COMMISSION OF THE EUROPEAN COMMUNITIES

THE DESIGNING OF SPECIAL PURPOSE SLIDERULES AND THE RELATED CODES "ACCESS" AND "COOLER"

by

I. DE WOLDE

1970

Joint Nuclear Research Center
Ispra Establishment - Italy
Scientific Data Processing Center (CETIS)
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One may distinguish a class of technical and scientific computation problems for which a problem-oriented sliderule might be very useful. Several sliderules have already been developed by Cetis-Euratom, together with some tools to facilitate the designing.

This report describes the obtained experiences together with two computer programmes i.e. "ACCESS" and "COOLER".

"ACCESS" converts the numerical descriptions of sliderules into the actual drawings. "COOLER" is a programme which designs and draws circular sliderules for the conversion of leak-rates but by programming other relations it may be used for other problems also.
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ABSTRACT

One may distinguish a class of technical and scientific computation problems for which a problem-oriented sliderule might be very useful. Several sliderules have already been developed by Cetis-Euratom, together with some tools to facilitate the designing. This report describes the obtained experiences together with two computer programmes i.e. “ACCESS” and “COOLER”. “ACCESS” converts the numerical descriptions of sliderules into the actual drawings. “COOLER” is a programme which designs and draws circular sliderules for the conversion of leak-rates but by programming other relations it may be used for other problems also.

KEYWORDS

COMPUTERS
TOOLS
DESIGN
PROGRAMMING
LEAKS
FORTRAN
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</table>
INTRODUCTION *)

It has been experienced that there exists a class of technical and scientific computation problems which might be solved conveniently by a specially designed sliderule.

This class is characterized by:

1. not too many input parameters,
2. few output data,
3. rather complicated calculation process, specially including algebraic or numerical functions,
4. frequent executions,
5. instantaneous results requested.

Thus, characterized problems may be handled by special computer produced tables, by nomograms or by special purpose sliderules. For several problems the latter solution has been applied by CETIS-EURATOM. Also some tools have been developed to facilitate the designing of special purpose sliderules. This report describes these aids and the obtained experiences.

Two computer programmes are mentioned:
The code "ACCESS" converts numerical descriptions of sliderules into the actual drawings with the aid of a CALCOMP-plotter. This programme can be applied as an independent programme or as a part of larger code.

The code "COOLER" designs and draws circular sliderules for leak-rate conversion calculations. "COOLER" might be used more generally by removing the two subroutines where the actual relations are calculated and substituting them by other FORTRAN programmed expressions. The problem of the leak-rate conversions has been described somewhat extensively as an illustration for the entire report.

No distinction has been made as far as concerns the basic shape

*) Manuscript received on 21 April 1970
of the sliderules, circular or rectangular. The most important
difference is that a circular sliderule can easily be provided
with more moving parts.

THE SLIDERULE

A sliderule may be considered as a primitive analog machine.
The two reversible basic principles are:
1. function value representation for a given argument only for
   strict monotonic functions,
2. addition of function values.

The first principle is illustrated by a scale for the function
\( f[x] = x^2 - 1 \) with \( x \geq 1 \) to have a monotonic branch of the func-
tion

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>+ x values</th>
</tr>
</thead>
<tbody>
<tr>
<td>f[x]=0</td>
<td></td>
<td></td>
<td></td>
<td>length represents the value of</td>
<td>( [x^2-1] )</td>
</tr>
<tr>
<td>setpoint</td>
<td></td>
<td></td>
<td></td>
<td>+ the distance from the setpoint to +</td>
<td>the argument value is a measure for</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+ the function value</td>
<td></td>
</tr>
</tbody>
</table>

The addition of two function values is performed physically as
is illustrated for the relation \( \sqrt{z} = x^2 - 1 + y^2 \):

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>+ x values</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x^2 - 1 = 0 )</td>
<td></td>
<td>length represents</td>
<td>( [x^2-1] )</td>
<td></td>
</tr>
<tr>
<td>setpoint</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 1 2 3</td>
<td>+ y values</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( y = 0 )</td>
<td>length represents</td>
<td>y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>setpoint</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 1 4 9 144</td>
<td>+ z values</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \sqrt{z} = 0 )</td>
<td>length represents</td>
<td>( \sqrt{z} )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
If now the latter example is executed as a traditional sliderule, the x-scale and the z-scale will be engraved on the body of the rule and the y-scale on the central slide (cs.). Furthermore, a windowslide (ws.) is necessary.

The elaborations for the calculation of $\zeta$ at given $\chi$ and $y$ will be:

1. put the ws. on the x-value,
2. move the cs. until the setpoint is under the marker,
3. move the ws. to the y-value,
4. read the z-value.

A certain simplification of the tool is possible by combinations of scales which leads ultimately to sliderule applications for more complex functions.

In the given example, the positive direction of each scale points to the right. However, the procedure will be simplified if the positive direction of the x-scale points to the left as is shown in the next example:

<table>
<thead>
<tr>
<th>x-values</th>
<th>length for $y^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

$x^2 - l = 0$
$y^2 = 0$

<table>
<thead>
<tr>
<th>x-values</th>
<th>y-values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>144</td>
</tr>
</tbody>
</table>

The necessary elaborations to calculate $z$ from $\sqrt{z} = x^2 - l + y^2$ at given $x$ and $y$ become:

1. move the cs. until the x-value coincides with the setpoint of the z-scale,
2. move the ws. over the y-value,
3. read the z-value.
Appropriate location of the scales within the limited size of a sliderule may be obtained by introducing a place correction term \( c \). The example relation may be written as:

\[
\sqrt{z} + c = [x^2 - 1 + c] + y^2
\]

For \( c = -5 \) the sketch of the sliderule becomes:

<table>
<thead>
<tr>
<th>x-values</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta )</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>+ y-values</td>
</tr>
<tr>
<td>( \Delta )</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>( \Delta )</td>
<td>144</td>
<td>+ z-values</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The given example shows a very important by-product of the sliderule construction:

The represented expression can be solved in any direction that is for a \( n \)-parameter relation, each of the variables can be calculated if the other \( n-1 \) parameters are given.

Not every relation can be represented by a sliderule.

The most simple class of elaborative expressions is of the type:

\[
f_1[x_1] + f_2[x_2] + \ldots = 0
\]

The addition may easily be performed by moving line-intervals.

Sometimes a transformation of a more complex function may yield the previous form:

\[
f_1[x_1] \cdot f_2[x_2] = f_3[x_3]
\]

By taking the logarithms of the functions in this case, the standard form is obtained.

A more complicated system is required by:

\[
f_1[x_1] \cdot f_2[x_2] + f_3[x_3] = f_4[x_4]
\]
As an intermediate result has to be calculated:

\[ y = f_1[x_1] \cdot f_2[x_2] \]

or transformed by taking the logarithms:

\[ \log y = \log f_1[x_1] + \log f_2[x_2] \]

but the calculated result \( f_1[x_1] \cdot f_2[x_2] \) appears now as an argument value and not as an interval-length as is required for the addition with \( f_3[x_3] \).

The solution for this type of expressions will be given by the next example.

Consider the function:

\[ x_1^2 \cdot \sqrt{x_2 - 2} + x_3^3 = x_4 + 8 \]

A scale diagram for the values \( x_1 = 2, x_2 = 6, x_3 = s = 2.24 \) shows:

\[
\begin{align*}
1 & \quad 2 \quad 3 \quad 4 \\
\text{argument} = x_1 & \quad \text{distance} = \log x_1^2 \\
\text{log } x_1^2 = 0 & \\
3 & \quad 4 & \quad 5 & \quad 6 & \quad 7 \\
\text{argument} = x_2 & \quad \text{distance} = \log \sqrt{x_2 - 2} \\
\text{log } \sqrt{x_2 - 2} = 0 & \\
1 & \quad 2 & \quad 3 & \quad 4 & \quad 5 & \quad 6 & \quad 7 & \quad 8 & \quad 9 & \quad 10 \\
\text{argument} = x_2^2 \cdot \sqrt{x_2 - 2} & \quad \text{distance} = \log x_1^2 + \log \sqrt{x_2 - 2} \\
\text{log } x_1^2 + \log \sqrt{x_2 - 2} = 0 & \\
0 & \quad 1 & \quad 2 & \quad 3 & \quad 4 & \quad 5 & \quad 6 & \quad 7 & \quad 8 & \quad 9 & \quad 10 \\
\text{argument} = x_2^2 \cdot \sqrt{x_2 - 2} & \quad \text{distance} = x_1^2 \cdot \sqrt{x_2 - 2} \\
\text{x_1^2 \cdot \sqrt{x_2 - 2} = 0} & \\
0 & \quad 1 & \quad 2 & \quad 3 \\
\text{argument} = x_3 & \quad \text{distance} = x_3^2 \\
x_3 = 0 & \\
-2 & \quad -2.5 & \quad -1 & \quad 0 & \quad 1 & \quad 1.5 & \quad 2 \\
\text{argument} = x_4 & \quad \text{distance} = x_4^3 + 8 \\
x_4 + 8 = 0 &
\end{align*}
\]
If the 2nd and the 5th scale of this diagram were engraved on the movable part of an actual slide-rule, the elaborations for the calculation of the $x_4$-value would be:

1. put the windowslide on the $x_1$-value,
2. adjust the central slide,
3. move the ws. to the $x_2$-value,
4. read the $\frac{x_1^2}{\sqrt{x_2^2 - 2}}$-value on the 3rd scale,
5. move the ws. to the $\frac{x_1^2}{\sqrt{x_2^2 - 2}}$-value on the 4th scale,
6. adjust the cs,
7. move the ws. to the $x_3$-value,
8. read the $x_4$-value.

However, the design of the slide-rule and the procedure of the calculation can be simplified by:

1) choosing opposite positive directions for the scales 1 and 2 on the cs. of the slide-rule,
2) combining the scales 3 and 4 to a "go to scale",
3) choosing opposite positive directions for the "go to scale" and the $x_3$-scale.

Now the procedure of the calculation has been reduced to:

1. move the cs. until the $x_2$-value coincides with the setpoint of the "go to scale",

\[
\begin{array}{cccccccccc}
\text{go to:} & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 \\
\hline
\text{to:} & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 \\
\hline
x_2 + & 7 & 6 & 5 & 4 & 3 \\
\hline
-2 & -1.5 & -1 & 0 & 1 & 1.5 \\
\hline
3 & 2 & 1 & 0 & + x_3 \\
\hline
\end{array}
\]
2. move the ws. on the $x_1$-value and read value on upper part of the "go to scale",
3. move the ws. over this value on lower part of this scale,
4. move the cs. until the setpoint of the $x_4$-scale coincides with the given $x_3$-value,
5. read the $x_4$-value under the marker of the ws.

A MATHEMATICAL DEVICE

As has been shown by the previous examples, a function of the type:

$$y = \sum_{i=1}^{I} \sum_{j=1}^{J} f_{ij}[x_j]$$

is accessible for sliderule application.

Now arises the problem of converting a function of the type:

$$y = f[x_1, x_2, \ldots, x_n]$$

into the standard form.

If normal algebraic operations do not yield results, a mathematical device for this conversion, as developed by Mrs. C. TAMAGNINI (see ref.), might help. The applied approximation has shown to be useful in many cases, although it is not a general solution.

The method will be explained for a three-parameter function, $y = f[x_1, x_2]$. The extension to more parameters is easy.

Consider the function $y = f[x_1, x_2]$ in a defined range:

The approximating function must be of the type:

$$y^* = \sum_{i=1}^{I} f_{1i}[x_1] \cdot f_{2i}[x_2]$$
to make it accessible for sliderule application.

Choose a point \([x_{10}, x_{20}]\) in the definition field of \(y\) and consider the two curves \(f_{11}[x]\) and \(f_{21}[x]\) obtained by the intersection of the \(y\)-surface with the two planes parallel to the planes \(x_1 = 0\) respectively \(x_2 = 0\) and passing through the point \([x_{10}, x_{20}]\).

As a first approximation one may try:

\[
y_1 = \frac{f_{11}[x_1] \cdot f_{21}[x_2]}{f[x_{10}, x_{20}]} = c_1 f_{11}[x_1] f_{21}[x_2]
\]

in which \(f[x_{10}, x_{20}] = \frac{1}{c_1}\) can be calculated numerically.

The choice of the point \([x_{10}, x_{20}]\) may be performed by covering the definition field of \(y\) by a lattice and successive tryings of the lattice points for the best approximation.

Sequentially, the surface

\[
y - y_1 = f[x_1, x_2] - c_1 f_{11}[x_1] f_{21}[x_2]
\]

can be treated in the same way etc., until

\[
z = y - c_1 f_{11}[x_1] f_{21}[x_2] - c_2 f_{12}[x_1] f_{22}[x_2] - c_3 f_{13}[x_1] f_{23}[x_2] - \ldots
\]

is small enough within the field of definition.

Then:

\[
y* = \sum_{i=1}^{I} c_i f_{1i}[x_1] f_{2i}[x_2]
\]

is the requested approximation.

**A MECHANICAL DEVICE**

A handy tool in the laboratory is the sliderule with exchangeable scales. The annexed design has proofed to be very useful. The actual scales can be calculated and drawn on graph-paper. The drawing is then adjusted on the body of the rule and the transparent
covers are fastened. The protruding part of the drawing can be removed by a razor blade.

**THE PROGRAMME "ACCESS"**

"ACCESS" (for Automatic Compiling of Circular Sliderule Scales), converts numerical descriptions of sliderule scales into actual drawings with the aid of a CALCOMP-plotter. "ACCESS" may be used as an independent programme or it can be incorporated in another programme which provides the numerical descriptions as has been done in the case of the programme "COOLER" which is described also.

Programme "ACCESS" may produce drawings in the frame of a rectangular coordinates system with $0 \leq x$ and $0 \leq y \leq 70$ cm, combining the components:

1. dotted arcs of any length,
2. full-line arcs of any length,
3. straight lines given in polar coordinates with regard to a centre point in cartesian coordinates.

The straight lines (division marks), may be given with an absolute length or in ratio to the radius, thus enabling an automatic scale enlargement of the components.

The programme contains also an option for suppressing a division mark if the distance between two division marks becomes smaller than a specified value.

A complete description of the options will be given in the input list.

**"ACCESS" INPUT DESCRIPTION**

The actual input for the "ACCESS" programme consists of a collection of fixed point-, (I-format) and floating point-numbers (E-format). A fixed point number is written without a decimal point,
Floating point data are written with a decimal point and are eventually supplied with a fixed point exponent of 10. The position of such a number in its field is irrelevant, only the exponent must be placed at the utmost right.

The next list gives a detailed description of the input. The symbols refer to the input sheet.

\[ N = \text{number of drawings to be performed}; \]
\[ \text{format: I6} \]

For each drawing the next specifications have to be repeated:

Card 1 format: 2I3, I6, E12.4, 4(2I1, E10.4)

- \( I_0 = 0 \) the angle and size of each division mark are given in one card,
- \( I_0 = 1 \) all the angles are specified first, followed by a set of cards with the lengths of the division marks in the same sequence,
- \( I_1 = 0 \) the angles are given in radians,
- \( I_1 = 1 \) the angles are given in degrees, minutes and seconds,
- \( I_2 = 0 \) the lengths of the division marks are given in cm (size\((I)\)),
- \( I_2 = 1 \) the lengths of the division marks have to be calculated from given ratios in relation to the radius \( R \),
- ARCMIN the minimum arc length in cm between two division marks: in the case that two division marks come closer than arcmin, the smallest is suppressed. If they are equal in size no action will be taken,

\[ J \]

- four additional arcs or circles may be specified on the centre coordinates \( x_o, y_o \), but with different radius,

\[ C(I) \]

- \( J = 0 \): an arc between the smallest and the largest angle of the division marks' specification will be
drawn with a radius of C(I) cm,
J = 1: a full circle around x_o, y_o will be drawn
with a radius of C(I) cm,
K = 0: continuous arc,
K = 1: dotted arc.
More contrasting arcs may be obtained by repeating
the definitions, eventually with a somewhat smaller
radius.

Card 2 format: 4E6.2

R  radius in cm,
S  (only if I_2=1).
The length of a divisionmark at radius 10 cm and
size(I)=1. The actual lengths of the division marks
are calculated: S_{ACT}(I) = 0.1 \times R \times S \times \text{SIZE}(I).
This factor is used for automatic scale enlargement.

\begin{align*}
X_o & \quad \text{Coordinates of the centre point. The drawings are} \\
Y_o & \quad \text{produced in a frame of rectangular coordinates with} \\
& \quad 0 \leq X \text{ and } 0 \leq Y \leq 70 \text{ cm.} \\
& \quad \text{Thus } R_{\text{MAX}} \leq X_o \text{ and } R_{\text{MAX}} \leq Y_o \leq 70 - R_{\text{MAX}}^2, \\
& \quad \text{in which } R_{\text{MAX}} \text{ is the radius of the largest circle.}
\end{align*}

The angles and the lengths of the division marks may be specified
in several ways depending on the indicators I_0, I_1 \text{ and } I_2, \text{ as al-
ready been described. The symbols on the input sheet have the fol-
lowing meaning:}

\begin{align*}
\text{DEG}(I) & \quad (\text{only if } I_1=1). \\
\text{MIN}(I) & \quad \text{The angles of the division marks with the X-axis,} \\
\text{SEC}(I) & \quad \text{counterclockwise, in degrees, minutes and seconds,} \\
\text{RAD}(I) & \quad (\text{only if } I_1=0). \\
& \quad \text{The angles of the division marks with the X-axis,} \\
& \quad \text{counterclockwise, in radians} \\
\text{SIZE}(I) & \quad \text{if } I_2=0;
\end{align*}
the lengths of the division marks in cm, if $I_2 = 1$

the length ratios; the actual lengths will be calculated: $S_{\text{ACT}}(I) = 0.1 \times R \times S \times \text{SIZE}(I) \text{ cm}$. If SIZE(I) has a positive value, the division mark is pointing outwards from the outer point of the radius $R$, otherwise the division marks point to the centre.

* the last card of the angles specification must have a "*" in the first column.

The number of scales [$N$] to be drawn in one run is not limited.
<table>
<thead>
<tr>
<th>PROBLEM</th>
<th>ACCESS</th>
<th>INPUT EXAMPLE</th>
<th>DATE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>5</td>
<td>65</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>5</td>
<td>65</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>18</td>
<td>4</td>
<td>65</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>51.1</td>
<td>0</td>
<td>65</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>32.5</td>
<td>0</td>
<td>65</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>6</td>
<td>65</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>0.5</td>
<td>6</td>
<td>65</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>3.6</td>
<td>0.2</td>
<td>65</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>6.0</td>
<td>0.2</td>
<td>65</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>0.3</td>
<td>0</td>
<td>65</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>17.4</td>
<td>0.2</td>
<td>65</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>53.2</td>
<td>0.3</td>
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<tr>
<td>13</td>
<td>26.0</td>
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<td>32.4</td>
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<td>1</td>
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<td>15</td>
<td>69.8</td>
<td>0.4</td>
<td>65</td>
<td>1</td>
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<tr>
<td>16</td>
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*Note: The table represents a list of entries with various values and labels.*
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<th>EXAMPLE</th>
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<th>OF</th>
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THE FORTRAN LISTING OF "ACCESS"

The next pages give the FORTRAN listing of "ACCESS". The programme has been written in FORTRAN IV for the IBM 360/65 with a CALCOMP-plotter. The subroutines which are called for and not presented in the next listing, are special CALCOMP-routines which are published elsewhere (see ref.).
PROGRAM ACCESS DRAWS CIRCULAR SLIDE RULE SCALES

THE DIVISION MARKS MAY BE GIVEN IN RADIANS OR DEGREES

THE LENGTH OF EACH MARK IS SPECIFIED IN CM

AT A STANDARD RADIUS OF 10 CM

OR IN ABSOLUTE LENGTH UNITS ACCORDING TO IND(2)

DIMENSION IND(10),C(4),RAD(1000),DIVL(1000),MC(4),KC(4),X(1000,2),
Y(1000,2)

DATA STAR/*

PI=3.14159

READ INPUT DATA-----------------------------------------

CALL FINIT(0.0,1.0)
READ (15,102) N
IM=0
IF (IM.LE.1) GO TO 110
CALL FINTRA
WRITE (6,106) N
GO TO 240
READ (5,111) IA,IB,IC,ID,ARC(1,1000),MC(1),KC(1),C(1),I=1,4
READ (5,116) R,S,XC,YC
WRITE (6,115) R,S,XC,YC
IND(1).=18
IND(2).=1
IND(3).=1
READ (5,116) R,S,XC,YC
WRITE (6,115) R,S,XC,YC
IF (IND(1).LE.0) GO TO 130
I=0
IF (I.LE.1) GO TO 118
READ (5,122) ALF,RA,RC,DIVL(I)
WRITE (6,123) ALF,RA,RC,DIVL(I)
FORMAT (I1,ALF,RA,RC,DIVL(I))
IF (RA+RC).LE.0.0 GO TO 130
RA=RA+RC/3600.
RAD(I) = (RA/180.) * PI
IF (ALF.EQ.2.*STAR) GO TO 140
GO TO 118

I = 0
I = I + 1
READ (5, 134) ALF, RAD(I), DIVL(I)
WRITE (6, 133) ALF, RAD(I), DIVL(I)
FORMAT (1H ALF, 1F17.5, 1F6.2)
FORMAT (1H ALF, 1F17.5, 1F6.2)
IF (ALF.ME.STAR) GO TO 132

--- ORDER THE ANGLES ----------------------------------

I = 1
IF (INDO.EQ.0) GO TO 143
READ (5, 136) (DIVL(I), I = 1, NA)
WRITE (6, 137) (DIVL(I), I = 1, NA)
FORMAT (12F6.2)
FORMAT (12F6.2)
IF (I.GT.(17/10).EQ.0) WRITE (6, 138)

RA = 180.*RAD(1)/PI
RAA = INT(RA)
RBB = INT(RB)
RCC = 60.*RBB
WRITE (6, 139) RA, RBB, RCC, DIVL(1)
FORMAT (3F12.0, F12.2)
CONTINUE
CONTINUE
I = 1
I = I + 1
IF (I.GT.NA) GO TO 146
IF (RAD(I) - RAD(I-1)) 144, 142, 142

AA = RAD(1A)
AB = DIVL(1A)
RAD(1A) = RAD(1A-1)
RAD(1A) = AA
DIVL(1A) = DIVL(1A-1)
CONTINUE
CONTINUE
I = 1
I = I + 1
IF (I.GT.NA) GO TO 142
IF (RAD(1A) - RAD(1A-1)) 145, 142, 142
CONTINUE

LENGTHS OF DIVISION MARKS

IF (IND(2).LE.0) GO TO 152
DO 150 I=1,NA
150 DIVL(I)=0.1*R*S*DIVL(I)
152 CONTINUE

DRAW THE REQUESTED ARCS

CALL FINI:H(XC,YC)
AA=RAD(I)
AB=RAD(NA)
PSIA=AA
PSIB=AB
K=1
CALL ARC(R,AA,AB,K)

DRAW THE REQUESTED DIVISION MARKS

DO 160 I=1,4
IF (C(I).LT.0.0) GO TO 160
K=KC(I)+1
AA=PSIA
AB=PSIB
IF (MC(I).NE.0) AB=PSIA+2.*PI
CALL ARC(C(I),AA,AB,K)
160 CONTINUE

TEST AND DRAW THE DIVISION MARKS

DO 164 I=1,NA
X(I,1)=R*COS(RAD(I))
X(I,2)=(R+DIVL(I))*COS(RAD(I))
Y(I,1)=R*SIN(RAD(I))
Y(I,2)=(R+DIVL(I))*SIN(RAD(I))
164 CONTINUE

IF (DIVL(I).EQ.DIVL(I-1)) GO TO 170
IF (DIVL(I)*DIVL(I-1).LT.0.0) GO TO 170
AA=X(I-1,1)**2+(Y(I-1,1)-Y(I-1,1))**2
IF (AA.GE.(ARCMIN**2)) GO TO 170
IF (ABS(DIVL(I)).GT.ABS(DIVL(I-1))) GO TO 168
X(I-1,2)=X(I-1,1)
Y(I-1,2)=Y(I-1,1)
168 CONTINUE
DO 180 I=1,NA
XX(I)=X(I,1)
XX(2)=X(I,2)
YY(I)=Y(I,1)
YY(2)=Y(I,2)
CALL LINE (XX,YY,2,1,1)
180 CONTINUE
CALL FINIM (-XC,-YC)
GO TO 104
200 CONTINUE
STOP
END
SUBROUTINE ARC (R, PSIA, PSIB, K)

SUBROUTINE ARC draws an arc counter clockwise from 'PSIA' to 'PSIB', both being angles with the X-axis.

R = radius in cm
K = 1, FULL LINE
K = 2, DASHED LINE

DIMENSION X(1000), Y(1000)

PI = 3.141593

DO 99 I = 1, 1000

99 Y(I) = R

IF (PSIA .EQ. PSIB) PSIB = PSIA + 2.*PI

DEL = 1./(R*20.)

IA = 1

X(IA) = PSIA

100 IA = IA + 1

X(IA) = X(IA-1) + DEL

IF (IA .EQ. 1000) GO TO 110

IF (X(IA) .LE. PSIB) GO TO 100

GO TO (104, 106), K

104 CALL LINEPO(X, Y, IA, 1, 1)

106 CALL DASHPO(X, Y, IA, 1, 1)

108 CONTINUE

109 CONTINUE

110 GU TJ 120

112 IK = 1000

113 IA = 1

114 IK = 1000

115 CALL DASHPO(X, Y, IK, 1, 1)

116 GU TJ 113

117 CONTINUE

118 RETURN

END
COMPUTER DESIGNED SLIDERULES

In this chapter a complete case of a special purpose sliderule is described. It concerns a problem for which a general solution could not be found. So a computer programme "COOLER" has been developed which designs and draws the abacus scales for each demanded case. The previously described programme "ACCESS" has been incorporated into "COOLER", so no extensive data transfers were required.

The actual relations are calculated in the subroutines "QLIQ" and "QGAS". By programming other subroutines, one might apply the programme "COOLER" also for other sliderules.

The applied CALCOMP-subroutines are published elsewhere.

The leaktightness of technical installations and components is often tested under circumstances which differ completely from the intended operation condition. The differences may concern temperature, pressure and filling medium. In the Euratom report, EUR 2982.e, one has derived the relations between the leak rate Q, the diameter D, and the length of a capillary L, for gases and for liquids, in the range $10^{-2} < D < 10^2$, especially concerning sealings.

It has been assumed that leaks of sealings and joints always occur through a number of small capillaries. The assumption of a mean diameter for all capillaries, where the leak flow-rate is caused by capillaries of various diameter, has been justified in the same report.

The flow rate of gases, in and around the transient range of pure molecular flow and viscous flow is given by:

$$Q_g = 10^{-4} \times \frac{D^3}{L} \left[ 0.093 \times \frac{D}{n} \times \left[ p_1^2 - p_2^2 \right] + 2.88 \times \sqrt{T} \times \left[ p_1 - p_2 \right] \right]$$

closec (1)
in which: \( Q_g \) = gas leak rate in centilusec

(A flow rate of 1 lusec causes a pressure increase of \( 10^{-3} \) mm Hg in a vacuum of 1 litre in 1 sec.

\[ 1 \text{ lusec} = 1.32 \times 10^{-3} \text{ atm.cc/sec.} \]

\( D \) = the diameter of the capillary in \( \mu \)

\( L \) = the length of the capillary in cm

\( \eta_g \) = the dynamic viscosity of the gas in centipoise

\( \Theta \) = the temperature in \(^\circ\)K

\( M \) = the molecular weight of the gas

\( p_1 \) = the fill pressure in atm.

\( p_2 \) = the exit pressure in atm.

The basic formula for a laminar liquid flow is:

\[
Q = 0.882 \times 10^{-6} \times \frac{D^4}{L} \times \frac{\rho_l}{\eta_l} \times \frac{p_1 - p_2}{\rho_l} \text{ mg/hour}
\]

in which: \( Q \) = leak rate in mg/hour

\( \rho_l \) = the viscosity in centipoise

\( \eta_l \) = the specific gravity of the liquid

In some cases a liquid leak flow rate is influenced by two phenomena, i.e. surface tension effect and evaporation of the liquid during leaking. Then, the basic formula should be corrected according to the formulae given in the above mentioned report.

The conversion of, for example, a gas leak to a liquid leak at different pressure and temperature, may be performed by a graphical presentation of the relations (1) and (2) for a standard capillary of 1 cm length.
Assume a gas leak of $Q_{g1}$ clusec has been estimated. This leak might have been caused by one capillary of diameter $D_1$ and of 1 cm length, (see the above figure). Such a capillary would cause a liquid leak of $Q_{l1}$ mg/hour. However, if there is not only one single capillary, but more than one with, for example, an average diameter $D_2$, the liquid leak rate will be different. The number of capillaries with an arbitrary average diameter, $D_2$, causing a total gas leak $Q_{g1}$, can be calculated:

$$n = \frac{Q_{g1}}{Q_{g2}}$$  \hspace{1cm} (3)

in which $Q_{g2}$ is the gas leak of one capillary.

The equivalent liquid leak rate will now be:

$$Q_{l3} = \frac{Q_{g1}}{Q_{g2}} \times Q_{l2}$$  \hspace{1cm} (4)

in which $Q_{l2}$ is the liquid leak rate for one capillary of diameter $D_2$. In logarithmic notation:

$$\log Q_{l3} = \log Q_{l2} + [\log Q_{g1} - \log Q_{g2}]$$  \hspace{1cm} (5)

The second term in expression (5) is equal to the distance $A$ in the above figure. By shifting this distance, as done in the figure, one point ($Q_{l3}$, $D_2$) of the liquid leak curve has been found. More points may be constructed by choosing other $D_1$ values.
The final liquid leak curve gives an impression of the prospective leak range. A more accurate information is obtained if the gas test is repeated with another medium or at another temperature c.q. pressure. The intersection of the two leak curves gives the liquid leak and at the same time the average diameter of the capillaries.

For multiple conversion calculations, it is easier to design a slide rule.

The principles of this system will be shown for a conversion calculation as sketched in the aforegoing figure.

\[
\begin{align*}
Q_g = 1 & \quad \frac{Q_{gl}}{D} \quad \log Q_g \\
Q = 1 & \quad \frac{Q_{gl}}{D_l} \quad \log Q_2
\end{align*}
\]

The length of the interval \((Q_g = 1, Q_{gl})\) represents the function's value \(\log Q_{gl}\). For \(Q_g = 1\) the function value \(\log Q_g\) is zero. The calculation according to expression (5) can thus be performed by moving line intervals. The marks on both sides of each scale denote respectively the values of \(Q\) and \(D\), belonging to the value of \(\log Q\), which is in turn expressed in mm.

Assume a gas leak of \(Q_{gl}\) closec has been estimated. The appropriate diameter of the capillary, \(D_1\), can be read directly. The same \(D_1\) on the liquid scale gives immediately \(Q_{gl}\). Next a \(D_2\) is chosen on the gas scale. The scales are positioned so that the \(D_2\)'s on both scales coincide:
If in this position the window slide is put over $Q_{g1}$, $Q_3$ may be read immediately because:

$$B = \log Q_{g2}$$

$$A = \log Q_{g1} - \log Q_{g2}$$

The summation of $A$ and $B$ is equivalent to the expression (5); the combined manipulations to calculate a $Q_3$ from a given $D_2$ are thus:

1. put the window slide on the $D_1$-value (gas scale),
2. move the central slide until $D_2$-value (liquid scale) is under the marker,
3. move the ws. over the $D_1$-value,
4. read the $Q_{g3}$-value under the marker.

It is clear that the actual zero points of the functions, $\log Q$, are not used.

The actual sliderule is designed circular.

The disadvantage of the sliderule system in this case is that the for each medium, temperature and pressure a separate scale must be designed, as it is not possible to write expression (1) in additive form, adapted for sliderule summation.

It would be possible to design a sliderule with general scales for liquids, expressing $\rho, n$ and $p_1 - p_2$ out of expression (2), com-
bined with specific scales for gaseous media at desired temperatures and pressures. However, this type of sliderule would be of a more complicated structure, so only the type with specific scales for gases and specific scales for liquids has been developed until now.

A computer programme has been written which calculates the relations (1) and (2) for given pressures, temperatures, viscosities and specific gravities.

This programme, named "COOLER" from Conversion Of Leak Rates, draws the curves with log versus log scales and designs also a circular abacus for quick and multiple use. A simple example with only four scales is given for illustration. However, any combination of media may be treated in the same way and the number of scales is not limited except for considerations of clearness and handiness.

Also two or three scales on the same circumference and more than two sliderule plates can be designed in one run.

The output of the program "COOLER" consists of:

1. a graph which may be used for the conversion of leak rates as is shown in the figure on page 28,
2. a drawing of the scales for an abacus, without the D, respectively Q-values,
3. for each scale of the abacus, a table of D, respectively Q-values for the principal scale division marks.
The slide rule

Computer Output 1

Computer Output 2
"COOLER" INPUT DESCRIPTION

The symbols refer to the input sheet where also a numerical example is given. The input example originates a simple slide-rule as is given by the illustrations.

NSCAL = number of specified scales

For each scale the programme requires the data:

DMIN = minimum diameter of the capillaries,
DMAX = maximum diameter of the capillaries,
ETHA = viscosity of the medium,
PL = pressure at the entrance of the capillaries (atm.),
P2 = pressure at the exit of the capillaries (atm.),
T = temperature (°K) only for gases,
EM = molecular weight only for gases,
CORDA = accumulating x coordinate,
CORDB = accumulating y coordinate,
R = radius of the scale,
PSI = initial angle with the x-axis in radians,
SCALE = the length of one decade in cm,

(the first scale as specified in the example input requires 2 cm between Q=10^{-6} and Q=10^{-5}),

RHO = specific gravity only for liquids,
RCIR, RCIRA = full dotted circles around the latest specified x-y coordinates,
TITLE = any alphamerical description of the scale which appears in the printed output to identify the scales.
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</table>
'CONVERSION OF LEAK RATES

PROGRAM 'COOLER' BY HERMAN I. DE WOLDE

C

DIMENSION QQD(2,400), DQTAB(3,100)

ICX(30)

REAL (5,98) : NSCAL

DO 100 I = 1, NSCAL

A = 100

REAL (5,100) DMIN, DMAX, ETHA, P1, P2, T

B = 101

REAL (5,103) RH0, RCIR, CORDB, R, PSI, SCALE

C = 103

FORMAT (5E12.4)

CALL FINIM(CQRDA, C0RD3)

D = 104

IF (RCIR .LT. 1.E-5) GO TO 101

CALL CIRCLE(RCIR, 2)

E = 101

IF (RCIRA .LT. 1.E-5) GO TO 104

CALL CIRCLE(RCIRA, 2)

F = 104

CONTINUE

G = 102

DMIN = DMIN - 0.1*DMIN

H = 103

IND = 1

IF (EM .GT. 0.0) GO TO 102

I = 102

CONTINUE

J = 103

CALL CIRCLE(0.25, 1)

K = 104

CALL D3VAL(OMIN, UMAX, ETHA, RHO, PI, P2, T, EM, DQ, DQTAB, NPOIN, IND, NDQT)

L = 105

WRITE (6, 103) R

M = 106

WRITE (6, 104) (TIT(INSC, I), I = 1, 6)
WRITE (6, 136) DQTAB(1, I)
C 137 CONTINUE

C NPOIN=UPQ1+1
AMAX=DQO(1, NQDT)
IF (AMAX .GT. DQO(1, NPOIN)) GO TO 106
AMAX=DQO(1, NPOIN)
106 AMI=DQO(1, NQDT+1)
IF (AMI .LT. DQO(1, 1)) GO TO 108
AMI=DQO(1, 1)
108 RANGE=ALOG10(AMAX)-ALOG10(AMI)
CALL CIRCS(R, PSI, SCALE, QDI, RANGE, XF, YF, NPOIN)
C 200 CONTINUE

C DRAW THE GRAPHS
C
CALL FINIMO(0.1, -20.)
CALL GRL0G(XX, YY, NSCX, NSCAL)
CALL FINIMO(0., 0.)
CALL FINTRA
STOP END
SUBROUTINE CIRC(R, PSI, SCALE, JDQ, RANGE, XF, YF, NPOIN)

C SUBROUTINE CIRC DRAWS A SEGMENT FOR A Q-INTERVAL GIVEN BY RANGE
C NPOIN SCALE DIVISIONS ARE DRAWN ACCORDING TO JDQ.
C 'SCALE' IS THE LENGTH OF ONE DECADE

DIMENSION JDQ(2,400), X(1000), Y(1000)

DEL = 1./R*20.
PI = 3.14159
ANG = PSI + (RANGE*SCALE)/R
X(1) = PSI
IA = 1

100 IA = IA + 1
IF (X(IA) LT ANG) GO TO 120

102 Y(I) = R
CALL LINEP0(X, Y, IA, 1, 1)
CALL LINEP0(X, Y, IA, 1, 1)
CALL LINEP0(X, Y, IA, 1, 1)
XF = X(IA)
YF = Y(IA)

DJ = JDQ(1, 1)
A11 = ALOG10(JMIN)
DJ = JDQ(1, 1) - JMIN
ORD = PSI + (ALOG10(JDQ(1, 1)) - A11)*SCALE
DI = JDQ(2, 1)
CALL DJRQ(R, DI)
CONTINUE
RETURN
END
SUBROUTINE DQVAL(DMIN, DMAX, ETA, RH0, P1, P2, T, EM, QDQ, DQTAB, NPOIN, IND)

C DQVAL CALCULATES THE VALUES OF Q WHERE THE Q DIVISION MARKS AND THE D DIVISION MARKS MUST BE PLACED.

DIMENSION QDQ(2,400), DQTAB(3,100), DQTAB(2,300)

GO TO (100, 102), IND 100 CALL QGAS(DMIN, ETA, P1, P2, T, EM, QMIN)
GO TO 104 102 CALL QLIQ(DMIN, ETA, P1, P2, RH0, QMIN)
104 CALL DIVMRK(DMIN, DMAX, QMIN, QMAX, DQTAB, NQDT, NDQT)

DO 110 I = 1, NPOIN QDQ(1, I) = DQTAB(1, I)
DO 118 I = 1, NQDT IA = I + NDQT DD = DQTAB(1, I)
DO 112 I = 1, 114, IND 112 CALL QGAS(DD, ETA, P1, P2, T, EM, QA)
116 CALL QLIQ(DD, ETA, P1, P2, RH0, QA)
114 CALL DIVMRK(DD, DMAX, QMIN, QMAX, DQTAB, NQDT, NDQT)
118 CONTINUE QA = QDQ(1, IA) = QA QA = DQTAB(2, I)

CONTINUE NPOIN = NQDT + NDQT RETURN
SUBROUTINE QLIQ(D,ETHA,P1,P2,RHO,QL)

C SUBROUTINE QLIQ Calculates the leak rate for a liquid
C through a standard capillary of unit length.

QL=2.45*D**4*(P1-P2)*1.E-10/ETHA
QL=JL*RH0*3.6*1.E+6
RETURN
END
SUBROUTINE JGAS

SUBROUTINE JGAS CALCULATES THE LEAK RATE FOR A GAS THROUGH A STANDARD CAPILLARY OF UNIT LENGTH.

ARGA=2.88*(PI-P2)*SORT(T/EH)

ARGB=0.893*D*(PI**2-P2**2)/ETHA

QG=D**3*(ARGA+ARGB)*1.E-6

RETURN

END
SUBROUTINE DIVMRK(DMIN,DMAX,QMIN,QMAX,DYTAB,QDTAB,NDQT,NQDT)

C SUBROUTINE DIVMRK CALCULATES THE NECESSARY DIVISION MARKS FOR THE
C 10/2 SCALES AND GIVES ALSO THE LENGTHS OF THE MARKS IN CM.

C DIMENSION QTAB(3,100),QDTAB(2,300),AA(18),EN(18)
DATA AA(18) / 1.C, 1.5, 2.C, 2.5, 3.C, 3.5, 4, 4.5, 5.C, 5.5, 6, 6.5, 7, 7.5, 8, 0.8, 0.9, 0.57 /
DATA EN(18) / 0.4, 0.1, 0.2, 0.1, 0.2, 0.1, 0.2, 0.1, 0.2, 0.1, 0.2, 0.1, 0.2, 0.1, 0.2, 0.1, 0.2, 0.1, 0.2, 0.1, 0.2, 0.1 /

C NDQT=0
C NQDT=0
C FACT=1.E-20
C DJ 1C2 I=1,30
C DU 10C J=1,13
C ARGA=FACT*AA(J)
C ARGB=C.-EN(J)
C IF(ARGA.GT.DMAX) GO TO 98
C IF(ARGA.LT.DMIN) GO TO 98
C NDQT=NDQT+1
C QDTAB(1,NDQT)=ARGA
C QDTAB(2,NDQT)=ARGB
C 98 IF(ARGA.LT.JMIN) GO TO 100
C IF(ARGA.GT.DMAX) GO TO 100
C NDQT=NDQT+1
C QDTAB(1,NDQT)=ARGA
C QDTAB(2,NDQT)=EN(J)
C 100 CONTINUE
C FACT=FACT*10.
C 102 CONTINUE
C RET JUN
C END
SUBROUTINE DIV(PHI,R,CH)

DIV DRAWS A LINE OF LENGTH "CH" CM
PERTICULAR ON A CIRCLE WITH RADIUS "R".
THIS LINE POINTS INWARDS IF "CH" IS NEGATIVE.
"PHI" IS THE ANGLE OF THE RADIUS WITH THE X-AXIS.

DIMENSION X(2), Y(2)
X(1) = R*COS(PHI)
Y(1) = R*SIN(PHI)
X(2) = (R+CH)*COS(PHI)
Y(2) = (R+CH)*SIN(PHI)
CALL LINE(X,Y,2,1,1)
RETURN
END
SUBROUTINE CIRCLE(R,IK)

C SUBROUTINE CIRCLE DRAW A CIRCLE WITH RADIUS R
C ABOUT THE POINT (C,0)
C IK=1:CONTINUOUS LINE
C IK=2:DASHED LINE

DIMENSION X(1000),Y(1000)

PI=3.14159
DEL=1./(R*C.)
IA=1

X(IA)=9.

100 IA=IA+1
    X(IA)=X(IA-1)+DEL
    IF((IA)*LT(2.*PI)) GO TO 100

102 Y(1)=R

104 CALL LINEPO(IY,IA,1,1)
106 CALL OASMP(X,Y,IA,1,1)

103 CONTINUE

RETURN
END
SUBROUTINE GRLOG(XX, YY, NSCX, NSCAL)

CURVE I IS GIVEN BY IABS(NSCX(I)) POINTS
IF NSCX IS NEGATIVE A DOTTED CURVE WILL BE DRAWN.

DIMENSION XX(20,100), YY(20,100), NSCX(20)
DIMENSION AA(9), EN(9), V(100), W(100), BC(1), ALX(15), ALY(9)
DATA AA/1.0,2.0,3.0,4.0,5.0,6.0,7.0,8.0,9.0/
DATA EN/0.3,0.1,0.1,0.1,0.2,0.1,0.1,0.1,0.1/
DATA BC/10/
DATA ALX/1.IN CLUSEC FOR DASHED LINES OR IN MG/HOUR FOR FULL LINE

ISN 0003
DATA ALY/'DIAMETER OF CAPILLARY IN MU UNITS '/

IMM 0010
YLENG=15.
XLENG=23.

IMM 0012
XMIN=XX(1,1)
XMAX=XX(I,1)

IMM 0013
YMIN=YY(1,1)
YMAX=YY(I,1)

IMM 0014
DO I=1,NSCAL
N=IABS(NSCX(I))

IMM 0016
DO JOC I=1,NSCAL
N=IABS(NSCX(I))
DO 100 J=1,N

IMM 0018
IF(XMIN.GT.XX(I,J))XMIN=XX(I,J)
IF(XMAX.LT.XX(I,J))XMAX=XX(I,J)

IMM 0020
IF(YMIN.GT.YY(I,J))YMIN=YY(I,J)
IF(YMAX.LT.YY(I,J))YMAX=YY(I,J)

CONSTRUCT AX=XLENG/(ALOG10(XMAX)-ALOG10(XMIN))
BX=0.-ALOG10(XMIN)
AY=YLENG/(ALOG10(YMAX)-ALOG10(YMIN))
BY=0.-ALOG10(YMIN)

---DRAW THE AXIS-----------------------------------------

V(1)=0.0
W(1)=G.0
V(2)=AX*(ALOG10(XMAX)+BX)
W(2)=C.0
CALL LINE(V, W, 2, 1, 1)

V(2)=0.0
W(2)=AY*(ALOG10(YMAX)+BY)
CALL LINE(V, W, 2, 1, 1)

FACT=1.E-20
DO 104 I=1,30
102 CONTINUE
FACT=FACT*10.
104 CONTINUE
FACT=FACT*10.
DU 102 J=1,9
ARGA=FACT*AA(J)
ARGB=EN(J)
IF(ARGA.LT.XMIN) GO TO 102
IF(ARGA.GT.XMAX) GO TO 102
V(1)=AX*(ALOG10(ARGA)+DX)
W(1)=0.0
V(2)=V(1)
W(2)=C-ARGB
CALL LINE(V(1),2,1.1)
IF(ABS(ARGB).LT.0.15) GO TO 102
ARGA=ARGA+0.001*ARGA
ARGA=ALOG10(ARGA)
YF=V(2)-0.15
XT=V(1)
CALL NUM3CR(XT,YT,-0.15,0.0,ARGA,-1)
XT=V(1)-0.25
YT=YT-0.2
CALL SYM3L4(XT,YT,0.2,0.0,BC,2)
110 CONTINUE
FACT=FACT*10.
DRAW THE ACTUAL CURVES

DO 126 IN=1,NSCAL
  INP=ABS(NSCAL(IN))
  DO 120 I=1,INP
     V(I)=AX*(ALOG10(X)(IN(I)))+BX
     W(I)=AY*(ALOG10(Y)(IN(I)))+BY
  IF(NSCL(IN),GT,0) GO TO 124
  CALL DASH(V,W,INP,1,1)
  GO TO 126
124 CALL LINE(V,W,INP,1,1)
126 CONTINUE

XT=1.
YT=1.
CALL SYM3L4(XT,YT,0.2,0.0,ALX,6C)
XT=1.
YT=AY*(ALOG10(YMAX)+BY)+0.5
CALL SYM3L4(XT,YT,0.2,0.0,ALY,36)
RETURN
END
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H.I. DE WOLDE; J. AMESZ: Computer Designed Sliderules for the
Conversion of Leak Flow Rates. Vacuum, 19, 8 (1969)
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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