Strøkøøp

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

Input Description (Status April 1971)

by

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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.
1. ABSTRACT

2. DESCRIPTION OF THE PROGRAM
   2.1 Calculation of fixed and variable cost
      2.1.1 For power plants of fossil fuel
      2.1.2 Nuclear power plants
   2.2 Minimization of cost for electricity generation
      2.2.1 Avoidance of convergence difficulties
   2.3 Accessory conditions
      2.3.1 Availability of capacity required
      2.3.2 Running-in limitation
      2.3.3 Running-out limitation
   2.4 Material balances
      2.4.1 Calculation of through-put factors
      2.4.2 Plutonium and $^{233}$uranium balances
      2.4.3 Cumulative total consumption
      2.4.4 Amount bonded in the inventory
      2.4.5 Through-put of fabrication plants
      2.4.6 Through-put of reprocessing plants
      2.4.7 Calculation of demand of uranium separation
   2.5 Price for fuel
   2.6 Cumulative and actualized cost

3. SPECIAL CALCULATIONS
   3.1 Advanced calculation for an optimization for an average uranium ore price
   3.2 Burning-in system
   3.3 Demand of foreign exchange and capital
   3.4 Uncertainties of input data
   3.5 Through-put dependence of fabrication and processing cost

4. REFERENCES

5. INPUT DESCRIPTION

6. INPUT ILLUSTRATION

7. OUTPUT ILLUSTRATION
1. Abstract.

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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 Fossil Fuel.

\[ k_f = K_B \cdot \alpha + K_{Betr} \]  \hspace{1cm} \text{[DM/KWe\cdot a]} \tag{1} \]

\[ k_v = \frac{860}{\eta} H_f \left(1 + b_v \left(p_z + p_s\right)\right) \]  \hspace{1cm} \text{[DM/KWh]} \tag{2} \]

with being

- \( K_B \) \hspace{1cm} \text{[DM/KWe]} \text{ the total value of direct and indirect capital cost actualized to that time when the power plant was taken into operation;}

- \( K_{Betr} \) \hspace{1cm} \text{[DM/KWe]} \text{ the total annual cost for operation and maintenance;}

- \( H_f \) \hspace{1cm} \text{[DM/Kcal]} \text{ average cost of heat value for fossil fuel;}

- \( \eta \) \hspace{1cm} \text{capital efficiency rate;}

- \( b_v \) \hspace{1cm} \text{fuel reserves referred to annual through-put;}

- \( p_z \) \hspace{1cm} \text{[l/a]} \text{ annual rate of interest;}

- \( p_s \) \hspace{1cm} \text{[l/a]} \text{ annual rate of tax;}

- \( P_v \) \hspace{1cm} \text{[l/a]} \text{ 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:

\[ \alpha = \frac{p_z + p_s}{1 - (1 + p_z + p_s)^{-t_{AB}}} + p_v \]  \hspace{1cm} \text{[1/a]} \tag{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:

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

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

with being:

\( x_{A,j}^k \) 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 \( \hat{e} \));

\( \alpha_{FAB} \) factor of high demand in fuel element fabrication for consideration of fabrication losses;

\( \alpha_{AUF} \) loss factor during reprocessing;

\( K_{FAB} \) [DM/kg] total fabrication cost of fuel elements;

\( K_{AUF} \) [DM/kg] total processing cost, inclusively transportation cost;

\( \gamma \) mass proportion of heavy metal (end : beginning).

Summarizing is made on the following materials: enriched uranium, depleted uranium, thorium, fissile plutonium, and \( ^{233}\text{Uranium} \).

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:

\[ k_f = K_B \alpha + K_{Betr} + \sum_j a_j (K_{A_j} f_A + K_{E_j} f_E) \left[ \frac{n \cdot R_j}{[DM/kW_{th} \cdot a]} \right] \]  

with being

\( \alpha \) \text{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:

\[ K_V = \sum_j a_j \left( K_{A_j} \left[ 1 + p_z \left( \frac{1}{2} t_{FAB} \right) \right] + p_s t_{FAB} \right) - K_{E_j} \left[ 1 + p_z \left( \frac{1}{2} t_{AUF} \right) \right] \]

\[ \left[ \frac{[DM/kWh]}{24 \cdot n \cdot A_j} \right] \]  

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:

\[ K_{Verb} = \frac{1}{C_{Verb}} \sum_{i=1}^{n} \left( k_{ri} + k_{vi} T_i \right) C_i \left[ \frac{[DM/kW_{th} \cdot a]}{[DM/kW_{th} \cdot a]} \right] \]
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:

\[ k_{v_i+1} > k_v \quad \text{falls} \quad T_{i+1} < T_i \]  

(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 \( K \) for an average operating time \( T \) at

\[
\bar{k} = \frac{1}{T} \sum_{i=1}^{n} \left\{ k_{f_i} (X_i - X_{i-1}) + k_{v_i} \right\} \int_{X_{i-1}}^{X_i} T(X) \, dx \quad \text{[DM/kWh]} \tag{12}
\]

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

\[
\frac{\delta \bar{k}}{\delta X_i} = 0 \tag{13}
\]

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

\[
k_{f_i} + \Theta_{i+1} k_{v_i} = k_{f_{i+1}} + \Theta_{i+1} k_{v_{i+1}} \tag{14}
\]

\[
\Theta_{i+1} = T(X_i) = \frac{k_{f_i} - k_{f_{i+1}}}{k_{v_{i+1}} - k_{v_i}} \quad \text{[h/a]}
\]

to limits of capacity portions \( X_i \) anticipated in the cost minimum for

\[
T(X_i) = \Theta_{i+1} \tag{15}
\]

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 \( k_{v_{i+1}} > k_{v_i} \) [Eq. 11], thus in a cost-optimum system for fix cost of neighboured types must valid

\[
k_{f_{i+1}} < k_{f_i}
\]

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.
Thus, to fulfill inequation

\[ T_{\text{max}} > \theta^2 = \frac{k_{f1} - k_{f2}}{k_{v2} - k_{v1}} \]  

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 too small that inequality (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

\[ \theta^2 = \frac{k_{f1} - k_{f2}}{k_{v2} - k_{v1}} < \theta^3 = \frac{k_{f2} - k_{f3}}{k_{v3} - k_{v2}} \]  

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

If in contrary to inequation (15)

\[ \theta^i_{i-1} \leq \theta^i+1 \]  

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 neighbours 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.

$$\sum_{i=1}^{n} C_i(t) = C_m(t)$$  \hspace{1cm} (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:

$$C_i(t) \geq C_i(t-1) - A_i(t-1)$$  \hspace{1cm} (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:

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

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 $DF_N$.

$$DF_{N,i,k} = \frac{\sum_{j} A_{i,j} \cdot x_{A,i,j} \cdot \alpha_{FAB,i}}{24 \cdot \eta} \quad [\text{MWh}] \quad (22)$$

2.4.1.2 Discharging Factor $DF_E$.

$$DF_{E,i,k} = \frac{\sum_{j} A_{i,j} \cdot x_{E,i,j} \cdot \gamma_{i,j} \cdot \alpha_{AUF,i}}{24 \cdot \eta} \quad [\text{MWh}] \quad (23)$$

2.4.1.3 Factor of Inventory Arrangement $DF_I$.

$$DF_{I,i,k} = \frac{\sum_{j} R_{i,j} \cdot \alpha_{Res,i} \cdot x_{A,i,j} \cdot \alpha_{FAB,i}}{\eta} \quad [\text{MW(e)}] \quad (24)$$
2.4.1.4 Factor of Excore Inventory of Fabrication Plants $DF_F$.

$$DF_F, i, k = \sum_{j}^{a_i,j} A_{i,j} \cdot x_{A, i, j}^k \cdot \alpha_{FAB} \cdot \frac{t_{FAB}}{24 \cdot \eta} \cdot \frac{a}{t_{FAB}} \text{[to/MW h]}$$ (25)

2.4.1.5 Factor of Excore Inventory of Processing Plant $DF_A$.

$$DF_A, i, k = \sum_{j}^{a_i,j} A_{i,j} \cdot x_{E, i, j}^k \cdot \gamma_{i,j} \cdot \frac{\alpha_{AUF} \cdot t_{AUF}}{24 \cdot \eta} \cdot \frac{a}{t_{AUF}} \text{[to/MW h]}$$ (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,
- $x_{A, i, j}^k$ the ratio of material $k$ in the fuel in the beginning or end of introduction into reactor field $j$ of reactor type $i$,
- $x_{E, i, j}^k$ the factor of surplus demand for fuel element fabrication of $i$-th reactor,
- $\alpha_{FAB,i}$ the loss factor during reprocessing for type $i$,
- $\alpha_{AUF,i}$ 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:

$$\sum_{i=1}^{n} \left\{ [DF_N, i - DF_E, i] \left[1 - (t_{AUF, i} + t_{FAB, i})\right]\right\} \cdot T_i + DF I, i \cdot C_i < M_v \text{ [to]}$$

Equation (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:
\[ V_k^i(t) = \sum_{t} \sum_{i} \left\{ (DF_{N,i}^k - DF_{E,i}^k) E_i(t) + DF_{I,i}^k (C_i - C_i(t-1)) \right\} + \left\{ (DF_{F,i}^k + DF_{A,i}^k) (E_i(t) - E_i(t-1)) \right\} \]  

(28)

with being

\[ E_i(t) \quad \text{[MWh]} \quad \text{the energy generation of power plant } i \text{ in time interval } t, \]

\[ C_i(t) \quad \text{[MW(e)]} \quad \text{the bottleneck capacity of plant type } i \text{ installed in time interval } t. \]

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 \( t \).

\[ M^k_{i}(t) = \sum_{i=1}^{n} \left\{ DF_{I,i}^k \cdot C_i(t) + E_i(t) \left( DF_{F,i}^k + DF_{A,i}^k \right) \right\} \]  

(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.

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

(30)

2.4.6 Through-put of Reprocessing Plants.

The calculation of the through-put of reprocessing plants is made analogously to 2.4.5.
\[ D_{\text{ADF}}(t) = \sum_{i=1}^{n} \{ D_{\text{E},i} \cdot E_i(t) + D_{\text{I},i} \cdot [C_i(t) - C_i(t-1)] + D_{\text{A},i} \cdot [E_i(t) - E_i(t-1)] \} \]  

(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 viewpoint 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:

\[
\begin{align*}
\text{TK}_i(t) &= (D_{\text{P},i} \cdot P_{\text{an}}(\varepsilon_A) - D_{\text{N},i} \cdot P_{\text{NAT}}) \cdot E_i(t) \\
&= (D_{\text{P},i} \cdot P_{\text{an}}(\varepsilon_E) - D_{\text{E},i} \cdot P_{\text{NAT}}) \cdot E_i(t) \\
&+ (D_{\text{I},i} \cdot P_{\text{an}}(\varepsilon_A) - D_{\text{I},i} \cdot P_{\text{NAT}}) \cdot (C_i(t) - C_i(t-1)) \\
&+ (D_{\text{F},i} \cdot P_{\text{an}}(\varepsilon_A) - D_{\text{F},i} \cdot P_{\text{NAT}}) \cdot (E_i(t) - E_i(t-1))
\end{align*}
\]

(32)

with being

\[ P_{\text{an}}(\varepsilon_A), P_{\text{an}}(\varepsilon_E) \ \text{[DM/kg]} \] the price for enriched uranium of enrichment \( \varepsilon_A \) (fresh fuel) or \( \varepsilon_E \) (unloaded fuel)

\[ D_{\text{NAT}}' \] the specific amount of natural uranium required for production of enriched uranium of enrichment \( \varepsilon \).

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:
\[
\begin{align*}
U'_{\text{NAT}}(t) - \varepsilon_f \cdot E_i(t) &= DF_{\text{NAT}}(t) - E_i(t) \varepsilon_p + DF_{\text{NAT}}(t) \varepsilon_t \cdot E_i(t) \\
\text{and:} \\
U'_{\text{NAT}}(t) - E_i(t) &= DF_{\text{NAT}}(t) - E_i(t) + DF_{\text{NAT}} \varepsilon_f - E_i(t)
\end{align*}
\]

with \( \varepsilon_p, \varepsilon_t, \varepsilon_f \) being \(^{235}\)uranium weight concentrations for flow of product, tail, and feed. In the case of discharge-factor, the uranium enrichment of depleted fuel \( \varepsilon_f \) is employed for \( \varepsilon_p \), and that of fresh fuel \( \varepsilon_A \) for all other factors.

Cost for enriched uranium of enrichment \( \varepsilon_p \) are determined by the theory of the ideal cascade for the optimal tail enrichment:

\[
U'_{\text{p}}(\varepsilon_p) = C_T \left( \frac{(\varepsilon_p - \varepsilon) (1 - 2 \varepsilon)}{\varepsilon (1 - \varepsilon)} - (1 - 2 \varepsilon_p) \ln \frac{\varepsilon_p (1 - \varepsilon)}{\varepsilon (1 - \varepsilon_p)} \right) 
\]

\[\text{[DM/kg]}\] (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

\[
U_{\text{P}} = 2.6 \cdot P_{\text{U3O8}} + C_c \text{ [DM/kg]} \] 

(35)

with \( C_c \) being cost for conversion of U\(_{3O8}\) into UF\(_6\). Factor 2.6 considers the portion of oxygen of U\(_{3O8}\) and the conversion of lb to kg.

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

\[
\frac{U_{\text{an}}}{DF(\varepsilon)} \cdot P(\varepsilon) - DF_{\text{NAT}}(\varepsilon) \cdot P_{\text{NAT}}
\]

TF = \[
\frac{U'_{\text{NAT}}(t) - E_i(t) \varepsilon_f - E_i(t)}{C_T}
\]

(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 \( t \)

\[
TB_i(t) = E_i(t) (TF_{N,i} - TF_{E,i}) + TF_{I,i} (C_i(t) - C_i(t-1)) + \]

\[ TF_{F,i} (E_i(t) - E_i(t-1)) \text{ [kg]} \] 

(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 holds 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:

$$ P_{3O8}^{U} = CK [$/lb] \text{ for } V_{k}^{Nat} \leq M_{Res}^{Nat} \tag{38} $$

$$ P_{3O8}^{U} = CK [$/lb] \frac{V_{k}^{Nat}}{M_{Res}^{Nat}} \text{ for } V_{k}^{Nat} > M_{Res}^{Nat} \tag{39} $$

with being

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

$$ M_{Res}^{Nat} $$ 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 analogous 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

\[
K_{akt}^k(t) = \sum_{i=1}^{n} C_i(t) \left[ X_{v,i}(t) \cdot T_i(t) + X_{f,i}(t) \right] [1 + p_z]^{-t} \text{DM}
\]  

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:

\[
U_{Nat} = \sum_{t=1}^{t_v} \frac{U_{Nat}}{P(t) \cdot V(t)} \left[ \frac{S}{1 - b_1} \right]
\]
with being

\[ U_{\text{Nat}}^{p} \] the average price for uranium ore in the considered time interval \( t_{v} \),

\[ U_{\text{Nat}}^{p}(t) \] the price for uranium ore in time interval \( t \),

\[ U_{\text{Nat}}^{v}(t) \] 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 considers 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 was 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 recyclers 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 indepen-
dent 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:

\[
k^*_V = k^*_V + [k^*_V - k^*_R] \cdot F_1 \quad \text{[DM/KWh]} \quad (42)
\]

\[
k^*_V = k^*_R \cdot F_2 \quad \text{[DM/KWh]} \quad (43)
\]

- \(k^*_V\) real cost
- \(k^*_R\) 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 choice 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 $\Delta K$ for plant cost which are still very uncertain to date. Cost curves of single plants are thereby 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 über Aussichten und Konsequenzen von Kernenergie zur Elektrizitätserzeugung.

[2] K. Wagemann:
Beitrag zu Systemuntersuchungen über die langfristigen wirtschaftlichen Einsatzmöglichkeiten verschiedener Kraftwerkstypen unter besonderer Berücksichtigung des Thorium-hochtemperaturreaktors.
JUL-590-RG (Februar 1969).

[3] A. Boettcher, H. Kraemer, K. Wagemann:
Voraussichtlicher Bedarf an Trennarbeit für 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.

[5] G. Memmert, H. Wellmann:
Studie über die optimale Verwertung von Plutonium in der Energiewirtschaft.
5. Input Description.

Card 1  Optional text.
Format (40I2).

Card 2  Input options NR$, NOUT, NKUP$, NCOST$, NTRENN, NGLEIT, NZUR, NEPS, NFAB, NCON, NFUM, NTAIL, NDEV, Format (40I2).

NR$  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).

NKUP$  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.

NCOST$  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 $\Delta K$ 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 calculat-  
       ed 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 for-  
       eign 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-inte-  
      rvals.  
      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

\( \hat{\Delta} \) Factor to increase converter costs.

\( = \frac{F_2}{F_1} \) from Eq. (43) (1)

FAC3\$

\( \hat{\Delta} \) Factor of cash value for plants 3 and 4

(see Eq. 42) (1)

FACP\$

\( \hat{\Delta} \) Factor of cash value for plants 5 and 6

(see Eq. 42) (1)

If NKUP\$ > 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.

NW\$

\( \hat{\Delta} \) Number of time interval at which the uranium price WN\$ should become valid.

WN\$

\( \hat{\Delta} \) Uranium price valid at time interval NW\$

(\$/lb U\(^{3}O_{8}\))

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 \( \neq 0 \) only.

Card 6

Region of uncertainties \( \Delta K \) for plant cost.

Format (5 E 16.8) 2 cards

EPLON(I), I = 1.10 \( \hat{\Delta} \) uncertainty region of plant cost of type I

(according to follow of input). It is translated into a band width for electricity generating cost (DM/KW(e)).

Card 7

Number of time interval.

Format (40I2).

NREP(I), I = 1.10 \( \hat{\Delta} \) 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 throughput dependent fabrication and processing cost.

Format 4012.

| 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 4012.

IZ1 = Number of zones of LWR for which throughput 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 4012.

N = Number of plants which are to optimize in that case. (1)
Card 14 Life-time of plants.  
L \[ \text{Life-time of plants in years (a).} \]

Card 15 Rate of tax, interest, and insurance.  
S \[ \text{Rate of tax per year (1/a)} \]
R \[ \text{Rate of interest per year (1/a)} \]
P \[ \text{Rate of insurance per year (1/a)} \]

Card 16 Data for cost calculation \( \frac{\text{DM}}{\text{kg}} \) of enriched uranium.  
CT \[ \text{Separation cost } [/\text{kg}] \]
CC \[ \text{Conversion cost } [/\text{kg}] \]
EPSN \[ \text{Enrichment of natural uranium } (1) \]
CK \[ \text{Cost of initial concentration } [/\text{lb } U_3 O_8] \]
EPS \[ \text{Optimum tail enrichment appertaining to } CK \ (1) \ (\text{estimated value nearly } 0.006) \text{ for } NTAIL=0. \]
For NTAIL=1 (procedure of salary increase) is put in the tail-enrichment.

Card 17 Cost of fuel and rate of exchange.  
BETA \[ \text{Cost for depleted uranium } [\text{DM/kg}] \]
BETP \[ \text{Cost for fissile plutonium } " \]
BET3 \[ \text{Cost for } ^{233}\text{uranium } " \]
BETT \[ \text{Cost for thorium } " \]
PARI \[ \text{Rate of exchange } [\text{DM/$}] \]

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

Card 18 Available amount of natural uranium and thorium.  
ZU \[ \text{Available amount } [\text{t}] \text{ of natural uranium at } CK \text{ price (see card 16)} \]
ZT \[ \text{Available amount } [\text{t}] \text{ of thorium at } BETT \text{ price (see card 17)} \]

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  $\equiv$ Amount of natural uranium [t]
ZJA  $\equiv$ Amount of depleted uranium [t]
ZJT  $\equiv$ Amount of thorium [t]
ZJP  $\equiv$ Amount of fissile plutonium [t]
ZJ3  $\equiv$ 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 $3\cdot N$ (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.

The 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)  $\equiv$ 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.

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Power portion</td>
<td>[1]</td>
</tr>
<tr>
<td>2</td>
<td>Specific power of reactor field</td>
<td>[MW/to]</td>
</tr>
<tr>
<td>3</td>
<td>Burn-up</td>
<td>[MWD/to]</td>
</tr>
<tr>
<td>4</td>
<td>Mass proportion γ</td>
<td>[1]</td>
</tr>
<tr>
<td>5</td>
<td>Uranium enrichment in fresh fuel</td>
<td>[1]</td>
</tr>
<tr>
<td>6</td>
<td>Uranium enrichment in depleted fuel</td>
<td>[1]</td>
</tr>
<tr>
<td>7</td>
<td>Mass portion of enriched uranium</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Mass portion of depleted uranium</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Mass portion of thorium</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Mass portion of fissile plutonium</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Mass portion of 233uranium</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Mass portion of enriched uranium</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Mass portion of depleted uranium</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Mass portion of thorium</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Mass portion of fissile plutonium</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Mass portion of 233uranium</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Total fabrication cost</td>
<td>[DM/kg]</td>
</tr>
<tr>
<td>18</td>
<td>Total processing cost</td>
<td>[DM/kg]</td>
</tr>
<tr>
<td>19</td>
<td>Total fabrication time</td>
<td>[a]</td>
</tr>
<tr>
<td>20</td>
<td>Total processing time</td>
<td>[a]</td>
</tr>
</tbody>
</table>

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.

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

Cards 23 - 25 serve for description of annual load curve.
Card 23  Amount of fields ( - 10).
Format 4012.
m  Amount of classification fields [1].

Card 24  Ordinates and abszissa values of annual load curve.
Format 5 E 16.8.
RLAM(I)  \( \geq m + 1 \) ordinate values
(supporting values) (h/a)
ZET(I)  \( \geq m + 1 \) standardized abszissa values (1)
EPSL(I)  \( \geq m \) 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  \( \lambda \) 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  Values for program-internal interrogation.
EPSK  
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.
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.
       0. no "coupled" 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
       gained 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 avail­
       able 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 limita­
       tions).

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.

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


C(I) ≡ NRECHS values of maximum capacity (MW) required for each time interval.
If NRECHS 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 NRECHS 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 NRECHS 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.

\( \triangleq \) 1,N = Number of time interval of initial input for each plant.


\( \triangleq \) 11 plotter code numbers for control of curves to be printed.


\( \triangleq \) 19 given symbols for plotter curves.

Card 51: Balance of plutonium and \(^{233}\)uranium. Format 40I2.

\( \triangleq \) Calculation number at which is to start with plutonium balance.

\( \triangleq \) 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**

**CONV, LWR, HTR-R, HTR-C, NAB**

---

**FINGABRÄTEN**

**INPUT-DATA**

---

**STUFE**

**GROSSEN**

**CONTROL SIZES**

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**INPUT**

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**DATEN AUS FELD 1**

**DATA OF FIELD 1**

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**DATEN AUS FELD 2**

**DATA OF FIELD 2**

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**DATEN AUS FELD 3**

**DATA OF FIELD 3**

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### Code Numbers for Control of Limitations / Through-puts

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### Initial Values

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<tbody>
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### Indices of Areas

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### Amount of Time Intervals

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### Lethal Rate per Time Interval

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### Limitations Upwards

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### Ergebnisse der Optimierung

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Berechnete Grössen für die Optimisierung

| Konzentratspeisung ($/Lr. u308) | 0.12400 02 |
| Tailleicheurung | 0.20000 02 |
| Kosten TH-232 (DM/Kg) | 0.50000 02 |
| Kosten U -235 (DM/Kg) | 0.41320 05 |
| Kosten Plutonium (DM/Kg) | 0.41320 05 |

Calculated Sizes for Optimization

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<th>LWR</th>
<th>HTR-R</th>
<th>HTR-C</th>
<th>NAB</th>
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<tbody>
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<td>0.30840-02</td>
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</table>

| Fix Kosten (DM/KVA) | 0.75540-02 | 0.73940-02 | 0.84410-02 |
| 0.11760 00 | 0.11760 00 | 0.11760 00 | 0.11760 00 |

Nachfüllfaktoren (T/MWH), (Ua, T, P, GESAMT)

| 0.7150-05 | 0.11680-04 | 0.35410-05 |
| 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 |

Entladefaktoren (T/MWH), (Ua, T, P, GESAMT)

| 0.7150-05 | 0.11680-04 | 0.35410-05 |
| 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 |

INVENTARFAKTOR (T/MWH), (Ua, T, P, GESAMT)

| 0.7150-05 | 0.11680-04 | 0.35410-05 |
| 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 |

Gesamtcost (RM) IN VOLLAST (PROZENT)

| 0.1040 00 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 |

STROMLEISTUNGSKOSTEN K (OPF/KWH) IN ABHÄNGIGKEIT VON LASTFAKTOR M BIE DR. OPTIMALISIERUNG

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TRENARBEITSEINHEITEN FUER ALLE ANLAGEN (VERS. 2)
FUEL SEPARATION UNITS FOR ALL SYSTEMS
INST. LEISTUNG (kW) (HOECHSTL.)  INSTALLED CAPACITY (kW) (MAXIMUM CAPACITY)