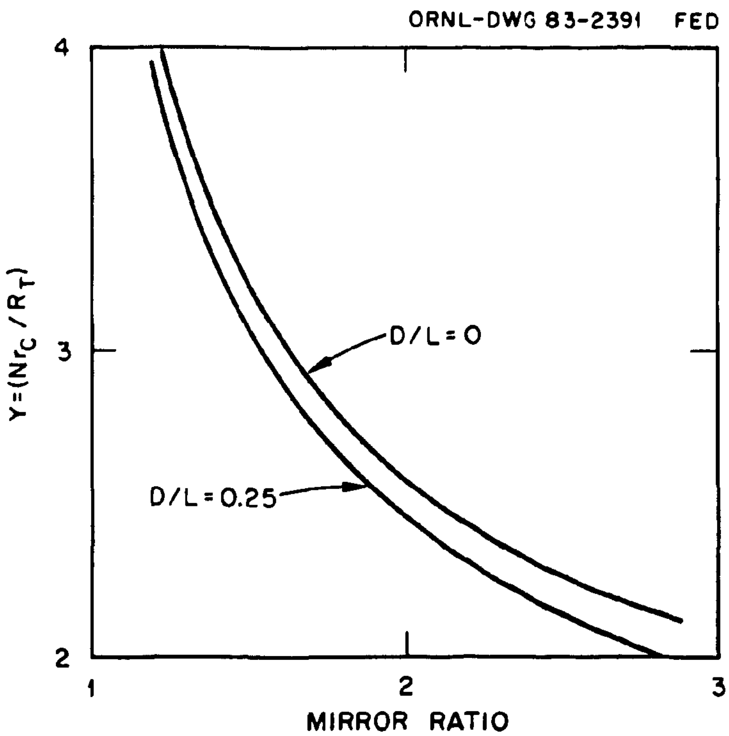


**Fig. 3. Relationship between mirror ratio $M$, number of coils $N$, coil radius $r_c$, and major radius $R_T$ for $D/L = 0$ and 0.25, where $D$ is the length of a coil and $L$ is the sector length.**

The coil radius is obtained by solving Eqs. (1) and (2) for the coil half-width $\Delta_c$, which is related to $r_c$ by

$$r_c = r_p + \Delta_{cz} + \Delta_{BS} + \Delta_M + \Delta_c \ , \tag{4}$$

where

$r_p$ = plasma radius under the coil,
$\Delta_{cz}$ = the thickness of the scrape-off zone (cold zone),
$\Delta_{BS}$ = blanket-shield thickness,
$\Delta_m$ = distance between the shield and magnet,
$\Delta_c$ = coil half-thickness.

In Eqs. (1) and (2), the total current $I$ is given by

$$I = J_0 D = J_{\max} A(\Delta_c) \ , \tag{5}$$

where

$J_0$ = current density in the sheet (in the limit that the coil width goes to 0),
$J_{\max}$ = maximum current density,
$A(\Delta_c)$ = cross-sectional area of the magnet calculated from $\Delta_c$.

In the code, the coil half-thickness $\Delta_c$ is fixed at 0.35 m, and the area is calculated assuming a length-to-width ratio of 3. A superconducting coil having a current density of $J_{\max} = 16$ MA/m$^2$ is also assumed. Equations (4) and (5) are substituted into Eqs. (1) and (2), which are solved for $\Delta_c$ with $B(r = 0, z = \pm L/2)$, and the ratio

$$R_T/N = r_c/y \tag{6}$$

is determined. Then, the mirror sector dimensions are obtained from

sector length = $L_s = 2\pi(R_T/N)$ ,
sector volume = $V_s = \pi L_s \langle a_p \rangle^2$ ,
sector surface area = $A_s = 2\pi L_s(\langle a_p \rangle + \Delta_{cz})$ ,

where $\langle a_p \rangle = \sqrt{M} a_p$ is the average plasma radius.

Subroutine MAGNET also calculates the dimensions of the mirror coils as well as those of symmetrizing (SYM) coils. SYM coils offer considerable promise for improving the magnetic field geometry and single particle confinement. The complications introduced into the magnetics by the inclusion of SYM coils are more than compensated for by the reduction (approximately by a factor of 2) in the size of the reactor and by the lower overall reactor cost. In the present version of the systems code, the mirror and SYM coil parameters are determined principally as input to the cost analysis routines.

The mirror coil dimensions and related parameters are obtained from

coil length = $C_L = 6\Delta_c$,
coil cross-section area = $C_A = 2\Delta_c C_L$,
coil current = $I_{coil} = J_{max} C_A$.

The SYM coil dimensions are obtained using the relations

$$\text{SYM coil current} = I_{SYM} = I_{SYM}(\%) \cdot I_{coil}\ , \tag{7}$$

where $I_{SYM}(\%)$ is determined from the curves in Fig. 4. All of the calculations are carried out assuming an aspect ratio enhancement (ARE) factor of 2. The variation of the ARE factor as a function of the SYM coil current is shown in Fig. 4 for a 24-sector EBT reactor. The SYM coil current used in estimating the SYM coil costs in a reactor containing $N$ coils is obtained using the scaling relation

$$I_{SYM}(\%) = \left[\frac{I^{24}_{SYM}(\%)}{N}\right] 24\ , \tag{8}$$

where $I^{24}_{SYM}$ is obtained in the calculation from the data given in Fig. 4. The SYM coil dimensions and parameters required for estimating the magnet system costs are obtained using the following expressions:

SYM coil cross-section area = $C_A = I_{SYM}(\%)/100 J_{max}$,
SYM coil length = $C_L = 2.0 C_A$,
SYM coil height = $C_H = 1/2(L - C_L)$.

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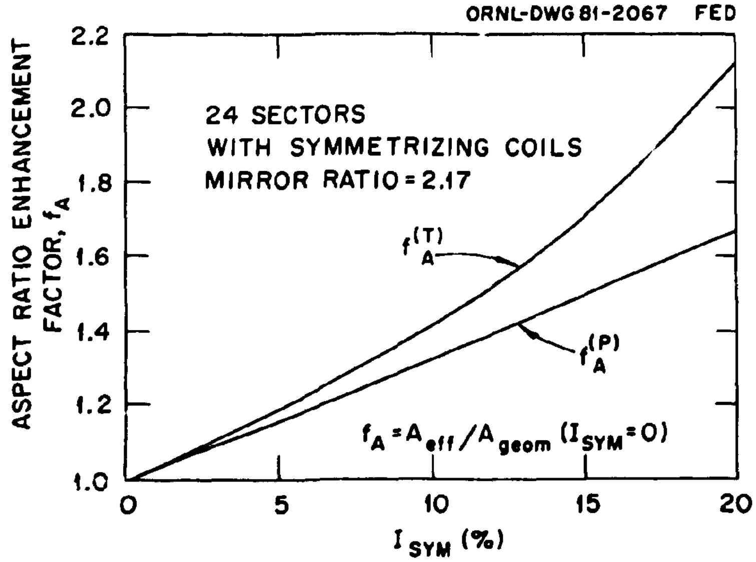


**Fig. 4. Variation of aspect ratio enhancement (ARE) factor $f_A$ with SYM coil current $I_{SYM}$ for trapped (T) and passing (P) particles.**

## 2.2 BLANKET-SHIELD CALCULATIONS (SUBROUTINE BLKSHD)

The blanket and shield dimensions under the mirror coil and the thickness of the scrape-off (cold zone) region are specified in subroutine **BLKSHD**. The dimensions are input to the code through a name list input INE (see Sect. 4) through the variables *TCS* and *TC*. Then,

$$\text{blanket-shield thickness} = \Delta_{BS} = TCS\ ,$$
$$\text{scrape-off layer thickness} = \Delta_{cz} = TC\ .$$

The blanket-shield and scrape-off layer dimensions are used to determine the mirror coil dimensions and to determine the reactor costs. The calculations of surface areas, volumes, and weights of the first wall, blanket, and shield are determined using the same algorithms developed for the design point blanket and shield assembly in ref. 3. The areas, volumes, and weights are varied in proportion to the plasma radius and the blanket-shield thickness.

## 2.3 RING-CORE STABILITY CALCULATIONS (SUBROUTINE STABIL)

The ring-core stability calculation, which is the principal calculational sequence in the systems code, defines a set of EBT reactors that fall within a stable operating region and have core and ring properties defined by core beta $\beta_c$, ring beta $\beta_h$, and ring temperature $T_h$ (see ref. 2 for details). The core beta limit is given by Nelson[5] and Van Dam and Lee[6] in that the core-pressure-driven interchange is stable if

$$\beta_c \leq \left(\frac{2\Delta}{R_c}\right)(1 + p_\parallel/p_\perp)\ , \tag{9}$$

where $p_\parallel$ and $p_\perp$ are the hot electron ring pressures parallel and perpendicular, respectively, to the magnetic field. This equation defines the core beta limit near the outside edge of the core plasma and is ~10%–15% for a reactor [the Lee-Van Dam-Nelson (LVN) limit]. The pressure anisotropy, $p_\parallel/p_\perp$, is taken to be 0.25 in the code, and it is further assumed in all cases that the core beta at which the reactor operates is 80% of the LVN limit. That is,

$$\beta_c(\text{operation}) = 0.8\beta_c(\text{LVN limit}) = 0.8(2\Delta/R_c)(1 + p_\parallel/p_\perp)\ . \tag{10}$$

For this beta value, the lower limit on the core density is determined from the low frequency, hot electron interchange mode given by

$$(f_R)_{\min} = n_c/n_h > [4/(k_\perp\Delta)^2] \cdot 1/q_0 \cdot \frac{1}{[1-\beta_c R_c/2\Delta + O(\Delta/R_c)]^2}\ . \tag{11}$$

Here $q_0$ is the ratio of the hot electron curvature drift frequency to the ion cyclotron frequency given by

$$q_0 = v_{cv}/\Delta\omega_{ci} \simeq 10^{-5}\mu(T/B_R^2 R_c \Delta) \ , \quad (12)$$

where

$\mu = m_i/m_p$ = ratio of the ion mass to proton mass ($\mu = 2.5$ for a 50-50 D-T plasma),
$B_R$ = magnetic field near the ring,
$k_\perp$ = wave number.

A more detailed discussion of the L'/N limit and an explanation of the terms in the equations given above may be found in Appendix A of ref. 2.

The magnetic field near the ring $B_R$ can be approximated by

$$B_R = 0.70 B_{min} \ , \quad (13)$$

where $B_{min} = B(r = 0, z = 0)$. For a given ring beta $\beta_h$, ring temperature $T_h$, and magnetic field $B_R$, the ring density is given by

$$n_n = 2.48 \times 10^{21}\beta_h B_R/T_h = 4.85 \times 10^{18}\beta_h B_R/(\gamma - 1) \ , \quad (14)$$

where $\gamma = 1 + T_h/m_0c^2$ is the relativistic factor.

The minimum plasma density near the ring that satisfies the stability criterion given by Eq. (11) is $(n_c)_{min} = n_h(f_R)_{min}$. Introducing an average core density $\langle n \rangle = Kn_c$, then

$$\langle n \rangle_{min} = Kn_h(f_R)_{min} \ , \quad (15)$$

where $K$ is a profile density factor. A detailed discussion of the derivation of this profile factor is given in Appendix B of ref. 2.

The maximum core plasma density, on the other hand, is calculated from the microwave cutoff or the compressional Alfvén mode, depending on which one is more stringent. In realistic reactor plasmas, however, the compressional Alfvén model limit exceeds the microwave cutoff. Taking the cutoff density to be the maximum allowable density,

$$\langle n \rangle_{max} = n_{cutoff} = 9.73 \times 10^{18} \cdot B^2_{resonance} \ , \quad (16)$$

where $B_{resonance} \simeq 2B_R$ is the resonance field (in tesla). Using Eqs. (15) and (16) the relation $\langle n \rangle = Kn_c$ yields

$$(f_R)_{max} = (n_c/n_h)_{max} \simeq 1.6 \times 10^{-2} T_h/f_n\beta_h \ . \quad (17)$$

At the present, the systems code treats the magnetic field, core pressure, and ring pressure profiles[2] in an approximate manner. A more detailed treatment of profile effects will be added to the code as improvements are made to include equilibrium calculations, along with more realistic magnetics and stability analyses. The approximate treatment of the radial dependence of the field does not, however, significantly affect the results of the code.

Equations (11) and (17) establish the extremes of the upper and lower boundaries of the operating space in which stable plasmas are achieved for the specified ring parameters. A typical reactor operating window defined by these equations is shown in Fig. 5. Depending on the desired core beta value, ring temperature, magnetic field, and ring beta, the stable reactor operating window can be opened or closed. The directions in which the window boundaries move with changes in these parameters are indicated in Fig. 5.

For $q_0$ calculated from the input parameters, there exists a finite range of $n_c/n_h$ that falls within the stable plasma region. This is shown in Fig. 5 as the vertical line plotted at $q_0 = 0.14$ (corresponding to $\beta_h = 15\%$, $T_h = 2$ MeV, $\langle B \rangle = 4$ T). An additional check is made in subroutine STABIL to ensure that the range of plasma temperatures of reactors operating within the allowed $n_c/n_h$ range always exceeds 5 keV (bremsstrahlung limit).

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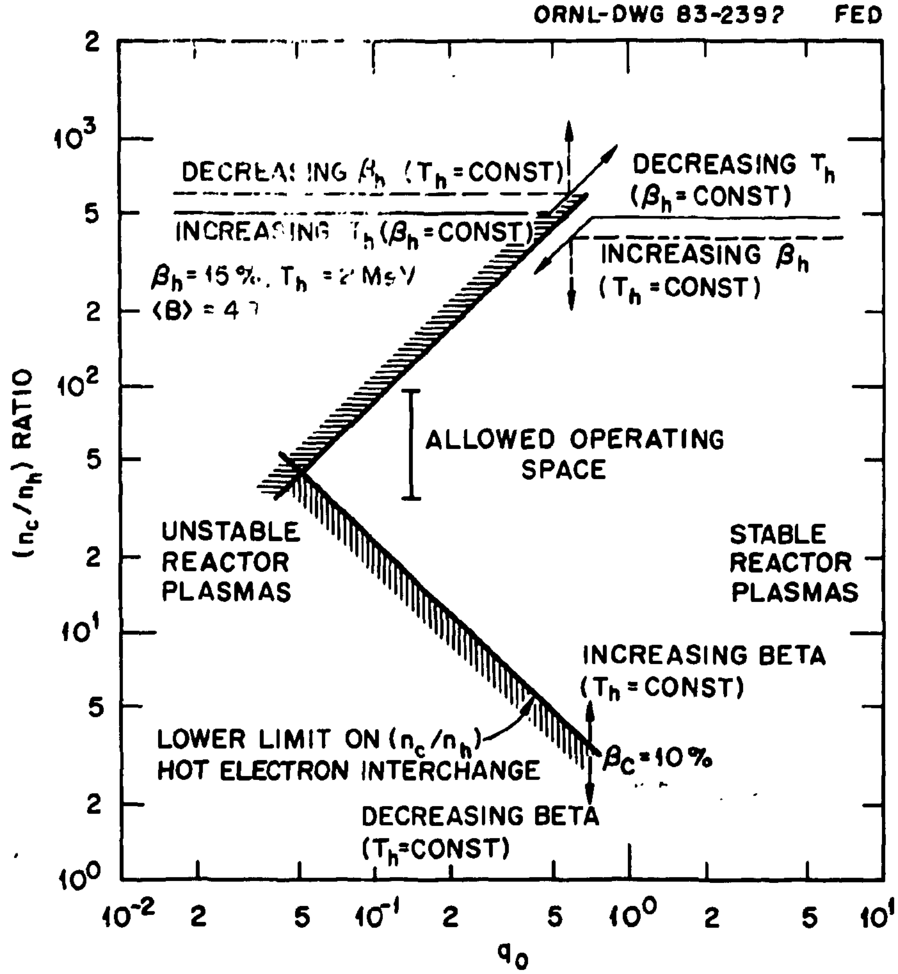


**Fig. 5. A typical reactor operating window obtained from the ring-core stability calculations.**

## 2.4 RING POWER CALCULATIONS (SUBROUTINE RINGS)

The set of EBT reactors stabilized by hot electron rings is specifically calculated in the stability subroutine. It is assumed that the reactors defined here in terms of electron ring stability criteria can also be equivalently stabilized by ion rings within the constraint that ion ring parameters can be scaled from the electron ring parameters (see Appendices C and D of ref. 2). The scaling is accomplished by assuming that the ion ring half-width $\Delta_i$ is

$$\Delta_i = \max(\Delta_e, \rho_i) \ , \tag{18}$$

where $\rho_i \sim T_h^{1/2}/\langle B_R \rangle$ is the ion gyroradius. The electron and ion ring volumes are calculated assuming that both ring species have the same overall length $l_R$ (see Fig. 2) but with the ring volume being a function of $\Delta_e$ for electron rings and $\Delta_i$ for ion rings. The ring temperature and beta specified in the input are taken to be the same for both electron and ion rings (however, different values can be assumed). Steady-state ring power requirements are calculated based on expressions developed in Appendix C of ref. 2 for electron rings and in Appendix D of ref. 2 for ion rings. These data are required to determine the recirculating power requirements and the net electric power produced by the reactors. For the case of electron rings, the power lost in the rings is due to synchrotron radiation, drag losses, and scattering. The required ring sustaining power is given by

$$P_{\mathrm{ring},e}\ (\mathrm{MW}) = 0.16\beta_h^4 B_R V_{\mathrm{ring},e} G(\gamma, \beta_h, n_c/n_h) \ , \tag{19}$$

where

$$G(\gamma, \beta_h, n_c/n_h) \simeq 1 + 2.5(\gamma - 1) + 7.4\beta_h (n_c/n_h) \frac{\gamma/(\gamma - l)^2}{(\gamma^2 - 1)^{1/2}} [(1 + 4/\gamma + 1)] \ . \tag{20}$$

For the case of ion rings, the power lost in the rings is due mainly to drag and scattering losses (charge-exchange losses are negligible for reactors with energetic ion temperatures exceeding several hundred kiloelectron volts) and can be approximated by

$$P_{\mathrm{ring},i}\ (\mathrm{MW}) \simeq 10^3 \beta_c \beta_h B_R^4 / (\mu_h T_{ec}^{5/2}) V_{\mathrm{ring},i} \ , \tag{21}$$

where $T_{ec}$ is the core electron temperature near the ring and $\mu_h = m_h/m_p$ is the ratio of the hot ion mass to proton mass. The ratio of the power required to sustain an ion ring to that required to sustain an electron ring is given by

$$P_{\mathrm{ring},i}/P_{\mathrm{ring},e} \simeq 2\mu^{-1}\beta_c (10/T_{ec})^{5/2} (V_{\mathrm{ring},i}/V_{\mathrm{ring},e}) \tag{22}$$

and

$$Q_j = P_{th}/P_{\mathrm{ring},j} = \eta_j/\epsilon_j \qquad j = e, i \ , \tag{23}$$

where $\epsilon$ is the required recirculating power fraction to sustain the rings and $\eta$ is the efficiency (which includes thermal-to-electric conversion efficiency and microwave coupling efficiency).

## 2.5 CONFINEMENT TIME AND REACTOR SIZE SCALING (SUBROUTINES PHYSIC AND CONFMT)

The reactor dimensions and the number of sectors are determined from neoclassical confinement scaling $n\tau \sim A^2T^{3/2}$, where $T$ is the plasma temperature and $A$ is the magnetic aspect ratio. Detailed discussions of confinement scaling and a full expression for $n\tau$ as a function of collisionality ($\nu/\Omega$) may be found in ref. 2. Calculations are carried out for the set of ignited reactors with a range of plasma densities determined for the operating space shown in Fig. 5. In determining the required confinement times for these ignited reactors, the only (core plasma) radiation loss terms considered are those due to bremsstrahlung and synchrotron radiation, that is,

$$(n\tau)_{\text{ignition}} = \frac{3n^2T}{P_\alpha - P_{\text{rad}}} , \tag{24}$$

where

$$P_{\text{rad}} = P_{\text{brem}} + P_{\text{synch}} . \tag{25}$$

Then the required aspect ratio for ignition is estimated from Eq. (24), that is, $A^2 \propto n\tau/T^{3/2}$, where $T$ is evaluated for the range of core plasma densities $n_c$ obtained from Fig. 5. The number of sectors $N$ is obtained by evaluating

$$N = A \cdot r_c/(R_T/N) , \tag{26}$$

where $r_c$ is obtained from Eq. (4) and $R_T/N$ is obtained from Eq. (6).

## 2.6 POWER BALANCE CALCULATIONS (SUBROUTINE FUSPWR)

The final set of calculations in the sequence of physics calculations determines the thermal power produced in a reactor sector, along with the neutron wall loading and fusion power density. The thermal power production includes the blanket multiplication factor $M_b$ as an input parameter, so the power production capabilities of the reactor options are assessed without considering specific blanket designs at this time.

All of the physics data are now available to carry out a systematic analysis of the reactor options that lie within an allowed operating window (Fig. 5). The physical dimensions of the reactors are specified, along with the ring parameters required to ensure stability. In addition, the blanket-shield and magnet coil dimensions are specified, and a sufficient data base exists to complete a cost analysis of each reactor option.

## 2.7 COST CALCULATIONS (SUBROUTINES COSTIT, MAINTOP, AVLSUB, AND SEGMENT)

The algorithms and sequence of calculations to determine the costs of the various reactor options that fall within the allowed operating space are the same as those used in the McDonnell Douglas EBT reactor systems code that was developed for the Los Alamos National Laboratory

(LANL) EBT reactor study.[3] However, most of the subroutines were modified for use with the code developed here and do not include the design optimization loops that were used to converge the reactor design envelope discussed in ref. 3.

Two modes of economic analysis are built into the cost subroutines. They are the "constant-year-dollar" (CYD) and "then-current-dollar" (TCD) modes. The CYD analysis assumes that the purchasing value of the dollar remains constant with time, and the reactor costs are expressed in 1980 dollars with inflation taken to be zero and the cost of capital at 5% per year. The TCD analysis assumes the purchasing value changes with time (5% per year) and that the cost of capital is 10% per year. The values for interest and escalation are standardized for comparative purposes with other fusion studies[7] and are not intended to reflect actual interest and inflation fluctuations.

The code is structured to provide the cost analysis as an option. If the computation of costs is selected, the option also exists to publish two different cost summaries. A simple cost summary of reactors stabilized by either electron or ion rings may be selected. These tables summarize the major cost accounts, the costs of the reactor plant equipment, total capital costs, and the cost of electricity. These data are presented for each EBT reactor option that falls within the stable operating window.

The second option allows for the publication of the costs broken down into the separate capital cost accounts. Also tabulated are operation and maintenance costs, including component replacement, outage, man-day, and total annual costs. The various capital cost accounts and the data used to estimate costs are described in detail in Appendix G of ref. 3. It should be noted that all of the costs reported in the various accounts are in constant-year 1980 dollars. The TCD analysis yields a nominal first-year facility cost with escalation computed only during the estimated period of construction.

# 3. LIMITS OF OPERATION AND APPROXIMATIONS

The sets of EBT reactors that fall within the allowed operating space are calculated for input parameters that are constrained within specified ranges. Also, to facilitate the calculations within the extent to which certain subroutines are presently written, certain approximations are imposed throughout the analysis. These constraints and approximations are based on data from current EBT theories and from data obtained from previous reactor studies or extrapolation of data obtained from EBT experiments to the reactor regime. In the development of this code, the main purpose was the self-consistent treatment of coupled ring-core stability and power balance requirements; thus some of the subroutines were kept rather basic and may not provide sufficient data to determine or estimate the other physical and/or engineering processes leading to the reactor.

## 3.1 LIMITS OF OPERATION

As noted previously, the input data to the code are physics parameters rather than engineering data. The input variables are listed in Table 1, along with the ranges over which input data yield acceptable results.

**Table 1. Input variables and other limits in the EBT reactor systems code**

| Parameter | Variable name | Limits |
|---|---|---|
| **Input Parameters** | | |
| Mirror ratio | XMR | 1.6 ≤ XMR ≤ 4.0 |
| Plasma minor radius | RADMIN | None |
| Core beta | BETA | 0.01 ≤ BETA ≤ 0.25 |
| Magnetic field,[a] T | BMIN | 0.5 ≤ BMIN ≤ 6.0 |
| Ring beta | BETARG | None |
| Ring temperature | RTEMP | None |
| **Others** | | |
| Blanket-shield thickness, m | DELBS | 0.5 ≤ DELBS ≤ 2.0 |
| Scrape-off layer thickness, m | DELCZ | 0.05 ≤ DELCZ ≤ 0.30 |

[a]Minimum magnetic field on-axis.

When any of the input falls outside the ranges specified in Table 1, the message

* * * * * * WARNING

MINIMUM VALUE ≤ VARIABLE NAME ≤ MAXIMUM VALUE

is returned to the user's terminal with the question

DO YOU WISH TO CONTINUE?

Execution of the program is continued with the response YES, but the results may be suspect and should be treated with caution. It is recommended that the response NO be given since, in most cases, interpolation and table lookup procedures are based on data within the specified ranges.

In addition, there are two error messages that, although not part of the interactive error message string, further caution the user. These messages indicate poor selection of the plasma scrape-off layer or blanket-shield thicknesses. The values for which these data are normally valid are also given in Table 1. The code will complete the analysis for values of these data outside the indicated range, but the results may not be acceptable from plasma physics and/or neutronics considerations.

## 3.2. APPROXIMATIONS INCORPORATED INTO THE CODE

Several approximations are incorporated to account for physical processes or effects which have not been accounted for specifically in the coding.

### 3.2.1. Aspect Ratio Enhancement

Aspect ratio enhancement (ARE) consists of modifying the vacuum magnetic field within the reactor by placing two or more relatively low-current supplementary coils in each mirror sector. Two types of supplementary coils are generally considered for this application: axis-circling ARE coils or SYM coils. In the code, ARE is accomplished using SYM coils. The effects of SYM coils on the magnetic field are shown in Fig. 6.

In the development of the systems analysis sections of the code (see Fig. 1), the magnetics modules were written in a rather simple manner. The principal purpose of the subroutines was to establish the mirror sector dimensions in a systematic fashion for the specified mirror ratio and for a fixed mirror coil thickness. The SYM coil dimensions are calculated on the basis of the dimensions of the mirror coils, the relationship between the ARE factor and the current required to drive the SYM coils (Fig. 4), and a specified value of the ARE factor. The ARE factor $f_A$ (specified in the code by FARE) is fixed at $f_A = 2.0$.

The overall dimensions of the reactors are determined from the relations between the geometrical aspect ratio

$$A_{\text{geometry}} = R_T/r_c \tag{27}$$

and the effective magnetic aspect ratio

$$A_{\text{eff}} = A_{\text{geometry}}/f_A = R_T/(f_A r_c) \tag{28}$$

(see Fig. 4). The number of sectors is determined from Eq. (26) by replacing $A$ with $A_{\text{eff}}$. (Note that $A_{\text{eff}}$ is the aspect ratio entering into the transport calculations.)

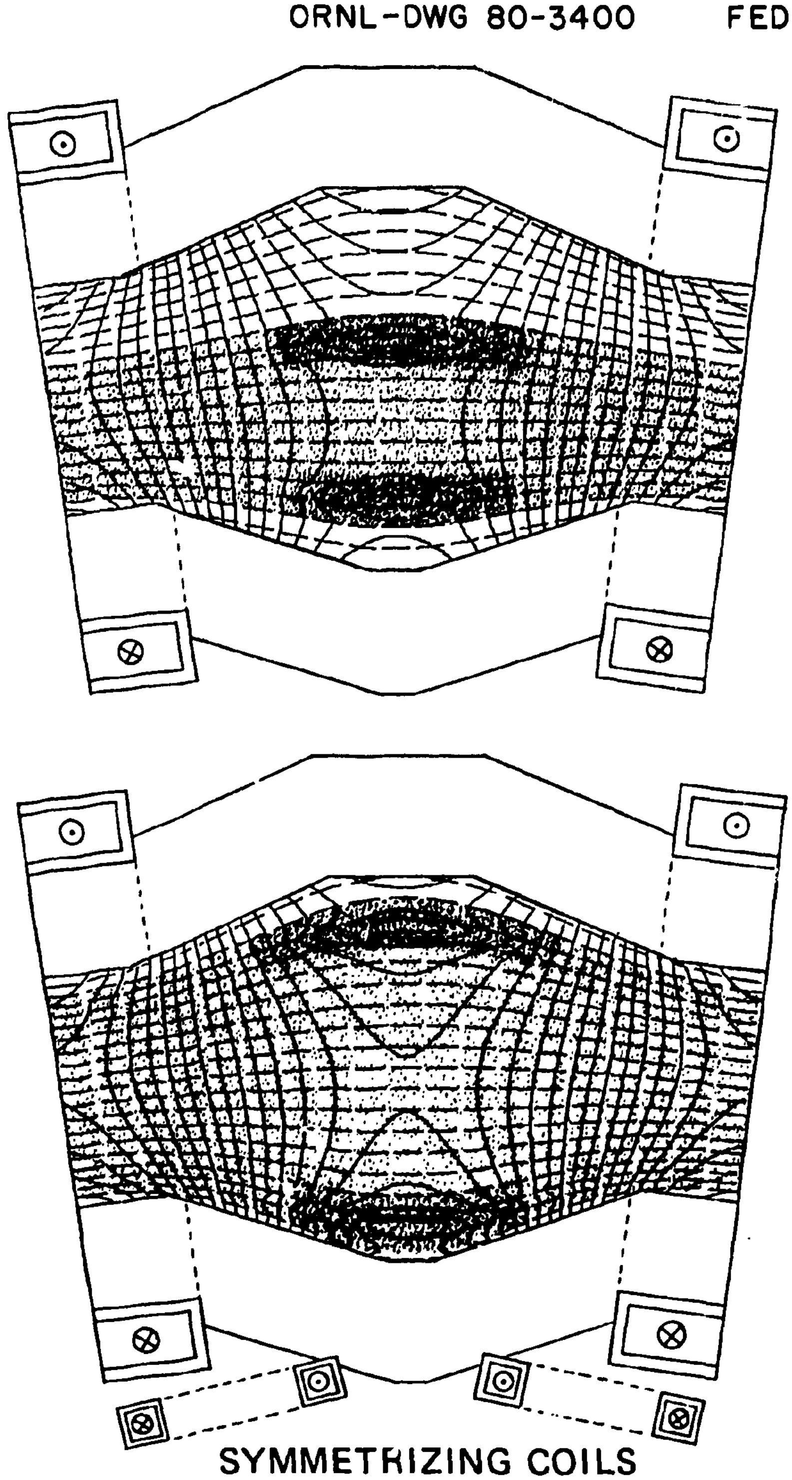


**Fig. 6.** Three-dimensional, finite-beta tensor pressure equilibria in one sector of a reactor without and with SYM coils ($I_{SYM}$ = 2%).

### 3.2.2. Profile Factors

Derivations of profile form factors are given in Appendices B and F of ref. 2. As discussed in ref. 2, the radial profile of core pressure $p_c$ can be derived from

$$p_c'(r)+\alpha(r)p_c(r) = 0 \tag{29}$$

to give

$$p_c(r) = C\exp[-\int\alpha(r)\,dr] \ , \tag{30}$$

where $C$ is constant and

$$\alpha(r) = \begin{cases} \dfrac{\gamma}{\langle R_B\rangle_{\mathrm{I}}} \simeq \dfrac{2\gamma r}{\langle r_0 R_c(r_0)\rangle} & 0 < r < r_0 - \Delta \\[2ex] \dfrac{\gamma}{\langle R_B\rangle_{\mathrm{II}}} \simeq \dfrac{2\gamma r}{\langle r_0 R_c(r_0)\rangle}\left[1+\beta_h\,\dfrac{\langle R_c\rangle}{4\Delta}\right] & r_0 - \Delta < r < r_0 \ . \\[2ex] \dfrac{1}{\Delta} & r_0 < r < r_0 + \Delta \end{cases} \tag{31}$$

Here, $\Delta$ is the ring half-width, $R_c$ is the radius of curvature, $r_0$ is the ring radius, $\beta_h$ is the ring beta, and $\gamma$ is the ratio of specific heats (see Fig. 7 and Appendix B of ref. 2).

Considering, for example, the central core plasma region [Region I in Fig. 7, $(0 < r < r_0 - \Delta)$],

$$p_c(r) = p_c(0)\exp\left[-\frac{\gamma}{r_0R_c(r_0)}\,r^2\right] \ , \tag{32}$$

where to a first-order approximation $rR_c = r_0R_c(r_0) \simeq$ constant. Because

$$\frac{p'}{p} = \frac{n'}{n} + \frac{T'}{T} \ ,$$

several combinations of density $n$ and temperature $T$ profiles can satisfy Eq. (32). For example, if $T'/T \ll n'/n$,

$$n(r) \simeq n(0)\exp\left[-\frac{\gamma}{r_0R_c(r_0)}\,r^2\right] = n(0)\exp(-\epsilon r^2) \ , \tag{33}$$

where $\epsilon = \gamma/r_0R_c(r_0)$. The density scale length is

$$l_n = -\left(\frac{1}{n}\,\frac{dn}{dr}\right)^{-1} \simeq \frac{R_c(r_0)}{2\gamma} \ , \tag{34}$$

ORNL-DWG 82-2812 FED

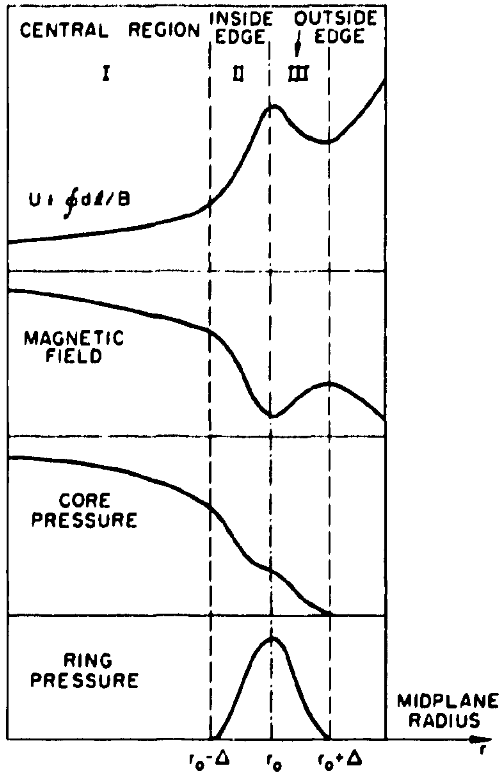


Fig. 7. Typical profiles of $U = \int dl/B$, the magnetic field $B$, and the pressures (core and ring) are given as a function of radius at the midplane of an EBT sector.

and the profile form factor is

$$f_n(r_0) = \frac{\langle n \rangle}{n(r_0)} \simeq (1/\epsilon r_0^2)[\exp(\epsilon r_0^2) - 1] \tag{35}$$

$$= 2(l_n/r_0)[\exp(\epsilon r_0^2) - 1] \; .$$

In the stability subroutine, Eq. (35) is approximated by

$$f_n = \frac{\langle n \rangle}{n(r_0)} = \frac{\langle n \rangle}{n_c} = 3 \; . \tag{36}$$

Then, the average core density near the ring is $\langle n \rangle = 3n_c$, and the average minimum core density near the ring (see Sect. 2.4) is

$$\langle n \rangle_{min} = 3 \cdot n_h \cdot (f_R)_{min} \; , \tag{37}$$

while the average maximum core density near the ring is

$$\langle n \rangle_{max} = 3 \cdot n_h \cdot (f_R)_{max} \; , \tag{38}$$

where $(f_R)_{min}$ and $(f_R)_{max}$ are given by Eqs. (12) and (18), respectively.

# 4. OPERATING INSTRUCTIONS AND EXAMPLE

The EBT reactor systems analysis and cost code has been written to operate on the CDC-7600 computer at the National Magnetic Fusion Energy Computing Center (NMFECC). Operation of the code requires that the user have access to this computer via an interactive terminal.

## 4.1. OPERATING INSTRUCTIONS

This sequence of operations for executing the code is shown schematically in Fig. 8. The sequence shows the procedure for accessing the code and input data files from storage, updating the input file, compiling and executing the code, and recovering the output data.

ORNL-DWG 82C 4079 FED

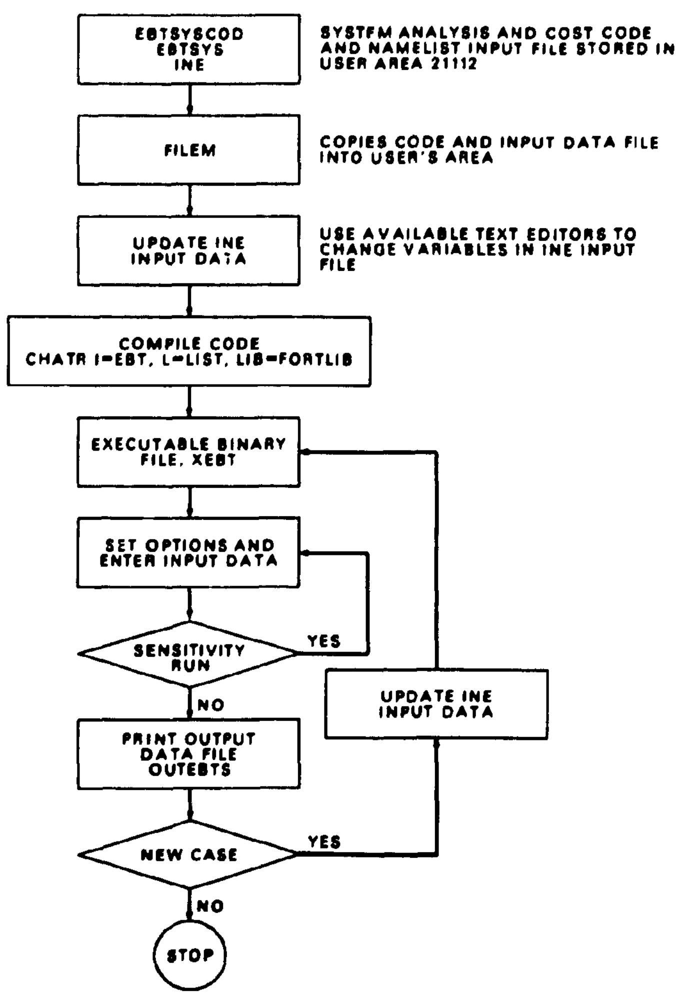


**Fig. 8. Sequence of operations for executing the EBT reactor systems analysis and cost code.**

The FORTRAN source deck and the input data file are initially copied into the user's area using the sequence of commands

READ 21112 .EBTSYSCOD EBTSYS INE

.END

where **EBTSYSCOD** is the file directory name, **EBTSYS** is the systems code, and **INE** is the input data file in **NAMELIST** format. A complete listing of the systems analysis and cost code is given in Appendix A. The input data file parameters are listed in Table 2. Revisions and modifications to the input data file may be made using any of the text editors available on the CDC-7600 computer.

**Table 2. INE input data NAMELIST variables**[a]

| | Description |
|---|---|
| CZ | Cold-zone thickness (m) |
| TBS | Blanket-shield thickness (m) |
| TBCS | Midplane distance between plasma and first wall (m) |
| PAUX | Auxiliary power requirement (MW) |
| ESC | Cost escalation factor |
| FLUENCE | Fluence limit (neutrons/cm$^2$) |
| ETATH | Thermal-to-electric conversion efficiency |
| ETAECH | Electron cyclotron heating efficiency |
| ETAICH | Ion cyclotron heating efficiency |
| ETALHH | Lower hybrid heating efficiency |
| SMPY | Scheduled BOP maintenance per year |
| USMPY | Unscheduled BOP maintenance per year |
| JSCMAX | Mirror coil current density (A/m$^2$) |
| ICPT | Cost summary and detailed cost account option (not used at present) |
| ICNST | Plant construction time (year) |
| IH | Heating option index<br>IH = −1 Ion cyclotron heating<br>IH = 0 Electron cyclotron heating<br>IH = +1 Lower hybrid heating<br>(see subroutine **COSTIT**) |

[a]Format: cz = 0.20, tbs = 1.00, tbcs = 1.42, paux = 100.0, esc = 1.55, fluence = 16.0, etath = 0.35, etaech = 0.5, etaich = 0.5, etalhh = 0.5, smpy = 28.0, unsmpy = 47.0, jscmax = 1.6E7, icpt = 0, icnst = 5, ih = 1 $ incost.

The code is compiled using the commands

CHATR I = EBTSYS,L=LIST,LIB=FORTLIB / 1 2

to create an executable binary deck called **XEBTSYS**. Execution is accomplished by typing the command **XEBTSYS**. The message shown in Fig. 9 then appears on the user's terminal. Several options under which the code may be executed are available. The code may be run with or without a cost analysis. If the response to the inquiry

OPERATING INSTRUCTIONS
*****************************

CODE IS SET UP TO RUN VARIOUS SENSITIVITIES
OF THE INPUT PARAMETERS

| SENSITIVITY | FUNCTION |
|---|---|
| 1 | COMPLETE CODE RUN |
| 2 | MIRROR RATIO |
| 3 | PLASMA MINOR RADIUS |
| 4 | CORE BETA |
| 5 | MAGNETIC FIELD (MIN) |
| 6 | BLANKET MULTIPLICATION |
| 7 | RING BETA |
| 8 | RING TEMPERATURE |

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

CONTROLS FOR ANALYSIS AND COST OPTIONS
COST ANALYSIS OPTION
0 – NO COST CALCULATION
1 – ANALYSIS PLUS COSTS
COST SUMMARY OPTION
1 – COST SUMMARY ONLY
2 – COST SUMMARY AND ACCOUNTS

COST ANALYSIS OPTION

Respond with 0 or 1

COST SUMMARY OPTION

Respond with 1 or 2

**Fig. 9. Image of initial instruction for executing the EBT systems analysis and cost code.**

COST ANALYSIS OPTION

is

0 – NO COST CALCULATIONS
1 – COST CALCULATIONS ARE MADE

when the response is 1, the message

COST SUMMARY OPTION

appears, to which either of the responses

1 – COST SUMMARY ONLY
2 – COST SUMMARY PLUS DETAILED COST ACCOUNTS

must be made (see Sect. 2). The statements shown in Fig. 10 then appear sequentially, with each requiring a response. For the first set of input data, the statement SENSITIVITY must be responded to with the value 1. The remaining input data are requested sequentially, with each requiring a response. Following input of the data shown in Fig. 10, the question is asked

DO YOU WISH TO EXECUTE AGAIN? <NO=STOP>

The response NO terminates execution and the output is written in file **OUTEBTS**. Continued execution is accomplished with a CARRIAGE RETURN or the response YES. At this point, two options are available. The code may be executed with a complete new set of input parameters by responding with a 1 after the inquiry SENSITIVITY, or a sensitivity analysis can be carried out by changing a single input parameter and holding all other input data constant. For example, responding to the inquiry SENSITIVITY with the value 4 returns the statement

CORE BETA

and a new value of core beta is specified and the code continues execution. All other input data remain the same. The sensitivity analysis may be repeated as often as required until the response to the inquiry

DO YOU WISH TO CONTINUE? <NO=STOP>

is NO.

Care must be taken to print the **OUTEBTS** file after a NO response and before executing the code again. Failure to do so will result in the file being overwritten, thereby destroying the results of the previous calculation. The **OUTEBTS** file may be saved, however, by renaming it with the command

SWITCH OUTEBTS filename

where **filename** is the renamed output file.

```
******************************************************

SENSITIVITY

ENTER PLASMA MINOR RADIUS

ENTER BETA VALUE

ENTER MINIMUM B VALUE

ENTER BLANKET MULTIPLICATION

ENTER RING BETA

ENTER RING TEMPERATURE



DO YOU WISH TO EXECUTE AGAIN?  <NO-STOP>
```

**Fig. 10. Variable input data to the EBT systems analysis and cost code.**

### 4.2. SAMPLE PROBLEM

The results of a typical reactor systems analysis and cost study are examined for a set of reactors that fall within the operating window shown in Fig. 5 and which are characterized by the following input parameters:

| | |
|---|---|
| Mirror ratio | 2.2 |
| Minimum plasma radius (under the coil) | 1.00 |
| Core beta | 0.10 |
| Minimum magnetic field (on-axis), T | 2.5 |
| Blanket multiplication factor | 0.25 |
| Ring beta | 0.15 |
| Ring temperature, keV | 2000 |

The code was executed with the cost option turned on to generate both the cost summary and the detailed cost accounts. The results of the calculations are shown in Figs. 11 through 14. The detailed cost accounts for this case are found in Appendix C.

Figure 11 shows the first page of output, which summarizes the input data and lists some key parameters used in the calculations or determined in the calculation. Figures 12 and 13 summarize the systems analysis portion of the calculation. For the set of input parameters, there are 11 reactor options that meet the stability criteria. The reactors range in size from a 20-sector configuration to several containing 36 sectors (but with slightly different aspect ratios). Finally, Fig. 15 shows the cost summary for the 11 reactor options stabilized by both electron and ion rings. The right four columns of the figure show the total capital cost and cost of electricity for the various reactors in constant-year and then-current dollars.

The allowed operating space, indicated in Fig. 5, is also valid for values of core beta $\beta_c$ between 5% and 15% (all other values of the input being constant). The comparisons of reactor performance and costs discussed in the remainder of this section are presented as a function of $\beta_c$ for a fixed average plasma density of $8 \times 10^{19}$ $m^{-3}$. (For displaying data, this value for the plasma density is chosen as a representative value, consistent with that anticipated in a typical EBT power reactor. However, it is not a "magic" number.) A complete data set is available, however, for all possible densities within the stable operating window shown in Fig. 5.

Figure 15 shows the variation of the reactor major radius $R_T$ and the number of sectors $N$ with core beta. The reactor size and the number of sectors decrease with increasing core beta for a fixed density because of the temperature increase. The major radius is decreased by ~3% where the number of sectors goes down by ~38%. The constant values for $R_T$ and $N$ for values of core beta between 6% and 8% arise from rounding off the calculation of the integer number of sectors. Also, near these beta values, the collisionality of electrons ($\nu/\Omega$) becomes nearly unity [i.e., transition from collisional to collisionless transport (see Appendix F, ref. 2)].

Figure 16 compares the power density (MW/m$^3$), the neutron wall loading (MW/m$^2$), and the thermal power produced per sector as a function of core beta for plasma density $n = 8 \times 10^{19}$ $m^{-3}$. These data were calculated assuming a blanket multiplication factor $M_b$ of 0.25. All of these power parameters increase with increasing core beta as expected.

The reactor performance as a function of core beta is plotted in Fig. 17, which shows the comparison between the total thermal power production and total power losses in both electron and ion rings. These data provide a basis for estimating the amount of power that must be recirculated to

```
                              INPUT VARIABLES

MIRROR RATIO (XMR)       2.200   PLASMA MINOR RADIUS(RADMIN)    1.000
BETA VALUE (BETA)        0.100   PRINT VALUE (ISEE)                 0
MINIMUM B (BMIN)         2.500   BLANKET MULT. (BLKMLT)         0.250
RING BETA (BETARG)       0.150   RING TEMP. (RTEMP)          2000.000
```

```
AVERAGE PLASMA RADIUS        = 1.483
TOROIDAL FIELD COIL RADIUS   = 2.750
TOROIDAL FIELD COIL LENGTH   = 2.100
AVERAGE MAGNETIC FIELD       = 4.000
ASPECT RATIO ENHANCEMENT     = 2.000
REFLECTION COEFFICIENT       = 0.900
MAJOR RADIUS/NUM SECTORS     = 1.094
```

**Fig. 11. Output for the sample problem.**

PHYSICS OUTPUT

| CASE | DENSITY (1/M**3) | PLASMA TEMPERATURE (KEV) | N-COLD/N-HOT | N-TAU (M**3/SEC) | ASPECT RATIO | MAJOR RADIUS (M) | NUMBER OF COILS |
|---|---|---|---|---|---|---|---|
| 1 | 6.ØØØØØE+19 | 3.3Ø827E+Ø1 | 3.511Ø8E+Ø1 | 1.72436E+2Ø | 1.2Ø876E+Ø1 | 3.324Ø8E+Ø1 | 3Ø |
| 2 | 7.ØØØØØE+19 | 2.63566E+Ø1 | 4.Ø9626E+Ø1 | 1.64857E+2Ø | 1.3Ø698E+Ø1 | 3.59419E+Ø1 | 32 |
| 3 | 8.ØØØØØE+19 | 2.4812ØE+Ø1 | 4.68144E+Ø1 | 1.6371ØE+2Ø | 1.39217E+Ø1 | 3.82847E+Ø1 | 36 |
| 4 | 9.ØØØØØE+19 | 2.2Ø551E+Ø1 | 5.26662E+Ø1 | 1.66416E+2Ø | 1.43812E+Ø1 | 3.95483E+Ø1 | 36 |
| 5 | 1.ØØØØØE+2Ø | 1.98496E+Ø1 | 5.8518ØE+Ø1 | 1.7266ØE+2Ø | 1.42733E+Ø1 | 3.92516E+Ø1 | 36 |
| 6 | 1.1ØØØØE+2Ø | 1.8Ø451E+Ø1 | 6.43698E+Ø1 | 1.81386E+2Ø | 1.35525E+Ø1 | 3.72694E+Ø1 | 34 |
| 7 | 1.2ØØØØE+2Ø | 1.65413E+Ø1 | 7.Ø2216E+Ø1 | 1.92479E+2Ø | 1.24129E+Ø1 | 3.41356E+Ø1 | 32 |
| 8 | 1.3ØØØØE+2Ø | 1.52689E+Ø1 | 7.6Ø734E+Ø1 | 2.Ø6Ø38E+2Ø | 1.11192E+Ø1 | 3.Ø5777E+Ø1 | 28 |
| 9 | 1.4ØØØØE+2Ø | 1.41783E+Ø1 | 8.19252E+Ø1 | 2.22297E+2Ø | 9.86665E+ØØ | 2.71333E+Ø1 | 24 |
| 1Ø | 1.5ØØØØE+2Ø | 1.32331E+Ø1 | 8.7777ØE+Ø1 | 2.41145E+2Ø | 8.74283E+ØØ | 2.4Ø428E+Ø1 | 22 |
| 11 | 1.6ØØØØE+2Ø | 1.2486ØE+Ø1 | 9.36288E+Ø1 | 2.62113E+2Ø | 7.7653ØE+ØØ | 2.13546E+Ø1 | 2Ø |

RING DATA

| ELECTRON RING PARAMETERS | | ION RING PARAMETERS | |
|---|---|---|---|
| LENGTH | Ø.7416 (M) | LENGTH | Ø.7416 (M) |
| THICKNESS | Ø.Ø688 (M) | THICKNES | Ø.1165 (M) |
| VOLUME | Ø.4752 (M**3) | VOLUME | 1.61Ø8 (M**3) |

| CASE | DRAG LOSS ELECTRON (MW) | SCATTERING LOSS-ELECT. (MW) | SYNCHROTRON LOSS-ELECT. (MW) | TOTAL ELECTRON RING POWER LOSS (MW) | TOTAL ION RING POWER LOSS (MW) |
|---|---|---|---|---|---|
| 1 | 2.69951E-Ø1 | 1.82588E-Ø1 | 1.11745E+ØØ | 1.56999E+ØØ | 4.96ØØ3E-Ø2 |
| 2 | 3.14943E-Ø1 | 2.13Ø19E-Ø1 | 1.11745E+ØØ | 1.64542E+ØØ | 7.292Ø8E-Ø2 |
| 3 | 3.59934E-Ø1 | 2.4345ØE-Ø1 | 1.11745E+ØØ | 1.72Ø84E+ØØ | 1.Ø1828E-Ø1 |
| 4 | [illegible]4926E-Ø1 | 2.73881E-Ø1 | 1.11745E+ØØ | 1.79626E+ØØ | 1.36682E-Ø1 |
| 5 | [illegible]9918E-Ø1 | 3.Ø4313E-Ø1 | 1.11745E+ØØ | 1.87168E+ØØ | 1.77871E-Ø1 |
| 6 | [illegible].491ØE-Ø1 | 3.34744E-Ø1 | 1.11745E+ØØ | 1.94711E+ØØ | 2.25729E-Ø1 |
| 7 | [illegible].399Ø2E-Ø1 | 3.65175E-Ø1 | 1.11745E+ØØ | 2.Ø2253E+ØØ | 2.8Ø582E-Ø1 |
| 8 | 5.84893E-Ø1 | 3.956Ø6E-Ø1 | 1.11745E+ØØ | 2.Ø9795E+ØØ | 3.4274ØE-Ø1 |
| 9 | 6.29885E-Ø1 | 4.26Ø38E-Ø1 | 1.11745E+ØØ | 2.17338E+ØØ | 4.125Ø2E-Ø1 |
| 1Ø | 6.74877E-Ø1 | 4.56469E-Ø1 | 1.11745E+ØØ | 2.2488ØE+ØØ | 4.9Ø156E-Ø1 |
| 11 | 7.19869E-Ø1 | 4.869ØØE-Ø1 | 1.11745E+ØØ | 2.32422E+ØØ | 5.75978E-Ø1 |

Fig. 12. Output for the sample problem (continued).

THERMAL POWER

SECTOR LENGTH 6.0716 (M)
SECTOR WALL AREA 72.6733 (M**2)
SECTOR VOLUME 47.4921 (M**3)

| CASE | POWER DENSITY (MW/M**3) | FIRST WALL LOAD (MW/M**2) | TOTAL THERMAL POWER (MWT) | ALPHA-PARTICLE POWER | POWER LOSS DUE TO RADIATION (MW) | POWER LOSS DUE TO TRANSPORT (MW) |
|---|---|---|---|---|---|---|
| 1 | 2.17520E+00 | 9.48786E-01 | 1.03305E+02 | 3.60388E-01 | 2.84485E-02 | 3.31940E-01 |
| 2 | 2.63189E+00 | 1.14799E+00 | 1.24994E+02 | 4.36053E-01 | 3.09870E-02 | 4.05066E-01 |
| 3 | 3.02456E+00 | 1.31926E+00 | 1.43643E+02 | 5.01111E-01 | 3.49341E-02 | 4.66177E-01 |
| 4 | 3.35417E+00 | 1.46303E+00 | 1.59297E+02 | 5.55721E-01 | 3.98001E-02 | 5.15921E-01 |
| 5 | 3.60846E+00 | 1.57395E+00 | 1.71373E+02 | 5.97851E-01 | 4.53347E-02 | 5.52516E-01 |
| 6 | 3.80204E+00 | 1.65839E+00 | 1.80567E+02 | 6.29923E-01 | 5.13965E-02 | 5.78527E-01 |
| 7 | 3.93919E+00 | 1.71821E+00 | 1.87081E+02 | 6.52647E-01 | 5.78996E-02 | 5.94748E-01 |
| 8 | 4.02399E+00 | 1.75520E+00 | 1.91108E+02 | 6.66697E-01 | 6.47877E-02 | 6.01989E-01 |
| 9 | 4.06096E+00 | 1.77132E+00 | 1.92864E+02 | 6.72822E-01 | 7.20220E-02 | 6.00800E-01 |
| 10 | 4.06189E+00 | 1.77173E+00 | 1.92908E+02 | 6.72975E-01 | 7.95742E-02 | 5.93481E-01 |
| 11 | 4.04242E+00 | 1.76323E+00 | 1.91983E+02 | 6.69750E-01 | 8.74228E-02 | 5.82327E-01 |

Q - VALUES

| CASE | TOTAL THERMAL POWER (MW) | TOTAL POWER LOSS IN THE RING (ELECTRON) | Q - PLASMA (ELECTRON) | Q - ELECTRIC (ELECTRON) | TOTAL POWER LOSS IN THE RING (ION) | Q - PLASMA (ION) | Q - ELECTRIC (ION) |
|---|---|---|---|---|---|---|---|
| 1 | 1.03305E+02 | 1.56999E+00 | 6.57996E+01 | 1.15149E+01 | 4.96003E-02 | 2.08275E+03 | 3.64480E+02 |
| 2 | 1.24994E+02 | 1.64542E+00 | 7.59651E+01 | 1.32939E+01 | 7.29208E-02 | 1.71411E+03 | 2.99968E+02 |
| 3 | 1.43643E+02 | 1.72084E+00 | 8.34727E+01 | 1.46077E+01 | 1.01820E-01 | 1.41076E+03 | 2.46882E+02 |
| 4 | 1.59297E+02 | 1.79626E+00 | 8.86824E+01 | 1.55194E+01 | 1.36682E-01 | 1.16545E+03 | 2.03954E+02 |
| 5 | 1.71373E+02 | 1.87168E+00 | 9.15610E+01 | 1.60231E+01 | 1.77871E-01 | 9.63467E+02 | 1.686[illegible]E+02 |
| 6 | 1.80567E+02 | 1.94711E+00 | 9.27360E+01 | 1.62288E+01 | 2.25729E-01 | 7.99927E+02 | 1.3998[illegible] |
| 7 | 1.87081E+02 | 2.02253E+00 | 9.24983E+01 | 1.61872E+01 | 2.80582E-01 | 6.66760E+02 | 1.16663E+[illegible] |
| 8 | 1.91108E+02 | 2.09795E+00 | 9.10926E+01 | 1.59412E+01 | 3.42740E-01 | 5.57589E+02 | 9.75779E+01 |
| 9 | 1.92864E+02 | 2.17338E+00 | 8.87392E+01 | 1.55293E+01 | 4.12502E-01 | 4.67546E+02 | 8.18203E+01 |
| 10 | 1.92908E+02 | 2.24880E+00 | 8.57825E+01 | 1.50119E+01 | 4.90156E-01 | 3.93564E+02 | 6.887[illegible]5E+01 |
| 11 | 1.91983E+02 | 2.32422E+00 | 8.26009E+01 | 1.44551E+01 | 5.75978E-01 | 3.33316E+02 | 5.83302E+01 |

**Fig. 13. Output for the sample problem (continued).**

ELECTRON RING COST SUMMARY

| CASE | NET POWER (MWE) | **** MAJOR COST ACCOUNTS **** STR/SITE FACLTS | REACTOR PLANT | TURBINE PLANT | ELECTRIC PLANT | ******** REACTOR PLANT BREAKDOWN ******** FW/B | SHIELD | COILS | RF | HEAT TRANS | FUEL HANDL | OTHER COSTS | TOTAL CAPITAL COST (CYD) | (TCD) | COST OF ELECTRICITY (CYD) | (TCD) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 890 | 273.9 | 1104.8 | 204.3 | 144.2 | 206.1 | 189.0 | 267.3 | 36.8 | 44.7 | 36.8 | 324.1 | 24[illegible]7 | 3058 | 41.36 | 76.19 |
| 2 | 1194 | 303.9 | 1215.6 | 245.4 | 152.8 | 219.9 | 201.6 | 285.1 | 40.3 | 57.7 | 47.5 | 363.6 | 2667 | 3388 | 3[illegible].18 | 62.95 |
| 3 | 1586 | 334.8 | 1399.7 | 295.5 | 168.6 | 247.3 | 226.8 | 320.8 | 46.5 | 74.5 | 61.4 | 422.3 | 3049 | 3873 | 29.43 | 54.21 |
| 4 | 1777 | 351.0 | 1444.3 | 318.5 | 170.2 | 247.3 | 226.8 | 320.8 | 47.7 | 82.7 | 68.1 | 451.0 | 3158 | 4024 | 27.29 | 50.26 |
| 5 | 1924 | 352.8 | 1475.6 | 335.8 | 171.9 | 247.3 | 226.8 | 320.8 | 48.9 | 88.9 | 73.2 | 469.6 | 3239 | 4114 | 23.81 | 47.51 |
| 6 | 1916 | 336.2 | 1422.9 | 334.6 | 166.0 | 233.6 | 214.2 | 302.9 | 47.3 | 88.5 | 72.9 | 463.6 | 3135 | 3982 | 25.16 | 46.27 |
| 7 | 1865 | 310.7 | 1362.3 | 328.5 | 159.9 | 219.9 | 201.6 | 285.1 | 45.5 | 86.3 | 71.1 | 452.8 | 3001 | 3812 | 24.81 | 45.59 |
| 8 | 1655 | 279.7 | 1215.5 | 302.9 | 146.1 | 192.4 | 176.4 | 249.5 | 40.7 | 77.1 | 63.5 | 415.9 | 2705 | 3436 | 25.32 | 46.46 |
| 9 | 1415 | 251.0 | 1055.8 | 272.7 | 131.9 | 164.9 | 151.2 | 213.8 | 35.7 | 66.7 | 55.0 | 368.5 | 2386 | 3031 | 26.27 | 48.11 |
| 10 | 1286 | 230.0 | 978.6 | 256.1 | 125.1 | 151.2 | 138.6 | 196.0 | 33.5 | 61.2 | 50.4 | 347.9 | 2220 | 2820 | 27.00 | 49.40 |
| 11 | 1150 | 212.5 | 899.6 | 238.3 | 118.1 | 137.4 | 126.0 | 178.2 | 31.1 | 55.3 | 45.6 | 326.0 | 2055 | 2611 | 28.02 | 51.22 |

ION RING COST SUMMARY

| CASE | NET POWER (MWE) | **** MAJOR COST ACCOUNTS **** STR/SITE FACLTS | REACTOR PLANT | TURBINE PLANT | ELECTRIC PLANT | ******** REACTOR PLANT BREAKDOWN ******** FW/B | SHIELD | COILS | RF | HEAT TRANS | FUEL HANDL | OTHER COSTS | TOTAL CAPITAL COST (CYD) | (TCD) | COST OF ELECTRICITY (CYD) | (TCD) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 981 | 273.9 | 1064.2 | 204.3 | 119.3 | 206.1 | 189.0 | 267.3 | 17.0 | 44.7 | 36.8 | 303.4 | 2318 | 2945 | 35.42 | 65.65 |
| 2 | 1295 | 303.9 | 1170.7 | 245.4 | 125.3 | 219.9 | 201.6 | 285.1 | 18.4 | 57.7 | 47.5 | 340.6 | 2568 | 3262 | 29.78 | 55.18 |
| 3 | 1702 | 334.8 | 1347.6 | 295.5 | 136.8 | 247.3 | 226.8 | 320.8 | 21.2 | 74.5 | 61.4 | 395.5 | 2935 | 3728 | 25.86 | 47.93 |
| 4 | 1897 | 351.0 | 1390.6 | 318.5 | 137.6 | 247.3 | 226.8 | 320.8 | 21.7 | 82.7 | 68.1 | 423.3 | 3051 | 3875 | 24.14 | 44.73 |
| 5 | 2046 | 352.8 | 1420.5 | 335.8 | 138.6 | 247.3 | 226.8 | 320.8 | 22.4 | 88.9 | 73.2 | 441.0 | 3119 | 3961 | 22.93 | 42.45 |
| 6 | 2033 | 336.2 | 1369.9 | 334.6 | 134.0 | 233.6 | 214.2 | 302.9 | 21.9 | 88.5 | 72.9 | 435.9 | 3019 | 3835 | 22.41 | 41.46 |
| 7 | 1977 | 310.7 | 1311.4 | 328.5 | 129.5 | 219.9 | 201.6 | 285.1 | 21.3 | 86.3 | 71.1 | 426.2 | 2891 | 3672 | 22.13 | 40.90 |
| 8 | 1753 | 279.7 | 1170.4 | 302.9 | 119.3 | 192.4 | 176.4 | 249.5 | 19.4 | 77.1 | 63.5 | 392.0 | 2607 | 3312 | 22.62 | 41.74 |
| 9 | 1500 | 251.0 | 1016.7 | 272.7 | 108.8 | 164.9 | 151.2 | 213.8 | 17.4 | 66.7 | 55.0 | 347.7 | 2301 | 2923 | 23.50 | 43.27 |
| 10 | 1363 | 230.0 | 942.5 | 256.1 | 104.0 | 151.2 | 138.6 | 196.0 | 16.7 | 61.2 | 50.4 | 328.5 | 2142 | 2721 | 24.16 | 44.43 |
| 11 | 1220 | 212.5 | 866.6 | 238.3 | 99.0 | 137.4 | 126.0 | 178.2 | 15.9 | 55.3 | 45.6 | 308.1 | 1984 | 2521 | 25.09 | 46.09 |

Fig. 14. Output for the sample problem (continued).

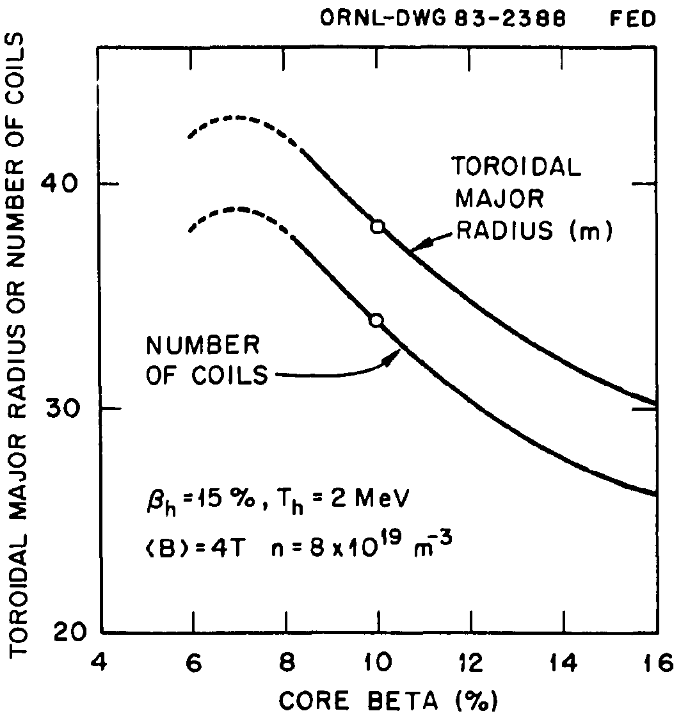


**Fig. 15. Variation of the major radius $R_T$ and number of sectors $N$ with core plasma beta $\beta_c$.**

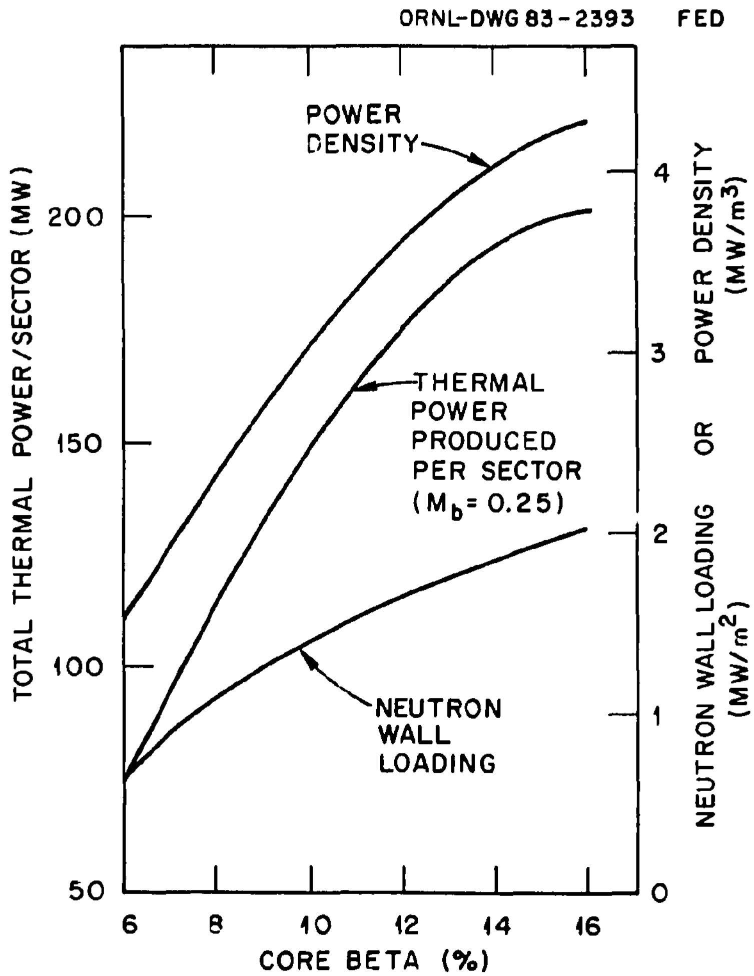


**Fig. 16. Variation of fusion power density, neutron wall loading, and thermal power with core plasma beta for core plasma density $n$ = $8 \times 10^{19}$ m$^{-3}$.**

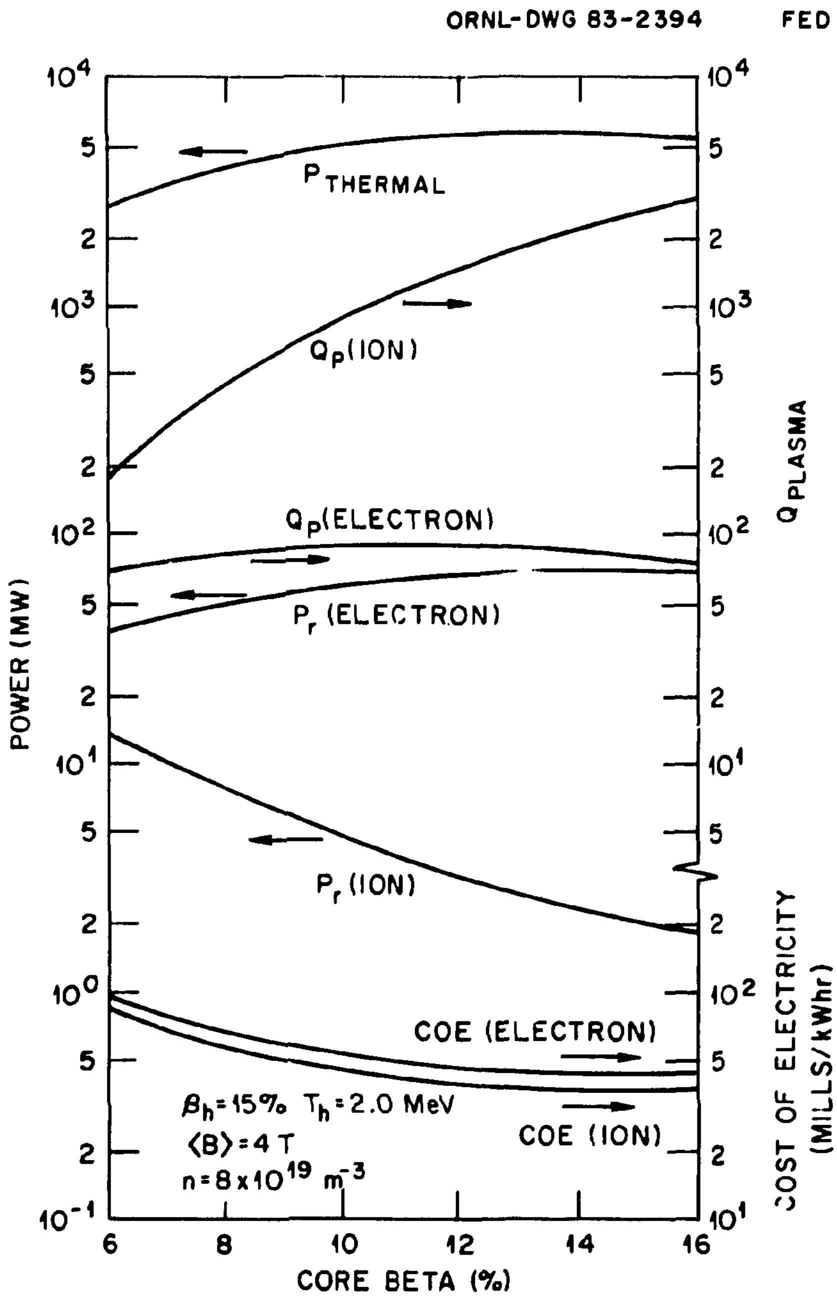


**Fig. 17. Reactor performance parameters (fusion power, ring sustaining power, plasma $Q$ value, cost of electricity, etc.) as a function of core plasma beta for $n = 8 \times 10^{19}$ m$^{-3}$.**

maintain the rings. This estimate is manifested in the $Q_P$(electron) and $Q_P$(ion) curves, which are the ratios of $P_{thermal}/P_{ring}$ for the appropriate rings. The reciprocal of $Q_P$ is the recirculating power fraction. The cost of producing electricity is plotted in the lower portion of the figure. The cost of electricity is ~10% larger when electron ring stabilization is used.

Table 3 lists a representative set of performance parameters for an EBT reactor with an average plasma density of $8 \times 10^{19}$ $m^{-3}$ and operating with a core beta of 10%. These data were taken from the curves plotted in Fig. 17 and from the code output in Figs. 11–13.

**Table 3. Results of the systems code analysis for an EBT reactor with core beta of 10%**

| | |
|---|---|
| Net electric power (MW) | |
| with electron ring | 1540 |
| with ion ring | 1650 |
| Thermal power (MW) | 5000 |
| Average plasma radius (m) | 1.5 |
| Number of sectors | 34 |
| Neutron wall loading (MW/m$^2$) | 1.4 |
| Average magnetic field (T) | 4 |
| Inner coil radius (m) | 2.75 |
| Aspect ratio enhancement | 2 |
| Average core plasma density (m$^{-3}$) | $8 \times 10^{19}$ |
| Average core ion temperature (keV) | 25 |
| Ring temperature (MeV) | 2 |
| Core-ring beta values (%) | 10–15 |
| Ring power losses (MW) | |
| Electron rings | 60 |
| Ion rings | 5 |
| Cost of electricity ($ millions/kWh) | |
| Electron rings | 51 |
| Ion rings | 45 |

## REFERENCES


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4. T. Uckan, *Straight Bumpy Field Calculations with Finite Coil Length* (unpublished).
5. D. B. Nelson, "Effects of Hot Electrons on Magnetohydrodynamic Modes in ELMO Bumpy Torus," *Phys. Fluids* **23**, 1850 (1980).
6. J. W. Van Dam and Y. C. Lee, in *EBT Ring Physics: Proceedings of the Workshop*, CONF-791228, Oak Ridge Natl. Lab., 1980, p. 471.
7. S. C. Shulte, T. L. Wilke, and J. R. Jovng, *Fusion Reactor Design Studies—Standard Accounts for Cost Estimates*, PNL-2648, Battelle Pacific Lab., May 1978. See also, S. C. Shulte, W. E. Bickford, C. E. Willingham, S. K. Ghose, and M. G. Walker, *Fusion Reactor Design Studies—Standard Unit Costs and Cost Scaling Laws*, PNL-2987, Battelle Pacific Lab., September 1979.

# APPENDIX A

## CODE LIST (FORTRAN)

```
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C       Elmo Bumpy Torus Reactor Systems Analysis Code
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C       R. T. Santoro, N. A. Uckan, and J. M. Barnes
C
C       This version of the code current as of 1 Aug 1983
C
C       The codo includes the cost analysis package
C       developed by MDAC and included in the code
C       by D. Driemeyer. The code processes reactor
C       options with both electron and ion rings.
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C .      NOTES
C        -----
C
C       (1).  This version of the code operates on the CDC 7600
C             at the Magnetic Fusion Energy Computer SystEM.
C       (2).  VERSION INCLUDES:
C                   (A). DRIVER PACKAGE
C                   (B). SOME REFINEMENTS ON THE PHYSICS PACKAGE.
C                   (C). CRUDE NEUTRONICS.
C                   (D). MAGNETICS PACKAGE BY D.DRIEMEYER.
C                   (E). MAGNET PACKAGE CHANGED BY RTS
C                                Feb 10,1983
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C       RUNNING INSTRUCTIONS FOR CDC-7600 AT LLL
C       ----------------------------------------
C
C       CHATR I=filename,L=LIST,LIB=(FORTLIB,NAG) / 1 2
C
C                WHERE  filename  IS THE NAME OF THE FILE
C                SENT TO THE CDC-7600 COMPUTER.
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C       COMMON STATEMENTS.
C
      COMMON/INPARM/ARATIO(25),PTHTOT(25),POWDEN(25),TORRAD(25),
     1  NCOIL(25),XMR,YYY,RTOVRN,RPAVG,RADMIN,BAVG,BMIN,BMAX,
     2  BETA,TEE,TAU,UFUS,FUSENG,BLKMLT,DELCZ,DELBS,DLCOIL,
     3  DLMAG,SECLEN,SECARA,SECVOL,COILNO,ISEE
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      COMMON/COILS/TFCRAD,TFCLEN,TFCARA,TFCCUR,SYMHIT,SYMWID,
     1  SYMARA,SYMCUR,SYMPCT
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      COMMON/RINGS/ PMU(25,2),QPLAS(25,2),QELEC(25,2),PSYNC(25,2),
     1  PDRAG(25),PSCATR(25),FR(25),BRING,RTEMP,BCORE,GAMMA,
     2  GGAMMA,AVGBRG,BETARG,AVBCOR,HGAMMA,HSGMMA,RNELEN,
     3  RNILEN,RNEVOL,RNIVOL,DELTE,DELTI
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      COMMON/RTS/ DEN(25),TP(25),SIGMAV(25),TAUN(25),PTHSEC(25),
     1  PALPHA(25),PBREM(25),PCYCL(25),PRAD(25),PLINE(25),
     2  PRECMB(25),PTRANS(25),WALLOD(25)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      COMMON/COSTCON/ PAUX,FLUENCE,CZ,TBS,TBCS,ESC,SMPY,USMPY,
     2  ETATH,ETAICH,ETAECH,ETALHH,JSCMAX,ICPT,ICNST,IH
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      COMMON/CFIXED/ FARE,KF,RC,COEFFR
```

```
      COMMON/L/IJK,JJJ
      COMMON/OPT/IANAL,JCOST
      REAL JSCMAX,KF
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
         NAMELIST/INCOST/ PAUX,FLUENCE,CZ,TBS,TBCS,SMPY,USMPY,
     2   ESC,ETATH,ETAICH,ETAECH,ETALHH,JSCMAX,ICPT,ICNST,IH
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C        INPUT STATEMENTS.
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
         LOGICAL ANS
C....     LINK I/O UNITS TO THE PROGRAM
      CALL LINK("I=INE,UNIT5=(I,OPEN),UNIT6=(OUTERTS,CREATE,TEXT),
     2    UNIT59=TTY//")
         IBEEN = Ø
         DATA AHSNO/"NO    "/
         DATA ITIME/1/
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C        THE FOLLOWING VARIABLES ARE TEMPORARILY FIXED IN THE
C        CODE.      RTS  MAY 28,1982
C        ASPECT RATIO ENHANCEMENT FACTOR SET TO 2.Ø
         FARE = 2.Ø
C        PROFILE FACTOR SET TO 3.Ø     JUNE 9,1982
         KF = 3.Ø
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C      READ IN CONSTANTS NEEDED FOR COST CALCULATION
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
         READ (5,INCOST)
         WRITE (59,1111)
1111     FORMAT(23X,"Operating Instructions",/
     X          23X,"**********************",//
     X     10X,"Code is set up to run various sensitivities of",/
     X     10X,"the input parameters",/
     X     16X,"Sensitivity",19X,"Function",/
     X     16X,"***********",19X,"********",//)
         WRITE (59,2222)
2222     FORMAT(2ØX,"1",2ØX,"Complete Code Run",/
     X          2ØX,"2",2ØX,"Mirror Ratio",/
     X          2ØX,"3",2ØX,"Plasma Minor Radius",/
     X          2ØX,"4",2ØX,"Core Beta",/
     X          2ØX,"5",2ØX,"Magnetic Field (MIN)",/
     X          2ØX,"6",2ØX,"Blanket Multiplication",/
     X          2ØX,"7",2ØX,"Ring Beta",/
     X          2ØX, 8",2ØX,"Ring Temperature")
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
         WRITE(59,3232)
3232     FORMAT(1H ,"*********************************************")
         WRITE(59,3333)
3333     FORMAT(2ØX,"Controls for Analysis and Cost Options",/
     X          2ØX,"IANAL = 1    No cost calculation         ",/
     X          2ØX,"IANAL = 2    Analysis plus costs         ",/
     X          2ØX,"JCOST = 1    Cost Summary Only           ",/
     X          2ØX,"JCOST = 2    Cost Summary and Accounts")
         WRITE(59,4343)
4343     FORMAT(1H ,"Cost Analysis Option")
         READ(59,4445) IANAL
4445     FORMAT(I1)
         IF(IANAL.EQ.1) GO TO 4446
         WRITE(59,9898)
9898     FORMAT(1H ,"Cost Summary Option ")
         READ(59,4445) JCOST
         GO TO 4448
4446     JCOST = Ø
4448     CONTINUE
         WRITE(59,3232)
```

```
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
9999    CONTINUE
        IBEEN=IBEEN+1
        IJK = Ø
        IF(IBEEN .EQ. 1) GO TO 444
        WRITE (59,445)
  445   FORMAT(//," DO YOU WISH TO EXECUTE AGAIN? <NO=STOP>" )
        READ (59,446) ANS
  446   FORMAT(A5)
        IF(ANS .EQ. ANSNO) STOP Ø1
  444   CONTINUE
        WRITE (59,8ØØ)
8ØØ     FORMAT(1H ," Sensitivity " )
        READ (59,9ØØ) ISENS
9ØØ     FORMAT(I1)
        IF(ITIME.EQ.1) GO TO 9ØØØ
        GO TO (1,2,3,4,5,6,7,8),ISENS
1       CONTINUE
9ØØØ    CONTINUE
2       WRITE (59,12)
12      FORMAT(1H ," Enter Mirror Ratio " )
        READ (59,13)  XMR
        IF(ISENS.EQ.2) GO TO 975
        IF(XMR.GT.4.Ø .OR. XMR.LT.1.6) CALL ERRMSG(1)
13      FORMAT(F1Ø.4)
3       WRITE (59,14)
        RADMIN = Ø.Ø
14      FORMAT(1H ," Enter Plasma Minor Radius " )
        READ (59,13) RADMIN
        IF(ISENS.EQ.3) GO TO 975
4       WRITE (59,16)
16      FORMAT(1H ," Enter Beta Value " )
        READ (59,13)  Beta
        IF(ISENS.EQ.4) GO TO 975
        IF(Beta.GT.Ø.35 .OR. Beta.LT.Ø.Ø1) CALL ERRMSG(5)
C       WRITE (59,17)
17      FORMAT(1H ," Enter Density Value " )
15      FORMAT(F1Ø.4)
5       WRITE (59,35)
35      FORMAT(1H ," Enter Minimum B Value " )
        READ (59,15)  Bmin
        IF(ISENS.EQ.5) GO TO 975
        IF(BMIN.GT.6.Ø .OR. BMIN .LT. 2.Ø) CALL ERRMSG(4)
6       WRITE (59,3Ø)
3Ø      FORMAT(1H ," Enter Blanket Multiplication "  )
        READ (59,31) BLKMLT
        IF(ISENS.EQ.6) GO TO 975
31      FORMAT(F12.5)
        IF(BLKMLT .GT. Ø.25 .OR. BLKMLT .LT. Ø.Ø)CALL ERRMSG(8)
7       WRITE (59,41)
41      FORMAT(1H ," Enter Beta Ring " )
        READ (59,31) Betarg
        IF(ISENS.EQ.7) GO TO 975
C
8       WRITE (59,42)
42      FORMAT(1H ," Enter Ring Temperature " )
        READ (59,31) RTEMP
        IF(ISENS.EQ.8) GO TO 975
        IF(ISENS.EQ.8) GO TO 975
C
975     CONTINUE
        D= Ø.ØØØ
        DO 25Ø I = 1,25
        NCOIL(I) = Ø
```

```
      RPAVG = Ø.Ø
250   CONTINUE
C * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      CALL BLKSHD
      CALL MAGNET
      CALL STABIL
      ITIME = 2
      GO TO 9999
      STOP Ø2
      END
```

```
      SUBROUTINE BLKSHD
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C       This routine sets the blanket and shield dimensions.
C       DELCZ = The thickness of the cold zone (m)
C       DELBS = The thickness of the blanket and shield (m)
C
C       The variables CZ and TBS are input to the code from
C       a NAMELIST input.  ( Called INE )
C
C       At the present time, no differentiation is made between
C       the thickness of the various blanket shield components.
C       The dimensions of these components are approximated
C       in the cost analysis.
C
C       R. T. Santoro         28 July 1983
C
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
      COMMON/INPARM/ARATIO(25),PTHTOT(25),POWDEN(25),TORRAD(25),
     1  NCOIL(25),XMR,YYY,RTOVRN,RPAVG,RADMIN,BAVG,BMIN,BMAX,
     2  BETA,TEE,TAU,UFUS,FUSENG,BLKMLT,DELCZ,DELBS,DLCOIL,
     3  DLMAG,SECLEN,SECARA,SECVOL,COILNO,ISEE
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
      COMMON/COSTCON/ PAUX,FLUENCE,TV,TCS,TBCS,ESC,SMPY,USMPY,
     2  ETATH,ETAICH,ETAECH,ETALHH,JSCMAX,ICPT,ICNST,IH
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
      DELCZ = TV
      IF(DELCZ.GT.Ø.3Ø .OR. DELCZ.LT.Ø.Ø5) CALL ERRMSG(3)
      DELBS = TCS
      IF(DELBS.GT.2.Ø .OR. DELBS.LT.Ø.5) CALL ERRMSG(2)
      RETURN
      END
```

```
      SUBROUTINE ERRMSG(N)
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C     This routine tests the range of the input variables
C     and prints appropriate messages cautioning the user.
C
C     The code does not terminate when a message is printed.
C     The user should, however, proceed with caution since
C     the answers may not be correct.
C
C     R. T. Santoro                           29 July 1983
C
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
      LOGICAL ANSNO,ANS
      DATA ANSNO/"NO    "/
      GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15),N
      WRITE (59,100)
  100 FORMAT(1H ,"$$$$$ Error out of range of this routine')
      WRITE (59,101)
  101 FORMAT(1H ,"# # # Process continuing")
      WRITE (59,102) N
  102 FORMAT(1H0," * * * * * Error number was ",I3)
      GO TO 999
C     Warning mes age    Mirror Ratio
    1 WRITE (59,103)
103   FORMAT(1H0,"* * * * * * Warning: ")
      WRITE (59,104)
  104 FORMAT(1H ,"*  Mirror ratio is > 4.0 or < 1.6 ")
  105 FORMAT(1H ,"* # # # # Process continuing ")
  106 FORMAT(1H ," * * * * * * ",///)
      GO TO 999
c     Warning message    Blanket-Shield Thickness
2     WRITE (59,103)
      WRITE (59,107)
107   FORMAT(1H ,"* Blanket thickness is > 2 or < 0.5 m")
      GO TO 999
3     WRITE (59,103)
      WRITE (59,108)
108   FORMAT(1H ,"* Cold zone thickness > 0.3 or < 0.05 m")
      GO TO 999
C     Warning message     B-Minimum
4     WRITE (59,103)
      WRITE (59,109)
109   FORMAT(1H ,"* B Minimum is > 6T or < 2T")
      GO TO 999
C     Warning message    Core Beta
5     WRITE (59,103)
      WRITE (59,110)
110   FORMAT(1H ,"* Core beta is > 0.25 or < 0.01")
      GO TO 999
C     Warning message   Core density
6     WRITE (59,103)
      WRITE (59,111)
111   FORMAT(1H ,"*  Density is >5.0E+20 or < 0.2E+20")
      GO TO 999
C     Warning message   Plasma tEMperature
7     WRITE (59,103)
      WRITE (59,112)
112   FORMAT(1H ,"* TP is > 1100 KEV or < 1 KEV")
      GO TO 999
8     CONTINUE
C     Warning message   Blanket multiplication
      WRITE (59,103)
      WRITE (59,113)
```

```
113     FORMAT(1H ,"* Blanket multiplication > Ø.25 or < Ø.Ø")
        GO TO 999
9       CONTINUE
1Ø      CONTINUE
11      CONTINUE
12      CONTINUE
13      CONTINUE
14      CONTINUE
15      CONTINUE
999     WRITE (59,998)
998     FORMAT(1H ,"* Do you wish to continue ? (YES/NO/CR)   " )
        READ (59,997) ANS
997     FORMAT(A5)
        IF(ANS .EQ. ANSNO) STOP Ø3
        WRITE (59,1Ø5)
        WRITE (59,1Ø6)
        RETURN
        END
```

```
      SUBROUTINE SPACER(U,XQ,RMU,AMPS,NOUTOT,N)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C     U array is the array of new X points.
C     RMU array is the array of old X data points.
C     AMPS array is the array of F(RMU) data.
C     NOUTOT = Number of U points.
C     N = Numbr of RMU points.
C     XQ(I) is the array of F(U(I)) returned to
C     the calling program.
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      DIMENSION U(1),XQ(1),RMU(1),AMPS(1)
 10   DO 110 I=1,NOUTOT
      N1=N-1
      DO 20 J=2,N1
      IF(U(I)-RMU(J))30,100,20
 20   CONTINUE
      J=N-1
 30   IF(AMPS(J-1))60,60,40
 40   IF(AMPS(J))60,60,50
 50   IF(AMPS(J+1))60,60,70
 60   XQ(I)=ALAG(U(I),RMU(J-1),RMU(J),RMU(J+1),AMPS(J-1),AMPS(J),AMPS(J+
     11))
      GO TO 110
 70   T1=ALOG(AMPS(J-1))
      T2=ALOG(AMPS(J))
      T3=ALOG(AMPS(J+1))
 80   XQ(I)=ALAG(U(I),RMU(J-1),RMU(J),RMU(J+1),T1,T2,T3)
 90   XQ(I)=EXP(XQ(I))
      GO TO 110
 100  XQ(I)=AMPS(J)
 110  CONTINUE
 120  RETURN
      END
```

```
      FUNCTION ALAG(XO,X1,X2,X3,Y1,Y2,Y3)
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C
C     Lagrange Interpolation SchEMe
C
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
      ALAG=(XO-X2)*(XO-X3)*Y1/((X1-X2)*(X1-X3))+(XO-X1)*
     1(XO-X3)*Y2/((X2-X1)*(X2-X3))+(XO-X1)*(XO-X2)*Y3/((X3-X1)*(X3-X2))
      IF((X1-XO)*(X2-XO))1Ø,1Ø,2Ø
 1Ø   IF((Y1-ALAG)*(Y2-ALAG))9Ø,9Ø,7Ø
 2Ø   IF((X2-XO)*(X3-XO))3Ø,3Ø,4Ø
 3Ø   IF((Y2-ALAG)*(Y3-ALAG))9Ø,9Ø,8Ø
 4Ø   IF(XO-X2)5Ø,5Ø,6Ø
 5Ø   IF(X1-X3)7Ø,7Ø,8Ø
 6Ø   IF(X1-X3)8Ø,8Ø,7Ø
 7Ø   ALAG=Y1+(Y2-Y1)*(XO-X1)/(X2-X1)
      GO TO 9Ø
 8Ø   ALAG=Y2+(Y3-Y2)*(XO-X2)/(X3-X2)
 9Ø   RETURN
      END
```

```
      SUBROUTINE RANGE(A,B,C,D,LOOP,STEP)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C     This routine calculates range of plasma densities
C     based on parameters determined by stability analysis.
C     The minimum and maximum plasma density is determined
C     along with the number of steps between these values
C     and the step size
C
C     The set of reactors are calculated for all
C     values of LOOP.
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      XLOW = Ø.Ø
      YLOW = Ø.Ø
      XXX=1.ØE+18
      DO 1Ø I = 1,18
      AA=A/XXX
      N = AA
      IF(N.GE.1.AND.N.LE.1Ø)   GO TO 4Ø
      XXX=1Ø.*XXX
1Ø    CONTINUE
4Ø    CONTINUE
      YYY=1.ØE+17
      DO 2Ø I = 1,18
      BB = B/YYY
      M = BB
      IF(M.GE.1Ø.AND.M.LE.1ØØ)   GO TO 5Ø
      YYY=1Ø.*YYY
2Ø    CONTINUE
5Ø    CONTINUE
      C = N
      D = M
      IF(N.LE.1Ø) L = 1
      XX = N
      YY = M
      X = AA - XX
      Y = BB - YY
      IF(X.GT.Ø.) XLOW = 1.Ø
      IF(Y.GT.Ø.) YLOW = 1.Ø
      STEP = L*XXX
      LOOP = (B - C*XXX)/STEP + 1.Ø + XLOW + YLOW
      C = C*XXX
      D = D*YYY
      RETURN
      END
```

```
      SUBROUTINE PHYSIC(INDEX,DDD)
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C
C       This routine calculates the D-T reaction probability
C       as a function of the plasma temperature.
C
C       Also calculated is the reactor aspect ratio for either
C       electron and ion scaling.  The number of coils is
C       determined from the aspect ratio as an integer number.
C
C
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
      COMMON/INPARM/ARATIO(25),PTHTOT(25),POWDEN(25),TORRAD(25),
     1  NCOIL(25),XMR,YYY,RTOVRN,RPAVG,RADMIN,BAVG,BMIN,BMAX,
     2  BETA,TEE,TAU,UFUS,FUSENG,BLKMLT,DELCZ,DELBS,DLCOIL,
     3  DLMAG,SECLEN,SECARA,SECVOL,COILNO,ISEE
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
      COMMON/CFIXED/ FARE,KF,RC,COEFFR
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
      COMMON/RTS/ DEN(25),TP(25),SIGMAV(25),TAUN(25),PTHSEC(25),
     1  PALPHA(25),PBREM(25),PCYCL(25),PRAD(25),PLINE(25),
     2  PRECMB(25),PTRANS(25),WALLOD(25)
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
       COMMON/COILS/TFCRAD,TFCLEN,TFCARA,TFCCUR,SYMHIT,SYMWID,
     1   SYMARA,SYMCUR,SYMPCT
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
      DIMENSION TMP(141),SIG(141)
      DATA (TMP(I),I=1,72)/
     X.10000E+01,.12000E+01,.14000E+01,.16000E+01,.18000E+01,.20000E+01,
     X.22000E+01,.24000E+01,.26000E+01,.28000E+01,.30000E+01,.32000E+01,
     X.34000E+01,.36000E+01,.38000E+01,.40000E+01,.42000E+01,.44000E+01,
     X.46000E+01,.48000E+01,.50000E+01,.52000E+01,.54000E+01,.56000E+01,
     X.58000E+01,.60000E+01,.62000E+01,.64000E+01,.66000E+01,.68000E+01,
     X.70000E+01,.72000E+01,.74000E+01,.76000E+01,.78000E+01,.80000E+01,
     X.82000E+01,.84000E+01,.86000E+01,.88000E+01,.90000E+01,.92000E+01,
     X.94000E+01,.96000E+01,.98000E+01,.10000E+02,.12000E+02,.14000E+02,
     X.16000E+02,.18000E+02,.20000E+02,.22000E+02,.24000E+02,.26000E+02,
     X.28000E+02,.30000E+02,.32000E+02,.34000E+02,.36000E+02,.38000E+02,
     X.40000E+02,.42000E+02,.44000E+02,.46000E+02,.48000E+02,.50000E+02,
     X.52000E+02,.54000E+02,.56000E+02,.58000E+02,.60000E+02,.62000E+02/
      DATA (TMP(I),I=73,141)/
     X.64000E+02,.66000E+02,.68000E+02,.70000E+02,.72000E+02,.74000E+02,
     X.76000E+02,.78000E+02,.80000E+02,.82000E+02,.84000E+02,.86000E+02,
     X.88000E+02,.90000E+02,.92000E+02,.94000E+02,.96000E+02,.98000E+02,
     X.10000E+03,.12000E+03,.14000E+03,.16000E+03,.18000E+03,.20000E+03,
     X.22000E+03,.24000E+03,.26000E+03,.28000E+03,.30000E+03,.32000E+03,
     X.34000E+03,.36000E+03,.38000E+03,.40000E+03,.42000E+03,.44000E+03,
     X.46000E+03,.48000E+03,.50000E+03,.52000E+03,.54000E+03,.56000E+03,
     X.58000E+03,.60000E+03,.62000E+03,.64000E+03,.66000E+03,.68000E+03,
     X.70000E+03,.72000E+03,.74000E+03,.76000E+03,.78000E+03,.80000E+03,
     X.82000E+03,.84000E+03,.86000E+03,.88000E+03,.90000E+03,.92000E+03,
     X.94000E+03,.96000E+03,.98000E+03,.10000E+04,.10200E+04,.10400E+04,
     X.10600E+04,.10800E+04,.11000E+04/
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
      DATA (SIG(I),I=1,72)/
     X.62700E-26,.18600E-25,.44400E-25,.91100E-25,.16700E-24,.28300E-24,
     X.44700E-24,.67200E-24,.96700E-24,.13400E-23,.18100E-23,.23800E-23,
     X.30600E-23,.38600E-23,.47900E-23,.58600E-23,.70700E-23,.84300E-23,
     X.99500E-23,.11600E-22,.13500E-22,.15500E-22,.17700E-22,.20000E-22,
     X.22600E-22,.25300E-22,.28100E-22,.31200E-22,.34400E-22,.37800E-22,
     X.41400E-22,.45200E-22,.49100E-22,.53100E-22,.57400E-22,.61700E-22,
     X.66300E-22,.70900E-22,.75700E-22,.80700E-22,.85700E-22,.90900E-22,
     X.96200E-22,.10200E-21,.10700E-21,.11300E-21,.17400E-21,.23900E-21,
```

```
     X.30600E-21,.37000E-21,.43100E-21,.48800E-21,.53900E-21,.58600E-21,
     X.62800E-21,.66500E-21,.69800E-21,.72700E-21,.75200E-21,.77400E-21,
     X.79300E-21,.80900E-21,.82300E-21,.83500E-21,.84500E-21,.85400E-21,
     X.86100E-21,.86600E-21,.87000E-21,.87400E-21,.87600E-21,.87700E-21/
        DATA (SIG(I),I=73,141)/
     X.87800E-21,.87800E-21,.87700E-21,.87600E-21,.87400E-21,.87200E-21,
     X.87000E-21,.86700E-21,.86400E-21,.86100E-21,.85700E-21,.85400E-21,
     X.85000E-21,.84600E-21,.84200E-21,.83700E-21,.83300E-21,.82900E-21,
     X.82400E-21,.77700E-21,.73100E-21,.68900E-21,.65000E-21,.61600E-21,
     X.58500E-21,.55700E-21,.53200E-21,.51000E-21,.49000E-21,.47200E-21,
     X.45500E-21,.44000E-21,.42600E-21,.41300E-21,.40100E-21,.39100E-21,
     X.38100E-21,.37100E-21,.36300E-21,.35500E-21,.34700E-21,.34000E-21,
     X.33400E-21,.32800E-21,.32200E-21,.31600E-21,.31100E-21,.30700E-21,
     X.30200E-21,.29800E-21,.29400E-21,.29000E-21,.28600E-21,.28300E-21,
     X.27900E-21,.27600E-21,.27300E-21,.27000E-21,.26800E-21,.26500E-21,
     X.26200E-21,.26000E-21,.25800E-21,.25500E-21,.25500E-21,.25500E-21,
     X.25500E-21,.25500E-21,.25500E-21/
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C
C       Set up constants.
                XK1 = 1.2406E+21
                XK2 = 3.1300E-18
                PI=3.14159
        I = INDEX
C       SCALE = 5.0     Ion scaling used in the determination
C                       of the aspect ratio.
C       Scale = 1.0     Electron Scaling used in the
C                       determination of the aspect ratio.
        SCALE = 1.0
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
        CALL SPACER(TP(I),SIGMAV(I),TMP,SIG,1,141)
C
C
C       Call routine to determine confinement time.
C
                CALL CONFMT(INDEX)
C
C       The calculation of the aspect ratio is based on electron
C       scaling. Calculations with ion scaling are performed
C       by changing the constant in ARATIO to 1.97E+17.
C
        IF(SCALE.EQ.1.0) GO TO 60
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C
C               Ion Scaling
C
        ARATIO(I)=SQRT(TAUN(I)/(1.95E+17*TP(I)**1.5*FARE*FARE))
        GO TO 70
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C
C       New version of NTAU calculation.    September 8, 1982
C               Electron Scaling
C
   60   WSUB0 = 1.0 + RC/RPAVG
        XNU   = XK2*DEN(I)*BAVG*RC*RPAVG/(TP(I)**2.5)
        W2 = WSUB0*WSUB0
        X2 = XNU*XNU
        AA = TAUN(I)/(4.11E+14*TP(I)**1.5*FARE*FARE*(X2+W2))
        ARATIO(I) = SQRT(AA)
70      CONTINUE
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C
C     Solve RT = A*RC.    Since A=RT/RC.
C
```

```
      TORRAD(I)=ARATIO(I)*TFCRAD
      COILNO = TORRAD(I)/RTOVRN
C
C    Convert the number of coils to an even integer.
C
         NCOIL(I) = COILNO
         NREMND = MOD(NCOIL(I),2)
         IF(NREMND .EQ. 1) NCOIL(I)=NCOIL(I)+1
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C        Old version of equation to determine ntau.
C        Saved for historical reasons.
C
C60       ARATIO(I)=SQRT(TAUN(I)/(3.ØE+15*TP(I)**1.5*FARE*FARE))
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
         RETURN
         END
```

```
      SUBROUTINE FUSPWR(INDEX)
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C       This routine calculates the fusion power parameters
C       for the set of EBT Reactors calculated by the code.
C
C       UN = Neutron Energy              = 14.1 MeV
C       UALFA = Alpha Particle Energy =  3.5 MeV
C       UFUS = Total fusion energy (MeV).
C       BLKMLT = Blanket multiplication factor.
C
C       PTHSEC = Thermal power produced per sector (MW)
C       POWDEN = Power Density per sector (MW/m**3)
C       WALLOD = Neutron Wall Loading (MW/m**2)
C
C       R. T. Santoro                          1 Aug 1983
C
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
     COMMON/INPARM/ARATIO(25),PTHTOT(25),POWDEN(25),TORRAD(25),
    1  NCOIL(25),XMR,YYY,R1OVRN,RPAVG,RADMIN,BAVG,BMIN,BMAX,
    2  BETA,TEE,TAU,UFUS,FUSENG,BLKMLT,DELCZ,DELBS,DLCOIL,
    3  DLMAG,SECLEN,SECARA,SECVOL,COILNO,ISEE
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
     COMMON/RTS/ DEN(25),TP(25),SIGMAV(25),TAUN(25),PTHSEC(25),
    1  PALPHA(25),PBREM(25),PCYCL(25),PRAD(25),PLINE(25),
    2  PRECMB(25),PTRANS(25),WALLOD(25)
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
      I = INDEX
      XK2 = 1.602E-19
      UN=14.1
      UALFA=3.5
      UT = UN + UALFA
C
C    Calculate the thermal power/sector and power density.
C
      UFUS=UN*(1.+BLKMLT) + UALFA
      PTHSEC(I)=SECVOL*(DEN(I)/4.0)*SIGMAV(I)*UFUS*XK2
      PTHSEC(I)=PTHSEC(I)*DEN(I)
      POWDEN(I) = PTHSEC(I)/SECVOL
C
C     Calculate the neutron wall loading.
C
      WALLOD(I)=(UN*PTHSEC(I))/(SECARA*UFUS)
      RETURN
      END
```

```
      SUBROUTINE CONFMT(INDEX)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C       Calculates the power losses in the EBT Reactors.
C       Calculates the confinement time n-tau.
C
C       Power losses are from
C
C               Cyclotron Radiation
C               Aplha-particle losses in the plasma.
C               Line radiation
C               1^HRecombination
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      COMMON/INPARM/ARATIO(25),PTHTOT(25),POWDEN(25),TORRAD(25),
     1  NCOIL(25),XMR,YYY,RTOVRN,RPAVG,RADMIN,BAVG,BMIN,BMAX,
     2  BETA,TEE,TAU,UFUS,FUSENG,BLKMLT,DELCZ,DELBS,DLCOIL,
     3  DLMAG,SECLEN,SECARA,SECVOL,COILNO,ISEE
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      COMMON/COILS/ TFCRAD,TFCLEN,TFCARA,TFCCUR,SYMHIT,SYMWID,
     1  SYMARA,SYMCUR,SYMPCT
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      COMMON/RINGS/ PMU(25,2),QPLAS(25,2),QELEC(25,2),PSYNC(25,2),
     1  PDRAG(25),PSCATR(25),FR(25),BRING,RTEMP,BCORE,GAMMA,
     2  GGAMMA,AVGBRG,BETARG,AVBCOR,HGAMMA,HSGMMA,RNELEN,
     3  RNILEN,RNEVOL,RNIVOL,DELTE,DELTI
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      COMMON/CFIXED/ FARE,KF,RC,COEFFR
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      COMMON/RTS/ DEN(25),TP(25),SIGMAV(25),TAUN(25),PTHSEC(25),
     1  PALPHA(25),PBREM(25),PCYCL(25),PRAD(25),PLINE(25),
     2  PRECMB(25),PTRANS(25),WALLOD(25)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C
C       Set the various constants to be used in this routine.
C
            I = INDEX
C       ZEFF set equal to 1.1Ø    August 2Ø,1982
            ZEFF = 1.1Ø
C       COEFFR set equal to Ø.9Ø  August 2Ø,1982
            COEFFR = Ø.9Ø
C       FALPHA is set to 1.Ø.  A value of Ø.8 is probably a
C       more nearly correct value.
              FALPHA = 1.Ø
              UALFA = 3.5
              XK1 = 1.6Ø2E-19
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C       Calculate the power lost by alpha-particles in the
C       plasma.  Alpha- particle energy = 3.5 MeV.
C
      PALPHA(I)=(DEN(I)/4.Ø)*SIGMAV(I)*FALPHA
      PALPHA(I)=PALPHA(I)*DEN(I)*UALFA*XK1
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C       Calculate the cyclotron power losses.
C
C      PCYCL(I)=6.2E-23*BAVG**2*DEN(I)*TP(I)
C     X *(1.Ø+TP(I)/2Ø4.Ø)*(1.Ø-COEFFR)
C
C       Equations for calculating the cyclotron power
C       modified 2Ø August 1982.  Per N.A. Uckan.
```

```
C
      PCYCL(I) = 2.4E-17*SQRT(DEN(I)*BAVG/RPAVG)*
     X           BAVG*BAVG*TP(I)**2.75*(1.Ø+TP(I)/2Ø4.Ø)*
     X           (1.Ø-COEFFR)
C
C
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C       Calculate the power loss due to bremmstrahlung radiation
C                  with ZEFF = 1.1Ø
C
      PBREM(I)=3.ØE-21*2.Ø*DEN(I)*SQRT(TP(I))
      PBREM(I)=1.6E-22*DEN(I)*PBREM(I)
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C
C
C       Power losses due to line radiation and
C       recombination are not calculated. The
C       formulae for these processes will be
C       included later.
C
      PLINE(I)=Ø.Ø
      PRECMB(I) = Ø.Ø
      PRAD(I)=PBREM(I)+PLINE(I)+PRECMB(I)+PCYCL(I)
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C
C       Calculate the power losses due to transport
C       processes.  Note P-RATIO = PADD/PRAD(I) = Ø.Ø
C
      PRATIO = Ø.Ø
      PTRANS(I) = (1.Ø + PRATIO)*PALPHA(I)-PRAD(I)
C
            ENTAU2=3.Ø*DEN(I)*TP(I)/PTRANS(I)
            TAUN(I)=ENTAU2*DEN(I)*1.6Ø2E-22
C
       RETURN
       END
```

```
      SUBROUTINE RINGS(INDEX)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C         Calculation of electron and ion ring power losses.
C
C
C         The electron and ion ring volumes are calculated
C         assuming that both ring species have the same
C         overall lengths but with the ring volumes being
C         a function of DELTE for electron rings and DELTI
C         for ion rings.
C
C                                                R.T.Santoro
C                                                October 19,1983
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      COMMON/INPARM/ARATIO(25),PTHTOT(25),POWDEN(25),TORRAD(25),
     1  NCOIL(25),XMR,YYY,RTOVRN,RPAVG,RADMIN,BAVG,BMIN,BMAX,
     2  BETA,TEE,TAU,UFUS,FUSENG,BLKMLT,DELCZ,DELBS,DLCOIL,
     3  DLMAG,SECLEN,SECARA,SECVOL,COILNO,ISEE
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      COMMON/COILS/ TFCRAD,TFCLEN,TFCARA,TFCCUR,SYMHIT,SYMWID,
     1  SYMARA,SYMCUR,SYMPCT
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      COMMON/RINGS/ PMU(25,2),QPLAS(25,2),QELEC(25,2),PSYNC(25,2),
     1  PDRAG(25),PSCATR(25),FR(25),BRING,RTEMP,BCORE,GAMMA,
     2  GGAMMA,AVGBRG,BETARG,AVBCOR,HGAMMA,HSGMMA,RNELEN,
     3  RNILEN,RNEVOL,RNIVOL,DELTE,DELTI
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      COMMON/RTS/ DEN(25),TP(25),SIGMAV(25),TAUN(25),PTHSEC(25),
     1  PALPHA(25),PBREM(25),PCYCL(25),PRAD(25),PLINE(25),
     2  PRECMB(25),PTRANS(25),WALLOD(25)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      COMMON/CFIXED/ FARE,KF,RC,COEFFR
      COMMON/L/IJK,JJJ
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
        I = INDEX
        PI = 3.14159
        IF(IJK.GT.1) GO TO 50
C
C       Ring length is set to the plasma radius divided by two
C       in order to account for the axial profile.
                RNELEN = RPAVG/2.0
                RNILEN = RNELEN
C       Calculate the ring volume using FWHM for fig thickness.
                RNEVOL = 2.0*PI*RPAVG*RNELEN*DELTE
                RNIVOL = 4.0*PI*RPAVG*RNILEN*DELTI
50      CONTINUE
        IJK = 5
C       GAMMA is the relativistic factor.
                GAMMA = 1.0 + RTEMP/511.0
        HGAMMA = GAMMA/((GAMMA-1.0)**2 * SQRT(GAMMA**2-1.0))
                TEMP1 = FR(I)*BETARG*BETARG*(AVGBRG**4)
C       Calculation of the drag term for electrons.
                PDRAG(I) = 1.15 * TEMP1 * HGAMMA
C       Calculation of the scattering term for electrons.
                PSCATR(I) = PDRAG(I)*4.0/(GAMMA+1.0)
C
C       GGAMMA=1.0 + 2.5*(GAMMA-1.0) +1.5*(GAMMA-1.0)/
C    >   ((GAMMA-1.0) +0.7)
C

                GGAMMA = 1.0 + 2.5*(GAMMA - 1.0)
C
C       Temporary revision for GAMMA per NAU 6/5/82.
```

```
C
C       Calculation of the synchrotron loss in electron rings.
        PSYNC(I,1) = Ø.155*BETARG*AVGBRG**2 * AVGBRG**2 * GGAMMA
C
C       Temporary calculation of PMUI (Ion Rings)
C       To be modified when better equation is obtained.
C
        PMU(I,2) = 5.ØE+2*BETA*BETARG*AVGBRG**4*(1.5/TP(I))**2.5
C
C
C       Calculation of the ring (electron and ion) sustaining
C       power terms.
                PDRAG(I) = PDRAG(I)*RNEVOL
                PSCATR(I) = PSCATR(I)*RNEVOL
                PSYNC(I,1) = PSYNC(I,1)*RNEVOL
                PMU(I,1) = PDRAG(I) + PSCATR(I) + PSYNC(I,1)
C       Calcuation of the ratio of the fusion power produced
C       to the ring sustaining power.  (Electron rings)
                QPLAS(I,1) = PTHSEC(I)/PMU(I,1)
                QELEC(I,1) = QPLAS(I,1)/5.7143
C       Calcuation of the ratio of the fusion power produced
C       to the ring sustaining power.  (Ion rings)
                PMU(I,2) = PMU(I,2)*RNIVOL
                QPLAS(I,2)  = PTHSEC(I)/PMU(I,2)
                QELEC(I,2)  = QPLAS(I,2)/5.7143
        RETURN
        END
```

```
      SUBROUTINE STABIL
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     Core-ring stability calculation to determine the set
C     of EBT Reactors that lie within a stable operating
C     region and that have core and ring properties
C     specified by core beta, rine beta, and ring temp-
C     erature.  Maximum allowable core beta is governed
C     by the core-pressure-driven interchange according
C     to the Lee-Van Dam-Nelson limit.
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
     COMMON/INPARM/ARATIO(25),PTHTOT(25),POWDEN(25),TORRAD(25),
    1  NCOIL(25),XMR,YYY,RTOVRN,RPAVG,RADMIN,BAVG,BMIN,BMAX,
    2  BETA,TEE,TAU,UFUS,FUSENG,BLKMLT,DELCZ,DELBS,DLCOIL,
    3  DLMAG,SECLEN,SECARA,SECVOL,COILNO,ISEE
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
     COMMON/COILS/ TFCRAD,TFCLEN,TFCARA,TFCCUR,SYMHIT,SYMWID,
    1  SYMARA,SYMCUR,SYMPCT
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
     COMMON/RINGS/ PMU(25,2),QPLAS(25,2),QELEC(25,2),PSYNC(25,2),
    1  PDRAG(25),PSCATR(25),FR(25),BRING,RTEMP,BCORE,GAMMA,
    2  GGAMMA,AVGBRG,BETARG,AVBCOR,HGAMMA,HSGMMA,RNELEN,
    3  RNILEN,RNEVOL,RNIVOL,DELTE,DELTI
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
     COMMON/CFIXED/ FARE,KF,RC,COEFFR
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
     COMMON/RTS/ DEN(25),TP(25),SIGMAV(25),TAUN(25),PTHSEC(25),
    1  PALPHA(25),PBREM(25),PCYCL(25),PRAD(25),PLINE(25),
    2  PRECMB(25),PTRANS(25),WALLOD(25)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
     COMMON/FR/ FRMIN,FRMAX
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      COMMON/OPT/IANAL,JCOST
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
     COMMON/COSTCON/ PAUX,FLUENCE,CZ,TBS,TBCS,ESC,SMPY,USMPY,
    2   ETATH,ETAICH,ETAECH,ETALHH,JSCMAX,ICPT,ICNST,IH
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
     REAL KF
C     Calculate magnetic field at the ring location.
              AVGBRG = Ø.7Ø*BMIN
              BRSQ   = AVGBRG*AVGBRG
C     Calculate the electron and ion ring widths.
              DELTE = RC/2.Ø*BETA
              RHO = 4.56E-3*SQRT(RTEMP)/AVGBRG
              DELTI = AMAX1(DELTE,RHO)
C     Begin calculation of stability parameters.
C
C     DENR is the ring density
C     QSUBO is the ratio of hot electron curvature drift
C          frequency to the ion cyclotron frequency.
C     FRMIN is the lower limit on the core density.
C     XNCLD is the minimum core density near the ring.
C     DENMIN is the average minimum core density near the
C          ring.
C     DENMAX is the average maximum core desity near the ring.
C     FRMAX is the upper limit on the core density.
C
      DENR = 2.48E+21*BETARG*BRSQ/RTEMP
      QSUBO = 2.5E-Ø5*RTEMP/(BRSQ*DELTE*RC)
      FRMIN = (Ø.1Ø/QSUBO)*(1.Ø/(BETA/2.Ø-Ø.25)**2)
      XNCLD = DENR*FRMIN
C     KF is a profile factor. See App. B, ORNL/TM-8712.
      DENMIN = KF*DENR*FRMIN
      DENMAX = 1.ØE+19*BAVG*BAVG
```

```
      FRMAX = DENMAX/(KF*DENR)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C      The extremes of the upper and lower boundaries of the
C      operating space have been determined. Now determine
C      the finite range of (n sub c / n sub h) that falls
C      within the stable plasma region.
C
C      The range of plasma temperatures operating within the
C      allowed (n sub c / n sub h) range must always exceed
C      5 keV (Bremsstrahlung limit).
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      DENMAX = AMIN1(2.ØE+2Ø,DENMAX)
      DENMIN = AMAX1(DENMIN,6.ØE+19)
      CALL RANGE(DENMIN,DENMAX,DLOW,DHI,LOOP,STEP)
      DEN(1) = DLOW
C
C      Calculate the allowed range of core plasma density.
C
      DO 5Ø I = 2,LOOP
      DEN(I)  = DEN(I-1) + STEP
5Ø    CONTINUE
      DO 55 I = 1,LOOP
      JJJ = I
C
C      Calculate the range of plasma temperatures for the
C      allowed range of core plasma densities.
C
      TP(I)=1.24Ø6E+21*(BETA*BAVG*BAVG)/DEN(I)
      IF(TP(I).LE.6.Ø)  GO TO 888
55    CONTINUE
888   LOOP = JJJ
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C      Main loop to determine the EBT Reactors that lie within
C      the stable operating region for the specified core and
C      ring betas and ring temperature.
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      DO 1ØØ I = 1,LOOP
      INDEX = I
      FR(I) = DEN(I)/(KF*DENR)
      CALL PHYSIC(INDEX,DEN(INDEX))
      CALL FUSPWR(INDEX)
      CALL RINGS(INDEX)
1ØØ   CONTINUE
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C      Output Loop and Cost Calculations.
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      CALL OUTPUT(LOOP)
      IF(IANAL.EQ.1) GO TO 999
      IPRNT = Ø
      DO 12Ø IR=1,2
      IRING = IR - 1
      IHEADR = 1
      DO 12Ø I=1,LOOP
      CALL COSTIT(TORRAD(I),NCOIL(I),RADMIN,RPAVG,PTHSEC(I),PMU(I,IR),
     2 BMAX,WALLOD(I),BETA,SECLEN,DEN(I),PALPHA(I),TAUN(I),SECVOL,
     3 COE,I,IHEADR,IPRNT,IRING)
 12Ø  CONTINUE
      IF(JCOST.EQ.2) ICPT = 1
      IF (ICPT) 999,999,13Ø
```

```
130  IPRNT = 1
     DO 140 IR=1,2
     IRING = IR - 1
     DO 140 I=1,LOOP
     CALL COSTIT(TORRAD(I),NCOIL(I),RADMIN,RPAVG,PTHSEC(I),PMU(I,IR),
    2  BMAX,WALLOD(I),BETA,SECLEN,DEN(I),PALPHA(I),TAUN(I),SECVOL,
    3  COE,I,IHEADR,IPRNT,IRING)
140  CONTINUE
999    RETURN
     END
```

```
      SUBROUTINE MIRROR(D)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C     This routine calculates the function
C
C           Y = f(Mirror Ratio)
C
C     Mirror ratio is calculated for a magnet having a
C     D/L ratio of Ø.25.  The data are based on a
C     calculation by T. Uckan.
C
C     <:::: D ::::>                         <:::: D ::::>
C     ************                          ************
C     *          *                          *          *
C     *   Coil   *                          *   Coil   *
C     *          *                          *          *
C     ************                          ************
C
C         <:::::::::::::::: L :::::::::::::::::>
C
C     Sector length = 2*Pi*RT/n
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
     COMMON/INPARM/ARATIO(25),PTHTOT(25),POWDEN(25),TORRAD(25),
    1  NCOIL(25),XMR,YYY,RTOVRN,RPAVG,RADMIN,BAVG,BMIN,BMAX,
    2  BETA,TEE,TAU,UFUS,FUSENG,BLKMLT,DELCZ,DELBS,DLCOIL,
    3  DLMAG,SECLEN,SECARA,SECVOL,COILNO,ISEE
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      COMMON/L/IJK,JJJ
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      DIMENSION XMM(25),DL(25)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      DATA DL/
    X4.9487,4.3285,3.83Ø2,3.4251,3.Ø919,2.8153,2.5835,2.3877,
    X2.2211,2.Ø875,1.9556,1.8492,1.7567,1.6758,1.6Ø48,1.5422,
    X1.487Ø,1.438Ø,1.3945,1.3588,1.3212,1.29Ø2,1.2625,1.2376,
    X1.2152/
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      IF(JJJ.GT.1) GO TO 1ØØ
      CALL REVER (25,DL)
      XMM(1) = 1.7
      DO 1Ø I = 2,25
      XMM(I) = XMM(I-1) + Ø.1
1Ø    CONTINUE
      CALL REVER (25,XMM)
      JJJ = 1Ø
1ØØ   CONTINUE
      IF(D.EQ.Ø.ØØØ) CALL SPACER(XMR,YYY,DL,XMM,1,25)
      RETURN
      END
```

```
      SUBROUTINE MAGNET
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C       This routine calculates the magnet coil and sector
C       dimensions for a specified mirror ratio and D/L value.
C
C       D = coil length
C       L = sector length
C
C
C
C               *****************
C               *               *
C               *     Coil      * --------------------
C               *               *   Coil half-thickness, DLCOIL
C               ***************** ---------------------
C
C                                   DLMAG
C
C       *****************************************************
C
C               Blanket and shield.  DELBS
C
C
C               Dimension set in SUBR BLKSHD
C       *****************************************************
C
C               Scrape-off region.   DELCZ
C       -----------------------------------------------------
C
C               Plasma with radius RADMIN
C
C       --------- Center line ------------------------
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      COMMON/INPARM/ARATIO(25),PTHTOT(25),POWDEN(25),TORRAD(25),
     1  NCOIL(25),XMR,YYY,RTOVRN,RPAVG,RADMIN,BAVG,BMIN,BMAX,
     2  BETA,TEE,TAU,UFUS,FUSENG,BLKMLT,DELCZ,DELBS,DLCOIL,
     3  DLMAG,SECLEN,SECARA,SECVOL,COILNO,ISEE
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      COMMON/COILS/TFCRAD,TFCLEN,TFCARA,TFCCUR,SYMHIT,SYMWID,
     1  SYMARA,SYMCUR,SYMPCT
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      COMMON/CFIXED/ FARE,KF,RC,COEFFR
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      COMMON/COSTCON/ PAUX,FLUENCE,CZ,TBS,TBCS,ESC,SMPY,USMPY,
     2  ETATH,ETAICH,ETAECH,ETALHH,JSCMAX,ICPT,ICNST,IH
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      DIMENSION AXMR(5),ASYM(4)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      REAL JSCMAX
      DATA XMUØ/12.5664E-7/,PI/3.141592654/
      DATA AXMR/4.41122,-.639896,Ø.171Ø34,-.Ø53Ø628,Ø.Ø19667Ø/
      DATA ASYM/Ø.2266Ø4,Ø.Ø988275,-.Ø135369,Ø.ØØ119448/
      DATA XMAVG/3.Ø347/,XMDEL/1.4748/
      DATA FAVG/1.561ØØ/,FDEL/Ø.561ØØ/
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
                     CALL MIRROR(D)
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C       Current density is input by JCSMAX = 16 MA/m**2
C
```

```
      DLMAG = Ø.2Ø
      DLCOIL = Ø.35
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C     The magnet coil radius is determined from
C          plasma radius.........................RADMIN
C          scrape-off zone thickness..............DELCZ
C          blanket-shield thickness...............DELBS
C          distance between shield and magnet......DLMAG
C          coil half-thickness....................DLCOIL
C
C     Coil length is 6 times the coil half-thickness
C     Aspect ratio = 3 : 1
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
      DWRRAD = RADMIN + DELCZ + DELBS + DLMAG + DLCOIL
      TFCRAD = DWRRAD
      TFCLEN = 6.Ø*DLCOIL
      TFCARA = 2.Ø*DLCOIL*TFCLEN
      TFCCUR = JSCMAX*TFCARA
C
     FNORM = (FARE - FAVG)/FDEL
     TM2 = 1.
     TM1 = FNORM
     SYMPCT = Ø.5*ASYM(1) + ASYM(2)*TM1
     DO 2ØØ I=3,4
     TM = 2.Ø*FNORM*TM1 - TM2
     SYMPCT = SYMPCT + ASYM(I)*TM
     TM2 = TM1
     TM1 = TM
 2ØØ CONTINUE
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C     Symmetrizing coil dimensions.
C
C     Calculate the SYM coil current
                SYMCUR = SYMPCT*TFCCUR
C     Calculate the SYM coil area
                SYMARA = SYMCUR/JSCMAX
C     Calculate the SYM coil length
                SYMHIT = 2.Ø*TFCRAD
C
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
            BMAX=XHR*BMIN
            BAVG=(BMAX+BMIN)*Ø.5
C     YYY = N*TFCRAD/RT; RT/NCOILRAD * TFCRAD => RT/N
            RTOVRN = TFCRAD/YYY
            RPAVG=SQRT(XMR*(RADMIN**2))
C     Calculate the reactor sector length (SECLEN)
            SECLEN=2*PI*RTOVRN
C     Calculate the volume of the reactor sector (SECVOL)
            SECVOL=PI*(RPAVG)**2*SECLEN
C     Calculate the wall area of the reactor sector (SECARA)
            SECARA=2.*PI*(RPAVG+DELCZ)*SECLEN
C     Calculate the SYM coil width
            SYMWID = Ø.5*(SECLEN - TFCLEN)
C     Impose enhancement condition.
            RC = TFCRAD/FARE
      RETURN
      END
```

```
      SUBROUTINE COSTIT(RØ,N,RL,RP,PTHSEC,PANNTH,BT,WALOAD,BETAP,SECLEN,
     2    DENI,PALPHA,TAUN,SECVOL,COEMM,INUM,IHEADR,IPRNT,IRING)
C*********************************************************************
      DIMENSION XIDC(7,2),EDC(7,2),COMT(6Ø),NSEG(6Ø),AVL(6Ø)
     #,B(1Ø4),JJ(132),COE(6Ø,2),COEM(2),C94(2),C95(2),CTOT(2),
     #CTOTP(2),JJ1(6Ø),CTOT1(2),CSETS(4),NSETS(6Ø)
C*********************************************************************
      COMMON/COILS/TFCRAD,TFCLEN,TFCARA,TFCCUR,SYMHIT,SYMWID,
     1  SYMARA,SYMCUR,SYMPCT
C*********************************************************************
      COMMON/COSTCON/ PAUX,FLUENCE,CZ,TBS,TBCS,ESC,SMPY,USMPY,
     2  ETATH,ETAICH,ETAECH,ETALHH,JSCMAX,ICPT,ICNST,IH
C*********************************************************************
      INTEGER A(1Ø4),C(1Ø4)
      DATA XIDC/.Ø84,.1Ø72,.13,.154,.1783,.2Ø32,.2288,
     #.191,.25Ø9,.3163,.3879,.466,.5611,.6439/
      DATA EDC/7*Ø.,
     #.1223,.1554,.1896,.225Ø,.2615,.2992,.3381/
      DATA CSETS/8.39,11.94,12.19,17.74/
      DATA (A(I),I=1,94)/"C2Ø","C21","  C21Ø1","  C21Ø2","  C21Ø3",
     #"  C21Ø4","  C21Ø5","  C21Ø6","C22","  C22Ø1","    C22Ø1Ø1",
     #"    C22Ø1Ø2","    C22Ø1Ø3","    C22Ø1Ø4","    C22Ø1Ø5","    C22Ø1Ø6",
     #"    C22Ø1Ø7","    C22Ø1Ø8","  C22Ø2","    C22Ø2Ø1","    C22Ø2Ø2",
     #"    C22Ø2Ø3","    C22Ø2Ø4","  C22Ø3","    C22Ø3Ø1","    C22Ø3Ø2",
     #"    C22Ø3Ø3","    C22Ø3Ø4","    C22Ø3Ø5","    C22Ø3Ø6","  C22Ø4",
     #"    C22Ø4Ø1","    C22Ø4Ø2","    C22Ø4Ø3","  C22Ø5","  C22Ø6",
     #"  C22Ø7","  C2298","  C2299","C23","  C23Ø1","  C23Ø2",
     #"  C23Ø3","  C23Ø4","  C23Ø5","  C23Ø6","  C23Ø7","C24",
     #"  C24Ø1","  C24Ø2","  C24Ø3","  C24Ø4","  C24Ø5","  C24Ø6",
     #"  C24Ø7","C25","  C25Ø1","  C25Ø2","  C25Ø3","  C25Ø4","C26",
     #"  C26Ø1","  C26Ø2","  C26Ø3","  C26Ø4","C91","C92","C93",
     #"C4Ø","C41","C42","C43","C44","C45","C46","C47","CØ2"
     #,"  CØ2Ø1","  CØ2Ø2","  CØ2Ø3","CØ3","C5Ø","C51","C52"/
      DATA (A(I),I=85,1Ø4)/"CTD","CTD1",
     #"  C2198","  C2199","  C2398","  C2399","  C2498","  C2499",
     #" ","C94"," ","C95"," ","CTOT"," ","CTOTP"," ","COE"/
      EQUIVALENCE (B(1),C2Ø),(B(2),C21),(B(3),C21Ø1),(B(4),C21Ø2),
     #(B(5),C21Ø3),(B(6),C21Ø4),(B(7),C21Ø5),(B(8),C21Ø6),(B(9),C22),
     #(B(1Ø),C22Ø1),(B(11),C22Ø1Ø1),(B(12),C22Ø1Ø2),(B(13),C22Ø1Ø3),
     #(B(14),C22Ø1Ø4),(B(15),C22Ø1Ø5),(B(16),C22Ø1Ø6),(B(17),C22Ø1Ø7),
     #(B(18),C22Ø1Ø8),(B(19),C22Ø2),(B(2Ø),C22Ø2Ø1),(B(21),C22Ø2Ø2),
     #(B(22),C22Ø2Ø3),(B(23),C22Ø2Ø4),(B(24),C22Ø3),(B(25),C22Ø3Ø1),
     #(B(26),C22Ø3Ø2),(B(27),C22Ø3Ø3),(B(28),C22Ø3Ø4),(B(29),C22Ø3Ø5),
     #(B(3Ø),C22Ø3Ø6),(B(31),C22Ø4),(B(32),C22Ø4Ø1),(B(33),C22Ø4Ø2),
     #(B(34),C22Ø4Ø3),(B(35),C22Ø5),(B(36),C22Ø6),(B(37),C22Ø7),(B(38)
     #,C2298),(B(39),C2299),(B(4Ø),C23),(B(41),C23Ø1),(B(42),C23Ø2),
     #(B(43),C23Ø3),(B(44),C23Ø4),(B(45),C23Ø5),(B(46),C23Ø6),(B(47),
     #C23Ø7),(B(48),C24),(B(49),C24Ø1),(B(5Ø),C24Ø2),(B(51),C24Ø3)
      EQUIVALENCE (B(52),C24Ø4),(B(53),C24Ø5),(B(54),C24Ø6),(B(55),C24Ø7
     #),(B(56),C25),(B(57),C25Ø1),(B(58),C25Ø2),(B(59),C25Ø3),(B(6Ø),C25
     #Ø4),(B(61),C26),(B(62),C26Ø1),(B(63),C26Ø2),(B(64),C26Ø3),(B(65),
     #C26Ø4),(B(66),C91),(B(67),C92),(B(68),C93)
     #,(B(69),C4Ø),(B(7Ø),C41),(B(71),C42),(B(72),C43),(B(73),C44),(B(74
     #),C45),(B(75),C46),(B(76),C47),(B(77),CØ2),(B(78),CØ2Ø1),(B(79),CØ
     #2Ø2),(B(8Ø),CØ2Ø3),(B(81),CØ3),(B(82),C5Ø),(B(83),C51),(B(84),C52)
     #,(B(85),CTD),(B(86),CTD1),
     #(B(87),C2198),
     #(B(88),C2199),(B(89),C2398),(B(9Ø),C2399),(B(91),C2498),
     #(B(92),C2499),(B(94),C94(1)),(B(96),C95(1)),(B(98),CTOT1(1)),
     #(B(1ØØ),CTOTP(1)),(B(1Ø2),COEM(1))
      DATA JJ/1,9,56,77,93,1Ø,57,78,2,11,58,79,3,12,59,8Ø,4,13,6Ø,93,5,
     #14,93,81,6,15,61,93,7,16,62,82,8,17,63,93,87,18,64,83,88,19,65,93
     #,93,2Ø,93,84,4Ø,21,69,93,41,22,93,66,42,23,7Ø,93,43,24,93,67,44,25
     #,71,93,45,26,93,68,46,27,72,93,47,28,93,85,89,29,73,93,9Ø,3Ø,93,
```

```
     #86,93,31,74,93,48,32,93,93,49,33,76,93,5Ø,34,93,93,51,35,76,93,52,
     #36,93,93,53,37,93,93,54,38,93,93,55,39,93,93,91,93,93,93,92,93,
     #93,93/
      DATA C/3,3,5,5,5,5,5,5,3,5,7,7,7,7,7,7,7,7,
     #5,7,7,7,7,5,7,7,7,7,7,7,5,7,7,7,5,5,5,5,
     #5,3,5,5,5,5,5,5,5,3,5,5,5,5,5,5,5,3,5,5,5,
     #5,3,5,5,5,5,3,3,3,3,3,3,3,3,3,3,3,5,5,5,3,3,3,3,3,3,5,
     #5,5,5,5,5,1/
      DATA JJ1/94,95,96,97,98,99,1ØØ,1Ø1,1Ø2,1Ø3/
      DATA B(93)/1.E1Ø/
C
      IF (IPRNT .EQ. 1) WRITE (6,1Ø) INUM
 1Ø   FORMAT("1",//,45X,"CASE NUMBER ",I4,":")
C
      PI = 3.141592654
      COEM(1) = 1.E1Ø
      COEM(2) = 1.E1Ø
      ITIME = 1
C
C....   SET UP INPUTS NEEDED FOR COST CALCULATION
C
      PTH = N*PTHSEC
      PG = PTH*ETATH
      PANNEL = N*PANNTH/(IRING*ETAICH + (1-IRING)*ETAECH)
      PNE = PG - PAUX - PANNEL
      IF (PNE) 2Ø,2Ø,4Ø
 2Ø   IF (IPRNT) 22,22,3Ø
 22   WRITE (6,24) INUM
 24   FORMAT(I4,2ØX,"**********  NET ELECTRIC POWER LESS THAN",
     1  " OR EQUAL TO ZERO FOR THIS CASE  **********")
      RETURN
 3Ø   WRITE (6,32) PG,PANNEL,PAUX
 32   FORMAT(/////,2(T2Ø,"**********  NET ELECTRIC POWER LESS THAN OR ",
     1 "EQUAL TO ZERO FOR THIS CASE  **********",/),T2Ø,"**",T1Ø1,"**"/
     1 T2Ø,"**",T41,"   GROSS ELECTRIC POWER (MW)  = ",F8.1,T1Ø1,"**"/
     3 T2Ø,"**",T41,"    RING ELECTRIC POWER (MW)  = ",F8.1,T1Ø1,"**"/
     4 T2Ø,"**",T41,"AUXILARY ELECTRIC POWER (MW)  = ",F8.1,T1Ø1,"**"/
     5 T2Ø,"**",T1Ø1,"**"/2(T2Ø,"**********  NET ELECTRIC POWER LESS",
     6 "THAN OR EQUAL TO ZERO FOR THIS CASE  **********",/))
      RETURN
 4Ø   CONTINUE
      PBULK = Ø.1*SECVOL*N
      BMAX = 2.Ø*BT
C
C....   D OR T BURNUP IN PARTICLES/SEC
C
      BURNUP = PALPHA/3.52/1.6Ø21E-19*SECVOL*N
C
C....   DEUTERIUM BURNUP IN KG/YR
C
      DEUT = BURNUP*1.Ø48E-19
C
C....   TRITIUM THRUPUT IN TORR-L/SEC  --  EVALUATED AT 743K ALA UMAK-1
C
      THRUPUT = (BURNUP + 3./14.*DENI**2/TAUN*SECVOL*N)/1.3E19
C
C....   CALCULATE REACTOR BLANKET/SHIELD DIMENSIONS
C
      CALL SEGMENT1(RØ,N,RL,RP,SECLEN,TFCLEN,CMPB,CMPS,CCB,CCS,ESC)
C
C         DIRECT COSTS
      C2Ø = 2.Ø576*ESC
      C21Ø1 = 2.35*C2Ø*ESC
      C21Ø2 = (1.46*RØ)**2*PI*1.2*(16.+2.*RP)*392.6*ESC*1.E-6
```

```
      C21Ø3 = 17.8*(PG/1ØØØ.)**Ø.7*ESC
      C21Ø4 = 4.6*(PG/1ØØØ.)**Ø.?*ESC
      C21Ø5 = 5.81*(PG/12ØØ.)*ESC
C     C21Ø6I = 22.5*ESC
C     C211 = C21Ø1+C21Ø2+C21Ø3+C21Ø4+C21Ø5
      C21Ø6 = 5Ø.35*ESC
      C21 = C21Ø1+C21Ø2+C21Ø3+C21Ø4+C21Ø5+C21Ø6
      C2198 = .ØØ65*C21
      C2199 = .15*C21
      C21 = C21+C2198+C2199
C
      C23Ø1 = 38.65*(PG/1ØØØ.)**Ø.7*ESC
      C23Ø2 = 2.14*(PTH/3Ø36.9)*ESC
      C23Ø3 = 22.9*(PTH/3Ø36.9)**Ø.8*ESC
      C23Ø4 = 8.92*(PG/1ØØØ.)**Ø.9*ESC
      C23Ø5 = 4.87*(PTH/3Ø36.9)**Ø.6*ESC
      C23Ø6 = 26.33*(PG/1ØØØ.)**Ø.6*ESC
      C23Ø7 = 4.41*(PG/1Ø66.)**Ø.8*ESC
      C23 = C23Ø1+C23Ø2+C23Ø3+C23Ø4+C23Ø5+C23Ø6+C23Ø7
      C2398 = .Ø16*C23
      C2399 = .15*C23
      C23 = C23+C2398+C2399
C
      C25Ø1I = 7.74*ESC
      C25Ø2 = 6.6*ESC
      C25Ø3 = 4.Ø1*ESC
      C25Ø4 = .52*ESC
      C25I = C25Ø2+C25Ø3+C25Ø4
C
      C26Ø1 = Ø.
      C26Ø2 = Ø.
      C26Ø3 = Ø.
      C26Ø4 = .16*ESC
      C26 = C26Ø1+C26Ø2+C26Ø3+C26Ø4
C
      C22Ø1Ø1 = (CCB+CMPB)*N
      C22Ø1Ø2 = (CCS+CMPS)*N
       CTFC = 1.Ø6*TFCRAD*N*TFCARA*ESC
       CSYMC = 1.Ø6/PI*2*N*SYMARA*ESC*(SYMHIT + SYMWID)
C      CSYMC = Ø.3*CTFC
      C22Ø1Ø3 = CTFC+CSYMC
       CECH = Ø.
       CICH = Ø.
       CLHH = Ø.
       IF (IH) 42,44,46
 42    CICH = PBULK/ETAICH
       GO TO 48
 44    CECH = PBULK/ETAECH
       GO TO 48
 46    CLHH = PBULK/ETALHH
 48    CONTINUE
       PBULK = CICH + CECH + CLHH
       CICH = Ø.14*(CICH + PANNEL*IRING)
       CECH = Ø.14*(CECH + PANNEL*(1 - IRING))
       CLHH = Ø.Ø37*CLHH
      C22Ø1Ø4 = (CECH + CICH + CLHH)*ESC
      C22Ø1Ø5 = 1.5*RØ**.6*(BMAX/8.)**.8*(PTH/3Ø36.)**.6*ES
      C22Ø1Ø6 = 195.5*(THRUPUT/8ØØØ.)**.9*ESC
       CICHP = Ø.Ø49*CICH/Ø.14
       CECHP = Ø.1Ø*CECH/Ø.14
       CLHHP = Ø.Ø48*CLHH/Ø.Ø37
      C22Ø1Ø7 = (CECHP + CICHP + CLHHP)*ESC
      C22Ø1Ø8 = .ØØ7*C22Ø1ØI
      C22Ø1 = C22Ø1Ø1+C22Ø1Ø2+C22Ø1Ø3+C22Ø1Ø4+C22Ø1Ø5+C22Ø1Ø6+C22Ø1Ø7
```

```
     #+C220108
C          ASSUME 92.5% OF THERMAL POWER TO WALL,7.5% TO LIMITER
      C220201 = .0093*PTH*.925*ESC
      C220202 = 0.
      C220203 = .0093*PTH*.075*ESC
C          ASSUME NO THERMAL POWER GENERATED DURING EMER. SHUTDOWN
      C220204 = 0.
      C2202 = C220201+C220202+C220203+C220204
      C220301 = 4.97*(TFCARA+SYMARA)/2.38*ESC
      C220302 = 2.32*(TFCARA+SYMARA)/2.38*ESC
      C220303 = 1.81*(TFCARA+SYMARA)/2.38*ESC
      C220304 = 0.52*(TFCARA+SYMARA)/2.38*ESC
      C220305 = 0.
      C220306 = 0.
      C2203 = C220301+C220302+C220303+C220304+C220305+C220306
      C220401 = 266.4E-6*PTH*ESC
      C220402 = 280.E-6*PTH*ESC
      C220403 = 203.4E-6*PTH*ESC
      C2204 = C220401+C220402+C220403
      C2205 = 7.66E-3*PTH*ESC
      C2206I = 7.1*ESC
      C2207 = (10.+1.28E-3*PTH)*ESC
      C221 = C2201+C2202+C2203+C2204+C2205+C2207
C
      C2401 =(1.28*(PNE/1200.)**0.8+2.8*((PAUX+PANNEL+PBULK)/100.))*.58
     #*ESC
      C2402 = 2.55*((PAUX+PANNEL+PBULK)/100.)*ESC
      C2403 = 1.56*((PAUX+PANNEL+PBULK)/100.)*ESC
      C2404 = 1.36*ESC
      C2405 = 3.49*((PAUX+PANNEL+PBULK)/100.)*ESC
      C2406 = 5.98*((PAUX+PANNEL+PBULK)/100.)*ESC
      C2407 = 5.29*ESC
      C24 = C2401+C2402+C2403+C2404+C2405+C2406+C2407
      C2498 = .012*C24
      C2499 = .15*C24
      C24 = C24+C2498+C2499
C
C          OPERATIONS & MAINTENANCE COSTS
   50 CALL MAINTOP(PNE,ESC,SMPY,USMPY,N,FLUENCE,WALOAD,C220101,
     #NSEG,DEUT,COMT,AVL,ITIME,JMIN,C40,C41,C42,C43,C44,C45,C46,PANNEL,
     #C47,C0201,C0202,C0203,C02,C03,C50,C51,C52,IPRNT,NSETS,NSEG1,NSEG2)
      JEND = N
      JBEG = 1
      IF (ITIME - 2) 54,52,54
 52   JEND = JMIN
      JBEG = JMIN
 54   CONTINUE
C          ITERATE OVER ALL MAINTENANCE OPTIONS TO FIND LOWEST COE
C          THEN GO THRU LOOP AGAIN FOR PRINTOUT OF LOWEST COE OPTION
      DO 500 I=JBEG,JEND
C      VOLFACIL = 1300.+150.*NSEG(I)
C      CFACIL = (266.*VOLFACIL+89600.)*ESC
C     C2106 = C2106I+CFACIL*1.E-6
C     C21J = C21I+C2106
C     C02198 = .0065*C021J
C     C2199 = .15*C21J
C     C21 = C21J+C2198+C2199
C
      IF(NSETS(I).LT.5) CMAINT = CSETS(NSETS(I))*ESC
      IF(NSETS(I).GE.5) CMAINT = (17.74+2.9*(NSETS(I)-4))*ESC
      C2206 = C2206I+CMAINT
       NEXTRA = NSEG(I)/10.+1
      C2298 = ((CMPB+CCB)*NEXTRA+.02*(C221-C220101))*ESC
      `2 = C221+C2206+C2298
```

```
      C2299 = .15*C22
      C22 = C22+C2299
C
      IF(NSETS(I)-2)61,62,63
   61 CRHCRANE = 1.94*ESC
      GO TO 64
   62 CRHCRANE = 2.9*ESC
      GO TO 64
   63 CRHCRANE = 3.87*ESC
   64 C2501 = C25011+CRHCRANE
      C25 = C251+C2501
      C2598 = .015*C25
      C2599 = .15*C25
      C25 = C25+C2598+C2599
C
C           TOTAL DIRECT COSTS
      CTD = C20+C21+C22+C23+C24+C25+C26
C
      C91 = .10*CTD
      C92 = .08*CTD
      C93 = .05*CTD
C
C           TOTAL DIRECT + INDIRECT
      CTDI = CTD+C91+C92+C93
C
      DO 150 K=1,2
C           INTEREST & ESCALLATION
      C94(K) = XIDC(ICNST-3,K)*CTDI
      C95(K) = EDC(ICNST-3,K)*CTDI
C           TOTAL CAPITAL COST FOR EACH OPTION
      CTOT(K) = CTDI+C94(K)+C95(K)
      CTOT1(K) = CTOT(K)
C           COST PER INSTALLED KILOWATT
      CTOTP(K) = CTOT(K)/PNE*1.E3
C
C           COE USING CONSTANT-YEAR DOLLARS
      IF(K.EQ.2)GO TO 100
      ACOC = .1*CTOT(K)
      TAC = ACOC+COMT(I)
      COE(I,K) = 114.16*TAC/(PNE*AVL(I))
      GO TO 150
C
C           COE USING THEN-YEAR DOLLARS
  100 ACOC = .15*CTOT(K)
      TAC = ACOC+COMT(I)*1.05**ICNST
      COE(I,K) = 114.16*TAC/(PNE*AVL(I))
  150 CONTINUE
C
C           CHECK FOR MINIMUM COE
  200 IF(COE(I,1).GT.COEM(1).OR.ITIME.EQ.2)GO TO 500
      COEM(1) = COE(I,1)
      COEMM = COEM(1)
      COEM(2) = COE(I,2)
      JMIN = I
  500 CONTINUE
      IF(ITIME.EQ.2)GO TO 600
      ITIME = 2
      KEND = JEND/10.+1
      IF (IPRNT.EQ.1) WRITE (6,940) JEND,(KK,COE(KK,1),KK=1,JEND)
C           REPEAT COE CALCULATION USING BEST MAINTENANCE OPTION
      GO TO 50
 600  IF (IPRNT) 610,610,690
 610  IF (IHEADR) 640,640,612
 612  IHEADR = 0
```

```
      IF (IRING) 620,620,630
620   WRITE (6,624)
624   FORMAT("1",///,5X,"ELECTRON RING COST SUMMARY",/
     1  5X,"--------------------------",///
     2"        NET     ****  MAJOR  COST  ACCOUNTS  ****   ********  REA",
     3"CTOR  PLANT  BREAKDOWN  ********         TOTAL           COST OF"/
     4"       POWER    STR/SITE REACTOR TURBINE ELECTRIC",18X,
     5"                HEAT  FUEL  OTHER    CAPITAL  COST    ELECTRICITY"/
     6" CASE (MWE)    FACLTS   PLANT   PLANT     PLANT       FW/B SHIELD",
     7"  COILS   RF   TRANS HANDL  COSTS     (CYD)   (TCD)   (CYD)   (TCD)
     8",//)
      GO TO 640
630   WRITE (6,634)
634   FORMAT(/////,5X,"ION RING COST SUMMARY",/
     1  5X,"---------------------",///
     2"        NET     ****  MAJOR  COST  ACCOUNTS  ****   ********  REA",
     3"CTOR  PLANT  BREAKDOWN  ********         TOTAL           COST OF"/
     4"       POWER    STR/SITE REACTOR TURBINE ELECTRIC",18X,
     5"                HEAT  FUEL  OTHER    CAPITAL  COST    ELECTRICITY"/
     6" CASE (MWE)    FACLTS   PLANT   PLANT     PLANT       FW/B SHIELD",
     7"  COILS   RF   TRANS HANDL  COSTS     (CYD)   (TCD)   (CYD)   (TCD)
     8",//)
640   IPNE = PNE
      ICTOT1 = CTOT(1)
      ICTOT2 = CTOT(2)
      CRPREM = C220105 + C220106 + C220107 + C220108 + C2203 + C2204 +
     2   C2206 + C2207 + C2298 + C2299
      WRITE (6,650) INUM,IPNE,C21,C22,C23,C24,C220101,C220102,
     2   C220103,C220104,C2202,C2205,CRPREM,ICTOT1,ICTOT2,
     3   COEM(1),COEM(2)
650   FORMAT(I4,I7,F10.1,2F8.1,F9.1,F10.1,2F7.1,3F6.1,F7.1,I9,
     2  I8,2F8.2)
      GO TO 1000
690   WRITE (6,930)R0,N,BT,RP,SYMPCT,PNE,JMIN
 401  DO 700 I=1,132,4
 402  WRITE (6,900)(A(JJ(I+K)),C(JJ(I+K)),B(JJ(I+K)),K=0,3)
 700  CONTINUE
      WRITE (6,915)
      DO 800 I=1,10,2
      WRITE (6,920)A(JJ1(I)),B(JJ1(I)),B(JJ1(I+1))
 800  CONTINUE
 900  FORMAT(2X,A10,"(" "),F8.2,T32,A10,"(" "),F8.2,T64,A10,"(" "),
     #F8.2,T96,A10,"(" "),F8.2)
 915  FORMAT(/T30,"CYD",T50,"TCD")
 920  FORMAT(2X,A10,T27,F8.2,T47,F8.2)
 930  FORMAT(/45X,"EBTR COSTS FOR:"/
     #T2,"R0=",F5.2,"  N=",I2,"  BT=",F4.2,"  RP=",F4.2,"  SYMPCT=",
     #F5.3,"  PNET=",F8.2,I6," SCHEDULED OUTAGES PER WALL LIFETIME")
 940  FORMAT(5X,"COE FOR ",I2," MAINTENANCE OPTIONS (CYD):"/
     #10X,"(PARENS REPRESENT THE NUMBER OF SCHEDULED OUTAGES)"/
     #(1X,10("(",I2,")",1X,F6.2,1X)))
1000  RETURN
      END
```

```
      SUBROUTINE MAINTOP(PNE,ESC,SMPY,USMPY,N,FLUENCE,WALOAD,CBMOD,
     #NSEG,DEUT,COMT,AVL,ITIME,JMIN,C4Ø,C41,C42,C43,C44,C45,C46,PANNEL,
     #C47,CØ2Ø1,CØ2Ø2,CØ2Ø3,CØ2,CØ3,C5Ø,C51,C52,IPRNT,NSETS,NSEG1,NSEG2)
C           OPERATIONS & MAINTENANCE COSTS
C
C           I = NUMBER OF OUTAGES FOR BLANKET REPL. DURING BLANKET LIFE
C           NSEG1 = NUMBER OF SECTORS REPLACED PER OUTAGE -- INTEGER
C           NSEG2 = MAXIMUM NUMBER OF SECTORS REPLACED PER OUTAGE
C           RPF = REPLACEMENT FRACTION
C
      REAL NMANPER
      DIMENSION COMT(6Ø),AVL(6Ø),NSEG(6Ø),NSETS(6Ø),DM(4)
      DATA DM/6.5,12.,19.,12./
      IF(ITIME.EQ.2)GO TO 5Ø
      STAFF = 96+INT(PNE/49Ø.)+INT(PNE/735.)+INT(6.566+PNE/7Ø8)
     #        +2*INT(PNE/1ØØØ.)+INT(PNE/14ØØ.)+3*INT(PNE/125Ø.)
      C4Ø = STAFF*(1Ø8Ø2-19.Ø3*STAFF)*6.Ø1*ESC*1.E-6
      C41 = (312163+5Ø3*PNE)*3.61*ESC*1.E-6
      C42 = (2.Ø8*(65ØØØ.+73.33*PNE)+SMPY*1425Ø)*.51*ESC*1.E-6
      C43 = .15*(C4Ø+C41+C42)
      C44 = Ø.
      C45 = .65*ESC
      C46 = Ø.
      C47 = (78842+83.5*PNE)*5.36*ESC*1.E-6
       WALIFE = FLUENCE/WALOAD
      CØ2Ø1 = 14ØØ*DEUT*ESC*1.E-6
      CØ2Ø2 = Ø.
      CØ2Ø3 = Ø.
      CØ2 = CØ2Ø1+CØ2Ø2+CØ2Ø3
      CØ3 = Ø.
      COM = C4Ø+C41+C42+C43+C44+C45+C46+C47+CØ2+CØ3
      IBEG = 1
      IEND = N
      IF(IPRNT.EQ.1) WRITE (6,9ØØ)
      GO TO 75
 5Ø   IBEG = JMIN
      IEND = JMIN
   75 DO 1ØØ I=IBEG,IEND
      NSEG1 = N/I
      XI = I
      XNSEG1 = N/XI
      IF(NSEG1-XNSEG1)76,77,76
   76 NSEG2 = NSEG1+1
      GO TO 8Ø
   77 NSEG2 = NSEG1
   8Ø NSEG(I) = NSEG2
      RPF = 1./I
      YRSPOTG = WALIFE*RPF
      NSETS(I) = (NSEG2[illegible].)/3.
      NMANPER = 18.35+2.69*NSEG2+1.93E-2*NSEG2**2-1.6E-4*NSEG2**3
C           ASSUME 3 SERIAL SECTOR REPLACEMENTS PER MAINT. PERIOD
C           WITH EACH SET WHERE 1ST SECTOR=6.5D,2ND=5.5D,& 3RD=6.5D
      IF(NSEG2-5)15Ø,2ØØ,2ØØ
  15Ø DAYSMAN = DM(NSEG2)
      GO TO 4Ø1
  2ØØ DAYSMAN = 19.
  4Ø1 CALL AVLSUB(DAYSMAN,SMPY,USMPY,YRSPOTG,AVL,I)
  4Ø2 SMIVL = WALIFE*RPF/AVL(I)*12.
      C5Ø = 7.11E-4*DAYSMAN*NMANPER*AVL(I)/YRSPOTG*ESC+(CBMOD*AVL(I)
     #/WALIFE)*.2
      C51 = 5.6*PANNEL/122.*ESC
      C52 = Ø.
      COMT(I) = COM+C5Ø+C51+C52
```

```
      IF(IPRNT.EQ.Ø.OR.ITIME.EQ.2) GO TO 1ØØ
      IF(NSEG2.EQ.NSEG1)
     #WRITE (6,91Ø)I,NSEG1,YRSPOTG,SMIVL,NSETS(I),NMANPER,
     #DAYSMAN,AVL(I),COMT(I)
 9ØØ  FORMAT(45X,"OPER & MAINT COSTS:"/
     #T2,"REPL",T7,"NO OF",T13,"YRS PER",T22,"SCH MAINT",T33,"NO EQP",
     #T41,"NO OF",T48,"DAYS OF",T56,"AVAIL",T62,"TOTAL ANN"/
     #T2,"FRAC",T7,"SEGS",T13,"OUTAGE",T22,"INTERVAL",T33,"SETS",T41,
     #"MEN",T48,"MAINT",T62,"COST(M$)")
 91Ø  FORMAT(T2,"1/",I2,T9,I2,T13,F6.2,T22,F6.2,T35,I2,T41,F6.2,T48,F6.2
     #,T56,F4.3,T62,F6.2)
 1ØØ  CONTINUE
      RETURN
      END
```

```
      SUBROUTINE AVLSUB(DAYSMAN,SMPY,USMPY,YRSPOTG,AVL,I)
C          AVAILABILITY CALCULATION
      DIMENSION AVL(60)
      IF(DAYSMAN.GT.SMPY.AND.YRSPOTG.GT.1.)AVL(I)=
     C365./(365.+USMPY+(DAYSMAN+SMPY*(YRSPOTG-1.))/YRSPOTG)
      IF(DAYSMAN.GT.SMPY.AND.YRSPOTG.LE.1.)AVL(I)=
     C365./(365.+USMPY+DAYSMAN/YRSPOTG)
      IF(DAYSMAN.LE.SMPY.AND.YRSPOTG.GT.1.)AVL(I)=
     C365./(365.+USMPY+SMPY)
      IF(DAYSMAN.LE.SMPY.AND.YRSPOTG.LE.1.)AVL(I)=
     C365./(365.+USMPY+SMPY+DAYSMAN*(1.-YRSPOTG)/YRSPOTG)
      RETURN
      END
```

```
      SUBROUTINE SEGMENT1(RØ,N,RL,RP,SECTL,TFCLEN,CMPB,CMPS,CCB,CCS,
     2   ESC)
C          SIMPLE CALCULATION OF REACTOR BLANKET/SHIELD DIMENSIONS
      REAL LCX,LMP
C          ALL COSTS IN 198Ø DOLLARS -- EXPRESSED IN M$
      ESC1 = ESC/1.66E6
      XN = N
      LCX = TFCLEN+1.Ø9876
      LMP = SECTL-LCX
      DT = LCX/3.Ø153
      DMP = LMP/3.Ø3153
      X1 = (RL+.Ø4)/.95
      X2 = (RP+.Ø4)/1.19
      X3 = (RL+.15)/1.Ø6
      X4 = (RP+.15)/1.3
      X5 = (RL+.28)/1.19
      X6 = (RP+.28)/1.43
      X7 = (RL+.49)/1.4Ø
      X8 = (RP+.49)/1.64
      X9 = (RL+.51)/1.42
      X1Ø = (RP+.51)/1.65
      X11 = (RL+.7)/1.61
      X12 = (RP+.7)/1.85
      X13 = (RL+.82)/1.73
      X14 = (RP+.82)/1.97
      X15 = (RL+.91)/1.82
      X16 = (RP+.91)/2.Ø6
      VOL1T = .138*X1*DT
      VOL1MP = .181*X2*DMP
      VOL2T = .138*X1*DT
      VOL2MP = .181*X2*DMP
      VOL3T = 1.29*X1*DT
      VOL3MP = 1.692*X2*DMP
      VOL4T = 5.82*X3*DT
      VOL4MP = 11.39*X4*DMP
      VOL5T = .4*X3*DT
      VOL5MP = .785*X4*DMP
      VOL6T = .27*X3*DT
      VOL6MP = .52*X4*DMP
      VOL7T = 2.34*X5*DT
      VOL7MP = 3.1*X6*DMP
      VOL8T = .78*X5*DT
      VOL8MP = 1.Ø3*X6*DMP
      VOL9T = 3.31*X7*DT
      VOL1ØT = .175*X7*DT
      VOL11T = .Ø75*X7*DT
      VOL12T = .187*X7*DT
      VOL13T = 1.784*X9*DT
      VOL13MP = 12.1*X1Ø*DMP
      VOL14T = .198*X9*DT
      VOL14MP = 1.343*X1Ø*DMP
      VOL15T = 5.625*X11*DT
      VOL15MP = 5.7*X12*DMP
      VOL16T = 2.367*X11*DT
      VOL16MP = 2.45*X12*DMP
      VOL17T = 5.21*X13*DT
      VOL17MP = 9.*X14*DMP
      VOL18T = 1.95*X15*DT
      VOL18MP = 3.4*X16*DMP
      WT1T = 7.81*VOL1T
      WT1MP = 7.81*VOL1MP
      WT2T = .75*VOL2T
      WT2MP = .75*VOL2MP
```

```
WT3T = 1.665*VOL3T
WT3MP = 1.665*VOL3MP
WT4T = 3.4*VOL4T
WT4MP = 3.4*VOL4MP
WT5T = 7.81*VOL5T
WT5MP = 7.81*VOL5MP
WT6T = .75*VOL6T
WT6MP = .75*VOL6MP
WT7T = 7.81*VOL7T
WT7MP = 7.81*VOL7MP
WT8T = .75*VOL8T
WT8MP = .75*VOL8MP
WT9T = 19.2*VOL9T
WT1ØT = 11.34*VOL1ØT
WT11T = VOL11T
WT12T = 7.94*VOL12T
WT13T = 7.94*VOL13T
WT13MP = 7.94*VOL13MP
WT14T = VOL14T
WT14MP = VOL14MP
WT15T = 7.94*VOL15T
WT15MP = 7.94*VOL15MP
WT16T = VOL16T
WT16MP = VOL16MP
WT17T = 3.9*VOL17T
WT17MP = 3.9*VOL17MP
WT18T = 7.94*VOL18T
WT18MP = 7.94*VOL18MP
C1T = ESC1*35ØØØ.*WT1T
C1MP = ESC1*35ØØØ.*WT1MP
C2T = Ø.
C2MP = Ø.
C3T = ESC1*33ØØØØ.*WT3T
C3MP = ESC1*33ØØØØ.*WT3MP
C4T = ESC1*4ØØØØ.*WT4T
C4MP = ESC1*4ØØØØ.*WT4MP
C5T = ESC1*35ØØØ.*WT5T
C5MP = ESC1*35ØØØ.*WT5MP
C6T = Ø.
C6MP = Ø.
C7T = ESC1*134ØØ.*WT7T
C7MP = ESC1*134ØØ.*WT7MP
C8T = Ø.
C8MP = Ø.
C9T = ESC1*33ØØØ.*WT9T
C1ØT = ESC1*33ØØØ.*WT1ØT
C11T = Ø.
C12T = ESC1*2ØØØØ.*WT12T
C13T = ESC1*955Ø.*WT13T
C13MP = ESC1*955Ø.*WT13MP
C14T = Ø.
C14MP = Ø.
C15T = ESC1*955Ø.*WT15T
C15MP = ESC1*955Ø.*WT15MP
C16T = Ø.
C16MP = Ø.
C17T = ESC1*2ØØØ.*WT17T
C17MP = ESC1*2ØØØ.*WT17MP
C18T = ESC1*2ØØØØ.*WT18T
C18MP = ESC1*2ØØØØ.*WT18MP
CCB = C1T+C2T+C3T+C4T+C5T+C6T+C7T+C8T
CCS = C9T+C1ØT+C11T+C12T+C13T+C14T+C15T+C16T+C17T+C18T
CMPB = C1MP+C2MP+C3MP+C4MP+C5MP+C6MP+C7MP+C8MP
CMPS = C13MP+C14MP+C15MP+C16MP+C17MP+C18MP

RETURN
END
```

```
      SUBROUTINE REVER (N,A)
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C
C     This routine reverses the order of an array.
C
C     The array 1 2 3 4 5 6  ...........     becomes
C               6 5 4 3 2 1  ...........
C
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
      DIMENSION A(1)
      NR=N/2
      DO 10 I=1,NR
      SAV=A(I)
      J=N-I+1
      A(I)=A(J)
      A(J)=SAV
10    CONTINUE
      RETURN
      END
```

```
      SUBROUTINE OUTPUT(LOOP)
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C
C       This routine publishes the results of the calculation
C       in tabular form.
C                                                                 C
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
      COMMON/INPARM/ARATIO(25),PTHTOT(25),POWDEN(25),TORRAD(25),
     1   NCOIL(25),XMR,YYY,RTOVRN,RPAVG,RADMIN,BAVG,BMIN,BMAX,
     2   BETA,TEE,TAU,UFUS,FUSENG,BLKMLT,DELCZ,DELBS,[illegible]COIL,
     3   DLMAG,SECLEN,SECARA,SECVOL,COILNO,ISEE
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
      COMMON/COILS/ TFCRAD,TFCLEN,TFCARA,TFCCUR,[illegible],SYMWID,
     1   SYMARA,SYMCUR,SYMPCT
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
      COMMON/RINGS/ PMU(25,2),QPLAS(25,2),QELEC(25,2),PSYNC(25,2),
     1   PDRAG(25),PSCATR(25),FR(25),BRing,RTEMP,BCORE,GAMMA,
     2   GGAMMA,AVGBRG,BETARG,AVBCOR,HGAMMA,HSGMMA,RNELEN,
     3   RNILEN,RNEVOL,RNIVOL,DELTE,DELTI
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
      COMMON/CFIXED/ FARE,KF,RC,COEFFR
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
      COMMON/RTS/ DEN(25),TP(25),SIGMAV(25),TAUN(25),PTHSEC(25),
     1   PALPHA(25),PBREM(25),PCYCL(25),PRAD(25),PLINE(25),
     2   PRECMB(25),PTRANS(25),WALLOD(25)
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
         COMMON/FR/FRMIN,FRMAX
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C
      WRITE(6,100)
  100 FORMAT(1H1,/////,T30," Input Variables",//)
      WRITE(6,101) XMR,RADMIN,BETA,ISEE,BMIN,BLKMLT,BETARG,RTEMP
  101 FORMAT(1H ,"Mirror Ratio (XMR)",T24,F6.3,T32," Plasma Minor",
     $" Radius(RADMIN)",T62,F6.3,/," Beta Value (BETA) ",T24,
     $F6.3,T32," Print Value (ISEE) ",T62,I6,/," Minimum B (BMIN)",
     $T24,F6.3,T32," Blanket Mult. (BLKMLT)",T62,F6.3,/,
     $" Ring Beta (BETARG)",T24,F6.3,T32," Ring Temp. (RTEMP)",
     $ T62,F8.3,///)
         WRITE(6,901)
901      FORMAT(///////)
         WRITE(6,900) RPAVG,TFCRAD,TFCLEN,BAVG,FARE,COEFFR,RTOVRN
900      FORMAT(25X,"Average Plasma Radius        =",F6.3,/,
     $             25X,"Toroidal Field Coil Radius =",F6.3,/,
     $             25X,"Toroidal Field Coil Length =",F6.3,/,
     $             25X,"Average Magnetic Field     =",F6.3,/,
     $             25X,"Aspect Ratio Enhancement   =",F6.3,/,
     $             25X,"Reflection Coefficient     =",F6.3,/,
     $             25X,"Major Radius/Num Sectors   =",F6.3)
      WRITE(6,29)
   29 FORMAT(1H1,///,5X,"Physics Output",/,5X,"--------------",////)
C
      WRITE(6,840)
  840 FORMAT(1H ,T28,"Plasma",/,
     -T13,"Density",T26,"Temperature",T40,"N-Cold/N-Hot",T58,"N-TAU",
     -T69,"Aspect Ratio",T84,"Major Radius",T100,
     -"Number of Coils",/,
     -" Index",T12,"(1/m**3)",T29,"(KeV)",T55,
     -'(m**3/sec)",T88,"(m)",//)
C
      DO 240  IJ=1,LOOP
      WRITE(6,235) IJ,
     xDEN(IJ),TP(IJ),FR(IJ),TAUN(IJ),ARATIO(IJ),TORRAD(IJ),
     xNCOIL(IJ)
```

```
  235 FORMAT(1H ,I5,T1Ø,1PE12.5,T25,1PE12.5,T41,1PE12.5,T55,1PE12.5,T69,
     x1PE12.5,T84,1PE12.5,T1Ø5,I6)
  24Ø CONTINUE
C
      WRIT~(6,2Ø)
   2Ø FORM T(1H ,///,5X," Ring Data",/,5X,"----------",//)
      WRITE(6,2222)
2222  FORMAT("     Electron Ring Parameters             Ion Ring
     X Parameters ",/)
        WRITE(6,399) RNELEN,RNILEN,DELTE,DELIT,RNEVOL,RNIVOL
399     FORMAT("   Length ",T18,F1Ø.4," (m)",
     X  5X,  "   Length  ",T48,F1Ø.4," (m)",/,
     X       "  Thickness ",T18,F1Ø.4," (m)",
     X  5X,  "   Thickness ",T48,F1Ø.4," (m)",/,
     X       "  Volume ",T18,F1Ø.4," (m**3)",
     X  2X,  "   Volume ",T48,F1Ø.4," (m**3)",//)
C
      WRITE(6,8ØØ)
  8ØØ FORMAT(1H ,T12,"Drag Loss",T32,"ScatteRing",T58,
     1"Synchrotron",T76,"Total Electron Ring",T1Ø1,"Total Ion Ring",/,
     2T13,"Electron",T31,"Loss-Elect.",T56,"Loss-Elect.",
     3T79,"Power Loss",T1Ø3,"Power Loss",/,
     4" Index",T15,"(MW)",T35,"(MW)",T6Ø,"(MW)",T83,"(MW)",T1Ø6,
     5"(MW)",///)
C
      DO 245 IJ=1,LOOP
       WRITE(6,23Ø) IJ,PDRAG(IJ),PSCATR(IJ),PSYNC(IJ,1),PMU(IJ,1),
     X PMU(IJ,2)
  23Ø FORMAT(1H ,I5,T11,1PE12.5,T31,1PE12.5,T56,1PE12.5,T79,1PE12.5,
     XT1Ø2,1PE12.5)
C
  245 CONTINUE
C
      WRITE(6,25)
   25 FORMAT(1H1,///,5X,"Thermal Power",/,5X,"-------------",//)
C
        WRITE(6,499) SECLEN,SECARA,SECVOL
499     FORMAT(" Sector Length",T24,F8.4," (M)",/,
     X          " Sector Wall Area  ",T24,F8.4," (M**2)",/,
     X          " Sector Volume",T24,F8.4," (M**3)",//)
C
      WRITE(6,82Ø)
  82Ø FORMAT(1H ,T44,"Total Thermal",T6Ø,"Alpha-Particle",T77,
     1"Power Loss Due",T94,"Power Loss Due",/,
     2T1Ø,"Power Density",T26,"First Wall Load",T48,"Power",T65,
     3"Power",T78,"To Radiation",T95,"To Transport",/,
     4" Index",T12,"(MW/M**3)",T29,"(MW/M**2)",T48,"(MWT)",
     5T82,"(MW)",T99,"(MW)",//)
C
      DO 35Ø IJ=1,LOOP
      WRITE(6,231) IJ,
     xPOWDEN(IJ),WALLOD(IJ),PTHSEC(IJ),PALPHA(IJ),PRAD(IJ),PTRANS(IJ)
  231 FORMAT(1H ,I5,T1Ø,1PE12.5,T28,1PE12.5,T45,1PE12.5,T61,1PE12.5,T78,
     x1PE12.5,T95,1PE12.5)
  35Ø CONTINUE
C
      WRITE(6,27)
   27 FORMAT(1H ,//,5X," Q - Values",/,5X," ----------",//)
C
      WRITE(6,83Ø)
  83Ø FORMAT(1H ,T1Ø,"Total Thermal",T25,"Total Power Loss",
     xT8Ø,"Total Power Loss",/,
     xT14,"Power",T28,"in the Ring",T47,"Q - Plasma",T63,
     x"Q - Electric",T82,"IN THE Ring",T1ØØ,"Q - Plasma",
```

```
     xT115,"Q - Electric",/,
     x" Index",T15,"(MW)",T28,"(Electron)",T47,"(Electron)",T64,
     x"(Electron)",T82,"(Ion)",T1Ø3,"(Ion)",T119,"(Ion)",//)
C
      DO 45Ø IJ=1,LOOP
      WRITE(6,234)IJ,
     x   PTHSEC(IJ),PMU(IJ,1),QPLAS(IJ,1),QELEC(IJ,1),PMU(IJ,2),
     x   QPLAS(IJ,2),QELEC(IJ,2)
  234 FORMAT(1H ,I5,T1Ø,1PE12.5,T28,1PE12.5,T46,1PE12.5,T63,1PE12.5,T82,
     x1PE12.5,T99,1PE12.5,T115,1PE12.5)
  45Ø CONTINUE
         RETURN
         END
```

## APPENDIX B

## LIST OF VARIABLES USED IN THE CODE

## Variables Used in the Code

| Code Variable | Description |
|---|---|
| ARATIO | Aspect ratio |
| AVBCOR | Not used. |
| AVGBRG | Average magnetic filed at the ring. (T) |
| BAVG | Average magnetic fiold. (T) |
| BETA | Core beta. |
| BETARG | Ring beta. |
| BLKMLT | Blanket mutiplication factor. |
| BMAX | Maximum magnetic field. (T) |
| BMIN | Minimum magnetic field. (T) |
| COEFFR | Synchrotron radiation reflection coefficient. |
| DELBS | Blanket-shield thickness. (m) |
| DELCZ | Scrape-off region thickness. (m) |
| DELTE | Electron ring radial thickness. (m) |
| DELTI | Ion ring radial thickness. (m) |
| DEN | Plasma ion density. (1./m**3) |
| DLCOIL | Mirror coil radial half-thickness. (m) |
| DLMAG | Distance between the shield and magnet. (m) |
| FALPHA | Alpha-particle power retention factor. |
| FARE | Aspect ratio enhancement factor. |
| FUSENG | Not used. |
| GAMMA | Relativistic factor. GAMMA = 1.Ø + RTEMP/511.Ø |
| JSCMAX | Maximum mirror coil current density. (A/m**2) |
| KF | Density-temperature profile factor. |
| NCOIL | Number of mirror coils. |
| PALPHA | Alpha particle power loss. (MW) |
| PBREM | Bremmstrahlung radiation power loss. (MW) |
| PCYCL | Cyclotron radiation pwer loss. (MW) |
| PDRAG | Power loss due to drag processes. (MW) |
| PLINE | Line radiation power loss. (MW) |
| PMU | Sum of the drag, synchrotron, and scattering radiation losses. |
| POWDEN | Power density. (MW/m**3) |
| PRAD | Total power lost by radiation processes. (MW) |
| PRECMB | Power lost by recombination processes. (MW) |
| PSYNCH | Synchrotron radiation pwer loss. (MW) |
| PTHSEC | Thermal power produced per mirror sector. (MW/sector) |
| PTRANS | Power lost by transport processes. (MW) |
| PTHTOT | total thermal power produced in the ractor. (MWt) |
| QELEC | Electric recirculating power fraction. |
| QPLAS | Ratio of fusion power to ring sustaining power. |
| RADMIN | Minimum plasma radius. (m) |
| RC | Magnetic radius of curvature. (m) |
| RNELEN | Length of the electron ring. (m) |
| RNILEN | Length of the ion ring. (m) |
| RNEVOL | Volume of the electron ring. (m**3) |
| RNIVOL | Volume of the ion ring. (m**3) |
| RTEMP | Ring temperature. (MeV) |
| RTOVRN | Torroidal major radius/Number of coils. |
| SECARA | Mirror sector area. (m**2) |
| SECLEN | Mirror sector length. (m) |
| SECVOL | Mirror sector volume. (m**3) |
| SIGMAV | Average DT reaction cross-section. |
| SYMARA | Symmetrizing coil cross-sectional area. (m**2) |
| SYMCUR | Symmetrizing coil current. (A) |
| SYMHIT | Symmetrizing coil height. (m) |
| SYMPCT | Fraction of current to symmetrizing coils. |
| SYMWID | Symmetrizing coil width. (m |

| | | |
|---|---|---|
| TAU | Confinement time. (s) | |
| TAUN | Product of density and confinement time - ntau. | |
| TEE | Not used. | |
| TFCARA | Mirror coil cross-sectional area. | (m**2) |
| TFCCUR | Mirror coil current. | (A) |
| TFCLEN | Mirror coil length. | (m) |
| TFCRAD | Mirror coil radius. | (m) |
| TORRAD | Torroidal major radius. | (m) |
| TP | Plasma temperature. (keV) | |
| UALPHA | Alpha particle energy. DT reaction. (3.5 MeV) | |
| UFUS | Total fusion energy. (MeV) | |
| UN | Neutron energy. DT reaction. (MeV) | |
| WALLOD | Neutron first wall loading. (MW/m**2) | |
| XMR | Mirror ratio. | |
| YYY | YYY = RC*(RTOVRN) | |

# APPENDIX C

# DETAILED COST SUMMARIES FOR SAMPLE CASE

CASE NUMBER 1:
OPER & MAINT COSTS:

| REPL FRAC | NO OF SEGS | YRS PER OUTAGE | SCH MAINT INTERVAL | NO EQP SETS | NO OF MEN | DAYS OF MAINT | AVAIL | TOTAL ANN COST(M$) |
|---|---|---|---|---|---|---|---|---|
| 1/ 1 | 30 | 16.86 | 243.95 | 10 | 112.10 | 19.00 | .030 | 26.74 |
| 1/ 2 | 15 | 8.43 | 121.97 | 5 | 62.50 | 19.00 | .030 | 26.75 |
| 1/ 3 | 10 | 5.62 | 81.32 | 4 | 47.02 | 19.00 | .030 | 26.77 |
| 1/ 5 | 6 | 3.37 | 49.79 | 2 | 36.15 | 19.00 | .030 | 26.80 |
| 1/ 6 | 5 | 2.81 | 40.66 | 2 | 32.26 | 19.00 | .030 | 26.82 |
| 1/10 | 3 | 1.69 | 24.39 | 1 | 26.59 | 19.00 | .030 | 26.89 |
| 1/15 | 2 | 1.12 | 16.26 | 1 | 23.01 | 12.00 | .030 | 26.85 |
| 1/30 | 1 | 0.56 | 8.23 | 1 | 21.06 | 6.50 | .020 | 26.82 |

COE FOR 30 MAINTENANCE OPTIONS (CYD):
(PARENS REPRESENT THE NUMBER OF SCHEDULED OUTAGES)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ( 1) 43.19 | ( 2) 42.14 | ( 3) 42.03 | ( 4) 41.57 | ( 5) 41.52 | ( 6) 41.53 | ( 7) 41.53 | ( 8) 41.52 | ( 9) 41.52 | (10) 41.37 |
| (11) 41.37 | (12) 41.30 | (13) 41.30 | (14) 41.39 | (15) 41.36 | (16) 41.36 | (17) 41.38 | (18) 41.44 | (19) 41.51 | (20) 41.58 |
| (21) 41.65 | (22) 41.72 | (23) 41.79 | (24) 41.86 | (25) 41.93 | (26) 41.99 | (27) 42.06 | (28) 42.13 | (29) 42.20 | (30) 41.83 |

EBTR COSTS FOR:

R0=33.24 N=30 BT=6.60 RP=1.40 SYMPCT= • PNET= 892.50 15 SCHEDULED OUTAGES PER WALL LIFETIME

| | |
|---|---|
| C20 | 3.19 |
| C21 | 273.85 |
| C2101 | 11.62 |
| C2102 | 102.40 |
| C2103 | 29.21 |
| C2104 | 7.31 |
| C2105 | 8.14 |
| C2106 | 70.04 |
| C2198 | 1.54 |
| C2199 | 35.52 |
| C23 | 204.26 |
| C2301 | 63.42 |
| C2302 | 3.30 |
| C2303 | 36.00 |
| C2304 | 14.00 |
| C2305 | 7.64 |
| C2306 | 42.86 |
| C2307 | 6.93 |
| C2398 | 2.00 |
| C2399 | 26.20 |
| C24 | 144.24 |
| C2401 | 12.97 |
| C2402 | 10.94 |
| C2403 | 11.59 |
| C2404 | 2.11 |
| C2405 | 25.92 |
| C2406 | 44.41 |
| C2407 | 8.20 |
| C2498 | 1.49 |
| C2499 | 10.62 |

| | |
|---|---|
| C22 | 1104.75 |
| C2201 | 786.70 |
| C220101 | 206.12 |
| C220102 | 188.98 |
| C220103 | 267.30 |
| C220104 | 36.78 |
| C220105 | 24.86 |
| C220106 | 25.41 |
| C220107 | 35.80 |
| C220108 | 1.44 |
| C2202 | 44.67 |
| C220201 | 41.32 |
| C220202 | 0. |
| C220203 | 3.35 |
| C220204 | 0. |
| C2203 | 10.93 |
| C220301 | 5.65 |
| C220302 | 2.64 |
| C220303 | 2.06 |
| C220304 | 0.59 |
| C220305 | 0. |
| C220306 | 0. |
| C2204 | 3.60 |
| C220401 | 1.28 |
| C220402 | 1.35 |
| C220403 | 0.98 |
| C2205 | 36.80 |
| C2206 | 24.01 |
| C2207 | 21.65 |
| C2298 | 32.29 |
| C2299 | 144.10 |

| | |
|---|---|
| C25 | 37.50 |
| C2501 | 15.00 |
| C2502 | 10.23 |
| C2503 | 6.22 |
| C2504 | 0.01 |
| C26 | 0.25 |
| C2601 | 0. |
| C2602 | 0. |
| C2603 | 0. |
| C2604 | 0.25 |
| C40 | 8.61 |
| C41 | 4.25 |
| C42 | 0.53 |
| C43 | 2.01 |
| C44 | 0. |
| C45 | 1.01 |
| C46 | 0. |
| C47 | 1.27 |

| | |
|---|---|
| C02 | 0.21 |
| C0201 | 0.21 |
| C0202 | 0. |
| C0203 | 0. |
| C03 | 0. |
| C50 | 2.26 |
| C51 | 6.70 |
| C52 | 0. |
| C91 | 176.01 |
| C92 | 141.45 |
| C93 | 88.41 |
| CTD | 1768.12 |
| CTD1 | 2174.79 |

| | CYD | TCD |
|---|---|---|
| C94 | 233.14 | 545.65 |
| C95 | 0. | 337.96 |
| CTOT | 2407.92 | 3050.40 |
| CTOTP | 2704.01 | 3434.47 |
| COE | 41.36 | 76.19 |

CASE NUMBER 2:
OPER & MAINT COSTS:

| REPL FRAC | NO OF SEGS | YRS PER OUTAGE | SCH MAINT INTERVAL | NO EQP SETS | NO OF MEN | DAYS OF MAINT | AVAIL | TOTAL ANN COST(M$) |
|---|---|---|---|---|---|---|---|---|
| 1/ 1 | 32 | 13.94 | 251.62 | 11 | 118.95 | 19.00 | .030 | 29.73 |
| 1/ 2 | 16 | 6.97 | 100.01 | 6 | 65.60 | 19.00 | .030 | 29.75 |
| 1/ 4 | 8 | 3.48 | 50.40 | 3 | 41.02 | 19.00 | .030 | 29.79 |
| 1/ 8 | 4 | 1.74 | 25.20 | 2 | 29.41 | 12.00 | .030 | 29.77 |
| 1/16 | 2 | 0.87 | 12.65 | 1 | 23.81 | 12.00 | .026 | 29.87 |
| 1/32 | 1 | 0.44 | 6.42 | 1 | 21.06 | 6.60 | .014 | 29.82 |

COE FOR 32 MAINTENANCE OPTIONS (CYD):
(PARENS REPRESENT THE NUMBER OF SCHEDULED OUTAGES)

```
( 1)  35.61 ( 2)  34.83 ( 3)  34.67 ( 4)  34.32 ( 5)  34.32 ( 6)  34.29 ( 7)  34.30 ( 8)  34.20 ( 9)  34.29 (10)
(11)  34.18 (12)  34.10 (13)  34.19 (14)  34.20 (15)  34.31 (16)  34.31 (17)  34.30 (18)  34.44 (19)  34.61 (20)
(21)  34.65 (22)  34.72 (23)  34.79 (24)  34.85 (25)  34.92 (26)  34.99 (27)  35.06 (28)  35.13 (29)  35.20 (30)
(31)  35.33 (32)  34.82 (
```

EBTR COSTS FOR:

```
R0=35.94  N=32  BT=5.50  RP=1.48  SYMPCT=  *  PNET= 1194.63   11 SCHEDULED OUTAGES PER WALL LIFETIME
 C20             3.19      C22           1216.57        C25            37.58       C02            0..
                  *          C2201         864.06         C2501          15.00       C0201          0
 C21            303.91         C220101       219.06       C2502          10.23       C0202          0.
   C2101          11.62        C220102       201.50       C2503           6.22       C0203          0.
   C2102         119.81        C220103       205.13       C2504           0.81                       *
   C2103          34.92        C220104        40.28                       *          C03            0.
   C2104           7.89        C220105        30.36     C26             0.25                       *
   C2105          10.51        C220106        36.39       C2601         0.          C50            2.98
   C2106          70.04        C220107        38.94       C2602         0.                         *
   C2198           1.71        C220108         1.54       C2603         0.          C61            7.49
   C2199          39.42      C2202          57.66         C2604         0.26                       *
                  *            C220201        63.33                     *          C62            0.
 C23            246.43         C220202        0.        C40             0.86                       *
   C2301          75.02        C220203        4.32                      *          C91          195.87
   C2302           4.37        C220204        0.        C41             5.11                       *
   C2303          44.24      C2203          10.93                       *          C92          166.69
   C2304          10.72        C220301        5.65      C42             0.57                       *
   C2305           8.90        C220302        ?.64                      *          C93           97.93
   C2306          49.94        C220303        ..06      C43             2.10                       *
   C2307           8.50        C220304        .59                       *          CTD         1958.69
   C2398           3.37        C220305        0.        C44             0.                         *
   C2399          31.57        C220306        0.                        *          CTDI        2409.18
                  *          C2204           4.65       C45             1.01                       *
 C24            152.76         C220401        1.65                      *                          *
   C2401          13.97        C220402        1.74      C46             0.                         *
   C2402          20.13        C220403        1.26                      *                          *
   C2403          12.31      C2205          47.49       C47             1.48                       *
   C2404           2.11      C2206          24.01                       *                          *
   C2405          27.55      C2207          23.44                       *                          *
   C2406          47.20      C2298          34.70                       *                          *
   C2407           8.20      C2299         150.55                       *                          *
   C2498           1.50                     *                           *                          *
   C2499          19.72                     *                           *                          *
```

| | CYD | TCD |
|---|---|---|
| C94 | 260.26 | 604.46 |
| C95 | 0. | 374.39 |
| CTOT | 2667.45 | 3380.04 |
| CTOTP | 2232.07 | 2836.06 |
| COE | 34.10 | 62.95 |

```
                                         CASE NUMBER    3:
                                         OPER & MAINT COSTS:
REPL NO OF  YRS PER   SCH MAINT  NO EQP   NO OF   DAYS OF AVAIL TOTAL ANN
FRAC SEGS  OUTAGE    INTERVAL    SETS    MEN     MAINT         COST(M$)
1/ 1   36    12.13    176.44        12    132.74  19.00  .030   33.96
1/ 2   18     6.06     87.72         6     72.89  19.00  .030   33.97
1/ 3   12     4.04     58.48         4     53.13  19.00  .030   33.99
1/ 4    9     3.03     43.86         3     44.01  19.00  .030   34.02
1/ 6    6     2.02     29.24         2     36.16  19.00  .030   34.07
1/      4     1.35     19.49         2     29.41  12.00  .030   34.01
1/1:    3     1.01     14.62         1     26.59  19.00  .030   34.22
1/16    2     0.67      9.88         1     23.81  12.00  .019   34.10
1/36    1     0.34      5.02         1     21.06   6.50  .006   34.03
    COE FOR 36 MAINTENANCE OPTIONS (CVD):
         (PARENS REPRESENT THE NUMBER OF SCHEDULED OUTAGES)
( 1)  30.67 ( 2)  29.92 ( 3)  29.80 ( 4)  29.64 ( 5)  29.64 ( 6)  29.62 ( 7)  29.62 ( 8)  29.62 ( 9)  29.61 (10)  29.51
(11)  29.61 (12)  29.43 (13)  29.53 (14)  29.63 (15)  29.74 (16)  29.85 (17)  29.96 (18)  29.81 (19)  29.88 (20)  29.95
(21)  30.01 (22)  30.08 (23)  30.15 (24)  30.22 (25)  30.28 (26)  30.35 (27)  30.42 (28)  30.49 (29)  30.55 (30)  30.62
(31)  30.69 (32)  30.76 (33)  30.82 (34)  30.89 (35)  30.96 (36)  30.27 (

                                          EBTR COSTS FOR:
R0=30.20  N=36  BT=5.60  RP=1.40  SYMPCT=    0  PNET= 1686.00    12 SCHEDULED OUTAGES PER WALL LIFETIME
 C20              3.19          C22             1399.65         C25             37.50           C02             0.35
                   .              C2201          975.67           C2501          16.00            C0201          0.35
 C21             334.00             C220101        247.34         C2502          10.23            C0202          0.
   C2101          11.62             C220102        226.77         C2503           6.22            C0203          0.
   C2102         136.94             C220103        320.77         C2504           0.01                           .
   C2103          41.79             C220104         46.60                          .              C03             0.
   C2104           0.62             C220105         36.70       C26              0.25                             .
   C2105          13.60             C220106         51.14         C2601           0.              C50             3.04
   C2106          70.04             C220107         44.65         C2602           0.                              .
   C2198           1.00             C220108          1.73         C2603           0.              C61             0.02
   C2199          43.42           C2202           74.64           C2604           0.25                            .
                   .                C220201         60.95                          .              C62             0.
 C23             255.47             C220202          0.         C40              9.23                             .
   C2301          90.75             C220203          5.59                          .              C91           223.95
   C2302           5.65             C220204          0.         C41              6.21                             .
   C2303          54.34           C2203           10.93                            .              C92           179.16
   C2304          23.60             C220301          5.65       C42              0.61                             .
   C2305          10.39             C220302          2.64                          .              C93           111.98
   C2306          50.26             C220303          2.06       C43              2.41                             .
   C2307          10.44             C220304          0.59                          .              CTD          2239.54
   C2398           4.05             C220305          0.         C44              0.                               .
   C2399          30.01             C220306          0.                            .              CTDI         2754.64
                   .              C2204            6.01         C45              1.01                             .
 C24             160.60             C220401          2.14                          .                               .
   C2401          15.60             C220402          2.24       C46              0.                               .
   C2402          22.36             C220403          1.63                          .                               .
   C2403          13.68           C2205           61.40         C47              1.76                             .
   C2404           2.11           C2206           24.01                            .                               .
   C2405          30.61           C2207           25.76                            .                               .
   C2406          52.45           C2298           30.77                            .                               .
   C2407           8.20           C2299          102.56                            .                               .
   C2498           1.74                            .                               .                               .
   C2499          21.76                            .                               .                               .

                        CVD               TCD
C94                   295.30            691.14
C95                     0.              420.07
CTOT                 3049.93           3873.84
CTOTP                1923.03           2442.52
COE                    29.43             54.21
```

CASE NUMBER 4:

OPER & MAINT COSTS:

| REPL FRAC | NO OF SEGS | YRS PER OUTAGE | SCH MAINT INTERVAL | NO EQP SETS | NO OF MEN | DAYS OF MAINT | AVAIL | TOTAL ANN COST(M$) |
|---|---|---|---|---|---|---|---|---|
| 1/ 1 | 36 | 10.94 | 150.20 | 12 | 132.74 | 19.00 | .030 | 35.62 |
| 1/ 2 | 18 | 5.47 | 79.10 | 6 | 72.09 | 19.00 | .030 | 35.64 |
| 1/ 3 | 12 | 3.65 | 52.73 | 4 | 53.13 | 19.00 | .030 | 35.66 |
| 1/ 4 | 9 | 2.73 | 39.55 | 3 | 44.01 | 19.00 | .030 | 35.69 |
| 1/ 6 | 6 | 1.82 | 26.37 | 2 | 36.15 | 19.00 | .030 | 35.74 |
| 1/ 9 | 4 | 1.22 | 17.58 | 2 | 29.41 | 12.00 | .030 | 35.67 |
| 1/12 | 3 | 0.91 | 13.24 | 1 | 26.69 | 19.00 | .026 | 35.90 |
| 1/18 | 2 | 0.61 | 8.94 | 1 | 23.81 | 12.00 | .015 | 35.77 |
| 1/36 | . | 0.30 | 4.54 | 1 | 21.06 | 6.50 | .002 | 35.68 |

COE FOR 36 MAINTENANCE OPTIONS (CVD):

(PARENS REPRESENT THE NUMBER OF SCHEDULED OUTAGES)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ( 1) 28.24 | ( 2) 27.65 | ( 3) 27.55 | ( 4) 27.31 | ( 5) 27.32 | ( 6) 27.30 | ( 7) 27.30 | ( 8) 27.30 | ( 9) 27.29 | (10) 27.29 |
| (11) 27.30 | (12) 27.34 | (13) 27.45 | (14) 27.56 | (15) 27.66 | (16) 27.77 | (17) 27.88 | (18) 27.69 | (19) 27.76 | (20) 27.83 |
| (21) 27.90 | (22) 27.97 | (23) 28.04 | (24) 28.10 | (25) 28.17 | (26) 28.24 | (27) 28.31 | (28) 28.38 | (29) 28.45 | (30) 28.52 |
| (31) 28.59 | (32) 28.66 | (33) 28.72 | (34) 28.79 | (35) 28.86 | (36) 28.13 ( | | | | |

EBTR COSTS FOR:

R0=39.55 N=36 BT=5.50 RP=1.40 SYMPCT= * PNET= 1777.81 9 SCHEDULED OUTAGES PER WALL LIFETIME

| | |
|---|---|
| C20 | 3.19 |
| C21 | 351.00 |
| C2101 | 11.62 |
| C2102 | 145.06 |
| C2103 | 44.93 |
| C2104 | 8.79 |
| C2105 | 15.06 |
| C2106 | 78.04 |
| C2198 | 1.97 |
| C2199 | 45.53 |
| C23 | 318.46 |
| C2301 | 97.56 |
| C2302 | 6.26 |
| C2303 | 59.02 |
| C2304 | 25.88 |
| C2305 | 11.05 |
| C2306 | 61.99 |
| C2307 | 11.34 |
| C2398 | 4.37 |
| C2399 | 40.97 |
| C24 | 170.25 |
| C2401 | 15.96 |
| C2402 | 22.58 |
| C2403 | 13.81 |
| C2404 | 2.11 |
| C2405 | 30.90 |
| C2406 | 52.95 |
| C2407 | 8.20 |
| C2498 | 1.76 |
| C2499 | 21.98 |

| | |
|---|---|
| C22 | 1444.27 |
| C2201 | 991.38 |
| C220101 | 247.34 |
| C220102 | 226.77 |
| C220103 | 320.77 |
| C220104 | 47.68 |
| C220105 | 39.91 |
| C220106 | 61.70 |
| C220107 | 45.49 |
| C220108 | 1.73 |
| C2202 | 82.67 |
| C220201 | 76.47 |
| C220202 | 0. |
| C220203 | 6.20 |
| C220204 | 0. |
| C2203 | 10.93 |
| C220301 | 5.65 |
| C220302 | 2.64 |
| C220303 | 2.06 |
| C220304 | 0.59 |
| C220305 | 0. |
| C220306 | 0. |
| C2204 | 6.66 |
| C220401 | 2.37 |
| C220402 | 2.49 |
| C220403 | 1.81 |
| C2205 | 68.09 |
| C2206 | 29.51 |
| C2207 | 26.88 |
| C2298 | 39.77 |
| C2299 | 188.38 |

| | |
|---|---|
| C25 | 39.31 |
| C2501 | 16.49 |
| C2502 | 10.23 |
| C2503 | 6.22 |
| C2504 | 0.81 |
| C26 | 0.25 |
| C2601 | 0. |
| C2602 | 0. |
| C2603 | 0. |
| C2604 | 0.25 |
| C40 | 9.29 |
| C41 | 6.75 |
| C42 | 0.64 |
| C43 | 2.50 |
| C44 | 0. |
| C45 | 1.01 |
| C46 | 0. |
| C47 | 1.89 |

| | |
|---|---|
| C02 | 0.38 |
| C0201 | 0.38 |
| C0202 | 0. |
| C0203 | 0. |
| C03 | 0. |
| C50 | 4.02 |
| C51 | 9.20 |
| C52 | 0. |
| C91 | 232.67 |
| C92 | 186.14 |
| C93 | 116.34 |
| CTD | 2326.73 |
| CTDI | 2061.88 |

| | CVD | TCD |
|---|---|---|
| C94 | 306.79 | 718.04 |
| C95 | 0. | 444.74 |
| CTOT | 3160.67 | 4824.66 |
| CTOTP | 1782.34 | 2263.83 |
| COE | 27.29 | 50.26 |

CASE NUMBER 5:
OPER & MAINT COSTS:

| REPL FRAC | NO OF SEGS | YRS PER OUTAGE | SCH MAINT INTERVAL | NO EQP SETS | NO OF MEN | DAYS OF MAINT | AVAIL | TOTAL ANN COST(M$) |
|---|---|---|---|---|---|---|---|---|
| 1/ 1 | 36 | 10.17 | 147.05 | 12 | 132.74 | 19.00 | .030 | 36.93 |
| 1/ 2 | 18 | 5.00 | 73.83 | 6 | 72.09 | 19.00 | .030 | 36.96 |
| 1/ 3 | 12 | 3.39 | 49.02 | 4 | 53.13 | 19.00 | .030 | 36.98 |
| 1/ 4 | 9 | 2.54 | 36.76 | 3 | 44.01 | 19.00 | .030 | 37.01 |
| 1/ 6 | 6 | 1.69 | 24.51 | 2 | 35.16 | 19.00 | .030 | 37.07 |
| 1/ 9 | 4 | 1.13 | 16.34 | 2 | 29.41 | 12.00 | .030 | 36.99 |
| 1/12 | 3 | 0.85 | 12.35 | 1 | 26.59 | 19.00 | .023 | 37.22 |
| 1/18 | 2 | 0.56 | 8.34 | 1 | 23.81 | 12.00 | .012 | 37.08 |
| 1/36 | 1 | 0.28 | 4.24 | 1 | 21.06 | 6.50 | .000 | 36.99 |

COE FOR 36 MAINTENANCE OPTIONS (CVD):
(P.RENS REPRESENT THE NUMBER OF SCHEDULED OUTAGES)

( 1) 26.60 ( 2) 26.14 ( 3) 26.04 ( 4) 25.83 ( 5) 25.83 ( 6) 25.81 ( 7) [illegible] ( 8 [illegible] .02 9) 25.81 (10 25.81
(11) 25.87 (12) 25.95 (13) 26.06 (14) 26.17 (15) 26.20 (16) 26.39 (17) [illegible] (18 [illegible] 19) 26.35 (20) 26.42
(21) 26.49 (22) 26.56 (23) 26.63 (24) 26.70 (25) 26.77 (26) 26.84 (27) 26.[illegible] (28 [illegible] 27.05 (30) 27.12
(31) 27.19 (32) 27.26 (33) 27.33 (34) 27.40 (35) 27.47 (36) 26.70 (

EBTR COSTS FOR:
R0=39.28 N=36 BT=5.50 RP=1.40 SYMPCT= * PNET= 1924.54 9 SCHEDULED OUTAGES PER WAL. LIF IME

| | |
|---|---|
| C20 | 3.19 |
| | * |
| C21 | 352.77 |
| C2101 | 11.62 |
| C2102 | 142.90 |
| C2103 | 47.29 |
| C2104 | 8.98 |
| C2105 | 16.20 |
| C2106 | 78.04 |
| C2190 | 1.98 |
| C2199 | 45.75 |
| | * |
| C23 | 335.79 |
| C2301 | 102.60 |
| C2302 | 6.74 |
| C2303 | 62.50 |
| C2304 | 27.64 |
| C2305 | 11.55 |
| C2306 | 64.77 |
| C2307 | 12.02 |
| C2390 | 4.61 |
| C2399 | 43.20 |
| | * |
| C24 | 171.85 |
| C2401 | 16.20 |
| C2402 | 22.79 |
| C2403 | 13.94 |
| C2404 | 2.11 |
| C2405 | 31.20 |
| C2406 | 53.45 |
| C2407 | 8.20 |
| C2498 | 1.77 |
| C2499 | 22.18 |

| | |
|---|---|
| C22 | 1475.49 |
| C2201 | 1004.92 |
| C220101 | 247.34 |
| C220102 | 226.77 |
| C220103 | 320.77 |
| C220104 | 40.05 |
| C220105 | 41.51 |
| C220106 | 71.61 |
| C220107 | 46.33 |
| C220108 | 1.73 |
| C2202 | 88.93 |
| C220201 | 82.26 |
| C220202 | 0. |
| C220203 | 6.67 |
| C220204 | 0. |
| C2203 | 10.93 |
| C220301 | 5.65 |
| C220302 | 2.64 |
| C220303 | 2.06 |
| C220304 | 0.59 |
| C220305 | 0. |
| C220306 | 0. |
| C2204 | 7.17 |
| C220401 | 2.55 |
| C220402 | 2.68 |
| C220403 | 1.95 |
| C2205 | 73.25 |
| C2206 | 29.51 |
| C2207 | 27.74 |
| C2298 | 40.50 |
| C2299 | 192.46 |
| | * |
| | * |

| | |
|---|---|
| C25 | 39.31 |
| C2501 | 16.49 |
| C2502 | 10.23 |
| C2503 | 6 22 |
| C2504 | 0.01 |
| | * |
| C26 | 0.25 |
| C2601 | 0. |
| C2602 | 0. |
| C2603 | 0. |
| C2604 | 0.25 |
| | * |
| C40 | 9.29 |
| | * |
| C41 | 7.16 |
| | * |
| C42 | 0.65 |
| | * |
| C43 | 2.57 |
| | * |
| C44 | 0. |
| | * |
| C45 | 1.01 |
| | * |
| C46 | 0. |
| | * |
| C47 | 1.99 |
| | * |
| | * |
| | * |
| | * |
| | * |
| | * |

| | |
|---|---|
| C02 | 0.41 |
| C0201 | 0.41 |
| C0202 | 0. |
| C0203 | 0. |
| | * |
| C03 | 0. |
| | * |
| C50 | 4.32 |
| | * |
| C51 | 9.59 |
| | * |
| C52 | 0. |
| | * |
| C91 | 237.07 |
| | * |
| C92 | 190.29 |
| | * |
| C93 | 118.93 |
| | * |
| CTD | 2370.65 |
| | * |
| CTDI | 2925.74 |
| | * |
| | * |
| | * |
| | * |
| | * |
| | * |
| | * |
| | * |
| | * |
| | * |

| | CVD | TCD |
|---|---|---|
| C94 | 313.64 | 734.07 |
| C95 | 0. | 454.66 |
| CTOT | 3239.30 | 4114.47 |
| CTOTP | 1603.20 | 2137.90 |
| COE | 26.01 | 47.51 |

```
                                        CASE NUMBER     6:
                                        OPER & MAINT COSTS:
REPL NO OF YRS PER  SCH MAINT  NO EQP  NO OF  DAYS OF AVAIL TOTAL ANN
FRAC SEGS  OUTAGE   INTERVAL   SETS    MEN    MAINT         COST(M$)
1/ 1   34    9.66   139.56      12    126.03  19.00  .030    36.71
1/ 2   17    4.02    69.70       6     60.07  19.00  .030    36.73
1/17    2    0.67     8.30       1     23.01  12.00  .013    36.86
1/34    1    0.28     4.26       1     21.06   6.50  .000    36.76
    COE FOR 34 MAINTENANCE OPTIONS (CYD):
         (PARENS REPRESENT THE NUMBER OF SCHEDULED OUTAGES)
( 1)  26.04 ( 2)  25.49 ( 3)  25.40 ( 4)  25.18 ( 5)  25.10 ( 6)  25.17 ( 7)  25.17 ( 8)  25.17 ( 9)  25.16 (10)  25.19
(11)  25.26 (12)  26.36 (13)  25.48 (14)  25.69 (15)  26.70 (16)  25.82 (17)  26.61 (18)  25.60 (19)  25.76 (20)  25.82
(21)  25.89 (22)  26.97 (23)  26.04 (24)  26.11 (25)  26.18 (26)  26.25 (27)  26.33 (28)  26.40 (29)  26.47 (30)  26.54
(31)  26.61 (32)  26.69 (33)  26.76 (34)  26.01 (

                                        EBTR COSTS FOR:
R0=37.27  N=34  BT=5.50  RP=1.48  SYMPCT=   *  PNET= 1916.34     9 SCHEDULED OUTAGES PER WALL LIFETIME
 C20              3.19        C22              1422.93      C25                39.31          C02               0.41
                  *             C2201           961.06        C2501              16.45          C0201             0.41
 C21            336.21           C220101         233.60        C2502              10.23          C0202             0.
   C2101         11.62           C220102         214.10        C2503               6.22          C0203             0.
   C2102        120.03           C220103         302.96        C2504               0.81                           *
   C2103         47.13           C220104          47.26                            *            C03               0.
   C2104          8.97           C220105          40.12      C26                  0.26                            *
   C2105         16.13           C220106          76.70        C2601              0.            C60               4.32
   C2106         70.04           C220107          44.55        C2602              0.                              *
   C2198          1.89           C220108           1.64        C2603              0.            C51               9.42
   C2199         43.61         C2202              80.50        C2604              0.25                            *
                  *              C220201          81.86                           *             C52               0.
 C23            334.60           C220202           0.        C40                  9.29                            *
   C2301        102.33           C220203           6.64                           *             C91             230.25
   C2302          6.71           C220204           0.        C41                  7.14                            *
   C2303         62.33         C2203              10.93                           *             C92             184.20
   C2304         27.62           C220301           5.65      C42                  0.66                            *
   C2305         11.52           C220302           2.64                           *             C93             115.12
   C2306         64.58           C220303           2.06      C43                  2.56                            *
   C2307         11.98           C220304           0.59                           *             CTD            2302.48
   C2398          4.59           C220305           0.        C44                  0.                              *
   C2399         43.04           C220306           0.                             *             CTDI           2832.05
                  *            C2204               7.14      C45                  1.01                            *
 C24            166.00           C220401           2.54                           *                               *
   C2401         15.65           C220402           2.66      C46                  0.                              *
   C2402         21.96           C220403           1.94                           *                               *
   C2403         13.43         C2205              72.89      C47                  1.98                            *
   C2404          2.11         C2206              29.51                          *                               *
   C2405         30.04         C2207              27.68                          *                               *
   C2406         51.48         C2298              39.62                          *                               *
   C2407          8.20         C2299             105.60                          *                               *
   C2498          1.71                           *                                *                               *
   C2499         21.43                           *                                *                               *

                         CYD                  TCD
 C94                   303.60               710.56
 C95                     0.                 440.10
 CTOT                 3135.65              3982.71
 CTOTP                1636.27              2070.29
 COE                    25.16                46.27
```

```
                                            CASE NUMBER    7:
                                            OPER & MAINT COSTS:
REPL NO OF YRS PER  SCH MAINT  NO EQP  NO OF  DAYS OF AVAIL TOTAL ANN
FRAC SEGS  OUTAGE   INTERVAL   SETS    MEN    MAINT         COST(M$)
1/ 1   32    9.31   134.71       11    118.95  19.00  .030   36.18
1/ 2   16    4.66    67.35        6     65.68  19.00  .030   36.20
1/ 4    8    2.33    33.68        3     41.02  19.00  .030   36.26
1/ 8    4    1.16    16.84        2     29.41  12.00  .030   36.23
1/16    2    0.58     8.58        1     23.81  12.00  .014   36.32
1/32    1    0.29     4.36        1     21.06   6.50  .001   36.24
   COE FOR 32 MAINTENANCE OPTIONS (CYD):
        (PARENS REPRESENT THE NUMBER OF SCHEDULED OUTAGES)
( 1)  25.66 ( 2)  25.16 ( 3)  25.06 ( 4)  24.04 ( 5)  24.04 ( 6)  24.02 ( 7)  24.02 ( 8)  24.01 ( 9)  24.02 (10)  24.07
(11)  24.94 (12)  25.06 (13)  25.18 (14)  25.29 (15)  25.41 (16)  26.22 (17)  25.30 (18)  25.37 (19)  25.44 (20)  25.52
(21)  25.59 (22)  25.66 (23)  25.74 (24)  25.81 (25)  25.89 (26)  25.96 (27)  26.03 (28)  26.11 (29)  26.18 (30)  26.25
(31)  26.33 (32)  25.62 (

                                            EBTR COSTS FOR:
R0=34.14  N=32  BT=5.50  RP=1.48  SYMPCT=    *  PNET= 1066.86     8 SCHEDULED OUTAGES PER WALL LIFETIME
 C20              3.19        C22             1362.29      C25            39.31          C02              0.40
                   *            C2201          913.99        C2501          16.49          C0201           0.40
 C21            310.71           C220101        219.86       C2502          10.23          C0202           0.
   C2101          11.62          C220102        201.58       C2503           6.22          C0203           0.
   C2102         100.07          C220103        286.13       C2504           0.81                          *
   C2103          46.30          C220104         45.62                        *            C03             0.
   C2104           8.90          C220105         37.49     C26              0.25                          *
   C2105          15.72          C220106         80.21       C2601           0.            C50             4.19
   C2106          70.04          C220107         42.68       C2602           0.                            *
   C2198           1.76          C220108          1.54       C2603           0.            C51             9.21
   C2199          40.30        C2202             86.30       C2604           0.25                          *
                   *             C220201         79.02                        *            C52             0.
 C23            320.54           C220202          0.       C40              9.29                           *
   C2301         100.54          C220203          6.47                        *            C91           220.42
   C2302           6.54          C220204          0.       C41              7.00                           *
   C2303          61.09        C2203             10.93                        *            C92           176.34
   C2304          26.90          C220301          5.65     C42              0.65                           *
   C2305          11.34          C220302          2.64                        *            C93           110.21
   C2306          63.61          C220303          2.06     C43              2.54                           *
   C2307          11.74          C220304          0.59                        *            CTD          2204.23
   C2398           4.51          C220305          0.       C44              0.                             *
   C2399          42.26          C220306          0.                          *            CTDI         2711.20
                   *           C2204              6.96     C45              1.01                           *
 C24            159.94           C220401          2.47                        *                            *
   C2401          15.06          C220402          2.60     C46              0.                             *
   C2402          21.08          C220403          1.89                        *                            *
   C2403          12.90        C2205             71.08     C47              1.95                           *
   C2404           2.11        C2206             29.51                        *                            *
   C2405          28.85        C2207             27.38                        *                            *
   C2406          49.44        C2298             38.45                        *                            *
   C2407           8.28        C2299            177.69                        *                            *
   C2498           1.65                            *                          *                            *
   C2499          20.65                            *                          *                            *

                          CYD                TCD
 C94                    290.64             680.24
 C95                      0.               421.32
 CTOT                  3001.04            3812.77
 CTOTP                 1608.02            2043.43
 COE                     24.81              45.59
```

CASE NUMBER 8:

OPER & MAINT COSTS:

| REPL FRAC | NO OF SEGS | YRS PER OUTAGE | SCH MAINT INTERVAL | NO EQP SETS | NO OF MEN | DAYS OF MAINT | AVAIL | TOTAL ANN COST(M$) |
|---|---|---|---|---|---|---|---|---|
| 1/ 1 | 28 | 9.12 | 131.07 | 10 | 105.29 | 19.00 | .830 | 33.92 |
| 1/ 2 | 14 | 4.66 | 65.93 | 5 | 59.35 | 19.00 | .830 | 33.96 |
| 1/ 4 | 7 | 2.28 | 32.97 | 3 | 38.07 | 19.00 | .830 | 34.01 |
| 1/ 7 | 4 | 1.30 | 18.84 | 2 | 29.41 | 12.00 | .830 | 33.97 |
| 1/14 | 2 | 0.65 | 9.56 | 1 | 23.01 | 12.00 | .810 | 34.07 |
| 1/28 | 1 | 0.33 | 4.86 | 1 | 21.06 | 6.50 | .805 | 33.99 |

COE FOR 28 MAINTENANCE OPTIONS (CYD):

(PARENS REPRESENT THE NUMBER OF SCHEDULED OUTAGES)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ( 1) 26.00 | ( 2) 25.65 | ( 3) 25.60 | ( 4) 25.35 | ( 5) 25.33 | ( 6) 25.33 | ( 7) 25.32 | ( 8) 25.32 | ( 9) 25.33 | (10) 25.36 |
| (11) 25.40 | (12) 25.60 | (13) 25.72 | (14) 25.60 | (15) 25.68 | (16) 25.76 | (17) 25.84 | (18) 25.91 | (19) 25.99 | (20) 26.07 |
| (21) 26.14 | (22) 26.22 | (23) 26.30 | (24) 26.37 | (25) 26.45 | (26) 26.53 | (27) 26.60 | (28) 26.00 ( | | |

EBTR COSTS FOR:

R0=30.58 N=28 BT=5.50 RP=1.48 SYMPCT= * PNET= 1665.37 7 SCHEDULED OUTAGES PER WALL LIFETIME

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| C20 | 3.19 | C22 | 1215.52 | C25 | 39.31 | C02 | 0.36 |
| | * | C2201 | 808.09 | C2501 | 16.49 | C0201 | 0.36 |
| C21 | 279.70 | C220101 | 192.38 | C2502 | 10.23 | C0202 | 0. |
| C2101 | 11.62 | C220102 | 176.38 | C2503 | 6.22 | C0203 | 0. |
| C2102 | 86.72 | C220103 | 249.48 | C2504 | 0.81 | | * |
| C2103 | 42.81 | C220104 | 40.75 | | * | C03 | 0. |
| C2104 | 8.61 | C220105 | 32.81 | C26 | 0.25 | | * |
| C2105 | 14.06 | C220106 | 76.94 | C2601 | 0. | C50 | 3.75 |
| C2106 | 70.04 | C220107 | 38.00 | C2602 | 0. | | * |
| C2198 | 1.57 | C220108 | 1.35 | C2603 | 0. | C51 | 8.36 |
| C2199 | 36.28 | C2202 | 77.14 | C2604 | 0.25 | | * |
| | * | C220201 | 71.35 | | * | C52 | 0. |
| C23 | 302.88 | C220202 | 0. | C40 | 9.23 | | * |
| C2301 | 92.96 | C220203 | 5.79 | | * | C91 | 198.69 |
| C2302 | 5.84 | C220204 | 0. | C41 | 6.41 | | * |
| C2303 | 65.84 | C2203 | 10.93 | | * | C92 | 160.95 |
| C2304 | 24.32 | C220301 | 5.65 | C42 | 0.62 | | * |
| C2305 | 10.60 | C220302 | 2.64 | | * | C93 | 99.35 |
| C2306 | 59.47 | C220303 | 2.06 | C43 | 2.44 | | * |
| C2307 | 10.73 | C220304 | 0.69 | | * | CTD | 1986.93 |
| C2398 | 4.16 | C220305 | 0. | C44 | 0. | | * |
| C2399 | 30.96 | C220306 | 0. | | * | CTD1 | 2443.92 |
| | * | C2204 | 6.22 | C45 | 1.01 | | * |
| C24 | 146.09 | C220401 | 2.21 | | * | | * |
| C2401 | 13.66 | C220402 | 2.32 | C46 | 0. | | * |
| C2402 | 19.11 | C220403 | 1.69 | | * | | * |
| C2403 | 11.69 | C2205 | 63.53 | C47 | 1.00 | | * |
| C2404 | 2.11 | C2206 | 29.51 | | * | | * |
| C2405 | 26.15 | C2207 | 26.12 | | * | | * |
| C2406 | 44.81 | C2298 | 36.44 | | * | | * |
| C2407 | 8.20 | C2299 | 168.55 | | * | | * |
| C2498 | 1.51 | | * | | * | | * |
| C2499 | 18.86 | | * | | * | | * |

| | CYD | TCD |
|---|---|---|
| C94 | 261.99 | 613.18 |
| C95 | 0. | 379.79 |
| CTOT | 2705.91 | 3436.89 |
| CTOTP | 1634.62 | 2076.20 |
| COE | 26.32 | 46.46 |

CASE NUMBER 9:
OPER & MAINT COSTS:

| REPL FRAC | NO OF SEGS | YRS PER OUTAGE | SCH MAINT INTERVAL | NO EQP SETS | NO OF MEN | DAYS OF MAINT | AVAIL | TOTAL ANN COST(M$) |
|---|---|---|---|---|---|---|---|---|
| 1/ 1 | 24 | 9.03 | 130.67 | 8 | 91.01 | 19.00 | .030 | 31.33 |
| 1/ 2 | 12 | 4.52 | 65.33 | 4 | 53.13 | 19.00 | .030 | 31.36 |
| 1/ 3 | 8 | 3.01 | 43.[illegible] | 3 | 41.02 | 19.00 | .030 | 31.39 |
| 1/ 4 | 6 | 2.26 | 32.67 | 2 | 35.16 | 19.00 | .030 | 31.42 |
| 1/ 6 | 4 | 1.51 | 21.78 | 2 | 29.41 | 12.00 | .030 | 31.37 |
| 1/ 8 | 3 | 1.13 | 16.33 | 1 | 26.59 | 19.00 | .030 | 31.66 |
| 1/12 | 2 | 0.75 | 10.99 | 1 | 23.01 | 12.00 | .022 | 31.47 |
| 1/24 | 1 | 0.38 | 5.50 | 1 | 21.06 | 6.50 | .010 | 31.40 |

COE FOR 24 MAINTENANCE OPTIONS (CYD):
(PARENS REPRESENT THE NUMBER OF SCHEDULED OUTAGES)

```
( 1)  27.11 ( 2)  26.67 ( 3)  26.38 ( 4)  26.36 ( 5)  26.36 ( 6)  26.35 ( 7)  26.36 ( 8)  26.27 ( 9)  26.27 (10)  26.40
(11)  26.52 (12)  26.49 (13)  26.57 (14)  26.65 (15)  26.74 (16)  26.82 (17)  26.90 (18)  26.98 (19)  27.06 (20)  27.14
(21)  27.22 (22)  27.30 (23)  27.38 (24)  26.89 (
```

EBTR COSTS FOR:

```
R0=27.13  N=24  BT=5.50  RP=1.48  SYMPCT=   *  PNET= 1415.73     8 SCHEDULED OUTAGES PER WALL LIFETIME
 C20             3.19        C22               1055.79        C25               37.50          C02            0.31
                 *             C2201            699.14          C2501           15.00            C0201        0.31
 C21           250.98            C220101        164.89          C2502           10.23            C0202        0.
   C2101        11.62            C220102        151.18          C2503            5.22            C0203        0.
   C2102        60.28            C220103        213.84          C2504            0.01                         *
   C2103        30.67            C220104         35.71                          *               C03           0.
   C2104         8.24            C220105         27.99        C26                0.25                         *
   C2105        12.16            C220106         71.23          C2601            0.              C50          3.44
   C2106        70.04            C220107         33.13          C2602            0.                           *
   C2198         1.41            C220108          1.15          C2603            0.              C51          7.42
   C2199        32.56          C2202             66.72          C2604            0.25                         *
                 *               C220201         61.72                          *               C52           0.
 C23           272.71            C220202          0.          C40                9.11                         *
   C2301        83.98            C220203          5.00                          *               C91         175.24
   C2302         5.06            C220204          0.          C41                5.73                         *
   C2303        49.73          C2203             10.93                          *               C92         140.19
   C2304        21.34            C220301          5.66        C42                0.59                         *
   C2305         9.72            C220302          2.64                          *               C93          87.62
   C2306        54.61            C220303          2.06        C43                2.31                         *
   C2307         9.55            C220304          0.59                          *               CTD        1752.38
   C2398         3.74            C220305          0.          C44                0.                           *
   C2399        35.08            C220306          0.                            *               CTD1       2155.43
                 *             C2204              5.38        C45                1.01                         *
 C24           131.88            C220401          1.91                          *                             *
   C2401        12.19            C220402          2.01        C46                0.                           *
   C2402        17.09            C220403          1.46                          *                             *
   C2403        10.45          C2205             54.96        C47                1.54                         *
   C2404         2.11          C2206             24.01                          *                             *
   C2405        23.38          C2207             24.60                          *                             *
   C2406        40.07          C2298             32.25                          *                             *
   C2407         8.20          C2299            137.71                          *                             *
   C2498         1.36                             *                             *                             *
   C2499        17.[illegible]                    *                             *                             *
```

| | CYD | TCD |
|---|---|---|
| C94 | 231.06 | 540.00 |
| C95 | 0. | 334.95 |
| CTOT | 2306.49 | 3031.10 |
| CTOTP | 1605.69 | 2141.06 |
| COE | 26.27 | 40.11 |

```
                                            CASE NUMBER   10:
                                            OPER & MAINT COSTS:
REPL NO OF  YRS PER  SCH MAINT  NO EQP  NO OF  DAYS OF AVAIL TOTAL ANN
FRAC SEGS  OUTAGE   INTERVAL   SETS    MEN    MAINT         COST(MS)
1/ 1   22    9.03    130.64       8    85.17  19.00  .030   30.06
1/ 2   11    4.52     66.32       4    50.06  19.00  .030   30.09
1/11    2    0.02     11.95       1    23.01  12.00  .025   30.19
1/22    1    0.41      6.06       1    21.06   6.50  .012   30.14
    COE FOR 22 MAINTENANCE OPTIONS (CVD):
        (PARENS REPRESENT THE NUMBER OF SCHEDULED OUTAGES)
( 1) ' 27.93 ( 2)  27.45 ( 3)  27.13 ( 4)  27.10 ( 5)  27.11 ( 6)  27.10 ( 7)  27.10 ( 8)  27.00 ( 9)  27.01 (10)  27.14
(11)  27.15 (12)  27.23 (13)  27.32 (14)  27.40 (15)  27.40 (16)  27.57 (17)  27.65 (18)  27.73 (19)  27.82 (20)  27.90
(21)  27.99 (22)  27.56 (

                                            EDTR COSTS FOR:
R0=24.04  N=22  DT=5.50  RP=1.40  SYMPCT=    *  PNET= 1206.44    0 SCHEDULED OUTAGES PER WALL LIFETIME
 C20            3.19       C22               970.53         C25            37.50        C02           0.20
                  *          C2201             644.90         C2501          15.00        C0201          0.20
 C21          229.96           C220101           151.15       C2502          10.23        C0202          0.
   C2101        11.62          C220102           130.50       C2503           6.22        C0203          0.
   C2102        53.61          C220103           196.02       C2504           0.81                       *
   C2103        36.39          C220104            33.46                        *          C03            0.
   C2104         8.03          C220105            24.71     C26             0.25                         *
   C2105        11.15          C220106            59.10       C2601          0.           C50            3.19
   C2106        70.04          C220107            30.00       C2602          0.                          *
   C2198         1.29          C220108             1.06       C2603          0.           C51            7.04
   C2199        29.03        C2202               61.10        C2604          0.25                        *
                  *            C220201            55.59                      *            C52            0.
 C23          286.15           C220202             0.       C40             9.05                         *
   C2301        79.03          C220203             4.59                      *            C91          163.09
   C2302         4.64          C220204             0.       C41             5.37                         *
   C2303        46.39        C2203               10.93                       *            C92          130.47
   C2304        19.74          C220301             5.65     C42             0.50                         *
   C2305         9.23          C220302             2.64                      *            C93           81.54
   C2306        51.75          C220303             2.06     C43             2.25                         *
   C2307         5.91          C220304             0.59                      *            CTD         1630.05
   C2398         3.51          C220305             0.       C44             0.                           *
   C2399        32.95          C220306             0.                        *            CTD1        2005.95
                  *          C2204                4.93      C45             1.01                         *
 C24          125.09           C220401             1.75                      *                           *
   C2401        11.40          C220402             1.04     C46             0.                           *
   C2402        16.12          C220403             1.34                      *                           *
   C2403         9.06        C2205               50.39      C47             1.55                         *
   C2404         2.11        C2206               24.01                       *                           *
   C2405        22.07        C2207               23.92                       *                           *
   C2406        37.01        C2298               30.55                       *                           *
   C2407         0.20        C2299              127.55                       *                           *
   C2498         1.29                               *                        *                           *
   C2499        16.15                               *                        *                           *

                       CVD                   TCD
 C94                 215.04                503.29
 C95                   0.                  311.72
 CTOT               2220.99               2020.97
 CTOTP              1726.46               2192.04
 COE                  27.00                 49.40
```

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                                          CASE NUMBER   11:
                                          OPER & MAINT COSTS:
REPL NO OF  YRS PER  SCH MAINT  NO EQP  NO OF  DAYS OF AVAIL  TOTAL ANN
FRAC SEGS   OUTAGE   INTERVAL   SETS    MEN    MAINT          COST(M$)
1/ 1  20     9.07    131.27       7     70.59  19.00   .030    20.57
1/ 2  10     4.54     65.63       4     47.02  19.00   .030    20.59
1/ 4   5     2.27     32.82       2     32.26  19.00   .030    20.66
1/ 5   4     1.81     26.25       2     29.41  12.00   .030    20.59
1/10   2     0.91     13.16       1     23.01  12.00   .027    20.69
1/20   1     0.45      6.60       1     21.06   6.50   .015    20.64
     COE FOR 20 MAINTENANCE OPTIONS (CYD):
          (PARENS REPRESENT THE NUMBER OF SCHEDULED OUTAGES)
( 1)  20.90 ( 2)  20.53 ( 3)  20.17 ( 4)  20.14 ( 5)  20.13 ( 6)  20.14 ( 7)  20.02 ( 8)  20.03 ( 9)  20.03 (10)  20.09
(11)  20.10 (12)  20.26 (13)  20.36 (14)  20.44 (15)  20.62 (16)  20.61 (17)  20.75 (18)  20.70 (19)  20.87 (20)  20.50

                                          EDTR COSTS FOR:
R0=21.36  N=20  BT=5.50  RP=1.40  SYMPCT=  *  PNET= 1150.91     7 SCHEDULED OUTAGES PER WALL LIFETIME
 C20             3.19         C22              899.56         C25            37.50         C02              0.26
                  *             C2201            509.77         C2501          15.00         C0201            0.26
 C21           212.52             C220101        137.41         C2502          10.23         C0202            0.
   C2101        11.62             C220102        120.99         C2503           6.22         C0203            0.
   C2102        42.29             C220103        170.20         C2504           0.01                          *
   C2103        33.93             C220104         31.07                          *           C03              0.
   C2104         7.79             C220105         21.67       C26             0.25                            *
   C2105        10.09             C220106         65.92         C2601           0.         C50              2.07
   C2106        70.04             C220107         20.54         C2602           0.                            *
   C2190         1.19             C220108          0.96         C2603           0.         C51              6.61
   C2199        27.56           C2202             55.35         C2604           0.25                          *
                  *               C220201         51.20                          *           C52              0.
 C23           230.30             C220202          0.         C40             0.06                            *
   C2301        73.60             C220203          4.15                          *           C91            150.95
   C2302         4.19             C220204          0.         C41             4.99                            *
   C2303        42.02           C2203             10.93                          *           C92            120.76
   C2304        10.04             C220301          5.65       C42             0.56                            *
   C2305         0.69             C220302          2.64                          *           C93             75.40
   C2306        40.73             C220303          2.06       C43             2.16                            *
   C2307         0.23             C220304          0.59                          *           CTD           1509.54
   C2390         3.27             C220305          0.         C44             0.                              *
   C2399        30.66             C220306          0.                            *           CTDI          1056.73
                  *             C2204              4.46       C45             1.01                            *
 C24           110.13             C220401          1.59                          *                            *
   C2401        10.75             C220402          1.67       C46             0.                              *
   C2402        15.14             C220403          1.21                          *                            *
   C2403         9.26           C2205             45.59       C47             1.45                            *
   C2404         2.11           C2206             24.01                          *                            *
   C2405        20.72           C2207             23.12                          *                            *
   C2406        35.49           C2290             29.00                          *                            *
   C2407         0.20           C2299            117.33                          *                            *
   C2490         1.22                                *                           *                            *
   C2499        16.25                                *                           *                            *

                          CYD                  TCD
 C94                    199.04               465.05
 C96                      0.                 200.54
 CTOT                  2055.77              2611.12
 CTOTP                 1706.21              2260.74
 COE                     20.02                51.22
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                                                   CASE NUMBER    1:
                                                   OPER & MAINT COSTS:
REPL NO OF YRS PER  SCH MAINT  NO EQF  NO OF  DAYS OF AVAIL TOTAL A&M
FRAC SEGS  OUTAGE   INTERVAL   SETS    MEN    MAINT         COST(M$)
1/ 1   30   16.86   243.95      10    112.10  19.00  .030   20.69
1/ 2   15    8.43   121.97       5     62.50  19.00  .030   20.70
1/ 3   10    5.62    81.32       4     47.02  19.00  .030   20.72
1/ 5    6    3.37    48.79       2     35.15  19.00  .030   20.75
1/ 6    5    2.81    40.66       2     32.26  19.00  .030   20.77
1/10    3    1.69    24.39       1     26.59  19.00  .030   20.85
1/15    2    1.12    16.26       1     23.01  12.00  .030   20.81
1/30    1    0.56     8.23       1     21.06   6.50  .020   20.77
    COE FOR 30 MAINTENANCE OPTIONS (CVD):
         (PARENS REPRESENT THE NUMBER OF SCHEDULED OUTAGES)
( 1)  37.08 ( 2)  36.12 ( 3)  36.03 ( 4)  35.61 ( 5)  35.57 ( 6)  35.57 ( 7)  35.50 ( 8)  35.56 ( 9)  35.57 (10)  35.43
(11)  35.43 (12)  35.44 (13)  35.44 (14)  35.44 (15)  35.42 (16)  35.42 (17)  35.43 (18)  35.49 (19)  35.55 (20)  35.61
(21)  35.67 (22)  35.73 (23)  35.79 (24)  35.85 (25)  35.91 (26)  35.96 (27)  36.02 (28)  36.08 (29)  36.14 (30)  35.82

                                                   EBTR COSTS FOR:
R0=33.24  N=30  BT=5.50  RP=1.40  SYMPCT=   *  PNET=  981.73    15 SCHEDULED OUTAGES PER WALL LIFETIME
 C20             3.19         C22             1064.24         C25             37.50        C02              0.21
                  *             C2201          762.53           C2501          15.00         C0201           0.21
 C21           273.85             C220101       206.12          C2502          10.23         C0202           0.
   C2101        11.62             C220102       180.98          C2503           6.22         C0203           0.
   C2102       102.40             C220103       267.30          C2504           0.01                        *
   C2103        29.21             C220104        16.99                          *            C03             0.
   C2104         7.31             C220105        24.86        C26              0.25                          *
   C2105         8.14             C220106        25.41          C2601          0.          C50             2.25
   C2106        78.04             C220107        21.43          C2602          0.                            *
   C2198         1.54             C220108         1.44          C2603          0.          C51             0.21
   C2199        35.52           C2202            44.67          C2604          0.25                          *
                  *               C220201        41.32                         *           C52             0.
 C23           204.26             C220202         0.          C40              8.67                          *
   C2301        63.42             C220203         3.35                         *           C91           :70.27
   C2302         3.38             C220204         0.          C41              4.51                          *
   C2303        36.00           C2203            10.93                         *           C92           136.22
   C2304        14.00             C220301         5.65        C42              0.54                          *
   C2305         7.64             C220302         2.64                         *           C93            85.14
   C2306        42.85             C220303         2.06        C43              2.06                          *
   C2307         6.93             C220304         0.59                         *           CTD          1702.71
   C2398         2.00             C220305         0.          C44              0.                            *
   C2399        26.20             C220306         0.                           *           CTDI         2094.33
                  *             C2204             3.60        C45              1.01                          *
 C24           119.35             C220401         1.20                         *                             *
   C2401        10.74             C220402         1.35        C46              0.                            *
   C2402        16.33             C220403         0.98                         *                             *
   C2403         9.30           C2205            36.00        C47              1.34                          *
   C2404         2.11           C2206            24.01                         *                             *
   C2405        20.99           C2207            21.65                         *                             *
   C2406        35.96           C2298            31.24                         *                             *
   C2407         8.20           C2299           130.01                         *                             *
   C2498         1.23                              *                           *                             *
   C2499        15.41                              *                           *                             *

                           CYD                    TCD
 C94                     224.51                 525.47
 C95                       0.                   325.46
 CTOT                   2318.84                2945.26
 CTOTP                  2362.81                3800.00
 COE                      35.42                  65.65
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                                                 CASE NUMBER    2
                                                 OPER & MAINT COSTS:
REPL NO OF  YRS PER  SCH MAINT  NO EQP  NO OF   DAYS OF AVAIL TOTAL ANN
FRAC SEGS  OUTAGE   INTERVAL   SETS    MEN     MAINT          COST(M$)
1/ 1   32   13.94   201.62      11     110.95  19.00  .030    23.20
1/ 2   16    6.97   100.81       6      65.60  19.00  .030    23.21
1/ 4    8    3.48    50.40       3      41.02  19.00  .030    23.25
1/ 8    4    1.74    25.20       2      29.41  12.00  .030    23.23
1/16    2    0.87    12.65       1      23.01  12.00  .026    23.34
1/32    1    0.44     6.42       1      21.06   6.50  .014    23.20
   COE FOR 32 MAINTENANCE OPTIONS (CYD):
         (PARENS REPRESENT THE NUMBER OF SCHEDULED OUTAGES)
( 1)  31.11 ( 2)  30.30 ( 3)  30.23 ( 4)  29.91 ( 5)  29.97 ( 6)  29.89 ( 7)  29.83 ( 8)  29.80 ( 9)  29.80 (10)  29.80
(11)  29.78 (12)  29.79 (13)  29.79 (14)  29.80 (15)  29.83 (16)  29.89 (17)  29.95 (18)  30.01 (19)  30.07 (20)  30.13
(21)  30.19 (22)  30.25 (23)  30.31 (24)  30.37 (25)  30.43 (26)  30.49 (27)  30.55 (28)  30.61 (29)  30.67 (30)  30.73
(31)  30.79 (32)  30.34 (

                                                 EBTR COSTS FOR:
R0=35.94  N=32  BT=5.50  RP=1.40  SYMPCT=    *  PNET= 1295.27    11 SCHEDULED OUTAGES PER WALL LIFETIME
 C20                3.19          C22            1170.74         C25               37.60          C02              0.27
                     *              C2201          816.26           C2501            15.00           C0201             0.27
 C21               303.91             C220101        219.86           C2502            10.23           C0202            0.
   C2101            11.62             C220102        201.60           C2503             6.22           C0203            0.
   C2102           119.81             C220103        206.13           C2504             5.05                            *
   C2103            34.92             C220104         18.44                              *             C03              0.
   C2104             7.89             C220105         30.36          C26               0.25                             *
   C2105            10.51             C220106         36.39            C2601            0.             C04              2.90
   C2106            70.04             C220107         22.97            C2602            0.                              *
   C2198             1.71             C220108          1.54            C2603            0.             C51              0.33
   C2199            39.42           C2202            57.65            C2604             0.25                            *
                     *                C220201         53.33                              *             C52              0.
 C23               245.43             C220202          0.            C40               9.05                             *
   C2301            75.82             C220203          4.32                              *             C91            180.64
   C2302             4.37             C220204          0.            C41               5.39                             *
   C2303            44.24           C2203            10.93                               *             C92            150.91
   C2304            18.72             C220301          5.65          C42               0.50                             *
   C2305             8.90             C220302          2.64                              *             C93             94.32
   C2306            49.94             C220303          2.05          C43               2.25                             *
   C2307             8.50             C220304          0.59                              *             CTD           1996.39
   C2398             3.37             C220305          0.            C44               0.                               *
   C2399            31.57             C220306          0.                                *             CTDI          2320.25
                     *              C2204             4.65           C45               1.01                             *
 C24               125.29             C220401          1.65                              *                              *
   C2401            11.61             C220402          1.74          C46               0.                               *
   C2402            16.15             C220403          1.26                              *                              *
   C2403             9.88           C2205            47.49           C47               1.55                             *
   C2404             2.11           C2206            24.01                               *                              *
   C2405            22.10           C2207            23.44                               *                              *
   C2406            37.07           C2298            33.61                               *                              *
   C2407             8.20           C2299           162.71                               *                              *
   C2498             1.29                              *                                 *                              *
   C2499            16.17                              *                                 *                              *

                        CYD                         TCD
 C94                  240.73                      502.15
 C95                    0.                        360.57
 CTOT                2560.99                     3262.90
 CTOTP               1993.37                     2519.16
 COE                   29.78                       65.10
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                                                   CASE NUMBER    3:
                                                   OPER & MAINT COSTS:
REPL NO OF YRS PER  SCH MAINT  NO EQP  NO OF  DAYS OF AVAIL TOTAL ANN
FRAC SEGS  OUTAGE   INTERVAL   SETS    MEN    MAINT         COST(M$)
1/ 1   36   12.13   176.44       12    132.74  19.00  .030   26.14
1/ 2   18    6.06    87.72        6     72.09  19.00  .030   26.16
1/ 3   12    4.04    68.48        4     53.13  19.00  .030   26.18
1/ 4    9    3.03    43.86        3     44.01  19.00  .030   26.20
1/ 6    6    2.02    29.24        2     36.15  19.00  .030   26.26
1/ 9    4    1.35    19.49        2     29.41  12.00  .030   26.19
1/12    3    1.01    14.62        1     26.69  12.00  .030   26.40
1/18    2    0.67     9.88        1     23.81  12.00  .019   26.29
1/36    1    0.34     6.02        1     21.06   6.50  .006   26.21
   COE FOR 36 MAINTENANCE OPTIONS (CYD):
         (PARENS REPRESENT THE NUMBER OF SCHEDULED OUTAGES)
( 1)  26.92 ( 2)  26.31 ( 3)  26.20 ( 4)  25.96 ( 5)  25.96 ( 6)  25.94 ( 7)  25.94 ( 8)  25.94 ( 9)  25.93 (10)  25.94
(11)  25.94 (12)  25.86 (13)  25.95 (14)  26.04 (15)  26.13 (16)  26.23 (17)  26.32 (18)  26.19 (19)  26.25 (20)  26.31
(21)  26.37 (22)  26.43 (23)  26.49 (24)  26.55 (25)  26.61 (26)  26.67 (27)  26.73 (28)  26.79 (29)  26.85 (30)  26.91
(31)  26.96 (32)  27.02 (33)  27.08 (34)  27.14 (35)  27.20 (36)  26.60 (

                                                   ERTR COSTS FOR:
R0-30.20  N-36  BT-6.50  RP-1.40  SYMPCT-    *  PNET- 1702.67    12 SCHEDULED OUTAGES PER WALL LIFETIME
 C20              3.19         C22             1347.65        C25              37.50        C02              0.35
                  *              C2201          931.73          C2501           15.00         C0201           0.35
 C21            334.00             C220101      247.34          C2502           10.23         C0202           0.
   C2101         11.62             C220102      226.77          C2503            6.22         C0203           0.
   C2102        135.94             C220103      320.77          C2504            0.81                         *
   C2103         41.79             C220104       21.20                         *           C03             0.
   C2104          8.62             C220105       36.70        C26              0.25                          *
   C2105         13.58             C220106       51.14          C2601          0.           C50             3.04
   C2106         70.04             C220107       26.00          C2602          0.                            *
   C2198          1.88             C220108        1.73          C2603          0.           C51             0.52
   C2199         43.42           C2202           74.64          C2604           0.25                         *
                  *                C220201       68.95                         *           C52             0.
 C23            295.47             C220202        0.          C40              9.23                          *
   C2301         98.76             C220203        5.59                         *           C91           215.56
   C2302          5.65             C220204        0.          C41              6.54                          *
   C2303         64.34           C2203           10.93                         *           C92           172.45
   C2304         23.68             C220301        5.65        C42              0.63                          *
   C2305         10.39             C220302        2.64                         *           C93           107.78
   C2306         58.26             C220303        2.06        C43              2.46                          *
   C2307         10.44             C220304        0.59                         *           CTD          2155.62
   C2398          4.05             C220305        0.          C44              0.                            *
   C2399         38.01             C220306        0.                           *           CTDI         2651.41
                  *              C2204            6.01        C45              1.01                          *
 C24            136.70             C220401        2.14                         *                             *
   C2401         12.83             C220402        2.24        C46              0.                            *
   C2402         17.76             C220403        1.63                         *                             *
   C2403         10.86           C2205           61.40        C47              1.04                          *
   C2404          2.11           C2206           24.01                         *                             *
   C2405         24.30           C2207           25.76                         *                             *
   C2406         41.64           C2298           37.45                         *                             *
   C2407          8.20           C2299          175.77                         *                             *
   C2498          1.41                            *                            *                             *
   C2499         17.66                            *                            *                             *

                        CYD                     TCD
 C94                   284.23                  665.24
 C96                    0.                     412.03
 CTOT                 2936.64                 3728.67
 CTOTP                1724.24                 2190.03
 COE                    25.86                   47.93
```

CASE NUMBER 4:
OPER & MAINT COSTS:

| REPL FRAC | NO OF SEGS | YRS PER OUTAGE | SCH MAINT INTERVAL | NO EQP SETS | NO OF MEN | DAYS OF MAINT | AVAIL | TOTAL ANN COST(M$) |
|---|---|---|---|---|---|---|---|---|
| 1/ 1 | 36 | 10.94 | 158.20 | 12 | 132.74 | 19.00 | .030 | 27.60 |
| 1/ 2 | 18 | 5.47 | 79.10 | 6 | 72.09 | 19.00 | .030 | 27.62 |
| 1/ 3 | 12 | 3.66 | 52.73 | 4 | 53.13 | 19.00 | .030 | 27.65 |
| 1/ 4 | 9 | 2.73 | 39.55 | 3 | 44.01 | 19.00 | .530 | 27.67 |
| 1/ 6 | 6 | 1.82 | 26.37 | 2 | 35.15 | 19.00 | .033 | 27.73 |
| 1/ 9 | 4 | 1.22 | 17.58 | 2 | 29.41 | 12.00 | .030 | 27.66 |
| 1/12 | 3 | 0.91 | 13.24 | 1 | 26.59 | 19.00 | .026 | 27.88 |
| 1/18 | 2 | 0.61 | 8.94 | 1 | 23.01 | 12.00 | .015 | 27.75 |
| 1/36 | 1 | 0.30 | 4.64 | 1 | 21.06 | 6.50 | .002 | 27.67 |

COE FOR 36 MAINTENANCE OPTIONS (CYD):
(PARENS REPRESENT THE NUMBER OF SCHEDULED OUTAGES)

```
( 1)  25.02 ( 2)  24.48 ( 3)  24.30 ( 4)  24.16 ( 5)  24.16 ( 6)  24.14 ( 7)  24.15 ( 8)  24.15 ( 9)  24.14 (10)  24.14
(11)  24.15 (12)  24.18 (13)  24.27 (14)  24.37 (15)  24.47 (16)  24.56 (17)  24.66 (18)  [illegible]9 (19)  24.85 (20)  24.61
(21)  24.67 (22)  24.73 (23)  24.79 (24)  24.85 (25)  24.92 (26)  24.98 (27)  25.04 (28)  25.10 (29)  25.16 (30)  25.22
(31)  25.28 (32)  25.34 (33)  26.40 (34)  26.46 (35)  25.53 (36)  24.87 (
```

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                                               EBTR COSTS FOR:
R0=39.55  N=36  BT=5.50  RP=1.40  SYMPCT=   *  PNET= 1097.30     9 SCHEDULED OUTAGES PER WALL LIFETIME
 C20               3.19       C22               1395.65        C25              39.31        C02              0.30
                   *            C2201            946.15          C2501           16.49         C0201           0.30
 C21             361.00           C220101        247.34          C2502           10.23         C0202           0.
   C2101          11.62           C220102        226.77          C2503            6.22         C0203           0.
   C2102         146.06           C220103        320.77          C2504            0.81                         *
   C2103          44.93           C220104         21.75                           *            C03             0.
   C2104           8.79           C220105         39.91        C26              0.25                           *
   C2105          15.06           C220106         61.70          C2601           0.            C50             4.02
   C2106          78.04           C220107         26.19          C2602           0.                            *
   C2198           1.97           C220108          1.73          C2603           0.            C51             0.70
   C2199          45.63         C2202             82.67          C2604            0.25                         *
                   *              C220201         76.47                           *            C52             0.
 C23             318.46           C220202          0.          C40              9.29                           *
   C2301          97.56           C220203          5.20                           *            C91           224.05
   C2302           6.26           C220204          0.          C41              7.09                           *
   C2303          59.02         C2203             10.93                           *            C92           179.24
   C2304          26.88           C220301          5.65        C42              0.65                           *
   C2305          11.05           C220302          2.64                           *            C93           112.02
   C2306          61.99           C220303          2.06        C43              2.55                           *
   C2307          11.34           C220304          0.59                           *            CTD          2240.40
   C2398           4.37           C220305          0.          C44              0.                             *
   C2399          40.97           C220306          0.                             *            CTD1         2765.79
                   *            C2204              6.66        C45              1.01                           *
 C24             137.62           C220401          2.37                           *                            *
   C2401          13.03           C220402          2.49        C46              0.                             *
   C2402          17.06           C220403          1.01                           *                            *
   C2403          10.92         C2205             68.09        C47              1.97                           *
   C2404           2.11         C2206             29.51                           *                            *
   C2405          24.44         C2207             26.88                           *                            *
   C2406          41.88         C2298             38.36                           *                            *
   C2407           8.20         C2299            101.39                           *                            *
   C2498           1.42                            *                              *                            *
   C2499          17.77                            *                              *                            *

                          CYD                   TCD
 C94                    295.42                691.43
 C96                      0.                  428.25
 CTOT                  3051.21               3875.47
 CTOTP                 1600.19               2042.62
 COE                     24.14                 44.73
```

CASE NUMBER 5:
OPER & MAINT COSTS:

| REPL FRAC | NO OF SEGS | YRS PER OUTAGE | SCH MAINT INTERVAL | NO EQP SETS | NO OF MEN | DAYS OF MAINT | AVAIL | TOTAL ANN COST(M$) |
|---|---|---|---|---|---|---|---|---|
| 1/ 1 | 36 | 10.17 | 147.05 | 12 | 132.74 | 19.00 | .030 | 28.95 |
| 1/ 2 | 18 | 5.00 | 73.53 | 6 | 72.09 | 19.00 | .030 | 28.97 |
| 1/ 3 | 12 | 3.39 | 49.02 | 4 | 53.13 | 19.00 | .030 | 29.00 |
| 1/ 4 | 9 | 2.54 | 36.76 | 3 | 44.01 | 19.00 | .030 | 29.03 |
| 1/ 6 | 6 | 1.69 | 24.51 | 2 | 36.16 | 19.00 | .030 | 29.09 |
| 1/ 9 | 4 | 1.13 | 16.34 | 2 | 29.41 | 12.00 | .030 | 29.01 |
| 1/12 | 3 | 0.85 | 12.35 | 1 | 26.59 | 19.00 | .023 | 29.24 |
| 1/18 | 2 | 0.56 | 8.34 | 1 | 23.81 | 12.00 | .012 | 29.10 |
| 1/35 | 1 | 0.28 | 4.24 | 1 | 21.06 | 6.50 | .000 | 29.01 |

COE FOR 36 MAINTENANCE OPTIONS (CYD):
(PARENS REPRESENT THE NUMBER OF SCHEDULED OUTAGES)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ( 1) 23.75 | ( 2) 23.24 | ( 3) 23.15 | ( 4) 22.95 | ( 5) 22.95 | ( 6) 22.93 | ( 7) 22.93 | ( 8) 22.94 | ( 9) 22.93 | (10) 22.93 |
| (11) 22.98 | (12) 23.05 | (13) 23.14 | (14) 23.24 | (15) 23.34 | (16) 23.44 | (17) 23.54 | (18) 23.34 | (19) 23.40 | (20) 23.46 |
| (21) 23.52 | (22) 23.59 | (23) 23.65 | (24) 23.71 | (25) 23.77 | (26) 23.84 | (27) 23.90 | (28) 23.96 | (29) 24.02 | (30) 24.09 |
| (31) 24.15 | (32) 24.21 | (33) 24.27 | (34) 24.33 | (35) 24.40 | (36) 23.71 ( | | | | |

EBTR COSTS FOR:

R0=39.25 N=36 BT=5.50 RP=1.40 SYMPCT= * PNET= 2046.50 9 SCHEDULED OUTAGES PER WALL LIFETIME

| | |
|---|---|
| C20 | 3.19 |
| C21 | 352.77 |
| C2101 | 11.62 |
| C2102 | 142.90 |
| C2103 | 47.29 |
| C2104 | 8.90 |
| C2105 | 16.20 |
| C2106 | 70.04 |
| C2198 | 1.98 |
| C2199 | 45.75 |
| C23 | 335.79 |
| C2301 | 102.60 |
| C2302 | 6.74 |
| C2303 | 62.58 |
| C2304 | 27.64 |
| C2305 | 11.55 |
| C2306 | 64.77 |
| C2307 | 12.02 |
| C2398 | 4.61 |
| C2399 | 43.20 |
| C24 | 130.66 |
| C2401 | 13.21 |
| C2402 | 17.97 |
| C2403 | 11.00 |
| C2404 | 2.11 |
| C2405 | 24.60 |
| C2406 | 42.15 |
| C2407 | 8.20 |
| C2498 | 1.43 |
| C2499 | 17.09 |

| | |
|---|---|
| C22 | 1420.60 |
| C2201 | 958.54 |
| C220101 | 247.34 |
| C220102 | 225.77 |
| C220103 | 320.77 |
| C220104 | 22.39 |
| C220105 | 41.61 |
| C220106 | 71.61 |
| C220107 | 26.41 |
| C220108 | 1.73 |
| C2202 | 88.93 |
| C220201 | 82.26 |
| C220202 | 0. |
| C220203 | 5.67 |
| C220204 | 0. |
| C2203 | 10.93 |
| C220301 | 5.68 |
| C220302 | 2.64 |
| C220303 | 2.06 |
| C220304 | 0.59 |
| C220305 | 0. |
| C220306 | 0. |
| C2204 | 7.17 |
| C220401 | 2.55 |
| C220402 | 2.60 |
| C220403 | 1.95 |
| C2205 | 73.25 |
| C2206 | 29.51 |
| C2207 | 27.74 |
| C2298 | 39.16 |
| C2299 | 105.28 |

| | |
|---|---|
| C25 | 39.31 |
| C2501 | 16.49 |
| C2502 | 10.23 |
| C2503 | 6.22 |
| C2504 | 0.01 |
| C26 | 0.25 |
| C2601 | 0. |
| C2602 | 0. |
| C2603 | 0. |
| C2604 | 0.25 |
| C40 | 9.46 |
| C41 | 7.51 |
| C42 | 0.67 |
| C43 | 2.65 |
| C44 | 0. |
| C45 | 1.01 |
| C46 | 0. |
| C47 | 2.0 |

| | |
|---|---|
| C02 | 0.41 |
| C0201 | 0.41 |
| C0202 | 0. |
| C0203 | 0. |
| C03 | 0. |
| C50 | 4.32 |
| C51 | 0.91 |
| C52 | 0. |
| C91 | 229.04 |
| C92 | 103.23 |
| C93 | 114.52 |
| CTD | 2290.37 |
| CTDI | 2817.15 |

| | CYD | TCD |
|---|---|---|
| C94 | 302.00 | 706.82 |
| C95 | 0. | 437.79 |
| CTOT | 3119.16 | 3961.76 |
| CTOTP | 1524.14 | 1936.07 |
| COE | 22.93 | 42.45 |

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                                              CASE NUMBER     6:
                                              OPER & MAINT COSTS:
REPL NO OF YRS PER  SCH MAINT  NO EQP  NO OF  DAYS OF AVAIL TOTAL ANN
FRAC SEGS  OUTAGE   INTERVAL   SETS    MEN    MAINT         COST(M$)
1/ 1  34    9.65    139.56      12    125.03  19.00  .030   29.06
1/ 2  17    4.82     69.78       6     68.07  19.00  .030   29.08
1/17   2    0.57      8.38       1     23.01  12.00  .013   29.20
1/34   1    0.28      4.26       1     21.06   6.50  .000   29.11
    COE FOR 34 MAINTENANCE OPTIONS (CYD):
         (PARENS REPRESENT THE NUMBER OF SCHEDULED OUTAGES)
( 1)  23.24 ( 2)  22.73 ( 3)  22.63 ( 4)  22.43 ( 5)  22.43 ( 6)  22.42 ( 7)  22.42 ( 8)  22.42 ( 9)  22.41 (10)  22.43
(11)  22.50 (12)  22.59 (13)  22.69 (14)  22.79 (15)  22.89 (16)  22.99 (17)  22.00 (18)  22.87 (19)  22.93 (20)  23.00
(21)  23.06 (22)  23.13 (23)  23.19 (24)  23.25 (25)  23.32 (26)  23.38 (27)  23.45 (28)  23.51 (29)  23.57 (30)  23.64
(31)  23.70 (32)  23.77 (33)  23.83 (34)  23.17 (

                                              EBTR COSTS FOR:
R0=37.27  N=34  BT=5.50  RP=1.40  SYMPCT=   *  PNET= 2033.40     9 SCHEDULED OUTAGES PER WALL LIFETIME
 C20             3.19         C22           1369.86            C25              39.31          C02              0.41
                  *              C2201         916.30            C2501           16.49           C0201            0.41
 C21           336.21             C220101      233.60            C2502           10.23           C0202            0.
    C2101        11.62            C220102      214.10            C2503            6.22           C0203            0.
    C2102       120.03            C220103      302.95            C2504            0.01                          *
    C2103        47.13            C220104       21.85                             *            C03              0.
    C2104         8.97            C220105       40.12          C26               0.25                           *
    C2105        16.13            C220106       76.70            C2601            0.           C50              4.32
    C2106        70.04            C220107       25.19            C2602            0.                            *
    C2190         1.09            C220108        1.64            C2603            0.           C51              1.09
    C2199        43.61         C2202            80.50            C2604            0.25                          *
                  *              C220201        81.86                             *            C52              0.
 C23           334.60            C220202         0.            C40               9.46                           *
    C2301       102.33            C220203        6.64                             *            C91            221.75
    C2302         6.71            C220204        0.            C41               7.47                           *
    C2303        62.33         C2203            10.93                             *            C92            177.40
    C2304        27.52            C220301        5.65          C42               0.57                           *
    C2305        11.52            C220302        2.64                             *            C93            110.07
    C2306        64.50            C220303        2.06          C43               2.64                           *
    C2307        11.90            C220304        0.59                             *            CTD           2217.46
    C2390         4.59            C220305        0.            C44               0.                             *
    C2399        43.04            C220306        0.                               *            CTDI          2727.47
                  *            C2204             7.14          C45               1.01                           *
 C24           134.04             C220401        2.54                             *                             *
    C2401        12.79            C220402        2.66          C46               0.                             *
    C2402        17.32            C220403        1.94                             *                             *
    C2403        10.60         C2205            72.09          C47               2.07                           *
    C2404         2.11         C2206            29.51                             *                             *
    C2405        23.71         C2207            27.60                             *                             *
    C2406        40.63         C2290            30.23                             *                             *
    C2407         0.20         C2299           170.60                             *                             *
    C2490         1.38                            *                               *                             *
    C2499        17.30                            *                               *                             *

                            CYD                TCD
 C94                      292.30             604.32
 C95                        0.               423.05
 CTOT                    3019.85            3035.64
 CTOTP                   1485.13            1006.32
 COE                       22.41              41.46
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                                                    CASE NUMBER     7:
                                                    OPER & MAINT COSTS:
REPL NO OF YRS PER  SCH MAINT  NO EQP  NO OF  DAYS OF AVAIL TOTAL ANN
FRAC SEGS  OUTAGE   INTERVAL   SETS    MEN    MAINT         COST(M$)
1/ 1   32    9.31    134.71      11    110.96  19.00  .030   20.77
1/ 2   16    4.66     67.36       6     66.60  19.00  .030   20.79
1/ 4    8    2.33     33.68       3     41.02  19.00  .030   20.85
1/ 8    4    1.16     16.84       2     29.41  12.00  .030   20.82
1/16    2    0.58      8.58       1     23.81  12.00  .014   20.91
1/32    1    0.29      4.36       1     21.06   6.50  .001   20.83
   COE FOR 32 MAINTENANCE OPTIONS (CYD):
        (PARENS REPRESENT THE NUMBER OF SCHEDULED OUTAGES)
( 1)  22.93 ( 2)  22.45 ( 3)  22.35 ( 4)  22.16 ( 5)  22.16 ( 6)  22.14 ( 7)  22.14 ( 8)  22.13 ( 9)  22.13 (10)  22.18
(11)  22.24 (12)  22.34 (13)  22.45 (14)  22.55 (15)  22.66 (16)  22.49 (17)  22.56 (18)  22.62 (19)  22.69 (20)  22.76
(21)  22.82 (22)  22.88 (23)  22.95 (24)  23.01 (25)  23.08 (26)  23.15 (27)  23.21 (28)  23.28 (29)  23.34 (30)  23.41
(31)  23.47 (32)  22.84 (

                                                    EBTR COSTS FOR:
R0=34.14  N=32  BT=6.50  RP=1.48  SYMPCT=    *  PRET= 1977.36     8 SCHEDULED OUTAGES PER WALL LIFETIME
 C20              3.19        C22             1311.43       C25          39.31          C02            0.40
                  *             C2201          871.10         C2501       16.49           C0201          0.40
 C21            310.71            C220101      219.86         C2502       10.23           C0202          0.
   C2101         11.62            C220102      201.50         C2503        6.22           C0203          0.
   C2102        100.07            C220103      205.13         C2504        0.81                          *
   C2103         46.30            C220104       21.33                      *            C03              0.
   C2104          8.90            C220105       37.49       C26           0.25                           *
   C2105         15.72            C220106       80.21         C2601        0.           C50              4.19
   C2106         70.04            C220107       23.90         C2602        0.                            *
   C2190          1.75            C220108        1.64         C2603        0.           C51              1.20
   C2199         40.30          C2202           86.30         C2604        0.25                          *
                  *               C220201       79.02                      *            C52              0.
 C23            320.54            C220202        0.         C40           9.35                           *
   C2301        100.54            C220203        6.47                     *             C91            212.29
   C2302          6.54            C220204        0.         C41           7.31                           *
   C2303         61.09          C2203           10.93                     *             C92            169.04
   C2304         26.90            C220301        5.65       C42           0.66                           *
   C2305         11.34            C220302        2.64                     *             C93            106.15
   C2306         63.61            C220303        2.06       C43           2.60                           *
   C2307         11.74            C220304        0.59                     *             CTD           2122.94
   C2398          4.51            C220305        0.         C44           0.                             *
   C2399         42.26            C220306        0.                       *             CTD1          2611.21
                  *             C2204            6.96       C45           1.01                           *
 C24            129.61            C220401        2.47                     *                              *
   C2401         12.34            C220402        2.60       C46           0.                             *
   C2402         16.60            C220403        1.09                     *                              *
   C2403         10.20          C2205           71.08       C47           2.03                           *
   C2404          2.11          C2206           29.51                     *                              *
   C2405         22.02          C2207           27.30                     *                              *
   C2406         39.11          C2298           37.12                     *                              *
   C2407          0.20          C2299          171.06                     *                              *
   C2498          1.34                           *                        *                              *
   C2499         16.72                           *                        *                              *

                       CYD                TCD
 C94                 279.92             655.16
 C95                   0.               405.70
 CTOT               2091.14            3672.15
 CTOTP              1462.13            1057.11
 COE                  22.13              40.90
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                                                CASE NUMBER     8:
                                                OPER & MAINT COSTS:
REPL NO OF YRS PER  SCH MAINT  NO EQP  NO OF  DAYS OF AVAIL TOTAL ANN
FRAC SEGS  OUTAGE   INTERVAL   SETS    MEN    MAINT         COST(M$)
1/ 1  20     9.12   131.07      10    105.29  19.00  .030   27.40
1/ 2  14     4.56    65.93       5     59.35  19.00  .030   27.42
1/ 4   7     2.28    32.97       3     30.07  19.00  .030   27.49
1/ 7   4     1.30    18.84       2     29.41  12.00  .030   27.45
1/14   2     0.65     9.56       1     23.0'  12.00  .018   27.54
1/20   1     0.33     4.05       1     21.06   6.50  .005   27.47
    COE FOR 20 MAINTENANCE OPTIONS (CYD):
         (PARENS REPRESENT THE NUMBER OF SCHEDULED OUTAGES)
( 1)  23.34 ( 2)  22.93 ( 3)  22.88 ( 4)  22.65 ( 5)  22.63 ( 6)  22.53 ( 7)  22.62 ( 8)  22.62 ( 9)  22.62 (10)  22.65
(11)  22.76 (12)  22.86 (13)  22.97 (14)  22.07 (15)  22.94 (16)  23.01 (17)  23.00 (18)  23.14 (19)  23.21 (20)  23.28
(21)  23.35 (22)  23.42 (23)  23.49 (24)  23.56 (25)  23.63 (26)  23.70 (27)  23.76 (28)  23.22 (

                                                EBTR COSTS FOR:
R0=30.50  N=20  BT=5.50  RP=1.40  SYMPCT=      *  PNET= 1753.67     7 SCHEDULED OUTAGES PER WALL LIFETIME
 C20            3.19        C22                1170.37       C25            39.31         C02            0.36
                 *            C2201             770.00         C2501         16.49          C0201         0.36
 C21          279.70            C220101         192.30         C2502         10.23          C0202         0.
   C2101       11.62            C220102         176.30         C2503          6.22          C0203         0.
   C2102       86.72            C220103         249.40         C2504          0.01                        *
   C2103       42.01            C220104          19.42                        *           C03            0.
   C2104        0.61            C220105          32.81       C26             0.25                         *
   C2105       14.06            C220106          76.94         C2601          0.          C50            3.75
   C2106       70.04            C220107          21.24         C2602          0.                          *
   C2198        1.57            C220108           1.35         C2603          0.          C51            1.37
   C2199       36.20          C2202              77.14         C2604          0.25                        *
                 *              C220201          71.35                        *           C52            0.
 C23          302.00            C220202           0.         C40             9.29                         *
   C2301       92.95            C220203           5.79                        *           C91          191.49
   C2302        5.04            C220204           0.         C41             6.68                         *
   C2303       55.04          C2203              10.93                        *           C92          163.20
   C2304       24.32            C220301           5.65       C42             0.63                         *
   C2305       10.60            C220302           2.64                        *           C93           95.75
   C2306       59.47            C220303           2.06       C43             2.49                         *
   C2307       10.73            C220304           0.69                        *           CTD         1914.94
   C2398        4.16            C220305           0.         C44             0.                           *
   C2399       30.96            C220306           0.                          *           CTDI        2365.30
                 *            C2204               6.22       C45             1.01                         *
 C24          119.26            C220401           2.21                        *                           *
   C2401       11.25            C220402           2.32       C46             0.                           *
   C2402       15.22            C220403           1.69                        *                           *
   C2403        9.31          C2205              63.53       C47             1.07                         *
   C2404        2.11          C2206              29.51                        *                           *
   C2405       20.03          C2207              26.12                        *                           *
   C2406       35.70          C2298              34.26                        *                           *
   C2407        8.20          C2299             152.65                        *                           *
   C2498        1.23                              *                           *                           *
   C2499       15.39                              *                           *                           *

                        CYD                      TCD
 C94                  252.50                   590.96
 C95                    0.                     366.03
 CTOT                 2607.00                 3312.37
 CTOTP                1407.10                 1800.03
 COE                    22.62                   41.74
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                                                   CASE NUMBER      ;;
                                                   OPER & MAINT COSTS:
REPL NO OF  YRS PER   SCH MAINT   NO EQP   NO OF   DAYS OF AVAIL  TOTAL ANN
FRAC SEGS   OUTAGE    INTERVAL    SETS     MEN     MAINT          COST(M$)
1/ 1   24     9.03     130.67        6      91.01   19.00   .030   25.05
1/ 2   12     4.52      65.33        4      53.13   19.00   .030   25.02
1/ 3    8     3.01      43.56        3      41.02   19.00   .030   25.06
1/ 4    6     2.25      32.67        2      35.16   19.00   .030   25.09
1/ 6    4     1.51      21.78        2      29.41   12.00   .030   25.03
1/ 8    3     1.13      16.33        1      26.59   19.00   .030   26.03
1/12    2     0.75      10.99        1      23.81   12.00   .022   25.34
1/24    1     0.38       5.58        1      21.06    F 50   .010   25.07
    COE FOR 24 MAINTENANCE OPTIONS (CYD):
          (PARENS REPRESENT THE NUMBER OF SCHEDULED OUTAGES)
( 1)  24.30 ( 2)  23.89 ( 3)  23.61 ( 4)  23.59 ( 5)  23.59 ( 6)  23.58 ( 7)  23.59 ( 8)  23.50 ( 9)  23.51 (10)  23.62
(11)  23.73 (12)  23.70 (13)  23.78 (14)  23.85 (15)  23.92 (16)  23.99 (17)  24.07 (18)  24.14 (19)  24.21 (20)  24.28
(21)  24.36 (22)  24.43 (23)  24.50 (24)  24.06 (

                                                   EBTR COSTS FOR:
R0=27.13  N=24  BT=5.50  RP=1.48  SYMPCT=     *  PNET= 1500.25      8 SCHEDULED OUTAGES PER WALL LIFETIME
 C20                3.19         C22            1016.66         C25                 37.58           C02                0.31
                     *              C2201          666.13          C2501               15.00           C0201              0.31
 C21               250.98            C220101          164.09          C2502               10.23           C0202              0.
    C2101           11.62            C220102          151.18          C2503                6.22           C0203              0.
    C2102           60.28            C220103          213.04          C2504                0.81                              *
    C2103           30.67            C220104           17.37                               *            C03                0.
    C2104            8.24            C220105           27.99        C26                  0.25                              *
    C2105           12.16            C220106           71.23          C2601                0.           C50                3.44
    C2106           70.04            C220107           18.46          C2602                0.                              *
    C2198            1.41            C220108            1.15          C2603                0.           C51                1.41
    C2199           32.55         C2202              66.72          C2604                0.25                              *
                     *               C220201           61.72                               *            C52                0.
 C23               272.71            C220202            0.          C40                  9.23                              *
    C2301           83.90            C220203            5.00                               *            C91              169.02
    C2302            5.06            C220204            0.          C41                  5.97                              *
    C2303           49.73         C2203              10.93                               *            C92              135.21
    C2304           21.34            C220301            5.65        C42                  0.60                              *
    C2305            9.72            C220302            2.64                               *            C93               84.51
    C2306           54.51            C220303            2.06        C43                  2.37                              *
    C2307            9.55            C220304            0.59                               *            CTD             1690.17
    C2398            3.74            C220305            0.          C44                  0.                                *
    C2399           35.00            C220306            0.                                 *            CTDI            2070.91
                     *            C2204               5.38        C45                  1.01                              *
 C24               100.01            C220401            1.91                               *                               *
    C2401           10.13            C220402            2.01        C46                  0.                                *
    C2402           13.75            C220403            1.46                               *                               *
    C2403            8.41         C2205              54.96        C47                  1.70                              *
    C2404            2.11         C2206              24.01                               *                               *
    C2405           10.01         C2207              24.68                               *                               *
    C2406           32.23         C2298              31.23                               *                               *
    C2407            8.20         C2299             132.61                               *                               *
    C2498            1.12                              *                               *                               *
    C2499           14.05                              *                               *                               *

                          CYD                 TCD
C94                      222.86              521.60
C95                        0.                323.06
CTOT                    2301.77             2923.57
CTOTP                   1534.26             1940.72
COE                       23.50               43.27
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                                          CASE NUMBER   10:
                                          OPER & MAINT COSTS:
REPL NO OF YRS PER  SCH MAINT  NO EQP  NO OF  DAYS OF AVAIL TOTAL ANN
FRAC SEGS  OUTAGE   INTERVAL   SETS    MEN    MAINT         COST(M$)
1/ 1   22    9.03   130.64       8     85.17  19.00  .030   24.87
1/ 2   11    4.52    66.32       4     58.06  19.00  .630   24.98
1/11    2    0.02    11.96       1     23.81  12.00  .025   25.00
1/22    1    0.41     6.06       1     21.06   6.50  .012   24.95
    COE FOR 22 MAINTENANCE OPTIONS (CYD):
          (PARENS REPRESENT THE NUMBER OF SCHEDULED OUTAGES)
( 1)  25.03 ( 2)  24.58 ( 3)  24.28 ( 4)  24.25 ( 5)  24.26 ( 6)  24.25 ( 7)  24.26 ( 8)  24.16 ( 9)  24.16 (10)  24.20
(11)  24.29 (12)  24.37 (13)  24.44 (14)  24.52 (15)  24.59 (16)  24.67 (17)  24.74 (18)  24.82 (19)  24.89 (20)  24.96
(21)  25.04 (22)  24.65 (

                                          EBTR COSTS FOR:
R0=24.04  N=22  BT=6.50  RP=1.48  SYMPCT=   *  PNET= 1363.82     8 SCHEDULED OUTAGES PER WALL LIFETIME
 C20             3.19        C22           942.48          C25              37.58          C02               0.20
                  *            C2201         614.49          C2501             15.00          C0201              0.20
 C21           229.96           C220101        161.15          C2502             10.23          C0202              0.
   C2101          11.62          C220102        130.58          C2503              6.22          C0203              0.
   C2102          53.61          C220103        196.02          C2504              0.81                            *
   C2103          36.39          C220104         16.66                              *          C03               0.
   C2104           8.03          C220105         24.71         C26               0.25                            *
   C2105          11.15          C220106         69.10          C2601              0.          C60               3.19
   C2106          70.04          C220107         17.19          C2602              0.                            *
   C2198           1.29          C220108          1.06          C2603              0.          C51               1.53
   C2199          29.03        C2202            61.18          C2604              0.25                            *
                  *             C220201         56.59                              *          C52               0.
 C23           256.15           C220202          0.          C40               9.05                            *
   C2301          79.03          C220203          4.59                             *          C91             157.36
   C2302           4.64          C220204          0.         C41               5.69                            *
   C2303          46.39        C2203            10.93                              *          C92             125.89
   C2304          19.74          C220301          6.66         C42               0.59                            *
   C2305           9.23          C220302          2.64                             *          C93              78.68
   C2306          61.76          C220303          2.06         C43               2.20                            *
   C2307           8.91          C220304          0.59                             *          CTD            1573.58
   C2398           3.51          C220305          0.         C44               0.                              *
   C2399          32.95          C220306          0.                               *          CTDI           1936.50
                  *            C2204             4.93         C45               1.01                            *
 C24           183.97           C220401          1.75                              *                           *
   C2401           9.59          C220402          1.84         C46               0.                              *
   C2402          13.06          C220403          1.34                             *                           *
   C2403           7.99        C2205            58.39         C47               1.60                            *
   C2404           2.11        C2206            24.01                              *                           *
   C2405          17.88        C2207            23.92                              *                           *
   C2406          30.64        C2298            29.70                              *                           *
   C2407           8.20        C2299           122.93                              *                           *
   C2498           1.87                          *                                 *                           *
   C2499          13.42                          *                                 *                           *

                             CYD              TCD
 C94                       207.49           485.62
 C95                         0.             300.70
 CTOT                     2142.99          2721.98
 CTOTP                    1571.31          1995.79
 COE                        24.16            44.43
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                                                    CASE NUMBER   11:
                                                    OPER & MAINT COSTS:
REPL NO OF YRS PER   SCH MAINT  NO EQP   NO OF   DAYS OF AVAIL  TOTAL ANN
FRAC SEGS  OUTAGE    INTERVAL   SETS     MEN     MAINT     .     COST(M$)
1/ 1   20    9.07    131.27       7      78.69   19.00   .030    23.87
1/ 2   10    4.54     65.53       4      47.02   19.00   .030    23.90
1/ 4    6    2.27     32.02       2      32.26   19.00   .030    23.97
1/ 5    4    1.81     26.26       2      29.41   12.00   .030    23.96
1/10    2    0.91     13.16       1      23.81   12.00   .027    24.00
1/20    1    0.45      6.60       1      21.06    6.50   .015    23.95
   COE FOR 20 MAINTENANCE OPTIONS (CYD):
        (PARENS REPRESENT THE NUMBER OF SCHEDULED OUTAGES)
( 1)  25.99 ( 2)  25.57 ( 3)  25.23 ( 4)  25.20 ( 5)  25.19 ( 6)  25.20 ( 7)  25.09 ( 8)  25.09 ( 9)  25.10 (10)  25.15
(11)  25.23 (12)  25.30 (13)  25.38 (14)  25.46 (15)  25.54 (16)  25.62 (17)  25.69 (18)  25.77 (19)  25.85 (20)  25.92

                                                    EBTR COSTS FOR:
R0=21.35  N=20  BT=5.50  RP=1.40  SYMPCT-     *  PNET= 1220.04     7 SCHEDULED OUTAGES PER WALL LIFETIME
 C20                3.19         C22                866.56         C25             37.50          C02             0.26
                      *            C2201             561.94          C2501           15.00          C0201           0.26
 C21              212.52            C220101           137.41          C2502           10.23          C0202          0.
   C2101           11.62            C220102           125.99          C2503            6.22          C0203          0.
   C2102           42.29            C220103           170.20          C2504            0.01                          *
   C2103           33.93            C220104            15.89                             *          C03             0.
   C2104            7.79            C220105            21.67         C26              0.25                           *
   C2105           10.09            C220106            55.92           C2601           0.           C50             2.07
   C2106           70.04            C220107            15.90           C2602           0.                            *
   C2198            1.19            C220108             0.96           C2603           0.           C51             1.64
   C2199           27.56          C2202               55.35            C2604           0.25                          *
                      *             C220201            51.20                             *          C52             0.
 C23              230.30            C220202             0.           C40              0.06                           *
   C2301           73.60            C220203             4.15                             *          C91           145.74
   C2302            4.19            C220204             0.           C41              5.10                           *
   C2303           42.02          C2203               10.93                              *          C92           116.60
   C2304           10.04            C220301             5.65         C42              0.57                           *
   C2305            0.69            C220302             2.64                             *          C93            72.07
   C2306           40.73            C220303             2.06         C43              2.19                           *
   C2307            0.23            C220304             0.59                             *          CTD          1457.45
   C2398            3.27            C220305             0.           C44              0.                             *
   C2399           30.66            C220306             0.                               *          CTDI         1792.66
                      *           C2204                4.46          C45              1.01                           *
 C24               99.05            C220401             1.59                             *                           *
   C2401            9.05            C220402             1.67         C46              0.                             *
   C2402           12.37            C220403             1.21                             *                           *
   C2403            7.67          C2205               45.59          C47              1.50                           *
   C2404            2.11          C2206               24.01                              *                           *
   C2405           16.93          C2207               23.12                              *                           *
   C2406           29.01          C2298               20.13                              *                           *
   C2407            0.20          C2299              113.03                              *                           *
   C2498            1.02                                 *                               *                           *
   C2499           12.79                                 *                               *                           *

                       CYD                  TCD
 C94                 192.17               449.70
 C95                   0.                 270.50
 CTOT               1904.03              2621.02
 CTOTP              1626.79              2064.98
 COE                  25.09                46.09
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