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A Program on Long-Term Investigation of Cost-Optimum Nuclear Power Systems

Input Description (Status April 1971)

by

Alfred Voss

Translated by Anneliese Wienands

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ABSTRACT.

For the purpose of a long-term planning in energy politics one needs some information support in order to reach an optimum extension of the energy supply grid. Arising problems might to-date be solved sufficiently precise by means of mathematical optimization processes. The program discussed here is appropriated to deliver such a support - a suitable employment provided. It was developed by HARDE and MEMMERT [1], and extended and modified by WAGEMANN [2].

It was determined the cost-optimum capacity distribution of up to 10 different power plants in a national grid under consideration of the classified curve of annual load curve and of various restrictions, e.g. limitation of capacity increase of fast plutonium breeders by limited availability of plutonium. The optimization is carried out for each period of time. Here, nuclear power plants were exclusively selected according to economic view points. The description of this calculational model corresponds in essential to that of Ref. [2], and is made in the following chapter. Henceforth is given a description on the accomplishment of special calculations, in the end a detailed description of all necessary input data. Also, an illustration is given for input and output.

CONTENT

1. ABSTRACT.

For the purpose of a long-term planning in energy politics one needs some information support in order to reach an optimum extension of the energy supply grid. Arising problems might to-date be solved sufficiently precise by means of mathematical optimization processes. The program discussed here is appropriated to deliver such a support - a suitable employment provided. It was developed by HARDE and MEMMERT [1], and extended and modified by WAGEMANN [2].

It was determined the cost-optimum capacity distribution of up to 10 different power plants in a national grid under consideration of the classified curve of annual load curve and of various restrictions, e.g. limitation of capacity increase of fast plutonium breeders by limited availability of plutonium. The optimization is carried out for each period of time. Here, nuclear power plants were exclusively selected according to economic view points. The description of this calculational model corresponds in essential to that of Ref. [2], and is made in the following chapter. Henceforth is given a description on the accomplishment of special calculations, in the end a detailed description of all necessary input data. Also, an illustration is given for input and output.

2. DESCRIPTION OF THE PROGRAM.

2.1 CALCULATION OF FIXED AND VARIABLE COST.

Fix and variable cost are calculated according to the method of cash value as follows:

2.1.1 For Power Plants of Fossile Fuel.

$$k_f = K_B \cdot \alpha + K_{Betr.} \qquad [DM/KWe \cdot a] \qquad (1)$$

$$k_v = \frac{860}{\eta} \, Hf \, [1 + b_v \, (p_z + p_s)] \qquad [DM/KWh] \qquad (2)$$

with being

K_B [DM/KWe] the total value of direct and indirect capital cost actualized to that time when the power plant was taken into operation;

K_{Betr} [DM/KWe] the total annual cost for operation and maintenance;

H_f [DM/Kcal] average cost of heat value for fossil fuel;

η capital efficiency rate;

b_v fuel reserves referred to annual through-put;

p_z [1/a] annual rate of interest;

p_s [1/a] annual rate of tax;

p_v [1/a] annual rate of insurance.

The annuity factor for a depreciation-time of t_{AB} years is calculated under consideration of the ratio of tax and insurance as follows:

$$\alpha = \frac{p_z + p_s}{1 - (1 + p_z + p_s)^{-t_{AB}}} + p_v \qquad [1/a] \qquad (3)$$

2.1.2 Nuclear Power Plants.

At first is determined for each reactor field j (core, blanket, etc.) the net-value K_A and K_E of fresh and depleted fuel elements:

$$K_{A,j} = \sum_k X_{A,j}^k \cdot p^k \cdot \alpha_{FAB,j} + K_{FAB,j} \quad [DM/kg] \tag{4}$$

$$K_{E,j} = \sum_k X_{E,j}^k \cdot p^k \cdot \alpha_{AUF,j} \cdot \gamma_j - K_{AUF,j} \quad [DM/kg] \tag{5}$$

with being

$X_{A,j}^k$ $X_{E,j}^k$	ratio of material k of the fuel in the origin or in the end of employment in field j, respectively;
p^k	[DM/kg] value of material k (with enriched uranium dependent from enrichment rate $\bar{\varepsilon}$);
α_{FAB}	factor of high demand in fuel element fabrication for consideration of fabrication losses;
α_{AUF}	loss factor during reprocessing;
K_{FAB}	[DM/kg] total fabrication cost of fuel elements;
K_{AUF}	[DM/kg] total processing cost, inclusively transportation cost;
γ	mass proportion of heavy metal (end : beginning).

Summarizing is made on the following materials: enriched uranium, depleted uranium, thorium, fissile plutonium, and ^{233}uranium. For consideration of cost of interest and tax, and for actualization of cost for fuel reserves during reactor life-time L, the following factors are employed:

$$f_A = \frac{p_z + p_s}{2} + \frac{p_z (1+p_z)^L}{(1+p_z)^L - 1} (\alpha_{Res} - 1) \tag{6}$$

$$f_E = \frac{p_z + p_s}{2} - \frac{p_z}{(1+p_z)^L - 1} (\alpha_{Res} - 1) \tag{7}$$

Hereby result the fix cost as follows:

$$k_f = K_B \alpha + K_{Betr.} + \sum_j \frac{aj(K_{A,j}\ f_A + K_{E,j}\ f_E)}{\eta \cdot R_j} [DM/kW_e \cdot a] \quad (8)$$

with being

α_{RES} factor for fuel element reserves;

a_j ratio of field j to total capacity;

R_j [KW(th)/kg] specific capacity in heavy metal of field j.

Variable cost are calculated as follows:

$$K_V = \sum_j \frac{a_j\ \{K_{A,j}\ [1+p_z(\frac{1}{2}+t_{FAB}) + p_s\ t_{FAB}] - K_{E,j}\ [1+p_z(\frac{1}{2}-t_{AUF}) - p_s\ t_{AUF}]\}}{24 \cdot \eta \cdot A_j} \quad [DM/KWh] \quad (9)$$

with being

t_{FAB}[a] total fabrication time of fuel elements;

t_{AUF}[a] total processing time of fuel elements;

A_j[KWd(th)/kg] burn-up in field j referred to employed heavy metal.

2.2 MINIMIZATION OF COST FOR ELECTRICITY GENERATION.

The optimization, i.e. minimization of annual cost for electricity generation is carried out under consideration of some accessory factors and of the ordered annual load curve of power consumption. For a connected grid the total capacity C_{Verb} of which distributes itself to n different types of power plants (index $_i$) of capacity C_i result the following annual grid cost:

$$K_{Verb} = \frac{1}{C_{Verb}} \sum_{i=1}^{n} (k_{fi} + k_{vi}\ T_i)\ C_i \left[\frac{DM}{KW_e \cdot a}\right] \quad (10)$$

with T_i being the average annual operating time of power plant i.

The connection between operating time T_i and capacity C_i is given by the annual load curve of power consumption in the connected grid (see Fig. 1). It shows the time [h/a] during which a relative grid capacity between X_{i-1} and X_i must be available with reference to bottleneck capacity.

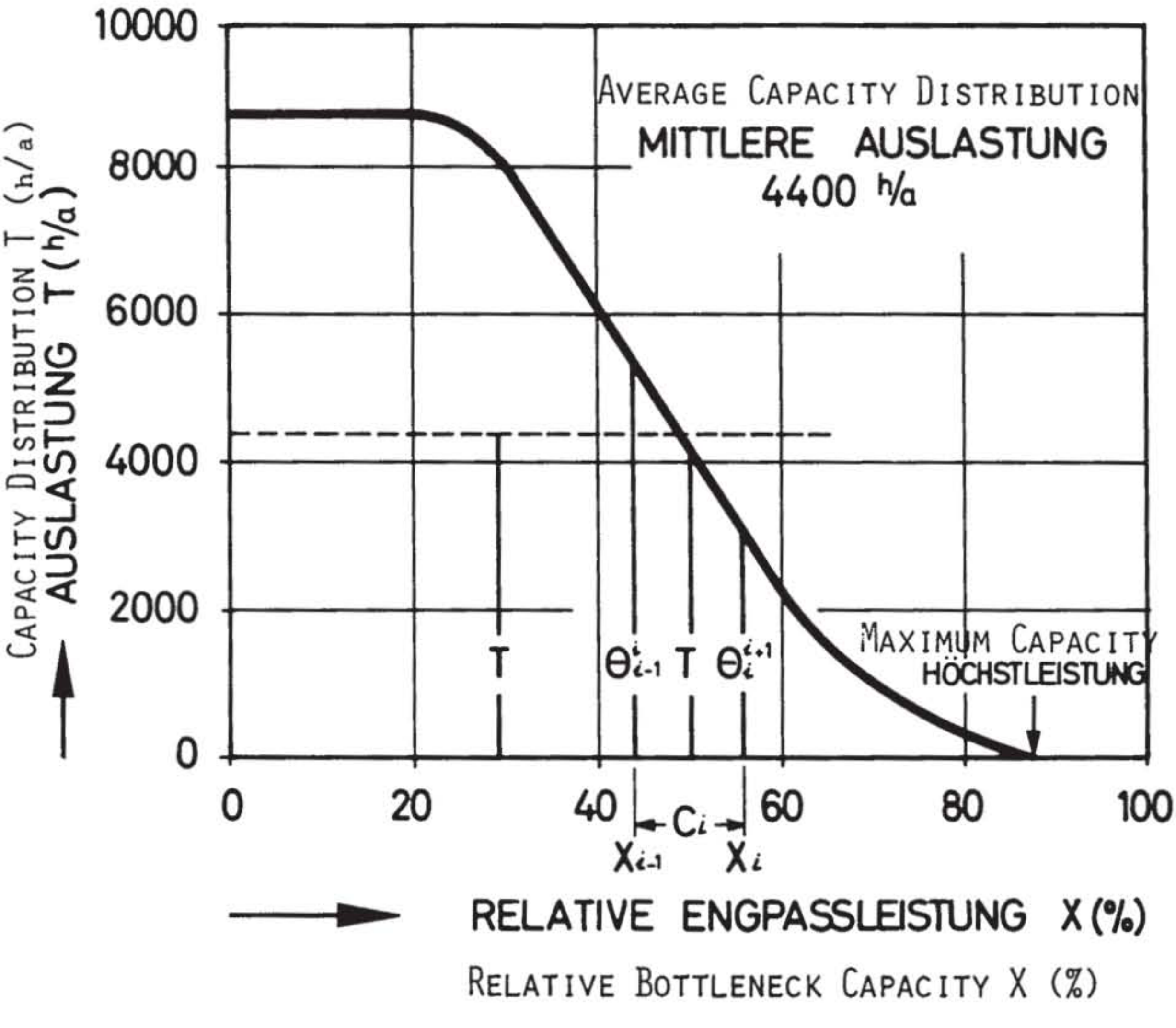


Fig. 1: Annual Load Curve

It is usual to employ power plants by the order of their variable cost:

$$k_{v_{i+1}} > k_{v_i} \quad \text{falls } T_{i+1} < T_i \qquad (11)$$

Thereby it is simultaneously determined the indication of several types of power plants. Using the annual load curve T(X) one receives the average cost for electricity generation $\bar{k}$ for an average operating time T at

$$\bar{k} = \frac{1}{T} \sum_{i=1}^{n} \left\{ k_{fi}(X_i - X_{i-1}) + k_{vi} \int_{X_{i-1}}^{X_i} T(X)\, dx \right\} \left[\frac{DM}{KWh}\right] \qquad (12)$$

The minimum of cost function (12) (the aim function) is given by

$$\frac{\delta \bar{k}}{\delta X_i} = 0 \qquad (13)$$

and leads via the calculation of limits of operating time between two power plants neighboured in the load diagram

$$k_{fi} + \Theta_i^{i+1} k_{vi} = k_{fi+1} + \Theta_i^{i+1} k_{vi+1} \qquad (14)$$

$$\Theta_i^{i+1} = T(X_i) = \frac{k_{fi} - k_{fi+1}}{k_{vi+1} - k_{vi}} \qquad \left[\frac{h}{a}\right]$$

to limits of capacity portions X_1 anticipated in the cost minimum for

$$T\ (X_i) = \Theta_i^{i+1}.$$

Since limits of operating times determined by Eq. 14 have to be positive, and the indication of types of power plants is made in accordance with increasing variable cost $k_{vi+1} > k_{vi}$ [Eq. 11], thus in a cost-optimum system for fix cost of neighboured types must valid

$$k_{fi+1} < k_{fi}$$

i.e. with increasing variable cost of neighboured types, fix cost have to decrease. Also, limited operating times have to fulfill the following inequation according to their definition in Eq. 14.

$$T_{max} = \theta^{1}_{0} > \theta^{2}_{1} > \cdots \theta^{i+1}_{i} > \cdots > \theta^{n+1}_{n} = 0 \tag{15}$$

Thus, to fulfill inequation

$$T_{max} > \theta^{2}_{1} = \frac{k_{f1}-k_{f2}}{k_{v2}-k_{v1}} \tag{16}$$

it means that with a given difference of variable cost, fix cost of type 1 might not be any higher than those of type 2. However, if the difference of fix cost is that big that inequation (16) is not fulfilled, it means that the cost advantage of lower variable cost might not compensate the disadvantage of high fix cost, and it is better to admit type 2 for the power system. On the other hand, if fix cost k_{f1} are that low that

$$\theta^{2}_{1} = \frac{k_{f1}-k_{f2}}{k_{v2}-k_{v1}} < \theta^{3}_{2} = \frac{k_{f2}-k_{f3}}{k_{v3}-k_{v2}} \tag{17}$$

then it were better not to admit type 2. We may state the following rule:

If in contrary to inequation (15)

$$\theta^{i}_{i-1} \leq \theta^{i+1}_{i} \tag{18}$$

is valid for the i-th power plant, then this power plant cannot appear in the cost-optimum system. Inequation (15) must again be determined for the system thus reduced; moreover, it has to be reduced that much that a decreasing follow of operating times will result.

2.2.1 Avoidance of Convergence Difficulties.

Difficulties arise with calculation of limited operating times according to Eq. (14), if variable cost of two neighboured power plants are equal to each other. In practice, however, it is shown that in cases of little cost difference (< 1 %) a convergence is either not reached at all, or only by an undesired high expense of time. In order to avoid these difficulties, the variable cost of power plants neighboures in the load diagram are compared with each other in the program for each time interval, prior to the optimization calculation. If the resulted values for variable cost are close together, then the difference is somewhat enlarged for that time interval in order to enable the program deciding the capacity increase.

2.3 ACCESSORY CONDITIONS.

For optimization of aim function [Eq. (12)] series of accessory conditions must be followed.

2.3.1 Availability of Capacity Required.

The sum of the capacities of all types of plants must in each time interval correspond to a total capacity given for each time interval.

$$\sum_{i=1}^{n} C_i(t) = C_m(t) \tag{19}$$

with $C_m(t)$ being the total capacity required for time interval t.

2.3.2 Running-in Limitation.

The capacity increase of new types of power plants is limited for the first years after initial employment by capacity limits of reactor and fuel cycle industry. This fact is considered by the program in so far as the total capacity of power plant types are given for each time interval and are thus flexible that they meet the conditioning factors of various industry areas as well as various lines of power plants.

2.3.3 Running-out Limitation.

Once being installed, a power plant can the earliest be removed from the system after an operation life-time of L years. If the economy of a power plant staying in the system is decreased by time, e.g. by employment of cheaper power plants, or by increase of uranium cost, the capacity of the corresponding type then remains either absolutely constant or decreases according to the capacity of the power plants of the namely types which had reached their life-time of L years. Thus, for the lower limit of capacity $C_i(t)$ of type i in time interval t results the following limitation:

$$C_i(t) \geq C_i(t-1)-A_i(t-1) \tag{20}$$

with $A_i(t-i)$ being the reduced capacity (rate of intermittent operation) in time interval (t-1) because of having reached operation life-time. Under the assumption that all power plants will be selected from the system after L time intervals after they had gone into operation, A_i might be calculated as follows:

$$A_i(t-1)=C_i(t-L)-C_i(t-L-1) \quad [\mathrm{MWe}] \tag{21}$$

Limitations of running-in and running-out might also have a formula in common for various types of power plants.

2.4 MATERIAL BALANCES

2.4.1 Calculation of Through-put Factors.

For reasons of determination of material balances, the following through-put factors are summarized over all reactor areas j and calculated for all materials k and all power plants i.

2.4.1.1 Refilling Factor DF_N.

$$DF_{N,i,k} = \sum_j \frac{a_{i,j}}{A_{i,j}} \cdot X^k_{A,i,j} \cdot \frac{\alpha_{FAB,i}}{24 \cdot \eta} \left[\frac{to}{MWh}\right] \tag{22}$$

2.4.1.2 Discharging Factor DF_E.

$$DF_{E,i,k} = \sum_j \frac{a_{i,j}}{A_{i,j}} \cdot X^k_{E,i,j} \cdot \gamma_{i,j} \cdot \frac{\alpha_{AUF,i}}{24 \cdot \eta} \left[\frac{to}{MWh}\right] \tag{23}$$

2.4.1.3 Factor of Inventory Arrangement DF_I.

$$DF_{I,i,k} = \sum_j \frac{a_{i,j}}{R_{i,j}} \cdot \alpha_{Res,i} \cdot X^k_{A,i,j} \cdot \frac{\alpha_{FAB,i}}{\eta} \left[\frac{to}{MW(e)}\right] \tag{24}$$

2.4.1.4 Factor of Excore Inventory of Fabrication Plants DF_F.

$$DF_{F,i,k} = \sum_j \frac{a_{i,j}}{A_{i,j}} \cdot X^k_{A,i,j} \cdot \frac{\alpha_{FAB}}{24 \cdot \eta} \cdot t_{FAB} \left[\frac{\text{to/MW h}}{\text{a}}\right] \tag{25}$$

2.4.1.5 Factor of Excore Inventory of Processing Plant DF_A.

$$DF_{A,i,k} = \sum_j \frac{a_{i,j}}{A_{i,j}} \cdot X^k_{E,i,j} \cdot \gamma_{i,j} \cdot \frac{\alpha_{AUF}}{24 \cdot \eta} \cdot t_{AUF} \left[\frac{\text{to/MW h}}{\text{a}}\right] \tag{26}$$

with being

$a_{i,j}$ the portion of reactor field j to the total capacity of type i,

$R_{i,j}$ [KW(th)/kg] the specific power in field j of reactor type i,

$A_{i,j}$ [KWd(th)/kg] the burn-up in reactor field j in type i referred to employed heavy metal,

$X^k_{A,i,j}$, $X^k_{E,i,j}$ the ratio of material k in the fuel in the beginning or end of introduction into reactor field j of reactor type i,

$\alpha_{FAB,i}$ the factor of surplus demand for fuel element fabrication of i-th reactor,

$\alpha_{AUF,i}$ the loss factor during reprocessing for type i,

$\alpha_{RES,i}$ the factor for fuel element reserves of i-th reactor type,

$\gamma_{i,j}$ the mass proportion of heavy metal (end : beginning) in reactor field j of i-th reactor type.

2.4.2 Plutonium and ^{233}Uranium Balances

In order to provide nuclear power plants with non-natural fissile material, the program involves the following possibilities:

2.4.2.1 Open System.

Any amount of non-natural fissile material can at a given price be put into the system. In such a case no balance-dependent limitations arise. This possibility of provisioning is at least not realistic for ^{233}uranium; as far as plutonium is concerned, it might be somewhat realistic in case of little countries. One might, however, state that it could not be employed for areas of big industry.

2.4.2.2 Closed System.

In a system which is locked externally, only those amounts of bred fissile materials can be exhausted as were generated in the system until that point of time. Thus, the following limitations result in a closed system for plutonium and ^{233}uranium:

$$\sum_{i=1}^{n} \{[DF_{N,i} - DF_{E,i} \ (1-(t_{AUF,i}+t_{FAB,i}))] \cdot T_i + DF_{I,i}\} \ C_i \leq M_v \ [to] \tag{27}$$

The amount M_v of plutonium or ^{233}uranium which is available in the system is calculated for each time interval of the program. For the case of a closed system, however, there exists the possibility of making a "coupled balance" or a "self-sufficient" balance. In the "coupled balance", plutonium or ^{233}uranium which was bred during the considered time intervals, is only made available for the following time interval (t+1) while the "self-sufficient balance" makes available in the same time interval plutonium and ^{233}uranium which was yielded in the considered time interval. The available amount of scrap uranium from diffusion plants is also balanced in order to refer to expensive natural uranium for inventory of fast breeders only if no depleted uranium is available in the system itself. Equation (27) occurs with the optimization of a closed system as an additional accessory condition.

2.4.3 Cumulative Total Consumption.

After having calculated the optimum distribution of capacity and energy generation to single types of power plants, material balances of fuel cycles are drawn. The cumulative plants, material balances of fuel cycles are drawn. The cumulative total consumption for materials (index k) as natural uranium, depleted uranium, thorium, and fissile plutonium, summarized over all nuclear power plants of the system (index i) is determined:

$$V_k^k(t) = \sum_t \sum_{i=1}^{n} \{(DF_{N,i}^k - DF_{E,i}^k)\ E_i\ (t) + DF_{I,i}^k\ (C_i \quad - C_i(t-1))$$

$$+ (DF_{F,i}^k + DF_{A,i}^k)\ (E_i(t) - E_i(t-1)\}\ [to] \qquad (28)$$

with being

$E_i(t)$ [MWh] the energy generation of power plant i in time interval t,

$C_i(t)$ [MW(e)] the bottleneck capacity of plant type i installed in time interval t.

2.4.4 Amount bonded in the Inventory.

The amount bonded in the inventory of all power plants i of the system is calculated for all materials k for each time interval t.

$$M_I^k(t) = \sum_{i=1}^{n} \{DF_{I,i}^k \cdot C_i(t) + E_i(t)\ (DF_{F,i}^k + DF_{A,i}^k)\}\ [to] \qquad (29)$$

2.4.5 Through-put of Fabrication Plants.

The total heavy metal through-put of the fabrication plant is calculated for each time interval t and for each type of power plant i. Thus it is feasible to specify different groups of power plants the through-put of which is to comprise.

$$D_{FAB}(t) = \sum_{i=1}^{n} \{DF_{N,i} \cdot E_i(t) + DF_{I,i}\ [C_i(t) - C_i(t-1)]$$

$$+ DF_{F,i}\ [E_i(t) - E_i(t-1)]\}\ [to] \qquad (30)$$

2.4.6 Through-put of Reprocessing Plants.

The calculation of the through-put of reprocessing plants is made analogeously to 2.4.5.

$$D_{AUF}(t) = \sum_{i=1}^{n} \{DF_{E,i} \cdot E_i(t) + DF_{I,i}\ [C_i(t) - C_i(t-1)] + DF_{A,i}$$

$$[E_i(t) - E_i(t-1)]\}\ [to] \qquad (31)$$

2.4.7 Calculation of Demand of Uranium Separation.

The knowledge of long-term demand of uranium separation is of particular importance because of its high specific investment cost of separation facilities and the resulting necessity of their utilization over a long period of time; another important view-point is the problems of energy supply techniques. The program performs the calculation of net demand for separation work, i.e. that separation work which is present in some reactors in removed fuel is reduced from the demand calculation. The exact cost of separation work for power plant i during time interval t then result under employment of corresponding throughput factors:

$$TK_i(t) = (DF_{N,i}^{U_{an}}(\varepsilon_A) \cdot P^{U_{an}}(\varepsilon_A) - DF_{N,i}^{U_{NAT}'} \cdot P^{U_{NAT}}) \cdot E_i(t)$$

$$- (DF_{E,i}^{U_{an}}(\varepsilon_E) \cdot P^{U_{an}}(\varepsilon_E) - DF_{E,i}^{U_{NAT}'} \cdot P^{U_{NAT}}) \cdot E_i(t)$$

$$+ (DF_{I,i}^{U_{an}}(\varepsilon_A) \cdot P^{U_{an}}(\varepsilon_A) - DF_{I,i}^{U_{NAT}'} \cdot P^{U_{NAT}})\ (C_i(t) - C_i(t-1))$$

$$+ (DF_{F,i}^{U_{an}}(\varepsilon_A) \cdot P^{U_{an}}(\varepsilon_A) - D_{F,i}^{U_{NAT}'}\ P^{U_{NAT}})\ (E_i(t) - E_i(t-1))$$

$$[DM] \qquad (32)$$

with being

$P^{U_{an}}(\varepsilon_A)$, $P^{U_{an}}(\varepsilon_E)$ [DM/kg] the price for enriched uranium of enrichment ε_A (fresh fuel) or ε_E (unloaded fuel)

$DF^{U_{NAT}'}$ the specific amount of natural uranium required for production of enriched uranium of enrichment ε.

The specific amount of natural uranium which is required for production of a certain amount of enriched uranium is received by a material balance for the separation plant. Here valids:

$$DF_{(t)}^{U_{NAT'}} \cdot \varepsilon_f \cdot E_i(t) = DF_{(t)}^{U_{an}} \cdot E_i(t)\ \varepsilon_p + DF_{(t)}^{U_{abg}}\ \varepsilon_t \cdot E_i(t)$$

and

$$DF^{U_{NAT'}} \cdot E_i(t) = DF^{U_{an}} \cdot E_i(t) + DF^{U_{abg}} \cdot E_i(t)$$

$$\rightarrow DF^{U_{NAT'}} = DF^{U_{an}} \frac{\varepsilon_p - \varepsilon_t}{\varepsilon_f - \varepsilon_t} \qquad (33)$$

with ε_p, ε_t, ε_f being ^{235}uranium weight concentrations for flow of product, tail, and feed. In the case of discharge-factor, the uranium enrichment of depleted fuel ε_E is employed for ε_p, and that of fresh fuel ε_A for all other factors.

Cost for enriched uranium of enrichment ε_p are determined by the theory of the ideal cascade for the optimal tail enrichment:

$$P_{(\varepsilon p)}^{U_{an}} = C_T \left[\frac{(\varepsilon_p - \varepsilon_t)\ (1 - 2\varepsilon_t)}{\varepsilon_t\ (1 - \varepsilon_t)} - (1 - 2\ \varepsilon_p)\ \ln \frac{\varepsilon_p(1-\varepsilon_t)}{\varepsilon_t(1-\varepsilon_p)}\right] \quad [DM/kg] \qquad (34)$$

with C_T [DM/kg] being cost for one unit of separation work.

For the price of natural uranium in form for UF_6 for the diffusion plant one receives

$$P^{U_{NAT}} = 2.6\ P^{U_3O_8} + C_c \ [DM/kg] \qquad (35)$$

with C_c being cost for conversion of U_3O_8 into UF_6. Factor 2.6 considers the portion of oxygen of U_3O_8 and the conversion of lb to kg.

If one applies now in Eq. (32) the specific factors of separation work

$$TF = \frac{DF_{(\varepsilon)}^{U_{an}} \cdot P_{(\varepsilon)}^{U_{an}} - DF^{U_{NAT'}} \cdot P^{U_{NAT}}}{C_T} \qquad (36)$$

for the portion of the fabrication plant to refilling discharge, inventory arrangement, and ex-core inventory, one receives for the separation work demand of power plant i in time interval t

$$TB_i(t) = E_i(t)\ (TF_{N,i} - TF_{E,i}) + TF_{I,i}\ (C_i(t) - C_i(t-1)) +$$
$$TF_{F,i}\ (E_i(t) - E_i(t-1)) \quad [kg] \qquad (37)$$

By summarizing over all plant types one receives separation work required for time interval t.

If reactors are separated from the system (e.g. after having reached operation life-time) the separation work still existent in the inventory is considered with the demand calculation for the following year.

2.5 PRICE FOR FUEL.

Future development of fuel prices is of decisive influence on the result of long-term investigations. The program holfs two possibilities for treatment of the uranium price:

[1] The price for natural uranium is calculated from the amount consumed. Starting from the fact that there is a limitation for uranium reserves the yield-cost of which are below a certain price CK [$/lb] the price for natural uranium will be calculated as follows:

$$P^{U_3O_8} = CK\ [\$/lb]\ \text{for}\ V_k^{U_{Nat}} \leq M_{Res}^{U_{Nat}} \tag{38}$$

$$P^{U_3O_8} = CK\ [\$/lb]\ \sqrt{\frac{V_k^{U_{Nat}}}{M_{Res}^{U_{Nat}}}}\ \text{for}\ V_k^{U_{Nat}} > M_{Res}^{U_{Nat}} \tag{39}$$

with being

$M_{Res}^{U_{Nat}}$ the amount of cheap uranium reserves [price < CK ($/kg)]

$V_K^{U_{Nat}}$ the amount which was completely consumed within the system.

[2] The price of natural uranium is given as a function of time. Here, the time procedure of uranium price is given as a step function. The treatment of thorium price occurs analogeously to Eq. 38 and 39.
For bred fissile materials Pu and ^{233}U one can either calculate with constant prices or one couples the prices of these fissile materials over appropriate factors (e.g. reactivity value) to the price of high-enriched ^{235}U.

2.6 CUMULATIVE AND ACTUALIZED COST.

For the evaluation of long-term potentials of different systems of power plants it is necessary to know the total cost which are required to cover the energy demand. Therefore the program calculated cumulative cost of electricity generation for all the grid. By actualizing these cost to the initial point of time of the calculation with the relation

$$K_k^{akt}(t) = \sum_t \sum_{i=1}^{n} Ci(t)\ [K_{v,i}(t) \cdot T_i(t) + K_{f,i}(t)]$$
$$[1 + p_z]^{-t}\ [DM] \tag{40}$$

the actualized saving resulting from the employment of a certain reactor line can directly be compared with development cost required for that line.

3. SPECIAL CALCULATIONS.

3.1 Advanced Calculation for an Optimization with an Average Uranium Ore Price.

The optimization of capacity portions of different power plants is normally carried out for a period of one year. This means that only those cost proportions are considered which were available during the time of decision on capacity increase. Such a decision might under certain circumstances not be the very optimum, because cost structure differs significantly by variation of one or more parameters (e.g. uranium ore price). The program, however, has the possibility of communicating the uranium price (e.g. on the expected life-time) to impede the additional construction of power plants the economy of which decreases with increasing uranium price.

Prior to each final time interval, an advanced calculation on a given period of time of t_v years is carried out. From the resulting price procedure of uranium is calculated an average value according to following relation:

$$P^{U_{Nat}} = \frac{\sum_{t=1}^{t_v} P_{(t)}^{U_{Nat}} \cdot V_{(t)}^{U_{Nat}}}{\sum_{t_v} V_{(t)}^{U_{Nat}}} \quad [\frac{\$}{1\ b}] \tag{41}$$

with being

$p^{U_{Nat}}$ [\$/lb U_3O_8] the average price for uranium ore in the considered time interval t_v,

$p^{U_{Nat}}_{(t)}$ [\$/lb U_3O_8] the price for uranium ore in time interval t,

$v^{U_{Nat}}_{(t)}$ [to] the amount of uranium ore consumed in time interval t.

The final decision on capacity increase is made under consideration of this average value for the uranium price; for each further final time interval t_v, advanced calculations are also made.

This method of advanced calculations thus consideres future development of uranium price for the decision on additional construction which is not synonymous with an optimization over a long period of time for determination of minimal expense covering electricity demand, the so-called "long-term optimization" [5].

Computing time increases linearly for these advanced calculations with the size of period of time, in comparison to normal computing time.

3.2 BURNING-IN SYSTEM.

The determination of optimum capacities of different power plant types for the prognosis period is made in the program under the assumption that charging and discharging vectors of nuclear power plants will remain constant. Thus it were impossible to sufficiently consider the burning-in phase of such reactors which in the equilibrium phase are operated with non-natural fissile material. Reactors, however, the cost of burn-in phase of which are somewhat higher than those of equilibrium phase (e.g. THTR) can be treated as follows:

Separated lines of power plants (converters and recyclers) are foreseen for the burning-in and equilibrium phase. By the common limitation of capacity increase, and by termination of converters and recyclers, capacity increase of recaclers occurs quasi-differential; capacity portions of both types then adjust themselves according to the amount produced in the system. During the first years after their employment, converters and recyclers are commonly limited, i.e. the reactor line is subject to the same limitations of capacity increase as other independent power plants are. However, if a reactor line shows the operation of a converter as remarkably more expensive than that of a recycler (e.g. fast converter as Pu supplier for fast breeder), the optimization would show that a converter would not reach its capacity increase as a follow of high costs. For such cases the program holds the possibility of deciding for such a reactor line according to fictive cost which range between real cost of converters and those of recyclers. The determination of fictive cost is made on following relation:

$$k^*_{VR} = k_{VR} + [k_{VK} - k_{VR}] \cdot F_1 \quad [\frac{DM}{KWh}] \qquad (42)$$

$$k^*_{VK} = k^*_{VR} \cdot F_2 \quad [\frac{DM}{KWh}] \qquad (43)$$

k_V real cost

k^*_V fictive cost

Index R recycler

Index K converter

Factor F_1 is chosen on the basis that the cash-value of fictive total cost after a given period of time (e.g. life-time of a power plant) will become equal to the cash-value of real cost. Factor F_2 effects the converter operation being somewhat more expensive in this case than that of the recycler; therefore the recycler capacity is preferably increased that much as bred plutonium reserves of the total system permit. Fictive cost are only employed for the purpose of capacity increase; the evaluation of the total system is in any case made according to real cost.

3.3 DEMAND OF FOREIGN EXCHANGE AND CAPITAL.

Because of their little industrialization some economies are forced to obtain power plants from abroad. The evaluation criteria for the choise of a power plant which is required to cover energy demand might not only be found in low electricity generating cost but also in necessary demand of foreign exchange and capital. The program has therefore the possibility of calculating the necessary demand of capital and foreign exchange for cost-optimum capacity distribution of single plant types determined in each time interval. Moreover, it is possible to minimize the demand of foreign exchange or capital itself, i.e. to determine that power system the demand for foreign exchange or capital of which is minimal for availability of required energy.

3.4 UNCERTAINTIES OF INPUT DATA.

With performing an optimum calculation, the capacity is thus distributed to single plant types that electricity generating cost become a minimum. If cost curves of competing systems are very close to each other over a long period of time without intersecting themselves, the program always increases the capacity of a power plant which is somewhat cheaper, although the difference in cost might be within the failure region of cost. In order to exclude such failure decisions one can give a failure region ΔK for plant cost which are still very uncertain todate. Cost curves of single plants are therby transferred to cost tapes; the program then equally distributes capacity of a load region to those plants the cost tapes of which heterodyne in the referring load region.

3.5 THROUGH-PUT DEPENDENCE OF FABRICATION AND PROCESSING COST.

Fabrication and processing cost of fuel elements are through-put dependent to a great extent. The program meets this fact by calculation of fabrication and processing cost as a function of through-put of fabrication and processing plants. Corresponding cost functions can be given for each power plant. Through-put of power plants which are loaded with the same or nearly the same fuel elements can be summarized for calculation of fabrication and processing cost. Fig. 2 shows the schematic procedure of the calculations.

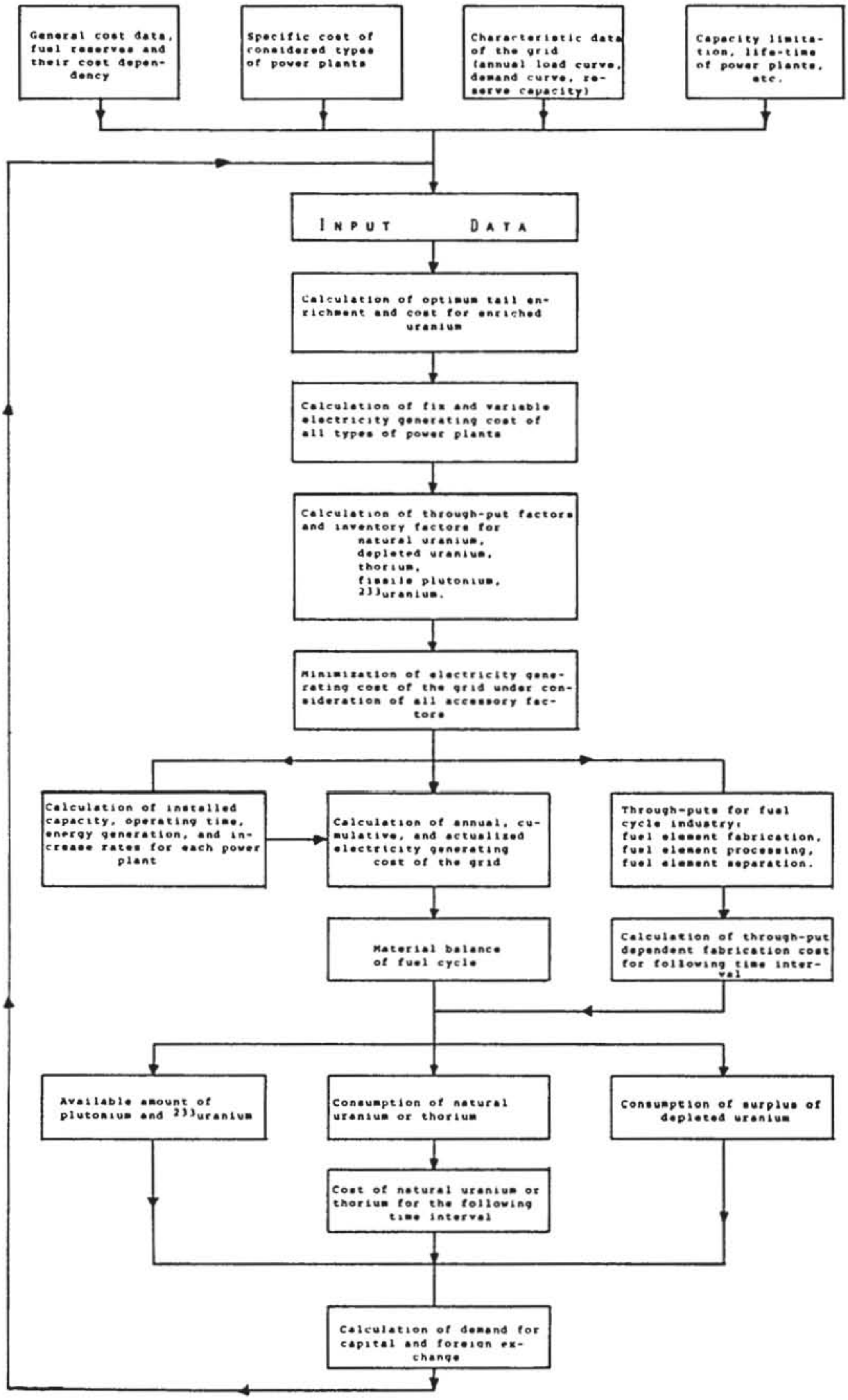


FIG. 2: FLOW SCHEME OF COMPUTER PROGRAM

4. REFERENCES.

[1] R. Harde, G. Memmert:
Modelluntersuchungen uber Aussichten und Konsequenzen von Kernenergie zur Elektrizitatserzeugung.
Atomwirtschaft 11, 164 (1966).

[2] K. Wagemann:
Beitrag zu Systemuntersuchungen ueber die langfristigen wirtschaftlichen Einsatzmoeglichkeiten verschiedener Kraftwerkstypen unter besonderer Beruecksichtigung des Thoriumhochtemperaturreaktors.
JUL-590-RG (Februar 1969).

[3] A. Boettcher, H. Kraemer, K. Wagemann:
Voraussichtlicher Bedarf an Trennarbeit fuer Uran in der Bundesrepublik Deutschland.
Atomwirtschaft 13, 249 (1968).

[4] A. Boettcher, H. Kraemer, K. Wagemann:
Prospects of nuclear energy in countries with restricted capital and foreign currency availability.
Symposium on Nuclear Energy Costs and Economic Development, Istanbul, 20 - 24 October 1969.

[5] G. Memmert, H. Wellmann:
Studie ueber die optimale Verwertung von Plutonium in der Energiewirtschaft.
EUR 4474d (1970).

5. Input Description.

Card 1	Optional text. Format (40I2).
Card 2	Input options NRØ, NOUT, NKUPØ, NCOSTØ, NTRENN, NGLEIT, NZUR, NEPS, NFAB, NKON, NFUM, NTAIL, NDEV, Format (40I2).
NRØ	Amount of time intervals over which an advanced calculation is to carry out.
NOUT	Size for output control. =1 Total output after each "final" time interval. =2 Total output after each time interval (also for advanced calculation) =3 Results are not plotted (output after each time interval). =0 It is plotted only (the other output is neglected).
NKUPØ	Size for control of calculation of uranium price. =0 Price of natural uranium is calculated from the amount consumed (see Eq. 39 and 40). =1 Uranium price is given as a function of time.
NCOSTØ	Size for control of cost calculation. =0 Electricity generating cost are not calculated. ≠0 Total electricity generating cost are calculated and indicated for each time interval and each type of power plant as a function of the load factor.
NTRENN	Size for control of calculation of separation cost. =0 Separation cost are calculated for each type of power plant and for each time interval. =1 No calculation of separation cost. =2 Units for separation work are calculated for all types of power plants and for each time interval (new procedure).
NGLEIT	Code number for control of calculation of ^{233}U and Pu price. =0 It is calculated with constant prices for ^{233}U and Pu (according to input) =1 Prices for ^{233}U and Pu are coupled by appropriate factors (input values) to the price for enriched ^{235}U.

NZUR — Size of control for treatment of burning-in systems.
- =0 No burning-in systems are considered.
- =1 Power plants 3 (recyclers) and 4 (converters) in the follow of their input are treated as burning-in systems.
- =2 Power plants 5 and 6 are treated as burning-in systems.
- =3 Power plants 3 and 4 as well as 5 and 6 are burning-in systems.

NEPS — Code number for control of calculation.
- =0 It is calculated with constant plant cost.
- =1 It is calculated with a failure region ΔK for plant cost.

NFAB — Size of control for calculation of fabrication and processing cost.
- =0 It is calculated with constant fabrication and processing cost.
- =1 Fabrication cost are calculated in function of through-put.
- =2 Processing cost are calculated in function of through-put.
- =3 Fabrication and processing cost are calculated in function of through-put.

NKON — Size for control of console output.
- =0 No console output.
- =1 The numbers of time intervals are put out at the console.

NFUM — Code number for manipulation of a plant type.
- =0 No plant type is manipulated.
- =1 A plant type is manipulated.

NTAIL — Code size for calculation of tail enrichment.
- =0 Optimum tail enrichment is calculated.
- =1 No calculation of optimum tail enrichment.

NDEV — Size of control for calculation of demand of capital and foreign exchange.
- =0 No calculation of demand of capital and foreign exchange.
- =1 Calculation of demand of capital and foreign exchange.

Card 3 — Indicating size for control of read-in of new data with which is to calculate from certain time-intervals.
Format 80I1.
NVAR has to be read-in for each time interval, i.e. max. 50 values.

NVAR	=0	No new data.
	=1	Data of cards 15 - 17 are newly read.
	=2	Data of card 20 are newly read.
	=3	Data of cards 21 and 22 are newly read.
	=4	Data of cards 15 - 17 and 20 - 22 are newly read.
	=5	Data of cards 15 - 17 and 21, 22 are newly read.
	=6	Data of cards 15 - 17 and 20 are newly read.
	=7	Data of cards 20 - 22 are newly read.

Card 4 follows for NZUR > 0 only.

Card 4 — Factors for modification of cost in the case of burning-in systems. Format E 16.8

ALLFAC ≙ Factor to increase converter costs. (= F_2 from Eq. (43) (1)

FAC3Ø ≙ Factor of cash value for plants 3 and 4 (see Eq. 42) (1)

FACPØ ≙ Factor of cash value for plants 5 and 6 (see Eq. 42) (1)

If NKUPØ > 0 card 5 then follows.

Card 5 — Step-function for description of time procedure of price for natural uranium.
Format (5 (I2, E14.5).
Up to 10 value pairs can be read in.

NWØ ≙ Number of time interval at which the uranium price WNØ should become valid.

WNØ ≙ Uranium price valid at time interval NWØ (\$/lb U_3O_8)

Card 5 must be given twice, with less than 10 value pairs it is necessary to give the rest "blank".

Cards 6 and 7 follow for NEPS ≠ 0 only.

Card 6 — Region of uncertainties ΔK for plant cost.
Format (5 E 16.8) 2 cards

EPLON(I),I = 1.10 ≙ uncertainty region of plant cost of type I (according to follow of input). It is translated into a band width forelectricity generating cost (DM/KW(e)).

Card 7 — Number of time interval.
Format (40I2).

NREP(I),I = 1.10 ≙ number of time interval at which for type I has to be calculated with uncertainty factor EPLON(I).

Only if NFUM > 0 card 8 then follows.

Card 8	Manipulation of one plant type (option increase of plant cost in order to prevent an additional construction of a certain type).	
NFUMPL	≙	Number of type, according to follow of input (see card 12) which is to manipulate (1).
NFUMNR	≙	Number of time interval at which the manipulation has to be started (1).

Cards 9 and 10 are necessary only if NFAB > 0.

Card 9 — Indication of the plants for calculation of through-put dependent fabrication and processing cost. Format 40I2.

			according to follow of input (card 12)
ITYP1	≙	Number of LWR	according to follow of input (card 12)
ITYP2	≙	" " THTR recycler	"
ITYP3	≙	" " THTR converter	"
ITYP4	≙	" " Na-Br	"
ITYP5	≙	" " NaB-C	"
ITYP6	≙	" " MSBR	"

With indication with 0 the fabrication and processing cost are calculated non-throughput dependent.

Card 10 — Number of reactor zones. Format 40I2.

IZ1	≙	Number of zones of LWR for which through-put dependent fabrication and/or processing cost have to be calculated. (1)
.		
.		
.		
IZ6	≙	Number of zones of MSBR ...

Card 11 — Caption of calculation.
5 cards, format 80A1.

Card 12 — Indication of plants.
2 cards, format 80A1.
The first card starts with column 13 (indication of first plant, e.g. LWR), then with column 25, then with column 37, etc.
The follow of input corresponds to the follow of admission (see card 48); it is optional for plants with the same admission point of time.

Card 13 — Number of plants.
Format 40I2.

N	≙	Number of plants which are to optimize in that case. (1)

Card 14 Life-time of plants.
Format 40I2.

L $\hat{=}$ Life-time of plants in years (a).

Card 15 Rate of tax, interest, and insurance.
Format 5 E 16.8.

S $\hat{=}$ Rate of tax per year (1/a)
R $\hat{=}$ Rate of interest per year (1/a)
P $\hat{=}$ Rate of insurance per year (1/a)

Card 16 Data for cost calculation $[\frac{DM}{kg}]$ of enriched uranium.
Format 5 E 16.8.

CT $\hat{=}$ Separation cost [$/kg]
CC $\hat{=}$ Conversion cost [$/kg]
EPSN $\hat{=}$ Enrichment of natural uranium (1)
CK $\hat{=}$ Cost of initial concentration [$/lb U_3O_8]
EPS $\hat{=}$ Optimum tail enrichment appertaining to CK (1) (estimated value nearly 0.006) for NTAIL=0. For NTAIL=1 (procedure of salary increase) is put in the tail-enrichment.

Card 17 Cost of fuel and rate of exchange.
Format 5 E 16.8.

BETA $\hat{=}$ Cost for depleted uranium [DM/kg]
BETP $\hat{=}$ Cost for fissile plutonium "
BET3 $\hat{=}$ Cost for ^{233}uranium "
BETT $\hat{=}$ Cost for thorium "
PARI $\hat{=}$ Rate of exchange [DM/$]

Instead of cost for plutonium and ^{233}uranium, factors for NGLEIT = 1 are employed with which cost for plutonium or ^{233}uranium are to couple with those for ^{235}uranium.

Card 18 Available amount of natural uranium and thorium.
Format 5 E 16.8

ZU $\hat{=}$ Available amount [t] of natural uranium at CK price (see card 16)
ZT $\hat{=}$ Available amount [t] of thorium at BETT price (see card 17)

If the cumulative consumption during a calculation does increase the available amounts ZU or ZT of natural uranium or thorium, then the program increases the price for natural uranium (CK) (if it is not given as a function of time) and for thorium (BETT) according to a root law.

Card 19 Already consumed (positive prefix) or yielded (negative prefix) amount of fuel in the beginning of a calculation.
Format 5 E 16.8.

ZJU ≙ Amount of natural uranium [t]
ZJA ≙ Amount of depleted uranium [t]
ZJT ≙ Amount of thorium [t]
ZJP ≙ Amount of fissile plutonium [t]
ZJ3 ≙ Amount of ^{233}uranium [t]

Data of card 15 to 19 appear in the output under "data of field 1" in the input-follow line by line for each card.

Card 20 Indicating data for single plant types.
Format 5 E 16.8.
Three cards 20 are required for read-in of indicating data in the following order:

(1) Cash value of total plant cost [DM/KW(e)]
(2) Cost for operation and maintenance [DM/KW(e)·a]
(3) Rate of foreign capital [1]
(4) Rate of interest to foreign capital [1/a]
(5) Rate of interest to own capital [1/a]
(6) Efficiency rate of power plant [1]
(7) Heat value of fossil fuel [DM/Kcal]
(8) Reservation with conventional power plants [1]
(9) Code number 1: 1 nuclear power plant
0 conventional power plant
(10) Code number 2: 1 processing
2 no processing
(11) Factor of multiple supply for fuel element fabrication [1]
(12) Loss factor of fuel element processing [1]
(13) Factor for fuel element reservation [1]

Sizes which are non-characteristic for a certain type are to employ with zero. The follow of input of plant data must correspond to the follow of indication of card 12.

Each plant type must be started with a new card. On the whole there are 3·N (number of plants) cards necessary for employment of indicating data. These data appear in the output under "data of field 2" in the follow of input, columnly for each type, with each column having a caption of the index of the follow of input and the indication of card 12.

Th following two cards are only required for plant types the indication number 1 of which is 0 on card 20, i.e. it is required for nuclear power plants only.

Card 21 Number of reactor fields
Format 40I2.

IP(I) ≙ Number of reactor fields of the I-th plant type according to input-follow (IP(I) $\leq$ 4).

Card 22 Indicating data for single nuclear power plants.
Format 5 E 16.8.

The following data are read-in one after the other for IP(I) reactor fields.

(1) Power portion [1]
(2) Specific power of reactor field [MW/to]
(3) Burn-up [MWd/to]
(4) Mass proportion γ [1]
(5) Uranium enrichment in fresh fuel [1]
(6) Uranium enrichment in depleted fuel [1]

in fresh fuel:
(7) Mass portion of enriched uranium
(8) Mass portion of depleted uranium
(9) Mass portion of thorium
(10) Mass portion of fissile plutonium
(11) Mass portion of ^{233}uranium

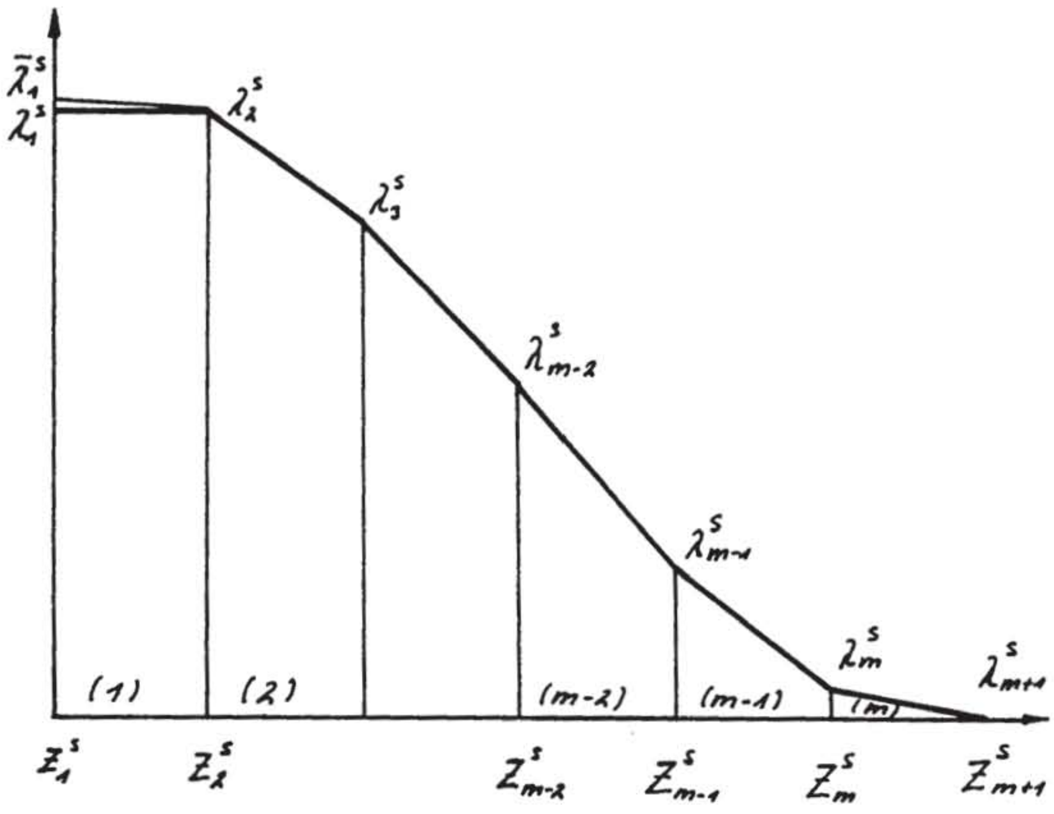
in depleted fuel:
(12) Mass portion of enriched uranium
(13) Mass portion of depleted uranium
(14) Mass portion of thorium
(15) Mass portion of fissile plutonium
(16) Mass portion of ^{233}uranium

(17) Total fabrication cost [DM/kg]
(18) Total processing cost [DM/kg]
(19) Total fabrication time [a]
(20) Total processing time [a]

Illustration to input: For IP(I) = 4, the power portions of single reactor fields are first punched on the cards in format 5 E 16.8 one after the other, then follow burn-ups in each field, etc. Punching for IP(I) = 2 looks as follows: first two values for power portion, then two values for burn-up, etc. Cards 20 and 22 have to be put in one after the other in input follow, for each plant time respectively; conventional plants have to be overgone.

$$\text{Amount of cards } 21 + 22 = \sum_{J=1}^{N} [1 + 4 \cdot IP(I)] \cdot \text{code number 1 (I)}$$

Cards 23 - 25 serve for description of annual load curve.



Card 23	Amount of fields (- 10). Format 40I2.	
m	≙	Amount of classification fields [1].
Card 24	Ordinates and abszissa values of annual load curve. Format 5 E 16.8.	
RLAM(I)	≙	m + 1 ordinate values (supporting values) (h/a)
ZET(I)	≙	m + 1 standardized abszissa values (1)
EPSL(I)	≙	m values as field addition to installed power of various types for compensation of non-availability and for covering reserves (1).

These data have to be put in one after the other (first of all (m+1) ordinate values, etc.) in format 5 E 16.8.

Card 25	Auxiliary size. Format 5 E 16.8.	
RLQ1	≙	λ_1^S auxiliary size indicating an increase of basic power region $\neq 0$ which is required for the calculation.

Data of cards 23 - 25 appear in the output under "data of annual load curve" printed in lines.

Card 26	Interrogation. Format 5 E 16.8.	
EPSU	≙	
EPSK	≙	Values for program-internal interrogation.
EPLA	≙	
	Appear in output under "interrogation.	
Card 27	Duration of time interval. Format 5 E 16.8.	
DELTAT	=	Duration of time interval [a].
	Appears in output under "duration of time interval".	
Card 28	Data for Pu balance. Format 5 E 16.8.	
WPG	1. "coupled" balance. 0. no "coupled" balance.	
WPS	1. "self-sufficient" balance. 0. no "self-sufficient" balance.	
BP	=	Pu amount already available in the beginning of the calculation [t].
	WPG + WPS may only be 0 or 1. These data appear in output under "data for Pu balance".	

Card 29 Data for ^{233}uranium balance.
Format 5 E 16.8.

W3G 1. "coupled" balance.
0. no "coupled" balance.

W3S 1. "self-sufficient" balance.
0. no "self-sufficient" balance.

B3 = ^{233}uranium amount already available in the beginning of a calculation.
W3G + W3S may only be 0 or 1. These data appear in output under "data for ^{233}uranium balance."

Remarks to cards 28 and 29:

"Coupled balance" means: Plutonium or ^{233}uranium which was gaines in the time interval considered will be available for the following time interval.

"Self-sufficient balance" means: Plutonium or ^{233}uranium which was gained in the time interval considered will be available in the same time interval.

The input of 00 calculates with an "open balance", i.e. plutonium or ^{233}uranium are unlimited available.

Cards 30 - 32 contain code numbers for control of common limitations downwards (running-in limitations).

Card 30 N code numbers: 0 or 1.
Format 40I2.

Card 31 N code numbers: 0 or 1.
Format 40I2.

Card 32 N code numbers: 0 or 1.
Format 40I2.

It must always be for each of the N-types: code number 30 + code number 31 + code number 32 = 0 or 1. Three commonly limited groups are possible:

1. all plants with code number 30 = 1.
2. all plants with code number 31 = 1.
3. all plants with code number 32 = 1.

Cards 33 - 36 contain code numbers for control of common and single limitations upwards (running-in limitations).

Card 33 N code numbers: 0 or 1.
Format 40I2.

Card 34 N code numbers: 0 or 1.
Format 40I2.

Card 35 N code numbers: 0 or 1.
Format 40I2.

Card 36 N code numbers: 0 or 1.
Format 40I2.

It must always be for each of the N-types: code number 33 + code number 34 + code number 35 + code number 36 = 0 or 1.
Three commonly limited groups are possible:

1. all plants with code number 33 = 1.
2. all plants with code number 34 = 1.
3. all plants with code number 35 = 1.

Via code numbers of card 36 it can be determined which of the N plants is to limit upwards in separate.

Cards 37 - 39 contain code numbers for combination with respect to fabrication and processing through-puts of single plants.

Card 37 N code numbers: 0 or 1.
Format 40I2.

Card 38 N code numbers: 0 or 1.
Format 40I2.

Card 39 N code numbers: 0 or 1.
Format 40I2.

Three partial sums of total through-puts are possible:

1. referring all plants with code number 37 = 1.
2. referring all plants with code number 38 = 1.
3. referring all plants with code number 39 = 1.

The input values of cards 30 - 39 appears in the output in lines in the input-follow under "code numbers for control of limitations/ through-puts".

Cards 40 - 42 contain initial values:

Card 40 N values: already installed power of different types without power addition (MW) in the beginning of a calculation.
Format 5 E 16.8.

Card 41 N values:Average starting time of N different types (estimated) [h/a]
Format 5 E 16.8.

Card 42 N values: Addition of fields relating to values of card 39; [1]; (estimated values).
Format 5 E 16.8, maximal 2 cards.

Values of cards 40 - 42 appear in the output in lines under "initial values"

Card 43 (N-1) values: field indices of first (N-1) plants.
Format 40I2.

Values of card 43 appear in the output under "field indices".

Card 44 Optimization time period.
Format 40I2.

NRECHØ ≙ Number of time intervals for which the optimization is to carry out [< 50].
Appears in the output under "Number of time intervals".

Card 45 Required maximum load.
Format 5 E 16.8.

C(I) ≙ NRECHØ values of maximum capacity (MW) required for each time interval.
If NRECHØ is < 50 then the rest is read-in with zero.
10 cards are necessary.
These values appear in the output under "maximum load capacity per time interval".

Card 46 Lethal rates.
Card 46 is necessary for each plant type, i.e. N times, in the input follow.
Format 5 E 16.8.

RKAP ≙ Lethal rate in (MW) of power installes before the beginning of the calculation of the i-th plant type in time interval t.

If NRECHØ is lower than 50 then zero has to be read-in for remaining values. Number of cards = N · 10.
Values appear in the output under "Lethal rate per time interval" per type in columns with each column having a caption of indication (see card 12).

Card 47 Running-in limitations.
Card 47 is necessary for each plant type, i.e. N times corresponding to the input follow.
Format 5 E 16.8.

RKST ≙ Limitation of capacity increase (MW) per type and time interval.

If the amount of actual time intervals NRECHØ is lower than 50, then zero has to be read-in for the remaining values, also for non-limited plants.
N · 10 cards are necessary.

These values appears in the output under "Limitation upwards" per type in columns.

Card 48 Time intervals of input.
Format 40I2.

NANF(I),I ≙ 1,N = Number of time interval of initial input for each plant.

Card 49 Plotter code numbers.
Format 40I2.

NK E(I) ≙ 11 plotter code numbers for control of curves to be printed.

Card 50 Symbols of plotter curves.
Format 19A1.

T(I) ≙ 19 given symbols for plotter curves.

Card 51 Balance of plutonium and ^{233}uranium.
Format 40I2.

NWP ≙ Calculation number at which is to start with plutonium balance.

NW3 ≙ Calculation number at which is to start with ^{233}uranium balance.

If NDEV=1 on card 2, then will now follow data for demand of capital and foreign exchange.

Card 52 Indicating size for read-in of data for demand of capital and foreign exchange with which is to calculate from certain time intervals.
Format 80I1.
NFOC has to be given for each time interval.

NFOC
- =0 No new data for demand of capital and foreign exchange.
- =1 Only new data for demand of capital. (Input corresponds to cards 14 - 22.)
- =2 Only new data for demand of foreign exchange. (Input corresponds to cards 14 - 22.)
- =3 New data for demand of capital as well as for demand of foreign exchange. (Input: at first cards 14 - 22 for capital demand, then cards 14 - 22 for demand of foreign exchange.)

Cards 53 - 61: The input corresponds to cards 14 - 22, with specified data for determination of demand of capital and foreign exchange, of course. Following are data for capital demand (corresponding to cards 14 - 22), and then data for demand of foreign exchange (corresponding to cards 14 - 22).

Further cards will only follow if NVAR and/or NFOC is > 0 at any time interval.

For NVAR and/or NFOC > 0 will now follow in chronological series for the single time intervals the new data corresponding to cards 3 and 52. If for the same time interval new data should be read for the optimization as well as for demand of capital and foreign exchange, then the series is as follows: at first the data for optimization, then data for demand of capital and foreign exchange.

```
          *** INPUT ILLUSTRATION ***

          STRATEGY CALCULATION FOR FIVE REACTOR TYPES                CARD 11
          CONV,LWR,HTR-R,HTR-C,NAB

EINGABEDATEN      INPUT-DATA


STEUERGROESSEN    CONTROL SIZES

  N       = 5  L       =25  NR$     = 0  NOUT    = 1  NKUP$   = 0
  NCOST$  = 1  NTRENN  = 2  NGLEIT  = 1  NZUR    = 0  NEPS    = 0   CARD 2, 13, 14
  NFAB    = 0  NKON    = 0  NFUM    = 0  NTAIL   = 1  NDEV    = 0

 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0   CARD 3
 0 0 0 0 0 0 0 0 0 0
DATEN AUS FELD 1          DATA OF FIELD 1
  0.2700D-01  0.7000D-01  0.1000D-01                                  CARD 15
  0.2870D 02  0.2700D 01  0.7115D-02  0.6500D 01  0.2000D-02               16
  0.1200D 02  0.1000D 01  0.1000D 01  0.5000D 02  0.4000D 01               17
  0.6000D 05  0.3000D 05                                                   18
  0.0        -0.1000D 03  0.0         0.0         0.0                      19

DATEN AUS FELD 2          DATA OF FIELD 2

    1           2           3           4           5
   LWR         CONV        HTR-R       HTR-C        NAB
0.5100D 03  0.4700D 03  0.5400D 03  0.5400D 03  0.5800D 03
0.7300D 01  0.7300D 01  0.7300D 01  0.7300D 01  0.7300D 01
C.1000C 01  0.1000D 01  0.1000D 01  0.1000D 01  0.1000D 01
0.7000D-01  0.7000D-01  0.7000D-01  0.7000D-01  0.7000D-01
0.0         0.0         0.0         0.0         0.0

0.3300D 00  0.3800D 00  0.4200D 00  0.4200D 00  0.4200D 00           CARD 20

0.0         0.7500D-05  0.0         0.0         0.0
0.0         0.1670D 00  0.0         0.0         0.0

0.1000D 01  0.0         0.1000D 01  0.1000D 01  0.1000D 01
0.1000C 01  0.0         0.1000D 01  0.1000D 01  0.1000D 01

0.1010C 01  0.0         0.1010D 01  0.1010D 01  0.1010D 01
C.9900D 00  0.0         0.9900D 00  0.9900D 00  0.9900D 00
0.1030D 01  0.0         0.1030D 01  0.1030D 01  0.1030D 01

DATEN AUS FELD 3          DATA OF FIELD 3

   LWR         CONV        HTR-R       HTR-C        NAB
    1           -1          2           2            1

0.1000D 01  0.1000D-49  0.7450D 00  0.5830D 00  0.1000D 01
0.1000D-49  0.1000D-49  0.2550D 00  0.4170D 00  0.1000D-49
0.1000D-49  0.1000D-49  0.1000D-49  0.1000D-49  0.1000D-49
0.1000D-49  0.1000D-49  0.1000D-49  0.1000D-49  0.1000D-49

0.3100D 05  0.1000D-49  0.6103D 05  0.1589D 06  0.2668D 05
0.1000D-49  0.1000D-49  0.6435D 06  0.6500D 06  0.1000D-49
0.1000D-49  0.1000D-49  0.1000D-49  0.1000D-49  0.1000D-49
0.1000D-49  0.1000D-49  0.1000D-49  0.1000D-49  0.1000D-49

0.33C0D C2  0.1000D-49  0.6542D 02  0.5886D 02  0.5290D 02
0.1000D-49  0.1000D-49  0.1502D 04  0.1629D 04  0.1000D-49
0.1000D-49  0.1000D-49  0.1000D-49  0.1000D-49  0.1000D-49
```

0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49
0.9670D 00	0.1000D-49	0.9351D 00	0.8344D 00	0.9720D 00
0.1000D-49	0.1000D-49	0.0	0.0	0.1000D-49
0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49
0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49
0.3100D-01	0.1000D-49	0.0	0.0	0.0
0.1000D-49	0.1000D-49	0.9315D 00	0.9315D 00	0.1000D-49
0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49
0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49
0.8500D-02	0.1000D-49	0.0	0.0	0.0
0.1000D-49	0.1000D-49	0.0	0.0	0.1000D-49
0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49
0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49
0.1000D 01	0.1000D-49	0.0	0.0	0.0
0.1000D-49	0.1000D-49	0.1000D 01	0.1000D 01	0.1000D-49
0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49
0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49
0.0	0.1000D-49	0.0	0.0	0.9430D 00
0.1000D-49	0.1000D-49	0.0	0.0	0.1000D-49
0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49
0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49
0.0	0.1000D-49	0.9542D 00	0.1000D 01	0.0
0.1000D-49	0.1000D-49	0.0	0.0	0.1000D-49
0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49
0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49
0.0	0.1000D-49	0.0	0.0	0.3970D-01
0.1000D-49	0.1000D-49	0.0	0.0	0.1000D-49
0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49
0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49
0.0	0.1000D-49	0.2772D-01	0.0	0.0
0.1000D-49	0.1000D-49	0.0	0.0	0.1000D-49
0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49
0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49
0.9900D 00	0.1000D-49	0.0	0.0	0.0
0.1000D-49	0.1000D-49	0.0	0.0	0.1000D-49
0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49
0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49
0.0	0.1000D-49	0.0	0.0	0.9230D 00
0.1000D-49	0.1000D-49	0.0	0.0	0.1000D-49
0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49
0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49
0.0	0.1000D-49	0.9501D 00	0.9568D 00	0.0
0.1000D-49	0.1000D-49	0.0	0.0	0.1000D-49
0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49
0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49
0.4400D-02	0.1000D-49	0.0	0.0	0.5370D-01
0.1000D-49	0.1000D-49	0.0	0.0	0.1000D-49
0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49
0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49
0.0	0.1000D-49	0.3024D-01	0.2937D-01	0.0
0.1000D-49	0.1000D-49	0.0	0.0	0.1000D-49
0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49
0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49
0.2900D 03	0.1000D-49	0.5200D 03	0.4800D 03	0.3150D 03
0.1000D-49	0.1000D-49	0.5600D 04	0.5900D 04	0.1000D-49
0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49
0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49	0.1000D-49

CARD 22

```
0.1400D 03   0.1000D-49   0.1500D 03   0.1500D 03   0.1550D 03
0.1000D-49   0.1000D-49   0.0          0.0          0.1000D-49
0.1000D-49   0.1000D-49   0.1000D-49   0.1000D-49   0.1000D-49
0.1000D-49   0.1000D-49   0.1000D-49   0.1000D-49   0.1000D-49

0.5000D 00   0.1000D-49   0.2500D 00   0.2500D 00   0.2200D 00
0.1000D-49   0.1000D-49   0.2500D 00   0.2500D 00   0.1000D-49
0.1000D-49   0.1000D-49   0.1000D-49   0.1000D-49   0.1000D-49
0.1000D-49   0.1000D-49   0.1000D-49   0.1000D-49   0.1000D-49

0.6000D 00   0.1000D-49   0.2500D 00   0.2500D 00   0.5000D 00
0.1000D-49   0.1000D-49   0.2500D 00   0.2500D 00   0.1000D-49
0.1000D-49   0.1000D-49   0.1000D-49   0.1000D-49   0.1000D-49
0.1000D-49   0.1000D-49   0.1000D-49   0.1000D-49   0.1000D-49
```

DATEN DER JAHRESDAUERLINIE — DATA OF ANNUAL LOAD CURVE

```
  4                                                                  CARD 23
0.8760D 04   0.8760D 04   0.7884D 04   0.1497D 04   0.0                   24
0.0          0.2800D 00   0.3500D 00   0.7250D 00   0.1000D 01
0.2870D 00   0.2310D 00   0.1760D 00   0.1760D 00
0.1000D 05                                                                25
```

ABFRAGEN — ASK

```
0.1000D-04   0.1000D 02   0.1000D 02                                      26
```

ZEITSCHRITTDAUER — DURATION OF TIME INTERVAL

```
0.1000D 01                                                                27
```

DATEN FUER PU-BILANZ — DATA FOR Pu BALANCE

```
0.1000D 01   0.0          0.0                                             28
```

DATEN FUER U-233-BILANZ — DATA FOR ^{233}U BALANCE

```
0.1000D 01   0.0          0.0                                             29
```

KENNZAHLEN ZUR STEUERUNG DER BESCHRAENKUNGEN/DURCHSAETZE — CODE NUMBERS FOR CONTROL OF LIMITATIONS / THROUGH-PUTS

LWR	CONV	HTR-R	HTR-C	NAB	
0	0	1	1	0	CARD 30
0	0	0	0	0	31
0	0	0	0	0	32
0	0	1	1	0	33
0	0	0	0	0	34
0	0	0	0	0	35
1	0	0	0	1	36
1	1	0	0	1	37
0	0	1	1	0	38
0	0	0	0	0	39

```
ANFANGSWERTE                          INITIAL VALUES

    LWR          CONV         HTR-R        HTR-C        NAB
0.0          0.4540D 05   0.0          0.0          0.0                                                                       CARD 40
0.8760D 04   0.5000D 04   0.8760D 04   0.8760D 04   0.8760D 04                                                                     41
0.2870D 00   0.1760D 00   0.2870D 00   0.2870D 00   0.2870D 00                                                                     42

GEBIETSINDIZES                        INDICES OF AREAS
  1            1            1            1                                                                                         43
ANZAHL DER ZEITSCHRITTE               AMOUNT OF TIME INTERVALS                                                                     44
  50
HOECHSTLAST JE ZEITSCHRITT  MAXIMUM CAPACITY PER TIME INTERVAL
0.4850D 05   0.5170D 05   0.5500D 05   0.5850D 05   0.6240D 05   0.6700D 05   0.7050D 05   0.7500D 05   0.7350D 05   0.8450D 05
0.9000D 05   0.9450D 05   0.9950D 05   0.1050D 06   0.1110D 06   0.1170D 06   0.1240D 06   0.1310D 06   0.1380D 06   0.1450D 06
0.1520D 06   0.1590D 06   0.1660D 06   0.1740D 06   0.1820D 06   0.1900D 06   0.1990D 06   0.2080D 06   0.2170D 06   0.2270D 06   CARD 45
0.2370D 06   0.2470D 06   0.2570D 06   0.2670D 06   0.2770D 06   0.2870D 06   0.2970D 06   0.3080D 06   0.3190D 06   0.3300D 06
0.3410D 06   0.3520D 06   0.3640D 06   0.3770D 06   0.3900D 06   0.4030D 06   0.4170D 06   0.4310D 06   0.4460D 06   0.4610D 06
ABSTERBERATE JE ZEITSCHRITT   LETHAL RATE PER TIME INTERVAL
    LWR          CONV         HTR-R        HTR-C        NAB
0.0          0.6000D 03   0.0          0.0          0.0
0.0          0.6000D 03   0.0          0.0          0.0
0.0          0.6000D 03   0.0          0.0          0.0
0.0          0.8000D 03   0.0          0.0          0.0
0.0          0.8000D 03   0.0          0.0          0.0
0.0          0.1000D 04   0.0          0.0          0.0
0.0          0.1100D 04   0.0          0.0          0.0
0.0          0.1200D 04   0.0          0.0          0.0
0.0          0.1400D 04   0.0          0.0          0.0
0.0          0.1400D 04   0.0          0.0          0.0
0.0          0.1600D 04   0.0          0.0          0.0
0.0          0.1700D 04   0.0          0.0          0.0
0.0          0.1700D 04   0.0          0.0          0.0
0.0          0.1900D 04   0.0          0.0          0.0
0.0          0.2000D 04   0.0          0.0          0.0
0.0          0.2100D 04   0.0          0.0          0.0
0.0          0.2100D 04   0.0          0.0          0.0
0.0          0.2300D 04   0.0          0.0          0.0
0.0          0.2400D 04   0.0          0.0          0.0
0.0          0.2700D 04   0.0          0.0          0.0
0.0          0.2900D 04   0.0          0.0          0.0
0.0          0.2900D 04   0.0          0.0          0.0
0.0          0.3000D 04   0.0          0.0          0.0
0.0          0.3200D 04   0.0          0.0          0.0
0.0          0.3400D 04   0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0                           CARD 46
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
BESCHRAENKUNGEN NACH OBEN     LIMITATIONS UPWARDS
```

IWR	CONV	HTR-R	HTR-C	NAB
0.1000D 04	0.0	0.0	0.0	0.0
0.1410D 04	0.0	0.0	0.0	0.0
0.2000D 04	0.0	0.0	0.0	0.0
0.2830D 04	0.0	0.0	0.0	0.0
0.4000D 04	0.0	0.0	0.0	0.0
0.5660D 04	0.0	0.0	0.0	0.0
0.8000D 04	0.0	0.0	0.0	0.0
0.1135D 05	0.0	0.5000D 03	0.5000D 03	0.0
0.1600D 05	0.0	0.7050D 03	0.7050D 03	0.0
0.2260D 05	0.0	0.1000D 04	0.1000D 04	0.0
0.3200D 05	0.0	0.1410D 04	0.1410D 04	0.0
0.4250D 05	0.0	0.2000D 04	0.2000D 04	0.0
0.6400D 05	0.0	0.2820D 04	0.2820D 04	0.0
0.9050D 05	0.0	0.4000D 04	0.4000D 04	0.0
0.1280D 06	0.0	0.5660D 04	0.5660D 04	0.0
0.1810D 06	0.0	0.8000D 04	0.8000D 04	0.1000D 04
0.2560D 06	0.0	0.1135D 05	0.1135D 05	0.1410D 04
0.3620D 06	0.0	0.1600D 05	0.1600D 05	0.2000D 04
0.5000D 06	0.0	0.2260D 05	0.2260D 05	0.2830D 04
0.5000D 06	0.0	0.3200D 05	0.3200D 05	0.4000D 04
0.5000D 06	0.0	0.4520D 05	0.4520D 05	0.5660D 04
0.5000D 06	0.0	0.6400D 05	0.6400D 05	0.8000D 04
0.5000D 06	0.0	0.9050D 05	0.9050D 05	0.1135D 05
0.5000D 06	0.0	0.1280D 06	0.1280D 06	0.1600D 05
0.5000D 06	0.0	0.1810D 06	0.1810D 06	0.2260D 05
0.5000D 06	0.0	0.2560D 06	0.2560D 06	0.3200D 05
0.5000D 06	0.0	0.3620D 06	0.3620D 06	0.4250D 05
0.5000D 06	0.0	0.5000D 06	0.5000D 06	0.6400D 05
0.5000D 06	0.0	0.5000D 06	0.5000D 06	0.9050D 05
0.5000D 06	0.0	0.5000D 06	0.5000D 06	0.1280D 06
0.5000D 06	0.0	0.5000D 06	0.5000D 06	0.1810D 06
0.5000D 06	0.0	0.5000D 06	0.5000D 06	0.2560D 06
0.5000D 06	0.0	0.5000D 06	0.5000D 06	0.3620D 06
0.5000D 06	0.0	0.5000D 06	0.5000D 06	0.5000D 06
0.5000D 06	0.0	0.5000D 06	0.5000D 06	0.5000D 06
0.5000D 06	0.0	0.5000D 06	0.5000D 06	0.5000D 06
0.5000D 06	0.0	0.5000D 06	0.5000D 06	0.5000D 06
0.5000D 06	0.0	0.5000D 06	0.5000D 06	0.5000D 06
0.5000D 06	0.0	0.5000D 06	0.5000D 06	0.5000D 06
0.5000D 06	0.0	0.5000D 06	0.5000D 06	0.5000D 06
0.5000D 06	0.0	0.5000D 06	0.5000D 06	0.5000D 06
0.5000D 06	0.0	0.5000D 06	0.5000D 06	0.5000D 06
0.5000D 06	0.0	0.5000D 06	0.5000D 06	0.5000D 06
0.5000D 06	0.0	0.5000D 06	0.5000D 06	0.5000D 06
0.5000D 06	0.0	0.5000D 06	0.5000D 06	0.5000D 06
0.5000D 06	0.0	0.5000D 06	0.5000D 06	0.5000D 06
0.5000D 06	0.0	0.5000D 06	0.5000D 06	0.5000D 06
0.5000D 06	0.0	0.5000D 06	0.5000D 06	0.5000D 06
0.5000D 06	0.0	0.5000D 06	0.5000D 06	0.5000D 06
0.5000D 06	0.0	0.5000D 06	0.5000D 06	0.5000D 06

CARD 47

```
 1 1 8 816
 1 1 1 1 1 1 1 1 1 1 1
1234567890PGIABCHE
16 8
```

CARD 48
49
50
51

30. TIME INTERVAL ERGEBNISSE DER OPTIMALISIERUNG RESULTS OF OPTIMIZATION

OUTPUT ILLUSTRATION

```
30.RECHNUNG                                                                                   ZEIT =    0.0          TIME = 0.0
ANZAHL DER U-ITERATIONEN =        2
ITERATIONSSCHRITTE       =       29
LAGRANGEFAKTOREN (DM/KW*A BZW.DM/KG*A)
0.0          0.0          0.0          0.3979D 01  0.0          0.0          0.0          0.0          0.0          0.2773D 04
0.0
KORREKTUR-MATRIX (DM/KW*A)
0.1339D 02  0.0          0.0          0.0
0.0         0.0          0.0          0.0
GEBIETSINDIZES  = 1 2 3 4
INDEXZUORDNUNG  = 5 3 4 1 2
DURCHS. FABRIKATION (T/A)
0.1574D 04  0.3353D 03  0.3695D 03  0.2426D 03  0.0
0.1816D 04  0.7047D 03
DURCHS. AUFARBEITUNG(T/A)
0.1236D 04  0.3029D 03  0.1306D 03  0.3771D 03  0.0
0.1613D 04  0.4335D 03
DURCHS. TRENNANLAGE (T/A)
0.0         0.1903D 04  0.6030D 04  0.6300D 03  0.0
0.8563D 04
NACHFUELL   INVENTAR    EXCORE-FAB   GESAMT
0.0         0.0         0.0          0.0
0.1505D 07 -0.9639D 04 -0.1731D 04  0.1493D 07
0.4039D 07  0.6338D 06  0.5773D 05  0.4731D 07
0.5170D 06 -0.2119D 06 -0.1214D 05  0.2930D 06
0.0         0.0         0.0          0.0
TRENNARBEITSEINHEITEN
0.0         0.1493D 07  0.4731D 07  0.2930D 06  0.0
0.6517D 07
KUMULATIVER GES.-VERBRAUCH BZW. -UEBERSCHUSS(T), (U,A,T,P,3)
0.2185D 06 -0.2074D 06  0.4251D 04 -0.7067D 02 -0.1677D 02
IM INVENTAR GEBUNDENE MENGE (T),(U,A,T,P,3)
0.4735D 05 -0.3836D 05  0.3586D 04  0.1447D 03  0.3391D 02
INST. LEISTUNG (MW),(HOECHSTL.)
0.4109D 05  0.3055D 05  0.8157D 05  0.4831D 05  0.2548D 05
0.1121D 06
GEBIETSZUSCHLAEGE
0.2870D 00  0.2310D 00  0.1760D 00  0.1760D 00  0.1760D 00
INST. LEISTUNG (MW),(ENGPASSL.)
0.5288D 05  0.3760D 05  0.9593D 05  0.5681D 05  0.2997D 05
0.1335D 06
ANTEILM. LEISTUNG ,(ENGPASSL.)
0.1936D 02  0.1376D 02  0.3511D 02  0.2080D 02  0.1097D 02
GRENZEINSCHALTDAUER (H/A)
0.8760D 04  0.8315D 04  0.2350D 04  0.6110D 03
EINSCHALTDAUER (H/A)
0.8760D 04  0.8701D 04  0.5403D 04  0.1258D 04  0.3055D 03
EFFEKTIVE EINSCHALTDAUER (H/A)
0.6807D 04  0.7068D 04  0.4594D 04  0.1070D 04  0.2598D 03
ENERGIE-ERZEUGUNG (MWH/A)
0.3599D 09  0.2658D 09  0.4407D 09  0.6080D 08  0.7785D 07
ANTEILM. ENERGIE-ERZEUGUNG
0.3171D 02  0.2342D 02  0.3883D 02  0.5356D 01  0.6859D 00
HOECHSTLAST (MW)            =      0.2270D 06
ENGPASSLEISTUNG (MW)        =      0.2732D 06
GES. EN.-ERZEUGUNG (MWH/A) =      0.1135D 10
STROMERZEUGUNGSKOSTEN (DM/KWH BZW. DM)
  PRO KWH     PRO JAHR     BARWERT
0.2045D-01  0.2322D 11  0.3050D 10
KUMULATIVE STROMERZEUGUNGSKOSTEN =  0.146978D 12  DM
GESAMTKOSTEN NICHT AKTUALISIERT  =  0.421919D 12  DM
PU- BZW. URAN-233-BILANZWERT (T)
0.2154D 03  0.5068D 02
```

BERECHNETE GROESSEN FUER DIE OPTIMALISIERUNG

CALCULATED SIZES FOR OPTIMIZATION

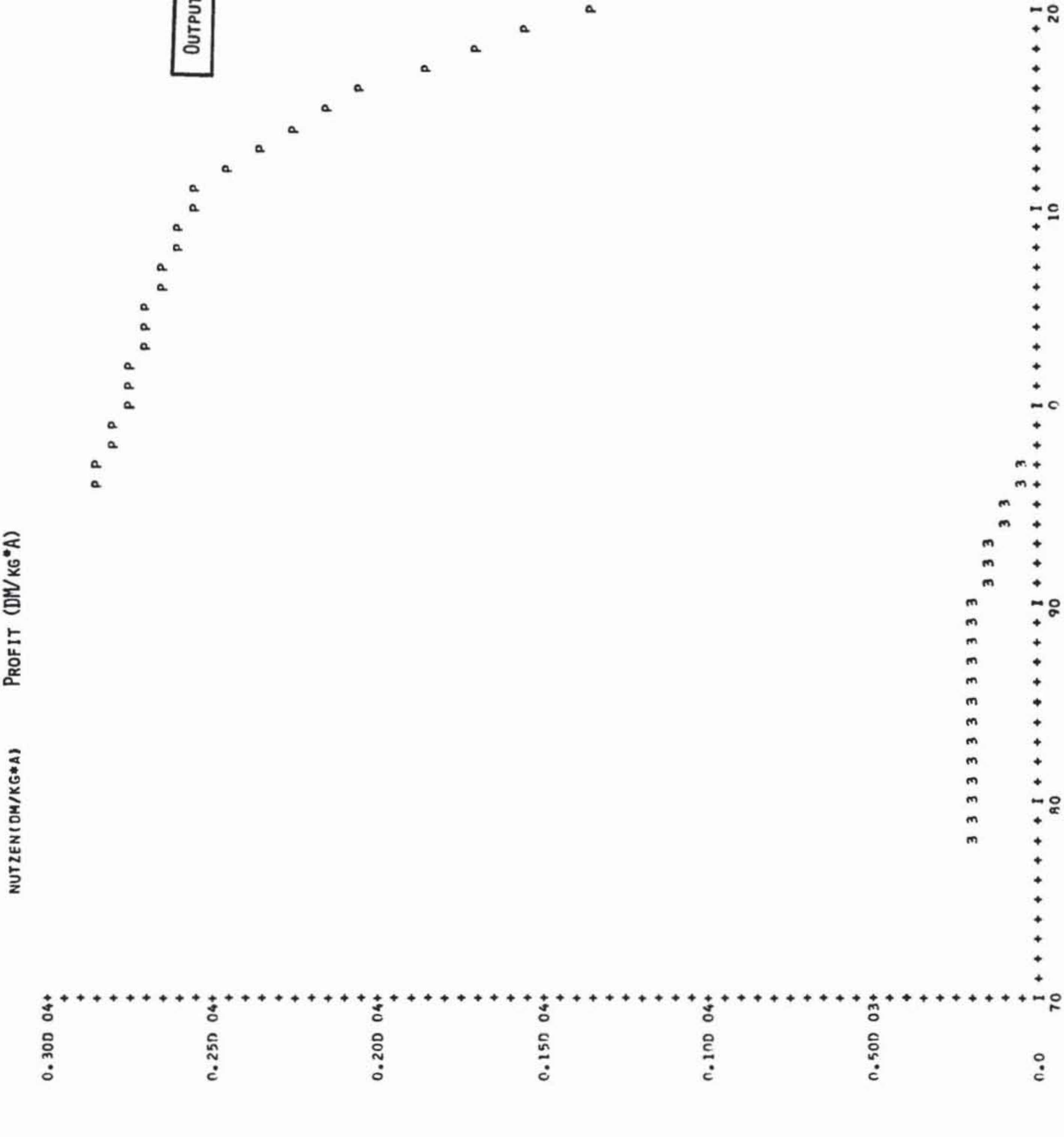
KONZENTRATPPEIS ($/LB U3O8)	=	0.1240D 02
TAILANREICHERUNG	=	0.2000D-02
KOSTEN-TH-232 (DM/KG)	=	0.5000D 02
KOSTEN-U -235 (DM/KG)	=	0.4132D 05
KOSTEN-U -233 (DM/KG)	=	0.4132D 05
KOSTEN-PLUTONIUM (DM/KG)	=	0.4132D 05

LWR	CONV	HTR-R	HTR-C	NAB
0.9637D 03	0.0	0.1200D 02	0.1200D 02	0.1200D 02
0.0	0.0	0.4132D 05	0.4132D 05	0.0
0.1188D 03	0.0	0.1200D 02	0.1200D 02	0.1200D 02
0.0	0.0	0.1200D 02	0.1200D 02	0.0
0.5670D 01	0.0	-0.3910D 00	-0.3910D 00	-0.3910D 00
0.0	0.0	0.1817D 03	0.1817D 03	0.0
VARIABLE KOSTEN (DM/KWH)				
0.4666D-02	0.1725D-01	0.2893D-02	0.3084D-02	0.4779D-03
FIXE KOSTEN (DM/KW*A),		ANNUITAET		
0.7426D 02	0.6259D 02	0.7558D 02	0.7399D 02	0.8441D 02
0.1176D 00	0.1176D 00	0.1176D 00	0.1176D 00	0.1176D 00
NACHFUELLFAKTOREN (T/MWH),(U,A,T,P,3,GESAMT)				
0.2332D-04	0.0	0.7215D-05	0.1168D-04	0.0
-0.1921D-04	0.0	-0.7175D-05	-0.1162D-04	0.3541D-05
0.0	0.0	0.1167D-05	0.3676D-06	0.0
0.0	0.0	0.0	0.0	0.1491D-06
0.0	0.0	0.3391D-07	0.0	0.0
0.4114D-05	0.0	0.1263D-05	0.4319D-06	0.3756D-05
ENTLADEFAKTOREN (T/MWH),(U,A,T,P,3,GESAMT)				
0.4905D-05	0.0	0.0	0.0	0.0
-0.1045D-05	0.0	0.0	0.0	0.3303D-05
0.0	0.0	0.1065D-05	0.2877D-06	0.0
0.2495D-07	0.0	0.0	0.0	0.1921D-06
0.0	0.0	0.3390D-07	0.8830D-08	0.0
0.3899D-05	0.0	0.1121D-05	0.3006D-06	0.3578D-05
INVENTARFAKTOREN (T/MW),(U,A,T,P,3,GESAMT)				
0.5416D 00	0.0	0.7641D-01	0.1152D 00	0.0
-0.4461D 00	0.0	-0.7599D-01	-0.1146D 00	0.4415D-01
0.0	0.0	0.2692D-01	0.2453D-01	0.0
0.0	0.0	0.0	0.0	0.1859D-02
0.0	0.0	0.7819D-03	0.0	0.0
0.9553D-01	0.0	0.2863D-01	0.2517D-01	0.4682D-01
EX-CORE-INV.-FAKT. DER FABR.(T/MW*H/A),(U,A,T,P,3,GESAMT)				
0.1166D-04	0.0	0.1804D-05	0.2920D-05	0.0
-0.9605D-05	0.0	-0.1794D-05	-0.2904D-05	0.7791D-06
0.0	0.0	0.2918D-06	0.9190D-07	0.0
0.0	0.0	0.0	0.0	0.3280D-07
0.0	0.0	0.8477D-08	0.0	0.0
0.2057D-05	0.0	0.3157D-06	0.1080D-06	0.8262D-06
GES. EX-CORE-INVENTAR BEI VOLLAST (PROZENT)				
0.4032D 02	0.0	0.1824D 02	0.6374D 01	0.4893D 02

STROMGESTEHUNGSKOSTEN K (DPFG/KWH) IN ABHAENGIKEIT VOM LASTFAKTOR M BEI DER OPTIMALISIERUNG

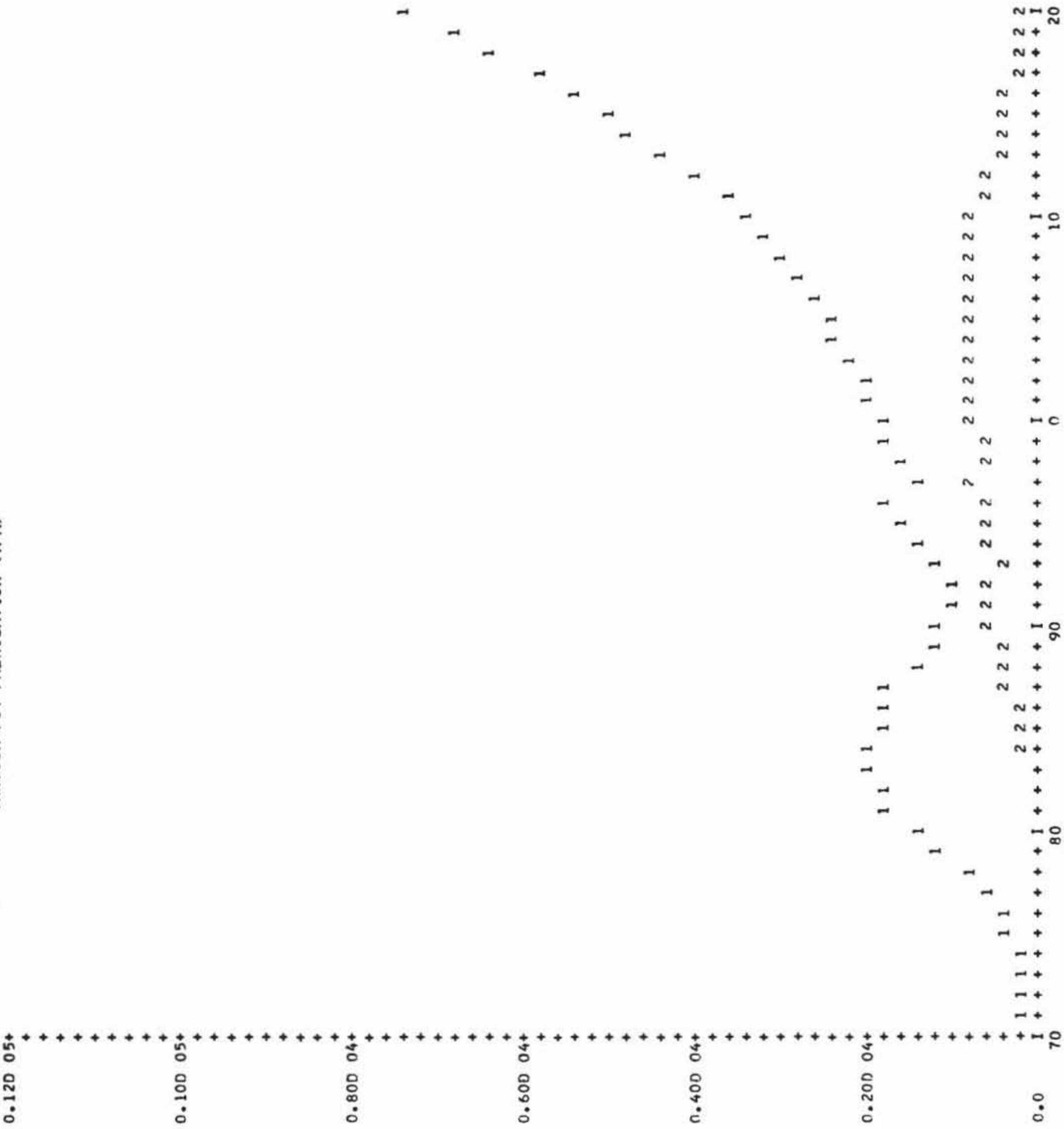
	M=1.0	M=0.9	M=0.8	M=0.7	M=0.6	M=0.5	M=0.4	M=0.3	M=0.2	M=0.1
LWR	1.3143D 00	1.4084D 00	1.5262D 00	1.6775D 00	1.8794D 00	2.1619D 00	2.5857D 00	3.2921D 00	4.7049D 00	8.9432D 00
CCNV	2.4394D 00	2.5187D 00	2.6180D 00	2.7456D 00	2.9157D 00	3.1538D 00	3.5111D 00	4.1065D 00	5.2973D 00	8.8697D 00
HTR-R	1.1521D 00	1.2480D 00	1.3678D 00	1.5219D 00	1.7273D 00	2.0149D 00	2.4463D 00	3.1653D 00	4.6033D 00	8.9173D 00
HTR-C	1.1531D 00	1.2469D 00	1.3643D 00	1.5151D 00	1.7162D 00	1.9978D 00	2.4201D 00	3.1240D 00	4.5318D 00	8.7551D 00
NAB	1.0114D 00	1.1185D 00	1.2523D 00	1.4244D 00	1.6538D 00	1.9750D 00	2.4568D 00	3.2598D 00	4.8658D 00	9.6839D 00

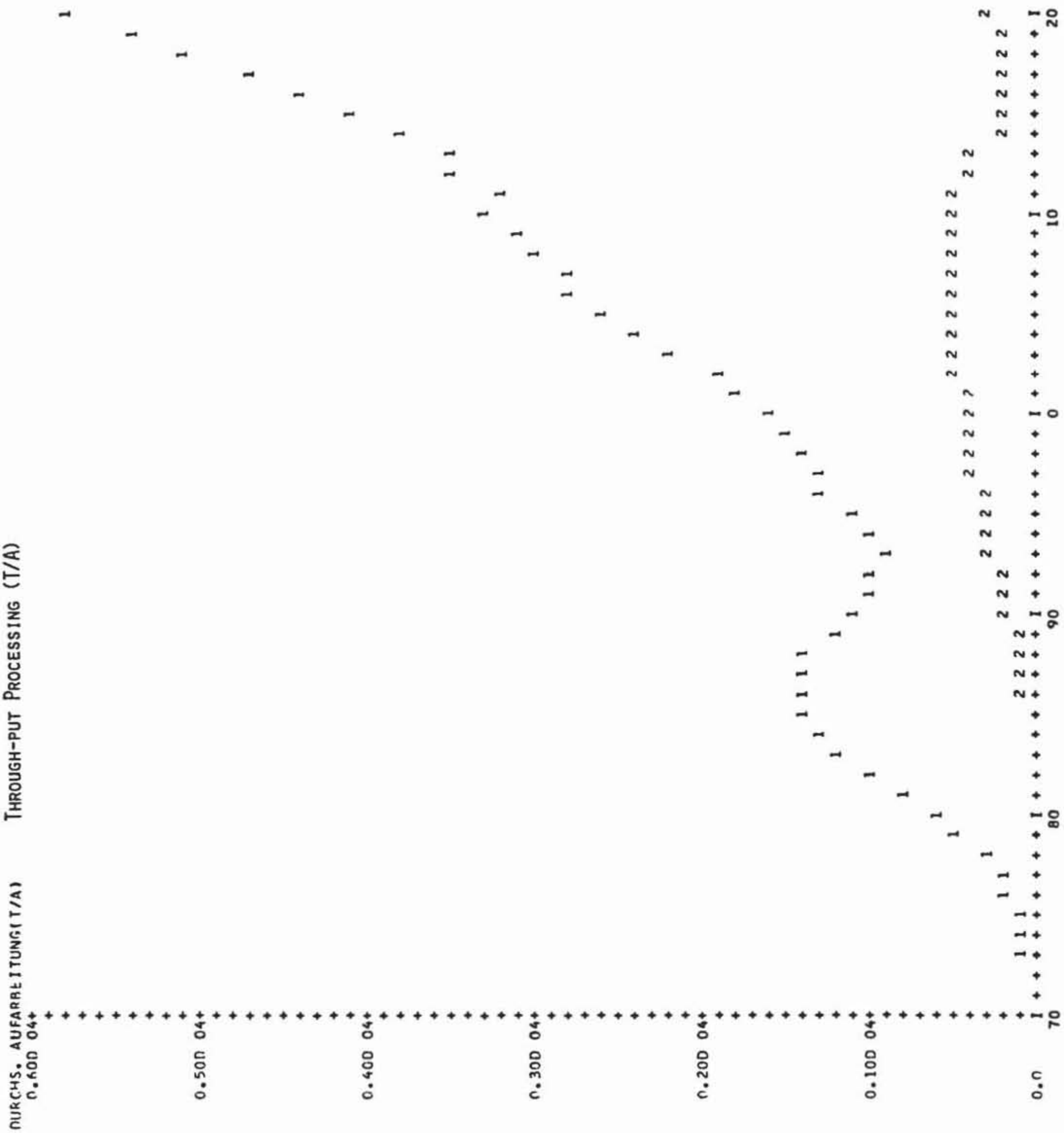
OUTPUT ILLUSTRATION

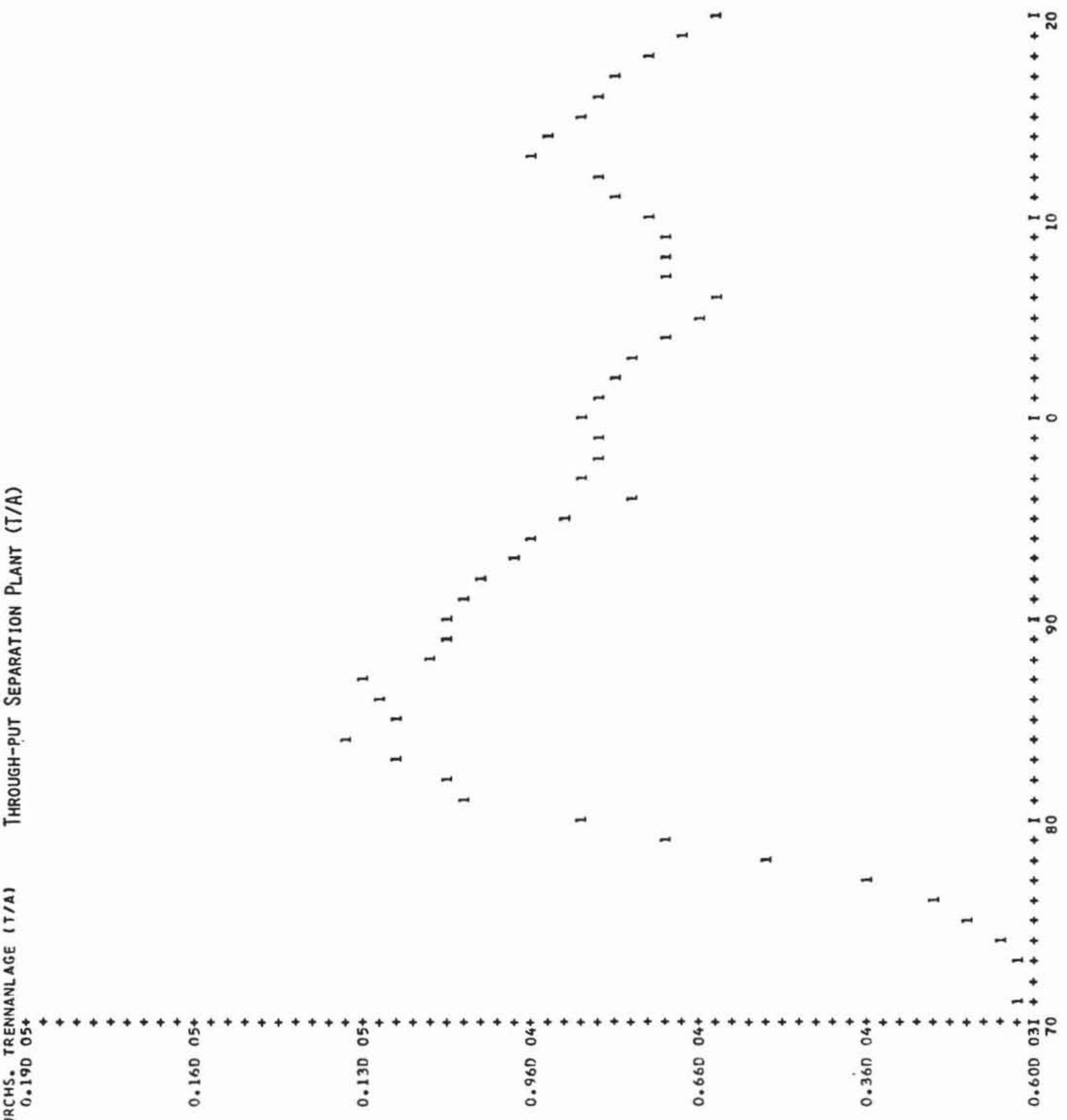


DURCHS. FABRIKATION (T/A)

THROUGH-PUT FABRICATION (T/A)

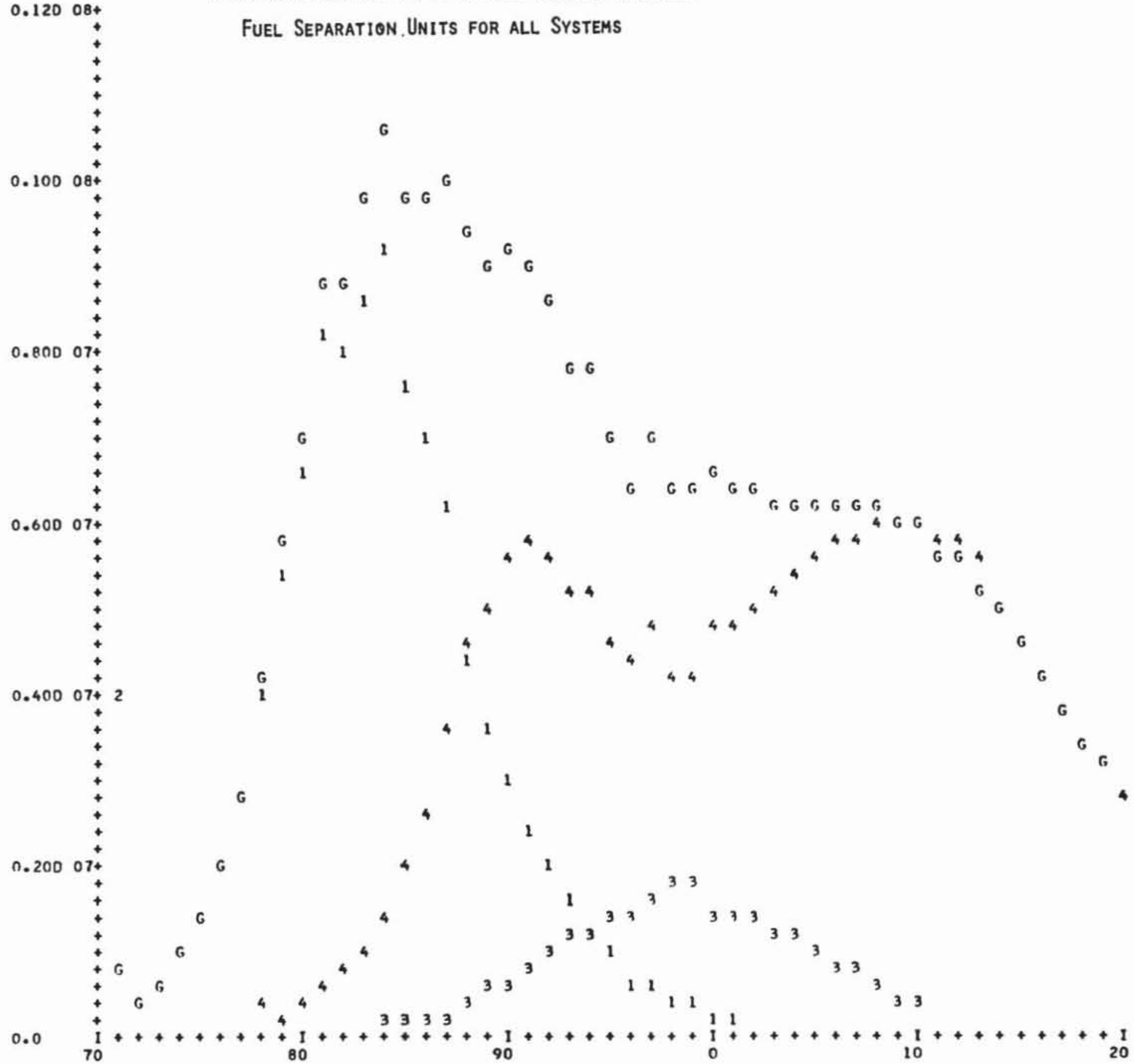


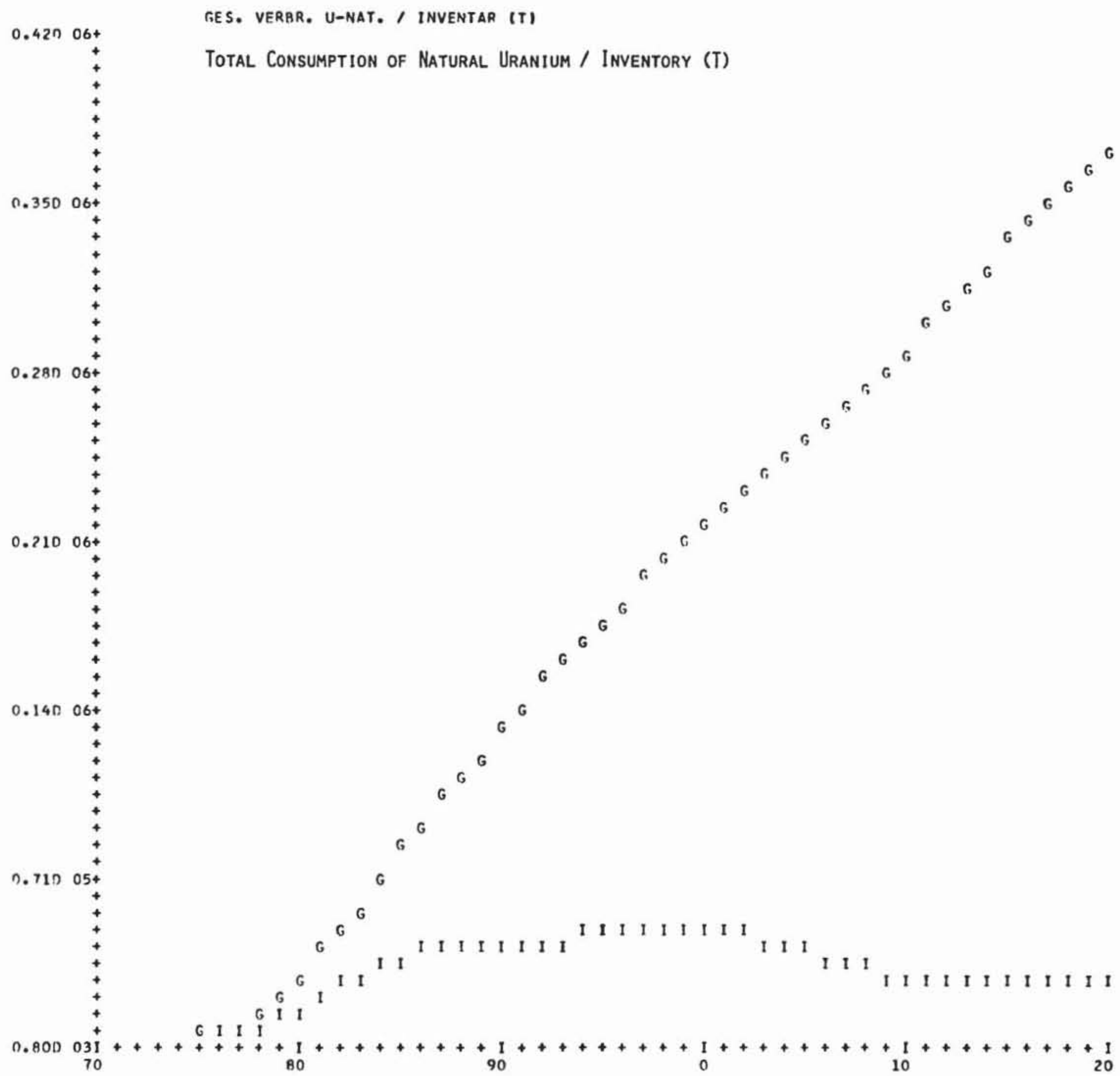

DURCHS. AUFARBEITUNG(T/A)
THROUGH-PUT PROCESSING (T/A)
0.600D 04
0.500D 04
0.400D 04
0.300D 04
0.200D 04
0.100D 04
0.0
70
80
90
0
10
20


DURCHS. TRENNANLAGE (T/A)
THROUGH-PUT SEPARATION PLANT (T/A)
0.19D 05
0.16D 05
0.13D 05
0.96D 04
0.66D 04
0.36D 04
0.60D 03
70
80
90
0
10
20

TRENNARBEITSEINHEITEN FUER ALLE ANLAGEN (VERS.2)

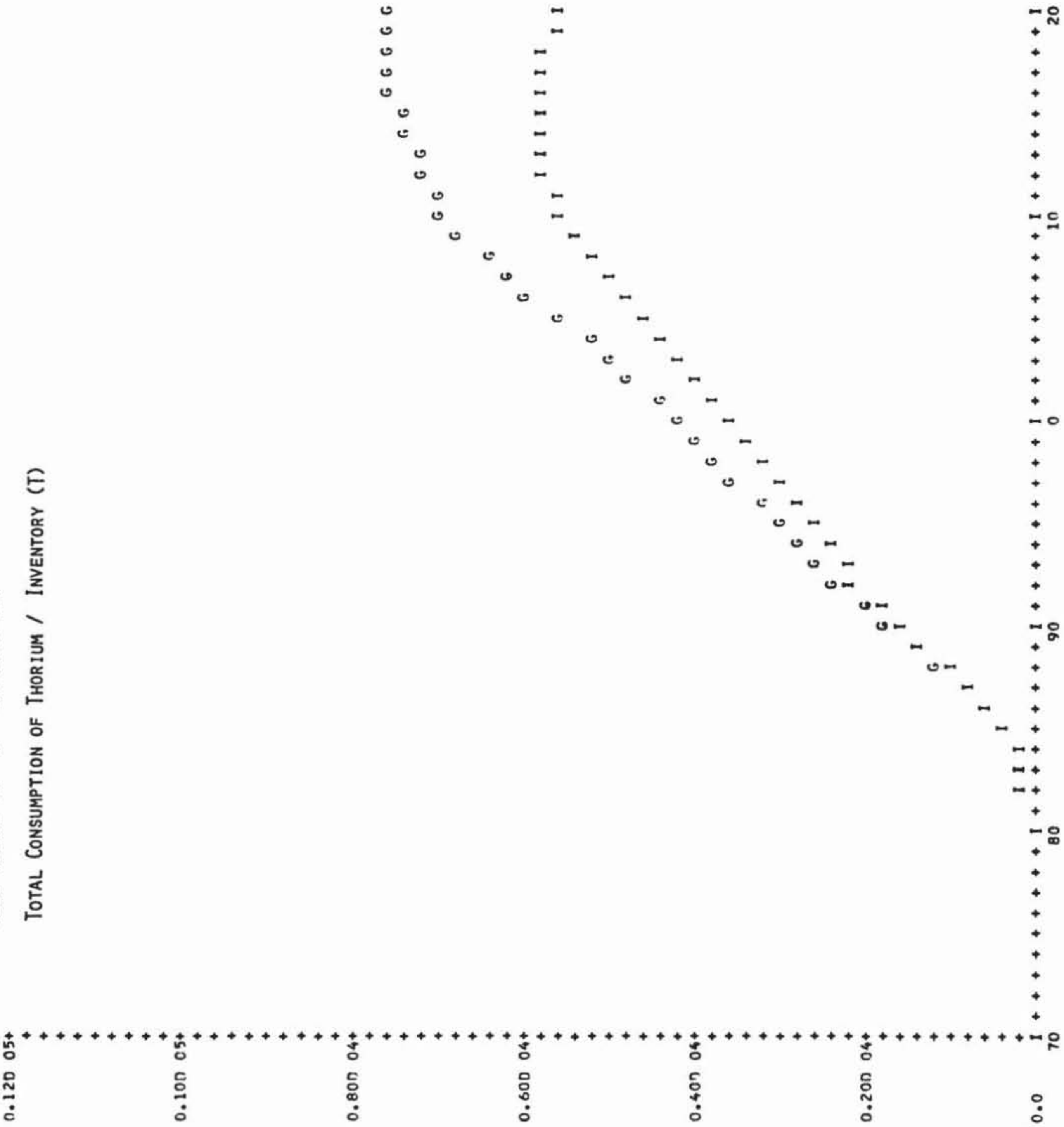
FUEL SEPARATION UNITS FOR ALL SYSTEMS



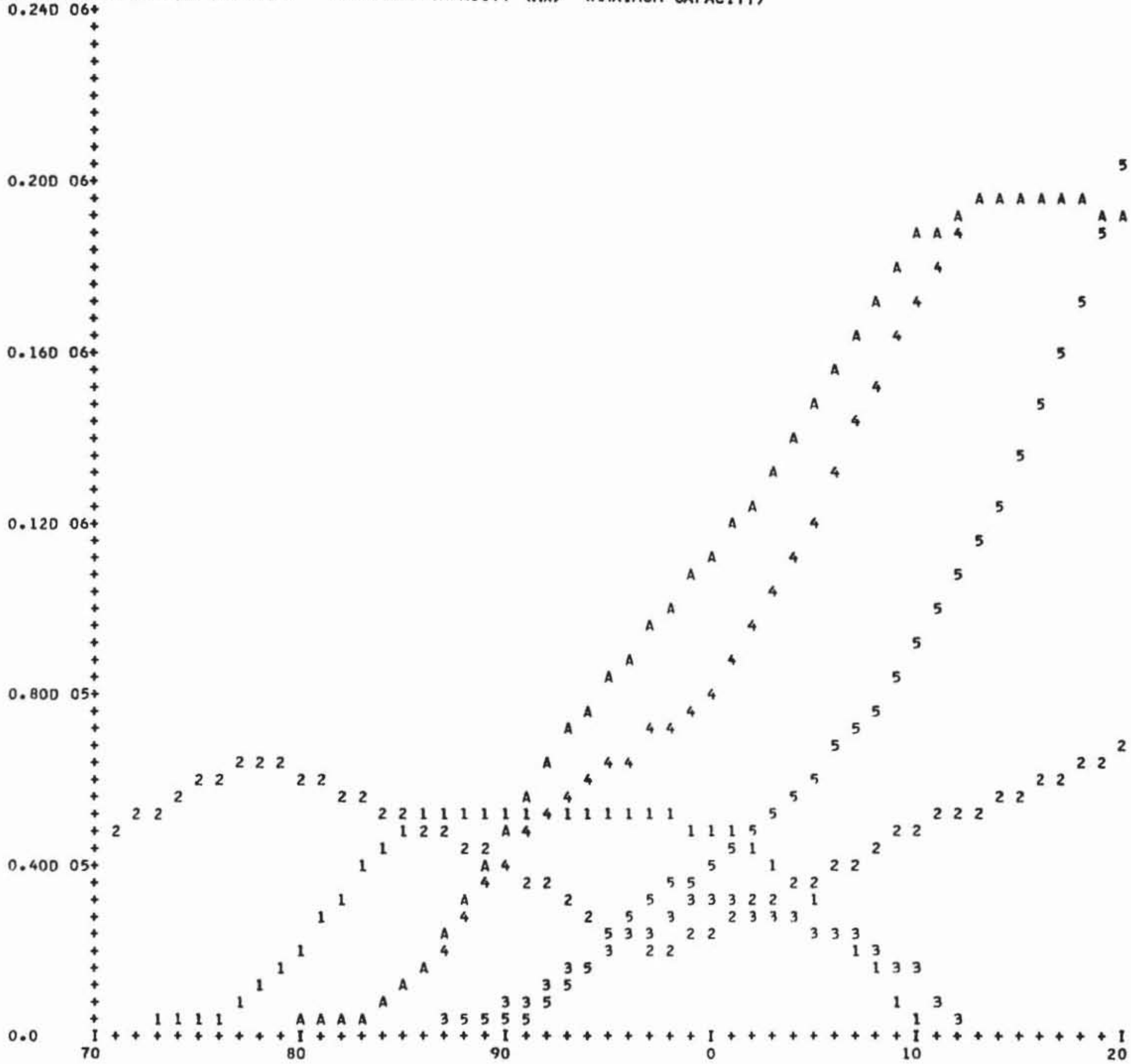

GES. VERBR. U-NAT. / INVENTAR (T)
TOTAL CONSUMPTION OF NATURAL URANIUM / INVENTORY (T)
0.420 06
0.350 06
0.280 06
0.210 06
0.140 06
0.710 05
0.800 03
70
80
90
0
10
20

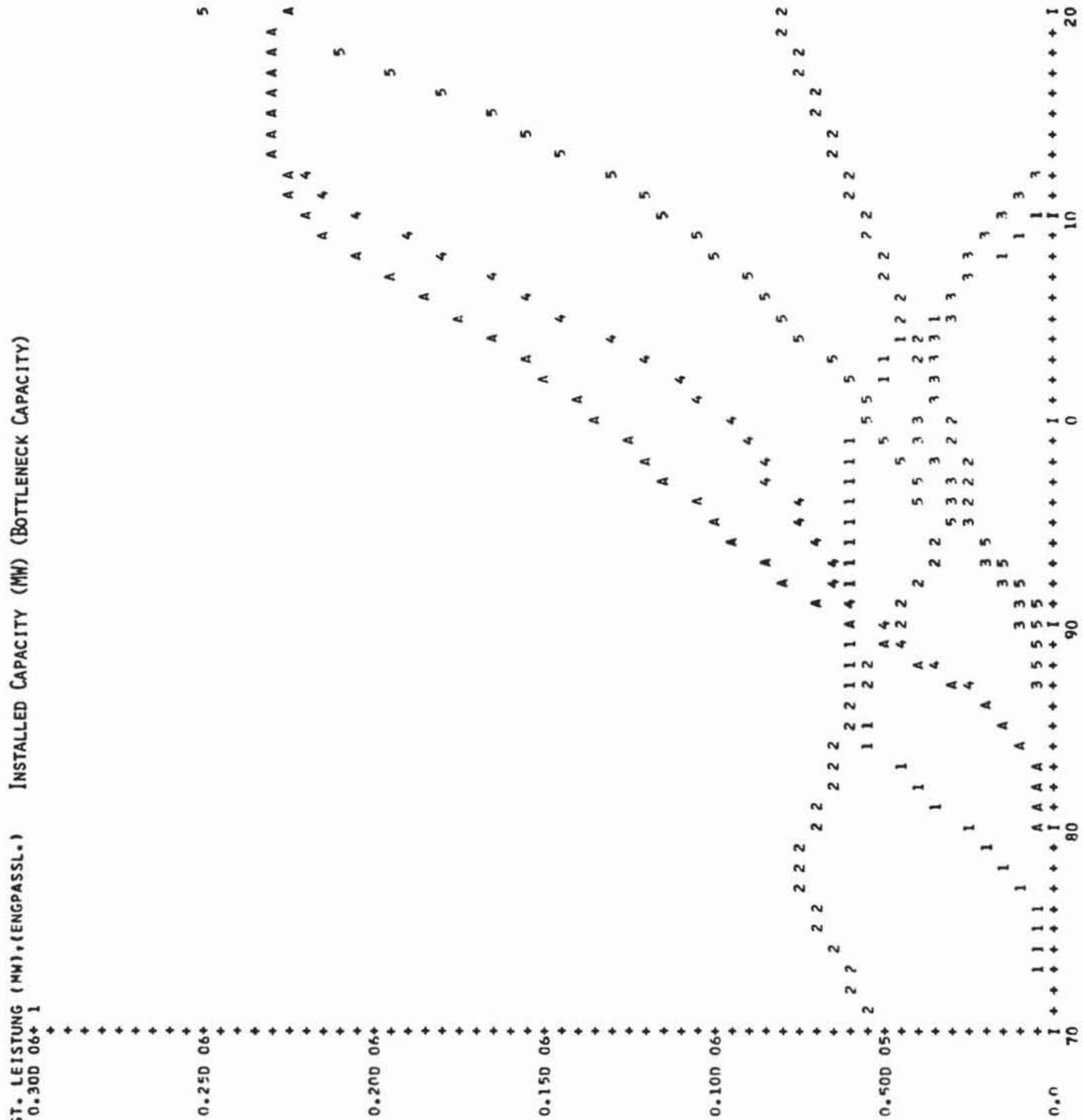
GES. VERBR. TH / INVENTAR (T)

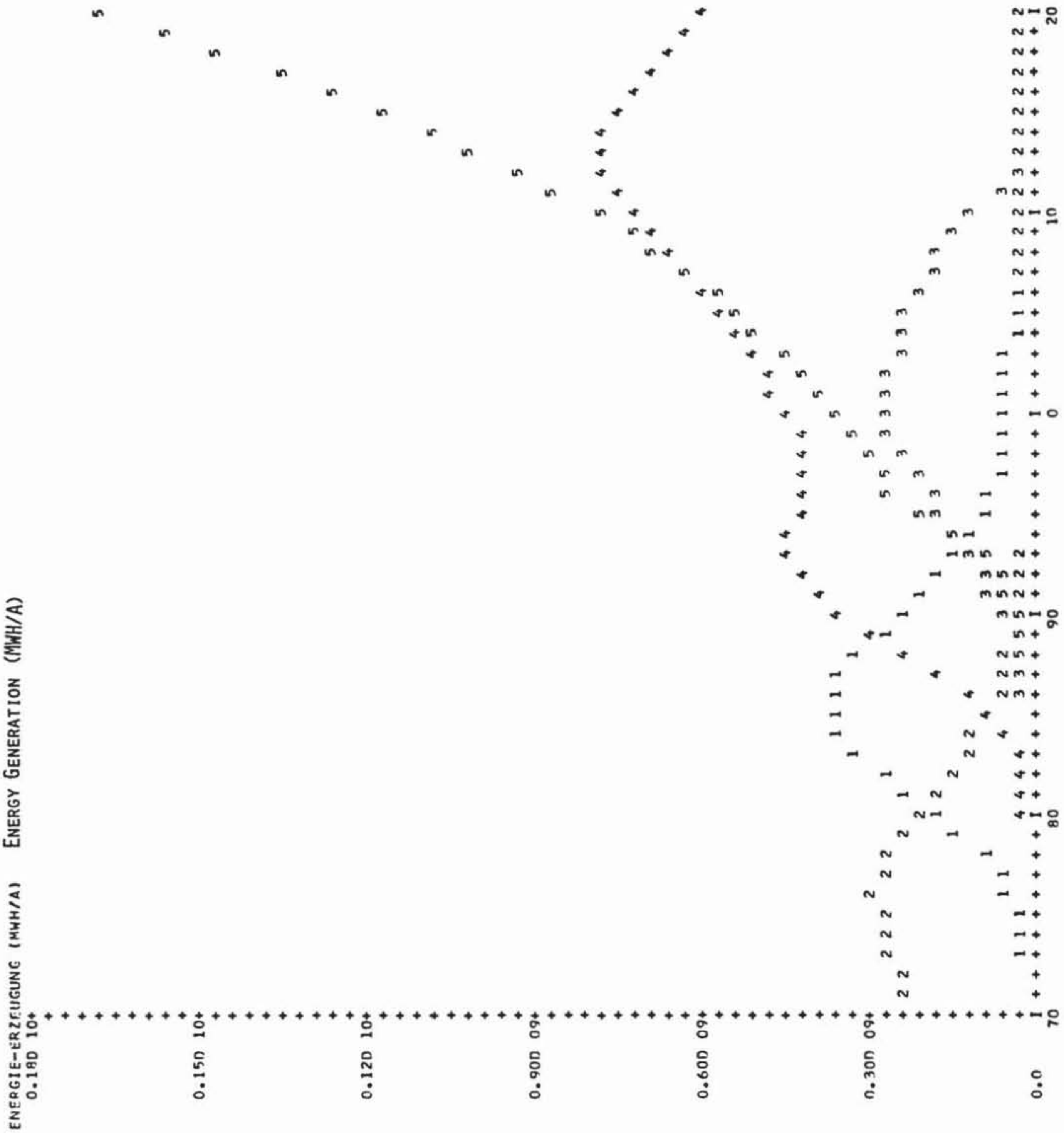
TOTAL CONSUMPTION OF THORIUM / INVENTORY (T)



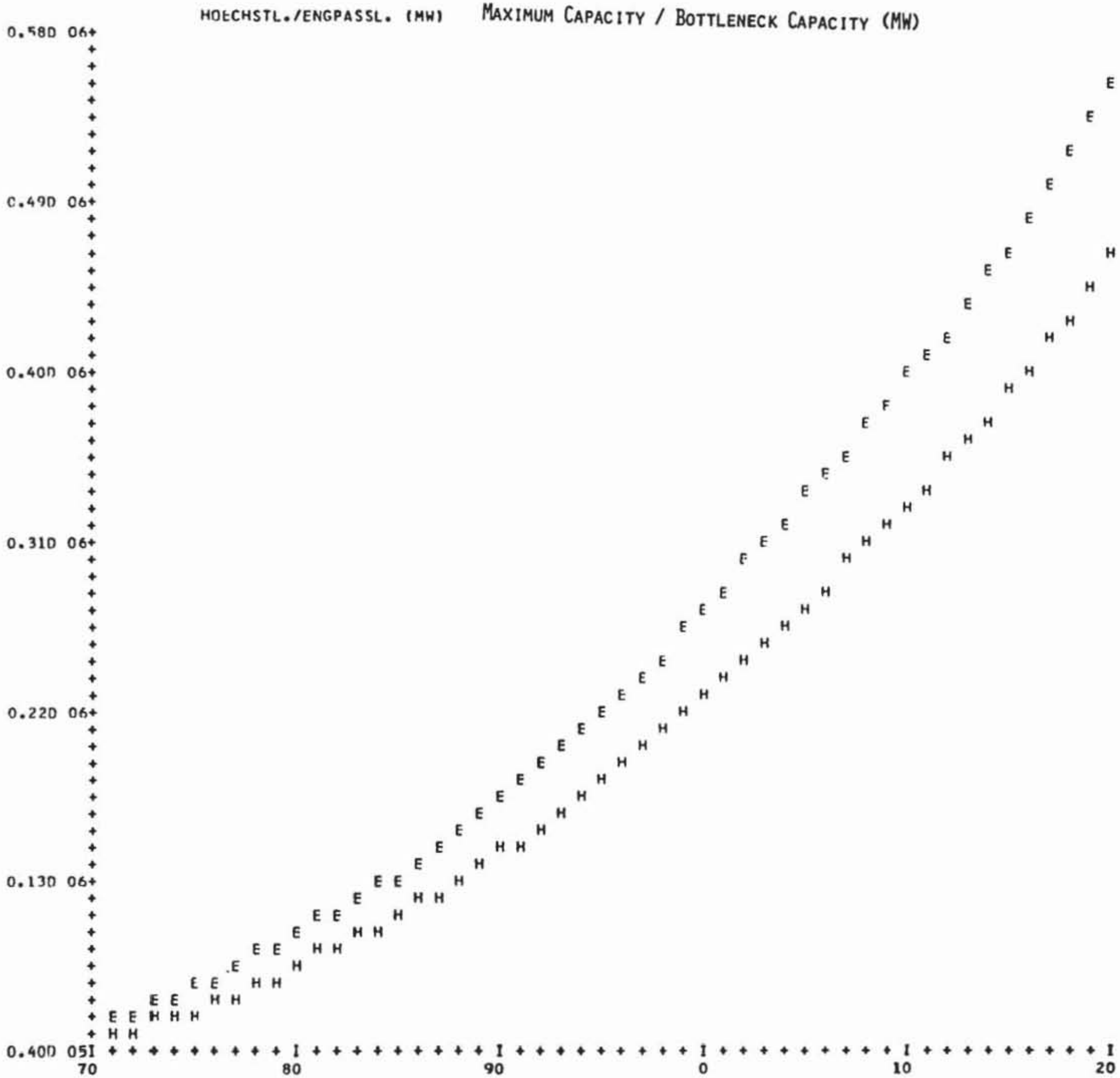
INST. LEISTUNG (MW),(HOECHSTL.) INSTALLED CAPACITY (MW) (MAXIMUM CAPACITY)




INST. LEISTUNG (MW),(ENGPASSL.)
INSTALLED CAPACITY (MW) (BOTTLENECK CAPACITY)
0.300D 06
0.250D 06
0.200D 06
0.150D 06
0.100D 06
0.500D 05
0.0
70
80
90
0
10
20


ENERGIE-ERZEUGUNG (MWH/A)
ENERGY GENERATION (MWH/A)
0.180D 10
0.150D 10
0.120D 10
0.900D 09
0.600D 09
0.300D 09
0.0
70
80
90
0
10
20

MAXIMUM CAPACITY / BOTTLENECK CAPACITY (MW)



STROMERZ.-KOSTEN (DM/KWH)

ELECTRICITY GENERATING COST (DM/KWH)