THE ESTIMATION OF MINERAL RESOURCES
BY THE COMPUTER PROGRAM "IRIS"

by

H.I. DE WOLDE and J. W. BRINCK

1971

Joint Nuclear Research Centre
Ispra Establishment - Italy
Scientific Information Processing Centre - CETIS
and
Directorate-General Energy
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This paper describes the mathematical formulation of a theory as developed by one of the authors, on the long term availability of minerals. By means of this method one may calculate the probable distribution of ore deposits of any size and grade starting from the known reserves. The method is based on a limited binomial expansion. A computer program “IRIS” performs the actual calculations.
COMMISSION OF THE EUROPEAN COMMUNITIES

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ABSTRACT

This paper describes the mathematical formulation of a theory as developed by one of the authors, on the long term availability of minerals. By means of this method one may calculate the probable distribution of ore deposits of any size and grade starting from the known reserves. The method is based on a limited binomial expansion. A computer program "IRIS" performs the actual calculations.

KEYWORDS

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PROGRAMMING
MINERALS
DEPOSITS
MATHEMATICS
DISTRIBUTION
EXPANSION
FORTRAN
ECONOMICS
MINING
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Introduction *)

Almost conventionally, ore reserves are considered as naturally defined, vanishing assets of mostly unknown, but certainly limited magnitude. This consideration, in view of the long term availability of sufficient raw materials has been of grave concern to mineral economists. So far all predictions on the exhaustion of the world's ore reserves have been answered by the mining industry with increased production. It therefore appears that such predictions were based on insufficient quantitative data on the mineral resources from which ore reserves of mineral commodities are developed continuously. One of the authors has developed a theory of which the kernel has been published previously, to increase the prognostic value of these estimations. The method applies a limited binomial expansion to the distribution of a metal in a defined region. The formulation is such that a single constant, the separation factor $q$, defines the dispersion of the metal in the considered region. The actual value of $q$ can be calculated out of the known reserves. Sequentially the distribution of ore deposits of any size and grade can be calculated. To facilitate the computations a computer program named 'IRIS' has been developed. 'IRIS' may calculate also the distributions of minerals according to the log-normal theory for comparison with the present results.

*) Manuscript received on 29 October 1970
A limited binomial expansion

Consider an environment, two- or three-dimensional, of undefined shape, existing out of:

1. A matrix material being the dominant part: \((1-x).R\)
2. An addition representing a small part: \(x.R\)

in which \(R\) is the size of the environment, expressed in surface units, weight units or volume units and \(x\) is the average grade of the addition.

If the environment is divided in two parts, equal in respect to the units in which \(R\) is expressed, the grades of the two parts may be described as:

\[
\begin{align*}
[1+q_{01}] & \cdot x \\
& \text{and} \\
[1-q_{01}] & \cdot x
\end{align*}
\]

in which \(q_{01}\) is the separation factor \(0 \leq q \leq 1\)

If the two parts are in turn divided in two other parts the grades of the four boxes will be:

\[
\begin{align*}
[1+q_{11}] & \cdot [1+q_{01}] \cdot x \\
& \text{,} \\
[1-q_{01}] & \cdot [1+q_{21}] \cdot x \\
[1+q_{01}] & \cdot [1-q_{11}] \cdot x \\
& \text{,} \\
[1-q_{11}] & \cdot [1-q_{21}] \cdot x
\end{align*}
\]

This is called the second order binomial expansion. Each of the four boxes has the size \(\frac{R}{4}\)

A third step gives \(2^3\) boxes of size \(\frac{R}{2^3}\) with the grades:

1. \([1+q_{21}] \cdot [1+q_{11}] \cdot [1+q_{01}] \cdot x\)
2. \([1-q_{21}] \cdot [1+q_{11}] \cdot [1+q_{01}] \cdot x\)
3. \([1+q_{22}] \cdot [1-q_{11}] \cdot [1+q_{01}] \cdot x\)

---------------------------------------

8. \([1-q_{24}] \cdot [1-q_{12}] \cdot [1-q_{01}] \cdot x\)
This division may be continued as illustrated by the diagram:

![Diagram](image)

The $K$-th term in the $N$-order expansion is of the type:

$$\left(\frac{1 \pm q_{NK}}{N}\right) \cdot \left(\frac{1 \pm q_{ij}}{i}\right) \cdots \left(\frac{1 \pm q_{01}}{1}\right) \cdot \bar{x}$$  \[4\]

A reasonable approximation for the $N$th order expansion may be obtained in case the many different $q_{ij}$'s are replaced by one average separation factor $q$, if $N$ is not too small. This has been proved by testcalculations at which arbitrary distributions were generated and approximated with an average separation factor $q$, which can be calculated out of the highest occurring grade $x_{\text{MAX}}$:

$$[1+q]^N \cdot \bar{x} = x_{\text{MAX}}$$  \[5\]

Thus:

$$q = \sqrt[\frac{x_{\text{MAX}}}{\bar{x}}]{N} - 1$$  \[5\]

Consequently the grades of all the $2^n$ boxes at an $N$th order expansion are given by:
\[ x = \left[1 + q\right]^{N-K} \cdot \left[1 - q\right]^K \cdot \sum_{K=0}^{N} C^K_N \times K \]  

in which \( N \) is the order and:

\[ C^K_N = \frac{N!}{K!(N-K)!} \]

For our goals this binomial expansion will be extended to orders of rational numbers and the average separation factor \( q \) will be calculated out of the known exploitable reserves but the general idea is represented by the foregoing description.

The BDW-Function

Consider an environment \( R \) divided in many equal parts \( [\text{boxes}] \), of size \( s \). After estimating the grade of each box a graphical presentation of grade distribution may be given:

\[ \text{grade} \]

\[ \text{boxes ordered to decreasing grade} \]

The BDW-function as developed hereafter, gives an approximation of this curve based on the binomial expansion.

The order \( \alpha \) of an expansion for the environment \( R \) and the box size \( s \), is given by:

\[ 2^\alpha = \frac{R}{s} \]

or

\[ \alpha = \frac{\log R - \log s}{\log 2} \]

In general \( \alpha \) will be a rational number and not an integer.
If the separation factor $q$ is known, a first approximation to the distribution, analogous to expression [6] is given by:

$$x = (1+q)^{\alpha-k} \cdot (1-q)^k \bar{x} \cdot c_k^\alpha \text{ times } k = 0, 1, \ldots$$

where $\bar{x}$ is the average grade of the environment.

However $c_k^\alpha$ is not an integer anymore:

$$c_k^\alpha = \frac{\alpha\cdot(\alpha-1)\cdot(\alpha-2)\cdots(\alpha-k+1)}{k!}$$

If this approximation is ordered according to decreasing grades versus boxnumbers, the graphical presentation becomes:

As such a step function is not very likely to occur in nature, a continuous function may be shaped by connecting the centres of the intervals.

So we obtain a series of points:

$$z_0 = 0.5 \cdot c_0^\alpha \quad ; \quad x_0 = (1+q)^{\alpha} \cdot \bar{x}$$

$$z_i = z_{i-1} + 0.5 \times [c_{i-1}^\alpha + c_i^\alpha] \quad ; \quad x_i = (1+q)^{\alpha-i} \cdot (1-q)^i \cdot \bar{x}$$

The actual calculation may be simplified by:

$$c_i^\alpha = \frac{\alpha - i + 1}{i} \times c_{i-1}^\alpha$$
The BDW-Function may be defined everywhere in the range \([z=0, \ z = 2^\infty]\) by considering the boxnumbers as size units and extrapolating the first branch to \(z=0\).

The function is then given as a series of points \(i\) in parameter representation:

\[
\begin{align*}
\text{BDW Function} \\
Z_i &= Z_{i-1} + 0.5\left[C_{i-1}^\chi + C_i^\chi\right] \\
x_i &= \left[1 + q\right]^{\chi-i} \cdot \left[1 - q\right]^i \cdot \bar{x} \\
i &= 1, 2, \ldots, \leq 2^\infty
\end{align*}
\]

Between these points the pairs of values \([z, x]\) may be obtained by linear interpolation.

Under the foregoing definition the BDW-Function is:

1. A monotonic decreasing continuous function
2. Defined over the interval \([z=0, \ z = 2^\infty]\)
3. Integrable
4. Reversible: the inverse function \([\text{BDWF}]^{-1}\) exists on the same interval.

It must be noted that the separation factor \(q\) is invariant for the environment \(R\) but the BDW-Function is depending on the number of blocks \(2^\infty\) thus also on the size of the blocks, \(s\).

The calculation of the separation factor \(q\)

Considering again an environment of \(R\) tons in which total exploitable reserves have been found of \(r\) tons metal in deposits of an average \(t\) tons metal with an average grade of \(x_r\) PPM, one may calculate the separation factor \(q\) for the environment \(R\).

The individual deposits contain an average of \(t\) tons metal and the grade of these deposits is \(x\) PPM. Thus the individual size is:

\[
s = \frac{t \cdot 10^6}{x_r} \text{ tons ore}
\]
If the whole environment is divided in boxes of size $s$ tons then the order of the division is:

$$\alpha = \frac{\log R - \log s}{\log 2}$$  \[16\]

and the reserves are:

$$10^6 \cdot s \cdot \int_0^{z_r} BDWF(z) \, dz = r$$  \[17\]

in which:

$$z_r = \frac{r}{s} \cdot \frac{10^6}{\alpha}$$ \[18\]

and

$$BDWF(\zeta) = \int_0^{z_r} BDWF(z) \, dz$$

In this stage of the calculations the BDW-Function is not yet known, only the points $z_i$ may be calculated according to the expressions $[14]$. By evaluating the relation $[17]$ we can calculate the value of the separation factor $q$ and sequentially compute the values $x_i$. If $z_m$ is the largest $z$ of the BDW-Function arguments for which $z_m < z_r$ then expression $[17]$ may be written as:

$$0.5 \left[ x_m + x_r \right] \cdot \left[ z_r - z_m \right] + \sum_{i=1}^{m} 0.5 \left[ x_i + x_{i-1} \right] r \left[ z_i - z_{i-1} \right] - \frac{r \cdot 10^6}{s} = 0$$  \[19\]

in which:

$$x_r = x_{m+1} \cdot \frac{\left[ x_m - x_{m+1} \right] \cdot \left[ z_{m+1} - z_r \right]}{\left[ z_{m+1} - z_m \right]}$$  \[20\]

and the expressions for $x_i$ are given by:

$$x_i = \left( 1 + q \right)^{x_{i-1}} \cdot \left[ 1 - q \right] \cdot x_{i-1} \quad i = 1, 2, \ldots$$  \[21\]

$$x_0 = \frac{1 + 3 q + \alpha + q \alpha}{1} \cdot \left[ 1 + q \right]^{x_{-1}} \cdot x_{-1}$$  \[22\]

Out of these equations the separation factor $q$ may be calculated by trial and error, as $q$ has been defined: $0 < q < 1$.

Once $q$ has been calculated one may construct the BDW-Function according to the definition $[14]$, for each order $\alpha$ that means for each boxsize $s$. 
The calculation of the reserves

Considering again the environment \( R \) with now a known separation factor \( q \), one may calculate the total reserves \( r_t \) of a certain quality. Suppose the target deposit is defined as \( s_t \) tons ore with an average grade of \( \bar{x}_t \) PPM of metal.

If the whole environment is divided in boxes of \( s_t \) tons then the order of the binomial expansion is

\[
\alpha = \frac{\log R - \log s_t}{\log 2}
\]  

[23]

As the order \( \alpha \) and the separation factor \( q \) are known, the tabulated BDW-Function can be calculated according to [14], for a boxsize of \( s_t \) tons.

The total reserves \( r_t \) in deposits of \( s_t \) tons and an average grade of \( \bar{x}_t \) PPM are given by:

\[
r_t = 10^{-6} \cdot s_t \cdot \int_0^{z_t} \text{BDWF}(z) \, dz
\]  

[24]

in which the upper boundary \( z_t \) has to be calculated from:

\[
\bar{x}_t = \frac{1}{z_t} \int_0^{z_t} \text{BDWF}(z) \, dz
\]  

[25]

The first step in solving this equation is the identification of the interval \([z_j, z_{j+1}]\) of the tabulated BDW-Function in which \( z_t \) occurs.

The averages of the BDW-Function over each interval \([0, z_i]\) are given by:

\[
\bar{x}_i = \frac{1}{z_i} \int_0^{z_i} \text{BDWF}(z) \, dz \quad i = 1, 2, 3, \ldots
\]  

[26]

or numerically written:

\[
\bar{x}_i = \frac{1}{z_i} \sum_{k=1}^{i} 0.5 \left[ x_k + x_{k-1} \right] \cdot \left[ z_k - z_{k-1} \right]
\]  

[27]

or with a recurrent relation:

\[
\bar{x}_i \cdot z_i = \bar{x}_{i-1} \cdot z_{i-1} + 0.5 \left[ x_i + x_{i-1} \right] \cdot \left[ z_i - z_{i-1} \right]
\]  

[28]
When all the averages \( x_i \) are calculated one can find an integer \( j \) for which:
\[
\bar{x}_j < \bar{x}_t \leq \bar{x}_{j+1}
\] [29]

By interpolation the next relations are derived:
\[
0.5 \left[ x_j + x_j^t \right] \frac{z_j - z_j^t}{z_j^t} + \bar{x}_j \cdot z_j = \bar{x}_t^t
\] [30]
\[
x_t = x_{j+1} + \left[ \frac{z_{j+1} - z_j}{z_{j+1} - z_j} \right] \left[ x_j - x_{j+1} \right]
\] [31]
out of which \( z_t \) can be solved.

We obtain a second degree equation in \( z_t \) by eliminating \( x_t \) and rearranging the terms:
\[
-Az_t + \left[ B + A (z_{j+1} + x_{j+1}) - 2\bar{x}_t \right] z_t + \left[ 2\bar{x}_j z_j - A z_{j+1} z_{j+1} - B z_j \right] = 0
\] [32]
in which
\[
A = \frac{x_j^t - x_{j+1}^t}{z_{j+1} - z_j}
\]
\[
B = x_j^t + x_{j+1}^t
\]
The upper boundary \( z_t \) of the integral [25] can now be calculated directly out of expression [32].

The total reserves in deposits of size \( s_t \) and an average grade of \( x_t \) PPM are \( z_t \) boxes of the same size. Thus:
\[
r_t = z_t \cdot s_t \cdot \bar{x}_t \cdot 10^{-6} \text{ tons of metal}
\] [33]

By this result the calculation is completed.

The Log-Normal Concept

One of the authors of this paper has previously published another approximation to the inventarisation of mineral resources. As the computer program 'IRIS' provides also an option for this method, a short outline of the log-normal theory will be given here.
The log-normal distribution of the element concentrations is the basic concept of the method and the applied calculations:

The weighted frequencies of the logarithms of the element concentrations, estimated from a series of regionally related samples, can be fitted into a normal probability distribution.

It is useful to express the weight of a geochemical sample as a linear equivalent which represents not only the actual quantity of material but also roughly the shape of the sample. The linear equivalent of a volume with the dimensions \(a \gg b \gg c\) is approximately equal to:

\[
d = a + b + c
\]

Generally a description of a deposit is given by its content \(V\) and the dimension ratios \(b/a\) and \(c/b\):

\[
a = \sqrt[3]{\frac{V}{\left(\frac{b}{a}\right)^2 \cdot c/b}} \quad \text{[34]}
\]

\[
d = a \cdot \left[1 + \frac{b}{a} + \frac{b}{a} \cdot \frac{c}{b}\right] \quad \text{[35]}
\]

The linear equivalent of a surface is given by:

\[
a = \sqrt{\frac{S}{b/a}} \quad \text{[36]}
\]

\[
d = a \cdot \left[1 + \frac{b}{a}\right] \quad \text{[37]}
\]

Considering now a random collection of geochemical samples with an average weight \(\overline{d}\), the relation between the average grade \(\bar{x}\) and the median \(\gamma\) is given by:

\[
\bar{x} = \gamma \cdot e^{0.5 \sigma^2} 
\]

in which \(\sigma\) is the standard deviation.

The probability of occurrence \(P_K\) of a concentration \(\geq x_K\) with size \(d\) in the same environment is given by:

\[
P_K = 0.5 - 0.5 \text{ ERF} \left[ \frac{\log x_K - \log \bar{x}}{\sqrt{2} \cdot \sigma} \right] \quad \text{[38]}
\]
Thus the probable available total quantity $r_K$ of all concentrations $\geq x_K$ with average weight $\bar{d}$ is:

$$r_K = p_K \cdot R$$

in which $R$ is the total quantity of the environment. The absolute dispersion coefficient $\alpha$ has been defined to express the relation between the standard deviation and the average size of the samples:

$$\alpha = \frac{G^2}{3 \log \frac{D}{d}}$$

in which $D$ is the linear equivalent of the environment. The dispersion coefficient $\alpha$ is a fractional value directly related to the occurrence of the considered metal in the environment $R$. It is invariant in relation to the collection of samples taken to evaluate the environment $R$.

The previous expressions can be written as:

$$\alpha = \frac{100 \cdot \log \frac{x_K}{\bar{d}}}{6 \log \frac{D}{d} \cdot E^2}$$

$$\frac{x}{\bar{d}} = \exp \left[0.015 \cdot \alpha \cdot \log \frac{D}{d}\right]$$

$$\gamma = \exp \left[-2E^2 + \log x_K + 2E \sqrt{E^2 - \log x_K + \log \frac{\bar{x}}{R}}\right]$$

in which $E = \text{ERF}^{-1} \left[1 - \frac{2r_K}{R}\right]$.

If now for a certain element, the average grade $\bar{x}$ in the environment $R$ is known and the present reserves $r_K$ occur in deposits of size $d$ with an average grade of $x_K$, then $\gamma$ and respectively $\alpha$ may be calculated. Reversible: for each given $x_K$ and $d_K$, the relations give the total occurring reserves of this quality.

Curves of equal metal content

Once the separation factor is known for a metal in a certain environment, one may calculate the total reserves of a given quality $[x, z]$, which means deposits with at least $z$ tons of metal and an average grade of $x$ PPM. The curves of equal metal content give the distribution of
deposits with a fixed quantity of metal, t tons, at varying grades.

Considering all deposits with t tons of metal, there is one with the highest grade: $x_{\text{MAX}}$. According to expression [14]:

$$[1+q]^\alpha \cdot \bar{x} = x_{\text{MAX}} \tag{44}$$

and $s \cdot x_{\text{MAX}} \cdot 10^{-6} = t \tag{45}$

in which $s$ is the yet unknown box size in tons of ore. The order of the expansion for size $s$ is:

$$\alpha = \frac{\log R - \log s}{\log 2} \tag{46}$$

Out of these expressions $x_{\text{MAX}}$ and $\alpha$ can be solved:

$$\frac{\log x_{\text{MAX}} - \log \bar{x}}{\log [1+q]} = \frac{\log R - \log t - \log 10^{-6} \cdot x_{\text{MAX}}}{\log 2}$$

or: $x_{\text{MAX}} = \exp \left[ \frac{\log \bar{x} \cdot 2 \cdot \log [1+q] \cdot \log \frac{R}{t \cdot 10^6}}{\log 2 - \log [1+q]} \right] \tag{47}$

The total reserve of the quality $[x_{\text{MAX}} \cdot t]$ is of course exactly t tons of metal because there is only one such a deposit. Then by choosing a series or $x_i < x_{\text{MAX}}$ and keeping the quantity of metal as t tons, one may calculate the corresponding series of total reserves. The lattice points for the curves of equal metal content are choosen as:

$$x_i = [1+q]^{-k} \cdot [1-q]^k \cdot \bar{x} \text{ with } k = 1, 2, 3, 4, 5 \tag{48}$$

But, as the metal content of t tons stays constant, $\alpha$ is dependent of $x_i$.

The lattice points can be solved by the two additional relations:

$$\alpha = \frac{\log R - \log s}{\log 2} \tag{49}$$

$$s = \frac{t \cdot 10^6}{x_i} \tag{50}$$
Out of these three equations $x_1$, $\alpha$ and $s$ can be solved:

$$\alpha = \frac{k \log \frac{1-q}{1+q} + \log \frac{xR_i}{t \cdot 10^6}}{\log \frac{2}{1+q}}$$

The program 'IRIS'

The program 'IRIS' calculates the probable reserves for a series of target deposits which are specified by size and grade. The basic input data are the presently known reserves. The grade and size of the targets can be given directly or by specifying a development goal which has to be reached in a number of years. In this case the input requests a size increase factor and a grade decrease factor. For example it may be stated that for uranium a deposit of 2/3 times the present deposit grade must contain at least 2.5 times the amount of metal and such a deposit will become exploitable in 20 years. 'IRIS' provides the intermediate targets by logarithmic interpolation. Furthermore curves of equal metal content can be computed i.e. an inventory of all deposits with a fixed quantity of metal and varying grades. These curves may also be obtained as graphical output. The probable reserves can be calculated also according to the long-normal theory for comparison with the binomial expansion results.

The next list gives a description of the input.
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Fortran Names</th>
<th>Rel. Expr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Title</td>
<td></td>
<td>A description of the case of up to 71 characters. A ' * ' in the first column indicates the last case of the run.</td>
</tr>
<tr>
<td>$I_1$</td>
<td>IND(1)</td>
<td>$= 0$ no action $= 1$ [only if the specified environment $R$ concerns the whole earth's crust] The probable reserves will also be calculated according to the Log normal concept.</td>
</tr>
<tr>
<td>$I_2$</td>
<td>IND(2)</td>
<td>$= 0$ each target deposit is given by size and grade $= 1$ the target deposits have to be calculated by a size increase factor $F_z$ and a grade decrease factor $F_x$.</td>
</tr>
<tr>
<td>$I_3$</td>
<td>IND(3)</td>
<td>Calculate also equal metal content curves.</td>
</tr>
<tr>
<td>$I_4$</td>
<td>IND(4)</td>
<td>Graphical output required</td>
</tr>
<tr>
<td>$r$</td>
<td>RSMALL</td>
<td>19 - 22 Present total reserves in tons of metal of quality $[z, x_r]$</td>
</tr>
<tr>
<td>$z$</td>
<td>ZA</td>
<td>19 - 22 Average size of the deposits in tons of metal</td>
</tr>
<tr>
<td>$x_r$</td>
<td>XRSRM</td>
<td>19 - 22 Average grade of the reserves in PPM</td>
</tr>
<tr>
<td>$\overline{x}$</td>
<td>XENV</td>
<td>19 - 22 Average grade of the environment $R$</td>
</tr>
<tr>
<td>$R$</td>
<td>$R$</td>
<td>Size of the environment in tons. The next card has to be present only if $I_1 &gt; 0$ and the environment $R$ is the whole earth's crust: $R = 10^{18}$ tons.</td>
</tr>
<tr>
<td>$\rho$</td>
<td>RHO</td>
<td>34 - 37 Specific gravity of the ore</td>
</tr>
<tr>
<td>$b/a$</td>
<td>BDA</td>
<td>34 - 37 dimension ratios for the average</td>
</tr>
<tr>
<td>$c/b$</td>
<td>CDB</td>
<td>34 - 37 } deposit $a \gg b \gg c$.</td>
</tr>
<tr>
<td>Symbol</td>
<td>Fortran Names</td>
<td>Rel. Expr.</td>
</tr>
<tr>
<td>--------</td>
<td>---------------</td>
<td>------------</td>
</tr>
<tr>
<td>( N )</td>
<td>( \text{NT} )</td>
<td>Number of equal metal content curves to be calculated</td>
</tr>
<tr>
<td>( F_x )</td>
<td>( \text{FACB} )</td>
<td>Grade decrease factor</td>
</tr>
<tr>
<td>( F_z )</td>
<td>( \text{FACA} )</td>
<td>Size increase factor</td>
</tr>
<tr>
<td>( N )</td>
<td></td>
<td>Total number of targets</td>
</tr>
<tr>
<td>( \text{RTAR}(i) )</td>
<td>( \text{RTAR}(i) )</td>
<td>Size of the target in tons of metal</td>
</tr>
<tr>
<td>( \text{XTAR}(i) )</td>
<td>( \text{XTAR}(i) )</td>
<td>Grade of the target in PPM</td>
</tr>
<tr>
<td>( \text{T(i)} )</td>
<td></td>
<td>Tons of Metal. For each ( \text{T(i)} ) 'IRIS' calculates the curve of the grades versus total reserves.</td>
</tr>
</tbody>
</table>

The next card has to be present only if \( I_2 > 0 \). The \( N \) target deposits will be calculated by:

\[
\begin{align*}
  z_i &= z \cdot F_z \frac{N_y}{i} \\
  x_i &= x \cdot F_x \frac{N_y}{i} \quad i = 1, \ldots, N
\end{align*}
\]

After \( N_y \) steps the target is \( F_z \cdot z \) tons metal and of grade \( F_x \cdot x \).
### Problem Title

#### Table

<table>
<thead>
<tr>
<th>I</th>
<th>Z</th>
<th>X₀</th>
<th>R</th>
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**NOTES**
- ONLY IF $I_2 > 0$
- ONLY IF $I_2 > 0$
- ONLY IF $I_2 = 0$
- ONLY IF $I_2 > 0$

### Uranium Resources

#### 1.11

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**TARGET DEPOSIT**

100000 TONS OF METAL

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**TARGET DEPOSIT**

50000 TONS OF METAL

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**TARGET DEPOSIT**

1000000 TONS OF METAL

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**TARGET DEPOSIT**

GRADE NUMBER DEPOSITS SIZE DEPOSIT TONS METAL ORDER

HIGHEST GRADE DEPOSIT

978 PPM
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**TARGET DEPOSIT**

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**TARGET DEPOSIT**

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**TARGET DEPOSIT**

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TARGET DEPOSIT: 500,000,000 TONS OF METAL

HIGHEST GRADE DEPOSIT: 1210 PPM
PROGRAM IRIS-B BY HERMAN I. DE WOLDE -- JANUARY 1970 --

IRIS CALCULATES MINERAL RESERVES OF SPECIFIED GRADES AND SIZES
ACCORDING TO A BINOIMAL DISTRIBUTION

THE BASIC DATA FOR THE BINOIMAL DISTRIBUTION ARE DERIVED
FROM PRESENTLY KNOWN RESERVES

DIMENSION ALF(18),RTAR(30),XTAR(30),ZXS(3,100)
DIMENSION X(100),CUT(100),BEX(100),AV(12),IND(6),T(100)
DIMENSION X(100),T(100),SC(100),ALFC(100),THC(100)
DIMENSION GRAD(2,100),PATT(2,100)
COMMON FX,FZ,XRSM,ZA,PATT,RTAR
DATA STAR/**/

READ THE INPUT

100 READ (5,102) STARA,(ALF(I),I=1,18)
102 FORMAT (16A4)
104 FORMAT (4E12.4)
97 READ (5,97) (IND(I),I=1,6)
98 READ (5,98) RSMALL,ZA,XRSM,XENV,R
99 READ (5,99) NY,FACA,FACB
101 READ (5,101) RSMALL,ZA,XRSM,XENV,R
102 READ (5,102) NQ,NCAS
103 CONTINUE
104 IF (IND(2).EQ.0) GO TO 107
105 READ (5,105) RTAR(I),XTAR(I)
106 CONTINUE
107 IF (IND(3).EQ.0) GO TO 111
108 READ (5,108) NCAS
109 CONTINUE
110 IF (IND(4).EQ.0) GO TO 1000
111 CONTINUE
112 IF (IND(5).EQ.0) GO TO 1000
113 IF (IND(6).EQ.0) GO TO 1000
114 CONTINUE

WRITE INPUT DATA

1000 CONTINUE
110 WRITE (6,112) [ALF(I)],I=1,18)
112 FORMAT (1H1/*,18A4//)
113 WRITE (6,116) RSMALL
116 FORMAT (*WORLD RESERVES*,15X,F10.0,*,TONS METAL*/)
117 WRITE (6,118) ZA
118 FORMAT (*INDIVIDUAL SIZE*,14X,F10.0,*,TONS METAL*/)
120 FORMAT (*AVERAGE GRADE*,16X,F10.0,*,PPM*/)
122 FORMAT (*AVERAGE GRADE ENVIRONMENT*,4X,F10.0,*,PPM*/)
124 FORMAT (*SIZE ENVIRONMENT*,13X,E10.4,*,TONS*/)
126 FORMAT (*AVERAGE CONTENT IN CRUST*,5X,E12.4,*,PPM*/
127 SPECIFIC GRAVITY*,13X,E12.4,*,GR/CM3*/
128 DIMENSION RATIO B/A*,10X,E12.4//
129 DIMENSION RATIO C/B*,10X,E12.4//
130 GAMMA (CALCULATED)*,11X,E12.4,*,PPM*/
131 ALFA (CALCULATED)*,12X,E12.4,*,PERCENT*/

C -------CALCULATE ALFA AND GAMMA-----------------------------
C IF(NINDO() .EQ. 0) GO TO 117
F=2*1.E-9/RHS
117 NINDO(1)=1
NINDO=1
ENP=EXP(SORT(2.))
ZJE=ENP**2*ALOG(XRSM)+4.*ENP*
150 GMIN=ENP**2*ALOG(XRSM)+ALOG(XENV)
GAMENV=EXP(GAMENV)**2
ALGB=100.*ENP**2*ALOG(XRSM)+ENP*2
NINDO=1
XENV=NRSM**2*BDH**2*ENP**2
XENV=NRSM**2*BDH**2*ENP**2
119 FORMAT (*AVERAGE CONTENT IN CRUST*,5X,E12.4,*,PPM*/
120 SPECIFIC GRAVITY*,13X,E12.4,*,GR/CM3*/
121 DIMENSION RATIO B/A*,10X,E12.4//
122 DIMENSION RATIO C/B*,10X,E12.4//
123 GAMMA (CALCULATED)*,11X,E12.4,*,PPM*/
124 ALFA (CALCULATED)*,12X,E12.4,*,PERCENT*/

C 117 CONTINUE
S=1.E+6*ZA/XRSM
ALFA=(ALOG(R)-ALOG(S))/ALOG(2.)
NORDER=ALFA
ADJ=R/(S**2*NORDER)
2R=SMALL**2**1.E+6/(XRSM**2)
C -------CALCULATE Z-VALUES OF THE BOW-FUNCTION-----------------
C ZXS(1,1)=0.5
CAI=1.
DO 130 I1=NORDER
130 CAI=CAI*ALFA+l.*FLOAT(I)/FLOAT(I)
130 CONTINUE
ZXS(1,1)=0.5
MAXZ=NORDER+1
C -------SELECT INTERVAL IN WHICH ZR OCCURS---------------------
C DO 140 I=1,MAXZ
IF(ZXS(I,1).GE.ZR) GO TO 146
140 CONTINUE
WRITE (6,142)
142 FORMAT ('ERROR EXIT 1*)
STOP
146 IPLM=I-1
M=I-2
IA=I
C
IWAY=1
Q=0.00001
CFAC=R SMALL*1.E+6/S
C
150 CONTINUE
CALL XEQ(XX,XENV,Q,ALFA,IA)
XR=XX(IA)+[XX(IA)-ZK]*[XX(IPLM)-XX(IA)]/[ZXS(1,IA)-ZXS(1,IPLM)]
AFAC=1*XX(IPLM)+XR*0.5*(ZK-ZXS(1,IPLM))
IF(M.EQ.0) GO TO 158
DO 154 I=1,M
AFAC=AFAC+[XX(I+1)-XX(1)]*0.5*(ZXS(1,I+1)-ZXS(1,I))
154 CONTINUE
158 AFAC=AFAC-CFAC
GO TO (162,166),IWAY
C
162 CONTINUE
DEL=1.0
DO 174 KI=1,6
DEL=DEL*0.1
DO 168 J=1,9
Q=Q+DEL
BFAC=AFAC
Q=Q+DEL
IWAY=2
151 GO TO 150
C
166 IF ((BFAC*AFAC).LE.0.0) GO TO 170
168 CONTINUE
GO TO 174
170 Q=QA
AFAC=BFAC
174 CONTINUE
WRITE (6,176)
176 FORMAT ('CALC. ENRICHMENT FACTOR Q',4X,F10.5/)
C
------ AND NOW THE TARGET DEPOSITS ----------------------------
C
250 NTAR=NCAS
DO 300 ITAR=1,NTAR
RT=RTAR(ITAR)
XT=XRTAR(ITAR)
ST=1.2+6.*RT/XT
AL=ALOG(R)-ALOG(ST)/ALOG(2.)
NT=AL
ADJA=R/*ST**2.*NT)
MAXZ=NT+1
C
----- CONSTRUCT THE BDW-FUNCTION FOR ORDER NT -----------------
C
ZXS(1,1)=0.5
QA=1.*Q
ZXS(2,1)=(1.+Q)**AL*XENV
QPLUS=1.+Q
QMIN=1.-Q
DD 254
I=1,NT
IPL=I+1
ZXS{1,IPL}={ZXS{1,IPL-1}+0.5*CAI*(AL+1./FLOAT(I))
CAI={AL-FLOAT(I)+1.)*CAI/FLOAT(I)}
ZXS(2,IPL)=QPLUS*(AL-FLOAT(I))*QMIN**I*XENV
254 CONTINUE
ZXS(1,I)=0.0
ZXS(2,I)=ZXS(2,2)+ZXS(1,2)*{ZXS(2,1)-ZXS(2,2)}/ZXS(1,2)*0.5
---CALCULATE THE AVERAGES FROM Z(I) TO 2**N---
ZXS(3,1)=0.
DO 264 I=1,NT
IPL=I+1
ZXS(3,IPL)=ZXS(3,IPL-1)+{ZXS(2,IPL)+ZXS(2,IPL-1)}*{ZXS(1,IPL)-ZXS(1,IPL-1)}
264 CONTINUE
ZXS(3,IPL)=ZXS(3,IPL)/ZXS(1,IPL)
268 CONTINUE
---SELECT THE (J,J+1) INTERVAL IN WHICH XT OCCURS---
DO 276 J=2,MAXZ
IF (ZXS(3JPl)*.LE.XT) GO TO 280
276 CONTINUE
WRITE (278)
278 FORMAT ('ERROR EXIT 2')
STOP
280 J=I-1
JPL=I-1
---CALCULATE THE RIGHT BOUNDARY OF THE INTEGRAL---
XJ=ZXS(2,JPL)
XJ1=ZXS(2,JPL+1)
XJ=ZXS(1,JPL)
XJ1=ZXS(1,JPL+1)
AFAC=(XJ-XJ1)/(XJ1-XJ)
BFAC=XJ+XJ1
AA=-AFAC
BB=BFAC+AFAC*(XJ1+XJ)-2.*XT
CC=2.*ZXS(3,JPL)*XJ-AFAC*XJ*XJ1-BFAC*XJ
ZT=I-BB-SQRT(BB**2-4.*AA*CC)/{2.*AA}
OUT(1,ITAR)=XT
OUT(2,ITAR)=RT
OUT(3,ITAR)=S
OUT(4,ITAR)=S*XT*1.E-6
OUT(5,ITAR)=0.
PAT(1,ITAR)=XT
PAT(2,ITAR)=OUT(2,ITAR)
IF (IND(1).EQ.0) GO TO 300
ZZZ=RTAR(ITAR)
GRA=XTAR(ITAR)
DDP=(ZZZ/GRA)*1.E+6
VD = (DDP/RH0)*E-9
AD = (VD/(BDA**2*CDB))**0.333333
DD = AD*(1. + BDA+BDA*CDB)
GAMD = XENV/EXP(0.015*ALFB*ALDG(24400./DD))
ENP = ALOG10(GAMD)/SIGD
IP = 2
CALL PNP(PP,ENP,IP)
ENDP = P*1.E+18/DDP
OUT(10,ITAR) = ENDP
CONTINUE
WRITE (6,308) (STAR, I=1,17)
308 FORMAT (1H1/PROBABLE RESERVES/*,17A1///)
WRITE (6,310) 310 FORMAT (7X,TARGET DEPOSIT*,9X,RESERVES
1*)
1X,NUMBER*,7X,ORDER*,12X,LOG*)
WRITE (6,318) 318 FORMAT (9X,PPM*,4X,T.METAL*,6X,T.ORE*,29X,OF DEP.*,21X,NORM
1AL*)
DD 322, I=1,NTAR
WRITE (6,326) (OUT(J,I), J=1,8) 326 FORMAT (3F12.0,2E12.4,F12.2,F12.3,F15.2/)
DO 322 I=1,NTAR
WRITE (6,326) (OUT(J,I), J=1,8)
322 CONTINUE
WRITE (6,410) 410 FORMAT (1H1/TABLES OF EQUAL METAL CONTENT
1*)
410 FORMAT (1H1/TABLES OF EQUAL METAL CONTENT
1*)
IF (IND(3).NE.O) GO TO 404
STOP
404 WRITE (6,420) TT,XMAX
420 FORMAT (TT,TMAX)
IF (IND(3).NE.O) GO TO 404
STOP
WRITE (6,420) TT,XMAX
WRITE (6,420) TT,XMAX
WRITE (6,422) 422 FORMAT (TMAX)
WRITE (6,422) 422 FORMAT (TMAX)
DO 450 IP=1,6
450 CONTINUE
DO 450 IP=1,6
IF (IND(3).NE.O) GO TO 404
STOP
WRITE (6,422) 422 FORMAT (TMAX)
WRITE (6,422) 422 FORMAT (TMAX)
DO 450 IP=1,6
450 CONTINUE
DO 450 IP=1,6
IF (IND(3).NE.O) GO TO 404
STOP
WRITE (6,422) 422 FORMAT (TMAX)
WRITE (6,422) 422 FORMAT (TMAX)
IPL=I+1
ZXS(1,IPL)=ZXS(1,1PL-1)+0.5*CAI*((AL+1.)/FLOAT(I))
CAI=(AL-FL0AT(D + 1.)*CAI/FL0ATTI)
ZXS(2,IPL)=QPLUS**(AL-FL0ATU))*QMIN**I*XENV
NP0IN=IP-1 304 GO TO 464 305 423 CONTINUE 306 RT=TT 307 XT=XC(IP) 308 ST=SC(IP) 309 AL=ALFC(IP) 310 NT=AL 311 MAXZ=NT+1 312 C 313 C CONSTRUCT THE BDW-FUNCTION FOR ORDER NT 314 C 315 ZXS(1,1)=0.5 316 CAI=1. 317 ZXS(2,1)=(1.+Q)**AL*XENV 318 QPLUS=1.+Q 319 QMIN=1.-Q 320 DO 554 I=1,NT 321 IPL=I+1 322 323 324 554 CONTINUE 325 ZXS(1,1)=0.0 326 ZXS(2,1)=ZXS(2,2)+ZXS(1,1,2)*(ZXS(2,1)-ZXS(2,2))/(ZXS(1,2)-0.5) 327 C 328 C CALCULATE THE AVERAGES FROM Z(I) TO 2**N 329 C 330 ZXS(3,1)=0. 331 DO 564 1=1,NT 332 IPL=I+1 333 334 564 CONTINUE 335 ZXS(3,1)=ZXS(3,1)/ZXS(1,1) 336 C 337 C SELECT THE (J,J+1) INTERVAL IN WHICH XT OCCURS 338 C 339 DO 576 I=2,MAXZ 340 IF (ZXS(1,I).LE.XT) GO TO 580 341 ZJ1=ZXS(1,JPL+1) 342 AFAC=(XJ-XJ1)/(ZJ1-ZJ) 343 BFAC=XJ+XJ1 344 AA=-AFAC 345 BB=AFAC*AFAC*(ZJ1+ZJ)-2.*XT 346 576 CONTINUE
CC=2.*ZXS(3,JPL)*ZJ-AFAC*ZJ1-BFAC*ZJ
ZT=((-BB-SQRT(BB**2-4.*AA*CC))/(2.*AA))
YC(IP)=ZT
TM(IP)=ZT*SC(IP)*XC(IP)*1.E-6
GRAD(1,IP)=TM(IP)
GRAD(2,IP)=XC(IP)
WRITE (6,440) XC(IP),YC(IP),SC(IP),TM(IP),ALFC(IP)
FORMAT (2F10.0,2E15.4,F10.2)
CONTINUE
IF(IIND(4).EQ.0) GO TO 438
CALL GRAPH (GRAD,R,XENV,TT,NPOIN,INT)
CONTINUE
IF (STAR.AN. STAR) GO TO 100
CALL FINTRA
STOP
END
SUBROUTINE XFQ(X,XAV,Q,A,M)

--- XFQ CALCULATES THE X TERMS OF THE BDW-FUNCTION ---

FOR GIVEN Q AND ORDER
ONLY M TERMS WILL BE CALCULATED

DIMENSION X(100)

X(1) = (1.+Q)**(A-1.)*(1.+A+3.*Q+A*Q)*XAV/(1.+A)

IF (M.EQ.1) RETURN

MM = M-1
QPLUS = 1.+Q
QMIN = 1.-Q

DO 100 I=1,MM

100 X(I+1) = QPLUS**(A-FLOAT(I))*QMIN**FLOAT(I)*XAV

RETURN

END
SUBROUTINE GRAPH (GRA,R,XENV,TT,N,INT)

`C`

```
DIMENSION GRA(2,100),X(100),Y(100),AL(9),EN(9)
DIMENSION PATT(2,100)
COMMON FX,FZ,XRSM,ZA,PATT,NTAR

DATA EN/0.6,0.2,0.2,0.2,0.4,0.2,0.2,0.2,0.2/
```

IF(N.LT.2) RETURN
IF(INT.GT.1) GO TO 148

```c
EN=EN(1)
SIZEX=15.
SIZEY=25.
SIZEX=15.
SIZEY=10.
SIZEX=14.

EN(I)=SIZEY
B=ALOG10(XENV*R*1.E-6)
A=AINT(B)
FACX=SIZEX/B
CALL FINIM0.0,2.0)
```

START=(B-A)*FACX
FLO=A

CALL NUMBER (START,-0.3,0.2,0.0,FL0,-1)

FL0=FL0-1
START=START+FACX
```

108 IF(FL0.GE.0.0) GO TO 108
X(1)=SIZEX
Y(1)=0.0
X(2)=0.0
Y(2)=0.0
CALL LINE (X,Y,2,1,1)
```

IA=IFIX(A)
```
112 IA=IA+1
```
116 CONTINUE
```c
```
H=0.3
YY=0.6
FLO=10.0
```

120 CALL NUMBER (XX,YY,H,0.0,FL0,-1)
124 CALL NUMBER (XX,YY,H,0.0,FL0,-1)
```

DRAW THE AXIS
```c
```
\[ YY = -1.0 \]
\[ \text{CALL SYMBOL4(XX, YY, H, 0.0, 'TONS OF METAL WORLD RESOURCES', 30)} \]

--- AND NOW THE Y-AXIS ---

\[ H = 0.3 \]
\[ EN[1] = \text{SIZE}X \]
\[ YMIN = \text{ALG10}(XENV) \]
\[ YMAX = YMIN \]
\[ YMAX = \text{ALG10}(\text{GRA}(2, 1)) \]
\[ YMAX2 = YMAX + \text{ALG10}(2.) \]
\[ C = \text{YMAX2 - YMIN} \]
\[ \text{FACY} = \text{SIZE}Y/C \]
\[ \text{FACY} = \text{FACY} \]
\[ \text{FLO} = \text{AINT} \times (\text{YMIN}) \]
\[ \text{FL0} = \text{FL0} + 1. \]
\[ \text{IF} [\text{FL0} \times \text{GT}, \text{YMAX2}] \text{ GO TO 132} \]
\[ \text{YY} = (\text{FL0} - \text{YMIN}) \times \text{FACY} + \text{H} \]

\[ \text{YY} = \frac{\text{YY} \times \text{H}}{\text{T}} \]
\[ \text{CALL NUMBER (XX, YY, 0.2, 0.0, FL0, -1)} \]
\[ \text{GO TO 128} \]

\[ \text{X}(1) = 0.0 \]
\[ \text{Y}(1) = \text{SIZE}Y \]
\[ \text{X}(2) = 0.0 \]
\[ \text{Y}(2) = 0.0 \]
\[ \text{CALL LINE (X1, Y1, 2, 1, 1)} \]
\[ \text{YY} = \text{START} + \text{AL}(1) \times \text{FACY} \]
\[ \text{IF} [\text{YY} \times \text{LT} \times 0.0] \text{ GO TO 136} \]
\[ \text{IF} [\text{YY} \times \text{GT} \times \text{SIZE}Y] \text{ GO TO 140} \]
\[ \text{YY} = \text{YY} \]
\[ \text{X}(2) = \text{EN}[1] \]
\[ \text{CALL LINE (X1, Y1, 2, 1, 1)} \]

\[ \text{CONTINUE} \]
\[ \text{START} = \text{START} + \text{FACY} \]
\[ \text{GO TO 134} \]

\[ \text{FL0} = 10. \]
\[ \text{YY} = \text{SIZE}Y \times 0.2 \]
\[ \text{CALL SYMBOL4 (XX, YY, H, 0.0, 'GRADE IN PPM', 13)} \]
\[ \text{START} = \text{YMAX2} \]

\[ \text{YY} = \text{AINT} \times (\text{START} - \text{YMIN}) \times \text{FACY} \]
\[ \text{IF} [\text{YY} \times \text{LT} \times 0.0] \text{ GO TO 150} \]
\[ \text{XX} = 16. \times \text{H7} \times \text{T} \]
\[ \text{CALL NUMBER (XX, YY, H, 0.0, FL0, -1)} \]
\[ \text{START} = \text{START} - 1. \]
\[ \text{GO TO 144} \]

--- DRAW THE CURVES ---

\[ \text{CONTINUE} \]

\[ \text{CONTINUE} \]

\[ \text{CONTINUE} \]
DO 160 I = 1, NTAR
X(I) = (B - ALG10(PATT(1, I))) * FACX
Y(I) = (ALG10(PATT(2, I)) - YMAN) * FACY
160 CONTINUE
CALL DASH (X, Y, NTAR, 1, 1)
DO 152 I = 1, N
X(I) = (B - ALG10(GRA(1, I))) * FACX
Y(I) = (ALG10(GRA(2, I)) - YMAN) * FACY
152 CONTINUE
XX = X(1)
YY = Y(1)
IF (XX.GT.999999.0) GO TO 153
CALL NUMBER (XX, YY, 0.15, 0.0, TT, -1)
153 CONTINUE
CALL LINE (XX, YY, N, 1, 1)
IF (INT.GT.1) GO TO 151
X(2) = 0.0
Y(2) = 0.0
CALL LINE (XX, YY, 2, 1, 1)
151 CONTINUE
CALL FINIM (0.0, 0.0)
RETURN
END
SUBROUTINE PNP(Ρ,ΕΝΡ,JA) DIMENSION XLPG(60),YNP(60) DATA 1XLPG(1),XLPG(2),XLPG(3),XLPG(4),XLPG(5),XLPG(6), XLPG(7),XLPG(8),XLPG(9),XLPG(10),XLPG(11),XLPG(12),XLPG(13),XLPG(14),XLPG(15),XLPG(16),XLPG(17),XLPG(18),XLPG(19),XLPG(20),XLPG(21),XLPG(22),XLPG(23),XLPG(24),XLPG(25),XLPG(26),XLPG(27),XLPG(28),XLPG(29),XLPG(30),XLPG(31),XLPG(32),XLPG(33),XLPG(34),XLPG(35),XLPG(36),XLPG(37),XLPG(38),XLPG(39),XLPG(40),XLPG(41),XLPG(42),XLPG(43),XLPG(44),XLPG(45),XLPG(46),XLPG(47),XLPG(48),XLPG(49),XLPG(50),XLPG(51),XLPG(52),XLPG(53),XLPG(54),XLPG(55),XLPG(56),XLPG(57),XLPG(58),XLPG(59),XLPG(60)/ 10.301030,0.337030,0.375936,0.417836,0.462712,0.510692, 0.616250,0.673960,0.735040,0.799545,0.367528,0.939039, 1.092821,1.175176,1.261225,1.351001,1.444539,1.541868, 1.633245,1.738199,1.856878,1.969639,2.086316,2.206930, 2.331499,2.461356,2.593575,2.729114,2.869674,3.016269, 3.162912,3.315615,3.472388, 3.633245,3.791899,3.967251,4.140412,4.317712,4.499115, 4.684625,4.874580,5.068057,5.265977,5.468369,5.674492, 5.884772,6.103623,6.336623,6.536745,6.760826,6.997476,7.247207, 7.475997,7.650689/ 0.561848,1.014122,1.643017,2.460042,3.472388,4.684625, 5.978211,7.270588,8.641825,10.000000,10.100000,10.200000/ THE CALCULATION OF NP AS FUNCTION OF Ρ ---------- 102 PP=ALOG10(Ρ) IF (PP<15.0)108,108,104 104 JA=3 WRITE (6,106) Ρ RETURN 106 FORMAT (29H ERROR ARGUMENT TOO SMALL P=,E12.5) RETURN 107 FORMAT (29H ERROR ARGUMENT TOO LARGE P=,E12.5) 108 IF (PP<7.650689)120,110,110 110 ENP=2.27316+0.465275*PP-0.00588*PP**2 IF (ENP=7.51114,114,112 112 JA=2 RETURN 114 IF (ENP<7.0)118,113,116 116 JA=1 RETURN 118 JA=0 RETURN 120 IF (PP.GT.XLP(1)) GO TO 121 121 DO 122 I=1,56 IF (PP-XLP(I))124,124,122 122 CONTINUE
GO TO 104

124 IN=I-1
ENP=((PP-XLPG(IN))/XLPG(IN+1)-XLPG(IN))*YNP(IN+1)-YNP(IN))*YNP(IN+1)
1IN)
JA=0
RETURN

C-----THE CALCULATION OF P AS A FUNCTION OF NP------------------------
C
200 IF(ENP-5.5)202,202,208
202 JA=0
DO 204 I=1,56
IF(ENP-YNP(I))206,206,204
204 CONTINUE
GO TO 208
206 IN=I-1
PP=(((ENP-YNP(IN))/(YNP(IN+1)-YNP(IN)))*(XLPG(IN+1)-XLPG(IN))+XLPG
1IN)
P=10.**(-PP)
JA=0
RETURN
IF(ENP-7.9)214,214,210
210 WRITE(6,212) ENP
212 FORMAT(13OH ERROR ARGUMENT TOO LARGE NP=,E12.5)
JA=3
RETURN
214 ROOT=2072.51-175.79*ENP
216 PP=40.9066-SQRT(ROOT)
P=10.**(-PP)
JA=0
IF(ENP-7.0)218,218,220
218 RETURN
220 IF(ENP-7.5)222,222,224
222 JA=1
RETURN
224 JA=2
RETURN
END
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To disseminate knowledge is to disseminate prosperity — I mean general prosperity and not individual riches — and with prosperity disappears the greater part of the evil which is our heritage from darker times.

Alfred Nobel
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