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LUCAS HEIGHTS

FURES – A COMPUTER CODE FOR SYSTEM ENERGY FLOW ANALYSIS

by

J. I. FAULKNER

K. J. STOCKS

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ABSTRACT

A computer code for the analysis of energy flows in an electricity generating system is described. Account is taken of the energy investment in new generating plant as well as the annual energy requirements to provide fuel. Time delays are introduced to place the demands when they occur. All energy inputs are divided into thermal and electrical components. The program can handle a mix of station types which may be conventional and/or nuclear.

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COMPUTER CALCULATION; ELECTRICITY; ENERGY CONSUMPTION; ENERGY CONVERSION; ENERGY SOURCES; F CODES; FORECASTING; FUEL CYCLE; POWER DEMAND; POWER GENERATION; SYSTEMS ANALYSIS

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ERRATA

P6, line 8

VESTT *should read* VESTTT

P19, line 1

D(j),j=1, (j) *should read* D(j),j=1,L(j)

Appendix A, line 8

// CLASS=A, TIME=1 *should read* // CLASS=A,TIME=1

line 9

// EXEC FORTHG, PRG=DATABANK, DSN='ENG.JIF.DATABANK'

should read

// EXEC FORTHG,PRG=DATABANK,DSN='ENG.JIF.DATABANK'

Appendix C, P C4, line 17

TOT233U *should read* TOTU233

line 25

233U *should read* U233

line 32

VESTT *should read* VESTTT

1. INTRODUCTION

Following the energy crises, there has been a heightened awareness that there is a need to know how much energy is used in producing particular goods and providing services. Work, on energy costs, before and after the crises, by the National Science Foundation Environmental Protection Group at Oak Ridge National Laboratory (ORNL-NSF-EP series), has been extended by others elsewhere such as Chapman at the Open University (England) and Slesser at Glasgow University. Attention has naturally progressed to energy conversion systems. Chapman & Mortimer [1974], whose work was extended by Price [1974], examined nuclear power systems assuming all energy investments came from fossil fuels.

While their analysis was consistent within the conventions they adopted, the results and conclusions they drew were open to serious misinterpretation. Hill & Walford [1975] proposed that those forms of energy used in manufacturing equipment or performing a service should be kept separate. In practice this means the separation of thermal energy in the form of fossil fuel and electrical energy. Following this form of system energy flow analysis, each component in a system has a quantity of electrical energy and a quantity of thermal energy associated with its manufacture; similarly with services and other activities. In this way the overall contributions of the various energy forms to the system can be analysed and sensitivity studies can be made. The Australian Atomic Energy Commission, as part of its work on energy flow analysis, is interested in the growth of electricity systems with nuclear power components.

System energy flow analysis of the type considered in this report is conveniently handled numerically using a digital computer. A computer program is required to accept as input, the growth and mix patterns of electricity supply systems and to calculate the separate electrical and thermal energy requirements together with the electrical output. Data on the energy required for the various goods and services can then be used to generate the necessary information on energy usage and production. A computer program FURES has been developed for this purpose.

This report consists basically of three parts: the first discusses the methodology employed for both the fuel cycle calculations and the energy analysis study (Sections 2-9); the second provides a user's guide for FURES (Section 10), while the third illustrates the program results by way of an example (Section 11).

2. GENERAL DESCRIPTION

The computer program FURES in its original (unpublished) form, was written to calculate fuel cycle requirements for a system which includes both nuclear and conventional stations. It has been extended to include the calculation of energy inputs needed to provide for both the construction and operation of plants. This enables the user to carry out an 'energy analysis' study for the particular system. Following the pattern set by Hill & Walford [1975] in their energy accounting studies, all energy inputs are divided into electrical and thermal components. In the final tabulation these components can be listed separately and/or combined into an 'equivalent thermal' component by applying the usually accepted conversion ratio of 4:1 to the electrical component (see for example Symonds, Essam & Stocks [1975]).

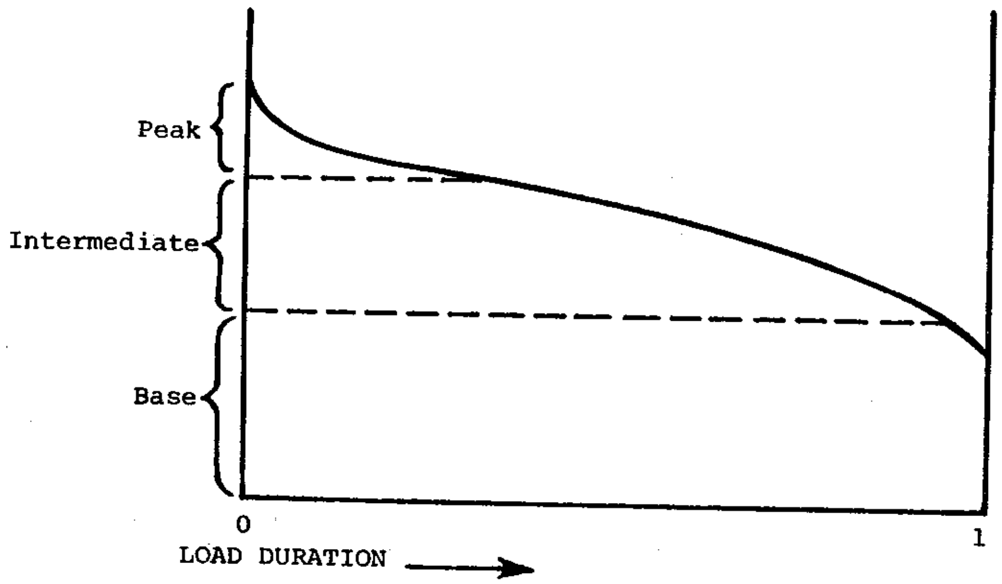
A standard data bank has been established for the program, enabling the user to have up to 13 choices for nuclear plant and five types of conventional plant. The data can be overwritten either partially to change the plant characteristics or completely to introduce a different type of plant.

The comprehensive output from the program is in both tabular and graphical form. The listing includes the yearly and cumulative requirements for both the nuclear fuel cycle and fossil fuels as well as the total installed capacity and the new capacity required each year for each plant type. The output from the energy analysis section consists of the electrical and thermal requirements for the provision of capital and fuel, as well as the thermal input as fuel to the conventional stations. The electrical energy generated each year is also given both as a gross figure and less the electrical energy investment.

It is common in an energy analysis study to compare both the thermal and electrical inputs required, for the same system growth with two different station mixes; for example, a conventional and nuclear mix compared with an otherwise all conventional program. For this purpose an option has been included in FURES whereby two such strategies can be compared.

3. SYSTEM DESCRIPTION

In an electricity generating system, the demand throughout the year can be represented by a load duration curve as shown overleaf.



SYSTEM LOAD DURATION CURVE

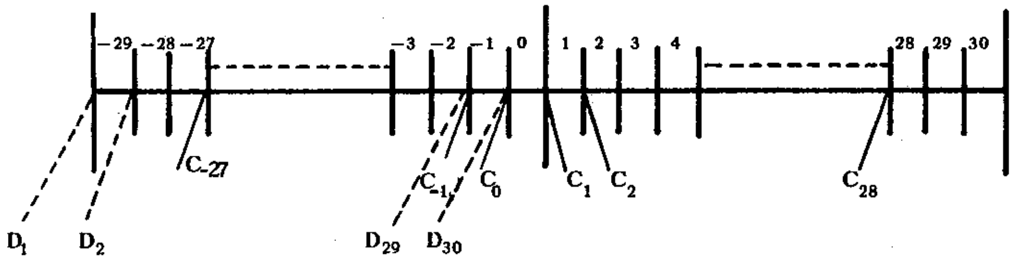
The continuous curve can be approximated by a number of discrete load zones in which the various plants operate. (It is usual to specify at least three zones - base, intermediate and peak.) The proportion of total system capacity in each zone, and the accompanying capacity factors are such that the system demand is satisfied for the year.

In this analysis, any number of load zones can be specified for each plant type with a particular capacity factor H(k) for each load zone k. The installed capacities, $C_{i,j,k}$ *MWe*, where

i = year index = 1, 2,...,NY
j = plant index = 1, 2,...,NS
k = load zone index = 1, 2,...,NZ

are read in for each year of the study; by altering the proportion of the installed capacity in each load zone, the average capacity factor for a particular station type can be made time dependent. All changes to the system are assumed to take place at the start of each year and the capacity factor for the year is based on the installed capacity at this time.

The nomenclature for the year index is illustrated below, where the station lifetime L is taken as 30 years and C_i is the installed capacity at the start of year i.



To allow for the retirement of old plant, the new capacity installed must be specified for one station lifetime before the start of the study period. Thus D_i is the new capacity installed at the start of period (i-L).

The total installed capacity of each plant type for each year is

$$C_{i,j} = \sum_{k=1}^{NZ} C_{i,j,k} \ \mathit{MWe} \quad , \tag{3.1}$$

and the average capacity factor for this type is

$$ACF(i,j) = \frac{\sum_{k=1}^{NZ} H(k)\, C_{i,j,k}}{\sum_{k=1}^{NZ} C_{i,j,k}} \quad . \tag{3.2}$$

Three sets of equations are required to calculate the capacity of each type installed and retired at the start of each year. They cover two successive periods, the duration of each being one station lifetime, as well as the first year of the study. The equations are

(1) $i = 1$ $\quad \Delta C_{1,j} = (C_{1,j} - C_{0,j}) + D_{1,j}$ and

$\Delta' C_{1,j} = D_{1,j}$,

(2) $2 \leqslant i \leqslant L$ $\quad \Delta C_{i,j} = (C_{i,j} - C_{i-1,j}) + D_{i,j}$ and

$\Delta' C_{i,j} = D_{i,j}$,

(3) $L+1 \leqslant i \leqslant 2L$ $\quad \Delta C_{i,j} = (C_{i,j} - C_{i-1,j}) + \Delta C_{i-L,j}$ and

$\Delta' C_{i,j} = \Delta C_{i-L,j}$,

where $\Delta C_{i,j}$, $\Delta' C_{i,j}$ *MWe* are respectively the capacities of type j installed and retired at the start of period i, and L(j) (years) is the lifetime of type j.

For the nuclear plants, the capacities in each load zone are now replaced by the total installed capacity operating at the average capacity factor. Because of the time delays involved in the nuclear fuel cycle and the energy investment calculation, the following boundary conditions must be applied for the system.

(i) After the end of the study period, the new capacity for each type installed at the start of following periods is the same as that installed new in the last period. The capacity retired is that at the end of its lifetime. Thus,

$$\Delta C_{NY+i,j} = \Delta C_{NY,j} \quad \text{for } i = 1,2,\ldots,\text{ICONST}(j) \text{ and}$$

$$\Delta' C_{NY+1,j} = \Delta C_{NY+1-L(j),j} \quad , \quad \Delta' C_{NY+2,j} = \Delta C_{NY+2-L(j),j}$$

where $\Delta C_{NY+i-L(j)} = D_{NY+i,j}$ if $NY+i-L \leqslant 0$, and

ICONST(j) for station type j is a constant depending on the construction time for this type. Consequently,

$$C_{NY+1,j} = C_{NY,j} + \Delta C_{NY+1,j} - \Delta' C_{NY+1,j} \quad .$$

(ii) The average capacity factor for years before the study horizon, is taken as that in the first period, while for years after the study period, it is put equal to that in the last year of the study. That is,

$$ACF_{NY+1,j} = ACF_{NY,j} \text{ and}$$

$$ACF_{i,j} = ACF_{1,j} \quad \text{for } i \leqslant 0 \quad .$$

4. ENERGY INVESTMENT IN NEW PLANT

For each plant type j, a construction period of NYC(j) years is assumed, followed by one year of testing before full commercial production begins. The electrical and thermal energy investments for each year of construction for plant type j are calculated. Thus

$$\text{electrical:} \quad \text{VESTE}(i,j) = \sum_{m=1}^{NYC(j)} \alpha_e(m,j)\, \Delta C_{i+m+1,j} \; J\, y^{-1} \qquad (4.1)$$

$$\text{thermal:} \quad VESTT(i,j) = \sum_{m=1}^{NYC(j)} \alpha_t(m,j)\ \Delta C_{i+m+1,j}\ J\ y^{-1} \quad , \qquad (4.2)$$

where $\alpha_e(m,j)$, $\alpha_t(m,j)$ are respectively the unit electrical and thermal energy requirements for each year of construction for plant type j $J\ MWe^{-1}$, and m=1,2.....,NYC(j) where m=1 corresponds to the last year of construction.

The total energy investments for each year to provide plant are then

$$\text{electrical:} \quad VESTET(i) = \sum_{j=1}^{NS} VESTE(i,j)\ J\ y^{-1} \quad , \qquad (4.3)$$

$$\text{thermal:} \quad VESTT(i) = \sum_{j=1}^{NS} VESTT(i,j)\ J\ y^{-1} \quad . \qquad (4.4)$$

5. NUCLEAR FUEL CYCLE

The nuclear fuel cycle is simulated by supplying an initial core and, for each year after the first year, a reload equal to the amount of fuel burnt in the year. Time delays are introduced to place the services when they usually occur. For nuclear fuel, three cases are considered

- fresh fuel enriched
- fresh fuel natural
- fresh fuel depleted.

The convention used throughout this report to identify the various uranium enrichments and isotopic fractions in the fuel is X_b^a, where X takes the values

e for uranium enrichment;
U for total uranium fraction($^{235}U + ^{238}U$),
Pu for fissile plutonium fraction;
Th for thorium fraction; and
$\bar{U}$ for ^{233}U fraction.

The superscript a takes the values

i for fresh initial core;
f for irradiated final core; and
if missing, indicates reload fuel.

The subscript b takes the values

o for fresh fuel;
r for irradiated fuel;
n for natural uranium enrichment; and
t for tails enrichment.

In Sections 5.1 to 5.7, the index for reactor type is omitted so that the derivation refers to requirements for a particular reactor type.

5.1 Uranium Requirements

All uranium is expressed in terms of natural uranium equivalent. If uranium is returned to the fuel cycle from the reprocessing plant at an enrichment e_r, different from the natural uranium enrichment e_n, it is expressed either as the amount of natural uranium which would supply (if $e_r > e_n$), or be supplied from (if $e_r < e_n$), the original amount at enrichment e_r. A depleted uranium stockpile is also considered, consisting of tails uranium from the enrichment plant as well as uranium from the reprocessing plant with an enrichment level below e_n. The uranium for the fast breeder reactors (FBR) is taken from this stockpile if there is stock. Otherwise they use natural uranium.

The quantity of natural uranium required to supply one unit of uranium at enrichment e_o is given by $\left(\frac{e_o - e_t}{e_n - e_t}\right)$. Thus to calculate the uranium requirements the following multiplication factors are needed.

initial core
$$OI = \begin{cases} \left(\dfrac{e_o^i - e_t}{e_n - e_t}\right) & \text{if } e_o^i \geqslant e_n \\ 1 & \text{if } e_o^i < e_n \end{cases} ,$$

fresh reload fuel
$$OO = \begin{cases} \left(\dfrac{e_o - e_t}{e_n - e_t}\right) & \text{if } e_o \geqslant e_n \\ 1 & \text{if } e_o < e_n \end{cases} ,$$

irradiated reload fuel
$$OR = \begin{cases} \left(\dfrac{e_r - e_t}{e_n - e_t}\right) & \text{if } e_r > e_t \\ 1 & \text{if } e_r \leqslant e_t \end{cases} , \text{ and}$$

irradiated final core
$$OF = \begin{cases} \left(\dfrac{e_r^f - e_t}{e_n - e_t}\right) & \text{if } e_f^f > e_t \\ 1 & \text{if } e_r^f \leqslant e_t \end{cases} .$$

The annual fuel throughput at full-load is

$$TP = \frac{365}{\eta \times \text{burnup}} \; t \; MWe^{-1} \; y^{-1}$$

where η = thermal efficiency

BURNUP = average end burnup $MWd(th)\ t^{-1}$.

The uranium requirements for the various stages of the cycle are then

initial core $\quad OREIC = (1+F)OI \cdot U_o^i \cdot I\ t\ MWe^{-1}$,

fresh reload fuel $\quad OREFR = (1+F)OO \cdot U_o \cdot TP\ t\ MWe^{-1}y^{-1}$,

and the unused uranium contained in the irradiated fuel is

irradiated reload fuel $\quad OREBR = (1-V)OR \cdot R \cdot U_r \cdot TP\ t\ MWe^{-1}\ y^{-1}$,

irradiated final core $\quad OREFC = (1-V)OF \cdot R \cdot U_r^f \cdot I\ t\ MWe^{-1}$,

where F = fabrication losses,

V = reprocessing losses,

R = heavy metals ratio $\left(\frac{\text{irradiated fuel}}{\text{fresh fuel}}\right)$, and

I = fuel inventory $t\ MWe^{-1}$.

The corresponding factors for the depleted uranium stockpile are

fresh reload $$t_o = (1+F)U_o \cdot TP \cdot \left(\frac{e_o - e_n}{e_n - e_t}\right) t\ MWe^{-1}\ y^{-1} ,$$

initial core $$t_i = (1+F)U_o^i \cdot I \cdot \left(\frac{e_o^i - e_n}{e_n - e_t}\right) t\ MWe^{-1} ,$$

final core $$t_f = R \cdot (1-V)U_r^f \cdot I \cdot \left(\frac{e_r^f - e_n}{e_n - e_t}\right) t\ MWe^{-1} , \text{ and}$$

irradiated reload $$t_r = TP \cdot (1-V)U_r \cdot R \cdot \left(\frac{e_r - e_n}{e_n - e_t}\right) t\ MWe^{-1}\ y^{-1} .$$

Using these definitions, the time dependent uranium flows for the three cases mentioned in Section 5 can now be calculated.

Case 1: *Fresh fuel enriched (e.g. PWR, BWR, SGHWR, HTGR)*

The time delays necessary for the provision of uranium for the initial core and reload fuel (i.e. mine-out to reactor-in) are about 2.3 years and 1.5 years respectively. The time delay for the initial core includes one year for commissioning. Thus for reactors coming on line in year i, the uranium mining is assumed to take place in year (i-3). For reload fuel the mining is assumed to take place in year (i-2). Further, the unused uranium in the fuel removed from reactors at this time is assumed to be available from the reprocessing plants for re-use in year (I+1). The uranium ore requirement for year i for reactor type j is then (with the reactor type subscript j omitted)

$$ORE(i) = OREFR \; . \; ACF(i+1)[C_{i+1} - \Delta'C_{i+2}] + OREIC \; . \; \Delta C_{i+3}$$

$$-OREBR \; . \; ACF(i-2)[C_{i-2} - \Delta'C_{i-1}] - OREFC \; . \; \Delta'C_{i-1} \; t \; y^{-1} \quad ,(5.1.1)$$

and the requirement from the depleted uranium stockpile is

$$DORE(i) = -\{t_o \; . \; ACF(i+1)[C_{i+1} - \Delta'C_{i+2}] + t_i \; . \; \Delta C_{i+2}$$

$$-t_r \; . \; ACF(i-2)[C_{i-2} - \Delta'C_{i-1}] - t_f \; . \; \Delta'C_{i-1}\} t \; y^{-1} \quad . \qquad (5.1.2)$$

The negative sign indicates that depleted uranium is added to the stockpile.

Case 2: *Fresh fuel natural (e.g. HWR, MAGNOX)*

The time delays for this case for the provision of uranium for the initial core and reload fuel are about 2 years and 1 year respectively. The uranium requirement for year i is

$$ORE(i) = OREFR \; . \; ACF(i+1)[C_{i+1} - \Delta'C_{i+2}] + OREIC \; . \; \Delta C_{i+3} \; t \; y^{-1} \quad ; \qquad (5.1.3)$$

while the amount taken from the depleted uranium stockpile is

$$DORE(i) = -OREBR \; . \; ACF(i-2)[C_{i-2} - \Delta C_{i-1}] - OREFC \; . \; \Delta'C_{i-1}$$

$$-\{t_o \; . \; ACF(i+1)[C_{i+1} - \Delta'C_{i+2}] + t_i \; . \; \Delta C_{i+2}\} \; t \; y^{-1} \qquad (5.1.4)$$

Once again the negative sign indicates that uranium is added to the stockpile.

Case 3: *Fresh fuel depleted, corresponding to the requirements for the fast breeder reactors (FBRs).*

The time delay for preparing the fuel in this case is assumed to be less than one year. The requirement for depleted uranium is

$$DORE(i) = OREFR \; . \; ACF(i)[C_i - \Delta'C_{i+1}] + OREIC \; . \; \Delta C_{i+2}$$

$$-OREBR \; . \; ACF(i-2)[C_{i-2} - \Delta'C_{i-1}] - OREFC \; . \; \Delta'C_{i-1} \; t \; y^{-1} \qquad (5.1.5)$$

5.2 Plutonium Requirements

The fissile plutonium removed from reactors at the start of period i is assumed available in year (i+1) for fabrication into new fuel elements. An adjustment is made in the equations for the plutonium production on the approach to equilibrium differing from the equilibrium value. The fissile plutonium factors per unit of installed capacity for equilibrium conditions are

initial core $\quad P = Pu_o^i(1+F)I \; t \; MWe^{-1}$,

fresh reload $\quad p = Pu_o(1+F)TP \; t \; MWe^{-1}y^{-1}$

irradiated reload $\quad p' = Pu_r(1-V)R \; . \; TP \; t \; MWe^{-1}$, and

irradiated final core $\quad P' = Pu_r^f(1-V)R \; . \; I \; t \; MWe^{-1}$.

The quantities $\bar{P}$, $\bar{P}'$, $\bar{p}$, $\bar{p}'$ are similarly defined using reactor characteristics for the approach to equilibrium. The annual plutonium requirement for a particular reactor type (with the subscript for type omitted) is then

$$\begin{aligned} PLUT(i) = {} & p \; . \; ACF(i)[C_i - \Delta'C_{i+1}] + P \; . \; \Delta C_{i+2} \\ & - p' \; . \; ACF(i-2)[C_{i-2} - \Delta'C_{i-1} - A(m)] - \bar{p}' \; . \; ACF(i-2) \; . \; A(i) \\ & - P'\Delta'C_{i-1} \; t \; y^{-1} \quad , \end{aligned} \tag{5.2.1}$$

where $\quad A(i) = \sum_{m=1}^{NYE} C_{i-m-1}$, and

NYE = number of years to equilibrium.

A negative sign for PLUT(i) indicates that the reactor is a net producer of plutonium.

5.3 ^{233}U Requirements

The time delays here are assumed to be the same as for plutonium. The ^{233}U requirement in year i is

$$\begin{aligned} U233(i) = {} & s \; . \; ACF(i)[C_i - \Delta'C_{i+1}] + S \; . \; \Delta C_{i+2} \\ & - s' \; . \; ACF(i-2)[C_{i-2} - \Delta'C_{i-1}] - S' \; . \; \Delta'C_{i-1} \; t \; y^{-1} \end{aligned} \tag{5.3.1}$$

where $\quad s = (1+F)TP \; . \; \bar{U}_o \quad$ (fresh reload) ,

$\quad S = (1+F)I \; . \; \bar{U}_o^i \quad$ (initial core) ,

$$S' = (1-V)R \,.\, TP \,.\, \bar{U}_r \qquad \text{(burnt reload), and}$$

$$S' = (1-V)R \,.\, I \,.\, \bar{U}_r^f \qquad \text{(burnt final core)} \quad .$$

5.4 Thorium Requirements

No account is taken of the thorium removed from the reactors although this may be stored for some years and used again. The thorium requirement in year i is

$$THOR(i) = w \,.\, ACF(i)[C_i - \Delta' C_{i+1}] + W \,.\, \Delta C_{i+2} \; t \; y^{-1} \qquad (5.4.1)$$

where $w = (1+F)TP \,.\, T_o$ (fresh reload), and

$W = (1+F)I \,.\, T_o^i$ (initial core) .

5.5 Enrichment Requirements

The enrichment work for fuel loaded into the reactors at the start of year i is assumed to occur in year (i-2). The actual delay times (i.e. for enrichment plant out - reactor in) for initial cores would be about 1.6 years, and for reload fuel about one year, thus placing the requirement for both in the year (i-2). A credit is given for any unused enrichment work contained in irradiated fuel after a delay time of one year to allow for cooling and reprocessing. The enrichment work requirement in year i is

$$ENR(i) = g \,.\, ACF(i+1)[C_{i+1} - \Delta' C_{i+2}] + G \,.\, \Delta C_{i+2}$$

$$- g' \,.\, ACF(i-2)[C_{i-2} - \Delta' C_{i-1}] - G' \,.\, \Delta' C_{i-1} \; t \; swu \; y^{-1} \quad , \qquad (5.5.1)$$

where $g = (1+F)TP \,.\, U_o \,.\, \chi_o$ (fresh reload) ,

$G = (1+F)I \,.\, U_o^i \,.\, \chi_o^i$ (initial core) ,

$g' = (1-V)R \,.\, TP \,.\, U_r \,.\, \chi_r$ (irradiated reload) ,

$G' = (1-V)R \,.\, I \,.\, U_r^f \,.\, \chi_r^f$ (irradiated final core), and

$$\chi_o = (2e_o - 1)\ell n\left(\frac{e_o}{1 - e_o}\right) + \left(\frac{e_o - e_n}{e_n - e_t}\right)(2e_t - 1)\ell n\left(\frac{e_t}{1 - e_t}\right)$$

$$-\left(\frac{e_o - e_t}{e_n - e_t}\right)(2e_n - 1)\ell n\left(\frac{e_n}{1 - e_n}\right) \quad .$$

χ_o^i, χ_r, χ_r^f are defined similarly to χ_o by replacing e_o by e_o^i, e_r, e_r^f respectively.

5.6 Fabrication Requirements

The delay time for fabrication of reload fuel elements is assumed to be less than one year, whilst for the initial cores an extra period of one year is required to allow for commissioning. The fabrication requirement in year i is therefore

$$FAB(i) = TP \,.\, ACF(i)[C_i - \Delta' C_{i+1}] + I \,.\, \Delta C_{i+2} \; t\, y^{-1} \quad . \qquad (5.6.1)$$

5.7 Reprocessing Requirements

The reprocessing is assumed to take place within one year of the removal of the fuel from the reactor. The reprocessing requirement in year i is

$$REP(i) = TP \,.\, R \,.\, ACF(i-1)[C_{i-1} - \Delta' C_i] + I \,.\, R \,.\, \Delta' C_i \; t\, y^{-1} \quad . \qquad (5.7.1)$$

5.8 Summary of Fuel Cycle Operations

In Sections 5.1 - 5.7, the requirements for each stage of the nuclear fuel cycle have been calculated. In the derivation, the index for the reactor type has been omitted so that the calculations refer to one particular reactor type. To obtain the total requirements for the entire system, a summation is made over all such reactor types. Thus with the introduction of index j for reactor type, the yearly totals become

uranium $$TOTORE(i) = \sum_{j=1}^{NN} ORE(i,j) \; t\, y^{-1} \quad ,$$

depleted uranium $$TOTDORE(i) = \sum_{j=1}^{NN} DORE(i,j) \; t\, y^{-1} \quad ,$$

fissile plutonium $$TOTPLUT(i) = \sum_{j=1}^{NN} PLUT(i,j) \; t\, y^{-1} \quad ,$$

U233 $$TOTU233(i) = \sum_{j=1}^{NN} U233(i,j) \; t\, y^{-1} \quad ,$$

thorium $$TOTTHOR(i) = \sum_{j=1}^{NN} THOR(i,j) \; t\, y^{-1} \quad ,$$

enrichment work $$TOTENR(i) = \sum_{j=1}^{NN} ENR(i,j) \ t \ swu \ y^{-1} \quad ,$$

fabrication $$TOTFAB(i) = \sum_{j=1}^{NN} FAB(i,j) \ t \ y^{-1} \quad , \text{ and}$$

reprocessing $$TOTREP(i) = \sum_{j=1}^{NN} REP(i,j) \ t \ y^{-1} \quad ,$$

where NN is the number of nuclear reactor types in the system.

6. ENERGY REQUIREMENTS FOR PROVISION OF NUCLEAR FUEL

The annual uranium mining, conversion, enrichment, fabrication and reprocessing demands are multiplied by the unit thermal and electrical energy requirements for the various stages to give the yearly energy requirements for provision of each stage of the nuclear fuel cycle. The coefficients are listed in Appendix A. The energy requirements for year i are

uranium :
$$EORE(i) = CEORE \ . \ TOTORE(i) \ J \ y^{-1} \quad ,$$
$$TORE(i) = CTORE \ . \ TOTORE(i) \ J \ y^{-1} \quad ,$$

enrichment :
$$EENR(i) = CEENR \ . \ TOTENR(i) \ J \ y^{-1} \quad ,$$
$$TENR(i) = CTENR \ . \ TOTENR(i) \ J \ y^{-1} \quad ,$$

conversion :
$$ECONV(i) = CECONV \ . \ TOTORE(i) \ J \ y^{-1} \quad ,$$
$$TCONV(i) = CTCONV \ . \ TOTORE(i) \ J \ y^{-1} \quad ,$$

fabrication :
$$EFAB(i) = CEFAB \ . \ TOTFAB(i) \ J \ y^{-1} \quad ,$$
$$TFAB(i) = CTFAB \ . \ TOTFAB(i) \ J \ y^{-1} \quad , \text{ and}$$

reprocessing :
$$EREP(i) = CEREP \ . \ TOTREP(i) \ J \ y^{-1} \quad ,$$
$$TREP(i) = CTREP \ . \ TOTREP(i) \ J \ y^{-1} \quad ;$$

where CEORE, CTORE $J \ t^{-1}$ are the electrical and thermal energy requirements respectively for the provision of uranium (i.e. mining and milling) with similar definitions applying for conversion, enrichment, fabrication and reprocessing.

7. ENERGY REQUIREMENTS FOR CONVENTIONAL FUEL CYCLE

The annual fossil fuel requirement for a particular plant (or fuel) type j is calculated in tonnes per year, except for natural gas which is calculated in cubic metres per year. The heat content, h(j), is specified in joules per tonne, or for natural gas, joules per thousand cubic metres. Thus,

$$FOS(i,j) = \sum_{k=1}^{NZ} \frac{3.1536 \times 10^{13} \cdot H(k)}{\eta(k) \cdot h(j)} \cdot C(i,j,k) \begin{cases} t\ y^{-1} \\ \text{or } 10^3 m^3 y^{-1} \text{ for gas,} \end{cases} \quad (7.1)$$

where $\eta(k)$ = plant efficiency in load zone k

$h(j)$ = heat content for fuel type j $\begin{cases} J\ t^{-1} \\ \text{or } J\ 10^{-3} m^{-3} \text{ for gas.} \end{cases}$

The overall average 'plant efficiency' for conventional stations is dependent on the capacity factors at which they operate. Hence η for these stations varies according to the load zone in which they operate. Only one value of η is defined for nuclear stations which operate mainly on base load.

The energy required to provide the fuel, (i.e. mining, processing, transport, etc.) is

electrical $\quad EFOS(i,j) = CEFOS(j) \cdot FOS(i,j)\ J\ y^{-1}$, (7.2)

thermal $\quad TFOS(i,j) = CTFOS(j) \cdot FOS(i,j)\ J\ y^{-1}$, (7.3)

where CEFOS(j) and CTFOS(j) $J\ t^{-1}$ are respectively the electrical and thermal energy coefficients to provide fuel of type j.

The thermal content of fuel burnt in fossil stations of type j is

$$FBURN(i,j) = FOS(i,j) \cdot h(j)\ J\ y^{-1} \quad . \quad (7.4)$$

8. TOTAL ENERGY REQUIREMENTS FOR COMPLETE PLANT MIX

The capital energy investment required to establish reprocessing plants, coal mines, etc., is included in the energy demands per unit of material or service. The total energy investment required for the provision of capital and fuel is given by (investment for plant) + (investment for nuclear fuel cycle) + (investment for fossil fuel), and becomes

electrical $\quad TOTEL(i) = VESTET(i) + EORE(i) + EENR(i) + EFAB(i) + ECONV(i) + EREP(i) + \sum_{\text{fossil stations}} EFOS(i,j)\ J\ y^{-1}$, (8.1) thermal

$$TOTTH(i) = VESTTT(i) + TORE(i) + TENR(i) + TFAB(i) + TCONV(i) + TREP(i) + \sum_{\substack{\text{fossil}\\ \text{stations}}} TFOS(i,j) \ J\ y^{-1} \quad . \tag{8.2}$$

The total thermal requirement including fuel burnt in fossil stations is

$$THERT(i) = TOTTH(i) + \sum_{\substack{\text{fossil}\\ \text{stations}}} FBURN(i,j) \ J\ y^{-1} \quad . \tag{8.3}$$

9. ELECTRICAL OUTPUT FROM COMPLETE SYSTEM

The total electricity generated in year i is

$$EP(i) = \sum_{j=1}^{NS} 3.1536 \times 10^{13} \cdot ACF(i,j) \cdot C_{i,j} \ J\ y^{-1} \quad . \tag{9.1}$$

The net electricity available to the system after allowing for the electrical investment is

$$EA(i) = EP(i) - TOTEL(i) \ J\ y^{-1} \quad . \tag{9.2}$$

To measure the conversion efficiency of the system, that is, the ultimate electricity available compared to total thermal input, yearly and cumulative net energy ratios are defined as,

$$\text{net energy ratio (yearly)} = \frac{EA(i)}{THERT(i)} \cdot 100\% \quad , \tag{9.3}$$

$$\text{net energy ratio (cumulative)} = \frac{\sum_{m=1}^{i} EA(m)}{\sum_{m=1}^{i} THERT(m)} \cdot 100\% \quad . \tag{9.4}$$

The electrical output as expressed so far makes no allowance for losses in the transmission system and the power stations themselves. The electricity available to the final consumer is

$$EP(i) = (1-\beta) \sum_{j=1}^{NS} 3.1536 \times 10^{13} \cdot ACF(i,j) \cdot C_{i,j} \cdot (1-\sigma_j) \ J\ y^{-1} \quad , \tag{9.4}$$

where σ_j = internal station usage in type j, and

β = transmission and distribution losses for the system.

10. OUTLINE OF COMPUTER PROGRAM FURES

FURES has been written in FORTRAN IV language for use on the IBM360/65 computer at the AAEC's Research Establishment at Lucas Heights. The program calls free input and graph plotting routines from a subroutine library package developed at the U.K.A.E.A., Risley. An average study requires 328K bytes of core storage, and has a running time of approximately 8 seconds.

FURES was designed to minimise input data requirements whilst producing detailed and comprehensive output. Since a large number of station characteristics are required for each installation type, an internal databank containing information on 13 nuclear plant types and five conventional stations has been included in the program (see Appendix A).

Output from FURES is in both tabular and graphical form and, with only one exception, input data are in free format. Decimal points may be omitted from whole real numbers if desired. Basically the input requirements fall into three categories

(i) details of generating system;
(ii) changes to station characteristics; and
(iii) output options.

10.1 System Details

Information follows which describes the system as a whole and gives details of the installation and the operation of each station type.

Input Requirement	Description
OT	identifies the entire study. Frequently in an energy analysis study, a comparison of the results of various strategies for a particular system is required. FURES has been designed to accept one or an unlimited number of runs per job. This item is printed as a heading on both tabular and graphical output. For example U.S.A. ENERGY ANALYSIS: 0.3% ORE
TITLE	is the heading for a run within a job and is printed on both tabular and graphical output. For example PWR, OIL & HYDRO INSTALLATIONS
RTYPE	specifies the station type. A keyword is required to specify each station type; these are given in Appendix A. The only input restriction imposed in the FURES code is that within each run all nuclear station types,

in any order, must precede all conventional installations, again in any order.

NZ	is the number of load zones for this station type.
NY	is the total number of years being studied.
XYEAR	specifies the year at which the study is to commence.
D(i), i=1, L	is used if a particular station type existed in the system being studied before the commencement year. A new installed capacity for each year before the commencement year is given for the lifetime of this station.
CO	is the installed capacity at the beginning of year zero *MWe* - (see Section 3).
C(i,j,k)	are the installed capacities at the beginning of each year, for each load zone specified, for station type j *MWe*.
H(k)	specifies the capacity factor for each load zone (as fraction).

10.2 Changes To Station Characteristics

As previously stated, to minimise user input requirements, a large bank of information pertaining to each station type has been built into FURES (Appendix A). However, an input option exists which allows the user to change any or all station characteristics if required. The total number of constants to be changed is specified (NC), followed by NC sets consisting of the number which identifies the particular constant (from Appendix A), and the new value for that constant.

10.3 Output Options

Graphical output is optional in FURES and if the indicator, JPLOT, is set to zero none will be generated. If JPLOT is set to -1, all available graphs will be produced. Alternatively, a positive number will indicate the number of graphs selected by the user, and must be followed by JPLOT numbers identifying the required graphs from Table 1.

If a comparison of two strategies is required, the keyword SAVE is specified in columns 77 to 80 of the first input card (the study title card). This will produce a table and graphical output of both the cumulative thermal energy savings as equivalent oil fuel, and the cumulative net nuclear-electric output. This keyword is the only input specification restricted to a definite format.

10.4 Input Data for FURES

Input data for a sample problem are shown in Appendix B. All input data are accepted by FURES in free format, with the exception of the SAVE option on the first input card. Separate cards are required only for the job heading and run title information. Thereafter the data are submitted with at least one blank between items, in the sequence

Input Item	Option Selected Item	Brief Description
OT		Columns 1 to 76 only, on first input card. Heading for entire study.
	SAVE	Columns 77 to 80 on first input card - only if a comparison of strategies is required.
† TITLE		Second input card. Title of individual run.
NS		Number of station types.
NY		Number of years.
XYEAR		Commencement year.
JPLOT		Graphical output requirements.
	NG(j),j=1,JPLOT	User selected graphs.

....

The next section is repeated NS times - i.e. once for each station type. It is essential within each run that ALL NUCLEAR station types, in any order, MUST PRECEDE ALL CONVENTIONAL station types in any order, when specifying RTYPE.

....

⊕ RTYPE		Station type.
NZ		Number of load zones.
NC		Number of characteristics to be changed, if any of the in-built characteristics pertaining to this station type are to be changed. If none NC must be set to 0.
	IC,VALUE(j),j=1,NC	If NC has been set to a positive number.
IP		Set to 1, if station type existed in the system before the commencement year. If not, IP must be set to 0.

Input Item	Option Selected Item	Brief Description
	D(j),j=1, (j)	If IP has been set to 1.
CO		Installed capacity at beginning of year zero.
C(i,j,k)		Installed capacities, NY values per load zone.
H(k),k=1,NZ		Capacity factors, one for each load zone.

....

Repeat from ⊕ for each station type in this run, then return to † to specify next run in this job if required.

....

11. EXAMPLE ILLUSTRATING THE USE OF FURES

The example which follows on the use of FURES is based essentially on published data for Japan, although extensive use is made of linear interpolations to obtain the installed capacities. The system consists of coal, oil, natural gas, hydro-electric and nuclear (PWR) plant, over the period 1961 to 2000, which includes the years of construction of the first nuclear plant, through to the time when the nuclear sector comprises about 50% of the system.

The installed capacities and capacity factors for all plant except oil are specified and the oil-fired capacity is evaluated to make up the system total. Thus,

$$C_{oil}(i) = C_i - \sum_{j=1}^{NS-1} C_{i,j} \quad , \text{ and}$$

$$ACF_{oil}(i) = \frac{C_i \cdot SACF(i) - \sum_{j=1}^{NS-1} C_{i,j} \cdot ACF(i,j)}{C_i - \sum_{j=1}^{NS-1} C_{i,j}} \quad ,$$

where $C_{oil}(i)$, $ACF_{oil}(i)$ are the installed capacity and capacity factor respectively for oil-fired plant in year i. C_i, SACF(i) are respectively the system installed capacity and average capacity factor in year i. The installed capacities are shown in Fig. 1.

Both the oil and hydro capacity factors are time dependent. This is handled in the program by defining two 'artificial' load zones, with capacity factors of 1% and 100%, and by varying the proportion of the installed capacity in each zone to give the required capacity factor.

In the analysis three cases have been examined. The first two involve a comparison between the system consisting of nuclear and conventional plant as outlined above, and the same system consisting wholly of conventional plant. In the third case, the nuclear-only portion of the system is analysed. A complete listing of the input data card deck, together with the job control language (JCL) cards necessary for running FURES, is given in Appendix B.

The results are not analysed in depth here as they will be documented fully in a subsequent publication. However, some tables and graphs are given to show the type of output available. Tables 2 and 3 give the fossil fuel annual and cumulative requirements as fuel in the conventional stations for both the all-conventional, and nuclear + conventional systems. The oil requirements for the latter case are also shown in Figures 2 and 3. It can be seen that the cumulative oil consumption as fuel over the study period drops from 5.63 gigatonnes for the all-conventional case, to 2.60 gigatonnes for the nuclear + conventional case. Tables 4 and 5 summarise the nuclear fuel cycle requirements.

Tables 6 to 10 show the output listing for energy requirements for the conventional + nuclear case, as well as the thermal savings when compared to the all conventional case.

It can be seen that the nuclear mix case gives a thermal saving in year 7 (the first year of nuclear production), and that the cumulative thermal saving over 40 years is 3.07 gigatonnes of oil equivalent. The thermal equivalent of the extra electricity needed for investment in the nuclear mix case is 0.27 gigatonnes, so that the nuclear + conventional program saves 2.80 gigatonnes of oil equivalent when compared to the all conventional case.

Table 11 gives a summary of the cumulative energy production and investment for the nuclear plant only. The final column indicates that this sector becomes a net energy producer (i.e., cumulative electrical output > cumulative electrical input + cumulative thermal input), in year eleven.

Figure 4 gives the annual uranium requirement for the nuclear mix case. Figures 5 to 13 illustrate the graphs for the energy analysis section of the program. They involve a comparison between the nuclear mix case and the conventional-only case, except for Figures 5, 10 and 11 which are for the nuclear mix case only.

12. ACKNOWLEDGEMENTS

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13. REFERENCES

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TABLE 1

LIST OF GRAPHICAL OUTPUT

Identifying Number	Graphical Output Produced
1	Total installed capacity for each station type
2	Annual and cumulative conventional fuel requirements
3	Annual uranium to be mined
4	Annual fabrication requirements
5	Annual reprocessing requirements
6	Annual enrichment requirements
7	Annual thorium requirements
8	Cumulative uranium requirements
9	Cumulative fabrication requirements
10	Cumulative reprocessing requirements
11	Cumulative enrichment work requirements
12	Plutonium stockpile
13	Depleted uranium stockpile
14	Cumulative thorium requirements
15	Energy analysis graphs consisting of annual electrical output both gross and net, after allowing for electrical investment; annual electrical investment; annual thermal input including fuel burnt in fossil stations; annual thermal investment; and equivalent thermal investment.

TABLE 2

ANNUAL FOSSIL FUEL REQUIREMENTS

	CONVENTIONAL ONLY				CONVENTIONAL + NUCLEAR		
YEAR	DMC* TONNES/YR	OIL TONNES/YR	GAS TH.CU.M/YR	YEAR	DMC TONNES/YR	OIL TONNES/YR	GAS TH.CU.M/YR
1	2.380E+06	1.350E+07	0.0	1	2.380E+06	1.350E+07	0.0
2	2.813E+06	1.722E+07	0.0	2	2.813E+06	1.722E+07	0.0
3	3.245E+06	1.771E+07	0.0	3	3.245E+06	1.771E+07	0.0
4	3.678E+06	2.233E+07	0.0	4	3.678E+06	2.233E+07	0.0
5	4.111E+06	2.643E+07	0.0	5	4.111E+06	2.643E+07	0.0
6	4.543E+06	3.060E+07	0.0	6	4.543E+06	3.060E+07	0.0
7	4.760E+06	3.856E+07	0.0	7	4.760E+06	3.830E+07	0.0
8	5.409E+06	4.813E+07	0.0	8	5.409E+06	4.786E+07	0.0
9	5.842E+06	5.361E+07	0.0	9	5.842E+06	5.335E+07	0.0
10	6.491E+06	5.906E+07	1.257E+06	10	6.491E+06	5.840E+07	1.257E+06
11	7.356E+06	6.914E+07	1.257E+06	11	7.356E+06	6.741E+07	1.257E+06
12	8.221E+06	7.717E+07	1.257E+06	12	8.221E+06	7.544E+07	1.257E+06
13	9.303E+06	8.541E+07	2.515E+06	13	9.303E+06	8.315E+07	2.515E+06
14	9.952E+06	9.031E+07	4.087E+06	14	9.952E+06	8.631E+07	4.087E+06
15	1.060E+07	9.224E+07	8.016E+06	15	1.060E+07	8.625E+07	8.016E+06
16	1.147E+07	9.218E+07	1.195E+07	16	1.147E+07	8.259E+07	1.195E+07
17	1.212E+07	9.459E+07	1.588E+07	17	1.212E+07	7.795E+07	1.588E+07
18	1.298E+07	9.727E+07	1.965E+07	18	1.298E+07	7.650E+07	1.965E+07
19	1.385E+07	1.003E+08	2.358E+07	19	1.385E+07	7.889E+07	2.358E+07
20	1.471E+07	1.009E+08	2.751E+07	20	1.471E+07	7.878E+07	2.751E+07
21	1.579E+07	1.045E+08	3.049E+07	21	1.579E+07	7.379E+07	3.049E+07
22	1.688E+07	1.087E+08	3.348E+07	22	1.688E+07	6.929E+07	3.348E+07
23	1.817E+07	1.132E+08	3.631E+07	23	1.817E+07	6.532E+07	3.631E+07
24	1.926E+07	1.146E+08	3.930E+07	24	1.926E+07	5.804E+07	3.930E+07
25	2.077E+07	1.196E+08	4.228E+07	25	2.077E+07	5.437E+07	4.228E+07
26	2.207E+07	1.312E+08	4.228E+07	26	2.207E+07	5.822E+07	4.228E+07
27	2.358E+07	1.437E+08	4.228E+07	27	2.358E+07	6.207E+07	4.228E+07
28	2.531E+07	1.569E+08	4.228E+07	28	2.531E+07	6.570E+07	4.228E+07
29	2.704E+07	1.712E+08	4.228E+07	29	2.704E+07	6.929E+07	4.228E+07
30	2.899E+07	1.865E+08	4.228E+07	30	2.899E+07	7.246E+07	4.228E+07
31	3.094E+07	2.040E+08	4.228E+07	31	3.094E+07	7.635E+07	4.228E+07
32	3.310E+07	2.227E+08	4.228E+07	32	3.310E+07	8.005E+07	4.228E+07
33	3.548E+07	2.426E+08	4.228E+07	33	3.548E+07	8.305E+07	4.228E+07
34	3.786E+07	2.641E+08	4.228E+07	34	3.786E+07	8.556E+07	4.228E+07
35	4.046E+07	2.869E+08	4.228E+07	35	4.046E+07	8.729E+07	4.228E+07
36	4.327E+07	3.114E+08	4.228E+07	36	4.327E+07	8.818E+07	4.228E+07
37	4.630E+07	3.375E+08	4.228E+07	37	4.630E+07	8.783E+07	4.228E+07
38	4.954E+07	3.654E+08	4.228E+07	38	4.954E+07	8.618E+07	4.228E+07
39	5.301E+07	3.953E+08	4.228E+07	39	5.301E+07	8.305E+07	4.228E+07
40	5.668E+07	4.274E+08	4.228E+07	40	5.668E+07	7.824E+07	4.228E+07

* Deep mined coal

TABLE 3

CUMULATIVE FOSSIL FUEL REQUIREMENTS

	CONVENTIONAL ONLY				CONVENTIONAL + NUCLEAR		
YEAR	DMC * TONNES	OIL TONNES	GAS TH.CU.M	YEAR	DMC TONNES	OIL TONNES	GAS TH.CU.M
1	2.380E+06	1.350E+07	0.0	1	2.380E+06	1.350E+07	0.0
2	5.192E+06	3.072E+07	0.0	2	5.192E+06	3.072E+07	0.0
3	8.438E+06	4.843E+07	0.0	3	8.438E+06	4.843E+07	0.0
4	1.212E+07	7.076E+07	0.0	4	1.212E+07	7.076E+07	0.0
5	1.623E+07	9.719E+07	0.0	5	1.623E+07	9.719E+07	0.0
6	2.077E+07	1.278E+08	0.0	6	2.077E+07	1.278E+08	0.0
7	2.553E+07	1.664E+08	0.0	7	2.553E+07	1.661E+08	0.0
8	3.094E+07	2.145E+08	0.0	8	3.094E+07	2.140E+08	0.0
9	3.678E+07	2.681E+08	0.0	9	3.678E+07	2.673E+08	0.0
10	4.327E+07	3.272E+08	1.257E+06	10	4.327E+07	3.257E+08	1.257E+06
11	5.063E+07	3.963E+08	2.515E+06	11	5.063E+07	3.931E+08	2.515E+06
12	5.885E+07	4.735E+08	3.772E+06	12	5.885E+07	4.685E+08	3.772E+06
13	6.815E+07	5.589E+08	6.287E+06	13	6.815E+07	5.517E+08	6.287E+06
14	7.810E+07	6.492E+08	1.037E+07	14	7.810E+07	6.380E+08	1.037E+07
15	8.870E+07	7.414E+08	1.839E+07	15	8.870E+07	7.243E+08	1.839E+07
16	1.002E+08	8.336E+08	3.034E+07	16	1.002E+08	8.069E+08	3.034E+07
17	1.123E+08	9.282E+08	4.621E+07	17	1.123E+08	8.848E+08	4.621E+07
18	1.253E+08	1.025E+09	6.586E+07	18	1.253E+08	9.613E+08	6.586E+07
19	1.391E+08	1.126E+09	8.944E+07	19	1.391E+08	1.040E+09	8.944E+07
20	1.538E+08	1.227E+09	1.169E+08	20	1.538E+08	1.119E+09	1.169E+08
21	1.696E+08	1.331E+09	1.474E+08	21	1.696E+08	1.193E+09	1.474E+08
22	1.865E+08	1.440E+09	1.809E+08	22	1.865E+08	1.262E+09	1.809E+08
23	2.047E+08	1.553E+09	2.172E+08	23	2.047E+08	1.327E+09	2.172E+08
24	2.239E+08	1.668E+09	2.565E+08	24	2.239E+08	1.385E+09	2.565E+08
25	2.447E+08	1.787E+09	2.988E+08	25	2.447E+08	1.440E+09	2.988E+08
26	2.668E+08	1.918E+09	3.411E+08	26	2.668E+08	1.498E+09	3.411E+08
27	2.903E+08	2.062E+09	3.834E+08	27	2.903E+08	1.560E+09	3.834E+08
28	3.157E+08	2.219E+09	4.257E+08	28	3.157E+08	1.626E+09	4.257E+08
29	3.427E+08	2.390E+09	4.679E+08	29	3.427E+08	1.695E+09	4.679E+08
30	3.717E+08	2.577E+09	5.102E+08	30	3.717E+08	1.768E+09	5.102E+08
31	4.026E+08	2.781E+09	5.525E+08	31	4.026E+08	1.844E+09	5.525E+08
32	4.357E+08	3.004E+09	5.948E+08	32	4.357E+08	1.924E+09	5.948E+08
33	4.712E+08	3.246E+09	6.371E+08	33	4.712E+08	2.007E+09	6.371E+08
34	5.091E+08	3.510E+09	6.793E+08	34	5.091E+08	2.093E+09	6.793E+08
35	5.495E+08	3.797E+09	7.216E+08	35	5.495E+08	2.180E+09	7.216E+08
36	5.928E+08	4.109E+09	7.639E+08	36	5.928E+08	2.268E+09	7.639E+08
37	6.391E+08	4.446E+09	8.062E+08	37	6.391E+08	2.356E+09	8.062E+08
38	6.887E+08	4.812E+09	8.485E+08	38	6.887E+08	2.442E+09	8.485E+08
39	7.417E+08	5.207E+09	8.908E+08	39	7.417E+08	2.525E+09	8.908E+08
40	7.983E+08	5.634E+09	9.330E+08	40	7.983E+08	2.603E+09	9.330E+08

* Deep mined coal

TABLE 4

ANNUAL REQUIREMENTS FOR NUCLEAR FUEL CYCLE

YEAR	URANIUM ORE (T/YR)	DEPLETED URANIUM ORE (T/YR)	FABRICATION (T/YR)	REPROCESSING (T/YR)	ENRICHMENT (T SWU/YR)	PLUTONIUM (T/YR)	U233 (T/YR)	THORIUM (T/YR)
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	7.73396E+01	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	-6.23916E+01	1.48000E+01	0.0	4.62647E+01	0.0	0.0	0.0
6	2.81267E+01	-2.37260E+01	0.0	0.0	1.84559E+01	0.0	0.0	0.0
7	1.44136E+02	-2.37260E+01	4.35721E+00	0.0	1.84559E+01	0.0	0.0	0.0
8	3.37485E+02	-1.17313E+02	2.65572E+01	4.20644E+00	8.78529E+01	0.0	0.0	0.0
9	6.50743E+01	-3.07726E+02	6.35572E+01	4.20644E+00	2.30674E+02	-4.59106E-02	0.0	0.0
10	3.32260E+02	-1.53063E+02	1.08930E+01	4.20644E+00	1.19439E+02	-4.59106E-02	0.0	0.0
11	6.80288E+02	-2.77847E+02	5.79218E+01	1.05161E+01	2.11969E+02	-4.59106E-02	0.0	0.0
12	8.04018E+02	-6.04328E+02	1.24522E+02	2.73419E+01	4.56286E+02	-1.03823E-01	0.0	0.0
13	1.43191E+03	-8.16318E+02	1.48036E+02	2.73419E+01	6.20417E+02	-2.87466E-01	0.0	0.0
14	2.64827E+03	-1.36861E+03	2.65158E+02	3.57548E+01	1.03643E+03	-2.87466E-01	0.0	0.0
15	2.16076E+03	-2.49769E+03	4.90237E+02	6.30967E+01	1.88597E+03	-3.62857E-01	0.0	0.0
16	1.87263E+03	-2.43261E+03	3.86259E+02	9.46451E+01	1.86273E+03	-6.17462E-01	0.0	0.0
17	2.26928E+03	-1.98061E+03	3.09325E+02	1.51432E+02	1.54343E+03	-9.61792E-01	0.0	0.0
18	4.58900E+03	-2.02433E+03	3.76862E+02	2.62903E+02	1.58249E+03	-1.55968E+00	0.0	0.0
19	4.52039E+03	-3.92478E+03	8.31755E+02	3.28103E+02	3.00269E+03	-2.70511E+00	0.0	0.0
20	5.31459E+03	-4.67797E+03	8.42648E+02	3.38619E+02	3.59438E+03	-3.33458E+00	0.0	0.0
21	6.25427E+03	-5.41498E+03	9.76857E+02	3.49135E+02	4.16976E+03	-3.30148E+00	0.0	0.0
22	7.14122E+03	-6.20252E+03	1.12587E+03	4.85844E+02	4.78217E+03	-3.12599E+00	0.0	0.0
23	7.61427E+03	-6.93607E+03	1.26530E+03	6.22554E+02	5.36495E+03	-4.44831E+00	0.0	0.0
24	8.62869E+03	-7.45125E+03	1.35511E+03	7.57160E+02	5.78581E+03	-5.91302E+00	0.0	0.0
25	9.54730E+03	-8.32071E+03	1.54852E+03	8.93869E+02	6.46619E+03	-7.35478E+00	0.0	0.0
26	1.06391E+04	-9.27264E+03	1.72667E+03	1.03058E+03	7.21090E+03	-8.49089E+00	0.0	0.0
27	1.18679E+04	-1.03700E+04	1.93488E+03	1.15257E+03	8.06647E+03	-9.62700E+00	0.0	0.0
28	1.32804E+04	-1.16094E+04	2.16574E+03	1.28928E+03	9.03006E+03	-1.06079E+01	0.0	0.0
29	1.48152E+04	-1.29945E+04	2.42361E+03	1.44071E+03	1.01072E+04	-1.17440E+01	0.0	0.0
30	1.66023E+04	-1.45061E+04	2.70326E+03	1.61107E+03	1.12841E+04	-1.30408E+01	0.0	0.0
31	1.85591E+04	-1.62366E+04	3.02908E+03	1.80246E+03	1.26295E+04	-1.45825E+01	0.0	0.0
32	2.07640E+04	-1.81585E+04	3.38626E+03	2.01699E+03	1.41245E+04	-1.63155E+01	0.0	0.0
33	2.31897E+04	-2.03145E+04	3.78874E+03	2.25465E+03	1.58014E+04	-1.82626E+01	0.0	0.0
34	2.60577E+04	-2.26969E+04	4.23130E+03	2.52176E+03	1.76554E+04	-2.04129E+01	0.0	0.0
35	2.89579E+04	-2.54483E+04	4.75530E+03	2.82042E+03	1.97922E+04	-2.28299E+01	0.0	0.0
36	3.24579E+04	-2.84059E+04	5.29196E+03	3.15483E+03	2.20956E+04	-2.55309E+01	0.0	0.0
37	3.64006E+04	-3.17587E+04	5.92226E+03	3.53718E+03	2.47040E+04	-2.85619E+01	0.0	0.0
38	3.93696E+04	-3.55584E+04	6.64271E+03	3.94564E+03	2.76574E+04	-3.20133E+01	0.0	0.0
39	4.26858E+04	-3.86730E+04	7.17646E+03	4.41256E+03	3.01166E+04	-3.57309E+01	0.0	0.0
40	4.60416E+04	-4.18664E+04	7.76904E+03	4.94928E+03	3.26422E+04	-3.99561E+01	0.0	0.0

TABLE 5

CUMULATIVE REQUIREMENTS FOR NUCLEAR FUEL CYCLE

YEAR	URANIUM ORE (T)	DEPLETED URANIUM STOCKPILE (T)	FABRICATION (T)	REPROCESSING (T)	ENRICHMENT (T SWU)	PLUTONIUM STOCKPILE (T)	U233 (T)	THORIUM (T)
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	7.73396E+01	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	7.73396E+01	6.23916E+01	1.48000E+01	0.0	4.62647E+01	0.0	0.0	0.0
6	1.05466E+02	8.61176E+01	1.48000E+01	0.0	6.47206E+01	0.0	0.0	0.0
7	2.49602E+02	1.09844E+02	1.91572E+01	0.0	8.31766E+01	0.0	0.0	0.0
8	5.87087E+02	2.27157E+02	4.57144E+01	4.20644E+00	1.71029E+02	0.0	0.0	0.0
9	6.52161E+02	5.34883E+02	1.09272E+02	8.41289E+00	4.01704E+02	4.59106E-02	0.0	0.0
10	9.84422E+02	6.87946E+02	1.20165E+02	1.26193E+01	5.21143E+02	9.18213E-02	0.0	0.0
11	1.06471E+03	9.65793E+02	1.78086E+02	2.31354E+01	7.33112E+02	1.37732E-01	0.0	0.0
12	2.47073E+03	1.57012E+03	3.02608E+02	5.04773E+01	1.18940E+03	2.41555E-01	0.0	0.0
13	3.90264E+03	2.38644E+03	4.50644E+02	7.78192E+01	1.80981E+03	5.29020E-01	0.0	0.0
14	6.55091E+03	3.75505E+03	7.15802E+02	1.13574E+02	2.84624E+03	8.16486E-01	0.0	0.0
15	8.71767E+03	6.25274E+03	1.20604E+03	1.76671E+02	4.73221E+03	1.17934E+00	0.0	0.0
16	1.05903E+04	8.68535E+03	1.59230E+03	2.71316E+02	6.59495E+03	1.79680E+00	0.0	0.0
17	1.28596E+04	1.06660E+04	1.90162E+03	4.22748E+02	8.13838E+03	2.75860E+00	0.0	0.0
18	1.74486E+04	1.26903E+04	2.27849E+03	6.85650E+02	9.72087E+03	4.31827E+00	0.0	0.0
19	2.19690E+04	1.66151E+04	3.11024E+03	1.01375E+03	1.27236E+04	7.02339E+00	0.0	0.0
20	2.72836E+04	2.12930E+04	3.95289E+03	1.35237E+03	1.63179E+04	1.03580E+01	0.0	0.0
21	3.35378E+04	2.67080E+04	4.92974E+03	1.70151E+03	2.04877E+04	1.36594E+01	0.0	0.0
22	4.06790E+04	3.29105E+04	6.05561E+03	2.18735E+03	2.52699E+04	1.67854E+01	0.0	0.0
23	4.82933E+04	3.98466E+04	7.32090E+03	2.80990E+03	3.06348E+04	2.12337E+01	0.0	0.0
24	5.69220E+04	4.72979E+04	8.67601E+03	3.56706E+03	3.64206E+04	2.71467E+01	0.0	0.0
25	6.64693E+04	5.56186E+04	1.02245E+04	4.46093E+03	4.28868E+04	3.45015E+01	0.0	0.0
26	7.71083E+04	6.48912E+04	1.19512E+04	5.49151E+03	5.00977E+04	4.29924E+01	0.0	0.0
27	8.89763E+04	7.52612E+04	1.38861E+04	6.64407E+03	5.81642E+04	5.26194E+01	0.0	0.0
28	1.02257E+05	8.68705E+04	1.60518E+04	7.93334E+03	6.71943E+04	6.32273E+01	0.0	0.0
29	1.17072E+05	9.98649E+04	1.84754E+04	9.37405E+03	7.73014E+04	7.49713E+01	0.0	0.0
30	1.33674E+05	1.14371E+05	2.11787E+04	1.09851E+04	8.85855E+04	8.80121E+01	0.0	0.0
31	1.52233E+05	1.30608E+05	2.42078E+04	1.27876E+04	1.01215E+05	1.02595E+02	0.0	0.0
32	1.72997E+05	1.48766E+05	2.75940E+04	1.48046E+04	1.15339E+05	1.18910E+02	0.0	0.0
33	1.96187E+05	1.69080E+05	3.13828E+04	1.70592E+04	1.31141E+05	1.37173E+02	0.0	0.0
34	2.22244E+05	1.91777E+05	3.56141E+04	1.95810E+04	1.48796E+05	1.57586E+02	0.0	0.0
35	2.51242E+05	2.17226E+05	4.03694E+04	2.24014E+04	1.68589E+05	1.80415E+02	0.0	0.0
36	2.83700E+05	2.45632E+05	4.56613E+04	2.55562E+04	1.90684E+05	2.05946E+02	0.0	0.0
37	3.20101E+05	2.77390E+05	5.15836E+04	2.90934E+04	2.15388E+05	2.34508E+02	0.0	0.0
38	3.59470E+05	3.12949E+05	5.82263E+04	3.30391E+04	2.43046E+05	2.66521E+02	0.0	0.0
39	4.02156E+05	3.51622E+05	6.54028E+04	3.74516E+04	2.73162E+05	3.02252E+02	0.0	0.0
40	4.48198E+05	3.93488E+05	7.31718E+04	4.24009E+04	3.05804E+05	3.42208E+02	0.0	0.0

TABLE 6

ENERGY INVESTMENT IN CONVENTIONAL STATIONS

YEAR	PLANT ELECTRICAL	PLANT THERMAL	FUEL ELECTRICAL IN MINING	FUEL THERMAL IN MINING	FUEL THERMAL IN FUEL CONSUMED	TOTAL ELECTRICAL	TOTAL THERMAL
1	8.97614E+15	1.30191E+16	0.0	1.28214E+16	6.58497E+17	8.97614E+15	6.84338E+17
2	9.54124E+15	1.38387E+16	0.0	1.61842E+16	8.33649E+17	9.54124E+15	8.63672E+17
3	8.95444E+15	1.29876E+16	0.0	1.69104E+16	8.67149E+17	8.95444E+15	8.97047E+17
4	9.92884E+15	1.44009E+16	0.0	2.10173E+16	1.08228E+18	9.92884E+15	1.11770E+18
5	1.19453E+16	1.73256E+16	0.0	2.46891E+16	1.27403E+18	1.19453E+16	1.31604E+18
6	1.37043E+16	1.98768E+16	0.0	2.84287E+16	1.46943E+18	1.37043E+16	1.51773E+18
7	1.51828E+16	2.20212E+16	0.0	3.48907E+16	1.81383E+18	1.51828E+16	1.87074E+18
8	1.61694E+16	2.34522E+16	0.0	4.32092E+16	2.25247E+18	1.61694E+16	2.31913E+18
9	1.56219E+16	2.26581E+16	0.0	4.80216E+16	2.50550E+18	1.56219E+16	2.57618E+18
10	1.40472E+16	2.03742E+16	0.0	5.61995E+16	2.79197E+18	1.40472E+16	2.86855E+18
11	1.24326E+16	1.80324E+16	0.0	6.42256E+16	3.21214E+18	1.24326E+16	3.29440E+18
12	1.09216E+16	1.58409E+16	0.0	7.14416E+16	3.58879E+18	1.09216E+16	3.67607E+18
13	1.15165E+16	1.67037E+16	0.0	8.21189E+16	4.00404E+18	1.15165E+16	4.10286E+18
14	1.28527E+16	1.86417E+16	0.0	8.96484E+16	4.21954E+18	1.28527E+16	4.32783E+18
15	1.32667E+16	1.92423E+16	0.0	1.01210E+17	4.38050E+18	1.32667E+16	4.50095E+18
16	1.37275E+16	1.99107E+16	0.0	1.09997E+17	4.38969E+18	1.37275E+16	4.51960E+18
17	1.39966E+16	2.03010E+16	0.0	1.17812E+17	4.34938E+18	1.39966E+16	4.48750E+18
18	1.31727E+16	1.91061E+16	0.0	1.27959E+17	4.44969E+18	1.31727E+16	4.59675E+18
19	1.24667E+16	1.80822E+16	0.0	1.41691E+17	4.72455E+18	1.24667E+16	4.88433E+18
20	1.36192E+16	1.97538E+16	0.0	1.53379E+17	4.88953E+18	1.36192E+16	5.06266E+18
21	1.48775E+16	2.15787E+16	0.0	1.58554E+17	4.81037E+18	1.48775E+16	4.99050E+18
22	1.61750E+16	2.34606E+16	0.0	1.64138E+17	4.75316E+18	1.61750E+16	4.94076E+18
23	1.73743E+16	2.52000E+16	0.0	1.69869E+17	4.71915E+18	1.73743E+16	4.91422E+18
24	1.83107E+16	2.65581E+16	0.0	1.73167E+17	4.53912E+18	1.83107E+16	4.73884E+18
25	1.92430E+16	2.79102E+16	0.0	1.79746E+17	4.52986E+18	1.92430E+16	4.73751E+18
26	2.03447E+16	2.95080E+16	0.0	1.83862E+17	4.73444E+18	2.03447E+16	4.94781E+18
27	2.13163E+16	3.09171E+16	0.0	1.88135E+17	4.94470E+18	2.13163E+16	5.16375E+18
28	2.28110E+16	3.30849E+16	0.0	1.92390E+17	5.15127E+18	2.28110E+16	5.37675E+18
29	2.39005E+16	3.46650E+16	0.0	1.96614E+17	5.35616E+18	2.39005E+16	5.58743E+18
30	2.39005E+16	3.46650E+16	0.0	2.00657E+17	5.54852E+18	2.39005E+16	5.78384E+18
31	2.38219E+16	3.45510E+16	0.0	2.05285E+17	5.77239E+18	2.38219E+16	6.01222E+18
32	2.40970E+16	3.49500E+16	0.0	2.09915E+17	5.99355E+18	2.40970E+16	6.23841E+18
33	2.30752E+16	3.34680E+16	0.0	2.14140E+17	6.19023E+18	2.30752E+16	6.43784E+18
34	2.28001E+16	3.30690E+16	0.0	2.17959E+17	6.36507E+18	2.28001E+16	6.61610E+18
35	2.29966E+16	3.33540E+16	0.0	2.21295E+17	6.51124E+18	2.29966E+16	6.76589E+18
36	2.29966E+16	3.33540E+16	0.0	2.24115E+17	6.62686E+18	2.29966E+16	6.88433E+18
37	2.26822E+16	3.28980E+16	0.0	2.26068E+17	6.69322E+18	2.26822E+16	6.95218E+18
38	2.30752E+16	3.34680E+16	0.0	2.27126E+17	6.70869E+18	2.30752E+16	6.96928E+18
39	2.30752E+16	3.34680E+16	0.0	2.27126E+17	6.66463E+18	2.30752E+16	6.92522E+18
40	2.30752E+16	3.34680E+16	0.0	2.25907E+17	6.55230E+18	2.30752E+16	6.81167E+18

TABLE 7

ENERGY INVESTMENT IN NUCLEAR STATIONS

FUEL

YEAR	MINING AND MILLING ELECTRICAL	MINING AND MILLING THERMAL	CONVERSION ELECTRICAL	CONVERSION THERMAL	ENRICHMENT ELECTRICAL	ENRICHMENT THERMAL	FABRICATION ELECTRICAL	FABRICATION THERMAL	REPROCESSING ELECTRICAL	REPROCESSING THERMAL
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	7.378E+13	4.455E+12	1.503E+13	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	4.031E+14	1.599E+13	2.901E+12	1.939E+12	0.0	0.0
6	0.0	2.683E+13	1.620E+12	5.468E+12	1.608E+14	6.378E+12	0.0	0.0	0.0	0.0
7	0.0	1.375E+14	8.302E+12	2.802E+13	1.608E+14	6.378E+12	8.540E+11	5.708E+11	0.0	0.0
8	0.0	3.220E+14	1.944E+13	6.561E+13	7.654E+14	3.036E+13	5.205E+12	3.479E+12	1.683E+11	0.0
9	0.0	6.208E+13	3.748E+12	1.265E+13	2.010E+15	7.972E+13	1.246E+13	8.325E+12	1.683E+11	0.0
10	0.0	3.170E+14	1.914E+13	6.459E+13	1.041E+15	4.128E+13	2.135E+12	1.427E+12	1.683E+11	0.0
11	0.0	6.490E+14	3.918E+13	1.322E+14	1.847E+15	7.326E+13	1.135E+13	7.588E+12	4.206E+11	0.0
12	0.0	7.689E+14	4.643E+13	1.567E+14	3.975E+15	1.577E+14	2.441E+13	1.631E+13	1.094E+12	0.0
13	0.0	1.366E+15	8.248E+13	2.784E+14	5.405E+15	2.144E+14	2.902E+13	1.939E+13	1.094E+12	0.0
14	0.0	2.526E+15	1.525E+14	5.148E+14	9.029E+15	3.582E+14	5.197E+13	3.474E+13	1.430E+12	0.0
15	0.0	2.067E+15	1.248E+14	4.212E+14	1.643E+16	6.518E+14	9.609E+13	6.422E+13	2.524E+12	0.0
16	0.0	1.786E+15	1.079E+14	3.640E+14	1.623E+16	6.438E+14	7.571E+13	5.060E+13	3.786E+12	0.0
17	0.0	2.165E+15	1.307E+14	4.411E+14	1.345E+16	5.334E+14	6.063E+13	4.052E+13	6.057E+12	0.0
18	0.0	4.378E+15	2.643E+14	8.921E+14	1.379E+16	5.469E+14	7.386E+13	4.937E+13	1.052E+13	0.0
19	0.0	4.312E+15	2.604E+14	8.788E+14	2.616E+16	1.038E+15	1.630E+14	1.090E+14	1.312E+13	0.0
20	0.0	5.070E+15	3.061E+14	1.033E+15	3.131E+16	1.242E+15	1.652E+14	1.104E+14	1.354E+13	0.0
21	0.0	5.967E+15	3.602E+14	1.216E+15	3.633E+16	1.441E+15	1.915E+14	1.280E+14	1.397E+13	0.0
22	0.0	6.813E+15	4.113E+14	1.388E+15	4.166E+16	1.653E+15	2.207E+14	1.475E+14	1.943E+13	0.0
23	0.0	7.264E+15	4.386E+14	1.480E+15	4.674E+16	1.854E+15	2.480E+14	1.658E+14	2.490E+13	0.0
24	0.0	8.232E+15	4.970E+14	1.677E+15	5.041E+16	2.000E+15	2.656E+14	1.775E+14	3.029E+13	0.0
25	0.0	9.108E+15	5.499E+14	1.856E+15	5.633E+16	2.235E+15	3.035E+14	2.029E+14	3.575E+13	0.0
26	0.0	1.015E+16	6.128E+14	2.068E+15	6.282E+16	2.492E+15	3.384E+14	2.262E+14	4.122E+13	0.0
27	0.0	1.132E+16	6.836E+14	2.307E+15	7.028E+16	2.788E+15	3.792E+14	2.535E+14	4.610E+13	0.0
28	0.0	1.267E+16	7.650E+14	2.582E+15	7.867E+16	3.121E+15	4.245E+14	2.837E+14	5.157E+13	0.0
29	0.0	1.413E+16	8.534E+14	2.880E+15	8.805E+16	3.493E+15	4.750E+14	3.175E+14	5.763E+13	0.0
30	0.0	1.584E+16	9.563E+14	3.227E+15	9.831E+16	3.900E+15	5.298E+14	3.541E+14	6.444E+13	0.0
31	0.0	1.771E+16	1.069E+15	3.608E+15	1.100E+17	4.365E+15	5.937E+14	3.968E+14	7.210E+13	0.0
32	0.0	1.981E+16	1.196E+15	4.037E+15	1.231E+17	4.881E+15	6.637E+14	4.436E+14	8.068E+13	0.0
33	0.0	2.212E+16	1.336E+15	4.508E+15	1.377E+17	5.461E+15	7.426E+14	4.963E+14	9.019E+13	0.0
34	0.0	2.486E+16	1.501E+15	5.066E+15	1.538E+17	6.102E+15	8.293E+14	5.543E+14	1.009E+14	0.0
35	0.0	2.766E+16	1.670E+15	5.637E+15	1.724E+17	6.840E+15	9.320E+14	6.229E+14	1.128E+14	0.0
36	0.0	3.096E+16	1.870E+15	6.310E+15	1.925E+17	7.636E+15	1.037E+15	6.932E+14	1.262E+14	0.0
37	0.0	3.473E+16	2.097E+15	7.076E+15	2.152E+17	8.538E+15	1.161E+15	7.758E+14	1.415E+14	0.0
38	0.0	3.756E+16	2.268E+15	7.653E+15	2.410E+17	9.558E+15	1.302E+15	8.702E+14	1.578E+14	0.0
39	0.0	4.072E+16	2.459E+15	8.298E+15	2.624E+17	1.041E+16	1.407E+15	9.401E+14	1.765E+14	0.0
40	0.0	4.392E+16	2.652E+15	8.950E+15	2.844E+17	1.128E+16	1.523E+15	1.018E+15	1.980E+14	0.0

(Continued)

TABLE 7 (Continued)

YEAR	PLANT ELECTRICAL	PLANT THERMAL	TOTAL ELECTRICAL	TOTAL THERMAL
1	1.072E+14	1.554E+14	1.072E+14	1.554E+14
2	1.072E+14	1.554E+14	1.072E+14	1.554E+14
3	1.072E+14	1.554E+14	1.072E+14	1.554E+14
4	2.680E+14	3.885E+14	2.680E+14	4.623E+14
5	6.968E+14	1.010E+15	1.103E+15	1.028E+15
6	5.896E+14	8.547E+14	7.504E+14	8.879E+14
7	8.040E+14	1.165E+15	9.656E+14	1.310E+15
8	1.501E+15	2.176E+15	2.272E+15	2.531E+15
9	2.144E+15	3.108E+15	4.166E+15	3.258E+15
10	3.162E+15	4.584E+15	4.205E+15	4.944E+15
11	6.003E+15	8.702E+15	7.862E+15	9.432E+15
12	7.450E+15	1.080E+16	1.145E+16	1.174E+16
13	7.022E+15	1.018E+16	1.246E+16	1.178E+16
14	6.486E+15	9.402E+15	1.557E+16	1.232E+16
15	8.522E+15	1.235E+16	2.505E+16	1.514E+16
16	9.166E+15	1.329E+16	2.547E+16	1.577E+16
17	1.093E+16	1.585E+16	2.445E+16	1.859E+16
18	1.415E+16	2.051E+16	2.802E+16	2.549E+16
19	1.737E+16	2.517E+16	4.370E+16	3.063E+16
20	1.699E+16	2.463E+16	4.848E+16	3.105E+16
21	1.699E+16	2.463E+16	5.352E+16	3.217E+16
22	1.742E+16	2.525E+16	5.932E+16	3.387E+16
23	1.828E+16	2.650E+16	6.529E+16	3.578E+16
24	1.967E+16	2.852E+16	7.037E+16	3.892E+16
25	2.203E+16	3.193E+16	7.870E+16	4.348E+16
26	2.460E+16	3.566E+16	8.780E+16	4.853E+16
27	2.755E+16	3.994E+16	9.825E+16	5.430E+16
28	3.082E+16	4.468E+16	1.100E+17	6.075E+16
29	3.446E+16	4.996E+16	1.231E+17	6.791E+16
30	3.848E+16	5.579E+16	1.374E+17	7.588E+16
31	4.320E+16	6.263E+16	1.539E+17	8.509E+16
32	4.829E+16	7.001E+16	1.721E+17	9.514E+16
33	5.398E+16	7.824E+16	1.925E+17	1.063E+17
34	6.046E+16	8.765E+16	2.152E+17	1.192E+17
35	6.598E+16	9.565E+16	2.395E+17	1.308E+17
36	7.022E+16	1.018E+17	2.639E+17	1.411E+17
37	7.332E+16	1.063E+17	2.898E+17	1.503E+17
38	7.504E+16	1.088E+17	3.175E+17	1.568E+17
39	7.504E+16	1.088E+17	3.390E+17	1.609E+17
40	7.504E+16	1.088E+17	3.611E+17	1.650E+17

TABLE 8

SUMMARY OF ANNUAL PRODUCTION AND INVESTMENT

YEAR	ELECTRICITY FROM NUCLEAR	ELECTRICITY FROM CONVENTIONAL	TOTAL ELECTRICITY PRODUCED	ELECTRICAL ENERGY INVESTMENT	THERMAL ENERGY INVESTMENT	NET ENERGY RATIO PERCENT
1	0.0	4.46874E+17	4.46874E+17	9.08334E+15	6.84493E+17	63.96
2	0.0	5.17701E+17	5.17701E+17	9.64844E+15	8.63827E+17	58.81
3	0.0	5.51470E+17	5.51470E+17	9.06164E+15	8.97203E+17	60.46
4	0.0	6.27080E+17	6.27080E+17	1.01968E+16	1.11816E+18	55.17
5	0.0	7.22449E+17	7.22449E+17	1.30481E+16	1.31707E+18	53.86
6	0.0	8.00425E+17	8.00425E+17	1.44547E+16	1.51862E+18	51.75
7	4.09968E+15	8.86782E+17	8.90882E+17	1.61485E+16	1.87205E+18	46.73
8	4.09968E+15	1.05604E+18	1.06014E+18	1.84410E+16	2.32166E+18	44.87
9	4.09968E+15	1.15419E+18	1.15829E+18	1.97882E+16	2.57943E+18	44.14
10	1.02492E+16	1.26426E+18	1.27451E+18	1.82525E+16	2.87349E+18	43.72
11	2.66479E+16	1.41782E+18	1.44447E+18	2.02942E+16	3.30383E+18	43.11
12	2.66479E+16	1.54031E+18	1.56695E+18	2.23726E+16	3.66761E+18	41.88
13	3.48473E+16	1.68584E+18	1.72068E+18	2.39733E+16	4.11454E+18	41.24
14	6.14952E+16	1.77741E+18	1.83890E+18	2.84210E+16	4.34015E+18	41.71
15	9.22428E+16	1.83721E+18	1.92945E+18	3.33183E+16	4.51609E+18	41.88
16	1.47588E+17	1.84390E+18	1.99148E+18	3.92008E+16	4.53536E+18	43.05
17	2.56230E+17	1.83641E+18	2.09264E+18	3.34440E+16	4.50609E+18	45.59
18	3.19775E+17	1.87187E+18	2.19164E+18	4.11942E+16	4.62224E+18	46.52
19	3.30024E+17	1.97154E+18	2.30156E+18	5.61686E+16	4.91496E+18	45.68
20	3.40273E+17	2.02963E+18	2.36990E+18	6.21034E+16	5.09371E+18	45.31
21	4.73513E+17	2.01517E+18	2.48868E+18	6.84010E+16	5.02267E+18	48.19
22	6.06752E+17	2.00527E+18	2.61202E+18	7.54973E+16	4.97462E+18	50.99
23	7.37942E+17	2.00352E+18	2.74146E+18	8.26642E+16	4.94999E+18	53.71
24	8.71182E+17	1.94751E+18	2.81869E+18	8.86838E+16	4.77777E+18	57.14
25	1.00442E+18	1.95127E+18	2.95569E+18	9.79453E+16	4.78099E+18	59.77
26	1.12331E+18	2.03590E+18	3.15921E+18	1.08148E+17	4.99634E+18	61.07
27	1.25655E+18	2.12560E+18	3.38215E+18	1.19567E+17	5.21805E+18	62.52
28	1.40414E+18	2.21093E+18	3.61507E+18	1.32777E+17	5.43750E+18	64.04
29	1.57018E+18	2.29875E+18	3.86893E+18	1.46952E+17	5.65534E+18	65.81
30	1.75671E+18	2.37910E+18	4.13581E+18	1.61286E+17	5.85972E+18	67.83
31	1.96580E+18	2.45745E+18	4.42325E+18	1.77717E+17	6.09731E+18	69.63
32	2.19743E+18	2.53486E+18	4.73229E+18	1.96188E+17	6.33355E+18	71.62
33	2.45776E+18	2.60370E+18	5.06146E+18	2.15545E+17	6.54417E+18	74.05
34	2.74883E+18	2.66489E+18	5.41373E+18	2.38005E+17	6.73526E+18	76.85
35	3.07476E+18	2.71605E+18	5.79081E+18	2.62453E+17	6.89566E+18	80.16
36	3.43758E+18	2.75652E+18	6.19410E+18	2.86873E+17	7.02541E+18	84.08
37	3.84550E+18	2.77975E+18	6.62524E+18	3.12530E+17	7.10252E+18	88.86
38	4.30056E+18	2.78516E+18	7.08572E+18	3.40526E+17	7.12605E+18	94.66
39	4.80892E+18	2.76974E+18	7.57866E+18	3.62074E+17	7.08507E+18	101.84
40	5.37673E+18	2.73042E+18	8.10715E+18	3.84215E+17	6.97667E+18	110.70

TABLE 9

SUMMARY OF CUMULATIVE PRODUCTION AND INVESTMENT

YEAR	ELECTRICITY FROM NUCLEAR	ELECTRICITY FROM CONVENTIONAL	TOTAL ELECTRICITY PRODUCED	ELECTRICAL ENERGY INVESTMENT	THERMAL ENERGY INVESTMENT	NET ENERGY RATIO PERCENT
1	0.0	4.46874E+17	4.46874E+17	9.08334E+15	6.84493E+17	63.96
2	0.0	9.64575E+17	9.64575E+17	1.87318E+16	1.54832E+18	61.09
3	0.0	1.51604E+18	1.51604E+18	2.77934E+16	2.44552E+18	60.86
4	0.0	2.14312E+18	2.14312E+18	3.79903E+16	3.56368E+18	59.07
5	0.0	2.86557E+18	2.86557E+18	5.10383E+16	4.88075E+18	57.67
6	0.0	3.66600E+18	3.66600E+18	6.54931E+16	6.39937E+18	56.26
7	4.09968E+15	4.55278E+18	4.55688E+18	8.16415E+16	8.27142E+18	54.10
8	8.19935E+15	5.60882E+18	5.61702E+18	1.00082E+17	1.05931E+19	52.08
9	1.22990E+16	6.76301E+18	6.77531E+18	1.19871E+17	1.31725E+19	50.53
10	2.25482E+16	8.02727E+18	8.04982E+18	1.38123E+17	1.60460E+19	49.31
11	4.91961E+16	9.44509E+18	9.49429E+18	1.58417E+17	1.93498E+19	48.25
12	7.58440E+16	1.09854E+19	1.10612E+19	1.80790E+17	2.30376E+19	47.23
13	1.10691E+17	1.26712E+19	1.27819E+19	2.04763E+17	2.71523E+19	46.32
14	1.72186E+17	1.44486E+19	1.46208E+19	2.33184E+17	3.14924E+19	45.69
15	2.64429E+17	1.62859E+19	1.65503E+19	2.71502E+17	3.60085E+19	45.21
16	4.12016E+17	1.81298E+19	1.85418E+19	3.10703E+17	4.05438E+19	44.97
17	6.68247E+17	1.99662E+19	2.06344E+19	3.49147E+17	4.50499E+19	45.03
18	9.88022E+17	2.18380E+19	2.28260E+19	3.90341E+17	4.96721E+19	45.17
19	1.31805E+18	2.38095E+19	2.51276E+19	4.46510E+17	5.45371E+19	45.21
20	1.65832E+18	2.58392E+19	2.74975E+19	5.08613E+17	5.96808E+19	45.22
21	2.13183E+18	2.78543E+19	2.99861E+19	5.77014E+17	6.47034E+19	45.45
22	2.73858E+18	2.98596E+19	3.25982E+19	6.52511E+17	6.96781E+19	45.85
23	3.47652E+18	3.18631E+19	3.53396E+19	7.35176E+17	7.46280E+19	46.37
24	4.34771E+18	3.38106E+19	3.81583E+19	8.23859E+17	7.94058E+19	47.02
25	5.35213E+18	3.57618E+19	4.11140E+19	9.21805E+17	8.41868E+19	47.74
26	6.47544E+18	3.77977E+19	4.42732E+19	1.02995E+18	8.91831E+19	48.49
27	7.73199E+18	3.99233E+19	4.76553E+19	1.14952E+18	9.44011E+19	49.25
28	9.13613E+18	4.21342E+19	5.12704E+19	1.28230E+18	9.98386E+19	50.07
29	1.07063E+19	4.44330E+19	5.51393E+19	1.42925E+18	1.05494E+20	50.91
30	1.24630E+19	4.68121E+19	5.92751E+19	1.59053E+18	1.11354E+20	51.80
31	1.44288E+19	4.92695E+19	6.36983E+19	1.76825E+18	1.17451E+20	52.73
32	1.66262E+19	5.18044E+19	6.84306E+19	1.96444E+18	1.23785E+20	53.70
33	1.90840E+19	5.44081E+19	7.34920E+19	2.17998E+18	1.30329E+20	54.72
34	2.18328E+19	5.70730E+19	7.89058E+19	2.41799E+18	1.37064E+20	55.80
35	2.49076E+19	5.97890E+19	8.46966E+19	2.68044E+18	1.43961E+20	56.97
36	2.83451E+19	6.25455E+19	9.08906E+19	2.96731E+18	1.50986E+20	58.23
37	3.21906E+19	6.53253E+19	9.75159E+19	3.27984E+18	1.58088E+20	59.61
38	3.64912E+19	6.81104E+19	1.04602E+20	3.62037E+18	1.65215E+20	61.12
39	4.13001E+19	7.08801E+19	1.12180E+20	3.98244E+18	1.72301E+20	62.80
40	4.60768E+19	7.36106E+19	1.20287E+20	4.36665E+18	1.79277E+20	64.66

TABLE 10

ENERGY BENEFIT OF NUCLEAR PROGRAM

TABLE OF BOTH CUMULATIVE THERMAL ENERGY SAVINGS AS EQUIVALENT OIL FUEL, AND NET NUCLEAR-ELECTRIC OUTPUT

YEAR	THERMAL ENERGY SAVING (GIGATONNES)		NET NUCLEAR-ELECTRIC OUTPUT (J X 10-19)	
1961	-0.000001	(-9.402E-07)	-0.000011	(-1.072E-05)
1962	-0.000002	(-1.874E-06)	-0.000021	(-2.144E-05)
1963	-0.000003	(-2.824E-06)	-0.000032	(-3.216E-05)
1964	-0.000007	(-6.872E-06)	-0.000059	(-5.896E-05)
1965	-0.000013	(-1.337E-05)	-0.000169	(-1.692E-04)
1966	-0.000019	(-1.929E-05)	-0.000244	(-2.443E-04)
1967	0.000243	(2.430E-04)	0.000069	(6.913E-05)
1968	0.000492	(4.923E-04)	0.000252	(2.519E-04)
1969	0.000741	(7.407E-04)	0.000245	(2.453E-04)
1970	0.001384	(1.384E-03)	0.000850	(8.497E-04)
1971	0.003077	(3.077E-03)	0.002728	(2.728E-03)
1972	0.004754	(4.754E-03)	0.004248	(4.248E-03)
1973	0.006963	(6.963E-03)	0.006487	(6.487E-03)
1974	0.010907	(1.091E-02)	0.011080	(1.108E-02)
1975	0.016870	(1.687E-02)	0.017799	(1.780E-02)
1976	0.026496		0.030010	
1977	0.043286		0.053189	
1978	0.064201		0.082364	
1979	0.085753		0.110996	
1980	0.107964		0.140175	
1981	0.138965		0.182174	
1982	0.178750		0.236917	
1983	0.227189		0.304182	
1984	0.284404		0.384263	
1985	0.350383		0.476835	
1986	0.424174		0.580385	
1987	0.506721		0.696216	
1988	0.598960		0.825633	
1989	0.702109		0.970345	
1990	0.817513		1.132277	
1991	0.946646		1.313468	
1992	1.090997		1.516002	
1993	1.252447		1.742529	
1994	1.433022		1.995891	
1995	1.635016		2.279419	
1996	1.860885		2.596789	
1997	2.113592		2.952353	
1998	2.396293		3.350663	
1999	2.712531		3.797655	
2000	3.066224		4.299213	

TABLE 11

SUMMARY OF CUMULATIVE PRODUCTION AND INVESTMENT FOR NUCLEAR SECTOR ONLY

YEAR	ELECTRICITY FROM NUCLEAR	ELECTRICITY FROM CONVENTIONAL	TOTAL ELECTRICITY PRODUCED	ELECTRICAL ENERGY INVESTMENT	THERMAL ENERGY INVESTMENT	NET ENERGY RATIO PERCENT
1	0.0	0.0	0.0	1.07200E+14	1.55400E+14	-68.98
2	0.0	0.0	0.0	2.14400E+14	3.10800E+14	-68.98
3	0.0	0.0	0.0	3.21600E+14	4.66200E+14	-68.98
4	0.0	0.0	0.0	5.89600E+14	9.28482E+14	-63.50
5	0.0	0.0	0.0	1.69236E+15	1.95651E+15	-86.50
6	0.0	0.0	0.0	2.44275E+15	2.84442E+15	-85.88
7	4.09968E+15	0.0	4.09968E+15	3.40839E+15	4.15437E+15	16.64
8	8.19935E+15	0.0	8.19935E+15	5.67993E+15	6.68577E+15	37.68
9	1.22990E+16	0.0	1.22990E+16	9.84619E+15	9.94390E+15	24.67
10	2.25482E+16	0.0	2.25482E+16	1.40514E+16	1.48879E+16	57.07
11	4.91961E+16	0.0	4.91961E+16	2.19131E+16	2.43201E+16	112.18
12	7.58440E+16	0.0	7.58440E+16	3.33641E+16	3.60633E+16	117.79
13	1.10691E+17	0.0	1.10691E+17	4.58209E+16	4.73419E+16	135.59
14	1.72186E+17	0.0	1.72186E+17	6.13892E+16	6.01629E+16	184.16
15	2.64429E+17	0.0	2.64429E+17	8.64408E+16	7.53003E+16	236.37
16	4.12018E+17	0.0	4.12018E+17	1.11914E+17	9.10677E+16	329.54
17	6.68247E+17	0.0	6.68247E+17	1.36361E+17	1.09657E+17	485.04
18	9.88022E+17	0.0	9.88022E+17	1.64383E+17	1.35144E+17	609.45
19	1.31805E+18	0.0	1.31805E+18	2.08085E+17	1.65778E+17	669.55
20	1.65832E+18	0.0	1.65832E+18	2.56569E+17	1.96832E+17	712.16
21	2.13183E+18	0.0	2.13183E+18	3.10092E+17	2.28998E+17	795.52
22	2.73858E+18	0.0	2.73858E+18	3.69415E+17	2.62864E+17	901.29
23	3.47652E+18	0.0	3.47652E+18	4.34704E+17	2.98643E+17	1018.55
24	4.34771E+18	0.0	4.34771E+18	5.05078E+17	3.37568E+17	1138.33
25	5.35213E+18	0.0	5.35213E+18	5.83780E+17	3.81048E+17	1251.38
26	6.47544E+18	0.0	6.47544E+18	6.71583E+17	4.29580E+17	1351.05
27	7.73199E+18	0.0	7.73199E+18	7.69834E+17	4.83881E+17	1438.81
28	9.13613E+18	0.0	9.13613E+18	8.79800E+17	5.44633E+17	1515.94
29	1.07063E+19	0.0	1.07063E+19	1.00285E+18	6.12538E+17	1584.14
30	1.24630E+19	0.0	1.24630E+19	1.14024E+18	6.88419E+17	1644.75
31	1.44288E+19	0.0	1.44288E+19	1.29413E+18	7.73512E+17	1698.06
32	1.66262E+19	0.0	1.66262E+19	1.46622E+18	8.68654E+17	1745.23
33	1.90840E+19	0.0	1.90840E+19	1.65869E+18	9.74378E+17	1787.25
34	2.18328E+19	0.0	2.18328E+19	1.87390E+18	1.09414E+18	1824.17
35	2.49076E+19	0.0	2.49076E+19	2.11335E+18	1.22491E+18	1860.88
36	2.83451E+19	0.0	2.83451E+19	2.37723E+18	1.36599E+18	1901.03
37	3.21906E+19	0.0	3.21906E+19	2.66708E+18	1.51633E+18	1947.04
38	3.64912E+19	0.0	3.64912E+19	2.98453E+18	1.67309E+18	2002.68
39	4.13001E+19	0.0	4.13001E+19	3.32352E+18	1.83394E+18	2070.76
40	4.66768E+19	0.0	4.66768E+19	3.68466E+18	1.99894E+18	2150.74

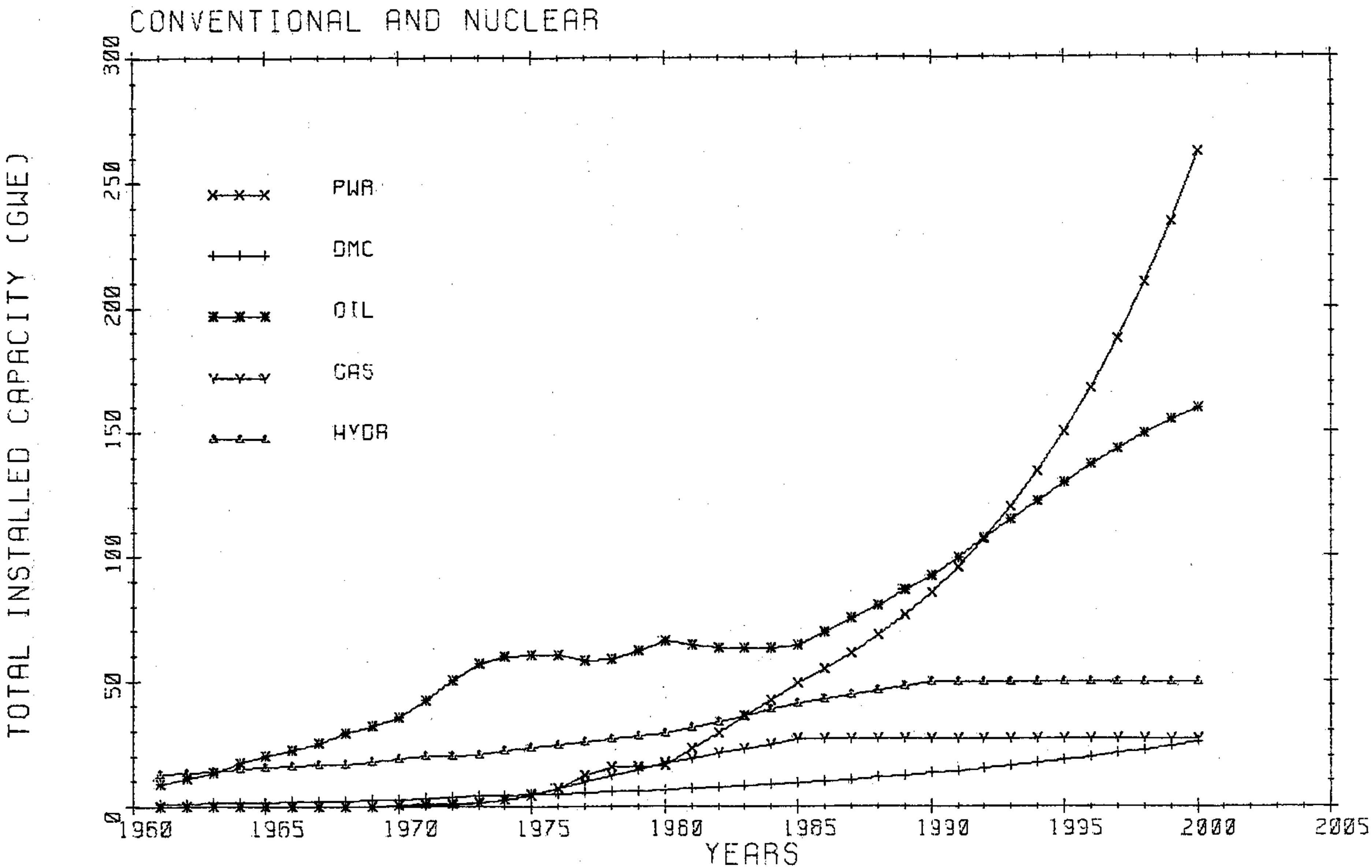

FIGURE 1 INSTALLED CAPACITIES FOR NUCLEAR AND CONVENTIONAL SYSTEM

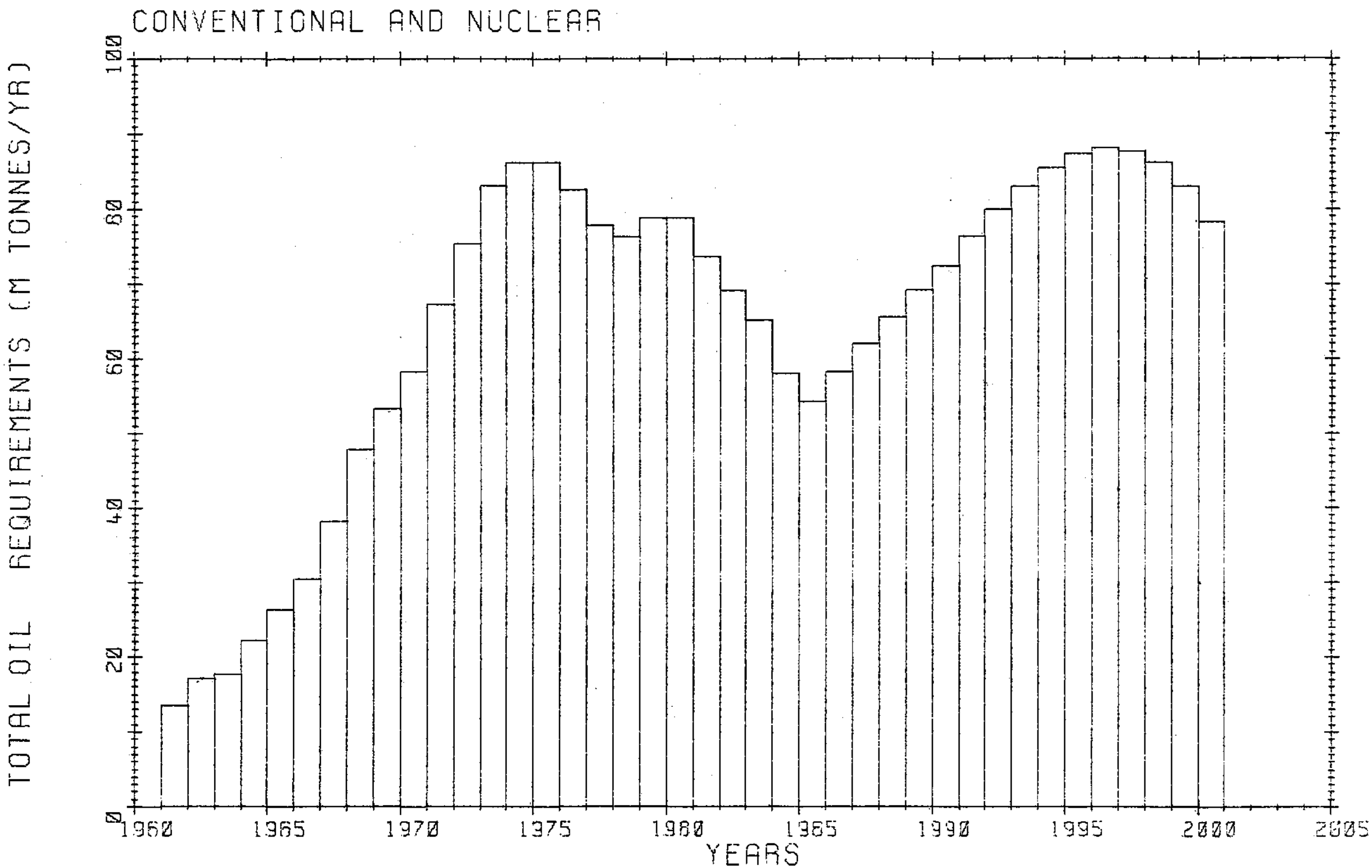

FIGURE 2 ANNUAL FUEL CONSUMPTION IN OIL-FIRED PLANTS FOR NUCLEAR AND CONVENTIONAL SYSTEM

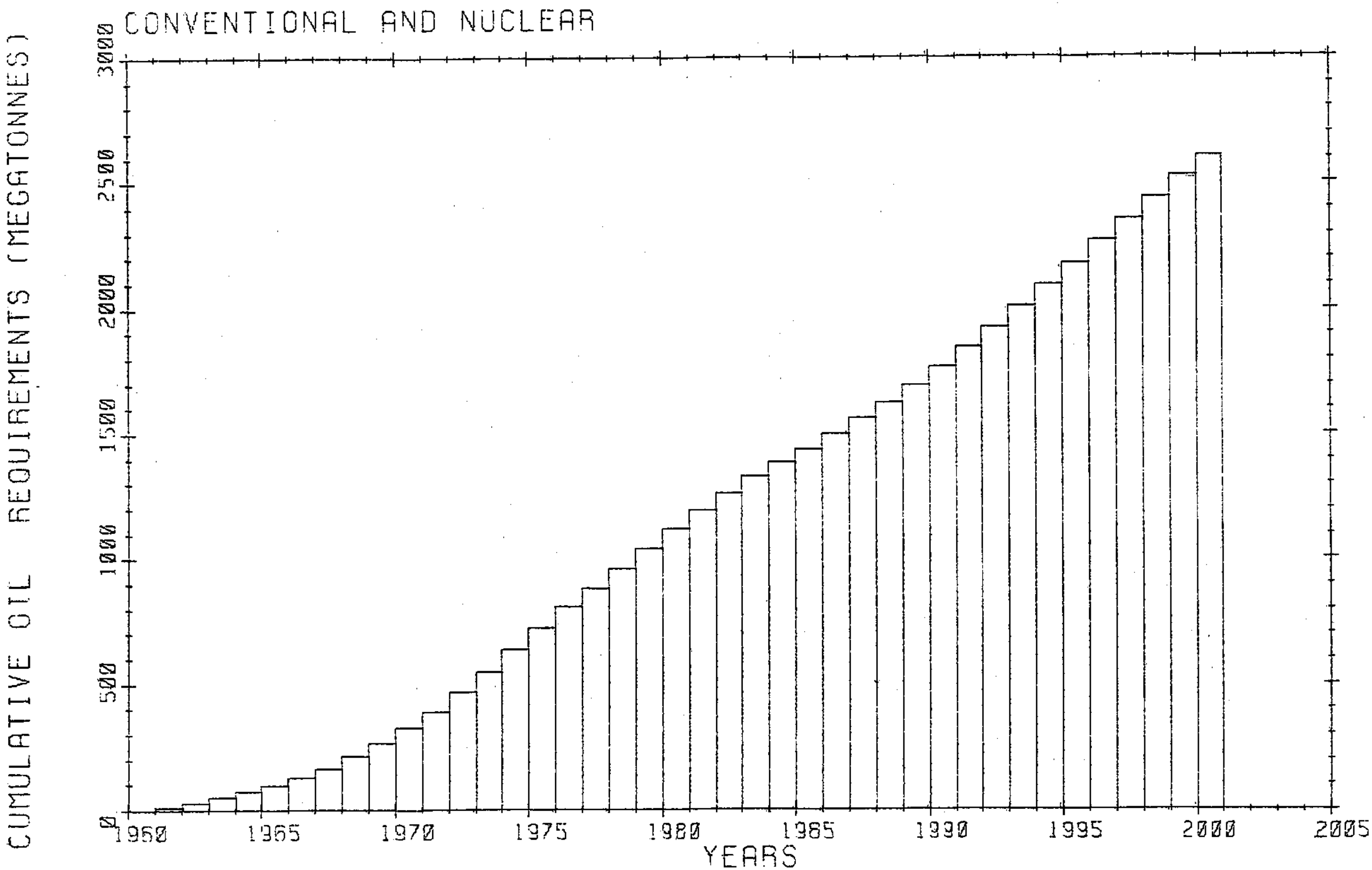

FIGURE 3 CUMULATIVE FUEL CONSUMPTION IN OIL-FIRED PLANTS FOR NUCLEAR AND CONVENTIONAL SYSTEM

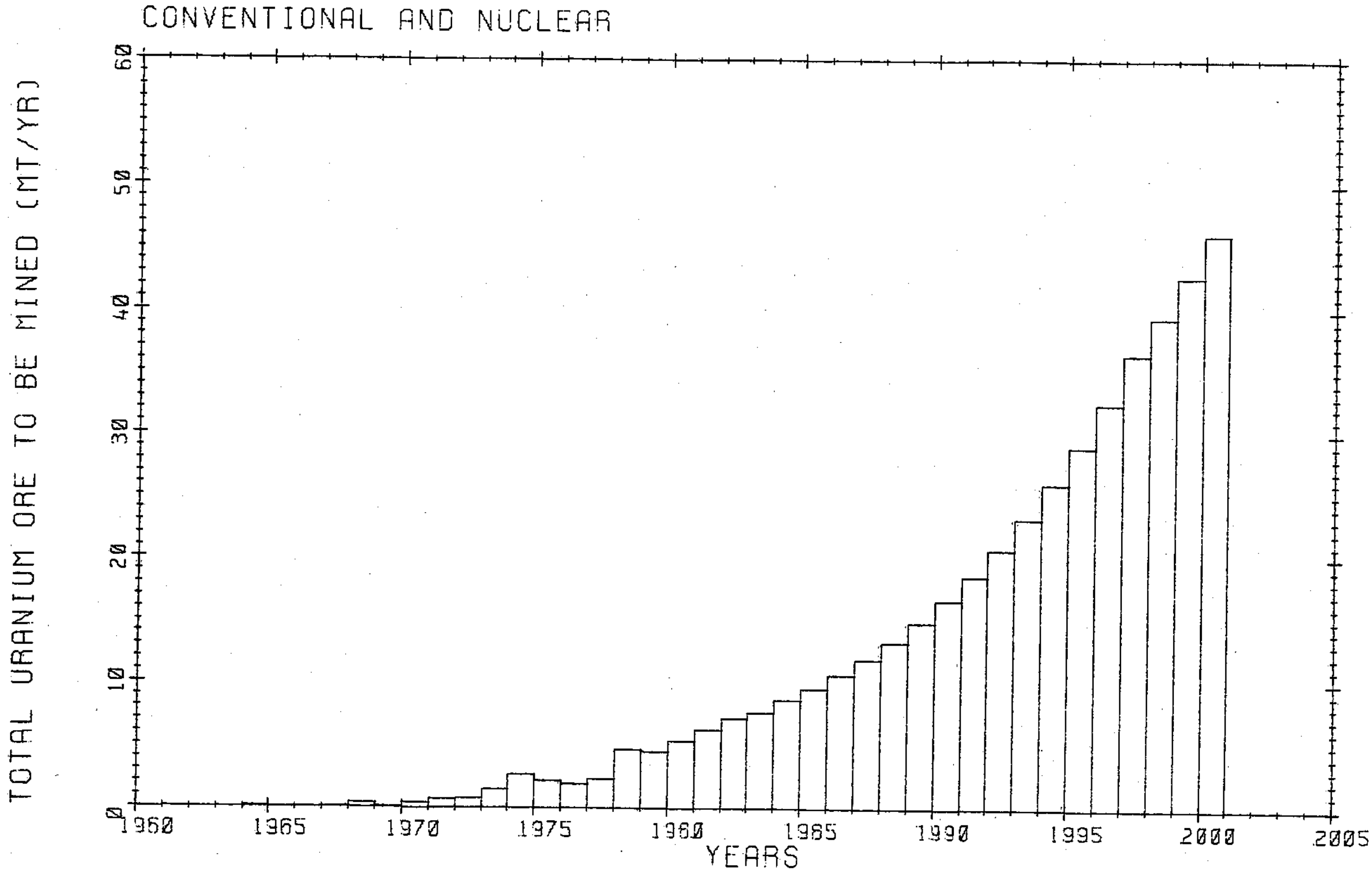

FIGURE 4 ANNUAL URANIUM REQUIREMENTS

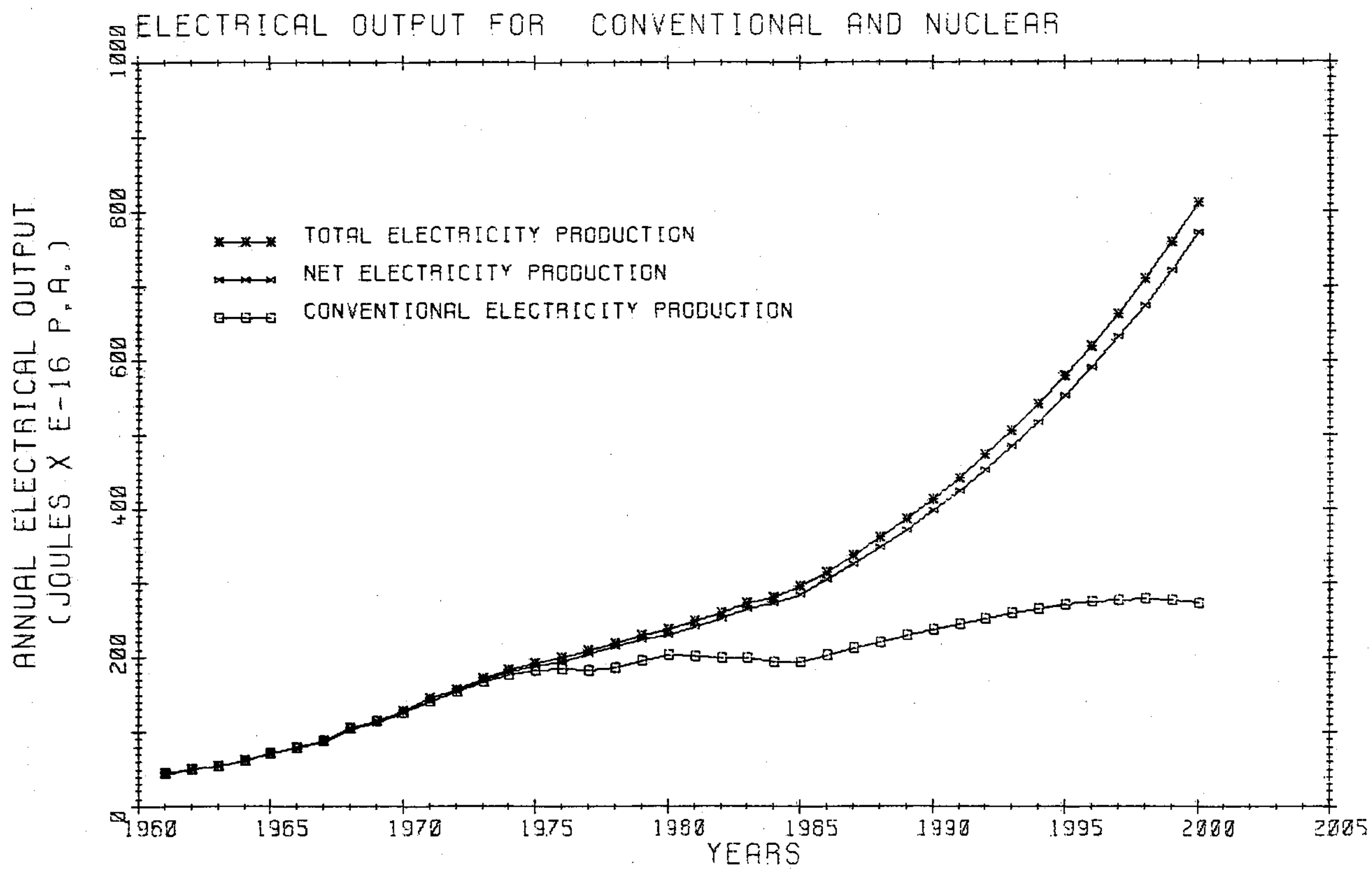

FIGURE 5 ELECTRICAL OUTPUT FOR CONVENTIONAL AND NUCLEAR SYSTEM

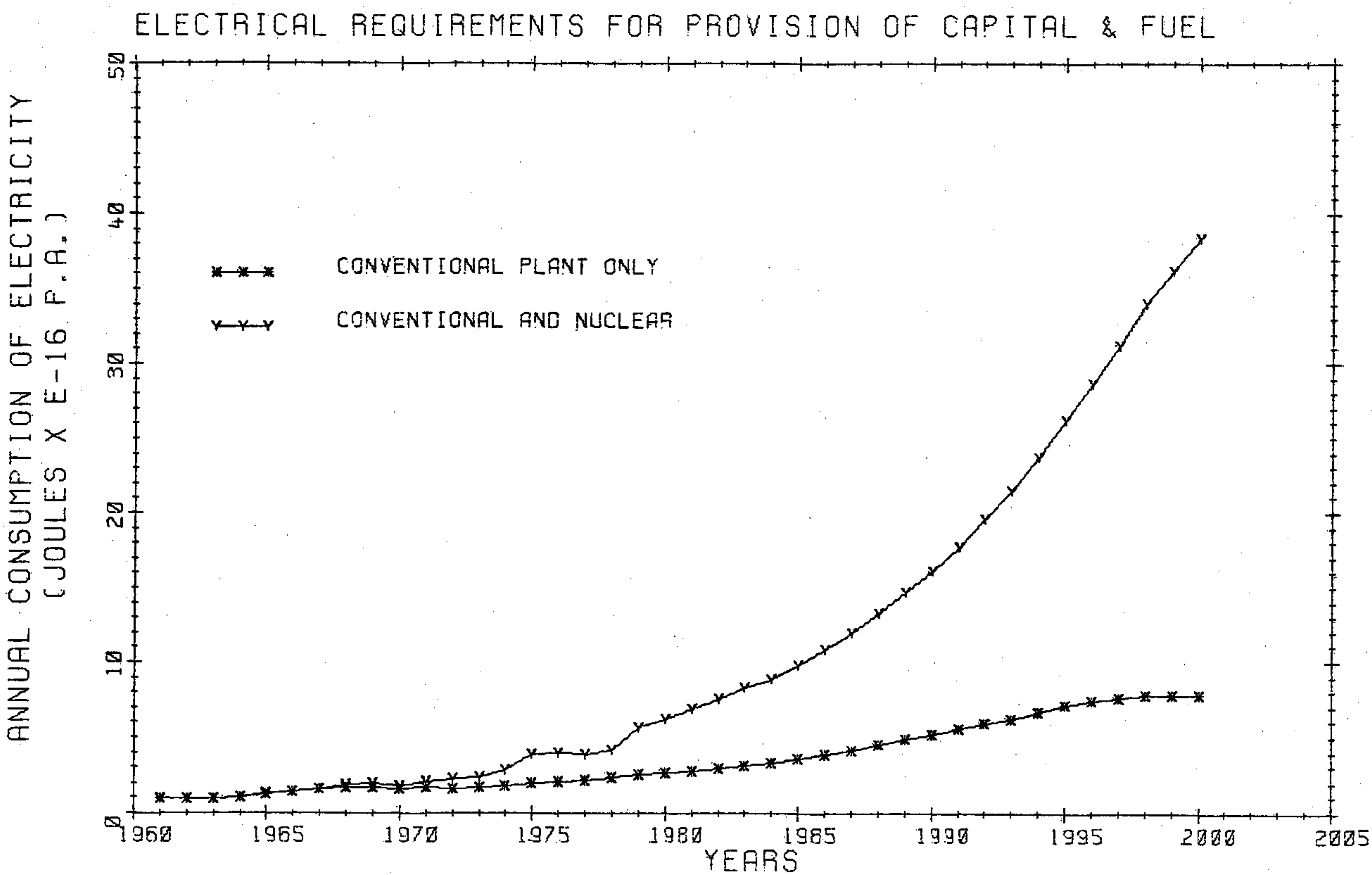

FIGURE 6 ELECTRICAL REQUIREMENTS FOR PROVISION OF CAPITAL AND FUEL

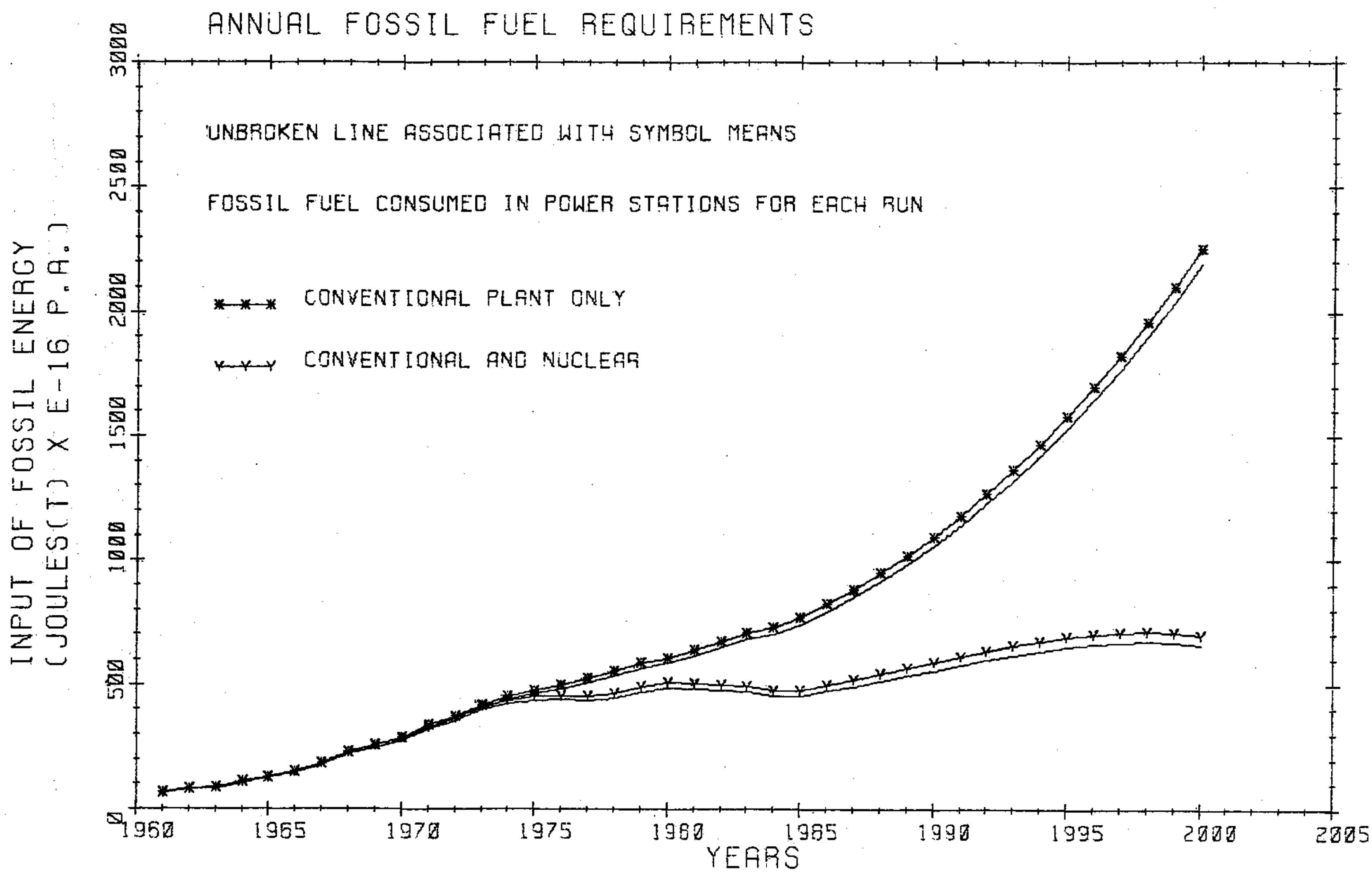

FIGURE 7 ANNUAL FOSSIL FUEL REQUIREMENTS

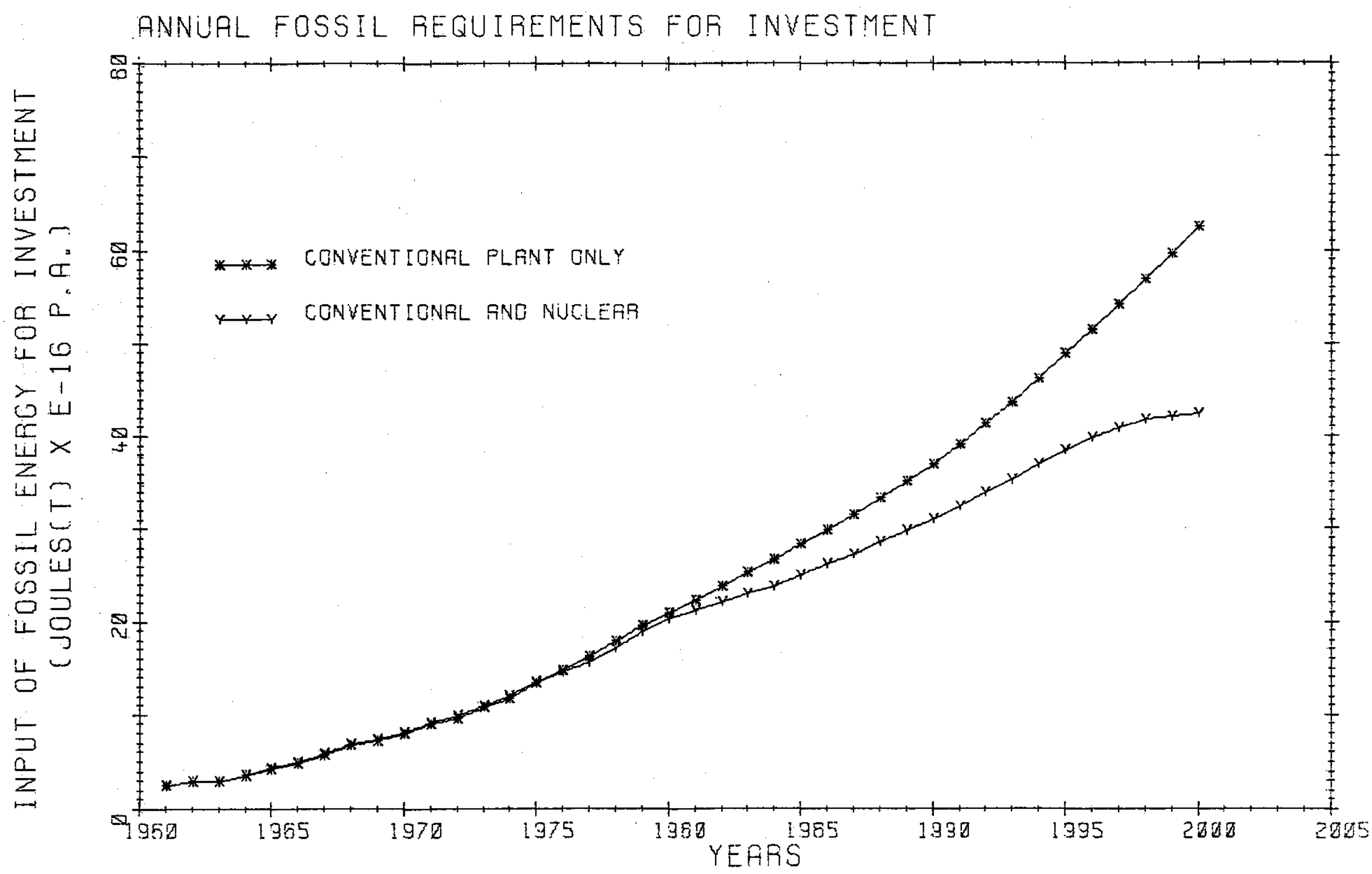

FIGURE 8 ANNUAL THERMAL REQUIREMENTS FOR INVESTMENT

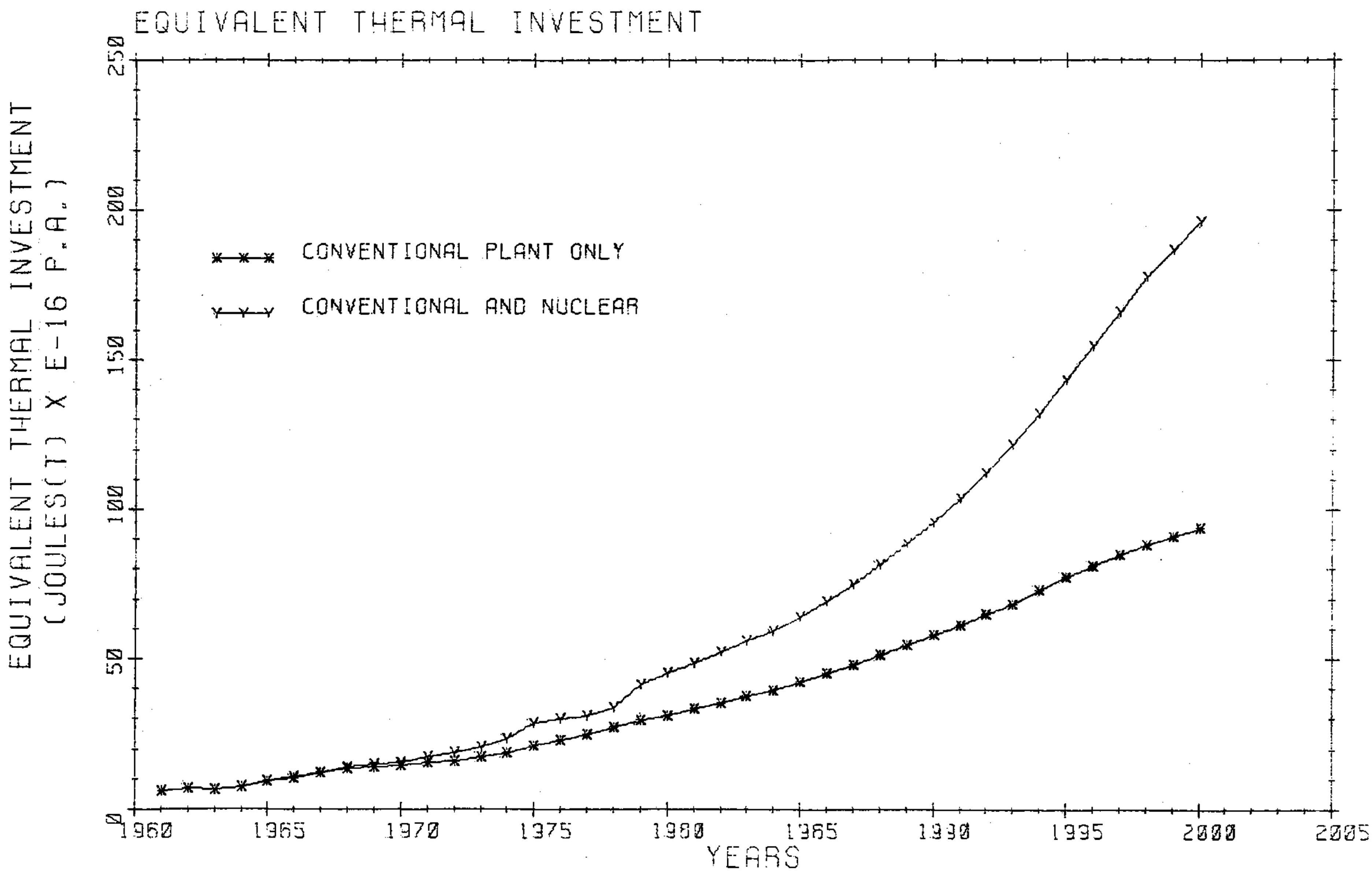

FIGURE 9 EQUIVALENT THERMAL INVESTMENT

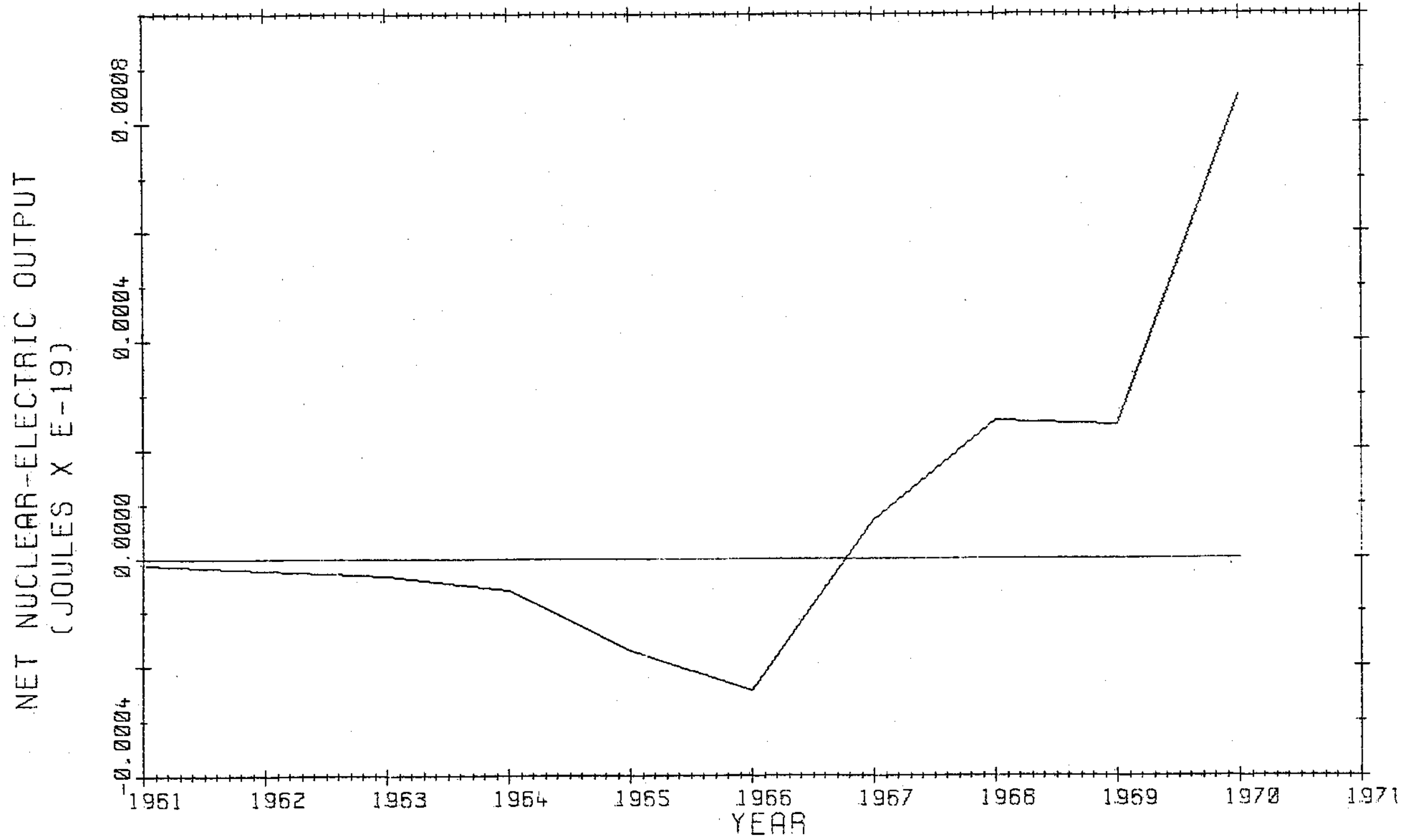

FIGURE 10 NET NUCLEAR ELECTRICAL OUTPUT (1961-1970)

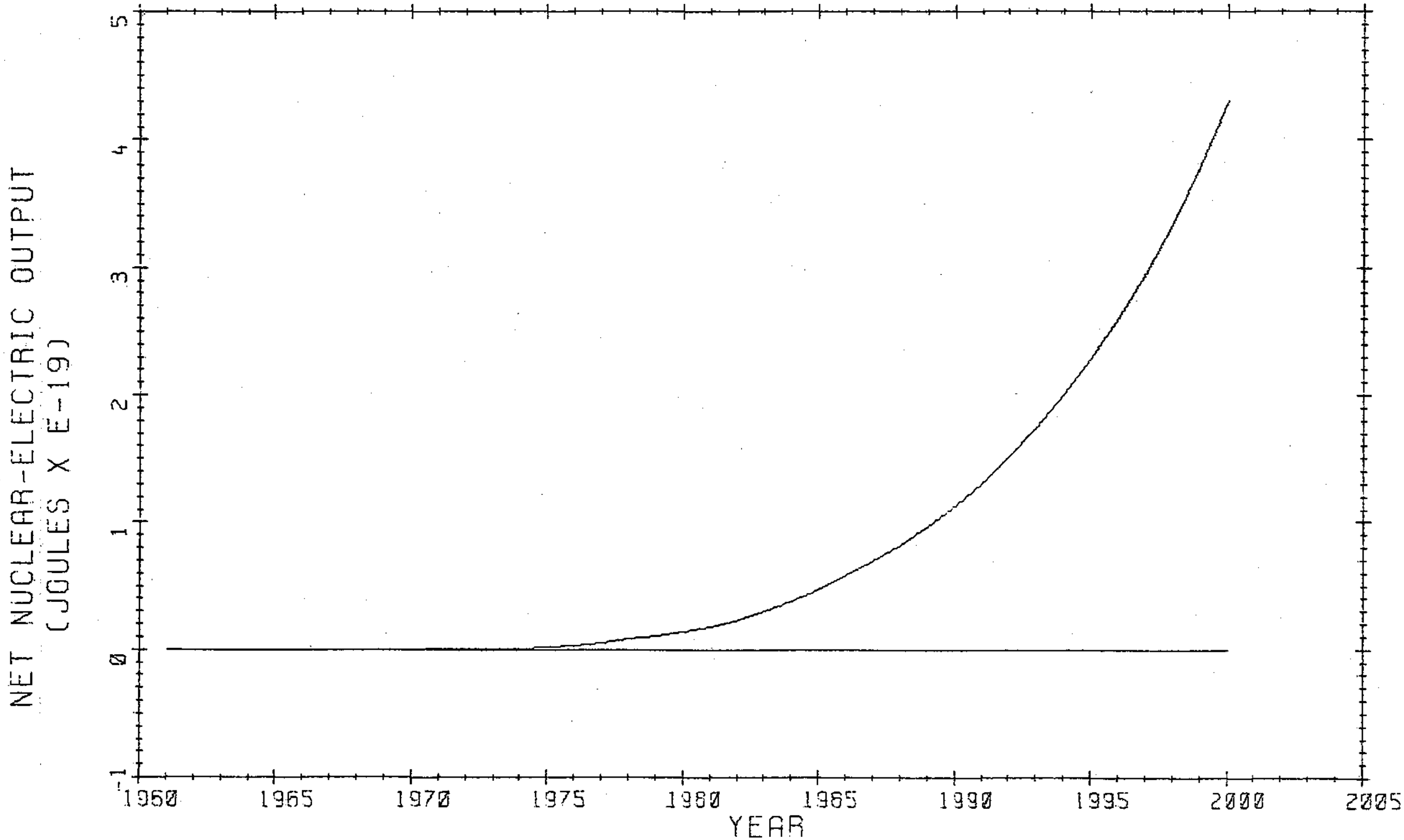

FIGURE 11 NET NUCLEAR ELECTRICAL OUTPUT (1961-2000)

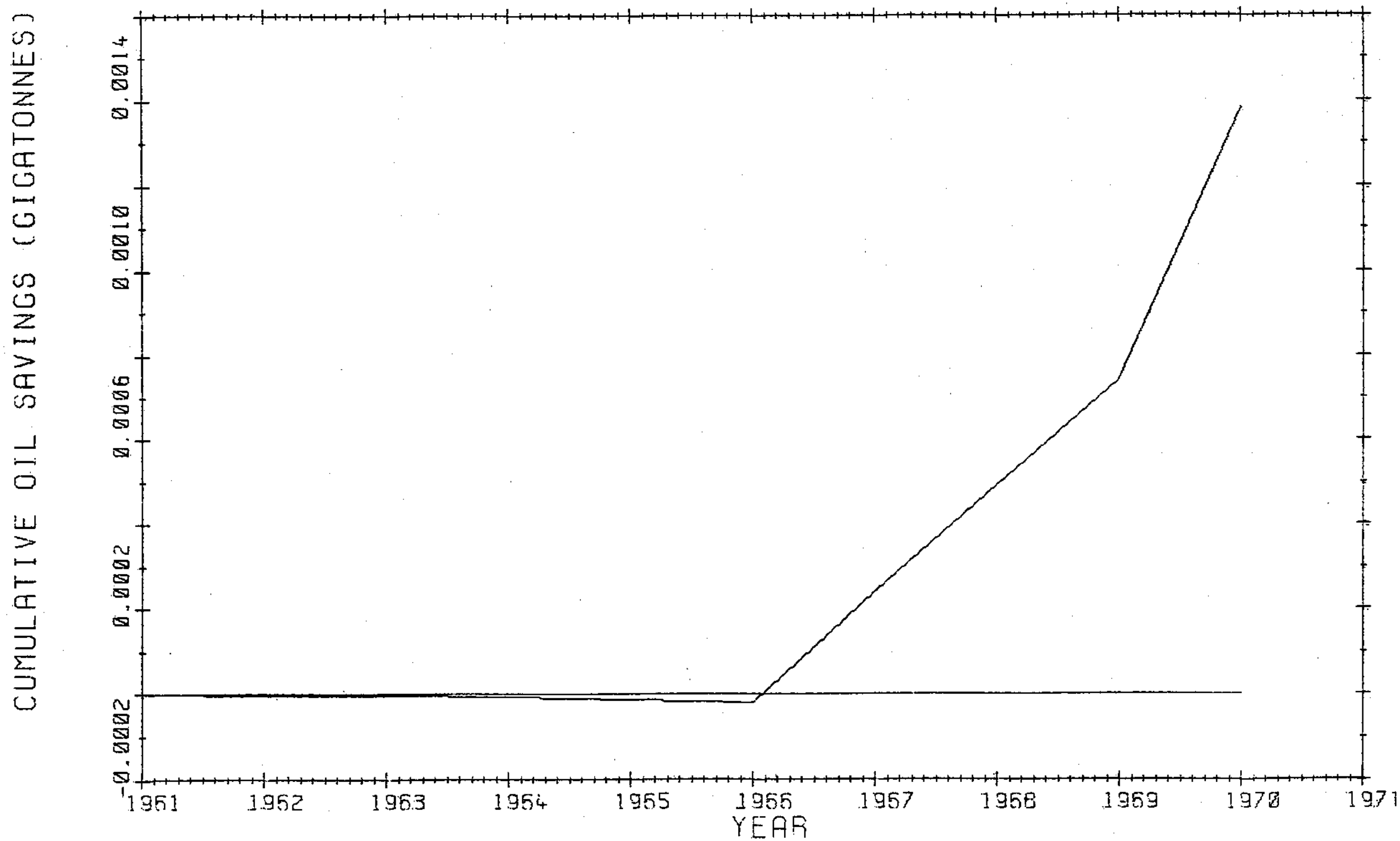

FIGURE 12 CUMULATIVE THERMAL SAVING AS OIL EQUIVALENT (1961-1970)

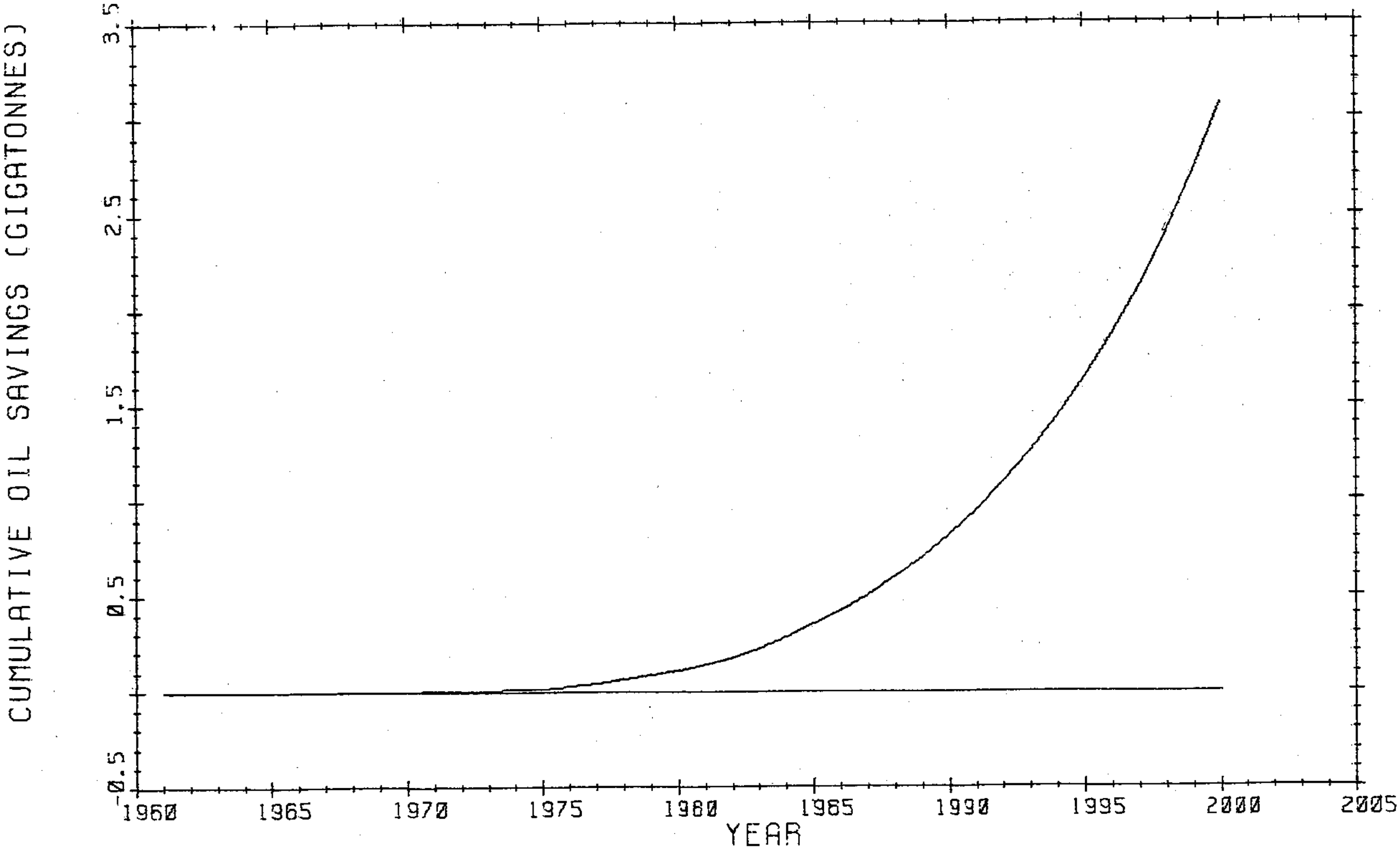

FIGURE 13 CUMULATIVE THERMAL SAVING AS OIL EQUIVALENT (1961-2000)

APPENDIX A

Databank For FURES

The station characteristics required for FURES are contained in a special databank. The user can obtain a listing of this information by use of an ancillary program, DATABANK. The listing also includes the keywords by which the station types are identified.

The following JCL cards are all that are required to run the DATABANK program

```
//JOBCARD   JOB......(normal user jobcard)
//      CLASS=A, TIME=1
//    EXEC  FORTHG, PRG=DATABANK, DSN='ENG.JIF.DATABANK'
```

A listing of output from the DATABANK program follows

EURES

A KEYWORD IS USED AS INPUT TO SPECIFY EACH PARTICULAR TYPE OF STATION REQUIRED FOR STUDY

FOLLOWING ARE THE STATION TYPES INCORPORATED IN EURES AT 17 MAR 76 AND THE INPUT KEYWORD APPLICABLE TO EACH:

STATION TYPE	KEYWORD
HEAVY WATER REACTOR	HWR
STEAM GENERATING HEAVY WATER REACTOR	SGHW
ADVANCED GAS COOLED REACTOR	AGR
PRESSURISED WATER REACTOR	PWR
PRESSURISED WATER REACTOR WITH PLUTONIUM RECYCLING	PWRP
BOILING WATER REACTOR	BWR
BOILING WATER REACTOR WITH PLUTONIUM RECYCLING	BWRP
FAST SODIUM OXIDE CONVERTER	FSOC
HIGH TEMPERATURE GAS COOLED REACTOR (LOW ENRICHMENT)	HTRL
HIGH TEMPERATURE GAS COOLED REACTOR (HIGH ENRICHMENT)	HTRH
LIQUID METAL (SODIUM OXIDE) FAST BREEDER	LMFB
CARBIDE FAST BREEDER	FBRC
MAGNOX REACTOR	MAGN
DEEP MINED COAL	DMC
SURFACE MINED COAL	SMC
OIL	OIL
GAS	GAS
HYDRO ELECTRIC	HYDR

EURES DATABANK

TYPE OF STATION	1 PLANT EFFICIENCY	2 BURNUP AT EQUILIBRIUM (MWD/T)	3 ENRICHMENT OF INITIAL CORE	4 ENRICHMENT OF FRESH RELOAD	5 ENRICHMENT OF BURNT RELOAD	6 ENRICHMENT OF BURNT FINAL CORE	7 HEAVY METAL RATIO	8 TAILS ENRICHMENT	9 NATURAL URANIUM ENRICHMENT
HWR	0.290	9600.	0.00710	0.00710	0.00160	0.00160	0.99030	0.00250	0.00710
SGHW	0.320	21000.	0.02130	0.02110	0.00630	0.00630	1.00000	0.00250	0.00710
AGR	0.420	18000.	0.01630	0.02230	0.00810	0.00810	0.97840	0.00250	0.00710
PWR	0.330	33000.	0.02630	0.03190	0.00840	0.00840	0.96540	0.00250	0.00710
PWRP	0.332	32000.	0.03250	0.03250	0.01400	0.01400	0.96540	0.00250	0.00710
BWR	0.340	27500.	0.02200	0.02560	0.00750	0.00750	0.97000	0.00250	0.00710
BWRP	0.340	27500.	0.02200	0.0	0.0	0.0	0.97000	0.00250	0.00710
FSOC	0.410	30270.	0.07390	0.07390	0.04750	0.04750	0.96730	0.00250	0.00710
HTRL	0.417	77000.	0.03950	0.06360	0.00880	0.00880	0.84100	0.00250	0.00710
HTRH	0.390	93500.	0.93150	0.93150	0.30000	0.30000	0.92450	0.00250	0.00710
LMFB	0.410	20898.	0.0	0.0	0.0	0.0	0.93790	0.00250	0.00710
FBRC	0.410	25530.	0.0	0.0	0.0	0.0	0.97240	0.00300	0.00711
MAGN	0.300	4000.	0.00710	0.00710	0.00400	0.00400	0.97840	0.00250	0.00710
CMC									
SMC									
OIL									
GAS									
HYDR									

TYPE OF STATION	10 FABRICATION LOSSES	11 TOTAL U FRACTION FOR INITIAL CORE	12 TOT U FRAC FOR FRESH RELOAD	13 TOT U FRAC FOR BURNT RELOAD	14 TOT U FRAC BURNT FINAL CORE	15 REPROCESSING LOSSES	16 PLUTONIUM INITIAL CORE	17 PLUTONIUM FRESH RELOAD	18 PLUTONIUM BURNT RELOAD (EQUILIBR'M)	19 PLUT FRAC IN BURNT INIT CORE
HWR	0.01000	1.00000	1.00000	0.99654	0.99554	0.02000	0.0	0.0	0.00346	0.00335
SGHW	0.01000	1.00000	1.00000	0.99513	0.99513	0.02000	0.0	0.0	0.00487	0.00487
AGR	0.01000	1.00000	1.00000	0.99609	0.99609	0.02000	0.0	0.0	0.00391	0.00391
PWR	0.01000	1.00000	1.00000	0.99152	0.99152	0.02000	0.0	0.0	0.00848	0.00807
PWRP	0.01000	0.98470	0.98470	0.98420	0.98420	0.02000	0.01030	0.01030	0.01070	0.01070
BWR	0.01000	1.00000	1.00000	0.99332	0.99332	0.02000	0.0	0.0	0.00668	0.00609
BWRP	0.01000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FSOC	0.01000	1.00000	1.00000	0.96850	0.96850	0.02000	0.0	0.0	0.03050	0.03050
HTRL	0.01000	1.00000	1.00000	0.98770	0.98770	0.02000	0.0	0.0	0.01230	0.00635
HTRH	0.01000	0.04400	0.06000	0.06000	0.06000	0.02000	0.0	0.0	0.0	0.0
LMFB	0.01000	0.96090	0.94130	0.93250	0.93250	0.02000	0.03910	0.05870	0.06750	0.06750
FBRC	0.01000	0.93740	0.93740	0.91900	0.91900	0.01000	0.04260	0.04260	0.05470	0.05470
MAGN	0.01000	1.00000	1.00000	0.99796	0.99796	0.02000	0.0	0.0	0.00204	0.00204
CMC										
SMC										
OIL										
GAS										
HYDR										

TYPE OF STATION	20 U233 INITIAL CORE	21 U233 FRESH RELOAD	22 U233 BURNT RELOAD	23 U233 BURNT FINAL CORE	24 THORIUM INITIAL CORE	25 THORIUM FRESH RELOAD	26 THORIUM BURNT RELOAD	27 THORIUM BURNT FINAL CORE	28 FUEL INVENTORY FOR INITIAL CORE
HWR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	156.70
SGHW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	158.60
AGR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	190.50
PWR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	74.00
PWRP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	88.60
BWR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	122.50
BWRP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	122.50
FSCC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	72.00
HTRL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.40
HTRH	0.0	0.02270	0.02510	0.02510	0.95600	0.91730	0.91490	0.91490	35.10
LMFB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	61.40
FBRC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	64.00
MAGN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	900.90
DMC									
SMC									
OIL									
GAS									
HYDR									

TYPE OF STATION	29 DUMMY	30 PLANT EFFICIENCY LOADZONE 1	31 PLANT EFFICIENCY LOADZONE 2	32 PLANT EFFICIENCY LOADZONE 3	33 PLANT EFFICIENCY LOADZONE 4	34 PLANT EFFICIENCY LOADZONE 5	35 PLANT EFFICIENCY LOADZONE 6	36 PLANT EFFICIENCY LOADZONE 7	37 PLANT EFFICIENCY LOADZONE 8	38 LIFETIME (YEARS)
HWR										30.
SGHW										30.
AGR										30.
PWR										30.
PWRP										30.
BWR										30.
BWRP										30.
FSCC										30.
HTRL										30.
HTRH										30.
LMFB										30.
FBRC										30.
MAGN										30.
DMC		0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	30.
SMC		0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	30.
OIL		0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	30.
GAS		0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	30.
HYDR										50.

TYPE OF STATION	39 BURNUP FOR INITIAL CORE (MWD/T)	40 NO. OF YEARS TO EQUILIBRIUM	41 CONSTRUCTION PERIOD (YEARS)	42 EL.ENERGY INV.IN FUEL MINING(J/T)	43 TH.ENGY INV FUEL MINING (J/T)	44 HEAT CONTENT (J/T)
HWR	8000.	4.	5.			
SGHW	21000.	5.	5.			
AGR	18000.	4.	5.			
PWR	24400.	3.	5.			
PWRP	24400.	3.	5.			
BWR	21000.	4.	5.			
BWRP	21000.	4.	5.			
FSCC	30270.	4.	5.			
HTRL	32500.	7.	5.			
HTRH	53000.	5.	5.			
LMFB	0.	0.	5.			
FBRC	0.	0.	5.			
MAGN	4000.	3.	5.			
DMC			5.	0.0	7.410E+08	2.707E+10
SMC			5.	0.0	6.100E+08	2.707E+10
OIL			5.	0.0	8.190E+08	4.400E+10
GAS			5.	0.0	2.834E+09	3.726E+10
HYDR			5.			

ELECTRICAL ENERGY INVESTMENT PER YEAR OF CONSTRUCTION OF PLANT (J/MW)

TYPE OF STATION	45 LAST YEAR	46 LAST BUT 1	47 LAST BUT 2	48 LAST BUT 3	49 LAST BUT 4	50 LAST BUT 5	51 LAST BUT 6	52 LAST BUT 7	53 LAST BUT 8	54 LAST BUT 9
HWR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SGHW	3.374E+11	3.374E+11	3.374E+11	3.374E+11	3.374E+11	0.0	0.0	0.0	0.0	0.0
AGR	2.508E+11	2.508E+11	2.508E+11	2.508E+11	2.508E+11	0.0	0.0	0.0	0.0	0.0
PWR	1.946E+11	1.946E+11	1.946E+11	1.946E+11	1.946E+11	0.0	0.0	0.0	0.0	0.0
PWRP	1.946E+11	1.946E+11	1.946E+11	1.946E+11	1.946E+11	0.0	0.0	0.0	0.0	0.0
BWR	1.946E+11	1.946E+11	1.946E+11	1.946E+11	1.946E+11	0.0	0.0	0.0	0.0	0.0
BWRP	1.946E+11	1.946E+11	1.946E+11	1.946E+11	1.946E+11	0.0	0.0	0.0	0.0	0.0
FSCC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTRL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HTRH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LMFB	9.216E+11	9.216E+11	9.216E+11	9.216E+11	9.216E+11	0.0	0.0	0.0	0.0	0.0
FBRC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MAGN	3.476E+11	3.476E+11	3.476E+11	3.476E+11	3.476E+11	0.0	0.0	0.0	0.0	0.0
DMC	1.428E+11	1.428E+11	1.428E+11	1.428E+11	1.428E+11	0.0	0.0	0.0	0.0	0.0
SMC	1.428E+11	1.428E+11	1.428E+11	1.428E+11	1.428E+11	0.0	0.0	0.0	0.0	0.0
OIL	1.428E+11	1.428E+11	1.428E+11	1.428E+11	1.428E+11	0.0	0.0	0.0	0.0	0.0
GAS	1.428E+11	1.428E+11	1.428E+11	1.428E+11	1.428E+11	0.0	0.0	0.0	0.0	0.0
HYDR	1.870E+11	1.870E+11	1.870E+11	1.870E+11	1.870E+11	0.0	0.0	0.0	0.0	0.0

APPENDIX B

FURES JCL AND INPUT DATA REQUIREMENTS

```
//JIFFURES JOB ('ER104430/P11ERSAA',J1),J.I.FAULKNER,
//  CLASS=J,MSGLEVEL=(2,0),
//         TIME=2
//  EXEC BUFFPROG,PRG=VPLOT
//FURES  EXEC  FORTHG,PRG=JIFFURES,DSN='ENG.JIF.FURESP',REGION.GO=360K
//GO.AEPLOT  DD  SYSOUT=C
//GO.SYSIN  DD  *
JAPANESE ENERGY ANALYSIS: 0.3% ORE                                            SAVE
CONVENTIONAL PLANT ONLY
4  40  1961  0
DMC  1  0  1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 200 200 200 200 200
1000.
1100 1300 1500 1700 1900 2100 2200 2500 2700 3000
3400 3800 4300 4600 4900 5300 5600 6000 6400 6800
7300 7800 8400 8900 9600 10200 10900 11700 12500 13400
14300 15300 16400 17500 18700 20000 21400 22900 24500 26200
0.65
OIL  2  0  1
250 250 250 250 250 250 250 250 250 250
250 250 250 250 250 250 2200 250 250 250
1800 1100 400 250 250 250 250 250 250 250
6700.
     6571.     8379.     8599.    10840.    12827.    14866.    18761.    23440.
    26117.    28766.    33661.    37544.    41539.    43911.    44839.    44785.
    45943.    47228.    48692.    48919.    50677.    52673.    54857.    55462.
    57843.    63440.    69485.    75874.    82824.    90215.    98650.   107701.
   117317.   127661.   138715.   150530.   163150.   176628.   191063.   206545.
     2229.     2821.     5001.     6660.     7773.     7734.     7039.     6360.
     6483.     7634.    10339.    14156.    17061.    18889.    20261.    22915.
    24857.    27172.    29808.    34181.    37123.    40527.    44343.    50538.
    55557.    60960.    66915.    73226.    80176.    87585.    96850.   106799.
   117383.   128739.   140885.   153870.   167750.   182572.   198437.   215455.
1.0  0.01
GAS  1  0  0
0.0
0 0 0 0 0 0 0 0 0 800
800 800 1600 2600 5100 7600 10100 12500 15000 17500
19400 21300 23100 25000 26900 26900 26900 26900 26900 26900
26900 26900 26900 26900 26900 26900 26900 26900 26900 26900
0.65
HYDR  2  0  1
300 300 300 300 300 300 300 300 300 300
300 300 300 300 300 300 300 300 300 300
300 300 300 300 300 300 300 300 300 300
300 300 300 300 300 300 300 300 300 300
300 300 300 300 300 300 300 300 300 300
12500.
6800 7100 7800 7800 8700 9000 7900 8400 8700 9000
9200 8900 8900 9400 9500 9600 9800 9800 9900 9900
10300 10600 10900 11100 11300 11700 12200 12600 13100 13500
13500 13500 13500 13500 13500 13500 13500 13500 13500 13500
6200 6400 6300 7300 6900 7300 8900 8800 9200 10300
10900 11300 11900 13100 14100 15100 16100 17200 18200 19300
21300 23400 25600 27800 30000 31300 32400 33700 34800 36100
36100 36100 36100 36100 36100 36100 36100 36100 36100 36100
1.0  0.01
CONVENTIONAL AND NUCLEAR
5  40  1961  4   1   2   3   15
PWR  1  0  0
```

```
0.
0        0        0        0        0        0        200      200
200      500      1300     1300     1700     3000     4500     7200
12500    15600    16100    16600    23100    29600    36000    42500
49000    54800    61300    68500    76600    85700    95900    107200
119900   134100   150000   167700   187600   209800   234600   262300
0.65
DMC  1  0  1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 200 200 200 200 200
1000.
1100 1300 1500 1700 1900 2100 2200 2500 2700 3000
3400 3800 4300 4600 4900 5300 5600 6000 6400 6800
7300 7800 8400 8900 9600 10200 10900 11700 12500 13400
14300 15300 16400 17500 18700 20000 21400 22900 24500 26200
0.65
OIL  2  0  1
250 250 250 250 250 250 250 250 250 250
250 250 250 250 250 250 2200 250 250 250
1800 1100 400 250 250 250 250 250 250 250
6700.
     6571.     8379.     8599.    10840.    12827.    14866.    18631.    23311.
    25988.    28442.    32821.    36703.    40439.    41972.    41930.    40130.
    37862.    37143.    38284.    38188.    35743.    33537.    31584.    27987.
    26167.    28014.    29856.    31591.    33304.    34812.    36655.    38400.
    39807.    40969.    41746.    42117.    41875.    41002.    39402.    36978.
     2229.     2821.     5001.     6660.     7773.     7734.     6969.     6289.
     6412.     7458.     9879.    13697.    16461.    17828.    18670.    20370.
    20438.    21657.    24116.    28312.    28957.    30063.    31616.    35513.
    38233.    41586.    45244.    49009.    53096.    57288.    62945.    68900.
    74993.    81331.    87854.    94583.   101425.   108398.   115498.   122722.
1.0  0.01
GAS  1  0  0
0.0
0 0 0 0 0 0 0 0 0 800
800 800 1600 2600 5100 7600 10100 12500 15000 17500
19400 21300 23100 25000 26900 26900 26900 26900 26900 26900
26900 26900 26900 26900 26900 26900 26900 26900 26900 26900
0.65
HYDR  2  0  1
300 300 300 300 300 300 300 300 300 300
300 300 300 300 300 300 300 300 300 300
300 300 300 300 300 300 300 300 300 300
300 300 300 300 300 300 300 300 300 300
300 300 300 300 300 300 300 300 300 300
12500.
6800 7100 7800 7800 8700 9000 7900 8400 8700 9000
9200 8900 8900 9400 9500 9600 9800 9800 9900 9900
10300 10600 10900 11100 11300 11700 12200 12600 13100 13500
13500 13500 13500 13500 13500 13500 13500 13500 13500 13500
6200 6400 6300 7300 6900 7300 8900 8800 9200 10300
10900 11300 11900 13100 14100 15100 16100 17200 18200 19300
21300 23400 25600 27800 30000 31300 32400 33700 34800 36100
36100 36100 36100 36100 36100 36100 36100 36100 36100 36100
1.0  0.01
/*
//
//
//
//
//
```

```
//JIFFURES JOB ('ER1Ø443Ø/P12ERSAA',J1),J.I.FAULKNER,
//  CLASS=J,TIME=2
//  EXEC BUFFPROG,PRG=VPLOT
//A  EXEC  FORTHG,PRG=FURES,DSN='ENG.JIF.FURESP',REGION.GO=35ØK
//GO.AEPLOT  DD  SYSOUT=C
//GO.SYSIN  DD  *
JAPAN NUCLEAR STUDY
NUCLEAR (PWR) ONLY
1  4Ø  1961  -1
PWR  1  Ø  Ø
Ø.
Ø         Ø         Ø         Ø         Ø         Ø         2ØØ       2ØØ
2ØØ       5ØØ       13ØØ      13ØØ      17ØØ      3ØØØ      45ØØ      72ØØ
125ØØ     156ØØ     161ØØ     166ØØ     231ØØ     296ØØ     36ØØØ     425ØØ
49ØØØ     548ØØ     613ØØ     685ØØ     766ØØ     857ØØ     959ØØ     1Ø72ØØ
1199ØØ    1341ØØ    15ØØØØ    1677ØØ    1876ØØ    2Ø98ØØ    2346ØØ    2623ØØ
Ø.65
/*
```

APPENDIX C

NOTATION

Symbol	Dimension	Introduced in Section	Description
ACF		3	Average capacity factor
BURNUP	$MWd(th)\ t^{-1}$	5.1	Average end burnup
C	MWe	3	Installed capacity
CECONV	$J\ t^{-1}$	6	Electrical energy requirement for conversion
CEENR	$J\ t^{-1}\ swu^{-1}$	6	Electrical energy requirement for enrichment
CEFAB	$J\ t^{-1}$	6	Electrical energy requirement for fabrication
CEFOS	$J\ y^{-1}$	7	Electrical energy requirement for provision of fossil fuel
CEORE	$J\ t^{-1}$	6	Electrical energy requirement for uranium mining and milling
CEREP	$J\ t^{-1}$	6	Electrical energy requirement for reprocessing
CTCONV	$J\ t^{-1}$	6	Thermal energy requirement for conversion
CTENR	$J\ t^{-1} swu^{-1}$	6	Thermal energy requirement for enrichment
CTFAB	$J\ t^{-1}$	6	Thermal energy requirement for fabrication
CTFOS	$J\ y^{-1}$	7	Thermal energy requirement for provision of fossil fuel
CTORE	$J\ t^{-1}$	6	Thermal energy requirement for mining and milling uranium
CTREP	$J\ t^{-1}$	6	Thermal energy requirement for reprocessing
D	MWe	3	New capacity installed prior to start of study
DORE	$t\ y^{-1}$	5.1	Annual requirement from depleted uranium stockpile
e		5	Uranium enrichment
EA	$J\ y^{-1}$	9	Net electricity available to system after allowing for investment
ECONV	$J\ y^{-1}$	6	Annual electrical requirement for conversion
EENR	$J\ y^{-1}$	6	Annual electrical requirement for enrichment

Symbol	Dimension	Introduced in Section	Description
EFAB	$J\ y^{-1}$	6	Annual electrical requirement for fabrication
EFOS	$J\ y^{-1}$	7	Annual electrical energy requirement to provide fossil fuel - i.e., mining, processing, transport, etc.
ENR	$t\ swu\ y^{-1}$	5.5	Annual enrichment work requirement for each station type
EORE	$J\ y^{-1}$	6	Annual electrical energy requirement for mining and milling uranium
EP	$J\ y^{-1}$	9	Total electricity generated per year
EREP	$J\ y^{-1}$	6	Annual energy requirement for reprocessing
F		5.1	Fabrication losses
FASB	$t\ y^{-1}$	5.6	Annual fabrication requirement for each station type
FBURN	$J\ y^{-1}$	7	Thermal content of fuel burnt in fossil stations
FOS	$t\ y^{-1}$ (oil,coal) $10^3 m^3 y^{-1}$ (gas)	7	Annual fossil fuel requirement for each station type
h	$J\ t^{-1}$ (oil,coal) $J\ 10^{-3} m^{-3}$ (gas)	7	Heat content of fuel
H		3	Capacity factor
i		3	Year index
I	$t\ MWe^{-1}$	5.1	Fuel inventory for nuclear stations
ICONST		3	Station construction time plus one year
j		3	Plant index
k		3	Load zone index
L	years	3	Station lifetime
NN		5.8	Number of nuclear reactor types in the system
NS		3	Total number of stations in the system
NY		3	Total number of years
NYC	years	4	Construction period for each plant type

Symbol	Dimension	Introduced in Section	Description
NYE		5.2	Number of years to equilibrium for nuclear stations
NZ		3	Number of load zones
ORE	$t\ y^{-1}$	5.1	Annual uranium ore requirement for each station type
OREBR	$t\ MWe^{-1}y^{-1}$	5.1	Unused uranium in irradiated reload fuel
OREFC	$t\ MWe^{-1}$	5.1	Unused uranium in irradiated final core
OREFR	$t\ MWe^{-1}y^{-1}$	5.1	Uranium requirement, fresh reload fuel
OREIC	$t\ MWe^{-1}$	5.1	Uranium requirement, initial core
PLUT	$t\ y^{-1}$	5.2	Annual plutonium requirement for each station type
Pu		5	Fissile plutonium fraction
R		5.1	Heavy metals ratio $(\frac{\text{end}}{\text{start}})$
REP	$t\ y^{-1}$	5.7	Annual reprocessing requirement for each station type
TCONV	$J\ y^{-1}$	6	Annual thermal energy requirement for conversion
TENR	$J\ y^{-1}$	6	Annual thermal energy requirement for enrichment
TFAB	$J\ y^{-1}$	6	Annual thermal energy requirement for fabrication
TFOS	$J\ y^{-1}$	7	Annual thermal energy requirement to provide fossil fuel - i.e., mining, processing, transport, etc.
Th		4	Thorium fraction
THERT	$J\ y^{-1}$	8	Total thermal requirement including fuel burnt in fossil stations
THOR	$t\ y^{-1}$	5.4	Annual thorium requirement for each station type
TORE	$J\ y^{-1}$	6	Annual thermal energy requirement for uranium
TOTDORE	$t\ y^{-1}$	5.8	Total annual requirement from depleted uranium stockpile for entire system
TOTEL	$J\ y^{-1}$	8	Total electrical energy investment for provision of capital and fuel

Symbol	Dimension	Introduced in Section	Description
TOTENR	t swu y^{-1}	5.8	Total annual enrichment work requirement for entire system
TOTFAB	$t\ y^{-1}$	5.8	Total annual fabrication requirement for entire system
TOTORE	$t\ y^{-1}$	5.8	Total annual uranium requirement for entire system
TOTPLUT	$t\ y^{-1}$	5.8	Total annual fissile plutonium requirement for entire system
TOTREP	$t\ y^{-1}$	5.8	Total annual reprocessing requirement for entire system
TOTTH	$J\ y^{-1}$	8	Total thermal energy investment for provision of capital and fuel
TOTTHOR	$t\ y^{-1}$	5.8	Total annual thorium requirement for entire system
TOT233U	$t\ y^{-1}$	5.8	Total annual ^{233}U requirement for entire system
TP		5.1	Annual fuel throughput at full-load
TREP	$J\ y^{-1}$	6	Annual thermal energy requirement for reprocessing
U		5	Total uranium fraction (^{235}U + ^{238}U)
$\bar{U}$		5	^{233}U fraction
233U	$t\ y^{-1}$	5	Annual ^{233}U requirement for each station type
V		5.1	Reprocessing losses
VESTE	J	4	Electrical energy investment
VESTET	J	4	Total electrical energy investment to provide plant
VESTT	J	4	Thermal energy investment
VESTT	J	4	Total thermal energy investment to provide plant
β		9	Transmission and distribution losses for the system
αe		4	Unit electrical energy requirement for the plant construction
αt		4	Unit thermal energy requirement for plant construction
η		5.1	Thermal efficiency
σ_j		9	Internal station usage in type j
$\Delta C_{i,j}$	MWe	3	Capacities of type j installed at start of period i

Symbol	Dimension	Introduced in Section	Description
$\Delta' C_{i,j}$	*MWe*	3	Capacities of type j retired at start of period i
superscript a		5	Used with different values of 'X' - assumes values i for fresh initial core, f for irradiated final core, if missing indicates reload fuel
subscript b		5	Used with different values of 'X' - assumes values o for fresh fuel, r for irradiated fuel, n for natural uranium enrichment, t for tails enrichment